Photographic Caries Assessment by Different Members of the Dental Team: A Mobile Teledentistry Model

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This thesis is presented for the degree of Doctor of Philosophy of The University of Western Australia

School of Human Sciences

2017
To My Beloved Parents & Family

إهداء إلى والديّ و عائلتي
Thesis Declaration

I, Mohamed Estai, certify that:

This thesis has been substantially accomplished during enrolment in the degree.

This thesis does not contain material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution.

No part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of The University of Western Australia and where applicable, any partner institution responsible for the joint-award of this degree.

This thesis does not contain any material previously published or written by another person, except where due reference has been made in the text.

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The research involving human data reported in this thesis was assessed and approved by The University of Western Australia Human Research Ethics Committee. Approval reference number # RA/4/1/6647.

Written patient consent has been received and archived for the research involving patient data reported in this thesis.

I declare no potential conflicts of interest with respect to the teledentistry system, including financial interests, scholarly activities and career development.

This thesis contains mostly published work, some of which has been co-authored.

Signature: [signature]

Date: 24 July 2017
Abstract

Despite the fact that dental caries is preventable, the burden of disease associated with poor oral health is immense. Oral health can be improved by the adoption of a range of systematic preventive measures. However, preventive strategies can be unsuccessful if not targeted at the population who need it most. Dental screening in asymptomatic people permits identifying the population at high-risk and allows targeted dental care. Unaided visual inspection by dentists remains the most popular technique for dental screening. However, high logistic costs can be prohibitive when visual screening is conducted in a large-scale epidemiological setting. The primary aim of this thesis was to validate a novel, potentially cost-saving photographic method performed by mid-level dental practitioners (MLDPs), using a smartphone camera and store-and-forward telemedicine as an alternative dental screening tool. Seven inter-related studies were conducted, which are described in three sections.

In the first section (Chapters 7 and 8), we evaluated the use of a photographic method for detecting dental caries at tooth level by MLDPs using smartphones and digital single-lens reflex (DSLR) cameras. In Chapter 7, a novel mobile teledentistry system consisting of an image acquisition Android ‘Teledental’ App and Remote-i server developed to facilitate the acquisition, transmission and reviewing of images. One hundred regularly attending patients participated in this study. Following an unaided visual examination by dentists, photographs of participants’ teeth were taken by a tele-assistant, using a smartphone camera. The smartphone-based photographic caries assessment by the two MLDPs ‘charters’ was compared to the reference visual inspection by dentists, yielding a moderate level of sensitivity (60-62%) and a moderate to substantial inter-examiner agreement (Kappa=0.54-0.66). In Chapter 8, the intraoral photographic records of 126 children obtained from routine clinical records that were taken pre-operatively using a DSLR camera. These photographs, along with patients’ information, were uploaded to the Remote-i server then reviewed by an expert panel to formulate a benchmark screening baseline. The DSLR-based photographic caries assessments by a dentist and MLDP when compared to the expert panel assessment had a high level of sensitivity (82-89%) and almost perfect inter-examiner agreement.
In the second section, the end-user’s acceptance of mobile teledentistry (Chapter 9) and the attitude of Australian dental practitioners towards the use of telemedicine in dental practice (Chapter 10) were explored. Chapter 9 includes the results of an end-user acceptance survey that was emailed to a panel of dental practitioners (charters) and tele-assistants (smartphone users). Generally, users showed optimism about the use of the mobile teledentistry, and strongly positively assessed items on content and service quality. However, the survey identified a number of factors that will be essential to improve the current system, such as optimisation of the smartphone camera and using oral retractors during the photography. Chapter 10 is a description of the results of an anonymous electronic survey questionnaire emailed to 169 dental practitioners to explore dentists’ perceptions of the usefulness of teledentistry and determine their perceived concerns. Over 80% of respondents agreed that teledentistry would improve dental practice through enhancing communication with peers and referral of new patients. Many of the respondents expressed concerns about the cost of setting up teledentistry, data security and technical reliability.

In the third section we sought to identify the least costly screening alternative, assuming that all Australian school children (2.7 million) were screened over 12 months. In Chapter 11, a cost model was developed to simulate the costs of dental screening in children using a visual examination and compare it with the cost of MLDPs screening the same cohort of children remotely using a teledentistry approach. Overall, the teledentistry model of screening resulted in a net saving of $85 million. In Chapter 12, we estimated the scale of resource transfer based on risk minimisation. The findings suggested that moving low-risk children to teledentistry screening has the potential to free up $40 million per annum.

The outcome of this thesis supports the hypothesis that MLDPs can detect carious lesions from a digital still photograph with a standard comparable to a dentist. The findings suggest that using a DSLR-based photographic method in the detection of dental caries could offer an accurate and reliable means of dental screening. The use of a smartphone to capture the desired oral anatomy with high-quality and correct composition was found to be challenging in this study, and therefore, our findings suggest that a smartphone-based photographic method only provides a moderate level of diagnostic performance. However, this research confirms the reliability of using a smartphone and store-and-forward technology as a cost
saving and user-friendly dental screening tool, particularly in a large epidemiological study. Whilst demonstrating real promise, there are still some challenges to overcome before teledentistry can be widely used as point-of-care devices in dentistry. The use of the teledentistry must, therefore, not be seen to replace existing traditional dental care, but it can be employed to supplement mainstream dental services particularly in underserved or remote communities.
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<td>ABS</td>
<td>Australian Bureau of Statistics</td>
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<tr>
<td>ACT</td>
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<tr>
<td>AEHRC</td>
<td>Australian e-Health Research Centre</td>
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<tr>
<td>AIHW</td>
<td>Australian Institute of Health and Welfare</td>
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<tr>
<td>ASGC</td>
<td>Australian Standard Geographical Classification</td>
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<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific Industrial and Research Organisation</td>
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<tr>
<td>DFT</td>
<td>Decayed and Filled Teeth</td>
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<td>DMFT</td>
<td>Decayed, Missing and Filled Teeth</td>
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<tr>
<td>DSLR</td>
<td>Digital Single-Lens Reflex</td>
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<tr>
<td>DT</td>
<td>Dental Therapist</td>
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<tr>
<td>FTE</td>
<td>Full-time Equivalent</td>
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<td>GDP</td>
<td>General Dental Practitioner</td>
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<tr>
<td>GIS</td>
<td>Geographic Information System</td>
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<tr>
<td>ICDAS-II</td>
<td>International Caries Detection and Assessment System</td>
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<tr>
<td>ICT</td>
<td>Information and Communication Technology</td>
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<td>IRCOHE</td>
<td>International Research Collaborative–oral Health and Equity</td>
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<tr>
<td>K</td>
<td>Kappa Statistic</td>
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<tr>
<td>MLDP</td>
<td>Mid-level Dental Practitioner</td>
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<tr>
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<td>R1</td>
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Statement of Candidate Contribution

This thesis comprises of a series of published research papers in peer reviewed journals. Due to the multidisciplinary and collaborative nature of this research, all published papers and accepted manuscripts have been co-authored. The research was conducted under the supervision of Winthrop Professor Marc Tennant, Professor Stuart Bunt and Professor Yogesan Kanagasingam. Contributions of other colleagues are mentioned accordingly and listed as co-authorships in the published papers. For all studies, I undertook the planning, supervised tele-assistants, collated and cleaned the data. In addition, I undertook the data analysis, interpretation and writing of all manuscripts. After obtaining advice from co-authors, I have been responsible for making relevant changes to the manuscripts and submitting the final version for publication in peer reviewed journals. I am the primary author on each of research papers, and my contribution to each of these studies was 80%.

Mohamed Estai

Date: 24th July 2017
I verify that the declaration made by Mohamed Estai is an accurate and true representation of his contribution to the co-authored publications and work in this thesis.

Winthrop Professor Marc Tennant  
Coordinating and Principle Supervisor  
Date: 24th July 2017

Professor Stuart Bunt  
Co-Supervisor  
Date: 24th July 2017

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Publications Arising from Thesis


### Other Publications Arising During PhD Study


Conference Oral Presentations Related to Thesis


Chapter One

1. General Introduction
1.1. BACKGROUND

The significant improvements in oral health, particularly for children over the recent decades, have led many to believe that most dental problems are solved. Yet dental caries is still the most prevalent chronic disease of childhood and results in serious health consequences such as sepsis and reduced development (Acs et al., 1999). The problem is particularly severe in those living in rural regions or exposed to greater levels of disadvantage, causing a significant burden not only on individuals but the government (Mejia et al., 2012). Globally, the economic burden of dental diseases remains high. For instance, in the US, the expenditure for dental care was estimated at over $100 billion in 2009 (Glick et al., 2012). In Australia, the cost of dental care increased from $6 to $9 billion between 2005 and 2013 (Australian Institute of Health and Welfare, 2015). The reasons for inequalities in oral health outcomes are various but relate predominantly to inequities in access to dental care often due to the maldistribution of dental workforce and socio-economic gradients (Schwarz, 2006).

Australia is one of the most sparsely populated countries in the world with the majority of the Australians living near the cities (Australian Bureau of Statistics, 2014a). Like in many countries, dental care in Australia faces existing workforce issues, particularly the shortage and uneven geographic distribution of dentists, with the majority are working in private practices, which are largely clustered in major cities (Chrisopoulos et al., 2016). There is also a marked variation in the average dentist-to-population ratio between urban and rural regions (Chrisopoulos et al., 2016). The large geographical area and the marked variation in the supply of dentists creates a barrier to access to dental care, particularly, for those living in rural or remote regions. The inequality in health outcomes is closely associated with a socio-economic gradient and this reflected in oral health. Good oral health is not enjoyed equally by different populations in Australia (Kilpatrick et al., 2012). Higher rates of oral disease and disability are concentrated in a minority of a population (Schwarz, 2006; Kilpatrick et al., 2012). Dental services are unevenly available across Australia and the utilisation of dental care is also uneven. People with high needs, who already have poor oral health, have limited care access; while people with the least needs, have easy access to care and consume the most expensive resources (Milsom et al., 2009). As a result, much dental disease amongst low socio-economic status (SES) groups goes untreated, widening the gap between the level of their dental health and the rest of population (Slade et al., 2007). These
reports are important to refute claims that oral health problems are greatly solved and that further investment in public dental care is not required.

Dental caries occur mainly during childhood and adolescence, their impact can be reduced by effective prevention measures. This, therefore, underlines the need to shift the focus of management of dental diseases to prevention and away from the provision of treatment. Improving oral health in underserved populations can be achieved through the adoption of a range of systematic preventive measures such as oral health promotion, access to community fluoridated water and improvements in diet and dental care (Selwitz et al., 2007). However, due to the scarcity of resources and unequal distribution of the dental workforce these long-term strategies may be ineffective if not directed towards populations at high-risk or with the greatest need. Assessment of oral health in populations by the right dental professionals using valid and inexpensive screening tools can provide a way to identify high-risk groups and offers a valuable strategy for more effective disease prevention and control (Greenberg and Glick, 2012).

There are many methods for screening for dental diseases. Unaided visual inspection (along with an explorer and a dental mirror) is still the most common technique of dental screening. However, previous reports demonstrated that this technique does not have a high level of diagnostic accuracy (Milicich, 2000; Forgie et al., 2003). Also, this technique is not suitable in large epidemiological surveys which require substantial human and economic resources. The high costs and significant need for logistics can be prohibitive when dental screening is conducted in a large-scale setting. Seeking other screening methods that can expedite early detection of dental problems at low-cost, without affecting the accuracy of diagnosis is required. One of the growing solutions to address inequalities in oral health is to use appropriate members of the dental team such as mid-level dental practitioners (MLDPs), embracing new and affordable technology like teledentistry to screen for dental diseases. Well trained MLDPs such as dental therapists (DTs)/oral health therapists (OHTs) are capable of providing an acceptable dental treatment under indirect supervision of a dental expert (Bader et al., 2011). Also training MLDPs would require far less time and money than training a dentist to perform screening and provide routine dental care (Nash et al., 2014). Full use of the right oral health professionals in the provision of routine dental care could offer a
reliable way to reduce the costs of dental services and increase the capacity of the existing dental workforce to meet the increasing demand for dental care.

Telemedicine emerged to address the inequity of care access by providing health services according to need rather than location. This service is ideal for rural or remote patients who have a limited access to existing healthcare services. Teledentistry is a domain of telemedicine that is specifically dedicated to dentistry that uses information and communication technology (ICT), the Internet and digital photography for consultation or continuing education. Despite dental imaging, including visible light photography (using digital single-lens reflex [DSLR] or fibre optic intraoral cameras) becoming an integral part of daily dental practice, it has rarely been used as means of diagnosis, consultation or referral in routine practice. Recent evidence indicates that the diagnostic performance of photographic methods in the detection of oral diseases is comparable to the unaided visual screening approach (Boye et al., 2013; Torres-Pereira et al., 2013; Morosini et al., 2014; Kopycka-Kedzierawski et al., 2007; Bradley et al., 2010). Mobile teledentistry which is a subdivision of mobile telemedicine that emerged from the incorporation of cellular technology and ICT into oral care services. The introduction of mobile telemedicine into epidemiological surveillances, in particular, audiology and dermatology, has been shown to be beneficial (Massone et al., 2007; Kroemer et al., 2011; Mahomed-Asmail et al., 2016; Hussein et al., 2016). However, currently, there has been only minimal research to evaluate the validity and reliability of the mobile teledentistry approach to dental screening by different oral health professionals.

In collaboration with the Australian eHealth Research Centre (AEHRC), Commonwealth Scientific Industrial and Research Organisation (CSIRO), a team led by Professor Kanagasingam at AEHRC, developed a suite of technology based on store-and-forward telemedicine (including an image acquisition Android App and cloud-based server) to serve as an infrastructure for remote dental screening. In view of the limitations of the traditional screening approach, mobile teledentistry could offer a valuable tool for dental screening by MLDPs at a distance, based on still dental photographs taken with a smartphone camera. This type of screening offers an effective strategy to identify populations with high needs or at risk and facilitates providing specific dental care to the right population by the right members of the dental team.
1.2. AIMS AND HYPOTHESES OF THE STUDY

The central aim of this PhD thesis is to evaluate the efficacy of a novel, potential cost-saving mobile teledentistry model of dental screening by MLDPs, using a smartphone camera and store-and-forward technology.

The hypotheses of this thesis are:

1. There is no difference in the diagnostic accuracy and reliability between a smartphone-based photographic method and direct visual caries assessment.

2. There is no difference in the diagnostic accuracy and reliability between an expert dental panel assessment and a DSLR-based photographic caries assessment.

3. There is no difference between the diagnostic accuracy and reliability of the photographic caries assessment completed by an MLDP and dentist.

4. End-users who participated in data collection and analysis would perceive the mobile teledentistry process positively.

5. A Survey of Australian dental practitioners would show they perceive the use of telemedicine in routine dental practice positively.

6. Using mobile teledentistry for dental screening would result in a substantial net saving when compared to traditional screening approaches.

7. Using mobile teledentistry to screen advantaged or low-risk children would free up significant resources that could be redistributed to provide better dental care for vulnerable children.

1.3. THESIS STRUCTURE

This thesis is, in accordance with the University of Western Australia Higher Degree by Research Rules Act, presented as a series of coherent research papers (mostly published)
that resulted from the PhD research. Therefore, each thesis chapter (except the introduction, literature review, general methods and general discussion chapters) contains an independent introduction, methods, results and discussion section. As such, some degree of overlap of research papers presenting data from the same series of studies is unavoidable. This thesis is structured into thirteen separate chapters as follows:

The introduction (Chapter 1) introduces the reader to the problem of caries, its prevention and alternative solution to reduce its impact, this chapter also outlines the thesis aims and hypothesis as well as describes the structure of the thesis. The Literature review (Chapter 2) introduces dental caries, its epidemiology and burden of disease, and also provides the background to the status of dental practice and care provision in Australia, as well as introducing telemedicine initiatives in dental screening.

The first systematic review (Chapter 3) establishes the gaps in the literature relating to the effectiveness and cost-effectiveness of teledentistry applications. The second systematic review (Chapter 4) provides a critique overview of literature concerned with the evaluation of diagnostic accuracy of teledentistry approach used to caries detection. Chapters 3 and 4 include abstract, introduction, methods, results and discussion, and presented as they were published papers in the respective journals.

The general methods (Chapter 5) contains the methods which are common to all the results chapters to avoid duplication. It summarises the methodologies used in the studies that allowed for validation of teledentistry system.

Chapters 6-12 contain the Results of studies employed to test the principle hypotheses and include abstract, introduction, methods, results and discussion for each separate study. Chapters 6-10 are presented as published papers in their respective journals, with the formatting in these papers retained as per the published version. Chapters 11 and 12 are presented as a manuscript which has been submitted to a peer-reviewed journal.

Chapters 6 to 8 are the first three core research papers produced based on the first three objectives. Chapters 6 and 7 list the studies that were used to validate the photographic caries assessment method (using a smartphone camera) by different members of the dental team. Chapter 8 outlines the study that was used to validate the photographic caries assessment method (using a DSLR camera) by different members of the dental team.
Chapter 9 is the fourth core research paper that was designed to address the fourth objective. It contains the results of a survey of end-users acceptance of a teledentistry system used in dental screening. Chapter 10 is the fifth core research paper addressing the fifth objective. It describes the results of a survey that explored Australian dental practitioners’ perceptions about the use of telemedicine in dentistry.

Chapter 11 is the sixth core research paper that sought to address the sixth objective. It contains estimates of the cost savings from using a teledentistry model for dental screening. Chapter 12 is the seventh core research paper that was designed to address the seventh objective. It contains estimates of the scale of resource transfer that could be achieved by shifting low-risk children from direct visual dental screening to teledentistry screening.

A general discussion and conclusion chapter (Chapter 13) closes out the thesis, which critiques the outcome of the study, relates study findings to the thesis’ aims, discusses the limitations of the study, future research directions and outlines the implications of this research.
Chapter Two

2. Literature Review

Part of this chapter was published in the following articles:


2.1. DENTAL CARE PROVISION IN AUSTRALIA

Unlike other healthcare services, dental care services are not covered by Medicare. Indicating that oral health is not considered a priority by health policy-makers. The provision of dental care is provided through both the private and public sector by dentists and OHTs/DTs (Mejia et al., 2012). However, dentistry in Australia is primarily a private practice-driven model, where dental care is provided on a fee-for-service basis (Schwarz, 2006). Public dental services are delivered in educational hospitals, community oral health centres and school-based clinics (Schwarz, 2006). Access to public dental services is determined by specific criteria governed by the Commonwealth Department of Human Services agency (Schwarz, 2006). This service extends to cover Health Care Cardholders, Pensioner Concession Cardholders, and Commonwealth Seniors Health Cardholders low-income earners and pensioners (Schwarz, 2006). The School Dental Service (SDS) is a State-funded programme providing free dental services to all school children aged 5-14 by school DTs (Satur et al., 2009). The history of SDS in Australia can be traced back to the 1920s, where it was designed to provide dental care for poor and disadvantaged children (Wang, 1990). Following the introduction of the Australian School Dental Scheme (ASDS) in 1973 (Mejia et al., 2012), the SDS has expanded to cover all primary schools in all states and territories (Wang, 1990). In recent years, Australia’s SDS has suffered a reduction in workforce participation, scarcity of resources, and services remain largely concentrated in the highly populated regions (Harford and Luzzi, 2013; Spencer, 2004). The decreased retention and recruitment of school DTs are attributed to their preferring to work in the private sector, leave the profession (Kruger et al., 2007) and the establishment of a Bachelor Degree of Oral Health Therapy in a number of Australian universities (Teusner et al., 2015).

Despite the widespread occurrence of dental caries in Australia, almost half of Australian adults usually visit a dentist at least once every year (Slade et al., 2007) and the majority of visits were paid to private practices (Chrisopoulos et al., 2016). Access to dental care and type of dental practice attended are often influenced by several factors such as remoteness, household income and insurance status (Harford and Islam, 2013). Unfortunately, many Australian children and adults lack regular access to dental services due to costs. Households with low income were more likely to delay or avoid seeing a dentist because of the cost than households with high income (Harford and Islam, 2013). Populations from remote or rural
areas face significant hardship in gaining appropriate and timely access to dental services. While many children (particularly in major cities) make their first visit to the SDS when they are either five or six (Mejia et al., 2012). A greater proportion of school children aged 5-14 had access to a dental care (Harford and Luzzi, 2013), 75% of these visits were made to private practices (Harford and Luzzi, 2013). In contrast, a small proportion of preschoolers (28%) had a visit to a dentist, where the majority attended a private practice (Harford and Luzzi, 2013). The majority of Australian preschoolers (70%) had no access to dental practice before they turned five years when all children become eligible to register with the SDS (Harford and Luzzi, 2013).

The majority of Australian dentists (85%) work in the private sector (Australian Institute of Health and Welfare, 2014). Most dental services in Australia are funded on a private basis with or without the assistance of private insurance (Schwarz, 2006; Australian Health Ministers’ Advisory Council, 2004) (Figure 2-1). A much smaller safety net (for those of low socio-economic background) is provided through government-supported community dental services (Tennant and Kruger, 2013). With less than half of Australians without dental insurance, they are responsible for meeting the full cost of dentistry in the private sector (Harford and Islam, 2013). This has proven difficult with reports indicating that over 25% of Australians aged 2 and over were unable to obtain dental care due to financial reasons (Harford and Islam, 2013). Inequities in access to dental care in Australia are shown by dental visiting patterns. Many people seek dental care, when dental service is available, easy to access, in emergencies or when a complicated disease is present (Schwarz, 2006). The rural populations have 15% more tooth extractions than the general populations when they seek dental care for a routine checkup (Schwarz, 2006). This points to the fact that the focus of dental care service is on providing treatment rather than prevention of dental diseases. The approach to oral disease management tends to focus on extraction rather than restoration of teeth (Schwarz, 2006). A visit to a dentist for a dental problem rather than a routine checkup is an indicator of inadequate or limited care access and is often due to a lack of comprehensive oral health system (Schwarz, 2006). This may highlight the need to shift the dental care services from ‘cure’ to ‘prevention’. 
2.2. DENTAL PRACTICES IN AUSTRALIA

Australia is the world’s sixth-largest country (by area) with a total area of over 7.5 million km$^2$ (3 million miles$^2$). In the 2013 census, the estimated population of Australia was 23 million (Australian Bureau of Statistics, 2014a). Australia is one of the most urbanised countries in the world with two-thirds of Australians living in major cities, including 21% in Sydney alone (Australian Bureau of Statistics, 2014a). Dentistry in Australia, like in many countries has a significant workforce problem, particularly the shortage and unequal geographic distribution of oral health professionals, which tends to be more acute in remote or rural regions (Tennant et al., 2013). In 2013, there were 20 469 dental practitioners registered in Australia, 75% of these practitioners (5479) were registered dentists (Chrisopoulos et al., 2016). The majority of dentists (85%) work in the private sector and are clustered in major cities (Chrisopoulos et al., 2016) (Figure 2-1). As a result, many residents of rural and remote regions of Australia and population sub-groups who cannot afford private care are left underserved and without regular access to dental care.
The dental workforce differs across Australian States and Territories with New South Wales having the largest number of dentists (4598) compared to the Northern Territory which has the smallest number of dentists (94) in Australia (Australian Institute of Health and Welfare, 2014). A greater proportion of dentists (10 567) were working in major cities compared with 116 dentists working in remote/very remote areas (Australian Institute of Health and Welfare, 2014). Although the average dentist to population ratio has increased from 57 dentists/100 000 capita in 2011 to 64 dentists/100 000 capita in 2012 (Australian Institute of Health and Welfare, 2014), there is a considerable variation in the number of dentists per capita between States and Territories. The number of dentists per capita was the highest in the Australian Capital Territory (71 dentists/100 000 capita) and the lowest in Tasmania and the Northern Territory (42 dentists/100 000 capita). The number of dentists to population was also higher in major cities (72 dentists/100 000 capita) than in remote/very remote areas (23 dentists/100 000 capita) (Australian Institute of Health and Welfare, 2014). The reluctance of dentists to practise in rural settings probably pertains to family reasons, low reimbursements and lack of continuing education opportunities (Kruger and Tennant, 2005).

### 2.2.1. Oral Health Therapist Practice in Australia

An OHT is an oral health professional registered with the Dental Board of Australia who has completed an accredited bachelor programme of study in the dual streams of dental therapy and dental hygiene while DTs are oral health professionals with a more limited scope of practice (without the periodontal component). A DT/OHT is an integral part of the dental team, they work with general dentists/consultants to provide dental care and oral health promotion within their scope of practice, in the public and private sectors. Before 2000, DTs were trained in non-university vocational colleges in a two-year Diploma programme. In recent years, a number of Australian universities have offered dual qualifications (3-years at university level) in dental hygiene and dental therapy, a Bachelor Degree of Oral Health Therapy. These programmes are intended to replace the existing (2-years vocational level) diploma programmes in Dental Therapy or Dental Hygiene (Teusner et al., 2015). The new Bachelor programmes allow the OHT to incorporate the skills of both the hygienist and therapist.
In 2013, there were an estimated 2050 registered DTs/OHTs engaged in practice. However, DTs/OHTs represent less than 10% of the dental workforce in Australia (Chrisopoulos et al., 2016). With the number of Oral Health Therapy programmes increasing (eight universities offered this Degree in 2015), the number of OHTs is projected to increase in near future (Teusner et al., 2015). Unlike the distribution of Australian dentists, DTs/OHTs are more evenly distributed across different geographical zones with an average of 6.5 per 100,000 population (Chrisopoulos et al., 2016). Historically, school DTs have been responsible for providing most of the dental services (examination, diagnosis, treatment and preventive care) through the SDS, under the indirect supervision of dentists (Nash et al., 2008). However, the Australian SDS rarely provides a sustainable oral care service for all children, with nearly half of the school children cared for in the SDS suffering from poor oral health (Harford and Luzzi, 2013; Spencer, 2004). Until the 2000s, the employment of DTs was limited to the state-operated SDS (Satur et al., 2009). Recently, many of DTs/OHTs have opted for private practice careers due to lack of competitive salaries in the SDS (Kruger et al., 2007). In the private sector, DTs/OHTs are often working as ‘hygienists’ responsible for performing scaling and root planing for adult patients, thus they have a minor role in the provision of dental care. OHTs have not been used effectively to increase the capacity of the existing dental workforce (i.e. mostly dentists) and address the inequity in access to dental care.

Given that the dental workforce supply and dental services are largely concentrated near the major cities, many argue that the development of alternative workforce models to dental care provision could increase the supply of dental services to rural or remote communities (Mertz and Glassman, 2011). Due to these factors and the global economic climate’s impact on healthcare funding, many countries are considering potential models of dental service delivery including the greater use of an MLDP surrogate model (Nash, 2009). The Alaskan Native Tribal Health Consortium (ANTHC) in partnership with the University of Washington established a telemedicine-based workforce model with a long-term strategy that centres on developing and training Alaskan students as dental health aide therapists (DHATs) in Alaska to provide dental care to Alaskan residents under indirect supervision by dental experts (Wetterhall et al., 2011; Williard and Fauteux, 2011). The use of role substitution such as DTs/OHTs to provide primary care for children has been well accepted in many countries because of the inability of the current dental workforce to address the unmet dental care needs (Nash, 2009).
The OHTs have the potential to take up more substitute-type roles and be more self-reliant in treatment planning. Previous reports indicated that OHTs are capable of providing restorative dental treatment (on the prescription of a dentist) with similar standards to that of general dentists (Calache et al., 2009; Bader et al., 2011). The availability of DTs/OHTs in rural regions could play an effective role in the provision of routine dental care within their scope of practice. Opponents (largely dentists) of using role substitution in dentistry had concerns relating to quality, effectiveness and safety of practice of MLDPs and seeing this as a threat to their professions. Advocates debate that role substitution can enhance the efficiency and effectiveness of dental professionals working in the primary care environment (Edelstein, 2011), thereby saving resources to improve access to care and alleviate inequalities in oral health (Edelstein, 2010; Glassman and Subar, 2010; Skillman et al., 2010).

The use of MLDPs to screen for oral disease among regular dental care seekers or asymptomatic people could save significant resources. As a result, these could be employed to increase the capacity to dental care (Nash et al., 2008).

2.2.2. Emerging Dental Workforce Models

Although the average dentist-to-population ratio has increased over recent decades, a significant discrepancy between the ratio in urban and rural regions still exists (Tennant and Kruger, 2013). With the availability of oral care services very unevenly distributed in regional and remote areas, underserved people seek oral care from non-dental care providers, most commonly physicians, hospital emergency departments or pharmacies (Maunder and Landes, 2005; Cohen et al., 2011; Okunseri et al., 2011). Non-dental care providers often help to provide symptomatic relief and/or issue a referral to a dentist rather than providing effective dental care (Maunder and Landes, 2005; Cohen et al., 2011).

Several strategies have been developed to address unmet oral health needs, including the use of role substitution to provide dental care (Brocklehurst et al., 2012; Macey et al., 2015). The DHATs programme is a notable workforce model that makes use of the role substitution concept (using native DTs) and telemedicine to address the inequity in access to dental care in rural Alaska. In early 2000, the ANTHC developed a workforce model ‘DHAT’ that utilises telemedicine to address oral health disparities and lack of access to oral care in Alaska (Williard and Fauteux, 2011). Alaska’s DHAT model was developed based on the New Zealand
school-based program for DTs (Wetterhall et al., 2011). In 2008, ANTHC partnered with the University of Washington to develop a 2-year training programme specifically designed for Alaska’s DHATs. In the first year of the programme, students received basic training held at the University of Washington DENTEX centre in Anchorage, Alaska and the second year of the programme consisted of intensive clinical training in Bethel, Alaska (Williard and Fauteux, 2011). Following completion of 3000 hours of training during a 2-year dental therapy programme, DHATs must undergo a mandatory preceptorship lasting 400 hours, under the direct supervision of licensed dentists, before they begin to work under general supervision (Williard and Fauteux, 2011). DHATs are closely connected with their supervisory dentists through telemedicine, with dentists providing direct, indirect and general supervision (Williard and Fauteux, 2011; Daniel and Kumar, 2014). Since 2004, DHATs have provided dental care and prevention services for more than 40,000 Alaska Natives (Alaska Native Tribal Health Consortium, 2017). A recent study found that Alaskan DHATs provide high-quality and appropriate care that is within their scope of practice (Wetterhall et al., 2011).

Despite the unwillingness of dentists to work in rural communities, with the majority preferring to work in major cities (Campbell et al., 2005), the Alaska workforce model has faced opposition by dentists who express concerns about the scope of practice of DTs and their ability to fix dental care access problems (Gelmon and Tresidder, 2011; Blue et al., 2015). The American Dental Association also started unsuccessful legal action against the Alaska initiative (Smith, 2007). Despite ongoing opposition, such a workforce model has been welcomed by many in the oral health workforce who consider DTs as a viable solution for expanding dental services for underserved populations and enhancing the equity in care access (Nash and Nagel, 2005). A key feature of Alaska’s DHAT is that DTs are recruited from the rural communities which they serve. It is widely acknowledged that, after graduation, students with a rural background are more likely to return to the villages where they were raised (Lopez and Blue, 2011). This implies that locally recruited students will be willing to work and live in rural areas on a long-term basis as opposed to most of the dentists who are recruited from and train outside rural areas. Because the shortfall in the number of DTs/OHTs in rural Australia is projected to increase, recruitment of increased numbers of rural students should contribute to increasing the number of dental care providers practising in rural areas (Kruger et al., 2007).
Training this type of dental workforce that emphasises on providing preventive and routine dental care would need significantly less time and fewer resources compared with training a dentist. Because most dental care does not need in-depth specialist consultation, MLDPs with additional training would be able to examine and provide care to simple cases but to refer complicated cases to a dentist. Simply producing more dentists is unlikely to completely solve workforce maldistribution problems but deploying MLDPs (with appropriate scope of practice and support to serve underserved regions), may offer a viable approach to solving the shortage of dentists in remote areas.

2.3. INEQUALITY IN DENTAL HEALTH AND DENTAL CARE

Oral health is fundamental to general health, wellbeing and quality of life (Glick et al., 2012). Although Australia has one of the healthiest populations on the globe, good health is not enjoyed equally among populations. A minority of the population experiences higher rates of disease and disability. There is a relationship between socio-economic gradients and the general health of a population. People living in remote or rural areas have life expectancies seven years shorter than people living in major cities (Australian Institute of Health and Welfare, 2008). Socially disadvantaged populations also tend to have poorer oral and general health status than advantaged groups (Australian Health Ministers’ Advisory Council, 2001). This suggesting that general health inequalities and oral health inequalities may share similar causes (Watt et al., 2014).

Over the last 50 years, there has been significant progress in improving oral health in Australia, in particular reducing caries experience in school-age children (Mejia et al., 2012). This progress has been attributed to greater fluoride exposure (predominately via public water), oral health promotion and the SDS (Mejia et al., 2012; Armfield et al., 2007). As a result, many people, particularly from advantaged groups who attend for a routine checkup, are free of a dental disease; unlike some time ago where many people had a dental disease. The majority of dental care services received are related to the routine dental checkup. A large proportion of regular dental care seekers who visit for their checkup do not require active treatment or additional appointments, people with low needs consume the majority of the scarce resources. However, this is not the case for the socially disadvantaged
population that tends to have higher rates of oral diseases. The uneven distribution of care resources among different populations within the same country is likely to widen the inequality in health outcomes.

Poor health outcomes are not evenly distributed in the population and this is reflected in oral health. Despite the fact that many of dental diseases are preventable, major inequalities in oral health do exist. Many oral diseases, including dental caries, are largely diseases of social deprivation. Poor oral health is prominent among indigenous people, households with low income, rural or remote area dwellers and refugees (Australian Health Ministers’ Advisory Council, 2001). They all suffer a poorer oral health and more severe diseases than the population as a whole (Do and Roberts-Thomson, 2007). This can happen not only in remote regions where access to dental care is primarily limited by geographical remoteness but also in underserved urban regions where access is limited by socio-economic problems (Kilpatrick et al., 2012). Inequality in the distribution of dental disease indicates an increased susceptibility for a certain group of the population and may highlight the need to target care or preventive services to those people at high-risk. Against this background, it is important to continue to explore options to address the unmet oral health needs and expand access to care among populations with high needs.

2.4. DENTAL CARIES

According to the World Health Organisation (WHO) caries is defined as “a localized post eruptive pathological process of external origin involving softening of the hard tooth tissue and proceeding to the formation of a cavity”. Dental caries is a transmissible bacterial disease process caused by acidic by-products from bacterial (such as Streptococcus mutans) fermentation of dietary carbohydrates causing a localised destruction of susceptible dental tissues (Featherstone, 2004). Tooth enamel or dentin undergoes continues demineralisation and remineralisation process (Featherstone, 2004). Demineralisation and remineralisation process generally occurs several times daily, leading either to cavitation, to repair and reversal or maintenance (Featherstone, 2004). If the balance between demineralisation and remineralisation is disturbed, the subsequent chronic demineralisation leads to the
formation of cavities in the tooth surface (Mejia et al., 2012). Therefore, tooth cavity or hole is the end-point of dental caries process (Featherstone, 2004).

The Surgeon General of the USA has described caries as a ‘silent epidemic’ and the ‘single most common chronic childhood disease’ and they recommend early detection to halt the development of the disease (U.S. Department of Health and Human Services, 2000). Dental caries remains a major health problem especially for children that can be rampant due to existing barriers that hinder access to dental care. Low SES and Indigenous backgrounds have been regarded as independent risk factors for developing caries (Armfield et al., 2006; Hallett and O’Rourke, 2003). Several factors contribute to an increased prevalence of caries particularly in children, including limited access to dental care, poverty and lack of fluoridated water supply. Less than 25% of Australians, including many Indigenous people, have no access to community fluoridated water (National Health and Medical Research Council, 2007). With almost half of Australians without dental insurance, over one-third of Australians aged 2 and over have no access to dental care (Chrisopoulos et al., 2016). There is a relationship between oral health status and household income (Slade et al., 2007). Levels of untreated decay and decayed, missing, filled teeth (DMFT) are lower in high earners (over $80 000 per year) (Slade et al., 2007). Levels of untreated decay are more than twice as high among Indigenous Australians than non-Indigenous Australians (Slade et al., 2007). Similarly, people living in remote or rural regions have higher levels of untreated decay than those in major cities (Slade et al., 2007).

2.4.1. Dental Caries Epidemiology

People who have no history of caries in their teeth are described as ‘caries free’ while people with any teeth affected by caries are described as having had ‘caries experience’ (Mejia et al., 2012). According to the WHO protocol, the number of decayed, missing and filled teeth is a measure of caries experience for deciduous teeth (dmft) and permanent teeth (DMFT). Deciduous or permanent teeth are recorded as missing (M) due to caries if the tooth was extracted because of caries whereas the tooth surface is coded as filled (F) if it has a permanent restoration (World Health Organisation, 2013).
Caries is regarded as a chronic and slowly progressive disease, despite being preventable, and is the most prevalent disease worldwide (Pitts, 2004). People remain vulnerable to caries throughout their life and are estimated to affect up to five million people in Australia each year (Mejia et al., 2012). Dental caries remains the most prevalent chronic disease of childhood, being five times more common than asthma (U.S. Department of Health and Human Services, 2000; Armfield et al., 2009). There has been a decline in caries experience in Australian children over the past few decades. Caries experience has been significantly reduced in the permanent teeth of children aged 12. In 2010, 48% of children aged 12 had a history of decay in their permanent teeth (Chrisopoulos et al., 2016), with the mean DMFT estimated to be 1.05 (Ha et al., 2013). However, the percentage of children with caries experience is rising particularly in the deciduous teeth (Ha et al., 2013). In 2010, 55% of children aged 6 had experienced decay in their deciduous teeth (Chrisopoulos et al., 2016), with mean dmft of 2.36 (Ha et al., 2013). In 2013, almost one-fifth of adults aged 65 and over had no natural teeth (Chrisopoulos et al., 2016). Results from the National Survey of Adult Oral Health 2004-2006, showed that DMFT for adults aged 65 and over (23.70) was the highest compared with DMFT for adults aged 15-24 (3.17) (Slade et al., 2007). Missing teeth contributed the most to DMFT for the elderly while filled teeth contributed the most to the DMFT for younger adults (Slade et al., 2007). There is an apparent variation in caries experience in children between the Australian States and Territories. In 2007, the proportion of children with an untreated decay was the highest in the Northern Territory (10%) and lowest in the Australian Capital Territory (3%) (Mejia et al., 2012).

2.4.2. The Burden of Dental Caries

Oral health status acts like a mirror, reflecting the socio-economic status, self-esteem and wellbeing of individuals and provides an indication of overall health. Poor oral health is still a major public issue, contributing greatly to the overall burden of disease and costs of healthcare. Dental caries is a potentially preventable disease which, if it remains untreated, can result in severe morbidity requiring costly treatment (Donahue et al., 2005). Dental caries is the second most costly diet-related chronic disease in Australia, even ahead of coronary artery disease and diabetes mellitus (National Advisory Committee on Oral Health, 2004). Dental extractions and restorations are the most common reported causes for hospital
separations or admission among Australian children (Australian Institute of Health and Welfare, 2011). In WA, dental caries has been reported as the fifth most common cause of hospitalisation for preschool children (Kruger et al., 2006). A recent study by Alsharif et al. (2015) reported a total of 43 937 children (0-14 years) were hospitalised due to various oral conditions in WA between 2000 and 2009. This study showed that the total costs of hospitalisation (in both the public and private sector) were over AUS $92 million (Alsharif et al., 2015). In the year 2010-11, Australia recorded 129 084 of hospital admissions for dental procedures requiring general anaesthesia, or 5.8 separations per 1000 population (Chrisopoulos et al., 2016).

In response to the growing demand for dental service in Australia, total dental care expenditure increased from $6133 to $8706 million between 2005 and 2013, almost $380 was spent per capita (Australian Institute of Health and Welfare, 2015). Dental care expenditure represents 10% of the total healthcare expenditure and it comes second after cardiovascular disease which accounted for the greatest spending (11%) (Australian Institute of Health and Welfare, 2015). The largest source of funds for dental care expenditure is individuals, who paying directly out-of-pocket for 60% of total dental costs (Australian Institute of Health and Welfare, 2015). The cost of dental care services in Australia is prohibitive. Most of the time, dental costs are not completely covered by health insurance. In 2010, over half of Australians had some level of dental insurance, the majority (79%) reported that the dental costs of their last visit were partially paid for by insurance (Harford and Islam, 2013). The proportion of people with untreated caries is closely associated with household income, the level of untreated caries is lower among higher SES groups (Slade et al., 2007).

Poor oral health is linked to serious health consequences impacting physical and psychosocial status. The impact of dental caries on people’s everyday lives is obvious, affecting their eating, drinking, sleep, work and social roles (Guarnizo-Herreño and Wehby, 2012). Tooth loss due to caries has an impact on both chewing ability and quality of life (Brennan et al., 2008). Caries is the primary cause of oral pain and tooth loss (Fejerskov and Kidd, 2003), leading to repeat prescriptions of antibiotics (North et al., 2007), severe pain, sepsis, and sleep loss (Shepherd et al., 1999). Children with caries have been linked with quality of life issues including below average height, weight, and head circumference, and absenteeism.
from school (Li et al., 2008; Pahel et al., 2007). Poor dental health early in life may negatively affect children’s self-esteem and school performance (Locker, 2009). In the USA, school children with dental-related illness miss on average one school day a year more than other children (Holt and Barzel, 2013). The relationship between oral and general health has been confirmed in the literature (Kandelman et al., 2008). There is a growing body of evidence linking tooth loss and periodontal disease with increased risk of heart disease (Beck and Offenbacher, 2001) and diabetes mellitus (Grossi and Genco, 1998). Poor oral health has been associated with increased risk of pre-term labour and low birth weight (Vogt et al., 2010).

2.5. PREVENTION OF DENTAL CARIES

Temporary solutions such as relying on visiting services or volunteerism to overcome the lack of dental services in underserved areas can help but are often only stop-gap measures. Looking for long-term and systematic approaches for an ongoing solution is essential. Historically, the management of dental disease has been largely focused on treatment rather than on prevention of disease (Glick et al., 2012). Dental caries is often not a self-limiting disease but its impact can be arrested or reduced through early detection, early intervention, and preventive care, particularly in young children. Therefore, there is a need to shift the approach to oral health from the treatment of dental disease towards effective preventive care (Glick et al., 2012). This concept is considered the cornerstone of cost-effective delivery of dental care, with the potential to save hundreds of millions of dollars. There is a range of long-term and systematic preventive measures that can reduce the impact of dental caries including oral health promotion, access to community fluoridated water, sealants and improvements in diet (Selwitz et al., 2007). However, scarcity of resources and maldistribution of dental workforce makes the transition to effective prevention of dental diseases is challenging. Also, these preventive strategies might be unsuccessful if they are not targeted at high-risk populations. Dental screening offers an effective approach to identify people at risk of disease yet unaware of their high risk and who may gain benefits from proven prevention or intervention strategies (Greenberg and Glick, 2012). Regular screening for dental diseases can be a valuable approach for more effective disease control.
2.5.1. Dental Screening

Screening is defined as “a process of identifying apparently healthy people who may be at increased risk of a disease or condition” (National Screening Committee, 2013). Caries occurs mainly during childhood and adolescence, its impact can be minimised through early detection (Macey et al., 2015; Brocklehurst et al., 2012). This is important because once carious lesion develops in one tooth, the disease can rapidly flare up and spread to other teeth. Therefore, it is crucial to maintain regular contact with populations at risk to prevent caries from developing in the first place. More than other chronic disorders, dental diseases can easily be detected in either clinical or community-based setting. Dental screening can be carried out by different members of the dental team (depending on the scope of dental practice in each country). However, clinical dentists have been traditionally used to performing routine dental checkups with a dental assistant often needed to record the DMFT/dmft. Recent studies have been undertaken to investigate the efficacy of dental screening by different members of the dental team, indicated that MLDPs are capable of screening for dental caries to a similar standard as general dentists (Brocklehurst et al., 2011; Brocklehurst et al., 2012; Macey et al., 2015).

Screening for dental diseases can be conducted using different detection techniques. However, tactile, visual or face-to-face (supported by a dental mirror, light, an air syringe to dry tooth surfaces and dental explorer) and radiography examination have been the most common methods used to assess oral health in the clinical setting (Young et al., 2015; Neuhaus et al., 2009a). Although screening for dental caries in a community setting has been traditionally relied on the use of visual inspection alone, a number of studies showed that failure to use radiography in diagnosis could underestimate the actual level of caries (Gowda et al., 2009). The combination of visual inspection and radiography examination is the ideal method for establishing the diagnosis of dental caries particularly for poorly visible interproximal surfaces, which are the most vulnerable sites for dental caries (Neuhaus et al., 2009a). However, the use of radiography in community-based surveys is often difficult due to its high costs, the risk of radiation and lack of equipment to carry out a standard clinical examination. Other lesion detection techniques have been also used for dental screening include fibre-optic transillumination, laser fluorescence, quantitative light-induced
fluorescence and electrical caries measurements (Neuhaus et al., 2009a; Neuhaus et al., 2009b).

Despite unaided visual inspection being the primary method used for dental screening, it has certain limitations. This technique is inappropriate to screen for caries among a large population as this requires significant economic and increased professional human resources. This method requires sterile equipment and adherence to infection control at all the time. Evidence shows that forceful probing with an explorer may cause traumatic defects in occlusal fissures and bacteria to spread into the underlying tooth substance (Ekstrand et al., 1987). Visual inspection is problematic in comparative epidemiological surveys; examiners remain non-blinded to certain characteristics of participants (Boye et al., 2013) and a very large sample size may be required when the prevalence of a disease like oral malignancy is low (Brookehurst et al., 2015). Searching for a low-cost and valid alternative that can expedite early detection of dental problems among asymptomatic populations, while maintaining a good level of diagnostic accuracy, is essential.

2.5.2. Dental Photography and Screening

The integration of ICT into healthcare services has provided health professionals with alternatives to the direct patient assessment. The use of dental photography has evolved rapidly over recent years and it has become an integral part of routine dental practice and dental education (Wander and Ireland, 2014). It has a large number of potential applications that includes dental recording, dentolegal documentation, patient communication, and education as well as clinical assessment, diagnosis and treatment planning (Wander and Ireland, 2014; Ahmad, 2009a). However, dental photography has rarely been used as a means of diagnosis, care delivery or education. Principal reasons for its use were dentolegal reasons, patient instruction and interest (Morse et al., 2010).

Image capturing methods, information quality, and connectivity have become essential factors in the success of a teledentistry service (Park et al., 2009). To date, three types of image acquisition devices have been used in dental practices. The DSLR camera remains the popular imaging device and produces the best quality images even in low-light or at high magnification situations. DSLR camera which is capable of capturing portraits, close up or
macro images of the dentition and soft dental tissues (Ahmad, 2009b). However, its relatively bulky size and large weight make this device less convenient to use and intimidating to young children. DSLR cameras also require a special flash set up for optimal intraoral illumination. Intraoral or fibre optic cameras are commonly used in dental photography and readily available in many dental practices. An intraoral camera is an excellent tool for demonstration of oral problems on a monitor but its quality may be inadequate for documentation or archiving (Ahmad, 2009b).

With cellular technology improving significantly, there has been increasing interest in using smartphone cameras in dentistry (Birur et al., 2015; Daniel and Kumar, 2016; Purohit et al., 2016). Cellular technology is an attractive innovation; almost all smartphones have a built-in camera and are readily affordable and available to general population. The inbuilt computational power and mobile connectivity of these devices simplify the processing, storage and transmission of data, and they have been shown to be effective in telemedicine, particularly in the early detection of skin malignancy (Massone et al., 2007; Kroemer et al., 2011) and hearing screening (Hussein et al., 2016; Mahomed-Asmail et al., 2016). Similar to DSLR cameras, smartphone cameras have zoom and flash features, as well as manual adjustments that allow easier capturing of intraoral or extraoral photographs. The portability and accessible features of smartphones can provide an effective means for capturing photographs in less time than other photographic devices and with minimal training (Daniel and Kumar, 2014). All photographic devices have limitations that lie in technical problems related to the resolution of the camera and its autofocusing, anti-movement effects and external flash functions (Park et al., 2012).

A still photograph has been the commonest type of photograph used in teledentistry studies concerned with the detection of oral diseases and the majority of these were undertaken in clinical or in vivo settings (Meurer et al., 2015). Evidence showed that the use of photographs in telediagnosis of dental diseases can maintain at a good level of diagnostic accuracy, comparable to that of a visual inspection (Kopycka-Kedzierawski et al., 2007; Gomez et al., 2013; Boye et al., 2013; Elfrink et al., 2009; Amável et al., 2009), thus can be used in epidemiological surveys with some degree of confidence. The majority of studies concerned with telediagnosis of oral diseases in vivo have used an intraoral camera (Kopycka-Kedzierawski and Billings, 2013; Patterson and Botchway, 1998; Boye et al., 2013; Kopycka-
Kedzierawski et al., 2007) or DSLR camera (Amável et al., 2009; Torres-Pereira et al., 2013; Morosini et al., 2014; Wong et al., 2005; Golkari et al., 2011; Martins et al., 2009; Chen et al., 2013). Similarly, the majority of studies on photographic assessments compared the reference visual assessment to intraoral photographs evaluated by clinical dentists. However, little evidence exists on the use of different members of the dental team in the detection of dental caries from a still photograph taken by a smartphone camera.

2.6. TELEMEDICINE

The decreasing cost of and innovations in ICT, coupled with increasing costs of healthcare services and the shortage of health workforce supply, have led to increasing interest in the adoption of telemedicine (Moffatt and Eley, 2010). Telemedicine or telehealth is a broad term for the use of ICT to deliver health care services and continuing education at a distance (Roine et al., 2001). Telemedicine is defined by the Institute of Medicine as “the use of electronic information and communication technologies to provide and support health care when distance separates the participants” (Rothchild, 1999). Telemedicine has emerged as one solution to address limited access to health care, particularly in places far from care centres (Ward et al., 2015). This technology has the potential to address various shortcomings that affect the healthcare delivery system, such as poor infrastructure, shortage of practitioners and delay in the delivery of care as a result of long waiting lists or the long distance to travel to tertiary centres (Clark, 2000; Folke, 2001). Although telemedicine has been researched for more than a century (Fatehi and Wootton, 2012), only a small number of health disciplines that utilise telemedicine have been clinically effective (Hersh et al., 2006) such as teleradiology and teledermatology (Hartvigsen et al., 2007).

Mobile telemedicine, mobile health or mHealth refers to the use of mobile devices to facilitate data and information exchange between patients and medical professionals (Gleason, 2015). In recent years, mobile telemedicine projects have become increasingly popular due to improved global cellular infrastructure and increasing affordability of mobile devices. Most mobile telemedicine applications rely on mobile devices. With the majority of the world’s population adopting mobile devices, mobile telemedicine is a promising solution to rising health care costs particularly in the developing world (Gleason, 2015). As a relatively
new concept, the effectiveness of mobile telemedicine is not well-known. The majority of mHealth initiatives fail in the pilot or proof-of-concept stage, thus limiting long-term impact. Despite these limitations, mobile health interventions present enormous potential particularly in the developing world and rural regions. As mobile devices are readily carried and used at any time, this technology can be used as point-of-care devices to improve the delivery and effectiveness of patient-centred care in places where primary care is unavailable (Waegemann, 2010).

2.6.1. Teledentistry

Teledentistry holds great promise not only in an urban setting where barriers to access dental services are attributed to socio-economic problems or financial hardship but also in rural regions where geographical isolation, poor infrastructure and absence of dental care services represent a great concern to rural residents as it can pose a big hurdle to seeking dental care. Teledentistry is a form of telemedicine that is specifically dedicated to dentistry that uses electronic medical records, ICT and the internet to provide consultation at a distance (Fricton and Chen, 2009). The term ‘teledentistry’ was first used by Cook in 1997, who defined it as “the practice of using video-conferencing technologies to diagnose and provide advice about treatment over a distance” (Cook, 1997). More recently, mobile teledentistry emerged from the integration of cellular technology and ICT into dental care services. Their use in epidemiological screenings, in particular, audiology and dermatology, has been proven to be beneficial (Massone et al., 2007; Kroemer et al., 2011; Mahomed-Asmail et al., 2016; Hussein et al., 2016). However, the body of literature on mobile health applications in dentistry is still limited.

The history of teledentistry can be traced back to the 1990s, when the US Army established the first teledentistry project ‘Total Dental Access’ within the Department of Defense which enabled the referring general dentists located in a dental clinic at a military base, to consult with dental specialists at a distance (Rocca et al., 1999). Ever since, the number of teledentistry projects has rapidly increased, particularly in the USA, Europe, Australia and Brazil (Mariño and Ghanim, 2013). Even though telemedicine has been practised since the late 1950s (Viegas and Dunn, 1998), there has been a relatively slow integration of telemedicine services into the mainstream oral health system (Schleyer et al., 2012). This
could pertain to dental practitioners’ concerns with costs, time management and the security threats of teledentistry, as well as the absence of reimbursement guidelines (Mandall et al., 2005b; Flores-Mir et al., 2006), this can also be attributed to the fact that many of teledentistry projects are still ongoing or in proof-of-concept stages (Mariño and Ghanim, 2013).

Consultation through teledentistry can take on two modes, real-time and store-and-forward. Real-time (synchronous) consultation involves a video conferencing between a patient and his/her practitioner at a remote site, as well as another practitioner (often a consultant) at a hub site simultaneously. The real-time application is more useful for continuing education and consultation between general dental practitioners (GDPs) and consultants (Berndt et al., 2008; Stephens et al., 2002). With the majority of consultants working in the private-sector, in the long-term, the use of the real-time modality in consultation can be inconvenient, time-consuming and costly, as it requires all parties to be online at the same time. In store-and-forward (asynchronous) consultation, clinical data (radiography, photographs and personal information) is stored, before being forwarded electronically for a consultant advice. The practices of store-and-forward teledentistry have proven to be more cost-saving and efficient compared to real-time and in-person consultation (Bradley et al., 2010; Mariño et al., 2016). Taking advantage of ICT and increasingly widespread global connectivity, as well as access to low-cost, secure cloud storage, has the potential to improve referrals and make oral care services more accessible.

The role of MLDPs such as OHTs in the delivery of teledentistry service has not been extensively investigated in the literature. The telemedicine model of dental care delivery suits role substitution in dentistry. Developing and deploying OHTs to provide routine dental services are considered rational and cost-saving approaches (Croucher, 2011). The average annual earnings of OHTs are considerably lower than that of a dentist (Pay Scale, 2016). OHTs have the potential to provide safe and effective dental care at low cost (Nash et al., 2014; Croucher, 2011). The majority of dental cases are ranged from simple to moderate and do not require complex procedures. Telemedicine consultations often need a role substitution to perform examinations, diagnosis and provide simple treatment, and a dental team member other than a dentist could be used safely to undertake this tasks. Effective and full utilisation of the right members of the dental team offer a reliable means of addressing
unmet needs and increasing the capacity of existing dental care. This is important particularly in remote or rural regions where the shortage of dental manpower is severe. However, opponents of role substitution argue that using low-cost resources in the provision of dental care may not necessarily result in cost-savings (Sanders and Bashshur, 2009). A dental practitioner with minimal training may spend longer time to reach a diagnosis and check fewer patients. They may also consume more materials or over-refer patients (Macey et al., 2016).

Several areas in dentistry that are particularly appropriate for teledentistry are remote consultations for preparing treatment plans, facilitation of patient referrals, supervision of dental practitioners working in rural settings and continuing education (Fricton and Chen, 2009). The use of teledentistry can overcome the problems caused by geographical inaccessibility whilst permitting clinical training and can enable a clinical examination and consult with a specialist via video-conferencing on accurate diagnosis and for formulating a treatment plan. Evidence indicates that trained rural MLDPs can successfully perform dental procedures under the supervision of a dental expert at a distance (Wetterhall et al., 2011). The use of telemedicine to supervise rural MLDPs remotely also offers a reliable approach to ensuring competence and safe practice (Williard and Fauteux, 2011). This approach would reduce the isolation of local providers and allow them to implement treatment plans under the guidance of a dentist at a distance as well as treating simple cases independently of a dentist while permitting collaboration for complicated cases.

In summary, the implementation of a large-scale, cost-effective epidemiological oral survey requires an economical and effective screening tool that is used by trained dental or non-dental personnel, with MLDPs evaluating dental photographs at a distance. The mobile teledentistry model (including smartphone and store-and-forward telemedicine) of dental screening can provide a methodology for dental practitioners with limited training such as OHTs/DTs to remotely screen for dental caries among general populations without being physically present, to identify high risk groups and those in which referral is necessary and to provide a quick treatment pathway for those who require urgent intervention. This offers an ideal means for an effective use of MLDPs to remotely screen large numbers at a low cost. This type of screening can also help to address the inequity in care access and inequalities in oral health particularly in populations that are struggling to obtain sustained dental services.
Chapter Three

3. A Systematic Review of the Research Evidence for the Benefits of Teledentistry

This chapter is presented as published paper in the following citation:

PREAMBLE

The previous literature review (Chapter 2) briefly highlighted the definition, history, benefits and implications of teledentistry in several areas in dentistry. This systematic review was undertaken, as an extension to earlier literature review chapter, with the intention of weighing existing evidence and identifying knowledge gaps to provide an overview for decision makers on the status of teledentistry. The introduction of telemedicine services into dentistry has led to research to evaluate teledentistry applications in different settings. However, there is still comparatively little information on the effectiveness and economic efficiency of this approach which is important for decision makers. A quality appraisal approach developed by Hailey et al. (2004) was adopted to assess the quality for teledentistry studies that takes into account both study design and study performance as well as implications for future decisions.
3.1. ABSTRACT

**Objective:** This review is designed to inform future decisions about the benefits of integrating teledentistry into routine health services, by presenting an overview of the evidence for the effectiveness and economic impact of teledentistry.

**Methods:** Two reviewers searched PubMed, EMBASE and CINAHL databases through November 2016 to identify published peer-reviewed studies in English. Teledentistry studies were included if they were; (a) controlled (randomised or non-randomised) assessment studies; and (b) compared outcomes of a teledentistry intervention in terms of clinical or economic evaluation with the outcomes of traditional clinical alternatives. The quality of the studies was evaluated using a quality appraisal tool that considered study performance and design.

**Results:** This review identified 385 publications, of which 217 full-text articles were retrieved for further inspection. Of these, only 11 articles met the inclusion criteria. Nine of the included articles showed some clinical outcomes; the other two were primarily economic analyses. The balance of these studies assessed the efficacy of teledentistry interventions rather than their effectiveness. Four studies (36%) achieved higher quality scores and have greater potential to influence health-care decision-making. To date, the most convincing published evidence regarding the efficacy of teledentistry was provided by studies on paediatric dentistry, orthodontics and oral medicine. The economic analysis referred only to cost-minimisation, suggesting that the use of teleconsultation in dentistry can be cost-saving when compared to a conventional consultation. However, high-quality economic studies on teledentistry are rare.

**Conclusion:** There is emerging evidence supporting the efficacy of teledentistry. However, there is not yet enough conclusive evidence, particularly for its effectiveness, cost-effectiveness and long-term use, to make evidence-based policy decisions on teledentistry.

**Keywords:** Teledentistry, oral health, future decisions, efficacy, effectiveness, cost.
3.2. INTRODUCTION

Dental manpower shortages, remoteness, funding challenges and the decreasing cost of and advances in technology, have increased the interest in the use of telemedicine applications (Moffatt and Eley, 2010). “Telemedicine being a subset of telehealth, uses communications networks for delivery of healthcare services and medical education from one geographical location to another, primarily to address challenges like uneven distribution and shortage of infrastructural and human resources” (Sood et al., 2007). Teledentistry is a domain of telemedicine that is specifically dedicated to dentistry, and it emerged from the combination of digital and telecommunication technology and dentistry (Yoshinaga, 2001). The implications of teledentistry for oral care services and oral health in rural or remote areas are significant (Moffatt and Eley, 2010). Teledentistry has the potential to identify high-risk populations, facilitate patients’ referrals to a dental consultant and support locally-based treatment, thus reducing waiting lists and unnecessary travel and loss of productivity (Salazar-Fernandez et al., 2012; Estai et al., 2016e; Bradley et al., 2010; Rocca et al., 1999).

A number of areas in dentistry that are particularly appropriate for teledentistry are remote consultations for preparing treatment plans, providing preventive care and supervising practitioners working in rural settings as well as continuing education (Fricton and Chen, 2009). The Dental Health Aide Therapists (DHATs) programme is a notable workforce model that makes use of role substitution (using native dental therapists) and telemedicine to address inequity in access to dental care in Alaska. In 2002, the DHATs Programme began in Alaska as an expansion of the Community Health Aide Programme (CHAP) (McKinnon et al., 2007). The CHAP has been the basis of the health care delivery system for rural Alaskan residents, providing 350 000 patient visits annually (McKinnon et al., 2007). Alaskan Natives are trained and employed as DHATs with an expanded scope of practice to perform prophylaxes, restorations and uncomplicated extractions as well as provide preventive care in Alaska Native villages (Williard and Fauteux, 2011). The DHAT’s scope of practice was established by supervising dentists who provided general supervision via telemedicine (Williard and Fauteux, 2011).

The emergence of telemedicine has led to many research studies that have evaluated teledentistry applications in different settings. Despite the heterogeneity of the studies, there is a growing body of evidence supporting the use of teledentistry, in particular, for early
detection of dental diseases (Morosini et al., 2014; Elfrink et al., 2009; Boye et al., 2013; Kopycka-Kedzierawski et al., 2007). A database search for systematic reviews and meta-analyses on teledentistry identified only four systematic reviews but, to date, no meta-analyses on teledentistry have been published (Meurer et al., 2015; Daniel et al., 2013; Mariño and Ghanim, 2013; Estai et al., 2016a). The systematic reviews, however, were descriptive, as none considered the quality of evidence or research rigour in the evaluation of studies, and mainly addressed the feasibility or accuracy of various teledentistry applications. This poses a difficulty in determining the impact of teledentistry on clinical outcomes, resultant cost-benefits and the implications for future decisions. This systematic review aims to inform decision-makers who are doubtful about the capability and merit of integrating teledentistry into routine health services by presenting an objective overview of good-quality evidence for the effectiveness and economic impact of teledentistry.

3.3. METHODS

3.3.1. Data sources

Following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines for systematic reviews (Moher et al., 2009), literature searches for teledentistry studies were conducted through November 2016 using the PubMed, EMBASE and CINAHL databases. Research on teledentistry uses the term ‘teledentistry’ inconsistently in the literature. As a result, various queries were used in the database search to ensure no relevant studies would be missed. Database searches in this review were carried out using a combination of the following keywords: ‘dental’ and ‘real-time’; ‘dental’ and ‘remote consultation’; ‘dental’ and ‘remote screening’; ‘dental’ and ‘store-and-forward’; ‘dental’ and ‘teleconsultation’; ‘dental’ and ‘tele-diagnosis’; ‘dental’ and ‘videoconferencing’; ‘teledentistry’ and ‘oral medicine’; ‘teledentistry’ and ‘oral surgery’; ‘teledentistry’ and ‘orthodontics’, ‘teledentistry’ and ‘maxillofacial surgery’; ‘teledentistry’ and ‘periodontics’; ‘teledentistry’ and ‘preventive dentistry’; ‘teledentistry’ and ‘prosthodontics’ and ‘teledentistry’ and ‘endodontics’; ‘tele-health/tele-medicine’ and ‘dentistry’.
3.3.2. Eligibility Criteria

The inclusion criteria were studies: (a) published in a peer-reviewed journal; (b) controlled (randomised or non-randomised) assessment studies; and (c) compared outcomes of a teledentistry intervention in terms of clinical or economic assessment with the outcomes of traditional clinical approaches. Studies were excluded if they were; (a) without a comparison between a teledentistry and a conventional alternatives; (b) limited to describing the technical feasibility of a certain application; (c) non-controlled studies (e.g. cross-sectional, case report or case series) due to their high risk of bias; (d) presented in the format of reviews, editorials or letters; (e) dissertations, books, reports or unpublished materials; (f) provided inadequate information such as abstract or conference proceedings; and (g) written in a language other than English.

3.3.3. Study Selection and Data Extraction

Two authors (ME and MT) screened the titles of identified publications independently and in duplicate when titles fulfilled the eligibility criteria or were unclear, the abstracts were read. The same process was used in assessing abstracts, the selection of the relevant studies was based on the data collected from the abstracts, which gave an indication that the eligibility criteria would be met, and was agreed upon discussion among the authors. In the next stage, relevant full-text articles were obtained and independently evaluated for the eligibility criteria by the two authors, who then reached an agreement on whether an article should be included. Full-text articles meeting the eligibility criteria were selected and abstracted into the evidence table (Table 3-1). The first author (ME) extracted data from the full-texts, and the other reviewer (MT) independently verified the extracted data. Discrepancies between the two reviewers were resolved through discussion. Additional details of each selected paper are presented in the evidence table, in which studies are tabulated by type of speciality, application considered; problem concerned, the technology used; outcome favour and the conclusion reached. In addition, the author’s name; country; study sample, study design and type of economic analysis are also listed here.
<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Country</th>
<th>Problem</th>
<th>Specialty</th>
<th>Application</th>
<th>Modality/Equipment</th>
<th>Study Design</th>
<th>Sample/Participant</th>
<th>Outcome Favour</th>
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<tbody>
<tr>
<td>Berndt et al. (2008)</td>
<td>USA</td>
<td>Training of postgraduate dental students</td>
<td>Orthodontics</td>
<td>Teleconsultation</td>
<td>Real-time Videoconferencing unit (Polycom VXS 7000, Polycom)</td>
<td>Prospective non-randomised controlled studies (category C)</td>
<td>Children age= 8-11 yr n=96 (control) n=30 (case)</td>
<td>Comparable</td>
<td>Peer assessment rating index was 35.6% in the teledentistry group and 44% in the direct supervision group (P&lt;0.001).</td>
</tr>
<tr>
<td>Birur et al. (2015)</td>
<td>India</td>
<td>Screening for oral diseases</td>
<td>Oral Medicine</td>
<td>Telediagnosis</td>
<td>Store-and-forward Smartphone camera (HTC Wildfire S)</td>
<td>Prospective non-randomised controlled studies (category C)</td>
<td>Targeted cohort (n=2000) Opportunistic cohort (n=1440)</td>
<td>Comparable</td>
<td>In the targeted cohort, among 51 of 81 (61%) interpretable images, 23 of 51 (45%) of the lesions were confirmed by specialists, while the opportunistic cohort (control) showed 100% concordance with the specialists (106 of 106).</td>
</tr>
<tr>
<td>Kopycka-Kedzierawski et al. (2011)</td>
<td>USA</td>
<td>Screening for caries</td>
<td>Paediatric Dentistry</td>
<td>Telediagnosis</td>
<td>Store-and-forward Dr. Camscope intraoral camera</td>
<td>Large-sample RCT Good (category A)</td>
<td>Age=12-60 month Power calculated Control=126 Test=108</td>
<td>Comparable</td>
<td>The mean dfs score for the children examined by means of teledentistry was 1.75 (SD±2.45) and for the children examined by means of teledentistry was 1.40 (SD±0.07).</td>
</tr>
<tr>
<td>Kopycka-Kedzierawski et al. (2013)</td>
<td>USA</td>
<td>Screening for caries</td>
<td>Paediatric Dentistry</td>
<td>Telediagnosis</td>
<td>Store-and-forward Dr. Camscope intraoral camera (Somotech)</td>
<td>Large-sample RCT Good (category A)</td>
<td>Age=12-60 month Power calculated Control=162 Test=129</td>
<td>Comparable</td>
<td>After follow-up examinations at 12 months, the mean dfs score for the children examined by means of teledentistry was 3.02, and for the children examined by means of the clinical method was 1.70.</td>
</tr>
<tr>
<td>Mandall et al. (2005)</td>
<td>UK</td>
<td>Patient referrals to consultant</td>
<td>Orthodontics</td>
<td>Telereferal</td>
<td>Store-and-forward Camera type not reported</td>
<td>Large-sample RCT Good (category A)</td>
<td>Patients Power calculated n=247 (control) n=80 (test)</td>
<td>Teledentistry</td>
<td>The sensitivity and specificity of the teledentistry system were 0.80 and 0.73 respectively. The inappropriate referral rate for the teledentistry group was 8.2% and for the controls 26.2% (P=0.037).</td>
</tr>
<tr>
<td>Marino et al. (2016)</td>
<td>Australia</td>
<td>Screening for oral diseases</td>
<td>Other dental fields</td>
<td>Telediagnosis</td>
<td>Store-and-forward Real-time Intraoral camera (SOPROLIFE)</td>
<td>Cost-minimisation Study (category D)</td>
<td>Aged care residents n=100</td>
<td>Store-and-forward Teledentistry</td>
<td>The net cost of store-and-forward teleconsultation was AU$32.35 while, the total cost of real-time consultation was AU$41.28 per resident. The total cost of the face-to-face examinations by a dentist was AU$36.59 per resident.</td>
</tr>
<tr>
<td>Nickenig et al. (2008)</td>
<td>Germany</td>
<td>Pre-implant dental assessment</td>
<td>Prosthodontics</td>
<td>Teleconsultation</td>
<td>Real-time Videoconference type not reported</td>
<td>Prospective non-randomised controlled studies (category C)</td>
<td>Adult patients n=772 (control) n=85 (test)</td>
<td>Comparable</td>
<td>In three cases (3%), a basic change in the prosthodontic concept was required as compared to the teledentistry plan; in the control group, the concept changed in 7% of cases.</td>
</tr>
</tbody>
</table>
Inflammation and oral hygiene between the baseline and the 3-month examination were significant in study group ($P=0.046$, $0.027$, $0.028$ and $0.028$, respectively), whereas in control group, only differences in indices of plaque accumulation and oral hygiene were significant ($P=0.026$ and $0.018$, respectively).

### Salazar-Fernandez et al. (2012)
- **Spain**
- Temporomandibular Joint Disorders
- Oral Medicine
- Telediagnosis
- Teledentistry
- Store-and-forward camera type not reported
- Prospective non-randomised controlled studies (category C)
- Patients: Average age=38-41yr, n=710 (control), n=342 (test)
- Teledentistry

Of the 342 patients with TMJD were assisted by teleconsultation, only 35 (10%) patients presented some other TMJ pathology that required maxillofacial surgery. The remaining 307 (89.7%) received non-surgical treatment in the primary care centre in a mean time of 2.3 days ($P<0.05$), and a mean cost of 16 lost working hours/patient ($P<0.05$).

### Scuffham and Steed (2002)
- **UK**
- Consultation about dental and oral diseases
- Restorative Dentistry
- Teleconsultation
- Real-time videoconference codec cards (Zydacron)
- Cost-minimisation study (category D)
- Mean age 46 years, n=25
- Teledentistry

Cost savings are greatest where the cost of travel is greatest. For Orkney (a remote island) patients, dental teleconsultation resulted in cost savings of £270 per patient compared with hospital visits. When the value of patient time was included, there were cost savings of around £900 per Orkney patient compared with hospital visits.

### Zamzam and Luther (2001)
- **UK**
- Lip position in patients with cerebral palsy
- Oral Medicine
- Telediagnosis
- Real-time remote video surveillance camera (Videomech, Newport, UK) and Videoplayer (Panasonic)
- Prospective non-randomised controlled studies (category C)
- Age: 4 yr, n=8 (control)
- Age 2 mo-12 yr, n=8 (case)
- Comparable

The agreement between the real-time videoconference and in-person clinical assessment was good (Kappa=0.68)

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dfs: decayed and filled surface; RCT: randomised controlled trial; SD: standard deviation; TMJD: temporomandibular joint disease.
3.3.4. Evaluation of Study Quality

The quality of each study, other than those aspects related to economic analysis, was evaluated independently by two authors using the protocol established by Hailey et al. (2004) (originally modified from the Jovell and Navarro-Rubio classification), taking into account the study performance and study design (Table 3-2). This protocol is a useful approach, as it can provide a quantitative measure of scientific rigour. For assessing the design of included studies, large randomised controlled trials (RCTs) were assigned a score of five. Small RCTs were assigned a score of three, prospective non-randomised controlled trials a score of two, retrospective non-randomised controlled trials a score of one and non-controlled studies a score of zero (Hailey et al., 2011; Hailey et al., 2004). For assessing the study performance, five criteria were taken into account: patient selection, description of the interventions, analysis of the study, patient disposal and outcomes reported (Hailey et al., 2011; Hailey et al., 2004). Each of the five criteria of study performance received a score of zero (if relevant information was not provided or unclear), a score of one (if relevant information was provided but there were some significant shortcomings) or a score of two (if the information provided was satisfactory, with no significant shortcomings).

The maximum overall quality scores (performance plus design) for each selected study was 15. The overall quality scores for each study provide an indication of the degree of confidence that can be placed in its findings and implications for future decisions making on teledentistry. Each study was designated to one of five categories (A to E), according to the totals of the quality scores. A study that had a high degree of confidence in its result was put in category A, whilst studies provided findings of unacceptable uncertainty and had a potential for selection bias were put in category E (Table 3-2) (Hailey et al., 2011; Hailey et al., 2004).
Table 3-2  Study Quality Classification by Hailey et al. (2004).

<table>
<thead>
<tr>
<th>Category</th>
<th>Study Design</th>
<th>Strength of Evidence</th>
<th>Overall Quality Score (a)</th>
<th>Potential Impact on Future Decisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Large RCTs</td>
<td>High quality</td>
<td>11.5-15.0</td>
<td>High degree of confidence in study findings</td>
</tr>
<tr>
<td>B</td>
<td>Small RCTs</td>
<td>Good quality</td>
<td>9.5-11.0</td>
<td>Some uncertainty regarding the study findings</td>
</tr>
<tr>
<td>C</td>
<td>Prospective non-randomised controlled studies</td>
<td>Fair to good quality</td>
<td>7.5-9.0</td>
<td>Some limitations that should be considered in any implementation of study findings</td>
</tr>
<tr>
<td>D</td>
<td>Retrospective non-randomised controlled studies</td>
<td>Poor to fair quality</td>
<td>5.5-7.0</td>
<td>Substantial limitations in the study; findings should be used cautiously</td>
</tr>
<tr>
<td>E</td>
<td>Non-controlled series</td>
<td>Poor quality</td>
<td>1-5.0</td>
<td>Unacceptable uncertainty for study findings</td>
</tr>
</tbody>
</table>

\(a\) Total score for study design and study performance.

RCT = Randomised Controlled Trials.

3.3.5. Quality of Economic Evaluation

The quality of studies relating to the economics of teledentistry was assessed against Drummond et al.’s criteria which includes a 10-point checklist (Drummond et al., 2015):

1. Was a well-defined question posed in answerable form?
2. Was a comprehensive description of the competing alternatives given?
3. Was the effectiveness of the programmes or services established?
4. Were all the important and relevant costs and accurately in appropriate physical units?
5. Were costs and consequences measured accurately in appropriate physical units?
6. Were costs and consequences valued credibly?
7. Were costs and consequences adjusted for different timing?
8. Was an incremental analysis of costs and consequences of alternatives performed?
9. Was allowance made for uncertainty in the estimates of costs and consequences?
10. Did the presentation and discussion of the study results include all issues of concern to users?

For each selected paper, a score of one was assigned for each criterion that was fulfilled. Therefore, the score for the economic evaluation of each study, ranged from 1-10.
3.4. RESULTS

3.4.1. Retrieved Articles

The database search identified a total of 385 titles, of which 287 abstracts were reviewed to determine if they were relevant to the scope of the study and were retrieved in full-text. Based on a review of the abstracts, 217 full-text articles were obtained for closer inspection. Of these, 11 were considered to fulfil the preset inclusion criteria (Figure 3-1). Nine of the included articles considered some clinical outcomes (Salazar-Fernandez et al., 2012; Berndt et al., 2008; Birur et al., 2015; Kopycka-Kedzierawski and Billings, 2013; Kopycka-Kedzierawski and Billings, 2011; Mandall et al., 2005a; Nickenig et al., 2008; Ojima et al., 2003; Zamzam and Luther, 2001). The remaining two were mainly economic analyses (Mariño et al., 2016; Scuffham and Steed, 2002). Some kind of economic analysis was considered in one study (Salazar-Fernandez et al., 2012). The Kappa statistic (as a measure of inter-reviewer reliability for the process of study selection and quality assessment) ranged from 0.62-0.70. This suggests that the concordance between the two reviewers was substantial/good at all stages.

Studies were clustered into two major applications, telediagnosis and teleconsultation. A minority of the reviewed studies were concerned with the referral, (Salazar-Fernandez et al., 2012; Mandall et al., 2005a) clinical training (Berndt et al., 2008) or oral health promotion (Ojima et al., 2003). The majority of the reviewed studies were solely focused on the speciality of oral medicine, (Salazar-Fernandez et al., 2012; Birur et al., 2015; Zamzam and Luther, 2001) paediatric dentistry (Kopycka-Kedzierawski and Billings, 2013; Kopycka-Kedzierawski and Billings, 2011) and orthodontics (Berndt et al., 2008; Mandall et al., 2005a). Two types of consultation technique were used in the studies, store-and-forward (n=5) or real-time (n=4). The studies included in this review were conducted in seven different countries, with the majority of studies from Europe (n=5) and the USA (n=3), with one each from Japan, India and Australia. The majority of the reviewed articles did not explicitly report the setting of the study (rural or urban); however, it appears that studies were carried out in either urban or rural settings such as hospitals, clinics, childcare centres or workplaces. More information on characteristics of the reviewed studies is provided in Table 3-3.
Figure 3.1 PRISMA flow diagram of included studies.
Table 3-3 Proportion of studies as per type of intervention, type of application, type of technology and location of study.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Number of Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intervention/speciality</td>
<td></td>
</tr>
<tr>
<td>Paediatric dentistry</td>
<td>2</td>
</tr>
<tr>
<td>Oral medicine</td>
<td>3</td>
</tr>
<tr>
<td>Orthodontics</td>
<td>2</td>
</tr>
<tr>
<td>Prosthodontics</td>
<td>1</td>
</tr>
<tr>
<td>Periodontics</td>
<td>1</td>
</tr>
<tr>
<td>Restorative dentistry</td>
<td>1</td>
</tr>
<tr>
<td>Other dental fields</td>
<td>1</td>
</tr>
<tr>
<td>Type of application</td>
<td></td>
</tr>
<tr>
<td>Telediagnosis</td>
<td>4</td>
</tr>
<tr>
<td>Teleconsultation</td>
<td>4</td>
</tr>
<tr>
<td>Tele-referral</td>
<td>1</td>
</tr>
<tr>
<td>Telediagnosis and teleconsultation</td>
<td>1</td>
</tr>
<tr>
<td>Telediagnosis, teleconsultation and tele-referral</td>
<td>1</td>
</tr>
<tr>
<td>Type of technology</td>
<td></td>
</tr>
<tr>
<td>Store-and-forward</td>
<td>5</td>
</tr>
<tr>
<td>Real-time</td>
<td>4</td>
</tr>
<tr>
<td>Both</td>
<td>2</td>
</tr>
<tr>
<td>Country of study</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>5</td>
</tr>
<tr>
<td>USA</td>
<td>3</td>
</tr>
<tr>
<td>Australia</td>
<td>1</td>
</tr>
<tr>
<td>Japan</td>
<td>1</td>
</tr>
<tr>
<td>India</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
</tr>
</tbody>
</table>

3.4.2. Study Scores and Classification

Several publications that had a comparison of outcomes between teledentistry and traditional clinical settings were omitted because they were non-controlled, corresponding to category E of Hailey et al.’s protocol (Hailey et al., 2004). Of the 11 studies included in this review, three were based on large RCTs (Kopycka-Kedzierawski and Billings, 2013; Kopycka-Kedzierawski and Billings, 2011; Mandall et al., 2005a), one was based on small RCTs (Ojima et al., 2003), five were non-randomised controlled trials (Salazar-Fernandez et al., 2012; Berndt et al., 2008; Birur et al., 2015; Nickenig et al., 2008; Zamzam and Luther, 2001), and a further two were non-controlled series (Mariño et al., 2016; Scuffham and Steed, 2002). Of the 11 studies, four were considered to be of high or good quality (category A or B) (Kopycka-Kedzierawski and Billings, 2013; Kopycka-Kedzierawski and Billings, 2011; Mandall et al., 2005a; Ojima et al., 2003), five studies (Salazar-Fernandez et al., 2012; Berndt et al., 2008; Birur et al., 2015; Nickenig et al., 2008; Zamzam and Luther, 2001) of fair to good
quality (category C) and the remaining two studies (Mariño et al., 2016; Scuffham and Steed, 2002) were of poor to fair quality (category D). In many papers, procedures for the selection of patients and randomisation were inadequately described. In large RCT studies (Kopycka-Kedzierawski and Billings, 2013; Kopycka-Kedzierawski and Billings, 2011; Mandall et al., 2005a), little detail was provided on the randomisation procedure and patient disposals. A further report of a small RCT (Ojima et al., 2003), had a very small sample size and a more limited description of the randomisation procedure. All studies reported sample size, with the majority of the included studies using convenience sampling in the recruitment. However, only three studies reported power calculations (Kopycka-Kedzierawski and Billings, 2013; Kopycka-Kedzierawski and Billings, 2011; Mandall et al., 2005a).

The study design and performance were a good indication of study quality. Studies that had higher overall quality scores had high study design and performance scores. The three large RCTs (Kopycka-Kedzierawski and Billings, 2013; Kopycka-Kedzierawski and Billings, 2011; Mandall et al., 2005a) achieved the highest performance scores (7.0-7.50), indicating high quality in their performance and relatively high confidence in their results. Implications for the possible impact of a study on healthcare decision-making regarding teledentistry arise from the reliability of a study as indicated by the overall quality scores and the degree of confidence put in their findings. Studies with higher overall quality scores had a high degree of confidence in their findings, and therefore, greater potential to influence future decisions on teledentistry. Six studies were found to have implications for future decision-making on teledentistry (Salazar-Fernandez et al., 2012; Birur et al., 2015; Kopycka-Kedzierawski and Billings, 2013; Kopycka-Kedzierawski and Billings, 2011; Mandall et al., 2005a; Ojima et al., 2003). The remaining studies reported more preliminary results, which may be useful to guide decision-making. The distribution of study design and performance scores with implications for future decisions for individual studies is given in Table 3-4.
Table 3-4  Quality score and potential of future decisions making on teledentistry.

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Reference</th>
<th>Overall Quality Score</th>
<th>Impact on Future Decisions</th>
<th>Economic Quality Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paediatric dentistry</td>
<td>Kopycka-Kedziewska et al. (2011)</td>
<td>12.5</td>
<td>A</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Kopycka-Kedziewska et al. (2013)</td>
<td>12.5</td>
<td>A</td>
<td>-</td>
</tr>
<tr>
<td>Oral medicine</td>
<td>Birur et al. (2015)</td>
<td>8.5</td>
<td>C</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Salazar-Fernandez et al. (2012)</td>
<td>7.5</td>
<td>C</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>Zamzam and Luther (2001)</td>
<td>7.5</td>
<td>C</td>
<td>-</td>
</tr>
<tr>
<td>Orthodontics</td>
<td>Mandall et al. (2005)</td>
<td>12</td>
<td>A</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Berndt et al. (2008)</td>
<td>7.5</td>
<td>C</td>
<td>-</td>
</tr>
<tr>
<td>Prosthodontics</td>
<td>Nickenig et al. (2008)</td>
<td>7</td>
<td>C</td>
<td>-</td>
</tr>
<tr>
<td>Periodontics</td>
<td>Ojima et al. (2003)</td>
<td>9.5</td>
<td>B</td>
<td>-</td>
</tr>
<tr>
<td>Restorative dentistry</td>
<td>Scuffham and Steed (2002)</td>
<td>6</td>
<td>D</td>
<td>6</td>
</tr>
<tr>
<td>Other dental fields</td>
<td>Marino et al. (2016)</td>
<td>5.5</td>
<td>D</td>
<td>5</td>
</tr>
</tbody>
</table>

*Total score for study design and study performance.

3.4.3. Economic Analyses

The economic analyses in the reviewed papers were methodologically more like cost-analysis studies. Cost-minimisation was said to be conducted in two studies (Mariño et al., 2016; Scuffham and Steed, 2002), since the benefits were calculated as cost-savings (direct and indirect costs) compared with the non-telemedicine alternative. One study included some indirect costs estimation (mainly lost working hours) (Salazar-Fernandez et al., 2012). The effectiveness of a teledentistry intervention was reported to be established in one study (Salazar-Fernandez et al., 2012) and assumed in two studies (Mariño et al., 2016; Scuffham and Steed, 2002). The perspective of the economic analysis was explicitly reported in two studies, with one being from both the patient’s and healthcare perspective (Scuffham and Steed, 2002) and one from only the healthcare perspective (Mariño et al., 2016). Only one study applied sensitivity analyses to evaluate the robustness of the results (Scuffham and Steed, 2002). Cost-benefit, cost-effectiveness or cost-utility were not considered in the reviewed studies. None of the selected studies considered incremental economic analysis (except Scuffham and Steed) (Scuffham and Steed, 2002). Of three studies that included economic evaluation, two studies satisfied five or six criteria given by Drummond et al. (2015) and were judged to be of fair to good quality (Table 3-4).
3.4.4. Clinical Outcomes

Despite the included studies using different objectives, methods and outcome measures, all studies indicated that teledentistry interventions were comparable to, or had advantages, over non-telemedicine approaches. The overall conclusions reached in the selected studies are given in Table 3-1. Two of the large RCT studies considered store-and-forward telediagnosis for detection of early childhood caries (ECC), and suggested that remote screening for ECC in preschool children using teledentistry was comparable to clinical visual examinations (Kopycka-Kedzierawski and Billings, 2013; Kopycka-Kedzierawski and Billings, 2011). A further report of a large RCT (Mandall et al., 2005a) which used a tele-referral system to screen new patient orthodontic referrals, indicated that teledentistry offered a valid tool for identifying appropriate new referrals and avoiding inappropriate referrals. Another report of a small RCT study considered a web-based system for promoting periodontal health in a workplace, suggesting the use of this system allowed the public to access useful health information and enabled effective intervention of oral care professionals (Ojima et al., 2003).

The non-randomised controlled studies were diverse in their quality, as evaluated by the descriptions of methods, analysis of results and outcomes. For example, Salazar-Fernandez et al. (2012) evaluated the effectiveness of store-and-forward teledentistry to perform diagnosis and provide treatment for patients with temporomandibular joint disorder (TMJD). The authors indicated that teledentistry can offer valid diagnosis and adequate treatment of TMJD from primary care sites. Nickenig and colleagues evaluated real-time teledentistry for pre-implant dental evaluation (Nickenig et al., 2008). Nickenig et al. (2008) suggested that teledentistry has the potential to facilitate preoperative assessment of the implantation operation. Another study by Berndt and colleagues indicated that interceptive orthodontic procedures performed by supervised general dentists via teledentistry can help in reducing the severity of malocclusions among children (Berndt et al., 2008). Another study by Birur and colleagues examined the effectiveness of remote oral cancer surveillance programme using the mHealth application (Birur et al., 2015). Birur et al. (2015) showed that the mHealth-based approach aided remote screening for oral cancer by primary care practitioners. A further report of a non-randomised trial considered teledentistry to assess lip position in children with cerebral palsy (Zamzam and Luther, 2001). Results indicated that
lip position assessed by real-time videoconferencing and direct clinical assessment are comparable, suggesting that videoconferencing offers a more unobtrusive approach than direct clinical assessment.

The effectiveness of teledentistry interventions was reported to be assessed in four studies (Salazar-Fernandez et al., 2012; Kopycka-Kedzierawski and Billings, 2013; Kopycka-Kedzierawski and Billings, 2011; Birur et al., 2015), however, none of the studies considered cost-effectiveness. Only a few economic analysis studies (Salazar-Fernandez et al., 2012; Scuffham and Steed, 2002; Mariño et al., 2016), particularly those concerning with cost-minimisation, were identified and included in this review. Marino et al. (2016) compared the cost and benefits of visual examination conducted by a dentist at a residential aged-care facility in rural areas with a teledentistry approach. The authors concluded that store-and-forward teleconsultation was the lowest cost service model compared to the in-person and real-time model of care. Scuffham and Steed (2002) undertook a cost-minimisation analysis to compare the costs of teledentistry with two alternatives, outreach visits and hospital visits. Scuffham and Steed (2002) reported that cost-savings could be significantly higher when teledentistry was used in remote/very remote regions and even with additional costs, teledentistry can help in reducing oral health inequalities. Another cost-minimisation study by Salazar-Fernandez et al. (2012) suggests that the use of store-and-forward telemedicine system for management of patients with TMJD can shorten the delay in treatment onset and prevent or reduce the loss of productivity by patients.

3.5. DISCUSSION

There is a consistent trend in the literature supporting the validity and reliability of teledentistry applications in comparison to non-telemedicine alternatives (Morosini et al., 2014; Elfrink et al., 2009; Boye et al., 2013; Kopycka-Kedzierawski et al., 2007; Estai et al., 2016g; Amável et al., 2009). However, most of the available literature (217 full-text articles screened) is limited to technical reports or feasibility studies, and only a small number of the studies reported a controlled comparison of a teledentistry application with conventional alternatives. In many cases, the balance of the reviewed studies was towards assessing the efficacy of teledentistry application rather than assessing its effectiveness. Controlled
assessments of the clinical outcomes and costs of teledentistry applications are needed to provide scientific evidence of the appropriateness of teledentistry.

Generally, RCTs remain the gold standard for assessing the effectiveness and cost-effectiveness of an intervention within biomedicine, due to their ability to reduce the chances of bias and control for the potential impact of confounding factors (Taylor, 2005). However, many argue that the complexity and methodological limitations of conducting RCTs to evaluate eHealth technologies may impact the generalisability of the findings (Greenhalgh and Russell, 2010). Therefore, there is a call for alternative strategies to evaluate the effectiveness of eHealth technological interventions such as using qualitative evaluation methods that allow consideration of socio-technical contextual issues (Greenhalgh and Russell, 2010). Nevertheless, in this review, a robust and scientific approach to evaluating the literature on teledentistry was used that focused on assessing controlled assessment studies reporting a comparison of outcomes of a teledentistry approach with non-telemedicine or conventional alternatives. This approach could provide more conclusive evidence of the performance of teledentistry than those without a comparator.

This review indicates that there are only a few good-quality comparative studies of teledentistry available, especially those evaluating the efficacy of teledentistry (Kopycka-Kedzierawski and Billings, 2013; Kopycka-Kedzierawski and Billings, 2011; Mandall et al., 2005a; Ojima et al., 2003). Apart from few studies that assess the effectiveness of teledentistry (Birur et al., 2015; Salazar-Fernandez et al., 2012), none of the reviewed studies considered the effectiveness, cost-effectiveness or long-term outcome of teledentistry applications. A growing body of evidence supporting the efficacy of teledentistry is provided by some of the studies on paediatric dentistry (Kopycka-Kedzierawski and Billings, 2013; Kopycka-Kedzierawski and Billings, 2011), oral medicine (Birur et al., 2015; Salazar-Fernandez et al., 2012), orthodontics (Mandall et al., 2005a) and periodontics (Ojima et al., 2003). The majority of the research in these areas reported that teledentistry had similar or better outcomes than the conventional alternative. To date, the most convincing published evidence regarding the economic benefits of teledentistry deals with teleconsultation and telediagnosis. However, cost-minimisation analysis was being considered, rather than cost-effectiveness, cost-utility or cost-benefits. The absence of good-quality economic studies in teledentistry has also been cited in previous reviews (Daniel et al., 2013; Mariño and Ghanim,
Although some useful clinical and economic outcomes have been identified in a few teledentistry applications, conclusive evidence is still rare, and therefore, the generalisability of results is difficult to ascertain.

Teledentistry is an innovative method of oral health service delivery that can connect dental practitioners and patients with a dental consultant anywhere on the globe. This is important particularly for underserved communities that lack access to oral care due to geographical barriers, socio-economic issues or dental workforce shortages. Despite its great potential to address the needs of rural or remote populations, our findings indicated that more than half of the reviewed studies were undertaken in urban areas rather than rural settings. This could be attributed to funding difficulties in rural or remote areas or to the fact that the majority of the trials of teledentistry are still in proof-of-concept or pilot stages (Daniel et al., 2013).

The present review also shows that the majority of reviewed studies are clustered in developed countries, in particular, the USA and Europe, and little research work has been done in developing countries. The dearth of teledentistry projects in developing countries could be attributed to the conservatism of decision makers, a lack of resources, information and communication technology infrastructure and equipment. In addition, the provision of dental care services in developing countries is based on emergency rather than preventive care.

There were several limitations in most of the reviewed studies, so that even though the present review was restricted to good-quality publications on teledentistry, at present they provide an inadequate indication of the status of this technology. It is possible that a large body of literature on teledentistry assessment was not located. Since the focus of this review was only on identifying controlled assessments of teledentistry and comparative outcomes, there was no attempt to review all the relevant ‘grey literature’ (e.g. education, technical reports, reviews and dissertations) as it is unlikely that there would be many articles fulfilling the inclusion criteria.

### 3.6. CONCLUSION

The present review identifies a growing body of evidence supporting the efficacy of teledentistry, particularly, in some areas of dentistry. However, in many cases, the reviewed
studies provide only preliminary results and considered only the feasibility and short-term use of teledentistry. Due to limited conclusive evidence and to the heterogeneity of the methods used, interventions and outcomes assessed in the reviewed studies, the generalisability of the findings is limited. Well-designed research into the assessment of teledentistry, taking into account its effectiveness, cost-effectiveness and long-term use, will be required before future decisions on whether to establish teledentistry services can be made.
Chapter Four

4. Diagnostic Accuracy of Teledentistry Approach for Detection of Dental Caries: A Systematic Review

This chapter is presented as published paper in the following citation:

PREAMBLE

This chapter builds on the previous systematic review study and represents an extension of our earlier literature review of teledentistry studies. Several studies have evaluated the performance of the photographic method in detecting carious lesions, and the range of reported results has been extensive and contradictory. As a result, studies are necessary to investigate how accurate teledentistry really is. Systematic reviews provide the best evidence on the effectiveness of a procedure and allow investigation of factors that may affect the performance of a screening method. To the best of our knowledge, the present systematic review is among the first to implement the quality assessment of diagnostic accuracy studies (QUADAS-2) checklist to evaluate the overall accuracy of teledentistry applications in the detection of carious lesions.
4.1. ABSTRACT

Objective: This study sought to systematically review the literature for research evidence for the diagnostic accuracy of teledentistry in the detection of dental caries.

Methods: Two reviewers searched PubMed, EMBASE, and Scopus databases through January 2016 for comparative studies that examined the diagnostic accuracy of teledentistry for detecting caries compared with non-telemedicine alternatives. Retrieved studies were screened for inclusion criteria and were evaluated for methodological quality using the quality assessment of diagnostic accuracy studies (QUADAS-2) checklist.

Results: Of 287 citations identified, 10 met the preset inclusion criteria. Sensitivity and specificity were the most common measures of diagnostic accuracy used in 10 studies. Despite very limited published evidence on the diagnostic accuracy of teledentistry, the reviewed teledentistry studies showed comparable diagnostic performance compared with non-telemedicine alternatives. The average methodological quality of the selected articles is low, since none of the selected studies satisfied all 4 QUADAS-2 domains. Only 6 articles were scored as having a low risk of bias in 3 of 4 of QUADAS-2 domains. All the selected studies had low concerns regarding applicability. The main shortcoming was that in most of the selected studies, the methodology, in particular patient selection and index tests, was insufficiently described.

Conclusions: Teledentistry has an acceptable diagnostic performance in the detection of dental caries. However, due to the heterogeneity of the reviewed studies, the generalization of results may be difficult. Further well-designed research to investigate the effectiveness of the teledentistry approach to caries detection is needed to determine the capability of this technology in epidemiologic oral surveys.

Keywords: Validity, dental caries, diagnosis, photography, telemedicine.
4.2. INTRODUCTION

Despite considerable improvement in children’s oral health over the past problem, being 5 times more common than asthma (U.S. Department of Health and Human Services, 2000). Caries is a potentially preventable infectious disease, which, if left without treatment, can result in acute morbidity necessitating costly treatment (Donahue et al., 2005). Among children, restorations and dental extractions are considered the leading causes for hospital separations in Australia (Australian Institute of Health and Welfare, 2011). In adults, caries remains the second most costly diet-related chronic disease ahead of heart diseases and diabetes mellitus (National Advisory Committee on Oral Health, 2004). Regular screening and early detection of oral problems have the potential to improve oral health and save significant resources (Brocklehurst et al., 2011).

Although visual examination remains the primary technique for caries detection (Gimenez et al., 2015), this method has some subjective limitations (related to the examiner), such as inconsistency in the charting and inability to blind examiners to particular characteristics of the subjects (Boye et al., 2013). The visual approach to caries detection is inappropriate in large-scale epidemiologic oral surveys as it necessitates excessive and expensive travel and time. It is essential to seek cost-saving alternatives that can expedite early detection of caries and provide a comparable diagnostic performance to a visual examination. Teledentistry is an increasingly popular alternative to the traditional visual approach to screen for oral diseases at a distance. Teledentistry is a new field of telemedicine which results from the incorporation of information and communication technology and dentistry (Yoshinaga, 2001). Teledentistry incorporates a store-and-forward technology and digital dental photography into oral care services, where electronic clinical data (e.g. radiographs and photographs) can be acquired by oral health professionals and then stored and forwarded for later evaluation by dental experts. Although the introduction of digital photography into dentistry has increased rapidly in recent years, it has rarely been used for diagnosis, consultation, or referrals (Chossegros et al., 2010).

There is an increasing interest in the use of teledentistry services in daily dental practice, but the quality of evaluation of this technology is still unclear. Teledentistry has been the subject of evaluation studies for over 15 years now, with several studies having been conducted to examine the diagnostic accuracy and reliability of the photographic method for the screening
for oral diseases. Recent systematic reviews on a broad range of teledentistry applications found generally positive results concerning the conventional non-telemedicine approaches (Daniel et al., 2013; Mariño and Ghanim, 2013). However, these systematic reviews have to date provided qualitative reviews, rather than a quantitative synthesis. Thus, in view of the relatively frequent use of teledentistry in screening for caries, we conducted a systematic review of the literature to evaluate the diagnostic accuracy of the teledentistry approach for caries detection as compared to the traditional non-telemedicine alternatives.

4.3. METHODS

4.3.1. Search Strategy

A comprehensive review of the literature was conducted for peer-reviewed studies that reported the diagnostic accuracy of a teledentistry approach to the detection of caries, published until January 2016. We searched the PubMed, EMBASE, and Scopus databases. The database search strategy is described in Table 4-1. The systematic reviews were conducted in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (Figure 4-1) (Moher et al., 2009).

<table>
<thead>
<tr>
<th>Search</th>
<th>Syntax</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dentistry AND (intraoral photography OR ‘photography, dental, oral’) AND (Dental caries OR Occlusal caries OR Root caries)</td>
</tr>
<tr>
<td>2</td>
<td>Dental AND (Remote screening OR Teleconsultation OR Tele-diagnosis)</td>
</tr>
<tr>
<td>3</td>
<td>Teledentistry [Title/Abstract] OR (Telemedicine AND Dentistry) OR (Telehealth AND Dentistry)</td>
</tr>
</tbody>
</table>
4.3.2. Eligibility Criteria and Study Selection

All titles and abstracts of articles identified were first assessed against the inclusion criteria: (1) examined the accuracy of the teledentistry method in the detection of dental caries; (2) had a reference standard; (3) compared the teledentistry approach to caries detection to visual oral examination or non-telemedicine methods; (4) had some mention of a teledentistry approach for caries detection using different photography techniques (video or still photograph); and (5) examined primary or permanent human teeth, either in vivo or in vitro settings.

A 3-stage screening strategy (title, abstract, and full-text study) for identified studies was performed independently and in duplicate by 2 authors (M.E. and E.K.). All titles and abstracts were reviewed by both reviewers who selected relevant articles based on the data collected from identified abstracts, which gave an indication that the inclusion criteria would be met. In the next stage, relevant full-text articles were obtained and evaluated.
independently for the eligibility criteria. Discrepancies between the 2 reviewers were sorted out by discussion and consensus. Studies in languages other than English that provided inadequate information or with no abstract available were excluded. Studies that evaluated oral diseases other than dental caries (dentine or enamel) or reported detection performance using artificial caries were also excluded from the analysis.

4.3.3. Data Extraction

The first author (M.E.) collected the relevant data from the included full-text articles into an evidence table (Table 4-2). The extracted data included the following: author and year of publication; country; equipment used (including modality, camera type, type of images ‘still or video’); study setting; sample characteristics; and study design. In addition, the scoring system to classify the disease; part of tooth analysed (per teeth and/or surface); experimental setting (in vivo or in vitro); and conclusion were considered. The second author (E.K.) checked and verified the collected data independently. Discrepancies between the 2 reviewers were settled by discussion. The strength of the evidence in each of the included studies was evaluated according to the classification scheme developed by Jovell and Navarro-Rubio (1995), in which the research design is sorted in descending order of strength from level 1 to 9.

4.3.4. Quality Assessment

In an attempt to improve the quality of the present review, 2 reviewers (M.E. and E.K.) conducted a quality assessment independently and in duplicate. Disagreement on the quality assessments was sorted out by discussion. The Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) instrument established by Whiting et al. (2011) was used to evaluate the applicability and risk of bias of the selected studies. The QUADAS-2 checklist comprised 4 domains: patient selection, index test, reference standard, and flow and timing. The 4 domains were evaluated regarding the risk of bias. The first 3 domains were additionally evaluated regarding the applicability.
Table 4-2 Summary of teledentistry studies included in the review.

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Country</th>
<th>Setting</th>
<th>Study Design</th>
<th>Sample</th>
<th>Technology used</th>
<th>Category of Experiment</th>
<th>Scoring System</th>
<th>Teeth/ surface</th>
<th>Reference</th>
<th>Main Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amavel et al. (2009)</td>
<td>Portugal</td>
<td>kindergartens</td>
<td>Cross-sectional</td>
<td>Convenient sampling</td>
<td>Store-and-forward photograph</td>
<td>In vivo</td>
<td>Scoring system created by the authors</td>
<td>Per tooth</td>
<td>Visual Examination (General dentist)</td>
<td>The sensitivity and specificity values for the photographic method ranged from 94% to 100% and 52% to 100%, respectively. The average PPV and NPV were 80% and 97%. In comparison to the reference histology, the median sensitivity for the photographic and visual assessments were 81.3% and 65.5%, respectively. The 2 methods had comparable specificities. The median intra-examiner agreement for the visual and photographic assessment was 0.85 and 0.74, respectively.</td>
</tr>
<tr>
<td>Boye et al. (2012)</td>
<td>UK</td>
<td>University Oral Health Unit</td>
<td>Cross-sectional</td>
<td>n=50 extracted human permanent teeth</td>
<td>Store-and-forward photograph</td>
<td>In vitro</td>
<td>BASCD</td>
<td>Per occlusal surfaces</td>
<td>Histology Examination</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Primary School</td>
<td>Cross-sectional</td>
<td>Age=5 year; n=130</td>
<td>Intraoral camera (Sopro 717, Acteon Group)</td>
<td>In vivo</td>
<td>DMFT/dft</td>
<td>Per tooth</td>
<td>Visual Examination (General dentists)</td>
<td>The teledentistry method had a sensitivity of 88% to 96% in the 5-y-olds and 59% to 72% in the 10- to 11-y-olds. Teledentistry method had a specificity of 82-93% in the 5-y-olds and 65-78% in the 10- to 11-y-olds. The median intra-examiner agreement for the visual examinations was 0.98 in the 5-y-olds and 0.93 in the 10- to 11-y-olds. The median intra-examiner agreement for the photographic method was 0.93 in the 5-y-olds and 0.81 in the 10- to 11-y-olds.</td>
</tr>
<tr>
<td>Elfrink et al. (2009)</td>
<td>Netherland</td>
<td>Dental practice</td>
<td>Cross-sectional</td>
<td>Convenient sampling</td>
<td>Store-and-forward photograph</td>
<td>In vivo</td>
<td>dft</td>
<td>Per tooth and surface</td>
<td>Visual Examination (Paediatric dentists)</td>
<td>The sensitivity and specificity values for the photographic assessment were 86% and 84%, respectively. The interobserver agreement for the photographic</td>
</tr>
<tr>
<td>Study</td>
<td>Country</td>
<td>Subjects</td>
<td>Study Design</td>
<td>n</td>
<td>Materials and Methods</td>
<td>Assessment Method</td>
<td>Assessment Result</td>
<td>Inter-examiner Agreement</td>
<td></td>
<td></td>
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<tr>
<td>Erten et al. (2005)</td>
<td>Turkey</td>
<td>Cross-sectional</td>
<td>n=62</td>
<td>Store-and-forward Still image, Intraoral camera (Rydalmere NSW 2116, Australia)</td>
<td>In vitro</td>
<td>ERK scale, Per occlusal surfaces, Histology Examination</td>
<td>In comparison to the reference histology, the sensitivity and specificity of the photographic method were 43% and 80%, respectively. The PPV ranged from 75% to 84% and NPV ranged from 43% to 49%. The inter-observer kappa for the photographic ranged from 0.33 and 0.46.</td>
<td></td>
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<tr>
<td>Estai et al. (2016)</td>
<td>Australia</td>
<td>Cross-sectional</td>
<td>n=100</td>
<td>Store-and-forward Photograph, Smartphone camera (Motorola Moto G)</td>
<td>In vivo</td>
<td>Scoring system Based on WHO guideline for oral health survey, Visual Examination (General dentist)</td>
<td>The sensitivity and specificity of the photographic method ranged from 60% to 68%, and 97% to 98%, respectively. The PPV and NPV ranged from 57% to 66% and 97% to 98%, respectively. The inter-examiner agreement between the visual and photographic assessment ranged from 0.57 to 0.61. The intra-examiner agreement for the photographic method was 0.89.</td>
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</tr>
<tr>
<td>Forgie et al. (2003)</td>
<td>UK</td>
<td>Cross-sectional</td>
<td>n=80</td>
<td>Store-and-forward Video and photograph, Intraoral camera, Video (Clear-Vu, dental practical systems)</td>
<td>In vitro</td>
<td>Scoring system created by the authors, Per occlusal surfaces, Histology Examination</td>
<td>In comparison to the reference histology examination, the visual inspection had a sensitivity of 43% and a specificity of 92%, the photographic assessment had a sensitivity of 68% and specificity of 64% and video assessment had a sensitivity of 77% and specificity of 60%.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Country</td>
<td>Setting</td>
<td>Design</td>
<td>Sample size</td>
<td>Methodology</td>
<td>Equipment</td>
<td>In vivo/In vitro</td>
<td>Diagnosis System</td>
<td>Method</td>
<td>Other</td>
</tr>
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<tr>
<td>Gomez et al. (2013)</td>
<td>UK</td>
<td>Oral care centre</td>
<td>Cross-sectional</td>
<td>n=112</td>
<td>Store-and-forward photograph</td>
<td>Intraoral camera (SoproLife)</td>
<td>In vitro</td>
<td>ICDAS</td>
<td>Per occlusal surfaces</td>
<td>Histology Examination</td>
</tr>
<tr>
<td>Kopycka-Kedzierawski et al. (2007)</td>
<td>USA</td>
<td>Childcare centre</td>
<td>Cross-sectional</td>
<td>Age=4-6 year n=50</td>
<td>Store-and-forward photograph</td>
<td>Dr. Camscope intraoral camera</td>
<td>In vivo</td>
<td>dfs</td>
<td>Per surfaces</td>
<td>Visual Examination (General dentist)</td>
</tr>
<tr>
<td>Morosini et al. (2014)</td>
<td>Brazil</td>
<td>Juvenile detention facility</td>
<td>Cross-sectional</td>
<td>Age=15-19 year n=102</td>
<td>Store-and-forward photograph</td>
<td>DSLR camera (Canon)</td>
<td>In vivo</td>
<td>DMFT</td>
<td>Per tooth</td>
<td>Visual Examination (NR)</td>
</tr>
</tbody>
</table>

DMFT=Decayed, missing, and filled teeth; dfs = decayed, and filled surface; dft=decayed, and filled teeth, NR = not reported; ICDAS = International Caries Detection and Assessment System; WHO = World Health Organization; ERK = Ekstrand, Ricketts and Kidd; BASCD = British Association for the Study of Community Dentistry; PPV = Positive Predictive Value; NPV = Negative Predictive Value.
4.4. RESULTS

The bibliographic databases search identified a total of 287 titles, of which 244 abstracts were reviewed to determine if they were relevant to the scope of the study and were retrieved in full-text. Of these, 10 full-text articles satisfied the eligibility criteria and were included in the final analysis (Figure 4-1). All 10 included studies came from PubMed database.

4.4.1. Characteristics of the Included Studies

Teledentistry studies included in the present review were carried out in 7 different countries, with 6 studies from Europe. All the reviewed studies (n=10) were published during 2003 to 2016, and 5 of these studies were published in the past 5 years (since 2011). Six of the studies were conducted in clinical (in vivo) and 4 studies in laboratory (in vitro) settings. Four studies used a histology examination as a reference standard and 6 studies used a visual oral examination as the reference standard. The review shows clustering of the studies in paediatric dentistry, 2 studies evaluated adult participants (Estai et al., 2016b; Morosini et al., 2014) and the studies that considered children had a broad range in age groups. Most of the reviewed studies did not explicitly report the setting of the study (rural or urban). Three studies were carried out in childcare centres or schools, and the remaining studies conducted in hospitals, oral health centres, or dental clinics. Different scoring systems were used to evaluate dental caries, including some established by the authors. The type of equipment used to acquire the photographs showed significant variations, most of the included studies (n=7) used intraoral cameras as a photographic device, 2 studies used digital single-lens reflex (DSLR) cameras and 1 study used a smartphone camera (Estai et al., 2016b). All studies used store-and-forward technology, and except for 1 study, all studies used still photographs rather than video in the analysis (Table 4-2).

4.4.2. Diagnostic Outcomes and Study Design

Sensitivity and specificity were the most common measures of diagnostic accuracy used in 10 studies. Only 4 studies reported positive and negative predictive values. Diagnostic
reliability (interobserver or intraobserver kappa) of the teledentistry approach compared with the gold standard was used in 8 studies. The collected diagnostic accuracy and reliability data show contrasting results (Table 4-2). The sensitivity of the photographic assessments ranged from 43% to 100% and the specificity ranged from 52% to 100%. Kappa, as a measure of interobserver agreement for the photographic method as compared with the gold standard, ranged from 0.33 to 0.86. Kappa as a measure of intraobserver agreement of photographic method ranged from 0.65 to 0.98. Three studies (Boye et al., 2013; Forgie et al., 2003; Erten et al., 2005) favoured the photographic caries assessment to visual examination, and in the remaining 7 studies, the diagnostic accuracy for the photographic method and visual caries assessment were comparable. All 10 reviewed studies were uncontrolled descriptive studies corresponding to category VII according to the Jovell and Navarro-Rubio criteria. Sample sizes ranged from 50 to 270 individuals, with only one study having sample size estimates and power calculations (Estai et al., 2016b).

4.4.3. Risk of Bias and Applicability Assessment

The results of quality assessment for the 10 included studies are presented in Table 4-3. Most authors did not provide a comprehensive description of the eligibility criteria for their studies, nor did they explicitly state if the examiners independently evaluated photographs without knowledge of the results of the gold standard. In addition, it was not clear whether the gold standard was calibrated or not. All studies used convenience sampling in the recruitment. The domains of index test and patient selection contributed the most to the risk of bias, being insufficient in 30% and 40% of the studies, respectively. Erten et al. (2005), Forgie et al. (2003), Boye et al. (2012), and Gomez et al. (2013) had a high risk of bias as a result of the lack of randomization and blindness during the sampling process. Amável et al. (2009), Estai et al. (2016b), and Morosini et al. (2014) had an unclear risk of bias because of the lack of information about the eligibility criteria of patients, sampling, and randomization procedures. Elfrink et al. (2009) and Kopycka-Kedzierska et al. (2007) had a high risk of bias because the same examiners were used to interpret both the reference standard and index test. The reference standard and flow and timing domains were considered adequate in 100% and 92%, respectively, of the studies (Figure 4-2). Boye et al. (2013) had the highest risk of bias because the index test was not interpreted independently from the reference
standard, and the study showed no adequate time interval between the reference standard and index test. All the selected studies had good applicability (Figure 4-3). Due to the lack of high-quality diagnostic accuracy studies and variations of study design, it was not possible to carry out a meta-analysis.
Table 4-3  Quality assessment outcomes of the selected studies using the QUADAS-2 checklist (Whiting et al., 2011).

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Patient Selection</th>
<th>Index Test</th>
<th>Reference Standard</th>
<th>Flow and Timing</th>
<th>Patient Selection</th>
<th>Index Test</th>
<th>Reference Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amavel et al. (2009)</td>
<td>?</td>
<td>?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Boye et al. (2012)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Boye et al. (2013)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Elfrink et al. (2009)</td>
<td>?</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Erten et al. (2005)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Estai et al. (2016)</td>
<td>?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Forgie et al. (2003)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Gomez et al. (2013)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Kopycka-Kedziewski et al. (2007)</td>
<td>?</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Morosini et al. (2014)</td>
<td>?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Yes = Low Risk  
No = High Risk  
? = Unclear Risk
4.5. DISCUSSION

The present review sought to assess the diagnostic accuracy of the teledentistry approach for detection of caries compared with reference visual inspection or non-telemedicine alternatives. Ten studies were found that met the criteria for inclusion in this review, and more than half of the included studies (Estai et al., 2016b; Boye et al., 2012; Forgie et al., 2003; Gomez et al., 2013; Erten et al., 2005; Morosini et al., 2014) were scored as having a
low risk of bias, and all the included studies had low concerns regarding applicability (Figures 4-2 and 4-3). All the selected studies (n=10) were dominated by uncontrolled descriptive studies and assessed the efficacy of teledentistry rather than its effectiveness, thus providing poor evidence. Randomised controlled trials are regarded as the most reliable method of evaluating the effectiveness and cost-effectiveness of an intervention in health care. However, conducting randomised controlled trials in telemedicine to evaluate the effectiveness of an intervention is often challenging, expensive, and not always practical, depending on local variations in administration and organisation.

Sensitivity and specificity as a measure of diagnostic accuracy for the teledentistry approach ranged from moderate to high. Kappa statistic as a measure of interobserver agreement between a teledentistry approach and the reference alternative ranged from fair to almost perfect agreement. Most of the reviewed research on photographic caries assessment showed at least equivalent diagnostic accuracy and reliability when compared to non-telemedicine alternatives. The QUADAS-2 instrument established by Whiting et al. (2011) was used to evaluate the risk of bias and applicability for the included articles. The average methodological quality of the included articles is low, since none of the studies satisfied all 4 QUADAS domains. Only 6 articles (Estai et al., 2016b; Boye et al., 2012; Forgie et al., 2003; Gomez et al., 2013; Erten et al., 2005; Morosini et al., 2014) were scored as having a low risk of bias in 3 of 4 of QUADAS-2 domains (Figure 4-2). The major issue was that in most of the selected studies, patient selection and index tests were not very clearly described.

Dental caries is considered the fifth leading reason for admission to the hospital for preschool children in Western Australia (Kruger et al., 2006). From 2013 to 2014, the total expenditure on dental care in Australia increased to $9 billion (Australian Institute of Health and Welfare, 2015). Caries not only requires costly treatment, but it can impact on the quality of life of children. In the long term, if caries remain untreated, it may influence the growth and cognitive development of young children (Anderson et al., 2004). There has been increasing interest in research into caries detection in children. This is reflected in this review with a substantial number of the included studies that having been carried out in childcare or school settings and most studies involved preschool-aged or school-aged participants.

Less than half of the reviewed studies were conducted in **in vitro** settings. **In vivo** studies are more costly and time consuming than **in vitro**. However, **in vitro** studies have certain
shortcomings in that they are inappropriate for the evaluation of the effectiveness of a new diagnostic method. The in vitro approach may also present difficulties in the generalization of findings as this approach is often conducted in a highly standardized way and under ideal conditions which are absent under normal clinical settings. Although the photographic method has the potential to maintain diagnostic performance at the level of visual oral examination, this method has certain limitations. Neither visual examination nor the photographic method can detect precavitated lesions. The shortcomings of the photographic method are mainly related to the inability to detect small carious lesions, difficulty in distinguishing lesions from artifact spots, quality of images, and two-dimensional view which only allows the detection of carious lesion on the occlusal surface (Estai et al., 2016b). The quality of the photographs and equipment used to acquire the photographs may influence interpretation and analysis of images and consequently result in suboptimal sensitivity and specificity and reduced inter-examiner or intra-examiner reliability.

There is increasing interest in store-and-forward technology; the store-and-forward method is more attractive than real-time consultation as it can provide good results at low cost, without the additional costs for equipment or connectivity. All 10 of the selected studies used a store-and-forward method. Store-and-forward telemedicine has the potential to prioritize new patient appointments and facilitate patient referrals to a consultant, especially in places that require lengthy travel. It has also proven to be more cost saving than real-time and in-person clinical consultation in dentistry and some clinical disciplines (Butler and Yellowlees, 2012; Okunseri et al., 2011; Mariño et al., 2016). The photographic method and store-and-forward telemedicine have been used widely to screen for diseases in ophthalmology, dermatology, and audiology. Traditionally, a DSLR camera is the primary photography device due to its ability to generate high-quality images even in a low-illumination situation or at a high-magnification. However, this review shows variations in the type of equipment used to acquire the photographs, with most studies using intraoral cameras as the primary photographic technique. Compared with DSLR camera, the intraoral camera often produces images with poor quality. Besides these devices being relatively expensive and not always providing satisfactory images, intraoral cameras are also not yet readily available to rural dental providers, and even less so for patients.

More recently, mobile telemedicine is often regarded as a subdivision of telemedicine. It emerges as a combination of cellular technology and store-and-forward technology (Estai et
Mobile telemedicine has recently proven beneficial, in particular in tele-audiology (Mahomed-Asmail et al., 2016) and teledermatology (Kroemer et al., 2011), as well as dentistry (Estai et al., 2016b; Estai et al., 2016d). Cellular technology is an attractive innovation due to its inherent digital imaging capabilities, mobile connectivity, and sharing as well as being readily available to the general population. In addition, the relatively low-cost, small weight, portability, and ability of users to provide satisfactory photographs with less training make these devices appropriate to use in epidemiologic oral surveys. Further research is required to determine the capability of smartphone technology in dental screening.

The store-and-forward teledentistry approach for assessment of oral health has advantages in rural settings, where nurses or non-licensed health care providers such as teachers or parents could be employed to obtain clinical data (photographs, radiograph, or clinical information) for a dental expert to evaluate at a distance (Estai et al., 2016b). The photographic approach could facilitate the archiving of the photographs and allow dental experts at a hub site to assess dental photographs at their desktop quickly and easily. This can reduce the introduction of potential bias and increase the diagnostic accuracy. As telemedicine and digital imaging technologies, including visible light photography, radiographic, and other modalities, rapidly evolve, the reduction in the size and improvement of features of the various technology-supporting equipment will reduce the cost of establishment of telemedicine services. Therefore, the use of photographic methods in large-scale epidemiologic studies becomes feasible. In epidemiologic oral surveys, this strategy offers a practical and potentially cost-saving method for screening for oral diseases among unreachable and high-risk populations, who have limited access to oral care.

4.6. CONCLUSION

Based on this systematic assessment of the literature and taking into account the limitations of photographic caries assessment, it can be concluded that the teledentistry approach has an acceptable diagnostic value in the detection of caries lesions. Despite very limited published evidence on the diagnostic accuracy of teledentistry, the reviewed studies showed at least comparable results between photographic methods and the non-telemedicine
alternatives of caries assessment. However, due to the diversity in the research methodology used, the generalization of results may be difficult. Further well-designed research to investigate the effectiveness of teledentistry in the detection of dental caries is needed to determine the capability of this technology in epidemiologic oral surveys.
Chapter Five

5. General Methods

Part of this chapter was published in the following article:

PREAMBLE

The studies employed to test the principle hypothesis are presented in Chapters 6 through to 12. The methods which are common to all the Results chapters are presented here to avoid repetition. The specific details of the methods used in each study are provided separately in the published and submitted paper chapters and are not described in detail in this chapter. Seven inter-related studies form the body of this PhD thesis, five observational cross-sectional studies and two cost modelled data studies. Of these five observational studies, two studies used a survey questionnaire and three studies validated the photographic caries assessment method by different members of the dental team. All studies are completed and there are no studies are ongoing. Human Research Ethics approval required for the studies are outlined and none of the studies received external funding.
5.1. SECTION 1 (Chapters 6-8): Validation of a photographic caries assessment method by different oral health professionals.

5.1.1. Overall Design

This section consists of three cross-sectional studies that evaluate the use of:

- Smartphone camera-based photographic caries assessment by different oral health professionals (Chapters 6 and 7).
- DSLR-based photographic caries assessment by different oral health professionals (Chapter 8).

All data collection was completed under ethics approval from the Human Research Ethics Committees of the University of Western Australia, the James Cook University and Department of Health Western Australia Human Research Ethic Committee (Appendix B, C and D).

5.1.2. System Architecture

5.1.2.1. Remote-i server

A cloud-based storage system, ‘Remote-i’, based on a store-and-forward technology, was developed by the AEHRC to work as a platform for data storage and management (Xiao et al., 2015). The Remote-i is a comprehensive data management system that has been previously used, in particular, in teleophthalmology in China, to screen for diabetic retinopathy (Xiao and Kanagasingam, 2015). This system is capable of image acquisition, data entry, storage and retrieval of data through a password-protected system as well as enabling uploading and storing of images online either directly from any Remote-i display devices (mobile or computer). The Remote-i server uses Microsoft ASP.NET server technology under the Windows 2008 server and is built using the ASP.NET MVC framework. Dental screening data is stored on the server using the Microsoft SQL Database engine. The website is built using modern web standards (HTML5, JavaScript and CSS technologies), and can be rendered
in any mobile/desktop web browsers with proper size proportions. Users can log in to the Remote-i using any web browser, including Chrome, Mozilla Firefox and Safari, from any location. The database is highly portable across various platforms, including Microsoft Windows, Mac OS X, and Linux. For security purposes, all data transmissions go over encrypted internet connections such as Secure Socket Layer (SSL) and hypertext transfer protocol over SSL. The speed of data transmission depends on the network bandwidth available at the facility, but at a maximum, it may take 2-3 minutes (using the 3G network in rural areas) to transmit data from the smartphone to the server. To ensure privacy, the patients' information stored in the server were anonymous and unidentifiable, the record for each patient had an ID that corresponds to the hospital ID and only authorised users were allowed to access the database using user IDs and passwords (Figure 5-1).

Figure 5-1  Figure A illustrating the database stored in the Remote-i server; Figure B depicting a dental record for a patient that includes sections for personal patient details, photographs and an oral assessment chart.
5.1.2.2. **Image acquisition App**

An image acquisition Android ‘Teledental’ App was developed and installed on the Motorola® Moto G smartphone (8.0 megapixels camera) to facilitate entering patient personal details and capturing dental images and then uploading data corresponding to each patient to cloud storage, using Wi-Fi hotspots or the cellular data networks (Figure 5-2). At this stage, the Teledental App only supports Android devices, but an App that can support other operating systems such as IOS and Windows is under consideration. The patients’ data stored in the database system are accessible via a specially designed web interface. The web interface also allows users to plug in any USB dental camera, capture images and add them to the current patient’s record without the need to import them from the mobile device. The research team can also access the server and follow up with the remote screening site for further action.

![Motorola Moto G smartphone](image.png)

*Figure 5-2  Image for Motorola® Moto G (2nd gen) smartphone device used in dental photography.*

The Teledental App is developed using Java on the Android platform. The App uses an SSL to transfer information to and from the cloud server. The cloud server and Teledental App
communicate using the JSON (JavaScript object notation) messaging standard to promote open interoperability within different kinds of systems. The Teledental App is designed to invoke any Android camera App to capture images, which provides the user with the flexibility to choose suitable camera apps for dental photography or use the default one. The Teledental App can seamlessly take control after image capture and manage the captured images using adding, deleting, clipping and reviewing functions (Figure 5-3).

![Figure 5-3 Image illustrating the acquisition Teledental App used in dental photography.](image)

### 5.1.3. Sample Size Estimation

The sample size calculation was based on a two-sided 95.0% CI for a single proportion using the Z-test approximation, an effect size of 0.1 and expected the observed proportion of 0.90. The number of participants with caries that met a power of 0.8 was estimated to be 35 \[n \geq (Z^2/m^2)*p (1 – p)\] (Brocklehurst et al., 2012). With the prevalence of dental caries at 35%
(1.86x35=65), 65 participants without dental caries were needed for the study. So a sample of at least 100 participants was needed for each study.

5.1.4. Study Population

- Chapters 6 and 7: This was a prospective observational study that examined a convenience sample of 100 participants of different ages in 2014. The recruitment of patients took place in two dental clinics, the dental department at the James Cook University in Cairns and ‘Absolute Care’, a dental practice in Perth. After obtaining informed consent from adults and the parents/guardians of children who attended dental clinics, eligible participants were recruited to obtain a few dental photographs using a smartphone camera (Appendix E). All dental photographs were unidentifiable, showed only intraoral and extraoral structures.

- Chapter 8: This study was a retrospective observational study that examined intraoral photographic records of 126 children (2 to 18 years old), who were regularly attending patients to the dental department at the Princess Margaret hospital for children between the years 2010 and 2014.

5.1.5. Screening Procedure (Visual and Photographic)

- Chapters 6 and 7: Using the screening protocol established in our previous proof-of-concept trial (Estai et al., 2016d), each participant received an unaided visual oral examination (using a sterile probe and dental mirror) by a registered dentist to record caries and existing restorations at tooth level (Figure 5-4). In the visual screening procedure, no radiographic examination was used to detect carious lesions. The dentist recorded data on an oral assessment sheet aligned with WHO protocol (World Health Organisation, 2013) (Appendix F). This screening (unaided visual inspection) was to provide baseline data which was used as the gold standard. In a separate visit, a trained tele-assistant (dental students or nurses) acquires still photographs from each participant’s oral cavity using Moto G camera. Cheek retractors, tooth-drying procedures and intraoral mirrors were not used during photography, and patients were not asked to
brush their teeth prior to the dental photography as to simulate the final expected working conditions in a large-scale epidemiological screening. To ensure appropriate infection control, patient’s mouth was not touched during photography and tele-assistants were asked to wear a surgical mask and use a disposable tongue depressor when necessary. An average of five dental photographs were taken per participant including one anterior view; one upper occlusal view; one lower occlusal view and two lateral view photographs. Techniques for obtaining each oral view were demonstrated during training, and each tele-assistant was provided with a dental photography protocol (Appendix G). Each tele-assistant had also the opportunity to practice using the smartphone’s camera on adult volunteers for as long as it took for them to feel competent. The photographs or records were directly transmitted from the smartphone to the Remote-i server for a later evaluation by an offsite charter (Figure 5-5). The uploaded photographs were 500-2000 KB in size and saved as JPEG format to the Remote-i server.

Figure 5-4     Diagram showing visual/tactile oral inspection by a dentist.
Chapter 8: A DSLR camera (Canon EOS 7D, EF 100mm f2.8 Macro USM Lens, Macro Ring Lite MR-14EX) with 18.0 megapixels resolution, was used to obtain dental photographs from all 126 patients undergoing dental treatment under general anaesthesia (Figure 5-6). Dental photography was completed pre-operatively by a trainee specialist dental registrar. A standard series of three intraoral photographs per patient was obtained (anterior, upper occlusal and lower occlusal views), and these were uploaded to the Remote-i server at a later time. The uploaded photographs were 1000-4000 KB in size and saved as JPEG format to the Remote-i server. All intraoral photographs were then reviewed by an expert panel (three dental practitioners) to formulate a baseline screening database. A dentogram based on the collaborative assessment of the panel was formulated for each record to reflect the dental status at the time the photographs were taken pre-operatively. The expert panel assessment was considered the benchmark against which the other charters’ assessments were compared.
Figure 5-6  DSLR camera (Canon EOS 7D) used to acquire dental photographs.

5.1.6. **Outcome Assessment**

Because photographs only provide a two-dimensional view, it was difficult to inspect all surfaces of the teeth, particularly the interproximal surfaces of the posterior teeth. Therefore, doing analysis based on the International Caries Detection and Assessment System (ICDAS-II) (which is based on tooth surfaces) was difficult. In order to make a comparison between the visual and photographic assessments, the entire tooth, rather than tooth surface, was used as a unit of analysis, with the teeth scored as either having caries or being sound. We used a method developed by WHO based on tooth-by-tooth assessment (World Health Organisation, 2013), which is simple and easy to use in the field in large epidemiology surveys. Interproximal or root caries was excluded, due to the difficulty of detecting these carious lesions from photographs. Filled and missing teeth were also excluded from the analysis. Based on observations from a previous proof-concept study, charters were asked to score any tooth not amenable to be scored as ‘unrated’ for the purpose of facilitating the charting process (Estai et al., 2016d).

All dental records obtained by the tele-assistants were screened by an independent colleagues to ensure that the photographs were complete, colour-balanced, focused and
clear. The photographic caries assessments were independently carried out by four charters (two dentists and two MLDPs) using a Remote-i display device (Figure 5-7). A simple user manual and cover letter were sent to the four charters explaining the study purpose and how to use the system. To ensure image persistence and better viewing of photographs in an appropriate size, charters used a desktop monitor rather than mobile devices to display intraoral photographs and undertake charting. Different colour spectra of Remote-i display devices were not considered at that stage, because it is out of the scope of the thesis and thought to be insignificant when detecting carious lesions. Charters can access the database using individual user IDs and passwords. After selecting a record, a list of dental photographs and a predefined assessment chart appears for the charter to insert their comments (Figure 5-1). The chart includes an oral health assessment form aligned with the WHO protocol for oral health assessment (World Health Organisation, 2013). The system enabled each charter to evaluate photographs independently and submit reports or recommendations into the Remote-i. These independent assessments created the database which was used to compare with the benchmark panel assessment and between the charters.

Figure 5-7 A charter accessing the database to review dental photographs.
5.1.7. **Statistical Analysis**

The weighted kappa statistic was used to estimate the inter-examiner reliability of the photographic (done by charters) and visual caries assessment methods (Landis and Koch, 1977). To estimate the intra-examiner agreement, fifteen percent of the photographic records were re-evaluated again by charters, at least four weeks after the initial evaluation of the dental photographs. Diagnostic accuracy measures were used to compare the validity of the new screening tool (the photographic method) to the existing screening tool (visual inspection) to determine the presence or absence of caries. Diagnostic accuracy was represented by four measures, sensitivity and specificity as well as positive and negative predictive values.

5.2. **SECTION 2 (Chapters 9-10):** End-users’ acceptance of a mobile teledentistry system and the perceptions of Australian dental practitioners about the use of telemedicine in dentistry.

5.2.1. **Overall Study Design**

This section consists of two cross-sectional studies involving an anonymous electronic survey. The first survey (Chapter 9) was completed by the end-users of the mobile teledentistry system. The second survey (Chapter 10) was completed by a sample of Australian dental practitioners. Both studies were approved by the University of Western Australia’s Human Research Ethics Committee prior to the commencement of the study (Appendix B).

5.2.2. **Study Population**

- Chapter 9: A total of 17 tele-assistants (nurses and dental students) were responsible for obtaining dental photographs from participants’ mouths using a smartphone camera. Five dental practitioners (charters) evaluated the dental photographs. An end-user acceptance survey was sent to the charters and smartphone users following completion of the screening program.
Chapter 10: A sample of 169 registered dental practitioners working in Australia was randomly identified from the directory of the International Research Collaborative—oral Health and Equity (IRCOHE) (IRCOHE has over 1000 members). The sample shared common demographic and professional characteristics with the Australian dental workforce.

5.2.3. Survey Questionnaire

Chapter 9: The survey consisted of four sections, the first section included questions about the users’ demographic characteristics. The second section comprised of 11, five-point, Likert-type questionnaires (never/almost never=1; seldom=2; about half the time=3; most of the time=4; always/almost always=5) used to assess the quality of the system. The questionnaire items in the second section covered five dimensions; content, format, information quality, ease of use, and service quality and support. An additional two items were included to assess the usefulness and overall satisfaction. The third section examined the average time that was spent to create a record and complete photography using the Teledental App, and charting a record on the Remote-i server. The fourth section solicited free comments about whether users have suggestions to improve existing systems (Appendix H).

Chapter 10: The survey consisted of two sections, the first section of the survey solicited demographic and professional background information, as well as internet access time and preferred methods of communication. The second section of the survey comprised 24 five-point Likert-type questions and was divided into four domains; the practitioners’ concerns relating to data security; the capability of teledentistry to improve practice; the usefulness of teledentistry for patients and for dental practice (Appendix I).

5.2.4. Distribution of Questionnaires

An e-mail list of the sample population was obtained from the contact directory of IRCOHE. The two surveys were then distributed electronically by e-mail and also enclosed with a cover
letter detailing the purposes of the study. Following the initial correspondence, a reminder was sent to all participants who did not respond to the first e-mail at fortnightly intervals.

5.2.5. **Instrument Validity and Reliability**

The first survey questionnaire (Chapter 9) was based on a standard, validated, and reliable instrument for end user satisfaction modified for telemedicine (Otieno et al., 2007; Top et al., 2013). The second survey questionnaire (Chapter 10) was adapted from Mandall et al’s questionnaire which was originally developed to evaluate perceptions of UK general dental practitioners about a teledental system to screen new patient orthodontic referrals (Mandall et al., 2005b). Both survey questionnaires were vetted and revised by independent dental practitioners, to gain feedback and overall acceptability of the questionnaire and minimal corrections were made based on their response.

5.2.6. **Data Entry and Analysis**

Upon receipt of the responses, completed responses were entered into an Excel spreadsheet v2013 (Microsoft; Redmond, WA, USA) and coded for data analysis. The data were analysed using SPSS (version 17.0). Descriptive statistics were used to summarise demographic data. Data were expressed as frequencies and valid percentages.

5.3. **SECTION 3 (Chapters 11-12): Cost savings from the teledentistry model for dental screening and an estimation of resource re-allocation.**

5.3.1. **Overall Study Design**

This section consists of two chapters.

- Chapter 11: A cost-minimisation analysis based on a model of two dental screening methods (teledentistry and in-person) performed from the perspective of the health system. A scenario was developed to simulate the costs (over a 12 months period) of
two models of dental screening, a mobile teledentistry (screening based on dental photographs taken by a smartphone camera evaluated by MLDPs) or a traditional in-person approach (screening based a visual oral screening conducted by dentists). The fixed cost and the variable costs (including staff salary, travel and accommodation costs, and cost of supply) of the two models of dental screening were calculated to determine potential net-savings.

- Chapter 12: A cross-sectional study design was used integrating data from the cost-minimisation study (Chapter 11). The modelled cost data of the two screening methods (teledentistry and direct visual) were linked to statistical local areas (SA2) and then mapped in relation to State, Remoteness Areas (RA) and Socio-economic Indexes for Areas (SEIFA) indexes. It sought to examine the distribution of cost-savings resulting from shifting the traditional screening approach to a teledentistry model of dental screening. Resource transfer scenarios based on risk minimisation were then developed and analysed.

All the data were collected from web-based open access sources; therefore, no ethics approval was required.

5.3.2. Study Population

All school children aged 5-14 years living in Australia, about 2.7 million children based on 2011 Census.

5.3.3. Data Collection

The data related to cost model were collected from web-based open access sources. The data for the population of Australian children was obtained from the Australian Bureau of Statistics (ABS) 2011 Census.
5.3.4. Data Entry and Analysis

All data analysis including the estimation of costs was completed using Excel v2013 (Microsoft; Redmond, WA, USA). The geographic information system (GIS) was used to superimpose integrated cost data on the geographical map to provide visual representations of data by State, RA and SEIFA indexes.
Chapter Six

6. Comparison of a Smartphone-Based Photographic Method with the Face-to-Face Caries Assessment: Mobile Teledentistry Model

This chapter is presented as a published paper in the following citation:

Our initial efforts led to the development and establishment of a prototype mobile teledentistry system, consisting of the store-and-forward platform ‘Remote-i’ and a novel image acquisition Android ‘Teledental’ App that was used for dental screening purposes. A preliminary study, proof-of-concept trial (Estai et al., 2016d) suggested that the combination of a smartphone camera and store-and-forward technology has the potential to be utilised as a dental screening tool. Therefore, an efficacy study involving a larger population sample was undertaken to evaluate the diagnostic accuracy and reliability of the mobile teledentistry system in detecting dental caries at tooth level, by two dentists.
6.1. ABSTRACT

Objectives: This study sought to evaluate the efficacy of a mobile teledentistry approach using a smartphone camera for remote screening for dental caries.

Methods: An image acquisition Android ‘Teledental’ App was created to facilitate the acquisition and transmission of dental images to a store-and-forward based telemedicine server One hundred participants who were attending for routine checkups at dental clinics were enrolled in 2014. Following a face-to-face oral screening by a screener (dentist), images of patients’ teeth were obtained using a smartphone camera. These images, along with patient information, were then transmitted from the Teledental App to the server via the internet for later independent assessment by two charters (off-site dentists). The assessments of these charters were then compared to the benchmark face-to-face caries assessment.

Result: Sensitivity values for the photographic method when compared to the benchmark face-to-face caries assessment were moderate, and ranged from 60-63%. Weighted kappa (K) as a measure of intra-grader agreement for the photographic assessment was estimated as almost perfect (K=0.84). The inter-grader agreement for the photographic method as compared to the face-to-face caries assessment ranged from moderate to substantial (K=0.54-0.66).

Conclusion: Despite some limitations, the mobile teledentistry approach shown the potential to detect occlusal caries from photographs taken by a smartphone camera with an acceptable diagnostic performance to traditional face-to-face screening. This study suggests that teledentistry and cellular phone technology can be combined to create an inexpensive and reliable screening tool.

Keywords: Caries, dental photography, dental screening, rural, smartphone, teledentistry.
6.2. INTRODUCTION

Caries is the second most costly diet-related chronic disease in Australia, ahead of coronary artery disease and diabetes (National Advisory Committee on Oral Health, 2004). Rural populations often have poorer oral health than other groups, primarily due to geographical remoteness and the uneven distribution of the dental workforce (Harford and Islam, 2013). Caries is often not a self-limiting disease, but it can be prevented or reduced through regular screening, water fluoridation and oral health promotion (Deep, 2000). The shift from the ‘treatment’ to ‘prevention’ concept is the key to reducing or preventing dental caries among a population. Reaching rural/remote populations to assess their oral health status is challenging, as this necessitates lengthy travel, time and funding. Although face-to-face screening has remained the gold standard approach to routine oral examination, this method is inappropriate in large epidemiological surveys as it requires substantial economic and human resources. Searching for an inexpensive and valid alternative that can expedite diagnosis of oral diseases among rural populations, while maintaining a good level of diagnostic accuracy, is essential.

One of the potentially viable solutions to address geographical hurdles and unavailability of dentists, is mobile teledentistry (Estai et al., 2016b). Mobile teledentistry is a subset of telemedicine that incorporates cellular phone technology and store-and-forward telemedicine into oral care services. Almost all smartphones have a built-in camera, mobile connectivity and are readily accessible at a low cost. These technologies can be combined to create an effective teledentistry screening alternative. Despite dental photography becoming an integral part of daily dental practice, it has rarely been used as means of diagnosis, consultation or referral in routine practice. Recent evidence indicates that the diagnostic performance of photographic methods in the detection of oral diseases is comparable to the traditional visual approach (Boye et al., 2013; Torres-Pereira et al., 2013; Morosini et al., 2014; Kopycka-Kedziewski et al., 2007; Bradley et al., 2010). A flash equipped digital single-lens reflex (DSLR) camera can produce high-quality images even in a low-illumination setting. However, its relatively high cost, large size weight and complexity makes it difficult to use (Park et al., 2009). In contrast, camera-equipped smartphones are readily available, affordable, portable, easy to handle and can produce good-quality images (Park et al., 2009). The power of cellular technology enables their usage in various tasks.
such as processing, storing and subsequent sharing of images. Their introduction into other health disciplines, in particular, tele-audiology and teledermatology, has been shown to be beneficial (Massone et al., 2007; Kroemer et al., 2011; Mahomed-Asmail et al., 2016; Hussein et al., 2016).

A number of teledentistry studies have been conducted using DSLR or intraoral cameras to evaluate the accuracy and reliability of photographic methods in oral screening (Boye et al., 2013; Torres-Pereira et al., 2013; Morosini et al., 2014; Kopycka-Kedzierzawski et al., 2007; Bradley et al., 2010). However, evidence on the use of smartphone cameras in epidemiological dental research is rare (Estai et al., 2016b; Daniel and Kumar, 2016). As an initial phase, a validation study was completed to establish and test a robust store-and-forward teledentistry system and Android App for use in remote dental screening (Estai et al., 2016d). In view of the limitations of a face-to-face screening approach and towards finding a valid and inexpensive screening solution, the purpose of this study was to evaluate the efficacy of a mobile teledentistry approach in remote screening for dental caries.

### 6.3. METHODS

#### 6.3.1. Study Sample

Adults or parents/guardians of children visiting the dental clinic were invited to participate in dental screening, including obtaining photographs from their mouth. Information sheets and consent forms were provided to participants (Appendix E). 100 participants were recruited. The study is an observational cross-sectional study carried out in a dental clinic in 2014, where a sample of 100 participants was recruited. The inclusion criteria for the participation were; patients of any age, attending for a routine checkup and providing informed consent. All captured photographs were anonymous and only showed the participant’s dentition. The research was completed under ethics approval from the Human Research Ethics Committee, the University of Western Australia (ref no: RA/4/1/6647).
6.3.2. Architecture of the Mobile Teledentistry System

A store-and-forward telemedicine server, ‘Remote-i’, was developed to facilitate the storage, retrieval and management of the database (Xiao et al., 2015; Estai et al., 2016d). The Remote-i allows the transmission and storage of photographs online, from either a smartphone or computer via the internet. Users can access the database from any mobile/desktop web browser using individual user IDs and passwords. An image acquisition Android ‘Teledental’ App was also created to operate the existing default camera on a Motorola® Moto G smartphone (USA). The Teledental App enabled patient information to be entered, dental photographs to be captured, and then allowed subsequent transmission of these records to the server, using Wi-Fi or mobile data networks (Estai et al., 2016d).

6.3.3. Screening (Visual and Photographic) Procedures

Using the screening protocol used in our previous trial (Estai et al., 2016b; Estai et al., 2016d), the face-to-face oral screenings of all the participants were carried out by a registered dentist to screen for caries visually. This assessment was used as the benchmark standard. The face-to-face assessment scores were recorded on an oral screening form that followed the guidelines for oral health surveys developed by the WHO (World Health Organisation, 2013) a treatment plan or referral was provided when necessary. In a separate subsequent visit, a trained tele-assistant (dental student or dental assistant) took photographs of each participant’s mouth using a smartphone camera (Figure 6-1). The tele-assistants were provided with a photography protocol and received hands-on training on how to capture good images (Appendix G). They also had the opportunity to practice using a smartphone camera on volunteers. Only the room lighting and built-in flash of the smartphone camera were used during the photography. Neither cheek retractors nor intraoral mirrors were used for the dental photography. A minimum of five dental images per patient were taken, front, right lateral, left lateral, upper occlusal and lower occlusal views (Figure 6-2). Following the completion of photography and creating a record on the Teledental App, each participant’s set of data was then directly transmitted from the Teledental App to the Remote-i server via the internet, for later evaluation by an off-site dentist (charter).
Figure 6-1  Illustration showing the relationship between a smartphone camera and the mouth during the dental photography.

Figure 6-2  Example of smartphone camera shots showing five dental views. (a) Front view; (b) Upper occlusal view; (c) Lower occlusal view; (d) Left lateral view; (e) Right lateral view.
6.3.4. **Outcome Assessment**

The charting of the photographs was conducted independently by two dentists (charter) using a separate web-based data and image-viewing App built upon the Remote-i system. Dental photographs were charted without any knowledge of the results of the benchmark standard. Both charters received instructions about how to use the database, review photographs, insert findings and submit their reports into the system. Charters accessed the database using user IDs and passwords. After selecting a record, each charter reviewed images and commented on the dentition status for each tooth on a predefined assessment chart. The external reviewers (screeners/charter) also had access to other personal information about the participants such as date of birth, gender and postcode as well as Indigenous status. These independent assessments by charters formulated the database, which was compared to the benchmark face-to-face caries assessments. Caries assessment was completed at tooth level based on a protocol developed by the WHO (World Health Organisation, 2013) (Appendix F). This protocol has the advantage that it has been designed to be simple and easy to use in large-scale oral health surveys. At the screening level, the use of the International Caries Detection and Assessment System (ICDAS) method was not possible because intraoral photographs only provide a two-dimensional view which makes it difficult to carry out the analysis based on the tooth surface.

6.3.5. **Statistical Analysis**

Weighted kappa ($K$) statistics were used to estimate the inter-grader reliability of the photographic and face-to-face caries assessment methods (Landis and Koch, 1977). To estimate the intra-grader agreement, fifteen percent of the records were re-charted again, at least four weeks after the initial charting of the dental photographs. The sensitivity, specificity, accuracy, positive predictive value (PPV) and negative predictive value (NPV) of the photographic method for each charter were calculated. Because photographs only provide a two-dimensional view, it is difficult to inspect all surfaces of the teeth, particularly interproximal surfaces of posterior teeth. Therefore, the assessment of caries was based on the entire tooth rather than tooth surface, with the teeth scored as either caries or sound. Interproximal or root caries were excluded, due the difficulty of detecting these carious lesions in photographs. Filled and missing teeth were also excluded from the analysis. The
sample size calculation was based on a two-sided 95.0% CI for a single proportion using the Z-test approximation, an effect size of 0.1 and expected observed proportion of 0.90. The number of participants with caries that met a power of 0.8 was estimated to be 35 \[ n \geq (\frac{Z^2}{m^2})p (1 – p) \] (Brocklehurst et al., 2012). With the prevalence of caries at 35\% (1.86x35=65), 65 participants without caries are needed. So a sample of 100 participants was recruited.

6.4. RESULTS

The demographic characteristics of the sample are presented in Table 6-1. Approximately 500 dental photographs (five photographs per subject) were obtained from the participants using the smartphone’s camera. Of 3200 teeth scored, the percentage of unrated (not amenable to be scored) teeth was 8\% (266 teeth) for charter 1, and 19\% (596 teeth) for charter 2. Sensitivity and specificity values for the photographic method as compared to the benchmark face-to-face caries assessment ranged from 60\% to 63\% and from 96\% to 99\% respectively. The sensitivity value for the photographic caries assessment (charter 1 versus charter 2) was 85\%. Weighted kappa as a measure of intra-grader agreement for the photographic assessments was almost perfect (K=0.84). The inter-grader agreement between the two methods of screening (photographic versus face-to-face) ranged from moderate to substantial (K=0.54-0.66). The level of inter-grader agreement between charter 1 and charter 2 was substantial (K=0.68). The accuracy measures and level of agreements for both photographic and face-to-face screening methods are presented in Table 6-2.
Table 6-1  Demographic characteristics of the sample.

<table>
<thead>
<tr>
<th></th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
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</tr>
<tr>
<td>Female</td>
<td>36</td>
</tr>
<tr>
<td>Male</td>
<td>64</td>
</tr>
<tr>
<td>Aboriginal and Torres Strait Islander</td>
<td>20</td>
</tr>
<tr>
<td>Non-Indigenous</td>
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</tr>
<tr>
<td>0-14 years</td>
<td>20</td>
</tr>
<tr>
<td>15-24 years</td>
<td>23</td>
</tr>
<tr>
<td>25-44 years</td>
<td>22</td>
</tr>
<tr>
<td>45-64 years</td>
<td>22</td>
</tr>
<tr>
<td>65 + years</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 6-2  Accuracy and reliability measures.

<table>
<thead>
<tr>
<th></th>
<th>Benchmark Screening versus Charter 1</th>
<th>Benchmark Screening versus Charter 2</th>
<th>Charter 1 versus Charter 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity (%)</td>
<td>63</td>
<td>60</td>
<td>85</td>
</tr>
<tr>
<td>Specificity (%)</td>
<td>99</td>
<td>96</td>
<td>97</td>
</tr>
<tr>
<td>Accuracy (%)</td>
<td>97</td>
<td>94</td>
<td>96</td>
</tr>
<tr>
<td>PPV (%)</td>
<td>79</td>
<td>52</td>
<td>58</td>
</tr>
<tr>
<td>NPP (%)</td>
<td>98</td>
<td>97</td>
<td>99</td>
</tr>
<tr>
<td>Kappa statistic (95% CI)</td>
<td>0.66 (0.59-0.75)</td>
<td>0.54 (0.41-0.63)</td>
<td>0.68 (0.56-0.77)</td>
</tr>
</tbody>
</table>

Positive predictive value (PPV), negative predictive value (NPV).

Benchmark screening – Face-to-face oral screening.

Charter – photographic caries assessment.

6.5. DISCUSSION

This study shows that the combination of store-and-forward telemedicine technology and inexpensive smartphone camera use, offers a valid and reliable means for remote screening for dental caries. Despite the scarcity of research evidence on the use of a smartphone camera in dental screening, the present findings strengthened our previous reports that the mobile teledentistry approach has the potential to detect caries from a photograph taken by a smartphone camera with an acceptable ‘moderate’ diagnostic validity and reliability.
(Estai et al., 2016b; Estai et al., 2016d). It is acknowledged that neither the photographic method, nor a standard face-to-face screening approach can detect interproximal or pre-cavitated carious lesions without radiography, and that the failure to use radiography could result in underestimation of caries occurrence. Therefore, at the screening level, the focus of the present study was on the evaluation of the efficacy of a mobile teledentistry approach for dental screening, not for the clinical estimation of caries prevalence.

The findings showed at least a moderate level of agreement between the two screening approaches (photographic versus face-to-face) and the two dentist charters. It is well acknowledged that different dentists can reach different diagnostic outcomes (Bader and Shugars, 1995). The moderate level of concordance (Kappa=0.68) between the two charters was most likely due to the difference in the clinical experience and training. Although both charters had a lower level of concordance relative to the benchmark face-to-face screening, the intra-grader reliability for the photographic assessment was considerably high, suggesting that the charters were uniform in the charting and the way they detected caries from the photographs.

Despite ‘unaided’ face-to-face oral examination being the primary method used to assess oral health status, previous research has shown that this technique is not accurate, with a sensitivity of less than 50% (Milicich, 2000; Forgie et al., 2003). Our results indicate that photographic caries assessment maintained a relatively moderate level of sensitivity and a very high specificity, comparable to that of face-to-face caries assessment. The specificity values were higher than sensitivity values across the two charters and the two screening approaches. The higher value for the specificity could be attributed to the inability of the charters to see some carious lesions on a photograph compared to the benchmark face-to-face assessment. The sensitivity of the photographic method (charter 1 versus charter 2) met the WHO’s reference standard of 0.85-0.90 (World Health Organisation, 2013). In contrast, the sensitivity scores for the photographic method (60-63%) compared to the benchmark face-to-face assessment were lower than the WHO’s reference standard. The lower value of the sensitivity is likely because filled and missing teeth were not included in the analysis. Missing teeth and restorations/fillings are more likely to be detected on a photograph (Estai et al., 2016d). Charter 1 had a slightly higher level of concordance and sensitivity relative to charter 2. This is likely explained by the potential of charter 1 to
identify carious lesions on the photographs more than the other charter or by rating a tooth as suspected caries under uncertainty.

Our previous research (Estai et al., 2017b), demonstrated that some photographs taken by smartphone were of low quality, we attributed this to a failure to comply with the photography protocol, or due to the presence of saliva, blood or debris. For the purpose of facilitating the charting process both charters were asked to score any tooth not amenable to be scored as ‘unrated’. The difficulty in detecting carious lesions on the photographs and distinguishing them from artefacts, could justify why charters scored some teeth as unrated. Such limitations could contribute to the sub-optimal sensitivity and specificity. This is consistent with previous research that reported variations in the inter-rater reliability in caries detection, mainly in the posterior teeth, attributed to fissure morphology or staining (Mialhe et al., 2009; Pereira et al., 2009). It is well-known that assessment of caries from photographs has a shortcoming in that a photograph can only provide a two-dimensional view, which prevents observing all tooth surfaces, particularly the interproximal surfaces of posterior teeth (molars) (Estai et al., 2017b; Estai et al., 2016b). The photographic method is also known to have limitations for the detection of caries on root surfaces (unless they are exposed through recession) or non-visible secondary caries. The two-dimensional view allows detection of carious lesions mostly on the occlusal surfaces, buccal and lingual surfaces of the teeth. The teledentistry approach to dental screening (incomplete oral examination), used within the framework of its limitations, does provide an effective tool for screening. The photographic method can be most effective when a shortened arch with a reduced number of surfaces of limited visibility are present; such as in children.

From a practical point of view, it seems reasonable to take advantage of the advances in information and communication technology and increasingly widespread global connectivity to utilize potential cost-saving solutions such as smartphone use to make oral care services more accessible. Until recently, the use of the smartphone in telemedicine was not well-received because of the low-quality of the built-in cameras, limited storage space and unsuccessful data transmission (Park et al., 2009). With many people now possessing smartphones; their use in routine dental practice is projected to increase due to their inherent digital imaging capabilities, computational power and sharing as well as access to low-cost, secure cloud storage.
Due to the shortage of dentists practising in rural communities, residents in these regions may seek dental care from general medical practitioners (GP) or emergency departments. This can result in under-referral or unselective referral of patients that need a specialist consultation, increasing the burdens on rural populations through additional travel and increased waiting times. The mobile teledentistry approach to caries detection holds great promise for rural or remote communities where dental care services are limited. At the screening level, GPs, nurses or even non-licenced health professionals such as teachers or caregivers can obtain digital data (dental photos) for later evaluation by a dentist at a distance (Sankaranarayanan et al., 2005; Nunn et al., 2009). A dental expert accessing the database from the desktop to assess the records and determine whether cases need a referral or can be delayed. This approach provides a way to identify those for whom the referral is unnecessary or prioritising those requiring an urgent assessment by a dental specialist. This has the potential to reduce inappropriate referrals and prioritize patient assessments, thus avoiding unnecessary travel and reducing waiting times (Mandall et al., 2005a; Stephens et al., 2002).

6.6. CONCLUSION

Despite some limitations, this study suggests that the mobile teledentistry approach has the potential to detect occlusal caries from photographs taken by a smartphone camera with an acceptable diagnostic level. In order to improve the oral health of a population, ongoing monitoring of oral health status, using valid and inexpensive screening tools, is necessary. In light of the limitations of the visual screening approach in a large epidemiological study, it is possible that a mobile teledentistry approach can provide a potential cost-saving alternative to address the problems of care access and the rising costs of dental care. Further well-designed research is required to address the existing limitations and improve the diagnostic performance of the teledentistry approach.
Chapter Seven

7. The Efficacy of Remote Screening for Dental Caries by Mid-Level Dental Providers Using a Mobile Teledentistry Model

This chapter is presented as a published paper in the following citation:

PREAMBLE

This study is among the first that evaluated the efficacy of using mid-level dental practitioners (MLDPs) in remote dental screening. This study was conducted as an extension of the previous efficacy study (Chapter 6) that demonstrated a moderate level of accuracy and reliability between photographic caries assessment by dentists (charters) and the reference visual inspection. Previous in vivo studies indicated that MLDPs and dentists make comparable diagnosis and treatment-planning decisions. However, evidence on the accuracy of photographic caries assessment by MLDPs is limited. Therefore, the present study sought to evaluate the efficacy of MLDPs in the detection of dental caries from still photographs taken with a smartphone camera.
7.1 ABSTRACT

Objectives: This study aimed to determine whether intraoral photographic assessment by mid-level dental providers (MLDPs) offers a valid and reliable means of dental caries screening.

Methods: A mobile teledentistry model was developed to facilitate the acquisition of dental images, and transmission and reviewing of data. One hundred regularly attending patients at a dental clinic participated in the study. Following an on-site clinical examination by a senior dentist, photographs of participants’ teeth were taken by a tele-assistant, using a smartphone camera. These intraoral photographs were directly uploaded from an Android ‘Teledental’ App to a cloud-based server, ‘Remote-i’, using an encrypted store-and-forward telemedicine technology. The photographic assessment carried out by two independent screeners (MLDPs), was compared to the visual oral examination scores of a benchmark examiner.

Results: The sensitivity and specificity values for the photographic assessment method (assessed by screeners) as compared to the direct visual examination ranged from 60% to 68%, and 97% to 98%, respectively. The intra-rater reliability for the photographic assessment was almost perfect, with a kappa score of 0.89. The inter-rater reliability between the photographic and visual oral assessments ranged from moderate to substantial agreement, with kappa scores ranging from 0.57 to 0.61.

Conclusion: A new smartphone-based mobile teledentistry model used by mid-level dental providers shows potential for remote screening of dental caries.

Keywords: Caries, digital imaging, mid-level dental providers, remote, screening, smartphone, teledentistry.
Dental caries is the most prevalent disease of childhood, being five times more common than asthma (U.S. Department of Health and Human Services, 2000). Compared to other chronic diseases, regular screening and early detection are more likely to prevent or halt the progress of many oral diseases (Deep, 2000). Mid-level dental providers (MLDPs), such as dental therapists, perform a range of clinical tasks, including screening and provision of routine dental care, in many countries, including Canada, the United States, the United Kingdom, the Netherlands, and New Zealand (Nash et al., 2014). Several studies have been undertaken to assess the efficacy of screening for oral diseases by different members of the dental team, and indicated that screenings by MLDPs are nearly the same as those of a clinical dentist (Brocklehurst et al., 2011; Macey et al., 2015). Substantial evidence indicates that MLDPs can provide quality, safe and effective dental care at low cost (Nash et al., 2014; Croucher, 2011; Blaikie and Weidenhofer, 1978). The use of MLDPs to screen for oral diseases among the asymptomatic population has the potential to free up considerable economic and human resources (Macey et al., 2015).

Although clinical oral examination is regarded as the most accurate method for correct diagnosis (Mariño et al., 2014), intraoral photographic assessment has a good level of sensitivity and specificity for visual detection of caries (Neuhaus et al., 2009a). As digital imaging becomes the cornerstone of telemedicine practice, image acquisition methods, information quality, and connectivity become essential factors in the success of a teledentistry service (Park et al., 2009). There is no doubt that the digital single-lens reflex (DSLR) camera is a better device in terms of flash units, illumination, and quality of images as it can produce sharp pictures, even in low-light situations, or at high magnification. However, its relatively large size and weight make it less convenient to use (Park et al., 2009). DSLR cameras also require a special flash setup for optimal intraoral illumination. DSLR cameras may not be readily accessible to rural dental providers. In contrast, the smartphone camera is readily accessible, lightweight, very easy to use, and provides satisfactory images with minimal training (Park et al., 2009; Daniel and Kumar, 2014). The inherent inbuilt connectivity of smartphone devices simplifies the processing, storage, and transmission of images, and they have been shown to be effective in telemedicine and particular in tele dermatology (Massone et al., 2007; Kroemer et al., 2011). It is predicted...
that, as the smartphone technology continues to advance, the image quality and technical challenges will be fixed in near future.

The utilization of telemedicine technology for telediagnosis of dental caries has had growing acceptance in recent years (Boye et al., 2013; Bradley et al., 2010). More recently, mobile teledentistry, which is considered to be a subset of telemedicine, has also shown potential to serve as a valid and reliable tool in the screening for caries (Estai et al., 2016d). However, the body of literature on mobile health applications in dentistry is limited to small clinical trials or pilot studies. This poses a difficulty in drawing conclusions about the use of a smartphone in remote screening for dental caries. Our initial development efforts have been aimed at finding an efficient and cost-effective caries screening solution using the digital imaging capabilities, mobile connectivity, and computational power of a camera-enabled smartphone to capture high-resolution dental images and perform subsequent image transmission to a cloud server for evaluation by a remote dentist (Estai et al., 2016d). The current study aims to evaluate the use of MLDPs in the remote screening for dental caries, utilizing an inexpensive smartphone camera, and store-and-forward telemedicine technology.

7.3. MATERIALS AND METHODS

7.3.1. Study Population

This is a cross-sectional study that examined a convenience sample of 100 participants of different ages in 2014. Prior to the start of the study, information sheets and consent forms were provided to adult participants and the parents or guardians of children who visited the dental clinic, inviting them to participate in a dental screening, including photographing the teeth, that would happen on the next appointed day in the dental clinic (Appendix E). Only adult participants and children whose parents/guardians gave informed consent were included in the study. Photographs showed only the teeth and gums, and individuals were thus not easily identifiable. All data collection was completed under ethics approval from the Human Research Ethics Committees of the University of Western Australia and James Cook University.
7.3.2. System and Acquisition Method

A telemedicine system, ‘Remote-i’, based on store-and-forward technology, was developed to serve as a platform for data storage and management (Xiao et al., 2015). The Remote-i is a comprehensive data management system that is capable of image acquisition, data entry, storage and retrieval of patient health information. It also enables uploading and storing images online, either directly from a smartphone or from a PC. Users can login to the Remote-i database via a secure web interface from any mobile phone or desktop computer using individual user IDs and passwords. An image acquisition ‘Teledental’ App was developed to invoke the existing camera App (8.0 megapixels) on the Android-based Motorola® Moto G smartphone (USA) (Estai et al., 2016d). The Teledental App was used to enter patient data and capture dental photographs, and then upload the data corresponding to each patient to the Remote-i server, using Wi-Fi hotspots or mobile data networks (Figure 7-1).

![Flow diagram of mobile teledentistry model.](image)

7.3.3. Examination Procedures

Following the protocol used in a previous pilot study (Estai et al., 2016d), each participant received a visual oral examination to record caries and existing restorations, according to
the WHO protocol (World Health Organisation, 2013) and treatment recommendations and referral were provided if necessary. This examination was used as the benchmark assessment. The onsite dentist had only 15 min per patient to complete the examination, and no radiographs were used to detect caries. In a separate room, a dental student with basic training in the use of the smartphone took photographs of each participant’s oral cavity (using a smartphone camera). Five intraoral photographs per patient were obtained (anterior, right lateral, left lateral, upper occlusal, and lower occlusal views) (Figure 7-2). Besides the room LED lighting, the built-in flash of the smartphone camera App was used during the dental photography. The smartphone camera flash was set up with ‘Torch mode’, which can keep the flashlight turned on during the initial focus and remain until the capturing is completed. The dental student was given a dental imaging protocol (Appendix G) and had the opportunity to practice using the smartphone camera on adult volunteers for as long as it took to feel comfortable (Figure 7-3). It is estimated that the total training took about 20 min. Records were then directly transmitted as encrypted data from the Teledental App to the Remote-i, for later scoring by screeners (MLDPs). The record for each participant was assigned a numeric code that was linked to the original Benchmark charting.

Figure 7-2 Example of smartphone camera shots showing five dental views. (a) Anterior view; (b) Upper occlusal view; (c) Lower occlusal view; (d) Right lateral view; (e) Left lateral view.
7.3.4. **Outcome Measure**

Doing analysis based on the International Caries Detection and Assessment System (ICDAS-II) (which is based on tooth surface) was not feasible because photographs only provide two-dimensional view. Also, to perform a comparison between visual oral examination and photographic screening, the entire tooth, rather than tooth surface, was used as a unit of analysis. At the screening level, we used a method developed by the WHO based on tooth-by-tooth assessment, which is simple and easy to use in the field in large epidemiologic surveys. The dental images were reviewed independently, by two Australian registered MLDPs who each had more than 10 experience, using a web-based data and image-viewing App built upon the Remote-i system. In this trial, the screeners were provided with written and oral instructions on how to securely access the database to review oral images and record findings. After selecting a record, a predefined dental chart appears, and the reviewers were able to insert their comments. This chart included an oral health assessment form based on the WHO protocol (World Health Organisation, 2013) (Appendix F). Both screeners reviewed the intraoral photographs independently and recorded the status for each tooth on their assessment forms. These independent assessments formed the base of the data used to compare with the benchmark examiner assessment and between the screeners. After completing the scoring, the screeners submitted their report and recommendations to the Remote-i server. For clarity, the term
examination (with substantial differences in the definitions of the word internationally) was used in the text to describe the process of direct visual examination of the teeth, while the word screening referred to the review of the teeth indirectly through the photographs.

7.3.5. Statistical Analysis

SPSS version 17.0 (IBM Company, Chicago, Il, USA) was used to compute kappa statistics as a measure to test the inter-rater and intra-rater reliability of the visual examination and the photographic assessments, using the Landis and Koch measurement of rater agreement for categorical data (Landis and Koch, 1977). To test the intra-rater agreement between the two screeners, 15% of the records were scored again, at least, 4 weeks after the initial scoring of the photographs. The sensitivity, specificity, accuracy, positive predictive value (PPV), and negative predictive value (NPV) of the photographic method for each screener were calculated. For this analysis, teeth were classified as either sound or carious. All teeth having arrested caries, caries into dentine or enamel level caries, were scored as carious. Because of difficulties to detect root caries from photographs, root caries was excluded. Filled and missing teeth were excluded from the analysis. Using the sample size methods devised by Brocklehurst et al. (2012) based on a two-sided 95% confidence interval for a single proportion (sensitivity or specificity) using the Z-test approximation, an effect size of 0.1 and expected observed proportion of 0.90, the number of cases with dental caries that would satisfy a power of 0.8 was calculated to be 35 \[n \geq (Z^2/m^2) \times p(1-p)\]. With a dental caries prevalence of 35%, 65 caries-free participants were required (1.86 \times 35 = 65), so the total sample size of 100 was considered appropriate for this study.

7.4. RESULTS

The demographic characteristics of the participants are summarized in Table 7-1. The quality of images obtained by the tele-assistants (dental students) was evaluated by an independent reviewer to ensure that the images were complete, colour-balanced, focused, and clear. A complete set of 500 oral images (five images per subject) were obtained from the 100 participants using the smartphone camera and uploading the images to the
Remote-i server. Ninety-four percent of the captured digital images were gradable. Of 3200 teeth reviewed, the proportions of teeth that were not amenable to be scored were 11% (345 teeth) for screener 1 and 15.4% (493 teeth) for screener 2. Across all assessment methods, the specificity was higher than sensitivity, ranging from 97% to 98% with the sensitivity ranging from 60% to 68%. The inter-rater reliability between the visual oral examination and photographic screening, and the two screeners (MLDPs) was calculated as a moderate-to-substantial agreement, with a kappa score ranging from 0.57 to 0.61. The intra-rater reliability for the photographic assessment was estimated as almost perfect, with a kappa score of 0.89. The accuracy and reliability measures for both visual and photographic assessments are presented in Table 7-2

Table 7-1  Demographic characteristics of the sample.

<table>
<thead>
<tr>
<th>Age Group (in years)</th>
<th>Indigenous</th>
<th>Non-Indigenous</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>6-14</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>15-24</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>25-44</td>
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<td>18</td>
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<td>45-64</td>
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<td>15</td>
</tr>
<tr>
<td>+65</td>
<td>2</td>
<td>11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gender</th>
<th>Indigenous</th>
<th>Non-Indigenous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>11</td>
<td>53</td>
</tr>
<tr>
<td>Female</td>
<td>9</td>
<td>27</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>100</td>
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</tbody>
</table>

Table 7-2  Accuracy and inter-rater reliability of photographic assessment.

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Accuracy</th>
<th>PPV</th>
<th>NPP</th>
<th>Kappa (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Benchmark Vs. Screener 1</td>
<td>62%</td>
<td>97%</td>
<td>95%</td>
<td>57%</td>
<td>98%</td>
<td>0.57 (0.48-0.66)</td>
</tr>
<tr>
<td>*Benchmark Vs. Screener 2</td>
<td>60%</td>
<td>98%</td>
<td>96%</td>
<td>66%</td>
<td>97%</td>
<td>0.61 (0.52-0.70)</td>
</tr>
<tr>
<td>Screener 1 Vs. Screener 2</td>
<td>68%</td>
<td>97.8%</td>
<td>97%</td>
<td>59%</td>
<td>98.5%</td>
<td>0.61 (0.52-0.70)</td>
</tr>
</tbody>
</table>

Positive predictive value (PPV), negative predictive value (NPV).

Benchmark refers to the visual oral examination scores of a benchmark examiner.
7.5. DISCUSSION

There is no photography-based method that can detect precavitated carious lesions. It is acknowledged that the screening was not a complete oral examination, and the failure to use radiography may underestimate caries diagnosis and prevalence. The purpose of this study, however, was to evaluate the applicability of using MLDPs and mobile teledentistry in the screening for dental caries. Our study suggested that the use of MLDPs offers a valid and reliable means for the remote screening for caries, using an inexpensive smartphone camera. This reflects recent research that examines the mobile teledentistry approach for the screening for dental caries by dental hygienists (Daniel and Kumar, 2015). Daniel and Kumar (2015) suggested that a dental hygienist’s clinical findings related to dental caries are comparable to those of the dentist. Our results are also consistent with previous research showing that photographic assessment using a DSLR camera (Morosini et al., 2014; Amável et al., 2009) and intraoral camera (Boye et al., 2013; Kopycka-Kedzierawski et al., 2007) offers a valid and reliable way of remote screening for dental caries. The findings demonstrated a good level of concordance between the two assessment modalities (visual and photographic) and the two screeners. Although both screeners had a marginally lower level of agreement in comparison with the benchmark standard, the intra-rater reliability for the photographic assessment was also high, suggesting that the screeners were consistent in the scoring and the way they identified caries from the photographs.

The specificity scores were higher than the sensitivity scores across all screeners and assessment methods. In contrast, the sensitivity scores were lower than the WHO’s reference standard of 0.85-0.90 (World Health Organisation, 2013). The higher value for the specificity could be explained by the inability of screeners to detect some carious lesions on a photograph compared to the visual oral examination. The lower value of the sensitivity is likely because filled and missing teeth were not included in the analysis. They can be easily identified on a photograph (Estai et al., 2016d). Screener 1 had a marginally higher sensitivity score and appeared to have a lower threshold for identifying lesions as carious on the photographs compared to screener 2. There was a moderate agreement ($K=0.61$) between the two screeners. This could be attributed to the difference in the clinical experience and training between the two screeners. Screener 1 was more experienced, and therefore she/he was used as a reference standard when compared to screener 2.
Previous research indicated that the inter-rater reliability in detecting caries is low, particularly in the posterior teeth (Kopycka-Kedzierawski et al., 2007; Mialhe et al., 2009; Patterson and Botchway, 1998). When a pilot study was conducted prior to the current study (Estai et al., 2016d), we have observed that some photographs had a poor quality, and to facilitate scoring of photographs by the screeners, they were advised to record any tooth not amenable to be scored as ‘unrated’. In some cases, there was the potential for loss of detailed diagnostic information due to image quality, or the presence of saliva, blood, or debris, particularly for the posterior permanent teeth. At the screening level, it was not possible to remove stains or plaques, as the onsite dentist (visual examination) had only 15 min to screen a patient. The difficulty in detecting caries and differentiation from staining or dark artifacts could explain why up to 15% of the screened teeth were not amenable to be scored. This uncertainty could contribute to the suboptimal sensitivity and specificity, particularly for the posterior permanent teeth. Although the dental students received training to produce good-quality oral images, adherence to the photography protocol provided was difficult to achieve, especially where patients were uncooperative or stressed, such as preschool children.

Despite ongoing opposition from some sectors of the profession, recent evidence from the Alaska workforce model has proven that deploying MLDPs to provide essential dental care to remote Alaskan communities has the potential to address the unmet needs of underserved populations (Williard and Fauteux, 2011). Australia has one of the healthiest populations in the world. As a result (unlike a few decades ago), many patients who attend for routine dental checkups will not have a disease. However, this is not the case for rural or under-served populations who often have the majority of oral diseases. MLDPs would be able to perform screening and treat simple cases, while only urgent or complicated cases are referred to dentists. MLDPs with limited training using mobile teledentistry can offer a practical and potential cost saving means to screen for oral diseases among a population with high levels of need who have no access to care.

Mobile teledentistry has great potential to address oral health needs, particularly in rural settings and among underserved populations. It is intended to expedite early detection of oral diseases, identify high-risk groups, and provide a treatment pathway for those who require urgent intervention. It has implications for improving the quality of care by facilitating the provision of timely information to dentists for better decision-making,
effectively triage patients, and reduces inappropriate referrals, thus reducing waiting lists and support locally based oral treatment wherever possible. It also has implications for providing consultation and guidance to local dental practitioners, thereby reducing their isolation and increase the capacity of the dental workforce in areas that are too isolated to attract dentists. In addition, nurses or non-licensed health professionals, such as teachers, can obtain clinical data (intraoral photographs or radiographs), store-and-forward to offsite dentists for review, diagnosis, and treatment planning. Therefore, this strategy has the potential to save significant economic and human resources, and contribute to reducing disparities in oral health between rural and metropolitan populations.

7.6. CONCLUSION

The main findings of this study suggest that visual and photographic assessments are comparable in the detection of dental caries. Dental providers with minimal training have the potential to detect dental caries from remotely sourced oral photographic records. Development of a method to reduce the time taken in dental photography, and to simplify transmission, processing, and reviewing of dental images that would also provide the comparable screening level to visual oral examination, would increase the adoption and acceptance of the mobile teledentistry model. This strategy has implications for supporting the use of MLDPs to perform screening for oral diseases and increasing the capacity to care for those who have limited or no access to care.
Chapter Eight

8. Validity and Reliability of Remote Dental Screening of Different Dental Professionals Using a Store-and-Forward Telehealth Model

This chapter is presented as a published paper in the following citation:

PREAMBLE

The majority of studies that investigate the use teledentistry in detection of dental caries, compared the visual inspection to intraoral photographs (taken either by DSLR or intraoral camera) evaluated by clinical dentists. However, little research has been conducted into the capability of mid-level dental practitioners (MLDPs) to carry out remote dental screening using a photographic method. Therefore, a retrospective cross-sectional study was conducted to evaluate the accuracy and reliability of different oral health professionals in detecting carious lesions form a still photograph taken using a DSLR camera.
8.1. ABSTRACT

Objective: This study was conducted to evaluate the validity and reliability of different members of a dental team in evaluating intraoral photographic records.

Methods: The intraoral photographic records of 126 children (2-to-18-years old) were obtained from routine clinical records taken prior to dental treatment. Photographs were obtained using a DSLR camera and then uploaded to a cloud-based server using store-and-forward telehealth technology. Images were reviewed by an expert panel to formulate a benchmark screening baseline, to which the screeners’ data were compared. The photographic assessments conducted by a mid-level dental practitioner (MLDP) and dentist, were compared to the benchmark expert panel assessment.

Results: The screeners’ assessments by means of intraoral photography, when compared to the expert panel assessment had a sensitivity value of 82-89% and specificity value of 97%. The inter-examiner agreement between the expert panel assessment and photographic method (assessed by a dentist and MLDP), was almost perfect, with a kappa score ranging from 0.82 to 0.88. The mean DFT/dft score for the children as determined by the expert panel’s review and photographic assessment ranging from 5.41 to 5.79, with mean scores between the two assessment methods not significantly different (P=0.746).

Conclusion: Our results suggested that oral health professionals (other than dentists) have the potential to screen for caries from intraoral photographs with the same validity and reliability as dentists. This strategy has implications for supporting the use of MLDPs such as dental therapists or hygienists to screen for oral disease using telehealth.

Keywords: MLDP, teledentistry, intraoral photograph, dental screening, caries.
8.2. INTRODUCTION

Most dental care services in developed countries are funded privately, with much of it provided on a fee-for-service basis (National Advisory Committee on Oral Health, 2004). This is coupled with limited dental insurance and a tendency for the uninsured to be those who are underserved and also experience the majority of the oral diseases (Harford and Islam, 2013). Australia, for example, has one of the healthiest populations in the world but significant healthcare disparities still exist (Kruger et al., 2010) where patients with high needs have less access to basic dental care, whilst patients with the least needs are treated using the most expensive resources (Milsom et al., 2009). Efficient and effective dental screening has the potential to reduce oral health disparities and optimize the use of limited resources (Brocklehurst et al., 2011). More than other chronic diseases, dental caries is preventable with regular screening and adoption of healthy dental behaviour. Early diagnosis, early intervention, and preventive treatment can prevent or reduce the progress of many oral diseases. This concept is considered the cornerstone of cost-effective delivery of dental care, with the potential to save hundreds of millions of dollars (Verdonschot et al., 1999). Therefore, there is a need to shift the oral healthcare system from a cure to care culture (Glick et al., 2012).

One of the growing solutions is the use of mid-level dental practitioners (MLDPs), specifically dental therapists or hygienists, to screen for oral diseases (Brocklehurst et al., 2011; Brocklehurst et al., 2012; Macey et al., 2015) and where only the more complex patients are referred to dentists, whilst simple cases are treated by dental therapists. Although the practices of dental therapists have been mostly limited to under-18-year-olds worldwide (Nash, 2009), dental therapists’ scope of clinical practice in some places has been extended to also treat adults (Hopcraft et al., 2015). Evidence suggests that non-dental practitioners with minimal training can successfully screen for oral diseases (Macey et al., 2015; Nunn et al., 2009) and perform complex dental procedures under the supervision of an off-site mentorship (Esfandiari et al., 2006). A recent report on the Alaskan workforce model has provided evidence that employing MLDPs utilizing a telehealth system have the potential to address the oral health needs of underserved populations in remote Alaska (Williard and Fauteux, 2011). This strategy can help in reducing the isolation of local
practitioners in rural or remote areas, and allow them to provide treatment under the guidance of a remotely located dentist.

Clinical examination methods have traditionally been used for caries screening, but this method is inappropriate in comparative studies where dental examiners remain non-blinded to certain characteristics of participants (Boye et al., 2013). Seeking approaches that can expedite early detection of oral problems, improve patients’ referrals and avoid treatment delay without affecting the accuracy of diagnosis is required. The growing interest in telehealth utilizing the rapidly evolving digital imaging has provided dental providers with alternatives to traditional methods (Sood et al., 2007). The use of photographs in dentistry has increased rapidly over recent years and it has become an integral part of routine dental practice (Chossegros et al., 2010). Several studies have examined the use of intraoral photographs in dental epidemiology. Most studies found that telediagnosis of oral diseases based on intraoral photographs can offer a valid and reliable alternative to traditional oral examination (Boye et al., 2013; Torres-Pereira et al., 2013; Bradley et al., 2010). Previous studies were focused on the assessment of the feasibility, validity and reliability of photographic assessment in comparison to visual oral examination as the reference standard. However, reports on comparing the assessment of intraoral photographs by different dental professionals are limited. Against this background, this study aimed to compare the validity and reliability of intraoral photographic assessment in screening for dental caries in children, between different levels of dental practitioners, and against a benchmark expert panel assessment.

8.3. METHODS

Ethical approval for this study was granted by The University of Western Australia Human Research Ethics Committee. This study was a retrospective descriptive study that examined intraoral photographic records of 126 children (2-to-18-years old), who were patients of one author (JW) between the years 2010 and 2014.
8.3.1. **Original Photograph Collection**

A digital single-lens reflex (DSLR) camera (Canon EOS 7D, EF 100mm f2.8 Macro USM Lens, Macro Ring Lite MR-14EX), was used to obtain intraoral photographs from all 126 patients undergoing dental treatment under general anaesthesia. Dental photography was completed pre-operatively by a trainee specialist dental registrar (Paediatric Dentistry). A standard series of three intraoral images per patient was obtained using retractors and intraoral photographic mirrors (anterior, upper occlusal and lower occlusal views), and these were uploaded to a Remote-i server at a later time (Figure 8-1). The uploaded images were 1000-4000 KB in size and saved as JPEG format to the server.

![Figure 8-1](image)

**Figure 8-1**  Intraoral photograph shots showing 3 views. (a) Anterior view; (b) Upper occlusal view; (c) Lower occlusal view.

8.3.2. **Expert Panel Review**

All intraoral photographs were reviewed by an expert panel to formulate a standard screening baseline, to which the screeners’ data could be compared. The panel consisted of three dental practitioners (including authors EK and MT). A dentogram based on the collaborative assessment of the panel was formulated for each patient to reflect the dental
status at the time the images were taken. This was at the level of screening, not a comprehensive examination. This was the benchmark against which the other screeners’ assessments were tested.

### 8.3.3. Data Assessment

The evaluation of the dental images was carried out by two independent, off-site dental practitioners, an MLDP and an internationally-trained dentist (not registrable in the jurisdiction) using a web-based data and image-viewing App built upon the Remote-i system. The Remote-i is a comprehensive data management server that has been widely used as a telehealth platform in various screening programs (Estai et al., 2016d). A simple user manual and cover letter were sent to the screeners explaining the study purpose and how to use the system. The system enabled each screener to evaluate photographs independently and insert comments on the predefined oral health assessment form and submit reports or recommendations into the Remote-i server. These independent assessments created the base of data used to compare with the benchmark panel assessment and between the screeners. We used a method developed by the WHO based on tooth-by-tooth assessment (Appendix F), which is simple and easy to use in the field in large epidemiology surveys (World Health Organisation, 2013). As the images are only two-dimensional we could not use the International Caries Detection and Assessment System (ICDAS) (which is based on tooth surface) as the unit of analysis.

### 8.3.4. Statistical Analysis

SPSS version 17.0 (IBM Company, Chicago) was used to compute Cohen’s kappa to test the inter-examiner reliability for the benchmark panel assessment, and the photographic assessments based on tooth-on-tooth comparisons (Landis and Koch, 1977). Fifteen percent of the intraoral photographs were re-graded to test the intra-examiner agreement, at least, 4 weeks after the initial scoring of the photographs. The sensitivity, specificity, accuracy, positive predictive value (PPV) and negative predictive value (NPV) of the photographic method for each examiner were calculated. For this analysis, all teeth were classified as sound or carious. Caries experience, using the DFT/dft (decay, filled teeth) index, were
calculated for each case and analysed through descriptive statistics. DFT/dft was used instead of DMFT/dmft, as the reasons for missing teeth (exfoliation, caries, other) could not be assessed. Statistical differences between group means were determined by one-way ANOVA. Using the sample size methods devised by Flahault et al. (2005) where the prevalence of the disease is less than 0.50. With an ideal sensitivity of 95% and a lower 95% confidence limit of 80%, the number of cases with caries required is 50. With dental caries prevalence of 40% (1.5x50=75), 75 cases are needed without caries. So the total sample size of 125 was required in this study.

8.4. RESULTS

The demographic characteristics of the participants are summarized in Table 8-1. All intraoral photographs were gradable, however, out of 4032 teeth reviewed, a small proportion of the individual teeth were scored as ‘unrated’ by an MLDP (142 teeth, 3.5%) and dentist (75 teeth, 1.9%) off-site screeners.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td></td>
</tr>
<tr>
<td>2-5 years</td>
<td>51 (41%)</td>
</tr>
<tr>
<td>6-11 years</td>
<td>56 (44%)</td>
</tr>
<tr>
<td>12-18 years</td>
<td>19 (15%)</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>58 (46%)</td>
</tr>
<tr>
<td>Female</td>
<td>68 (54%)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>126</td>
</tr>
</tbody>
</table>

*Tooth-by-tooth comparisons:* The inter-examiner agreement between the benchmark panel assessment and photographic method (assessed by a dentist and MLDP) was almost perfect, with the kappa score ranging from 0.82 to 0.88. The intra-examiner agreement for the photographic assessments for screeners was almost perfect, with the kappa score of 0.82. Across all the screeners and examination methods, the specificity (96-97%) was higher than sensitivity (81-89%). The level of agreement, sensitivity, specificity, accuracy, positive
predictive value and negative predictive value measures for both the benchmark panel and screeners’ photographic assessments are presented in Table 8-2.

Table 8-2  Accuracy and inter-examiner reliability of photographic assessment calculated on the basis of tooth-on-tooth comparisons.

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Accuracy</th>
<th>PPV</th>
<th>NPP</th>
<th>Kappa (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark Panel vs. MLDP</td>
<td>82%</td>
<td>97%</td>
<td>94%</td>
<td>91%</td>
<td>94%</td>
<td>0.82 (0.79-0.85)</td>
</tr>
<tr>
<td>Benchmark Panel vs. Dentist</td>
<td>89%</td>
<td>97%</td>
<td>96%</td>
<td>92%</td>
<td>97%</td>
<td>0.88 (0.86-0.90)</td>
</tr>
<tr>
<td>Dentist vs. MLDP</td>
<td>81%</td>
<td>96%</td>
<td>93%</td>
<td>88%</td>
<td>94%</td>
<td>0.80 (0.77-0.83)</td>
</tr>
</tbody>
</table>

Positive predictive value (PPV), negative predictive value (NPV).

MLDP = Mid-level dental practitioner.

The mean DFT/dft score (at the screening level) for the children, as determined by the expert panel was 5.79 (4.30±SD), and as determined by the off-site dentist and MLDP was 5.41 (3.94±SD) and 5.71 (4.31±SD) respectively. The mean DFT/dft was not significantly different between the three assessment groups (P=0.746). Approximately 90.5% of the children were classified as having caries experience by the expert panel and 88.9 to 90.6% of the children were classified as having caries experience by the screeners (Table 8-3). The sample also included 8 participants with genetic conditions affecting the teeth, such as dentinogenesis imperfecta and amelogenesis imperfecta. All these cases were identified by the expert panel and the screeners.

Table 8-3  Proportion of children with caries-experienced and mean DFT/dft score at the level of screening.

<table>
<thead>
<tr>
<th></th>
<th>Caries experience (%)</th>
<th>Mean DFT/dft (±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark panel</td>
<td>90.5%</td>
<td>5.79 (4.30±SD) *</td>
</tr>
<tr>
<td>MLDP</td>
<td>88.9%</td>
<td>5.71 (4.31±SD) *</td>
</tr>
<tr>
<td>Dentist</td>
<td>90.6%</td>
<td>5.41 (3.94±SD) *</td>
</tr>
</tbody>
</table>

* The level of significance between dentist, MLDP and the benchmark panel is (P=0.746).

MLDP = Mid-level dental practitioner.
8.5. Discussion

The assessment of two screeners (a dentist and MLDP) was compared to the benchmark expert panel. Our results indicate that assessment of intraoral photographs at a distance maintains a good level of sensitivity and specificity. Across all examination methods and screeners, specificity scores were slightly higher than the recommended threshold, falling outside of the 95% confidence interval around the WHO reference standard. In contrast, sensitivity scores were slightly lower than the WHO recommended threshold, except for the dentist, whose sensitivity score was high and met the WHO’s reference standard of 0.85-0.90 (World Health Organisation, 2013). The higher value for the sensitivity might be explained by the higher likelihood that the dentist scored a tooth as carious when in doubt, in order for it to be subjected to additional investigations (Tversky and Kahneman, 1974). Nevertheless, the MLDP was not significantly different to the dentist or benchmark panel assessments. The high values of the NPV are not of concern given that the low numbers of false negatives reported by all screeners are associated with the high level of agreement across the examiners (Landis and Koch, 1977).

Our findings demonstrated substantial to almost perfect inter-examiner agreement for both screeners (dentist versus MLDP) and against the benchmark expert panel. The intra-examiner reliability for photographic assessment was also high, suggested that screeners were consistent in the way they identify caries from the photographs. Although the MLDP had a marginally lower level of agreement in comparison to the benchmark panel, the MLDP had a slightly higher mean DFT/dft score compared to the dentist, suggesting that the MLDP has a lower threshold of identifying lesions as carious on photographs. The results of a recent study in which intraoral photographs were used to screen for caries in vivo that compared photographic assessments with a visual gold standard suggests that intraoral photographs can be a valid and reliable way of screening for caries (Morosini et al., 2014; Kopycka-Kedzierawski et al., 2007) and it can be used in large epidemiological studies with some degree of confidence (Boye et al., 2013). Our findings are also consistent with other studies testing the efficacy of dental screening by different members of the dental team in vivo, which indicated that MLDPs are capable of screening for dental caries to a similar standard as dentists (Brocklehurst et al., 2012; Macey et al., 2015; Daniel and Kumar, 2015; Estai et al., 2016b).
The quality of photographs and the capability to grade correctly are important factors when evaluating the feasibility of telediagnosis of oral diseases (Estai et al., 2017b). The DSLR camera used in this study produces images of 18.0 megapixels and is considered adequate for producing high-quality images, even in low-light situations, or at high magnification. However, in some cases, there was uncertainty about the loss of detailed diagnostic information due to the presence of saliva, blood or debris, particularly for the posterior permanent teeth. The difficulty in detecting lesions and differentiating them from staining or dark artefacts could explain why some teeth were scored as ‘unrated’ by the screeners. This uncertainty could contribute to the lower sensitivity in the posterior permanent teeth compared to other parts of the dentition. This reflects previous studies which have found variations in the inter-examiner reliability in detecting caries in posterior teeth largely due to the morphology of the fissures and staining (Mialhe et al., 2009; Pereira et al., 2009).

Photographic assessment utilizing store-and-forward telehealth technology has been used widely to screen for diseases (Jolliffe et al., 2001). The photographic method has the potential to facilitate the archiving of the images which can facilitate remote assessment of intraoral photographs in research studies that may need blinding (Boye et al., 2013). This strategy also has implications for prioritising new patient appointments, and facilitating patient referrals to a dental consultant, thus reducing waiting lists and travel, and delay in diagnosis and associated treatment (Sankaranarayanan et al., 2005). Health professionals or non-licensed health professionals such as teachers could obtain intraoral photographs for an off-site dentist to assess images remotely (Nunn et al., 2009; Boye et al., 2013; Aslam and Hamburger, 2010). The use of different members of the dental team to screen for oral diseases among an asymptomatic population could save considerable economic and human resources (Macey et al., 2015). Telehealth and digital imaging technology have rapidly evolved. Improvements in the size, features and costs of supporting technologies have reduced the cost of telehealth. The use of photographic methods in large-scale epidemiological studies is considered feasible. Thus, practitioners with limited training can offer a practical and potential cost saving means to screen for oral diseases using photographic methods, among populations with high levels of need, who have limited access to oral care.
8.6. CONCLUSION

The sample in this study was enriched with decay; these sorts of cases are those that you want strong assurance will be picked up urgently in a screening programme. Our results indicate that photographic assessment by either a dentist or MLDP is comparable to a benchmark expert panel assessment. In the context of a screening program, our study suggests that different members of the dental team, with minimal additional training, have the potential to detect dental caries with equivalent validity and reliability from web-based presented images. This offers potential for saving economic and human resources as well as facilitating remote screening and archiving of images. This approach also has implications for supporting the use of MLDPs to screen for oral diseases and increasing the capacity to care for those who have no access to oral care because of distance or social exclusion. In the future pattern recognition and artificial intelligence algorithms could be used to detect caries from the photographs without human intervention. However, at present, this technology is still under development. Further testing of the effectiveness of different dental professionals to screening for decay and other important oral conditions is required.
Chapter Nine

9. End-User Acceptance of a Cloud-Based Teledentistry System and Android Phone App for Remote Screening for Oral Diseases

This chapter is presented as published paper in the following citation:

PREAMBLE

This survey builds on the previous validation studies (Chapters 6 and 7) that tested the accuracy and reliability of mobile teledentistry systems in dental screening. Even though the perceived usefulness and ease of use are essential factors in the acceptance of a new technology, quality evidence regarding user’s acceptance of teledentistry service is still limited. The end-users of mobile teledentistry systems, including charters (who undertook screening from web-based presented images) and tele-assistants (who acquired dental photographs from participants’ mouths) were surveyed to identify the factors that contribute to the improvement of the acceptability of the proposed teledentistry system and to determine their satisfaction with it.
9.1. ABSTRACT

Objective: This study aimed to evaluate users’ acceptance of a teledentistry model utilizing a smartphone camera used for dental caries screening and to identify a number of areas for improvement of the system.

Methods: A store-and-forward telemedicine platform ‘Remote-i’ was developed to assist in the screening of oral diseases using an image acquisition Android ‘Teledental’ App operated by 17 tele-assistants. A total of 485 images (five images per case) were directly transmitted from the Teledental App to the server. A panel of five dental practitioners (graders) assessed the images and reported their diagnosis. A user acceptance survey was sent to the graders and smartphone users following completion of the screening program.

Results: Of the 22 surveys sent out, 20 (91%) were completed. Generally, users showed optimism towards the use of the teledentistry system, and strongly positively assessed items on content and service quality. The majority of graders took less than 15 min to read the images while phone users took 5-10 min to complete the dental photography using the ‘Teledental’ App. This study identified a number of factors that are essential for improving the current system, such as optimization of smartphone camera features, the format of the server, and the orientation of images and using oral retractors during photography.

Conclusions: Users appear to be generally satisfied with the proposed teledentistry model. However, they have specific concerns to address, many of which could be resolved through more effective training, coordination between sites and upgrading the current system.

Keywords: Attitude, dentist, dental screening, store-and-forward, smartphone, telemedicine.


9.2. INTRODUCTION

Teledentistry, as a subspecialty of telemedicine, can be defined as “the provision of real-time and off-line dental care such as diagnosis, treatment planning, consulting and follow up via electronic transmission from different sites” (Bradley et al., 2010). For several decades, telemedicine has played a role in bridging gaps and overcoming barriers through spreading healthcare to previously unreachable populations (Baer et al., 1997). Most teledentistry studies were at a small scale and limited to short-term outcomes (Mariño and Ghanim, 2013) utilizing now superseded technologies or expensive peer-to-peer system approaches. Evidence indicates that teledentistry examinations are comparable to clinical examinations in screening for caries (Kopycka-Kedziewskawski et al., 2007; Morosini et al., 2014). However, none has demonstrated superior clinical results (i.e. validity, reliability, and effectiveness) compared to traditional settings. It is postulated that teledentistry offers a cost-effective means to help reduce some obstacles to optimal oral health, particularly for underserved populations (Kopycka-Kedzierawski and Billings, 2013; Mariño et al., 2016).

There are many methods for screening for oral diseases. However, the most common method is the face-to-face examination. The rapid advances in digital imaging and other technologies have provided practitioners with alternatives to traditional settings (Kopycka-Kedziewskawski and Billings, 2006). Assessment of intraoral photographs can maintain a good level of sensitivity and specificity of visual detection of caries (Neuhaus et al., 2009a). Dental photography can also be less stressful and intimidating for young children than a conventional dental examination (Kopycka-Kedziewskawski and Billings, 2006). With smartphone camera technology improving significantly and widespread availability of the cellular networks, utilization of smartphone cameras in dental imaging has grown (Daniel and Kumar, 2015; Aziz and Ziccardi, 2009).

Derived from the theory of planned behaviour (TPB), the technology acceptance model (TAM) aims to explain user acceptance and to predict the adoption of technologies (Davis et al., 1989). TAM has been widely adopted in research, due to its parsimonious nature and wealth of recent empirical support of its role in predicting the acceptance behaviour of a technology (Hu et al., 1999; Agarwal and Prasad, 1999). TAM posits that behavioral intention is determined jointly by attitude and perceived usefulness, the latter also affects attitude directly. Meanwhile, the perceived ease of use directly influences both attitude and
perceived usefulness (Chau and Hu, 2002). TAM works as an appropriate framework for our survey as it gives attitude a key role in predicting the potential user’s behavioural intention to use a technology; a role that has been shown to be fundamental in the acceptance of telemedicine (Hu et al., 1999; Paré et al., 2006).

In response to the increasing demand for oral care services, particularly in remote or rural regions, we have developed a store-and-forward telemedicine platform called ‘Remote-i’ and a novel image acquisition Android App that can be used for screening purposes (Estai et al., 2016d). The present study builds on an initial validation (proof-of-concept trial) study that tested the validity and reliability of the teledentistry approach in the screening for dental caries (Estai et al., 2016d). The findings show that the proposed teledentistry model for dental screening using a smartphone camera offers a valid and reliable alternative to visual dental examination (Estai et al., 2016d). Since perceived usefulness and ease of use are critical factors in the acceptance of a technology, we sought to evaluate users’ acceptance of the teledentistry model and to identify the factors that contribute to the improvement of the current system.

9.3. METHODS

9.3.1. Teledentistry System

A telemedicine system, ‘Remote-i’, based on a store-and-forward method, was developed by the Australian e-Health Research Centre (AEHRC) to work as a platform for data storage and management (Xiao et al., 2015). The Remote-i is capable of image acquisition, data entry, storage and retrieval of data. An image acquisition ‘Teledental’ App was built and installed on a Motorola Moto G smartphone (8.0 megapixels camera) to facilitate entering patient details and capturing dental photos, and then uploading data corresponding to each patient to the Remote-i, using Wi-Fi hotspots or cellular data networks. After obtaining their informed consent, participants were enrolled in a trial to obtain oral images using smartphone cameras. Each participant received an in-person oral examination by a dentist to record caries and existing restorations, before trained tele-assistants took photographs from each participant’s oral cavity, using a Motorola smartphone camera. Records were
then directly transmitted as encrypted data from the smartphone to the Remote-i for evaluation by a dentist at a distance. The images captured using the smartphone were deleted from the phone immediately after transmission of the images to the Remote-i system to avoid any privacy issues (Figure 9-1). The components of the teledentistry system are summarized in Table 9-1.

Figure 9-1 Architecture of the teledentistry system.

Table 9-1 The components of the teledentistry system.

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<thead>
<tr>
<th>Items</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teledentistry system</td>
<td>A telemedicine platform that utilizes store-and forward and smart phone technology to screen for oral diseases at distance.</td>
</tr>
<tr>
<td>Remote-i server</td>
<td>Cloud-based platform that enables data entry, storage, image acquisition, retrieval of large amount of data.</td>
</tr>
<tr>
<td>Android app</td>
<td>An image acquisition App ‘Teledental’ installed on a smartphone device that enables entering patient data, taking dental images and uploading a record to remote-i using a 3G internet or Wi-Fi connection.</td>
</tr>
<tr>
<td>Smartphone</td>
<td>Motorola® Moto G, Android – 5.0 Lollipop.</td>
</tr>
<tr>
<td>Camera360 Ultimate</td>
<td>Third party android camera App that is used for dental photography instead of the default Motorola camera.</td>
</tr>
<tr>
<td>Tele-assistant</td>
<td>Obtain consent from the patient, create records and obtain dental photographs.</td>
</tr>
<tr>
<td>Grader</td>
<td>Review and assess records stored in remote-i.</td>
</tr>
</tbody>
</table>
9.3.2. Participants (Users)

Graders (dental practitioners): Reviewing of dental images was carried out by five independent dental practitioners using a web-based data and image-viewing App built upon the Remote-i system. Although graders did not receive any training on how to use the system, a simple user manual and cover letter were sent to graders explaining the purpose of the study and how to use the system. They were able to access the database using individual user identities (IDs) and passwords. The system enabled graders to review images and insert comments on the predefined oral assessment form and submit reports or recommendations into the Remote-i server (Figure 9-2).

Tele-assistants (smartphone users): Patient recruitment and dental photography were performed by 17 trained tele-assistants (dental students, dental assistants, dental practitioners) using a smartphone camera. The tele-assistants received hands-on training on how to capture good-quality images using a smartphone camera (Appendix G). Recruitment of patients and dental photography were completed in a series of locations; a
small practice, hospital, and large dental facility. Over six months, up to 100 records were uploaded to the Remote-i server; these comprised over 485 images (approximately five images per case) and anonymous patient demographic data.

9.3.3. Questionnaire Instrument

The survey questions are based on a standard, validated, and reliable instrument for end-user satisfaction modified for telemedicine (Otieno et al., 2007; Top et al., 2013). Our study has good content validity, as the survey items were vetted and revised by three dental practitioners, and the questions reflected their concerns and areas of satisfaction. The survey comprised four sections (Appendix H). The first section included questions about the users’ demographic characteristics. The second section comprised of 11, five-point, Likert-type questionnaire (never/almost never=1; seldom=2; about half the time=3; most of the time=4; always/almost always=5) used to assess the quality of the system which comprised five dimensions; content, format, information quality (accuracy), ease of use, service quality, and support. An additional two items were included to assess the usefulness and overall satisfaction with applications. The third section examined the average time that was spent to create a record and complete photography using the Teledental App and grade a record on the Remote-i server. The final section solicited free comments about whether users have suggestions to improve existing systems. Following completion of the trial, the survey was distributed by e-mail reminder was sent to all users who did not respond to the initial correspondence. The protocol for this study was approved by the Human Research Ethics Committee of The University of Western Australia.

9.4. RESULTS

A total of 22 requests for completion of the survey were sent to all users of either the smartphone (teledentistry assistants) or Remote-i (graders) users. A total of 20 completed surveys were received (91% response rate); only two smartphone users did not respond to the survey. The mean age of respondents was 34 years and the majority of respondents (80%) were women. The respondents’ professions were dentists (n=11; 55%), dental
therapists (n=3; 15%), dental students (n=3; 15%) and nurses (n=3; 15%). All respondents’
confirmed that they used computers both at home and work, and reported good typing
proficiency.

9.4.1. User Acceptance of Remote-i System and Android ‘Teledental’ App

The overall level of satisfaction with both the Remote-i server and Teledental App was
positive. Generally, smartphone users had strong positive assessments on items assessing
content, format and service quality (system’s stability). The answers to ‘How often is the
content presented in the App sufficient and appropriate?’; ‘How often does the content
meet your needs?’; ‘How often do you think the output is presented in a useful format?’;
and ‘How often is the information clear?’ were given as ‘most of the time’ or ‘always’ by
more than 87% of App users. The answer to ‘How often is the system subject to technical
problems or crashes?’ was answered with ‘seldom’ or ‘never’ by 80% the users.

Remote-i users had strong positive assessments on items assessing content, information
quality and service quality (system’s stability). The answers to ‘How often is the dental chart
content appropriate for oral health assessment?’ and ‘How often are you satisfied with the
accuracy of the system?’ were given ‘most of the time’ or ‘always/almost always’ by 80% of
respondents while the item ‘How often is the system subject to technical problems or
crashes?’ was answered with ‘seldom’ or ‘never’ by all users. Users were somewhat less
positive towards the Teledental App in terms of the information quality (quality of taken
images), the ease of use of camera and training received. Graders were somewhat less
positive towards the Remote-i server in terms of the format and ease of use. However, both
graders and smartphone users sometimes had negative assessments about whether they
get the assistance they need from the research team (Table 9-2 and 9-3).
Table 9-2 End-user acceptance survey of the Teledental App. Never/almost never=1; seldom=2; about half the time=3; most of the time=4; always/almost always=5. The percentage of respondents reporting ‘most of the time’/‘great’ and ‘always/almost always’/‘very great’ (Likert scales ‘4’ and ‘5’) within a given scale were charted as percent positive, while the percentage reporting ‘never’/‘not at all’ and ‘seldom’/‘very little’ (Likert scales ‘1’ and ‘2’).

<table>
<thead>
<tr>
<th>Items and subscale</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Negative (%)</th>
<th>Positive (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Content</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. How often is the content presented in the App sufficient and appropriate?</td>
<td>–</td>
<td>–</td>
<td>1 (7%)</td>
<td>6 (40%)</td>
<td>8 (53%)</td>
<td>–</td>
<td>93%</td>
</tr>
<tr>
<td>2. How often does the content meet your needs?</td>
<td>–</td>
<td>–</td>
<td>2 (13%)</td>
<td>8 (53%)</td>
<td>5 (33%)</td>
<td>–</td>
<td>87%</td>
</tr>
<tr>
<td><strong>Information Quality (Accuracy)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. How often are you satisfied with the accuracy of the app?</td>
<td>–</td>
<td>3 (20%)</td>
<td>2 (13%)</td>
<td>4 (27%)</td>
<td>6 (40%)</td>
<td>20%</td>
<td>67%</td>
</tr>
<tr>
<td>4. How often are the captured dental images clear?</td>
<td>–</td>
<td>3 (20%)</td>
<td>3 (20%)</td>
<td>9 (60%)</td>
<td>–</td>
<td>20%</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Format</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. How often do you think the output is presented in a useful format?</td>
<td>–</td>
<td>–</td>
<td>1 (7%)</td>
<td>8 (53%)</td>
<td>6 (40%)</td>
<td>–</td>
<td>93%</td>
</tr>
<tr>
<td>6. How often is the information clear?</td>
<td>–</td>
<td>–</td>
<td>2 (13%)</td>
<td>6 (40%)</td>
<td>7 (47%)</td>
<td>–</td>
<td>87%</td>
</tr>
<tr>
<td><strong>Ease of Use</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. How often is the smartphone camera easy to use?</td>
<td>–</td>
<td>3 (20%)</td>
<td>3 (20%)</td>
<td>9 (60%)</td>
<td>–</td>
<td>20%</td>
<td>60%</td>
</tr>
<tr>
<td>8. How often is the App user-friendly?</td>
<td>–</td>
<td>–</td>
<td>4 (27%)</td>
<td>7 (47%)</td>
<td>4 (27%)</td>
<td>–</td>
<td>73%</td>
</tr>
<tr>
<td><strong>Service Quality (System Stability)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. How often is the system subject to technical problems or crashes?</td>
<td>5 (33%)</td>
<td>7 (47%)</td>
<td>1 (7%)</td>
<td>2 (13%)</td>
<td>–</td>
<td>80%</td>
<td>13%</td>
</tr>
<tr>
<td><strong>Support</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. How often do you get the assistance you need from the research team?</td>
<td>1 (7%)</td>
<td>5 (33%)</td>
<td>5 (33%)</td>
<td>3 (20%)</td>
<td>1 (7%)</td>
<td>40%</td>
<td>27%</td>
</tr>
<tr>
<td>11. How often are you satisfied with training received?</td>
<td>–</td>
<td>3 (20%)</td>
<td>3 (20%)</td>
<td>7 (47%)</td>
<td>2 (13%)</td>
<td>20%</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Additional Items</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Do you feel the App useful?</td>
<td>–</td>
<td>–</td>
<td>4 (27%)</td>
<td>5 (33%)</td>
<td>6 (40%)</td>
<td>–</td>
<td>73%</td>
</tr>
<tr>
<td>13. Overall, are you satisfied with the App?</td>
<td>–</td>
<td>2 (13%)</td>
<td>3 (20%)</td>
<td>6 (40%)</td>
<td>4 (27%)</td>
<td>13%</td>
<td>67%</td>
</tr>
</tbody>
</table>
Table 9-3  End-user acceptance survey of the remote-i server. Never/almost never=1; seldom=2; about half the time=3; most of the time=4; always/almost always=5. The percentage of respondents reporting ‘most of the time’/’great’ and ‘always/almost always’/’very great’ (Likert scales ‘4’ and ’5’) within a given scale were charted as percent positive, while the percentage reporting ‘never’/’not at all’ and ‘seldom’/’very little’ (Likert scales ‘1’ and ’2’).

<table>
<thead>
<tr>
<th>Items and subscale</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Negative (%)</th>
<th>Positive (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Content</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. How often is the dental chart content appropriate for oral health assessment?</td>
<td>–</td>
<td>–</td>
<td>1 (20%)</td>
<td>3 (60%)</td>
<td>1 (20%)</td>
<td>0</td>
<td>80%</td>
</tr>
<tr>
<td>2. How often does the content meet your needs?</td>
<td>–</td>
<td>–</td>
<td>2 (40%)</td>
<td>3 (60%)</td>
<td>–</td>
<td>0</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Information Quality (Accuracy)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. How often are you satisfied with the accuracy of the system?</td>
<td>–</td>
<td>–</td>
<td>1 (20%)</td>
<td>2 (40%)</td>
<td>2 (40%)</td>
<td>0</td>
<td>80%</td>
</tr>
<tr>
<td>4. How often are patients’ images clear?</td>
<td>–</td>
<td>1 (20%)</td>
<td>1 (20%)</td>
<td>3 (60%)</td>
<td>–</td>
<td>20%</td>
<td>60%</td>
</tr>
<tr>
<td>5. How often are teeth gradable?</td>
<td>–</td>
<td>–</td>
<td>2 (40%)</td>
<td>3 (60%)</td>
<td>–</td>
<td>–</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Format</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. How often do you think the output is presented in a useful format?</td>
<td>–</td>
<td>–</td>
<td>2 (40%)</td>
<td>3 (60%)</td>
<td>–</td>
<td>0</td>
<td>60%</td>
</tr>
<tr>
<td>7. How often is the information clear?</td>
<td>–</td>
<td>1 (20%)</td>
<td>1 (20%)</td>
<td>3 (60%)</td>
<td>–</td>
<td>20%</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Ease of Use</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. How often is the system easy to use?</td>
<td>–</td>
<td>–</td>
<td>2 (40%)</td>
<td>2 (40%)</td>
<td>1 (20%)</td>
<td>0</td>
<td>60%</td>
</tr>
<tr>
<td>9. How often is the system user-friendly?</td>
<td>–</td>
<td>–</td>
<td>2 (40%)</td>
<td>1 (20%)</td>
<td>2 (40%)</td>
<td>0</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Service Quality (System Stability)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. How often is the system subject to technical problems or crashes?</td>
<td>3 (60%)</td>
<td>2 (40%)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>100%</td>
<td>0</td>
</tr>
<tr>
<td><strong>Support</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. How often do you get the assistance you need from the research team?</td>
<td>–</td>
<td>2 (40%)</td>
<td>2 (40%)</td>
<td>1 (20%)</td>
<td>–</td>
<td>40%</td>
<td>20%</td>
</tr>
<tr>
<td><strong>Additional Items</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Do you feel remote-i useful?</td>
<td>–</td>
<td>–</td>
<td>1 (20%)</td>
<td>2 (40%)</td>
<td>2 (40%)</td>
<td>–</td>
<td>80%</td>
</tr>
<tr>
<td>13. Overall, are you satisfied with the server?</td>
<td>–</td>
<td>1 (20%)</td>
<td>1 (20%)</td>
<td>3 (60%)</td>
<td>–</td>
<td>20%</td>
<td>60%</td>
</tr>
</tbody>
</table>
9.4.2. Time Taken for Dental Photography and Grading

The assessment time of records depended on the quality of the images and the severity of the oral diseases, but most graders spent less than 15 min to assess each record on the Remote-i system. On the other hand, the majority of smartphone users took 5-10 min to create a record in the Teledental App and complete the dental photography for a patient (Table 9-4).

Table 9-4 Duration of dental photography and grading process.

<table>
<thead>
<tr>
<th>Time taken to review a record on the server</th>
<th>&lt;5 min</th>
<th>5-10 min</th>
<th>10-15 min</th>
<th>15-20 min</th>
<th>&gt;20 min</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time taken to create a record and for photography</td>
<td>1</td>
<td>9</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>

9.4.3. Users' Suggestions of Ways to Improve the System

Users were enthusiastic about the use of the teledentistry system for screening for caries based on photographic assessments. The majority of smartphone users (67%) suggested a number of areas for improvement; in particular in the zoom and autofocus features of the smartphone camera. Similar opinions were expressed by other users (27%) who felt that the quality of some images was not good due to lighting issues related to the inbuilt camera flash (Figure 9-3). More than half of smartphone users (53%) suggested using disposable retractors during photography to help in obtaining clear images. Few users (20%) suggested developing an App that can support other operating systems such as iPhone operating system (iOS) and Windows, and also suggested making the Teledental App available in the Google or Apple stores.

Despite their satisfaction with the content, most dental graders asked for improvement of the format of the teledental system, in particular dental charting, as this would facilitate inserting comments and avoid making errors. One grader suggested improving the orientation and labeling of saved images as some labeling was incorrect. Others (two graders) suggested using oral retractors during photography for a better view of posterior
teeth as some images were difficult to read because some posterior teeth (molars) were not clear or not shown (Table 9-5).

Figure 9-3  Example of a smartphone camera shots. Figure 9-3 (a) depicts intraoral occlusal view of upper teeth with poor image quality (blurred) due to out of focus. It is not possible to observe teeth or soft tissue in that image. Figure 9-3 (b) shows intraoral occlusal view of upper teeth with excellent image quality. It is possible to see decayed first molars and decayed left second molar.
Table 9-5 Categories and frequencies of suggestion by respondents.

<table>
<thead>
<tr>
<th>Suggestions of way to improve the system</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Remote-i (5 users)</strong></td>
<td></td>
</tr>
<tr>
<td>The layout of the dental chart should be further improved. E.g. making the layout horizontal rather than vertical. It would be better if the server was upgraded to a system similar to the Dental4windows program.</td>
<td>1 (20%)</td>
</tr>
<tr>
<td>Make sure that the orientation and labeling of images are correct.</td>
<td>3 (60%)</td>
</tr>
<tr>
<td>An image must be closed in order to use the chart. It would be easier for the clinician if the image was kept open while recording on the chart.</td>
<td>1 (20%)</td>
</tr>
<tr>
<td>The headings of the columns for the dental chart are at the top, so when you record at bottom of the page, you need to scroll back to the top every time to identify the actual headings; this may lead to increased errors.</td>
<td>2 (40%)</td>
</tr>
<tr>
<td>The posterior teeth were the most difficult to review due to lack of buccal retraction. Simple retraction devices such as tongue depressors would be useful.</td>
<td>2 (40%)</td>
</tr>
<tr>
<td>It is impossible to edit or make corrections once a record is evaluated and the report submitted. It would be helpful to validate and double check some records if the system supported editing and corrections after submitting the records.</td>
<td>3 (60%)</td>
</tr>
<tr>
<td><strong>Android Teledental App (15 users)</strong></td>
<td></td>
</tr>
<tr>
<td>Improve camera features such as zooming and autofocus. The quality of some captured photos was poor because the camera features are not optimized.</td>
<td>10 (67%)</td>
</tr>
<tr>
<td>Improve the camera flash. Some photos were either over exposed or dark because the camera flash is not optimized.</td>
<td>4 (27%)</td>
</tr>
<tr>
<td>Uploading records from the Android App to the server depends on the availability of the internet connection. I would suggest improving the current App to allow storage of records in the smartphone memory to be uploaded into the server at a later time.</td>
<td>1 (7%)</td>
</tr>
<tr>
<td>Photography of lateral views or posterior teeth was difficult because photography was done without oral retractors as per image protocol. I would suggest using disposable retractors during photography as this will help in obtaining good dental images.</td>
<td>8 (53%)</td>
</tr>
<tr>
<td>Make this App available free in the Google or Apple stores.</td>
<td>2 (13%)</td>
</tr>
<tr>
<td>The phone App only works on Android devices. I would suggest developing an application that can support IOS and windows phones.</td>
<td>1 (7%)</td>
</tr>
</tbody>
</table>

9.5. DISCUSSION

Overall, our survey showed that users perceived the store-and-forward based teledentistry system positively as useful for screening purposes. This reflects previous research which has shown excellent levels of acceptance of real-time based teledentistry system by both patients and professionals (Mariño et al., 2014; Mariño et al., 2015). Although, most teledentistry systems utilize a real-time modality (Mariño and Ghanim, 2013) the practices of asynchronous or store-and-forward telemedicine have proven to be more cost-effective and efficient compared to real-time and in-person models in some clinical disciplines (Mariño et al., 2016; Butler and Yellowlees, 2012; Okunseri et al., 2011). Historically, mobile devices suffered from a low storage space and low-quality of imaging, and this could be a reason for underusing smartphones in dental photography. With recent significant improvements in smartphone camera technology, utilization of smartphones in dental
photography and for screening purposes has grown (Daniel and Kumar, 2015; Aziz and Ziccardi, 2009). Even when a telemedicine system proves to be useful, users also note room for improvement or offer suggestions. Collecting feedback on areas of satisfaction, barriers, and suggestions from users about a telemedicine program can help foster better-designed programs that can be more successfully implemented (Whitten and Love, 2005).

Despite the majority of users believing that the Remote-i system is accurate, stable, easy to use, and presented in a useful format, our findings showed that perceived accuracy, format, and ease of use could be improved. A few concerns persist among respondents, including difficulty in reviewing posterior teeth because the oral cavity was not retracted enough, system architecture such as dental chart layout and design, and orientation of images and labelling. Another matter affecting the graders’ ability to review images and grade teeth is the quality of the images that the tele-assistants send. The quality of images and the capability to grade images accurately are very important factors when evaluating the feasibility of telediagnosis of diseases (Vaziri et al., 2015). Many of the problems encountered could be overcome following further modification and optimization of the server.

Despite attention to many issues (over bright or dark images) related to smartphone camera use, and adjustment of photography protocols prior to starting the trial, concerns with the information quality and ease of use of smartphone camera were observed (Figure 9-3). Although, the majority of the smartphone users believed that the Teledental App was accurate and easy to use, the survey results showed that a substantial number of Android users (20%) experienced difficulty with the use of the smartphone camera and a majority of the smartphone users suggested that the quality of images and the smartphone camera need further improvement. Users’ concerns with the smartphone camera mainly pertained to the difficulty of obtaining good images due to issues relating to the optimization of phone camera features, the absence of oral retractors, or lack of training.

The survey shows that the average time spent on creating a record, uploading and grading was 20 min. Although this time is longer than an in-person oral assessment (10-15 min), a duration of 20 min is still considered acceptable as the only alternative is to spend hours traveling to the nearest practice or sending a practitioner to a remote site. Although training of tele-assistants to provide good-quality oral images was provided and does not consume
much time, adherence to the photography protocol provided was hard to achieve. Many Android users’ concerns could be resolved through more effective training and hands-on experience.

The results of this study partly support the TAM model of telemedicine acceptance. Similar to the assertion of TAM, perceived ease of use and usefulness was relatively high among users and was positively associated with users’ attitude toward using the system, and these results are consistent with previous reports (Davis et al., 1989; Chen and Hsiao, 2012). However, our data indicates that the perception of the system’s stability, content, and format have a strong influence on the attitude towards teledentistry system. The intention to use the system is not only predicted by its perceived usefulness but also determined by the system’s stability, format, and content which were rated consistently high in the survey. Perceptions of information quality and support were not found to influence the intention to use the system significantly and the latter could be attributed to the absence of coordination between sites and lack of prior personal experience with teledentistry. Another important factor that may affect a user’s intention to use telemedicine is the need for collaboration and coordination between remote and hub sites when implementing a telemedicine system (Fricton and Chen, 2009). Because the supervisory dental team at the hub site cannot do a hands-on examination, they have to rely on the assessment performed by the local practitioner at the remote site. Repeated practice, establishing confidence, and good working relationships between team members at both sites can establish a reliable and smooth teledentistry process (Fricton and Chen, 2009).

This study was not designed to examine in depth the users’ perception of teledentistry, but it gives insights on its acceptance. Further investigations on how different types of factors (external or internal) operate to support or hinder the adoption of a teledentistry model need to be addressed. Despite the rapid growth of teledentistry, it has not yet become an integral part of mainstream oral health care. Future research is needed to determine the obstacles that delay the implementation of teledentistry as an adjunct for a comprehensive health care system. Identifying and addressing the barriers to adoption of teledentistry could motivate dental providers to adopt the use of telemedicine services in daily practice.
9.6. CONCLUSION

Generally, users considered the teledentistry model as useful, despite their concerns with specific aspects of the system. This study provides developers with key observations about user needs when building a teledentistry system and can form the basis for the development of a more user-friendly system. Utilization of teledentistry approaches for caries screening has steadily gained acceptance in recent years. More recently mobile teledentistry, often seen as a sub-set of telemedicine, has also emerged as a possible means of screening for oral diseases. This area is particularly attractive due to the fact that many smartphones are now equipped with digital cameras, and there is widespread penetration of smartphones and cellular network reception globally even in underserved regions. We believe that these technologies (teledentistry and smartphones) can be combined to create an inexpensive and powerful tool for screening purposes. This approach could offer a practical and potential cost-saving means to screen for oral diseases among a population with high levels of need who have no access to care. The development of a cloud-based server and an image acquisition Android App for screening purposes is the first of its kind in Australia and has the potential to serve rural providers to reduce inappropriate referrals and waiting lists for consultation as well as facilitating timely information to the local practitioner for better decision-making. Evaluation of users’ acceptance provides valuable insight into the factors which impact professionals’ intentions to adopt teledentistry services. Building on these experiences, the next step will be the implementation of multi-site, community-based, and large-scale projects that can incorporate remote dental screening and oral health promotion, and involve different members of the dental team such as dental therapists, dental hygienists, and dental nurses.
Chapter Ten

10. Perceptions of Australian Dental Practitioners about Using Telemedicine in Dental Practice

This chapter is presented as published paper in the following citation:

PREAMBLE

This study is the first nationwide survey of the use of telemedicine in dentistry among Australian dental practitioners. Despite the wide use of telemedicine applications in healthcare, the practice of teledentistry in Australia is still limited. Many dental practitioners are still unaware of what teledentistry is, what its potential benefits are, or how they can use it in routine practice. A survey can fill a gap in the literature particularly with reference to the dentists’ perception towards usefulness of telemedicine and their perceived concerns about this technology. Identifying barriers to the implementation of teledentistry and addressing how teledentistry can benefit specific aspects of dental practice can be helpful in increasing its acceptance.
10.1. ABSTRACT

Objective: This study aimed to explore Australian dental practitioners’ perceptions of the usefulness of teledentistry in improving dental practice and patient outcomes.

Methods: A descriptive cross-sectional study involving an anonymous electronic survey of a sample of 169 Australian dental practitioners. We designed a 24-item, 5-point Likert-scale questionnaire assessing perceptions of dentists in four domains: usefulness of teledentistry for patients; usefulness of teledentistry for dental practice; capability of teledentistry to improve practice; and perceived concerns about the use of teledentistry.

Results: Of the 144 respondents (response rate 85%), 135 completed responses that were suitable for analysis. More than 80% of respondents agreed or strongly agreed that teledentistry would improve dental practice through enhancing communication with peers, guidance and referral of new patients. The majority also felt that teledentistry is quite useful in improving patient management, and increasing patient satisfaction. A substantial proportion of respondents expressed uncertainty with technical reliability, privacy, practice expenses, the cost of setting up teledentistry, surgery time and diagnostic accuracy.

Conclusion: Dental practitioners generally reported optimism and support to the concept of teledentistry and its integration into current dental practices. Addressing how teledentistry can benefit specific practice issues, would encourage more dentists to use telemedicine in routine practice.

Keywords: Attitude, dental practitioner, dental practice, technology, teledentistry.
10.2. INTRODUCTION

Teledentistry is the use of electronic medical records, information and communication technology (ICT), digital imaging, and the internet to facilitate teleconsultation with specialists, supervision of collaborative practitioners at a distance, and to continue education (Fricton and Chen, 2009). Before the emergence of ICT, dentists were often communicating via telephone or by sending patient clinical records via post, fax or telegraph. The rapid advance of ICT and availability of the internet have increased the potential of telemedicine applications, speed, and methods by which practitioners and patients can interact (Daniel and Kumar, 2014). Long waiting lists and increased consultation times, and inappropriate referrals have been a source of concern for care providers. Adoption of ICT in dental practice has the potential to reduce inappropriate referrals (Mandall et al., 2005a) and reduce waiting lists for specialist consultation (Mariño et al., 2015), as well as facilitating timely information to the dentist for better decision making (Rocca et al., 1999).

Although teledentistry is a fast-growing field, barriers to its increased use in practice still exist (Mariño and Ghanim, 2013). The most pressing challenges in teledentistry practice centre around cost, data security and time management (Daniel and Kumar, 2014). Despite the wide use of telemedicine applications in healthcare, many dentists are still unaware of what teledentistry is, what its potential benefits are, or how they can use it in routine practice (Chen et al., 2003). As the attitudes of dentists towards telemedicine has not been well examined in the literature, the focus of the present survey was to explore Australian dental practitioners’ perceptions of the usefulness of teledentistry for practice, as well as from the patients’ perspective, and determine their perceived concerns to the use of ICT.

10.3. METHODS

10.3.1. Survey Instrument

An anonymous electronic survey of obtained from the contact directory of the Australian dental practitioners was carried out in 2014. The survey was adapted from Mandall et al.’s questionnaire which was originally developed to evaluate perceptions of UK general dental
practitioners (GDPs) about a teledental system to screen new patient orthodontic referrals (Mandall et al., 2005b) (Appendix I). The first section of the survey solicited demographic and professional background information, as well as internet access time and preferred methods of communication. The second section of the survey comprised of 24 five-point Likert-type questions and was divided into four domains: practitioners’ concerns relating to data security; capability of teledentistry to improve practice; usefulness of teledentistry for patients; and dental practice. The survey was pretested on a group of seven practicing dentists to gain feedback and overall acceptability of the questionnaire and minimal corrections were made based on their response. Ethics approval for this study was obtained from the Human Research Ethics Committee of the University of Western Australia with the protocol number RA/4/1/6,647.

10.3.2. Survey Distribution

An email list of dental practitioners was obtained from the contact directory of the International Research Collaborative–Oral Health and Equity. A total of 169 registered dental practitioners working in Australia were randomly selected from that directory (over 1000 members) as the sample. The random sample shared common demographic and professional characteristics with the Australian dental workforce. The directory is a collective of dental practitioners, mostly general dentists, working in different settings but mainly in urban private practices across the nation. The survey was then distributed by email and was also enclosed with a definition of teledentistry and description of the benefits of telemedicine in addressing many issues in daily practice. Following the initial correspondence, a reminder was sent to all practitioners who did not respond to the first email at fortnightly intervals.

10.3.3. Data Analysis

Completed responses were entered into an Excel spreadsheet (Microsoft 2013) and coded for data analysis. The data were analysed using Excel and SPSS (version 17.0). Descriptive statistics were used to summarise demographics and data. Data were expressed as frequencies and valid percentages.
10.4. RESULTS

Of the 169 surveys emailed to dental practitioners, 144 responses were returned, indicating a response rate of 85%. Of the 144 respondents, nine provided incomplete responses. Therefore, only 135 completed responses were available for analysis.

10.4.1. Demographic and Professional Characteristics of Respondents

Demographic data found that more than half of the study population was aged above 45 years. Most respondents were practicing general dentists or specialists (75%), males (56%) and had more than 16 years of work experience (64%). The majority of practitioners were working in major cities (77%), and the remainder were either working in regional or remote Australia. While a large proportion of respondents (47%) worked 35-49 hours per week, almost a quarter of respondents worked over 50 hours per week. Despite the majority of respondents working either in private (37%) or public (35%) practices, the proportion of practitioners who worked in both public and private sectors was just less than 25% (Table 10-1).
Table 10-1 Description of demographic and professional characteristics of participants.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (in years)</strong></td>
<td></td>
</tr>
<tr>
<td>20-34 years</td>
<td>35 (26.0)</td>
</tr>
<tr>
<td>35-44 years</td>
<td>28 (21.0)</td>
</tr>
<tr>
<td>45-54 years</td>
<td>31 (23.0)</td>
</tr>
<tr>
<td>55-64 years</td>
<td>34 (25.0)</td>
</tr>
<tr>
<td>&gt; 65 years</td>
<td>7 (5.0)</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>76 (56.0)</td>
</tr>
<tr>
<td>Female</td>
<td>59 (44.0)</td>
</tr>
<tr>
<td><strong>Qualification</strong></td>
<td></td>
</tr>
<tr>
<td>Specialist</td>
<td>46 (34.0)</td>
</tr>
<tr>
<td>General Dental Practitioner</td>
<td>56 (41.0)</td>
</tr>
<tr>
<td>Dental Therapist/Hygienist</td>
<td>23 (17.0)</td>
</tr>
<tr>
<td>Resident/Graduate Research</td>
<td>9 (7.0)</td>
</tr>
<tr>
<td>Other</td>
<td>1 (1.0)</td>
</tr>
<tr>
<td><strong>Work experience (in years)</strong></td>
<td></td>
</tr>
<tr>
<td>0-5 years</td>
<td>18 (13.0)</td>
</tr>
<tr>
<td>6-10 years</td>
<td>19 (14.0)</td>
</tr>
<tr>
<td>11-15 years</td>
<td>12 (9.0)</td>
</tr>
<tr>
<td>&gt; 16 years</td>
<td>86 (64.0)</td>
</tr>
<tr>
<td><strong>Location of the main job</strong></td>
<td></td>
</tr>
<tr>
<td>Major City</td>
<td>104 (77.0)</td>
</tr>
<tr>
<td>Inner Regional</td>
<td>14 (10.0)</td>
</tr>
<tr>
<td>Outer Regional</td>
<td>16 (12.0)</td>
</tr>
<tr>
<td>Remote/Very Remote</td>
<td>1 (1.0)</td>
</tr>
<tr>
<td><strong>Work setting of the main job</strong></td>
<td></td>
</tr>
<tr>
<td>Private</td>
<td>50 (37.0)</td>
</tr>
<tr>
<td>Public</td>
<td>47 (35.0)</td>
</tr>
<tr>
<td>Both (private &amp; public)</td>
<td>33 (24.0)</td>
</tr>
<tr>
<td>Academic</td>
<td>5 (4.0)</td>
</tr>
<tr>
<td><strong>Working hours per week</strong></td>
<td></td>
</tr>
<tr>
<td>1-19 hours</td>
<td>17 (13.0)</td>
</tr>
<tr>
<td>20-34 hours</td>
<td>24 (18.0)</td>
</tr>
<tr>
<td>35-49 hours</td>
<td>64 (47.0)</td>
</tr>
<tr>
<td>50-64 hours</td>
<td>25 (18.0)</td>
</tr>
<tr>
<td>&gt; 65 hours</td>
<td>5 (4.0)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>135 (100.0)</td>
</tr>
</tbody>
</table>

10.4.2. Internet use and communication method preferences

Less than three-quarters of respondents spent less than four hours on the internet per day for the practice-related purpose (Table 10-2). With the emergence of ICT and the availability of the internet, tools traditionally used for communication, such as letters, fax or face-to-face, seem to be less preferable. For instance, a minority of respondents used in-person (5%), letters (3%) or fax (1%) as a tool of communication with others. A substantial proportion of respondents rated email (22%) and phone (16%) as a preferred medium for communication.
The adoption of social media, forums or video-conferencing was still slow among practitioners (Figure 10-1).

Table 10-2 Showing average daily internet use (in hours) by participants.

<table>
<thead>
<tr>
<th>Internet Access Time</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily general purpose use of internet</td>
<td></td>
</tr>
<tr>
<td>&lt; 1 hour</td>
<td>14 (10.0)</td>
</tr>
<tr>
<td>2-4 hours</td>
<td>75 (56.0)</td>
</tr>
<tr>
<td>5-7 hours</td>
<td>31 (23.0)</td>
</tr>
<tr>
<td>8-10 hours</td>
<td>10 (7.0)</td>
</tr>
<tr>
<td>&gt; 11 hours</td>
<td>5 (4.0)</td>
</tr>
<tr>
<td>Daily practice-related use of internet</td>
<td></td>
</tr>
<tr>
<td>&lt; 1 hours</td>
<td>35 (26.0)</td>
</tr>
<tr>
<td>2-4 hours</td>
<td>63 (47.0)</td>
</tr>
<tr>
<td>5-7 hours</td>
<td>24 (18.0)</td>
</tr>
<tr>
<td>8-10 hours</td>
<td>6 (4.0)</td>
</tr>
<tr>
<td>&gt; 11 hours</td>
<td>7 (5.0)</td>
</tr>
<tr>
<td>Total</td>
<td>135 (100.0)</td>
</tr>
</tbody>
</table>

Figure 10-1 Preferred communication tools among dental practitioners.
10.4.3. Practitioners' Concerns Relating to Security and Confidentiality Issues

Concerns about the incompatibility of software or hardware tended to be higher than those surrounding privacy, reliability of equipment, and gaining consent, with just over 60% of respondents a little, or very concerned, about technical incompatibility. Although a slim majority of 53% expressed little or great concerns with a potential violation of confidentiality, nearly a third of respondents were either a little or very concerned with gaining patient consent for teledental consultations. On the other hand, uncertainty was observed in the practitioners' views about the reliability of equipment and potential image forgery (Figure 10-2).

![Figure 10-2 Practitioners' concern about data security and patient consent.](image)

10.4.4. Capability of Teledentistry System to Improve Practice

Generally, advantages of the teledentistry system in improving practice were well perceived by most practitioners. More than 80% of respondents agreed or strongly agreed that communication with colleagues, guidance and referral of new patients would be enhanced. However, respondents were unsure if teledentistry would help shorten waiting lists with more than 40 of respondents indicating uncertainty about this statement. Respondents were
also unclear in their opinions about whether teledentistry can provide a valid diagnosis compared with a diagnosis within a clinical setting (Figure 10-3).

Figure 10-3  Practitioners’ perception of capability of the teledentistry to improve practice.

10.4.5.  Usefulness of a Teledentistry System for Dental Practice

The majority of respondents indicated that teledentistry could be quite useful in improving dental practice by saving time when compared to conventional referral, supplying sufficient diagnostic information, and enhancing clinical training. A slim majority of respondents (52%) felt that teledentistry would not require extra appointments for photography. In contrast, respondents were less convinced that teledentistry would reduce time spent on patients and be too expensive to set up, with over a third of respondents unsure about this statement. Similarly, more than half of respondents (54%) were doubtful as to whether teledentistry would reduce costs for their dental practices (Figure 10-4).
Usefulness of a Teledentistry System for Patients

Generally, practitioners' beliefs in the potential merits of teledentistry for patients were positive, and up to 70% of respondents agreed or strongly agreed with statements that highlighted the benefits of a teledentistry system. More than 65% of practitioners agreed strongly that a teledentistry system would benefit patients in remote or rural locations. The willingness of respondents to communicate with colleagues and liaise with their patients was also observed, and 80-90% of respondents showed that teledentistry would improve interaction with peers and patients (Figure 10-5).
10.5. DISCUSSION

To our knowledge, this study is the first to evaluate Australian dentists’ perceptions about the usefulness of telemedicine in dentistry. Generally, more optimism was expressed by respondents with respect to the advantages of teledentistry for patients, compared with its advantages to dental practice. Most respondents felt that teledentistry would be useful in improving dental practice, patient management, and patient satisfaction. This reflects previous studies that found that dentists are quite open to the use of telemedicine technology in dental practice (Mandall et al., 2005b; Flores-Mir et al., 2006; Palmer et al., 2005). A minority of respondents were wary of particular aspects of teledentistry practice. These aspects are largely attributed to practitioners’ concerns with cost, time, security and diagnostic accuracy. For some attributes such as the cost of setting up teledentistry, practice expenses and surgery time, the perceptions of usefulness were lower, as a larger proportion of respondents did not express strong views.

Cost, time, security, unclear remuneration guidelines, lack of direct contact and comfort with technology have been identified as barriers to the integration of ICT into clinical practice (Flores-Mir et al., 2006; Bodenheimer and Grumbach, 2003; John et al., 2003). Similarly, Australian dentists were solicitous for set-up costs, practice expenses, surgery time, technical
incompatibility and security issues. These findings were consistent with concerns expressed by UK GDPs (Mandall et al., 2005b). However, this contrasts with those of Canadian orthodontists in a survey which have considered remuneration, security issues and lack of comfort with technology as less important (Flores-Mir et al., 2006; Palmer et al., 2005). Concerns with long surgery times reflect previous reports which show that the time spent to prepare a patient for a teleconsultation is longer than conventional settings (Cook et al., 2001a; Cook et al., 2001b). Increased use of technology in practice has heightened concerns such as security vulnerabilities associated with transmitting unencrypted data, transferring data via an open Wi-Fi hotspot and inappropriate access to databases (Daniel and Kumar, 2014; Cederberg et al., 2015). With violation of patient privacy seeming to be easier than ever before, protecting patients’ privacy in an electronic environment becomes challenging (Fairweather and Rogerson, 2001). Therefore, practitioners of teledentistry should put maximum efforts to protect the confidentiality of information.

While increased risk of privacy violation has been cited as an initial barrier for using teledentistry, other issues such as remuneration, licensure, taxation, copyright and medicolegal issues may become a matter of concern (Golder and Brennan, 2000). Costs of telemedicine equipment and supporting technologies may also represent a burden on providers and governments (Khan and Omar, 2013). Nowadays in developed countries it is hard to imagine a dental practice without digital radiography, intraoral cameras, digital cameras, computerised patient registry, and computers with Internet access (Birnbach, 2000). Therefore, the use of available ICT infrastructure in practices would save the cost of teledental equipment, and reduce practice expenses and consultation costs. Furthermore, despite its ability to make accurate diagnoses (Kopycka-Kedziewska et al., 2007), there is a growing concern about the diagnostic validity of teledentistry compared with in-person oral examination (Mandall et al., 2005a). Uncertainty about diagnostic accuracy may arise from the inability to perform complete investigations when using teledentistry for certain clinical situations, thus, direct patient contact may still be needed to establish an accurate diagnosis (Finch et al., 2003). Oral diseases also vary in colour, shape, and consistency, and, therefore, a very high-quality of oral images is important to allow for online consultation (Al-Hashimi et al., 2007).
Despite reluctance to the use of digital and electronic technologies such as social media, forums or video-conferencing in communication, other tools like email and phone seem to be the favourable medium of communications. For instance, a survey of 4000 US doctors indicated that almost two-thirds were communicating with colleagues via email (Brooks and Menachemi, 2006). Email can provide clinicians practicing in remote locations with valuable access to the second opinion, since it allows low-cost communication of digital images (Goyder et al., 2015). Therefore, email can offer a richness of communication compared to traditional tools. Furthermore, respondents were more likely to communicate not only with colleagues, but with their patients. This was reflected in their support of the concept that teledentistry would enhance communication, clinical training and guidance among practitioners, and improve interactions with patients. These results were inconsistent with other research showing that dentists are more open to interacting electronically with other dentists than with patients or the public (Flores-Mir et al., 2006; Stephens and Cook, 2002).

Addressing how teledentistry can benefit specific practice aspects would motivate more dental practitioners to actively integrate this technology into daily practice. It would also be helpful to re-evaluate dental practitioners’ perceptions as new issues may emerge when teledentistry becomes more widely used. Furthermore, policy-makers must establish well-defined standards and laws that can regulate the use of teledentistry in dental practice.

10.6. CONCLUSION

The majority of respondents expressed positive views towards technology-based solutions and tools that can bring added benefits to dental practices. However, this study has identified certain barriers to the use of teledentistry, and identified where practitioners would need support to use teledentistry technology, especially in aspects related to practice expenses, equipment setup costs, time, technical incompatibility and security.
Chapter Eleven

11. Cost Savings from a Teledentistry Model for School Dental Screening: An Australian Health System Perspective

This chapter is presented as published paper in the following citation:

A review of the literature indicated that cost analysis of teledentistry is limited. To our best knowledge, this is the first national level cost model that has been developed to estimate the potential cost savings from a mobile teledentistry model of dental screening among Australian school children. Improving oral health requires continuous assessment of oral health status in the population using economical and valid screening tools. Previous chapters (Chapters 6-9) sought to validate the teledentistry system in dental screening and explore end-user’s acceptance of this system. In order to determine the low-cost screening alternative, the present study compared the costs of two methods of dental screening (teledentistry and visual) that provide comparable outcomes. Such studies can help to increase acceptance of this technology and guide future decisions on implementing teledentistry services.
11.1. ABSTRACT

Objective. The aim of the present study was to compare the costs of teledentistry and traditional dental screening approaches in Australian school children.

Methods. A cost-minimisation analysis was performed from the perspective of the oral health system, comparing the cost of dental screening in school children using a traditional visual examination approach with the cost of mid-level dental practitioners (MLDPs), such as oral health therapists, screening the same cohort of children remotely using teledentistry. A model was developed to simulate the costs (over a 12-month period) of the two models of dental screening for all school children (2.7 million children) aged 5-14 years across all Australian states and territories. The fixed costs and the variable costs, including staff salary, travel and accommodation costs, and cost of supply were calculated. All costs are given in Australian dollars.

Results. The total estimated cost of the teledentistry model was $50 million. The fixed cost of teledentistry was $1million and that of staff salaries (tele-assistants, charters and their supervisors, as well as information technology support was estimated to be $49 million. The estimated staff salary saved with the teledentistry model was $56 million, and the estimated travel allowance and supply expenses avoided were $16 million and $14 million respectively; an annual reduction of $85 million in total.

Conclusions. The present study shows that the teledentistry model of dental screening can minimise costs. The estimated savings were due primarily to the low salaries of oral health therapists and the avoidance of travel and accommodation costs. Such savings could be redistributed to improve infrastructure and oral health services in rural or other underserved areas.

Keywords: Cost-analysis, children, caries, dental screening, smartphone, teledentistry.
11.2. INTRODUCTION

In all Australian states and territories, the provision of free or low cost dental care for school children is provided by the School Dental Service (SDS) (Mejia et al., 2012). Historically, school dental therapists have been responsible for providing most of the SDS dental services (examination, diagnosis, treatment and preventive care) under the supervision of dentists (Nash et al., 2008). The employment of dental therapists was limited to the state-operated SDS, but now many dental therapists are employed in the private sector (Hopcraft et al., 2015). In recent years there has been a gradual reduction in workforce participation and scarcity of resources in SDS (Spencer, 2004). A recent report suggested that the SDS rarely provides sustainable dental care, less than a quarter of Australian school children attended a SDS for their last dental visit (Harford and Luzzi, 2013). The decreased retention and recruitment of school dental therapists is attributed to the preference of school dental therapists to work in the private sector or leave the profession (Kruger et al., 2007), as well as the establishment of a bachelor degree (3 years at university level) of Oral Health Therapy in several Australian universities. This degree is intended to replace the existing (2-years vocational level) diploma programs in Dental Therapy or Dental Hygiene (Teusner et al., 2015). The new bachelor programmes allow the oral health therapist (OHT) to incorporate the skills of both the dental hygienist and the therapist.

Despite improvements in oral health over past decades, nearly half the school children receiving dental care within the SDS do not enjoy good oral health (Spencer, 2004). In 2010, 55% of children aged 6 years had experienced decay in their deciduous teeth, whereas 48% of children aged 12 years had a history of decay in their permanent teeth (Chrisopoulos et al., 2016). Dental caries is a potentially preventable infectious disease, which, if left untreated, can lead to considerable morbidity requiring expensive treatment (Donahue et al., 2005). In 2013-14, the total national expenditure on dental care in Australia increased from $6 to $9 billion, with 60% of this estimated to be out-of-pocket spending (Australian Institute of Health and Welfare, 2015). Improving oral health in children is achieved through the implementation of a range of systematic preventive strategies, such as oral health promotion, systemic and topical fluorides, fissure sealants and improvements in the diet (Selwitz et al., 2007). However, these measures are often not directed towards children with the greatest needs. Dental screening using a reliable and low-cost screening tool offers a way
to identify high-risk groups, and thus provides a useful approach for the effective prevention and control of dental diseases (Greenberg and Glick, 2012).

In 2015, dentists made up 75% (n=15 500) of the dental workforce in Australia, compared with <10% (n=2050) dental therapists or OHTs (Chrisopoulos et al., 2016). However, most Australian dentists (85%) work in the private sector (Chrisopoulos et al., 2016). In recent years, many dental therapists or OHTs have opted for private practice careers because of a lack of competitive salaries in the SDS or public sector (Kruger et al., 2007). In the private sector, dental therapists or OHTs are often working as ‘hygienists’ responsible for performing scaling and root planing for adult patients; thus, they have a minor role in the provision of dental care. OHTs have not been used effectively to increase the capacity of the existing dental workforce (i.e. mostly dentists) and address the inequity in access to dental care. One way to address the inequality in oral health is role substitution in dentistry, where the duties performed by expensive dentists are delegated to mid-level dental practitioners (MLDPs), such as OHTs or dental therapists (Brocklehurst et al., 2012; Macey et al., 2015). The use of MLDPs to provide dental care has received increasing acceptance worldwide because of the inability of dentists alone to address all unmet oral care needs (Nash, 2009). There is evidence that OHTs have the potential to detect oral diseases in vivo with a standard comparable to that of dentists (Brocklehurst et al., 2012; Macey et al., 2015). It could be reasonable to use OHTs to screen, diagnose and provide simple treatment while reserving dentists for managing complicated cases. Using MLDPs for the dental screening of asymptomatic populations could improve oral health in underserved populations and free up significant resources (Brocklehurst et al., 2011).

Despite teledentistry still being in its infancy and not having been widely used as a screening tool, recent reports indicate that MLDPs have the potential to screen for dental caries using a smartphone camera, with acceptable diagnostic performance (Estai et al., 2016d; Estai et al., 2016b). These findings are consistent with previous research indicating that teledentistry provides a reliable and potential cost saving alternative to traditional screening (Kopycka-Kedzierawski and Billings, 2013; Mariño et al., 2016; Boye et al., 2013; Morosini et al., 2014; Salazar-Fernandez et al., 2012). Although teledentistry is becoming increasingly popular (Mariño and Ghanim, 2013; Khan and Omar, 2013), the number of economic analyses of teledentistry, particularly those looking at cost minimisation, remains small (Mariño et al., 2016; Scuffham and Steed, 2002; Salazar-Fernandez et al., 2012). A comparison of the costs
of teledentistry and its alternatives is of particular importance to those making future decisions about implementing a new screening service. The purpose of the present study was to model and evaluate the costs of a teledentistry approach to screen for dental caries and compare it with the modelled costs of the traditional alternatives from a national care provider’s perspective.

11.3. METHODS

In order to identify the least costly alternative, a cost-minimisation analysis was performed to compare the costs of two methods of dental screening that provide comparable outcomes (Estai et al., 2016d; Estai et al., 2016b). The analysis was conducted from the perspective of the health system and did not take into consideration costs incurred by the patients or their families. A model was developed to simulate the costs of screening all Australian school children (aged 5-14 years) using teledentistry (where therapists or OHTs performed online charting using dental photographs taken with a smartphone camera) and the traditional approach (a dentist performing a traditional visual screening). Because dental caries in children occurs rapidly and progressively, a 1-year time period was used in both dental screening models. All data were collected from web-based open-access sources; therefore, no ethics approval was required.

11.3.1. Screening Procedures for Teledentistry and Traditional Models

The teledentistry model was based on a mobile teledentistry system developed by a team at the Australian e-Health Research Centre, CSIRO. This system uses an Android ‘Teledental’ App and a ‘Remote-i’ cloud server, developed to facilitate the local acquisition of dental photographs, as well as the transmission and reviewing of the dental images remotely (Estai et al., 2016d; Xiao et al., 2015). Trained tele-assistants (teachers) acquire photographs from children’s mouths at their schools using their own mobile cameras. Dental records (including dental photographs and anonymous patient details) are then directly transmitted from the Teledental App to the server via the Internet (Figure 11-1).
Figure 11-1   Flow diagram of teledentistry model of dental screening.

The charting of dental records is performed by dental therapists (charters) under the indirect supervision of registered dentists at a distance. Charters are able to access the database using any web browser and from any location. After selecting a record from the database, a list of dental photographs and a predefined assessment chart appears for the charter to insert their findings (Figure 11-2). The chart includes an oral health assessment form aligned with the World Health Organization (WHO) protocol for oral health assessment (World Health Organisation, 2013) (Appendix F). The system enables charters to independently review dental photographs and submit reports or recommendations to the server. Detailed descriptions of the Remote-i system and screening process have been published previously (Estai et al., 2016b; Estai et al., 2016c).
Under the traditional model, operators (registered dentists) and their dental assistants are assumed to travel across the nation to perform on-site dental screening among the same cohort of children in their own schools. Using the screening protocol as in previous studies (Estai et al., 2016b; Estai et al., 2016c), the unaided visual examination of school children was performed by operators to screen for caries lesions and existing restorations, which were then recorded on an oral assessment form aligned with the WHO protocol (World Health Organisation, 2013) (Appendix F). No radiographs were used in the dental screening, but retractors and mirrors were used to permit visualisation of the teeth.
11.3.2. National Distribution of the Models

Australia is divided by the Australian Bureau of Statistics (ABS) into 54000 non-overlapping statistical areas level 1 (SA1) (Australian Bureau of Statistics, 2008). The population data of children across each of the 54000 SA1s are distributed by age, state and remoteness. The degree of remoteness of each SA1 was obtained from the ABS using the Australian Standard Geographical Classification (ASGC) (Australian Bureau of Statistics, 2008). According to the ASGC, Australia is divided into five remoteness zones: major Australian cities (R1), Inner regional Australia (R2), outer regional Australia (R3), remote Australia (R4) and very remote Australia (R5). The number of school children aged 5-14 years across all states and territories of Australia, as well as over the five remoteness area groups (Figure 11-3), was obtained from the ABS and entered into Microsoft Excel spreadsheet (2003).

![Figure 11-3](image)

**Figure 11-3** Distribution of Australian children aged 5-14 years in Australian states and territories according to the Australian Standard Geographical Classification remoteness category (RA).
11.3.3. Estimation of Costs

In the present cost model, the majority of unit costs were derived from real data and real values. However, some assumptions were used when data were not available. The costs for both models of dental screening were further divided into fixed and variable costs. All costs are given in Australian dollars and all salaries used in the calculation are based on the Australian government pay rates.

11.3.3.1. Fixed costs

No fixed costs were associated with the traditional method of dental screening. For the teledentistry option, we considered establishment costs, which included the annual software license fee, annual server host fee, marketing and training (online induction and self-practise to take good images), to be fixed costs. However, the costs of communication or the Internet and smartphone devices were not considered in the present economic evaluation because almost all schools in Australia have Internet access and most tele-assistants (local teachers) own suitable mobile devices.

11.3.3.2. Variable costs

11.3.3.2.1. Traditional model

The variable costs associated with the traditional alternative were divided into direct and indirect costs, which included staff salaries and the costs of travel and overnight accommodation at each site for operators and their assistants, as well as consumable items or materials used to conduct the visual screening. The costs of consumable items (e.g. gloves, mirror, and retractors) were assumed to be $5 per patient. The cost of office space rental was not taken into consideration because the screening process was assumed to be performed in schools:

- Based on a recent report (Estai et al., 2016b), an operator would need 15min for the oral examination and the assistant would spend 15min on chair-side charting. Typically, in Australia, a working year consists of 220 active days per year (after
deducting 20 days annual leave and 10 days sick or family leave) (Woking Days, 2017). After deducting education, administration and travel times from 220 working days, the active days per year remaining in which to perform traditional dental screening range from 90 (screening located in R4 or R5) to 162 (screening located in R1). Considering the movement between screening sites across different geographical zones, the estimated workload (number of children intended to be screened) ranged from 20 children per 5h per day located in R4 or R5 to 30 children per 7.5h per day located in R1 (i.e. in 12 months, the number of children who could be screened would range from 4860 (located in R1) to 1860 (located in R4 or R5)). The number of full-time equivalent (FTE) operators or dental assistants was 620. The estimation of FTE for the traditional model is provided in Table 11-1.

Table 11.1  Patient load assumptions for the teledentistry and traditional models.

<table>
<thead>
<tr>
<th>Patient loads in the traditional screening (for one operator plus one assistant per operator)</th>
<th>ASGC</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
<th>R5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients screened per day</td>
<td></td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>20</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Working days per year</td>
<td></td>
<td>220</td>
<td>220</td>
<td>220</td>
<td>220</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>Education days per year</td>
<td></td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Administration days per year</td>
<td></td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>Travel days per year</td>
<td></td>
<td>5</td>
<td>5</td>
<td>48</td>
<td>72</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Movement (weeks per year)</td>
<td></td>
<td>48</td>
<td>48</td>
<td>24</td>
<td>36</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Active days per year</td>
<td></td>
<td>162</td>
<td>162</td>
<td>117</td>
<td>93</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>Patients screened/ per year</td>
<td></td>
<td>4860</td>
<td>4860</td>
<td>2925</td>
<td>1860</td>
<td>1860</td>
<td></td>
</tr>
<tr>
<td>FTE</td>
<td></td>
<td>379</td>
<td>111</td>
<td>92</td>
<td>23</td>
<td>16</td>
<td>620</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patient loads in the teledentistry model (for one charter)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Records charted per day</td>
<td>36</td>
</tr>
<tr>
<td>Working days per year</td>
<td>220</td>
</tr>
<tr>
<td>Education days per year</td>
<td>10</td>
</tr>
<tr>
<td>Administration days per year</td>
<td>10</td>
</tr>
<tr>
<td>Active days per year</td>
<td>200</td>
</tr>
<tr>
<td>Records charted per year</td>
<td>7200</td>
</tr>
<tr>
<td>FTE</td>
<td>378</td>
</tr>
</tbody>
</table>

ASGC, Australian Standard Geographical Classification remoteness category; R1, major Australian cities; R2, inner regional Australia; R3, outer regional Australia; R4, remote Australia; R5, very remote Australia; FTE, full-time equivalent.

- Staff salaries included the salary for operators and their dental assistants. The average annual salary (base salary plus 20% on-costs, superannuation and workers compensation) of the operator (registered junior dentist) and the dental assistant would be $108 000 and $60 000 respectively (Pay Scale, 2017a; Pay Scale, 2017b).
Considering the incentive allowance for the operator and assistant performing screening in R4 and R5 regions, the annual salary was augmented with a 20% remote allowance, bringing these to salaries to $126,000 and $70,000 respectively.

- Because the majority of the target population and dentists or operators are clustered near cities, most screening sites would be located in R1 and R2, but dentists and their assistants would need to travel to screening sites located in R3, R4 and R5 areas to perform the on-site screening. Travel allowance expenses (transport, accommodation and incidentals) were adjusted for each remoteness zone. Flights and accommodation expenses were only considered for three geographical zones (R3, R4 and R5). Estimated costs for transport (flight, train or car) were allocated to each of the five geographical groups (R1-R5). The average transport costs (car, bus or train) plus incidentals for one operator or assistant performing screening in the R1 or R2 zones were estimated to be $75 per person. The average costs for flights, overnight accommodation and incidentals (i.e. 20% of total travel allowance) for one operator or assistant performing screening in the R3-R5 zones were estimated at $750 per person.

11.3.3.2.2. Teledentistry model

Variable costs for the teledentistry option include the salaries of the tele-assistants (e.g. teachers), charters and their supervising dentists, and technical experts:

- Based on a previous study (Estai et al., 2017b), a charter or OHT would require an average 10 min for charting and submission of the recommendation online. After deducting education and administration days from 220 working days, the active days per year remaining to perform charting would be 200. The patient load was estimated to be 36 records per 6 h per day or 7200 records per year. The number of FTE charters was 378. In addition, there would be IT support to respond to technical problems and the supervisory senior dentist to monitor the charter (therapists, OHTs) assessment; the FTE for IT support and the supervisory dentists was 1:20 of that for the charter (i.e. 19 FTE each). The tele-assistant (teacher) would need 10 min to photograph a child’s mouth (Estai et al., 2017b) and, if working 6 h per day, would need 453,408 h
to obtain intraoral photographs from all Australian children over a 1-year time horizon. It is expected that any available smartphone would be used and the data would flow through the existing Internet. The estimation of FTE for the teledentistry model is presented in Table 11-1.

- The average annual salary (base salary plus 20% on-costs) of a charter (OHT) was $72 000 (Pay Scale, 2017c). The average annual salaries of IT support and supervisory dentist were $72 000 and $144 000 respectively (Pay Scale, 2017a; Pay Scale, 2017d). The hourly tele-assistant salary was assumed to be $40.

11.3.4. Statistical Analysis

The cost model was built using a spreadsheet (Microsoft Excel 2003, Redmond WA, USA) to compare the costs and savings associated with dental screening using teledentistry versus visual examination over a 1-year period. The model outputs for traditional screening included variable direct and indirect costs incurred by the operators and their assistants; for the teledentistry model, the outputs consisted of fixed costs and variable direct costs incurred by charters and their supervisory dentists, tele-assistants and IT support. Total costs were also compared for both models. A threshold analysis was performed to determine the number of children at which the total costs (sum of variable and fixed costs) in the two models was similar. A sensitivity analysis was used to determine how the uncertainty in input variables would affect the overall costs of both models under a given set of assumptions.

11.4. RESULTS

The estimated number of school children (aged 5-14 years) assumed to have dental screening was 2.7 million. Children living in the R1 and R2 geographical zones (1.8 million and 0.5 million respectively) accounted for 87% of the school children population in Australia. The distribution of children across the five geographical zones is shown in Figure 11-3.
11.4.1. Costs of Traditional Screening

The total average variable cost of the traditional model of dental screening over 1 year was up to $135 million and the fixed cost of the traditional model was zero (Table 11-2). In total, the direct costs of the traditional model of screening (including the salaries for the operator and assistant) were $105 million, accounting for 78% of the total costs. The total indirect cost of the traditional model (travel and accommodation costs plus incidental costs) was up to $16 million. The total cost of materials and supply needed to perform dental screening was $14 million.

Table 11-2 Estimated costs of the traditional model of dental screening according to Australian Standard Geographical Classification remoteness category.

<table>
<thead>
<tr>
<th>Estimated cost (million AUD)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect cost (travel allowance expenses) incurred by operators and their Assistants</td>
<td></td>
</tr>
<tr>
<td>R1</td>
<td>$2</td>
</tr>
<tr>
<td>R2</td>
<td>$2</td>
</tr>
<tr>
<td>R3*</td>
<td>$7</td>
</tr>
<tr>
<td>R4*</td>
<td>$3</td>
</tr>
<tr>
<td>R5*</td>
<td>$2</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>$16</strong></td>
</tr>
<tr>
<td>Direct cost (base salary plus 20% oncosts) incurred by operators and their assistants</td>
<td></td>
</tr>
<tr>
<td>R1</td>
<td>$64</td>
</tr>
<tr>
<td>R2</td>
<td>$19</td>
</tr>
<tr>
<td>R3</td>
<td>$15</td>
</tr>
<tr>
<td>R4*</td>
<td>$4</td>
</tr>
<tr>
<td>R5*</td>
<td>$3</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>$105</strong></td>
</tr>
<tr>
<td>Cost of materials and disposables ($5.0/child)</td>
<td></td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td><strong>$135</strong></td>
</tr>
</tbody>
</table>

R1, major Australian cities; R2, inner regional Australia; R3, outer regional Australia; R4, remote Australia; R5, very remote Australia; AUD, Australian dollars.

* Flight fares applicable only to operators and assistants practicing in R3 and R4.

*Direct costs for operators and assistants practicing in the R4-R5 region include the standard base salary plus 20% on-costs and a 20% remote allowance.
11.4.2. Costs of Teledentistry Screening

Overall, the total cost of the teledentistry model over a 1-year period was $50 million (Table 11-3). The total fixed cost of the teledentistry model was $1 million, with the major part of these costs being marketing or advertisement costs. The total average variable cost of the teledentistry model was $49 million. The estimated direct costs (including salaries of the charter, IT support, supervisor dentist and tele-assistant) were up to $49 million, accounting for 98% of the total costs of the teledentistry model. The costs of salaries of the charters and tele-assistants were up to $27 million and $18 million respectively, accounting for 90% of the total cost of the teledentistry model. The estimated staff salary saved was $56 million, and the estimated travel allowance and material expenses avoided were up to $16 million and $14 million respectively, which represents a net saving of $85 million. The average cost per child for teledentistry was $19, compared with a cost of $41-187 per child with traditional screening (difference of $22-168), depending on the remoteness of residence (Table 11-4).

Table 11-3 Estimated costs of the teledentistry model of dental screening.

<table>
<thead>
<tr>
<th>Estimated cost (million AUD)</th>
<th>Estimated cost (million AUD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Costs</td>
<td></td>
</tr>
<tr>
<td>Marketing in media and the internet</td>
<td>$1</td>
</tr>
<tr>
<td>Software license fee (per year)</td>
<td>$0.004</td>
</tr>
<tr>
<td>Server host fee (per year)</td>
<td>$0.001</td>
</tr>
<tr>
<td>Training (online induction course and self-practice)</td>
<td>$0.015</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>$1</strong></td>
</tr>
<tr>
<td>Variable Costs (Staff Salaries)</td>
<td></td>
</tr>
<tr>
<td>Charter (378 FTE)</td>
<td>$27</td>
</tr>
<tr>
<td>IT team*</td>
<td>$1</td>
</tr>
<tr>
<td>Supervisory dentist^</td>
<td>$3</td>
</tr>
<tr>
<td>Tele-Assistant</td>
<td>$18</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>$49</strong></td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td><strong>$50</strong></td>
</tr>
</tbody>
</table>

* FTE for IT team is 1:20 FTE of charters.

^ FTE for supervisory dentist is 1:20 FTE of charter.
### Table 11-4
Individual costs of dental screening per child in the traditional and teledentistry models.

<table>
<thead>
<tr>
<th></th>
<th>Mean Cost Estimate per child (AUD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Traditional Model</strong></td>
<td></td>
</tr>
<tr>
<td>R1</td>
<td>$41</td>
</tr>
<tr>
<td>R2</td>
<td>$43</td>
</tr>
<tr>
<td>R3</td>
<td>$89</td>
</tr>
<tr>
<td>R4</td>
<td>$172</td>
</tr>
<tr>
<td>R5</td>
<td>$187</td>
</tr>
<tr>
<td><strong>Teledentistry Model</strong></td>
<td>$19</td>
</tr>
</tbody>
</table>

#### 11.4.3. Sensitivity Analysis

The cost analysis showed that the threshold at which the teledentistry alternative became cheaper than traditional dental screening occurred at a workload of 22,700 children (Figure 11-4). A series of scenarios were created to identify the effects of making different assumptions about the underlying variables on the total costs, as detailed below:

![Graph](image_url)  
**Figure 11-4** Costs of dental screening by traditional and teledentistry model at different workloads.
If a registered dentist was used to substitute a therapist or OHT as a charter, this assumption would make teledentistry costs increase from $50 to $61 million. Replacing a registered therapist or OHT with a qualified overseas-trained OHT (the average annual salary for dental therapists in New Zealand is $60 000) (Croucher 2011) would lead to a reduction in the teledentistry cost by $4 million (8%) from the baseline estimated cost for teledentistry. The latter assumption would make the teledentistry model cheaper.

If a registered dentist ‘operator’ was replaced with OHTs to perform traditional screening, travel allowance expenses plus total salaries for OHT ‘operators’ and their assistants (FTE=620) and their supervisory dentists (FTE=1:3 operators) would be $132 million. This assumption would result in an increase of 8% from the baseline calculated cost for the traditional model.

Assuming a charter or OHT reviews 24 records per day (rather than the proposed 36 records) and a tele-assistant recruits four children (instead of the proposed six children) per hour over 6hday (i.e.24 children per day) results in a teledentistry model cost of $75 million, an increase of 50% from the baseline of estimated costs for teledentistry. Alternatively, if we considered a charter or OHT reviewing 48 records per day (instead of the proposed 36 records) and a tele-assistant recruiting eight children (instead of the proposed six children) per hour over a 6-h day(i.e.48 children per day), the teledentistry model would cost $38 million, a decrease of 25% from the baseline calculated cost. The latter assumption would make the teledentistry model the cheapest of all the scenarios.

If we considered a charter or OHT charting 48 records per day (rather than the proposed 36 records) and a 15% reduction in the standard salary for charters was assumed in the calculation, the total costs of the teledentistry model would decline by 20% from the baseline estimated cost, resulting in a teledentistry model cost of $40 million. In contrast, if we considered charters or OHTs charting 24 records per day (instead of the proposed 36 records) and a 15% rise in the standard salary for charters in the calculation, the total costs for teledentistry would elevate from $50 to $72 million.
• If an operator spent 5 min (rather than the proposed 15 min) completing a visual examination and we assumed a 15% reduction in the standard salary for the operator or assistant, combining both assumptions leads to the traditional model costing an estimated $49 million, a decrease of approximately 64% on the baseline estimated cost. This would make the teledentistry model slightly more expensive than the traditional model of dental screening. Alternatively, if an operator spent 25 min (instead of the proposed 15 min) completing a visual examination and we assumed a 15% increase in the standard salary for operator or assistant in the calculations, the total costs of the traditional model would escalate from $135 to $241 million. This assumption would make the traditional model the most expensive alternative among all scenarios.

• When considering the lowest prices for travel and accommodation and a 15% drop in the standard salary for operators or assistants in the analysis, the total costs of the traditional model of screening would decrease from $135 to $114 million, giving a net saving of $64 million. In contrast, when the highest prices for travel and accommodation and a 15% increase in the standard salary for operators or assistants was taken into account, this increased the costs of the traditional model from $135 to $156 million, resulting in a net saving of $106 million with the teledentistry model.

11.5. DISCUSSION

A cost-minimisation analysis was undertaken in the present study to identify whether dental screening using teledentistry could reduce total costs compared with the traditional approach. Like previous studies (Mariño et al., 2016; Scuffham and Steed, 2002), the present study demonstrated significant savings, particularly in rural or remote areas. The analysis showed that the traditional approach used for dental screening was $85 million a year more expensive than the teledentistry model. The major contributions to the cost savings of the teledentistry model were the low cost of salaries for charters and OHTs and avoidance of travel and accommodation costs, as well as a reduction in the use of equipment or disposable supplies. Australia is the world's sixth largest country geographically with a total population of only 23 million, with the majority living in capital cities (Australian Bureau of Statistics,
Conducting traditional dental screening in large geographical areas and among such sparsely distributed populations would require lengthy travelling and huge expenses. The avoidance of travel and overnight accommodation contributed to 19% of the total net savings. The fixed costs of the teledentistry model were relatively low and represented a small proportion of the overall expenses. This could be attributed to improvements in telemedicine technology. As the technology for telemedicine evolves, the cost of equipment will decrease while the quality of teleconsultation improves.

In Australia, as in many other countries, the private sector remains the primary oral health delivery system, with most dental services funded on a private basis, and oral care is delivered on a fee-for-service basis (Schwarz, 2006). Given that less than half of all Australians have private dental insurance, these individuals are responsible for meeting the full cost of private oral care (Harford and Islam, 2013). Recent evidence indicates that a substantial number of Australians are unable to access oral care due to financial barriers (Harford and Islam, 2013). In addition, the SDS is unevenly distributed across Australia, largely concentrated in urban areas (Spencer, 2004). In addition, the SDS has been suffering from funding difficulties and chronic recruitment and retention issues that contribute to the inequity in access to dental care among school children (Spencer, 2004). Through the SDS, OHTs rarely provide sustainable dental services to large numbers of school children and are unable to reach those living in underserved or remote areas. The prohibitive costs of dental care (dentistry is not covered by Medicare), the uneven distribution of dental services across Australia and the scarcity of resources make providing dental care to all school children difficult.

Numerous strategies have been proposed to address unmet oral health needs, including the use of role substitution to provide dental care (Brocklehurst et al., 2012; Macey et al., 2015). MLDPs, such as OHTs and dental therapists, are often ideal for playing a role in dental screening. They have the potential to provide safe and good-quality dental care at a lower cost than a dentist (Nash et al., 2014; Croucher, 2011). Also, training and developing this type of dental workforce would require significantly less time and fewer resources than training a clinical dentist to perform clinical on-site screening (Estai et al., 2016f). The use of a teledentistry approach to screen for dental caries could offer a means for the effective use of OHTs to remotely screen large numbers of people at a low cost. Screening could be a first step towards the implementation of preventive services and the effective control of dental
caries. Dental screening in asymptomatic populations facilitates the identification of children at risk of developing the disease and allows them to receive specific dental care (Brocklehurst et al., 2011). Those children considered low risk do not need additional management other than to receive preventive care (Brocklehurst et al., 2011). This strategy can help direct specific dental care or preventive services towards a population that needs it more and allows for the optimal distribution of scarce resources, thus contributing to reducing inequalities in oral health.

The findings of the present study demonstrate that considering OHTs for the operator’s role in the traditional model is more costly than using dentists. Additional expenses incurred are related to the costs of supervising OHTs at screening locations. Under the SDS, OHTs have a limited scope of practice and therefore need to practice under the indirect supervision of a dentist (Kruger et al., 2007). This means that before OHTs can start providing treatment, supervisory dentists need to re-examine children in order to verify Treatment plans, particularly for those with a moderate or severe disease. With just less than half of Australian children expected to be free of decay (Chrisopoulos et al., 2016), sending dentists to review OHTs’ assessments at screening sites is costly. In contrast, in the teledentistry model, supervisory dentists can monitor OHTs indirectly through teleconsultations and have access to the database, which allows them to verify OHTs’ treatment plans easily and quickly. In the near future, with an extended scope of practice and increasing numbers of OHTs (the Bachelor of Oral Health Therapy is now offered in eight universities), it could be possible to delegate the operator’s role to OHTs under the traditional model.

In the sensitivity analysis, the charter’s role was modified, with qualified overseas-trained MLDPs considered, to enable costs comparison with other nations. The findings suggest that the teledentistry approach supports or facilitates the use of overseas trained OHTs with accredited qualifications, such as those from New Zealand, the UK, Ireland or Canada, to screen for dental diseases at a distance. When considering ethical and legal aspects, this approach is not intended to remove overseas OHTs from their existing jobs or activities. The teledentistry approach enables oral health professionals anywhere in the world to view and assess dental photographs at their desktops and at their convenience, without the need to be physically present at the screening locations. Using a limited number of off-site overseas OHTs with good mentorships could reduce the dependence on overseas trained dentists.
from developing countries who are primarily brought in to mitigate extreme shortages in rural areas.

To our knowledge, no attempt has been made to visually screen all school children in Australia. Undertaking traditional dental screening of all Australian children by dentists or any oral health professionals is challenging due to the high costs associated with such a screening program and maldistribution of the dental workforce. Apart from the economic evaluation, the teledentistry model would provide valuable data about the extent and severity of dental diseases among all Australian children. The data collected from the teledentistry model can be easily linked to existing oral health databases across the states and territories (there are no universal oral health databases in Australia). In addition to its great potential to save substantial costs and improve oral health, teledentistry also has the potential to enhance career or employment opportunities, particularly for those practitioners suffering from physical disabilities and occupational injuries (e.g. chronic shoulder or back disorders) or those nearing retirement age who would prefer to practice without interacting with patients.

The present study has some limitations. Dental services (e.g. restoration, preventive care or oral health promotion) that are often provided by school dental therapists through the SDS were not considered in the analysis. This is due to the scope of the study, which was focused on evaluating the use of teledentistry in dental screening and the difficulty of assigning a monetary value to these services. Despite the large sample size (all school children in Australia) considered in our model, the findings may not be generalisable to models of other dental services or age groups other than children. In a previous study (Estai et al., 2017b) we showed that in some situations there was a loss of diagnostic details due to the poor quality of dental photographs obtained using smartphone cameras. This may require repeating dental photography and result in a delay in the screening process. In addition, in the teledentistry model, the ability of charters and their supervisors to enquire about certain cases is limited compared with the traditional model, because they need to rely on local tele-assistants to obtain information. Because the supervisory dentists, charters and tele-assistants and IT team are working at different locations, they have to rely on telecommunication for liaison. The absence of collaboration or coordination between remote and hub sites may represent a barrier to the success of teledentistry.
11.6. CONCLUSION

To our knowledge, this study presents the first national-level cost model that has been developed to estimate the potential cost savings from using teledentistry for school dental screening. The results of the present study suggest that teledentistry is an applicable and economically viable approach for mass dental screening. The cost of the teledentistry model was substantially lower than that associated with conventional face-to-face dental screening, not only in remote and very remote regions, but also in urban areas. The primary driver of net savings is related to the lower salaries of MLDPs and the avoidance of travel and overnight accommodation costs. The economic evaluation of teledentistry services is essential to ensure efficient allocation of resources and redirection of net savings to improve oral care services in underserved regions. Such studies can be helpful in guiding future decisions on implementing teledentistry services. Further research on the cost-effectiveness of teledentistry considering other dental services (not only dental screening) is warranted to improve the current model.
Chapter Twelve


This chapter is presented as submitted paper for publication in the following citation:

PREAMBLE

The present study represents an extension of the previous cost model study (Chapter 11) that compared costs of two dental screening approaches, teledentistry and direct visual. The basic objective of any healthcare system is to improve and maintain the health of a population across the entire country. The equity in distribution of scarce resources are of utmost importance for improving oral health and tackling inequalities in oral health. Therefore, this chapter examined the distribution of costs for two methods of dental screening with the aim of estimating the scale of resource transfer that could be achieved by moving low-risk children from visual dental screening to a teledentistry method of screening. Findings from this study can be used to inform healthcare policy makers how to best allocate resources and target services for people with the highest needs.
12.1. ABSTRACT

Objective: This study sought to estimate the scale of resource transfer that could be achieved by shifting low-risk children from direct visual dental screening to teledentistry screening.

Methods: This study was based on a previous cost-minimisation study modelling the estimated costs of the two dental screening approaches (direct visual versus teledentistry) for school-age children. The data for the population of children aged 5-14 years, was obtained from the Australian Bureau of Statistics and divided across Australia by statistical local area (SA2). The cost models (for teledentistry and visual screening) for each SA2 relative to States, Remoteness Areas (RA) and Socio-economic Indexes for Areas (SEIFA) were estimated. The geographic information system was used to superimpose modelled cost data on the geographical map to provide visual presentation of data. Resource transfer scenarios based on risk minimisation were then developed and analysed.

Result: This study demonstrated a suboptimal allocation of dental care resources, with school children living in high socio-economic areas (mostly in major cities), with low disease burdens, consuming nearly half of the estimated resources for a universal visual dental screening system. The findings suggested that moving low-risk children to teledentistry screening has the potential to free-up $40 million per annum. Such resources can be reallocated to increase care access and improve the quality of dental care services for vulnerable children.

Conclusion: To reduce inequalities in dental health within a community, scarce care resources should be targeted at the population at high-risk. The findings of this study can be used to inform policy makers to guide the appropriate distribution of scarce resources and target dental services to benefit high-need children.

Keywords: Cost, distribution, caries, children, disadvantaged, dental screening, telemedicine.
12.2. INTRODUCTION

Over the last 50 years, there has been a significant progress in improving oral health in Australia, in particular reducing caries experience in school-age children (Mejia et al., 2012). This progress has been attributed to greater fluoride exposure (predominately via public water) and the school dental services programme (SDS) (Mejia et al., 2012; Armfield et al., 2007). As a result, many children, particularly from advantaged groups, who attend for a routine dental checkup, are free of dental disease; unlike previous decades where many children presented with a dental disease. Although Australians are one of the healthiest populations worldwide, health inequalities do exist. This inequality is more apparent in dental health, with the majority of disadvantaged children experiencing higher rates of dental caries and more severe dental disease than advantaged groups (Neuhaus et al., 2009b). Much dental disease amongst children with low socio-economic status (SES) goes untreated, widening the gap between the level of their dental health and the rest of population (Slade et al., 2007). The cause of this gap in dental health is various but is mainly attributed to the lack of dental care access, often due to maldistribution of the dental workforce as well as rural-urban and socio-economic determinants (Neuhaus et al., 2009b).

Caries occurs mainly during childhood and adolescence, but its impact can be minimised through early detection and regular dental screening programmes (Macey et al., 2015; Brocklehurst et al., 2012). This is important because once a carious lesion develops in one tooth, the disease can rapidly flare up and spread to other teeth. Therefore, it is important to regularly monitor the oral health of populations at high risk to prevent further dental disease from developing, and maintain good oral health. However, access for all children, particularly in remote or very remote regions, is challenging. One of the potentially viable alternatives to address the oral health inequities and inequalities is the use of teledentistry to screen for caries (Estai et al., 2016b; Kopycka-Kedziewski et al., 2007). A mass dental screening programme can be achieved at low-cost by using mobile teledentistry, where an onsite competent adult (e.g. a teacher at a school or caregiver at home) can use a smartphone camera to acquire dental photographs from a child’s mouth for later evaluation by a distantly located dental practitioner. The shift from a face-to-face dental screening approach to a teledentistry model of dental screening, can potentially save substantial
resources which can be redirected to provide targeted and tailored dental care to high-risk children.

The current study is built on a previous national cost model study that compared the cost of two approaches to screening for dental caries among all school children in Australia; teledentistry and direct visual oral examination (Estai et al., 2017a). This study sought to examine the distribution of cost-savings resulting from replacing the traditional approach with a teledentistry model of dental screening, with the aim of estimating the scale of resource savings that could be achieved by moving low-risk children to teledentistry screening.

12.3. METHODS

This study used population data obtained from the Australian Bureau of Statistics (ABS) 2011 Census. Australia is divided by the ABS into 2200 non-overlapping/no-gaps statistical local area (SA2) (approximate suburbs). These SA2s are clustered by States, Remoteness Areas (RA) and Socio-economic Indexes for Areas (SEIFA) indexes. SEIFA is a nationally accepted index for socio-economic status in Australia (Australian Bureau of Statistics, 2008). SEIFA groups are ranked into deciles, with decile 1 being the most disadvantaged, and decile 10 being the most advantaged. The degree of remoteness of each SA2 was obtained from the ABS website using the Australian Standard Geographical Classification (ASGC) Remoteness Area Correspondences, 2006 (Australian Bureau of Statistics, 2008). The ASGC classification divides Australia by remoteness into five groups: major cities of Australia (R1), inner regional Australia (R2), outer regional Australia (R3), remote Australia (R4) and very remote Australia (R5). All the data were obtained from open access internet-based sources, therefore no ethics approval was needed for this study.

12.3.1. Cost Model-revisited

A previous national cost-minimisation study was based on a model of two dental screening approaches performed from the perspective of the oral health system (Estai et al., 2017a). In short, a scenario was developed to simulate the costs of two models of dental screening over...
12-months for all Australian school children aged 5-14 years (2.7 million children). One screening method was a universal traditional approach (direct visual), whilst the alternative was teledentistry screening. The cost of traditional dental screening was weighted relative to the remoteness of SA2s (Estai et al., 2017a). Costs for screening increased directly with the increased remoteness of SA2s, which is related to overnight accommodation and travel expenses as well as the remote incentive allowance (Estai et al., 2017a).

12.3.2. Integrated Model Development

The modelled cost data of the two screening methods (teledentistry and direct) were linked to the 2200 SA2’s and then mapped in relation to State, RA and SEIFA indexes. Using Excel v2013 (Microsoft; Redmond, WA, USA) the costs were distributed on a per-child basis to each SA2 for each model (teledentistry and direct visual). The fully integrated database was then geo-coded and mapped using a free and open-source geographic information system application ‘QGIS’ (version 2.16) to provide visual presentation of the modelled cost data by State, RA, and SEIFA indexes.

12.4. RESULTS

The total number of Australian school children aged 5-14 years, was 2.7 million children, which represents less than 12% of the total Australian population. The distribution of children across the five remoteness regions and SEIFAs deciles is presented in Figure 12-1.
Figure 12-1  Distribution of child (5 to 14 years old) population (top), the cost for traditional dental screening (middle) and cost for teledentistry screening (bottom) across Remoteness Areas (R1 major cities to R5 very remote) and SEIFA indices (1 most disadvantaged to 10 most advantaged).
12.4.1. State-by-State

NSW had the highest child population with a total of 873,000 (which represents less than one-third of Australia’s total child population), followed by VIC (n=653,457), QLD (n=577,389), WA (n=288,458) and SA (n=191,000) (Figure 12-2). Across all Australian States (except the NT), the majority of Australian children reside in major cities and inner regional areas. In NSW, VIC and QLD there is a relatively equal distribution of children across the SEIFA deciles. However, this is not the case in SA and WA, where more than 60% of the child population in SA belong to SEIFAs 1-5 while up to 65% of children in WA belong to SEIFAs 6-10. The estimated annual costs for traditional dental screening in NSW, QLD and VIC were $39 million, $31 million and $28 million respectively, which represents nearly three-quarters ($98 million) of the estimated total budget for traditional screening. Undertaking dental screening by teledentistry in NSW, QLD and VIC would cost $40 million which generates a net saving of $58 million (Figure 12-3 and Figure 12-4).

Figure 12-2 Geographic distribution of children (5-14 years) across the Australian States (A) and New South Wales (NSW) (B).
Figure 12-3  Geographic modelling of the traditional screening costs (in AUD) across the Australian States (A) and New South Wales (NSW) (B).

Figure 12-4  Distribution of screening costs (in thousands AUD) using the teledentistry approach across the Australian States (A) and New South Wales (NSW) (B).
12.4.2. Socio-economic Status

In Australia, each SEIFA decile consists of an average 10% of the total child population. SEIFA 10 had the highest proportion of child population (n=315 000) in Australia. The majority of advantaged children (SEIFAs 6-10) across the nation live in or near cities, and just under 50% ($66 million) of the estimated budget for traditional screening is spent on advantaged children (SEIFAs 6-10) (Figure 12-1). The average cost of teledentistry screening per SEIFA decile was $5.5 million. Teledentistry screening for advantaged children (SEIFAs 6-10) in Australia would cost in total $26 million.

12.4.3. Remoteness

The primary focus of this study was to estimate the value of resources that could become available for redistribution by introducing a teledentistry screening programme for low-risk children (SEIFA 6-10). Moving Australian advantaged children (SEIFAs 6-10) to a teledentistry model of dental screening would cost $26 million in total, which would reduce annual screening costs by $40 million (Table 12-1). These resources could be then used to provide better dental care for underserved/high-risk children (SEIFA 1-5).

NSW had the largest number of advantaged children in Australia (n=438 000 children), they consume $19 million, which accounts for about 48% of NSW's proposed total budget for traditional screening. The transition from traditional screening to a teledentistry model of dental screening for NSW's advantaged children (SEIFAs 6-10) would reduce screening costs by $11 million. After NSW, VIC had the second largest number of advantaged children (n=300 000) in Australia, screening this group of children would cost $15 million, representing approximately 53% of the total budget for traditional dental screening in VIC ($28 million). Dental screening by teledentistry for advantaged children (SEIFAs 6-10) in VIC would cost $7 million which would lead to a net saving of $8 million. Data for the other Australian States is presented in Table 12-1.
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### 12.4.4. Resource Transfer Model

The primary focus of this study was to estimate the redistribution of resources that could be achieved by introducing a teledentistry screening programme for low-risk children (SEIFA 6-10). Moving Australian advantaged children (SEIFAs 6-10) to a teledentistry model of dental screening would cost in total $26 million which would reduce annual screening costs by $40 million (Table 12-1). These resources could be then used to provide better dental care for underserved/high-risk children (SEIFA 1-5).

NSW had the largest number of advantaged children in Australia (n=438,000 children), they consume $19 million, which accounts for about 48% of NSW’s proposed total budget for traditional screening. The transition from traditional screening to a teledentistry model of dental screening for NSW’s advantaged children (SEIFAs 6-10) would reduce screening costs by $11 million. After NSW, VIC had the second largest number of advantaged children (n=300,000) in Australia, screening this group of children cost $15 million, representing approximately 53% of the total budget for traditional dental screening in VIC ($28 million). Dental screening by teledentistry for advantaged children (SEIFAs 6-10) in VIC would cost $7 million which would lead to a net saving of $8 million. Data for the other Australian States is presented in (Table 12-1).
12.5. DISCUSSION

There is an obvious uneven distribution of children across the Australian States, with NSW having the highest density of children. However, child populations were relatively equally distributed across the different SEIFAs deciles in Australia, where advantaged children consumed as much care resources as disadvantaged children. A clear rural-urban divide with regard to the distribution of child populations exists, with the major cities of Australia having the highest density of the child population (n=1.8 million). Geographic inequalities in dental care delivery and resource distribution are related to the density of the child population, so is focused on those living in or near cities. The overall findings of this study demonstrated that the distribution of the estimated budget for traditional dental screening does not match the population characteristics and the burden of dental health diseases. This sub-optimal allocation of care resources can contribute to widening oral health inequalities.

There is a relationship between SES and the general health of a population. Advantaged groups have better oral and general health than low SES groups, which may indicate that dental health inequalities and general health inequalities share similar determinants or dimensions (Watt and Sheiham, 2012). The majority of the least disadvantaged children (SEIFAs 6-10) reside near city centres where dental care services are more available and easier to access, and these low-risk groups consume a large share of care resources. Disadvantaged children (SEIFAs 1-5), who experience higher levels of dental disease, receive a smaller budget relative to their levels of need. These findings are consistent with previous reports indicating that low SES populations not only have a higher burden of oral disease (Kilpatrick et al., 2012) but have less access to dental care compared to advantaged groups (Schwarz, 2006; Slade et al., 2007).

Access to health care is unequal across Australia and this is even more extreme in dental care. In order to achieve equity and equality in health care, a population with unequal needs should have access to unequal healthcare resources (positive discrimination), where people with high-needs should receive a larger amount of health care resources than the rest of population. However, reducing the dental health inequalities between different SEIFA levels is challenging due to the uneven distribution of dental care services across Australia, and the fact that dental care is fundamentally a private-driven practice delivered on a fee-for-service
basis. Unlike other general healthcare services, dental care is excluded from Medicare as dental care is considered a low priority by health policy makers (Schwarz, 2006). The annual total expenditure on dental care rose to $9 billion in 2013-2014, but up to 60% of that expenditure is out-of-pocket (Australian Institute of Health and Welfare, 2015).

Against this backdrop, telemedicine and, more recently, mobile teledentistry (which is a form of mobile telehealth specifically dedicated to dentistry emerging from the combination of cellular technology and store-and-forward telemedicine) has emerged as a model to contribute to the reduction of healthcare inequalities and inequities; particularly for remote or underserved communities. The introduction of dental research on the use of mobile teledentistry, particularly, in screening for oral malignancies (Haron et al., 2016; Birur et al., 2015) and dental caries (Estai et al., 2016b; Estai et al., 2016d), has produced outcomes proving its benefits. The shift from the traditional approach to a teledentistry model of dental screening, in particular for low-risk children, has the potential to meet appropriate dental care needs. Children with the lowest level of need can be treated by MLDPs based on the outcomes of teledentistry screening, given that many advantaged children who attend dental clinics on a regular basis do not need any treatment. In contrast, children with high needs could be examined and provided with dental care through traditional models, using the majority of resources. Dental care services designed in this form of workforce substitution (MLDPs) have the potential to allow reallocation of scarce resources to the target population with the highest need and help in alleviating dental health inequalities.

12.6. CONCLUSION

One of the basic objectives of any health care system is to provide accessible and appropriate services to the local community. To reduce dental health inequalities within a community, scarce care resources should be directed to high-risk groups. The use of teledentistry for dental screening, particularly among advantaged populations (who are likely to experience no or low levels of dental disease) has the potential to reduce care expenditure and achieve equity in distribution of care resources. The net savings can be used to address the specific dental care needs, and bridge the gap in dental health, between disadvantaged groups and the general population. The findings of this study can be used to inform future decisions to
guide the optimal allocation of scarce resources and targeted care services to benefit high-need populations, especially vulnerable groups and those living in remote/very remote regions. Such studies could be the backbone for public health initiatives that will assist in reducing inequalities and inequities in the provision of dental care.
Chapter Thirteen

13. General Discussion and Conclusion

Part of this chapter is presented as published paper in the following citation:

PREAMBLE

The findings, implications and limitations for each of the studies in Chapters 6 through to 12 have been presented and discussed in the relevant chapters. This general discussion chapter is divided into four parts: critique of findings, implications, study limitations and conclusion. Firstly, the critique of findings part is presented with five sections — in the first section we discuss the accuracy and reliability of a photographic caries assessment method, in the second, the feasibility of mid-level dental practitioners (MLDPs) in remote dental screening, in the third the end-user acceptance of the teledentistry model of screening, and in the fourth we discuss the Australian dentist’s perception of the use of telemedicine in routine practice. In the last section we discuss the economic evaluation of the teledentistry model of dental screening. In addition, we discuss directions for future research arising from this project. Finally, the limitations of present studies are outlined and the chapter concludes with a summary of the key findings.

The key findings of this thesis suggest that dental practitioners with minimal training have the potential to detect dental caries from web-based presented images with comparable diagnostic accuracy and reliability to dentists. The use of a DLSR camera in dental screening proved to be a more accurate and reliable screening tool than a smart phone. However, this research suggested that the use of a smartphone camera and store-and-forward technology could still offer a reliable and cost saving means of dental screening in large-scale epidemiological settings.
13.1. CRITIQUE OF FINDINGS

13.1.1. Reliability and Accuracy of Smartphone-based Photographic Caries Assessment (Chapter 6)

Although unaided visual inspection has been the primary method for dental screening in epidemiological settings, some investigations demonstrated that this technique cannot maintain a high level of diagnostic accuracy (Milicich, 2000; Forgie et al., 2003). It is well-known that neither a photographic method nor visual inspection can detect interproximal nor precavitated lesions without radiographs and the failure to use radiography may result in underestimation of caries occurrence. Therefore, the purpose of this study (Chapter 6) was to assess the accuracy and reliability of the digital photographic method of detecting caries at tooth level, not for the clinical estimation of caries prevalence. Despite the dearth of research evidence on the use of a smartphone camera in dental screening, this study suggests that the use of a smartphone camera in the detection of dental caries from a still photograph yielded a moderate level of accuracy and reliability when compared with the visual inspection approach. The photographic caries assessments by dentists maintained a relatively moderate level of sensitivity (60-63%) and a very high specificity (96-99%), comparable to that of the reference visual caries assessment. The sensitivity scores for the photographic method (compared to the reference visual assessment) were lower than the WHO’s recommended threshold of 85-90%. Our findings also showed an only moderate level of concordance between the photographic and visual caries assessment at tooth level, with Kappa ranging from 0.54 to 0.66. These results are consistent with findings from our previous proof-of-concept trial (Estai et al., 2016d).

The sensitivity, specificity and inter-examiner reliability values observed in our study were inconsistent with Purohit et al.’s study that used a moving/video photograph taken by a smartphone camera in the screening for dental caries (Purohit et al., 2016). Purohit and colleagues reported a sensitivity and specificity of 86% and 58% respectively and inter-examiner reliability score of 0.84 for the photographic caries assessment in a comparison to the visual inspection. The high sensitivity and inter-examiner reliability scores reported by Purohit et al. are likely attributed to the study sample (school children) and the imaging technique used. The use of the photographic method in detecting dental caries in children is
relatively easier than adults and the use of moving photographs may provide better access to view the oral cavity, particularly the posterior permanent teeth. In our study, the lower value for the sensitivity is due to excluding filled and missing teeth from the analysis. Missing teeth and, restorations/fillings are more likely to be identified in a photograph and do not require to detect. The relatively high specificity could be attributed to the inability of the charters to see some carious lesions in an intraoral photograph compared to the visual inspection. The moderate level of concordance between the two assessment methods is likely due to the difference in the clinical experience and training of screeners and charters as well as poor-quality of dental photographs. In some cases, the loss of diagnostic details due to the quality of images contributed to the difficulty in detecting carious lesions in a photograph. Permanent molars have a deep pit and fissure morphology, the shape of the pits and fissures on the occlusal surfaces (may contribute to difficulties in differentiating carious lesions from artifacts (saliva, blood or debris) in tooth fissures. These could justify why charters scored some teeth as ‘unrated’. The percentage of unrated teeth was less than 20% (approximately 596 teeth). This is in line with a previous research that reported a variation in the inter-examiner reliability in detection of carious lesions in permanent teeth, particularly the posterior teeth (Kopycka-Kedzierawski et al., 2007; Mialhe et al., 2009; Pereira et al., 2009; Patterson and Botchway, 1998). Such limitations could have introduced variability in the charting of teeth and would have potentially influenced the sensitivity and inter-examiner reliability.

The smartphone camera used in this study produces images of 8.0 megapixels and this is considered adequate for producing satisfactory images, even at high compression ratios. However, it should be noted that the use of a smartphone camera to capture the desired anatomy with correct composition was challenging in this study. Until recently, the use of smartphones in dental practice was not well received because of the low-quality of the built-in cameras, limited storage capacity, and unsuccessful data transmission (Park et al., 2009). Their use particularly in epidemiological surveys has advantages over other photographic devices such as DSLR or intraoral cameras. Smartphone devices are small, easy to use, readily carried and used at any time as well as capable of producing satisfactory images with minimal training. The inherent digital imaging capabilities, computational power and mobile connectivity of smartphone devices, as well as access to low-cost, secure, cloud storage enables their users to perform multiple tasks such as processing, storing, and subsequent
sharing of information. Therefore, smartphones were used in this study to reduce the time of data transmission and cost of equipment for acquiring dental photographs. If the photograph acquisition conditions are carefully controlled, smartphone cameras could be deployed as economic and user-friendly screening tools. This could make the use of these devices in community or large-scale epidemiological settings a possibility.

13.1.2. Reliability and Accuracy of DSLR-based Photographic Caries Assessment (Chapter 8)

This study sought to determine the concordance and reliability between the reference expert panel assessment and photographic caries assessment by different oral health professionals. A DSLR camera is a better device in terms of quality than other photographic devices and this was reflected in its higher diagnostic accuracy and reliability levels. This study suggests that the diagnostic performance of the DSLR-based photographic caries assessment is comparable to the expert panel assessment. The detection of dental caries at tooth level, taken from a still photograph taken by a DSLR camera, maintained a high level of the sensitivity and specificity. The photographic method, when compared to the expert panel assessment had a sensitivity of (82-89%) and it is almost within the WHO’s reference standard of 85-90%. The higher value for the sensitivity might be explained by the ability of charters to detect caries easily from photographs or attributed to scoring a tooth as having caries when in doubt. The present findings are in agreement with previous studies concerned with photographic caries assessment which demonstrated high sensitivity and specificity scores (Kopycka-Kedzierawski et al., 2007; Gomez et al., 2013; Boye et al., 2013; Elfrink et al., 2009; Amável et al., 2009). The higher level of diagnostic accuracy was also associated with a high level of inter-examiner agreement (i.e. almost perfect) between the photographic and visual caries assessment. This reflects previous research that reported no significant difference between photographic assessment and clinical screening for dental diseases, with Kappa scores for inter-examiner reliability between clinical and teledentistry screenings ranging from substantial, to almost perfect agreement (Morosini et al., 2014; Elfrink et al., 2009; Kopycka-Kedzierawski et al., 2007; Wong et al., 2005; Gomez et al., 2013).

Different types of image capturing devices are available, however, a DSLR camera remains the most common device used in clinical and epidemiological studies. In this study, a DSLR
camera showed better diagnostic performance when compared with a smartphone camera. Thanks to the camera resolution (Canon MR-14EX, 18.0 megapixels) which is capable of producing high-quality images. This may also be attributed to the conditions under which the dental photography was taken. All photographic procedures were conducted pre-operatively while patients were under general anaesthesia using sufficient lighting and oral retractors to view the oral anatomy. These conditions permitted acquiring dental photographs with good-quality and clearer oral anatomy. However, acquiring images with the correct composition is not guaranteed even when a DSLR camera with high resolution is used. The use of DSLR cameras in dental photography requires a longer time for preparation/setting up and much training. Although high-quality images are fundamental for reaching a correct diagnosis, the data transmission or sharing characteristics is also important for the success of teledentistry. The transmission of data from a DSLR camera is sometimes difficult, and even when data transmission is possible, the time for transmission of photographs would be longer than for a lower resolution image and a transmission failure could be more likely (Park et al., 2009). Because DSLR cameras may not be affordable and readily available, the use of these devices could be more suitable in clinical or dental practice settings rather than in community-based settings.

The recent improvements in quality and affordability of digital photography have had a great impact on the acceptance of this technology. Digital photography, particularly, using DSLR cameras has rapidly become one of the tools used routinely in dental practice today. In spite of its enormous potential, digital photography has rarely been used in diagnosis, consultation or treatment planning. Its use in dentistry has been limited to records made for legal reasons, patient instruction and practitioner interest (Morse et al., 2010). Like radiography, dental photography could be regarded as a diagnostic tool (Ahmad, 2009a). Dental photography can be useful to support the early detection and diagnosis of potentially malignant oral lesions, through sending a photographic record electronically to seek a speedy and informed opinion from a dental consultant at a distance (Wander and Ireland, 2014). It can also be useful for recording a baseline of oral health status pre-operatively which can be used to confirm the diagnosis and preparing an appropriate treatment plan (Ahmad, 2009a). In addition, this can be helpful to prioritise patients when referring them to consultants and avoid delay in treatment, particularly for urgent or complicated cases (Aslam and Hamburger, 2010).
13.1.3. The Use of MLDPs for the Detection of Dental Caries from Photographs (Chapters 7-8)

To our knowledge, our study is amongst the first to investigate the use of MLDPs in detecting dental caries from still photographs taken by different photographic devices such as smartphone and DSLR cameras. Our findings suggest that MLDPs have the potential to screen for dental caries from photographs with a comparable diagnostic accuracy and reliability as dentists. This is consistent with the previous studies that evaluated the use of different members of the dental team to screen for common dental diseases in vivo by, suggesting that MLDPs have the potential to screen for dental diseases to a standard equivalent to dentists (Brocklehurst et al., 2012; Macey et al., 2015; Daniel and Kumar, 2016).

In Chapter 7, the use of a smartphone camera in the detection of dental caries by two MLDPs (charters 1 and 2) was examined. The photographic assessment by both charters was compared against each other’s assessment and against the reference visual caries assessment. The relatively low level of sensitivity is due to the likelihood of charters having a higher threshold for identifying lesions as carious in the photographs or may be due to the difficulty of detecting carious lesion from a photograph. Similarly, there was a moderate level of sensitivity (68%) between the two charters, which could be attributed to the difference in the experience, and training between the two charters. It is well-known that different dentists can reach different diagnostic outcomes. The level of concordance between the two charters was not too high, with kappa=0.61. In contrast, the intra-examiner reliability for the charters was very high (i.e. almost perfect), suggesting that the both charters were consistent in the scoring and the way they identified caries from the photographs. These findings were almost comparable to the sensitivity, specificity and inter-examiner reliability scores reported in Chapter 6 that examined the feasibility of a smartphone camera in remote dental screening by two dentists. This indicates that there is no difference between judgement decisions for MLDPs and dentists. In chapter 8, two charters, a dentist and MLDP were used to screen for carious lesions from a still photograph taken by DSLR camera. The judgment decisions for both charters were compared against each other. The intra-examiner and inter-examiner agreement for the two charters (dentist versus MLDP) were substantial to almost perfect, with kappa ranged from 0.80 to 0.82. These findings are also consistent with Brocklehurst et al. (2015) study that evaluated the use of an MLDP in detecting oral diseases.
from photographs which showed that the accuracy level for primary care dentists and MLDPs was similar when compared against the reference histopathological diagnosis (Brocklehurst et al., 2015).

The use of role substitution such as OHTs/DTs is often ideal for undertaking dental screening. Training OHTs/DTs to perform screening would need significantly less time and funds. Compared to dentists, there are more OHTs/DTs available in remote and very remote Australia (Chrisopoulos et al., 2016). OHTs/DTs working in the private sector are responsible only for performing dental cleaning or polishing; thus they could have more time available to perform other tasks than dentists. As the oral health status in the general population improves further, many regular dental care seekers will receive routine dental checkups and therefore will need periodontal therapy or preventive care rather than active treatment. This highlights the need to delegate tasks that are often performed by dentists to other members of the dental team. Therefore, it would be advantageous to use MLDPs as front-line clinicians to perform screening and provide dental care to simple cases while let dentists focus on treatment of urgent or complicated cases (Brocklehurst et al., 2012). Besides its potential to support role substitution, teledentistry has implications for enhancing career or employment opportunities, particularly, for those practitioners suffering from physical disabilities and occupational injuries (e.g. chronic shoulder or back disorders) or those nearing the retirement age who would prefer to practice without interacting with patients.

### 13.1.4. End-Users Acceptance of Teledentistry Screening (Chapter 9)

This study (Chapter 9) was not designed to examine in depth the end-users’ (charters and tele-assistants) perception of teledentistry based dental screening, but to provide insights on its acceptance. Collecting feedback on areas of satisfaction, barriers, and suggestions from end-users about teledentistry can help foster better-designed applications that can be more successfully implemented. Generally, more optimism was expressed by end-users with respect to the use of mobile teledentistry for screening purposes. This reflects previous research which has shown excellent levels of acceptance of a real-time based teledentistry system by both patients and professionals (Mariño et al., 2014). This study partly supports the TAM model of telemedicine acceptance. Similar to the assertion of TAM (Davis et al., 1989; Chen and Hsiao, 2012), findings show that perceived ease of use and usefulness were
relatively high among users and were positively associated with users’ attitude toward using the teledentistry system. However, our data indicates that the perception of the system’s stability, content, and format have a strong influence on attitudes towards the teledentistry system. The intention of an individual to use the system is not only predicted by their perception of its usefulness but also determined by the system’s stability, format, and content, which were rated consistently high in the survey. Perceptions of information quality and support were not found to influence the intention to use the system significantly and the latter could be attributed to the absence of coordination between sites and lack of prior personal experience with teledentistry. Another important factor that may affect an end-user’s intention to use telemedicine, is the need for collaboration and coordination between remote and hub sites when implementing a telemedicine system (Fricton and Chen, 2009).

Most end-users (charters) found that the Remote-i system was accurate, stable, easy to use, and presented in a useful format. Our findings also showed that perceived accuracy, format, and ease of use could still be improved. However, a few concerns were expressed by charters, including difficulty in seeing posterior teeth because the oral cavity was not retracted enough during the photography process, as photographs were taken without oral retractors. Other issues related to the system architecture such as inappropriate dental chart layout and design, and incorrect orientation of images and labeling, were also identified. Many of the problems encountered by the charters could be avoided by further modification and optimization of the server and improving the quality of dental photographs.

Many problems related to the use of a smartphone camera in dental photography (such as over bright or dark photographs) were taken into account during the proof-of-concept stage. However, concerns with the information quality and ease of use of smartphone camera were raised by end-users. Although most smartphone end-users (tele-assistants) felt that the Teledental App was accurate and easy to use, a number of tele-assistants (20%) experienced difficulty with the use of the smartphone camera. The majority of the smartphone end-users suggested that the quality of photographs needed further improvement. End-users’ concerns with the smartphone camera were mainly attributed to the difficulty of getting high-quality photographs due to problems relating to the optimisation of camera features, including inadequate illumination of the oral cavity (due to problems with adjusting the smartphone camera’s flash) and the effect of blurring, produced by lack of focus, head motion when
taking a photograph. In addition to these concerns, the absence of oral retractors during dental photography and lack of adequate training, also contributed to the poor-quality of some images. Although tele-assistants were trained to produce good-quality oral photographs and the training does not take much time, it was hard to achieve adherence to the photography protocol. Many tele-assistants’ concerns could be resolved through more effective training and hands-on experience.

13.1.5. Dental Practitioners’ Perceptions about the Use of Telemedicine (Chapter 10)

In chapter 10, we sought to explore the perceptions of dental practitioners about the usefulness of teledentistry for the practice and patient, and determine their perceived concerns. Overall, the use of teledentistry in routine practice was well-received by dental practitioners, in particular with respect to the advantages of teledentistry for patient outcomes. The majority of the surveyed practitioners felt that teledentistry would be useful for improving dental practice through enhancing communication with peers and guidance as well as improving appropriate referrals. Most respondents also agreed that teledentistry is quite useful for improving patient management, and increasing patient satisfaction. This reflects previous studies that found that Canadian dentists/orthodontists are quite open to the use of digital and electronic technologies in dentistry and suggested that ICT is capable of improving patient satisfaction and increasing practice productivity and efficiency (Flores-Mir et al., 2006; Palmer et al., 2005; Mandall et al., 2005b). However, this survey has identified certain barriers to the use of teledentistry. A large proportion of respondents were concerned with particular aspects of teledentistry, including the cost of setting up the teledentistry system, data confidentiality and technical incompatibility. For certain aspects such as data accuracy, practice expenses, time management and surgery time, the usefulness of this approach were rated as low, with a large proportion of respondents unsure about the impact of these aspects. These findings were consistent with concerns expressed by UK GDPs and Canadian orthodontists, in particular, with respect to the cost, data security and time management (Mandall et al., 2005b; Palmer et al., 2005).

Concerns with prolonged surgery times are consistent with previous reports which show that the time to prepare a patient for a teleconsultation is longer than for traditional care settings.
Costs of equipment and setting up telemedicine may represent a burden on care providers and governments (Khan and Omar, 2013). Nowadays, almost all dental practices have the complement of equipment (e.g. digital cameras, radiographs and the internet) required for telemedicine practice. As telemedicine technology is evolving, the cost of equipment and set up will decrease while the quality will improve. Additionally, the use of readily available infrastructure could save the cost of teledental equipment, and reduce practice expenses and consultation costs. Increased use of technology in practice has heightened concerns about security vulnerabilities associated with transmitting unencrypted data, transferring data via an open Wi-Fi hotspot or inappropriate access to databases (Cederberg et al., 2015; Daniel and Kumar, 2014). With the violation of patient privacy appearing to be easier than ever before, protecting patients’ privacy in an electronic environment becomes challenging (Fairweather and Rogerson, 2001). This is in line with a previous survey of Canadian orthodontists, which demonstrated that security or privacy represents major obstacles to the use of the technology in dentistry (Palmer et al., 2005).

While increased risk of privacy violation, equipment cost and surgery time have been cited as major obstacles to the general use of teledentistry, legal and ethical considerations such as remuneration, licensure, jurisdiction and malpractice issues may become a matter of concern as teledentistry becomes more widespread (Golder and Brennan, 2000). These issues occur primarily due to the absence of well-defined legislatures that regulate teledentistry practice and the absence of a universal definition of teledentistry in different countries (Bhambal et al., 2010; Golder and Brennan, 2000). This survey has highlighted where dental practitioners would need support, in particular, the cost of setting up telemedicine, practice expenses, surgery time, accuracy, privacy and technical incompatibility. Addressing how teledentistry can benefit specific aspects of dental practice would motivate more dental practitioners to actively integrate this technology into routine practice. It would be helpful to re-evaluate dental practitioners’ perceptions in the future as new challenges may emerge when teledentistry becomes more widely used.
13.1.6. Economic Evaluation of Teledentistry-based Screening (Chapters 11-12)

A review of the literature shows there has been little research into, or analysis of, the cost of teledentistry (Mariño et al., 2016; Scuffham and Steed, 2002), and the majority of literature describes small-scale projects with short-term outcomes. Therefore, strong evidence on its impact on costs and efficiency is limited. Under the assumption that all school children in Australia were screened, a cost model was developed to identify the extent to which dental screening using teledentistry could reduce costs compared to the traditional approach. In Chapter 11, findings suggest that teledentistry offers a practical and cost saving alternative to the traditional approach of dental screening, particularly in remote locations. This is consistent with previous studies (Mariño et al., 2016; Scuffham and Steed, 2002), indicating that the use of teledentistry offers considerable cost savings. The cost minimisation analysis showed that the cost of the teledentistry model was lower than that of the traditional approach of dental screening ($50 million versus $135 million). The major contributors to the cost savings were the lower cost of charter (OHTs) salaries and avoidance of travel and overnight accommodation by dentists and their assistants.

Nearly half of the school children enrolled in the SDS suffer from poor oral health (Spencer, 2004). This problem is mainly attributed to funding difficulties and the concentration of these services in urban areas (Spencer, 2004). The teledentistry model offers the means for the effective use of OHTs to remotely screen large populations at a low cost. Our findings suggest that the use of OHTs as charters in teledentistry is a practical and cost-saving approach. In the SDS, OHTs have a limited scope of practice, and therefore they need to practice under direct supervision of a dentist. The teledentistry model enables supervisory dentists to supervise OHTs indirectly through teleconsultations and allow them to access the database to verify OHTs’ treatment plans easily and quickly. Teledentistry enables oral health professionals, anywhere on the globe, to view and assess dental photographs at their desktops at their convenience, without the need to travel to screening locations. Therefore, a teledentistry approach potentially would allow the use of overseas trained MLDPs with accredited qualifications (e.g. from New Zealand, the UK or Ireland), to screen for dental diseases in Australia at a distance. Deploying a limited number of off-site overseas MLDPs with good mentorships could reduce the dependence on overseas trained dentists from
developing countries who are primarily brought in to mitigate extreme shortages in rural areas.

In order to enhance dental care services for high-risk children, the scale of resource transfer that could be achieved by moving low-risk children to a teledentistry model of screening was estimated (Chapter 12). Although Australia has one of the healthiest populations in the world, inequalities in oral health do exist. Disadvantaged populations not only have a higher burden of oral diseases (Kilpatrick et al., 2012) but have less access to dental care compared to advantaged groups (Schwarz, 2006). The majority of the least disadvantaged children (SEIFAs 6-10) reside near major cities where dental care services are available and easy to access. Many advantaged children who visit dentists on a regular basis are free of dental diseases but they consume a large share of expensive resources. In contrast, disadvantaged children (SEIFAs 1-5) who already experience a high level of dental diseases and have limited or no access to dental care, receive a smaller budget relative to their high level of need. In order to achieve equity and equality in health care, a population with unequal needs should have access to unequal healthcare services (i.e. positive discrimination). One way of achieving equity and equality in oral health is to fully use all the available dental workforce whereby the right services are provided to the right people by right members of the dental team (Macey et al., 2016). Therefore, it is more efficient and cost-saving to have MLDPs perform triage and treat simple cases and have dentists to take care of complicated or urgent cases.

Tackling inequalities in dental health between different socio-economic (SEIFA) levels is challenging, due to the fact that dental care is not covered by Medicare but largely provided via the private sector, on a fee-for-service basis (Schwarz, 2006). Teledentistry has the potential to address inequalities and inequities in healthcare; particularly for remote or underserved communities. The shift from the traditional approach to a teledentistry model of dental screening, in particular for low-risk children (SEIFAs 6-10), has the potential to meet specific dental care needs. The provision of dental care to those children can be delegated to MLDPs, given that many advantaged children who visit a dentist regularly do not require further treatment other than preventive care. In contrast, children with the greatest needs can be examined and treated by dentists, using the majority of the dental care resources.
This strategy has the potential to allow distribution of scarce resources to the target population with the highest need, and help in alleviating dental health inequalities.

13.2. FUTURE DIRECTION OF RESEARCH

ICT is evolving and being integrated into all aspects of daily activities such as banking, mobile devices, emails, social networks, online shopping and distance education, thus making life easier in a rapidly changing world. Dental care providers and health policy makers need to recognise the opportunities presented by these technological advances to redesigning the delivery of dental care to poorly accessed or underserved areas.

13.2.1. Improving Oral Health in Children

If dental problems remain untreated in children it may not only result in pain, distress and disturbance of sleeping and eating patterns, but may also impact on child development and educational performance (Guarnizo-Herreño and Wehby, 2012). Good oral health in early life could form the foundation for good general health, well-being and quality of life in later years. Habits or behaviours established in early life are often carried into adulthood (Watt et al., 2014). Therefore, improving oral health is particularly important in childhood, by reducing dental caries, and preventing early tooth loss and other oral diseases during adulthood. Despite the fact that many dental diseases are preventable, the burden of disease associated with poor oral health is immense. Thus, much effort needs to be directed to the effective prevention of oral disease at the population level. Improving the public’s oral health is obtained by shifting the emphasis of dental care from the provision of treatment towards the effective prevention of dental diseases.

However, improving the oral health of the public is challenging, as the socio-economic gradients, unequal distribution of the dental workforce and limited resources make the transition to prevention difficult. Dental screening could be seen as a first step towards the implementation of preventive services and effective control of dental diseases like dental caries. The use of teledentistry to screen for dental diseases in children is a worthwhile initiative that might contribute to maintaining good oral health, by identifying groups at high-
risk or those suffering from severe dental disease and targeting them to receive dental care by dentists or MLDPs, depending on the severity of the disease. Children who are considered to be low-risk do not need additional management other than to receive preventive care by MLDPs (Brocklehurst et al., 2011). This strategy can help to direct specific dental care towards those most in need, thereby contributing to reduce inequalities in oral health.

13.2.2. Improving Oral Health in an Ageing Population

In addition to improving oral health in children, teledentistry holds great promise for the aged population living in rural regions or those living in residential care facilities. Like many developed countries, Australia's population is aging. Between 2009 and 2014, the number of people aged 65 and over increased by 20% to reach 3.5 million people, accounting for 15% of the total Australian population (Australian Bureau of Statistics, 2014b). As the population ages, there will be an increasing demand for healthcare or aged care which will be associated with increasing expenditure on healthcare services. Aged populations have been recognised as a significant risk group for oral diseases with increasing prevalence of dental caries and periodontal disease. A recent report on oral health and dental care in Australia published by the Australian Institute of Health and Welfare revealed that almost 20% of adults aged 65 or over are edentulous (Chrisopoulos et al., 2016). Reducing the impact of oral diseases among the aged population is challenging. There are significant barriers to seeking dental care for aged people. These are attributed to the uneven distribution of the dental workforce, an increasing proportion of aged people living in remote and regional Australia, many of whom are dependent on others and have special oral health needs (Commonwealth of Australia, 2004). Assessment of oral health among aged populations is difficult due to the prohibitive costs of traditional dental screening and the lack of dental services in rural regions. Research shows that early detection of oral diseases and consultation via telemedicine for aged residents offers a valid and reliable alternative to the traditional oral health examination (Mariño et al., 2015). This approach allows the provision of primary or specialist care to rural/remote residents at low cost, while supporting locally-based care services where they are available (Mariño et al., 2015; Mariño et al., 2016).
13.2.3. Early Detection of Oral Cancer

The incidence of oral cancer is relatively low in developed countries (Hartvigsen et al., 2007), however the use of teledentistry to screen for cancerous and precancerous oral lesions is of great value in many developing countries, where two-thirds of new cases and mortality take place (Ferlay et al., 2004). Early detection of oral cancer has shown effectiveness in reducing the disease burden and mortality rate in high-risk groups (Sankaranarayanan et al., 2005; Brocklehurst et al., 2013). However, the major challenges in the screening for oral cancer in a clinical environment lie in the difficulty in accessing isolated or sparsely populated regions to screen populations at risk of developing an oral malignancy. Also in epidemiological surveys, the use of visual inspection is problematic due to the low prevalence of oral cancer which means that a large sample of high-risk people would need to be examined to satisfy the power calculation.

Mobile telemedicine in combination with web-based evaluation by off-site expert diagnosis have been widely used for early detection of oral cancer (Birur et al., 2015), skin cancer (Lamel et al., 2012) and cervical cancers (Quinley et al., 2011) as an effort toward providing specialist expertise to inaccessible, low resource settings. The use of teledentistry in oral medicine, in a particularly distant diagnosis of diseases, has been shown to be an effective tool in the detection of oral diseases especially potentially malignant lesions (Birur et al., 2015; Torres-Pereira et al., 2013). The use of photography in the assessment of oral soft tissues has the potential to overcome problems encountered in the photography of the dentition, like the limited visibility of posterior teeth or unclear anatomy. The morphology of fissures and multi-surfaces of teeth often require 3-dimensional viewing to visualise all surfaces. Soft tissue lesions are likely to be detected in a photograph more quickly and easily when compared to carious lesions affecting teeth. However, the photographic method has its critique. The judgement of soft tissue lesions in a photograph is restricted to the visual appearance alone, and assumes that the color calibration of the acquisition device is not significantly different to that of with the distant display monitor for image persistence, and palpation of the lesion is not possible in this method (Brocklehurst et al., 2015).

Given the high usage of smartphones even in developing countries and the advancements in imaging technology within these devices, primary care doctors, nurses or trained non-licensed health professionals (e.g. teachers, caregivers or parents) could be deployed as
front-line clinicians to undertake opportunistic visual screening to identify populations at risk of developing oral cancer. Additionally, those front-line clinicians can collect oral health data (e.g. personal details and still or live photographs) from screen-positive patients using their mobile devices and then store-and-forward the records to a dental expert at a distance to confirm the diagnosis or to request further investigation. This is important, as this could alleviate the anxiety of patients and if necessary initiate an earlier intervention. Such a screening approach could enable effective early diagnosis, thereby reducing delays in referrals and improving treatment outcomes and survival rates of patients with oral cancer. In addition, trained non-licensed health professionals can be employed to provide oral health promotion to the population at risk to encourage reducing risk factors by stopping risky personal habits such as pan-tobacco chewing, tobacco smoking, and alcohol use that can help to reduce or prevent the occurrence of oral cancer (Sankaranarayanan et al., 2005).

13.2.4. Optimising Patient Referrals and Facilitating Access to a Specialist

In Australia, distances to the nearest referral centre continue to be a matter of concern for many rural and remote residents. Historically, the traditional paper-based referral pathway has been the key method for sharing clinical information between GDPs and specialists, however, there is a growing risk that the referral letters may lack essential clinical information (photos, radiographs or pathology results). The problem with the traditional paper-based referral is not about the quality of the referral letter but the inability of this method to provide timely information to specialists and provide digital data. This could lead to inappropriate referrals of cases and missing of cases which require referrals. Inadequate referral letters are often associated with delayed patient assessment and contribute to delayed diagnosis and treatment of even sinister lesions (e.g. oral cancer), and less favourable outcomes for the patient (McLeod et al., 2005). The issue in Australia is that the healthcare system does not allow patients direct access to specialist care, but it necessities a referral from a GDP. In addition, the majority of specialists in Australia work in the private sector and are concentrated in the major cities, which might contribute to longer travel time, increased costs and loss of productivity for those patients referred from rural and remote areas. In the traditional referral pathway, a patient is referred to a specialist accompanied by a referral letter. The additional digital information (clinical photographs and radiographs),
which typically is not available through a traditional referral pathway, may impact not only diagnostic validity but also clinical outcomes.

Many referred cases can easily be assessed by analyzing radiographs, clinical photographs or pathology tests and a treatment plan can be prepared without the need for a hospital visit. Alternatively, primary care practitioners can store-and-forward digital data (clinical photographs and x-rays) from patients to a secure, low cost, cloud-based storage system like the Remote-i directly from their mobile devices or computers, for later evaluation by a consultant at a distance. In the teledentistry-based referral model, patients do not need to travel to visit a consultant, as dental specialists can access the database from any location and at their convenience to assess dental records and determine whether a case needs a referral to a specialist or can be treated by a locally-based GDP. Available evidence indicates that store-and-forward based telemedicine has the potential to prioritise new patient appointments and facilitate patient referrals particularly in certain dental disciplines such as orthodontics (Stephens et al., 2002; Mandall et al., 2005a), oral surgery (Herce et al., 2011) and oral medicine (Salazar-Fernandez et al., 2012; Bradley et al., 2010; Birur et al., 2015).

Many dental specialists favour direct visual examination of patients to establish a valid diagnostic decision. However, due to the inability of consultants to travel to check patients in their hometown, a teledentistry-based referral system could provide an opportunity for consultants to identify those in which referral is unnecessary or could be delayed. In this way, patients with potentially malignant lesions, or those requiring urgent intervention can be prioritised for assessment by a specialist (Bradley et al., 2010). This could result in a reduction in time from referral date to the date treatment commenced, thus providing a quick pathway to a consultation. Therefore, teledentistry has implications for validation of referrals (and thus by corollary the optimisation of waiting times based on risk). From the dentists’ perspective, teledentistry has the potential to reduce inappropriate referrals, through providing a second opinion and timely information to the GDP for better decision-making and supporting locally-based treatment. Teledentistry could increase the integration of remote dental experts by reducing dental specialists’ need for travel and facilitate interactivity (consultations and sharing of patient health information) between rural practitioners and dental specialists. Reductions in travel time would also result in increased availability of the dental specialists’ services at their resident clinics.
13.2.5. Facilitating Archiving, Management and Sharing of Oral Health Data

The increase in the speed and methods of data transfer as well as the advancement in digital data compression technologies have made exchanging information feasible via electronic links connecting one computer to a network of computers or cloud storage (Vaziri et al., 2015). Also, the encryption of patient data expedites sharing of information over the internet and provides a way to view patient information in a timely manner which allows patients’ records to be seen in different locations (Chen et al., 2012). Teledentistry can overcome problems encountered in traditional settings (paper-based records) by enabling archiving the digital data (photographs and radiographs) generated. This approach provides a way to manage patient information effectively through enabling recording, monitoring and tracking data related to oral health status with much great versatility, clarity and accuracy. It also helps to improve the quality of dental services by avoiding the duplication of information (duplicative tests or imaging studies) or eliminating potential errors that could be introduced to collected data (Cederberg et al., 2015). Archived data can be used to provide remote training, teaching or wide-reaching research opportunities (Cederberg et al., 2015).

Undertaking traditional dental screening for all Australian children by dentists or any oral health professionals is challenging due to the high costs associated with dental screening and maldistribution of the dental workforce. Teledentistry based dental screening could offer a reliable tool for mass dental screening at low cost. This approach can provide valuable data about the prevalence/extent and severity of dental problems in Australia. The gathered patient data (include digital records with dentition and periodontal charting, treatment plans, moving or still photographs, and radiographs) can be stored in the Remote-i (central repository) for evaluation or charting by a dental practitioner at a distance. In addition, the data collected can be transferred simultaneously to existing oral health databases across the States and Territories (there are no universal oral health databases in Australia).

13.3. LIMITATIONS OF RESEARCH

Despite its usefulness in the detection of oral diseases (particularly using a DSLR camera), many dental practitioners have concerns about the diagnostic accuracy of the photographic method in the assessment of oral health status (Mandall et al., 2005a). Uncertainty about
the diagnostic accuracy of teledentistry may arise from the lack of comfort in the technology by some dental practitioners. Also, it may be attributed to the inability to perform complete assessment when using teledentistry for certain clinical situations. In some cases, a visual consultation may still be needed to establish a firm or an accurate diagnosis (Finch et al., 2003). Therefore, currently, teledentistry must be regarded as an adjunct that enhances the dental care services so as to improve the method of dental care delivery to the sparsely populated or remote regions, and not to replace direct visual patient interactions completely. Clearly, the technology of teledentistry will have to mature and stabilise before it can be used to provide care of a similar quality to traditional dental care in all areas of dentistry.

With digital photography and digital radiographic imaging becoming the mainstays of teledentistry practice, image quality and the ability to evaluate photographs accurately have become fundamental factors in the success of teledentistry. Oral diseases vary in colour, shape, and consistency, and, therefore, the quality of the oral images is invaluable for arriving at a correct diagnosis and preparing appropriate treatment options. The present research (Chapters 6, 7 and 9) demonstrated that some dental photographs acquired by the smartphone camera were of low-quality due to failure to optimise the smartphone camera during the photography, non-compliance with the photography protocol or the presence of artifacts on the occlusal surfaces of posterior teeth. These limitations may necessitate repeating dental photography in some cases and result in a delay in the screening process. This may also contribute to the suboptimal accuracy (sensitivity and specificity values) and reliability of the photographic method. Many of the problems encountered could be avoided through more effective training and hands-on experience with dental photography techniques. A recommendation for future studies is to use disposable oral retractors during photography as this can help in obtaining dental images with clearer anatomy. In addition, the optimisation of the smartphone camera and appropriate adjustment of the camera flash for adequate intraoral illumination, is essential for obtaining quality photographs. Even though the use of video recording in dental photography is rare, the use of video-graphic assessment in dental screening could help to overcome the limitations of still photographs and provide a better visualisation of the occlusal and interproximal surfaces of posterior teeth. More research should be conducted to evaluate the validity and reliability of using moving images in dental screening, and taking into account the transmission performance under different compression ratios.
It is acknowledged that the detection of carious lesions in a still photograph has a limitation in that the still photograph only provides a two-dimensional view, which prevents observing all tooth surfaces not visible in the photographs (particularly the occlusal surfaces of posterior permanent molar teeth and the interproximal surfaces, which are the most vulnerable sites for dental caries). The use of still photographs is also known to have limitations for detecting caries on root surfaces (unless they are exposed through the recession). Despite these limitations, the photographic method can be very useful when used in the detection of carious lesions into dentine level in the primary dentition. Our observations (Chapter 8) showed that the use of a DSLR camera in dental screening produced high-quality images and maintained a high level of diagnostic accuracy when compared with the visual inspection approach. This could be attributed to the study sample which mainly consisted of young children (below 11 years) unlike the study sample in the smartphone camera studies (Chapters 6 and 7) which consisted of different age groups. Dental screening using a photographic method could be more effective if used in young children. Young children have a shorter dental arch with fewer teeth (mostly primary teeth), which could allow for an adequate illumination of the oral cavity and provide a better access to view the occlusal, buccal and lingual surfaces of the primary dentition. These observations are consistent with previous research that reported lower sensitivity values in the permanent dentition as compared to the primary teeth dentition (Boye et al., 2013). In addition, the use of the photographic method in dental screening is more convenient for young children than visual inspection. The recent epidemiological survey reported that children were enthusiastic and co-operative during the photography and recording procedures (Kopycka-Kedzierawski and Billings, 2006). The process of capturing photographs using smartphones can, therefore, be noninvasive and less intimidating for children than visual inspection (Kopycka-Kedzierawski and Billings, 2006).

13.4. CONCLUSIONS

This thesis supports the hypothesis that the use of the photographic method, in particular, a DSLR camera, in the detection of dental caries can offer an accurate and reliable screening tool. The diagnostic accuracy and reliability of DSLR-based photographic caries assessment by MLDPs yielded almost perfect results in children, suggesting that the judgment decisions
of MLDPs in the detection of dental caries from still photographs were at an equivalent standard to dentists. Using a smartphone to capture the desired oral anatomy with correct composition and with high-quality was found to be challenging in this study, and therefore, our findings indicate that a smartphone-based photographic method only produces a moderate level of diagnostic performance. However, this research suggests that smartphone devices could still offer a cost saving and user-friendly alternative screening method and could be utilised in large-scale epidemiological screening, particularly in children, with some degree of confidence. After comparing the photographic method with the traditional visual approach of dental screening the following points can be concluded:

- The use of a smartphone camera for the detection of dental caries yielded relatively moderate levels of diagnostic reliability and accuracy when compared to the benchmark visual caries assessment. This observation needs further investigation to assess the effectiveness of a smartphone camera (using both still and moving photography) in dental screening among young children.

- Overall, there is no significant difference observed between the DSLR camera-based photographic method and the benchmark dental expert panel assessment in relation to the diagnostic reliability and accuracy.

- There is no significant difference between the diagnostic accuracy and reliability of the photographic caries assessment completed by an MLDP and dentist.

- End-users (tele-assistants, charters and examiners) who participated in data collection and analysis perceived the teledentistry model of dental screening positively and provided suggestions that can help foster better-designed applications.

- Despite some perceived concerns, surveyed Australian dental practitioners perceived the use of telemedicine in routine dental practice positively.

- The implementation of a large-scale epidemiological screening for Australian school children using the teledentistry model of dental screening could result in a substantial net saving when compared to the traditional approach of dental screening.

- Shifting low-risk (advantaged) Australian children to a teledentistry based model of
dental screening will have the potential to free up significant resources. Such savings can be used to provide better dental care for underserved/high-risk Australian children.

These studies have filled knowledge gaps, particularly, with the reference to the feasibility of MLDPs in remote dental screening using a smartphone camera. The full use of human resources like DTs or OHTs and embracing new and affordable technology, particularly, for screening, will improve oral health in the general population and allow earlier detection of dental diseases among patients who require urgent treatment (restoration or extraction), thereby reducing the burdens of poor oral health on the individuals and government. However, the technology of teledentistry is still not mature and stabilized enough to be used to deliver dental services of a similar standard to the existing mainstream dental care. Therefore, the use of teledentistry must not be seen as an alternative to conventional dental care but it can be used as an adjunct to optimise the delivery of dental care services particularly in sparsely populated, underserved or remote communities. Further well-designed research into the impact of long-term sustainability of outcomes, effectiveness and cost-effectiveness of teledentistry service in different settings is needed before it can be successfully integrated into the mainstream oral health system.
References


Pay Scale. (2017b) *Registered Dental Assistant Salary (Australia)*. Available at: http://www.payscale.com/research/AU/Job=Registered_Dental_Assistant_(RDA)/Salary/.

Pay Scale. (2017c) *Dental Hygienist Salary (Australia)*. Available at: http://www.payscale.com/research/AU/Job=Dental_Hygienist/Hourly_Rate/.


Appendix
Appendix A

PhD Research Proposal Approval

Ref: 21205302
11 February 2014

Mr M Estai
L 214 University Hall (prev Currie Hall)
UWA, M426 130 Winthrop Avenue
Crawley
WA 6009

Dear Mr Estai

RESEARCH PROPOSAL - DOCTOR OF PHILOSOPHY

I am pleased to inform you that the Board of the Graduate Research School has considered your Research Proposal and it is accepted but the Board suggest clarification of issues outlined below to the satisfaction of supervisor(s) and Head of School.

- Research Training Plan is not included

Please send me the Research Training Plan no later than Tuesday 25 February 2014.

In addition, approval of your research proposal is subject to:

- Your proposal indicates that approval from UWA Human Research Ethics Committee is currently being sought in relation to your research. Until you provide us with notification that you have approval, or otherwise, from the UWA Human Research Ethics Committee the status of your research proposal will be marked as provisional.

The supervisors for your research are recorded as being:

Coordinating supervisor: Professor S Bunt (50%)
Co-supervisor: Winthrop Professor M Tennant (50%)

On behalf of the Board please accept my best wishes for the remainder of your candidature.

Yours sincerely,

Gavin Fung
Candidate Officer
Graduate Research and Scholarships Office

cc: Associate Professor S Gaudieri (Graduate Research Coordinator)
Professor S Bunt
Winthrop Professor M Tennant
School of Anatomy, Physiology and Human Biology

Students please note:
* Please activate your UWA student email account and check it regularly. [Link]
* You can check your milestones on Student Connect [Link].

Click on the "Course and Unit" link in the list on the left side of the page, and you should see your current and previous courses displayed. For the course in which you are enrolled currently, click on the 'Milestones' link under the course details. You will see your list of milestones and the current status of each. There is a description of what each milestone status means. If you believe that there is an error in the list, please contact gavin.fung@uwa.edu.au.

Please note that your re-enrolment each year is dependent on all your milestones being up to date.
Appendix B

Human Research Ethics Approval – University of Western Australia

Our Ref: RA/4/1/6647

10 March 2014

Professor Stuart Bunt
School of Anatomy, Physiology & Human Biology
MBDP: M309

Dear Professor Bunt

HUMAN RESEARCH ETHICS APPROVAL - THE UNIVERSITY OF WESTERN AUSTRALIA

Dental Screening for Marginalised Communities: Using Teledentistry to Reduce Access Blocks & Improve Oral Health

Student(s): Mohamed R Abdulla Estai - PhD - 21265302, Mohamed Estai

Ethics approval for the above project has been granted in accordance with the requirements of the National Statement on Ethical Conduct in Human Research (National Statement) and the policies and procedures of The University of Western Australia. Please note that the period of ethics approval for this project is five (5) years from the date of this notification. However, ethics approval is conditional upon the submission of satisfactory progress reports by the designated renewal date. Therefore initial approval has been granted from 10 March 2014 to 01 March 2019.

You are reminded of the following requirements:

1. The application and all supporting documentation form the basis of the ethics approval and you must not depart from the research protocol that has been approved.
2. The Human Research Ethics Office must be approached for approval in advance for any requested amendments to the approved research protocol.
3. The Chief Investigator is required to report immediately to the Human Research Ethics Office any adverse or unexpected event or any other event that may impact on the ethics approval for the project.
4. The Chief Investigator must inform the Human Research Ethics Office as soon as practicable if a research project is discontinued before the expected date of completion, providing reasons.

Any conditions of ethics approval that have been imposed are listed below:

Special Conditions

None specified

The University of Western Australia is bound by the National Statement to monitor the progress of all approved projects up to completion to ensure continued compliance with ethical standards and requirements.

The Human Research Ethics Office will forward a request for a Progress Report approximately 60 days before the due date. A further reminder will be forwarded approximately 30 days before the due date.

If your progress report is not received by the due date for renewal of ethics approval, your ethics approval will expire, requiring that all research activities involving human participants cease immediately.

If you have any queries please contact the HREO at hreo-research@uwa.edu.au.

Please ensure that you quote the file reference – RA/4/1/6647 – and the associated project title in all future correspondence.

Yours sincerely

Dr Mark Dixon
Associate Director, Research Ethics and Biosafety
Appendix C

GEKO Approval – Department of Health, Government of Western Australia

16th February, 2017

Dear Mohamed,

Please find attached the email confirming that GEKO for the project “Quality Activity 14107 Proposal Approved - Clinical Photograph Treatment Predictive Study” is re-confirmed.

It is a pleasure to collaborate on this important work.

With Kind Wishes

Clinical Associate Professor John Winters

CC W/Professor Marc Tennant

Dental Department
GPO Box D184
Perth WA 6840
From: GEKO Application [GEKO.Application@health.wa.gov.au]
Sent: Friday, 27 January 2017 10:30 AM
To: Nicholls, Wendy; Winters, John; Siegelaar, Karen; Harwood, Sonia
CC: Logan, Julie
Subject: Quality Activity 14107 Proposal Approved – Clinical Photograph Treatment Predictive Study

Quality Activity 14107 Proposal Approved

Activity Area Research project (which does not require Ethics approval)
Organisation OAMS
Title of Activity Clinical Photograph Treatment Predictive Study Committee
Department of Dental Surgery; Surgical Services Clinical Care Unit

Activity has been approved by Department of Dental Surgery; Surgical Services Clinical Care Unit on 27-Jan-2017 and has been flagged with the intent to publish in the future.
You may now commence your Quality Activity.

NOTES: ACCESS TO PIMS

This email provides evidence of approval for your access to medical records for this audit. Please print this email and take it with you to PIMS in order to obtain the relevant records.

Further details are available online: Quality Activity 14107<https://geko.health.wa.gov.au:443/Activities/Activity/index?id=945a2694-b0de-e613-9ac0-00237dd39d0e>.

For further assistance, please contact the GEKO Administrator<https://geko.health.wa.gov.au:443/info/contacts> for your site.

Please do not respond to this email, it is automatically generated by the system and the address is not monitored.
Appendix D

Human Research Ethics Approval – James Cook University

James Cook University
Townsville Qld. 4811 Australia
Tina Lingford, Manager, Research Ethics & Grants
Research Services Ph: 47815011; Fax: 47815521
email: ethics@jcu.edu.au

Human Research Ethics Committee
APPROVAL FOR RESEARCH OR TEACHING INVOLVING HUMAN SUBJECTS

<table>
<thead>
<tr>
<th>PRINCIPAL INVESTIGATOR</th>
<th>Saori Hara</th>
</tr>
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<tbody>
<tr>
<td>SCHOOL</td>
<td>Dentistry</td>
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<tr>
<td>CO-INVESTIGATOR(S)</td>
<td>Boyen Huang</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SUPERVISOR(S)</th>
</tr>
</thead>
</table>

| PROJECT TITLE | Dental screening for marginalised communities: using teledentistry to reduce access blocks and improve oral health |

<table>
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<th>APPROVAL DATE:</th>
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</tr>
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<tbody>
<tr>
<td>EXPIRY DATE:</td>
<td>31/08/2015</td>
</tr>
<tr>
<td>CATEGORY:</td>
<td>2</td>
</tr>
</tbody>
</table>

This project has been allocated Ethics Approval Number H5819, with the following conditions:
1. All subsequent records and correspondence relating to this project must refer to this number.
2. That there is NO departure from the approved protocols unless prior approval has been sought from the Human Research Ethics Committee.
3. The Principal Investigator must advise the responsible Human Ethics Advisor:
   - periodically of the progress of the project,
   - when the project is completed, suspended or prematurely terminated for any reason,
   - within 48 hours of any adverse effects on participants,
   - of any unforeseen events that might affect continued ethical acceptability of the project.
4. In compliance with the National Health and Medical Research Council (NHMRC) “National Statement on Ethical Conduct in Human Research” (2007), it is MANDATORY that you provide an annual report on the progress and conduct of your project. This report must detail compliance with approvals granted and any unexpected events or serious adverse effects that may have occurred during the study.

Human Ethics Advisor: Woodward, Lynn
Email: lynn.woodward@jcu.edu.au

This project was Approved by Executive on 15 Sep 2014

Dr Anne Swinbourne
Chair, Human Research Ethics Committee

Printed on 15 Sep 2014
Appendix E

Informed Consent Form

PATIENT INFORMATION SHEET

Screening for dental decay with a camera:

PURPOSE
We are inviting people to participate in a research project looking at if we can use simple photographs of the teeth to look for decay. With many people (particularly in remote regions) unable to access dental care our thought is that maybe good close-up photographs remotely of the teeth that are then sent to a dental professional may be a way to screen people for dental decay. That way people can know if they need to go to a dentist urgently or not.

METHODS
All patients attending the dental clinic will be invited by the clinical dentist. We are asking for you to allow us to take some photographs of your (or your child’s) teeth with a simple handheld camera. The photos will be stored securely and a dental professional will look at them at a later date as part of the research project. We are also asking permission for the results of your dental examination (only, if any teeth have decay in them) to be shared with our research team. That way we can see how good the photographs were at finding the decay that your expert professional found. We would also like to share your age with the research team so we can see how well the procedures work for different ages. We do NOT need your name or health details. For data security reasons, we will not retain any personal records and all data will be anonymous. After completion of the study, data will be stored on university secured computers for a period of 5 years. After this period, stored data will be destroyed.

- Participation is completely voluntary and the choice to participate/not-participate will not impact access to dental care
- Participants can withdraw at any time, without reason and data/records will be destroyed unless otherwise agreed.

RISKS AND INCONVENIENCE
There is NO risk to you. Taking digital photos of your teeth will not cause you any pain or stress. They will be taken simply as if you were smiling to a camera at a birthday party. You will be helping fellow Australians. The results from this study may help many Australians who live far away from access to dentists and who at times suffer great pain as they do not know they need to see a dentist.

Approval to conduct this research has been provided by The University of Western Australia, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time. In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Research Ethics Office at The University of Western Australia on (08) 6488 3703 or by emailing to hrecresearch@uwa.edu.au. All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.
TIME REQUIREMENTS
Dental check up / screening and taking dental photos will take about 30 minutes.

DATA PROTECTION
- The data collected will be analyzed at The University of Western Australia, is treated as strictly confidential and the participants of the study will not be able to be identified.
- The results will be submitted for research publication in scientific journals.

INVESTIGATORS
W/Professor Marc Tennant, Associate/Prof Kate Dyson and Associate/Prof Estie Kruger are a registered dental practitioners and experts in the field of dental public health researches. The team (The International Research Collaborative – Oral Health and Equity) and the national expert centre for rural, remote and Indigenous Oral Health and has a very substantial national and international reputation in the field extending back some 15 years or more.

* Should you have any questions, issues or further information, please do not hesitate to contact the chief investigator W/Professor Marc Tennant by Phone: [+61 0 409202496] OR E-mail: marc.tennant@uwa.edu.au

Approval to conduct this research has been provided by The University of Western Australia, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time. In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Research Ethics Office at The University of Western Australia on (08) 6488 3703 or by emailing to hreo-research@uwa.edu.au. All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.
CONSENT FORM

Screening for dental decay with a camera:

I, ........................................... consent (or consent for my child .................................... ) to participating in this study which involves taking some close up photographs of my/child’s teeth.

I understand the information provided and any questions I have asked have been answered to my satisfaction. I agree to participate in this activity, realizing that I may withdraw at any time without reason and without prejudice. I am also aware that regardless of whether I take part in this study, my decision will not have any bearing on the type or quality of treatment provided.

I understand that all information provided is treated as strictly confidential and will not be released by the investigator. The only exception to this principle of confidentiality is if documents are required by law. I have been advised as to what data is being collected, what the purpose is, and what will be done with the data upon completion of the research.

I understand that the participation is completely voluntary and the choice to participate/not-participate will not impact access to dental care. I also understand that I can withdraw at any time, without reason and data/records will be destroyed unless otherwise agreed.

I agree that anonymous research data gathered for the study may be published.

Participant

Signed

Date

Approval to conduct this research has been provided by The University of Western Australia, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time. In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Research Ethics Office at The University of Western Australia on (08) 6488 3703 or by emailing to hreo-research@uwa.edu.au. All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.
Appendix F

Oral Health Assessment Form

Operator's Name & ID
Patient's Hospital ID*
Patient's Year of Birth

Date
Site

☐ Absolute Care
☐ ICU
☐ PMH

*Make sure this matches that used on the photo system

Did patient visit a dental practice in the last year?
☐ Yes
☐ No

What was the reason for the last dental visit?
☐ Routine Check-up
☐ Oral Problem

What was type of dental practice attended?
☐ Public Clinic
☐ Private Clinic
☐ School Dental Service

Was cost a reason for delaying/avoiding a dental visit?
☐ Yes
☐ No

Dental Insurance

Dental visiting patterns
☐ At Least One Visit/Year
☐ Visit But Not Every Year
☐ Do Not Visit At All

What was type of dental service received?
☐ Extraction
☐ Filling
☐ Scale/Clean
☐ Other

Was cost a reason for not receiving a recommended dental treatment?
☐ Yes
☐ No

Hospitalised for a dental problem in the last year?
☐ Yes
☐ No

Dentition Status

<table>
<thead>
<tr>
<th>Deciduous Teeth</th>
<th>Permanent Teeth</th>
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<tbody>
<tr>
<td></td>
<td>A 0 = Sound</td>
</tr>
<tr>
<td></td>
<td>B 1 = Small Caries</td>
</tr>
<tr>
<td></td>
<td>C 2 = Medium Caries</td>
</tr>
<tr>
<td></td>
<td>D 3 = Large Caries</td>
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<td></td>
<td>E 4 = Abscess</td>
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<tr>
<td></td>
<td>F 5 = Filled with Caries</td>
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<td></td>
<td>G 6 = Filled, no Caries</td>
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<td></td>
<td>H 7 = Misc due to Caries</td>
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<tr>
<td></td>
<td>I 8 = Missed treatment</td>
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<tr>
<td></td>
<td>J 9 = Fractured</td>
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<tr>
<td></td>
<td>K 10 = Unerupted</td>
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<tr>
<td></td>
<td>L 11 = Not Shown</td>
</tr>
<tr>
<td></td>
<td>M 12 = Uneruited</td>
</tr>
</tbody>
</table>

Plaque Score

| 0 = None |
| 1 = Little |
| 2 = Moderate |
| 3 = Heavy |

Urgency of Treatment

| 0 = No treatment needed |
| 1 = Preventive or routine treatment needed |
| 2 = Prompt treatment needed (e.g. Scaling) |
| 3 = Immediate treatment needed (e.g. Pain or infection) |
| 4 = Referred for medical/dental treatment |

Final comments:

Approval to conduct this research has been provided by The University of Western Australia, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time. In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Research Ethics Office of The University of Western Australia on (08) 6269 3703 or by emailing to bresearch@uwa.edu.au. All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.
Appendix G

Dental Photography Protocol

– HOW TO GET A GOOD PHOTOGRAPH WITH YOUR SMARTPHONE –

IMPORTANT: go as near as you can focus – this is at most 5-10 cm from the patient’s mouth

Take the pictures in LANDSCAPE mode with flash ON
• Ask the patient to sit down on a chair and make sure the room lighting is on and sufficient.

• No RETRACTORS to be used during photography.

• Ask the patient to swallow saliva before capturing photographs.

• The image acquisition using the smartphone to be at a MAXIMUM DISTANCE of 5 - 10 cm from the mouth.

• Hold the smartphone in the LANDSCAPE position.

• Always set FLASH to TORCH mode and FOCUS using the AUTO mode camera setting.

1- ANTERIOR VIEW

• Ask the patient to show their front teeth while biting in centric occlusion.

• Frame picture with as many teeth as possible in the composition, ideally including the canine teeth.

2- RIGHT LATERAL VIEW

• Ask the patient to bite in centric occlusion and pull their right mouth angle laterally using their fingers.

• Stand by the side of the patient while holding the smartphone in the LANDSCAPE position.

• Frame the picture with as many teeth as possible in the composition.
3- LEFT LATERAL VIEW
- Ask the patient to bite and pull their left mouth angle laterally using their fingers.
- Stand by the side of the patient while holding the smartphone in LANDSCAPE position.
- Frame the picture with as many teeth as possible in the composition.

4- UPPER OCCLUSAL VIEW
- Ask the patient to open his mouth as much as he/she can, and tilt his/her head a bit backwards.
- Ask the patient to keep their tongue back.
- Frame the picture with as many teeth as possible in the composition, ideally including upper molar teeth if they exist.

5- LOWER OCCLUSAL VIEW
- Ask the patient to open his/her mouth as much as he/she can.
- Ask the patient to keep their tongue back.
- Frame the picture with as many teeth as possible in the composition, ideally including lower molar teeth if they exist.
Appendix H

End-user Satisfaction Survey Tool

User Satisfaction Survey for Teledental Android App

* Please KEY IN “X” in the spot that most applicable to you:

<table>
<thead>
<tr>
<th>Questions</th>
<th>Never</th>
<th>Seldom</th>
<th>About half the time</th>
<th>Most of the time</th>
<th>always</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How often is the content presented in the app sufficient and appropriate?</td>
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<tr>
<td>2. How often does the content meet your needs?</td>
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<td>3. How often are you satisfied with the accuracy of the app?</td>
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<td>4. How often are the captured dental images clear?</td>
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<tr>
<td>5. How often do you think the output is presented in a useful format?</td>
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<tr>
<td>6. How often is the information clear?</td>
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<td>7. How often is the smart phone camera easy to use?</td>
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<tr>
<td>8. How often is the app user-friendly?</td>
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<tr>
<td>9. How often is the system subject to technical problems or crashes?</td>
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<tr>
<td>10. How often do you get the assistance you need from the research team?</td>
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<tr>
<td>11. How often are you satisfied with training received?</td>
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<tr>
<td>12. Do you feel the app useful?</td>
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<tr>
<td>13. Overall, are you satisfied with the app?</td>
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</tr>
</tbody>
</table>

Please comment briefly on the following:

14. What is the average time (in minutes) taken to create a record and take photographs using the android app?

15. Do you have any suggestion to improve the information content on the android app?

16. Have you experience any difficulties during using the android app? If yes please list some?

Appendix to conduct this research has been provided by The University of Western Australia, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time. In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Research Ethics Office at The University of Western Australia on (08) 6088 2700 or by emailing to human@research.uwa.edu.au. All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.
End-user Satisfaction Survey for the Remote-i Server

* Please KEY IN "X" in the spot that most applicable to you:

<table>
<thead>
<tr>
<th>Questions</th>
<th>Never</th>
<th>Seldom</th>
<th>About half the time</th>
<th>Most of the time</th>
<th>always</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How often is the dental chart content appropriate for oral health assessment?</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>2. How often does the content meet your needs?</td>
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<tr>
<td>3. How often are you satisfied with the accuracy of the system?</td>
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<tr>
<td>4. How often are patients' images clear?</td>
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<tr>
<td>5. How often are teeth gradable?</td>
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</tr>
<tr>
<td>6. How often do you think the output is presented in a useful format?</td>
<td></td>
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<tr>
<td>7. How often is the information clear?</td>
<td></td>
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</tr>
<tr>
<td>8. How often is the system easy to use?</td>
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</tr>
<tr>
<td>9. How often is the system user-friendly?</td>
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<tr>
<td>10. How often is the system subject to technical problems or crashes?</td>
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<tr>
<td>11. How often do you get the assistance you need from the research team?</td>
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<tr>
<td>12. Do you feel remote-i useful?</td>
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<tr>
<td>13. Overall, are you satisfied with the server?</td>
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</tbody>
</table>

Please comment briefly on the following:

14. What is the average time (in minutes) taken to read/grade each record?

15. Do you have any suggestion to improve dental chart content or the server?

16. Have you experience any difficulty during reading images? .... If yes please list some.

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Appendix I

Australian Dental Practitioners’ Survey Tool

Winthrop Professor Marc Tennant
International Research Collaborative – Oral Health and Equity
Department of Anatomy, Physiology and Human Biology
The University of Western Australia
E: marc.tennant@uwa.edu.au
P +61 (0)409 202 496

Australian Dental Practitioners’ Perceptions about the Use of Telemedicine In Dental Practice

* Please KEY IN character "X" in the spot that most applicable to you:

**PART I**

<table>
<thead>
<tr>
<th>General Data</th>
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<tr>
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<td>45–54 yr</td>
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<tr>
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<td>55–64 yr</td>
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<td>&gt; 65 yr</td>
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<td>Female</td>
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<tr>
<td></td>
<td>General Dental Practitioner</td>
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<td></td>
<td>Dental Therapist (Hygienist)</td>
</tr>
<tr>
<td></td>
<td>Student (Resident/Graduate Research)</td>
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<td>6-10 yr</td>
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<tr>
<td></td>
<td>11-15 yr</td>
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<td></td>
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<td>Location of Main Job</td>
<td>Major City</td>
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<td></td>
<td>Inner Regional</td>
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<td></td>
<td>Outer Regional</td>
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<tr>
<td></td>
<td>Remote or Very Remote Area</td>
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<tr>
<td>Work Setting of Main Job</td>
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<td>Public</td>
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<td></td>
<td>Both</td>
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<td></td>
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<tr>
<td>Average General Use of Internet (in hours/day)</td>
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<td></td>
<td>5-7 hr</td>
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<td></td>
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</tr>
<tr>
<td>Average Work-related use of Internet (in hours/day)</td>
<td>&lt; 1 hr</td>
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<td>2-4 hr</td>
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<td>5-7 hr</td>
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<td></td>
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<tr>
<td></td>
<td>&gt; 11 hr</td>
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<tr>
<td>How do you most commonly communicate with colleagues (e.g. other dentists or specialists)?</td>
<td>In person</td>
</tr>
<tr>
<td></td>
<td>Phone</td>
</tr>
<tr>
<td></td>
<td>Fax</td>
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<td></td>
<td>Letter</td>
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<td>Social media</td>
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<tr>
<td></td>
<td>Videoconferencing</td>
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<tr>
<td></td>
<td>Forum</td>
</tr>
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Please check more than one box if it is applicable.

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## PART 2

### Dental Practitioner’s Perceptions of Usefulness of Teledentistry System

<table>
<thead>
<tr>
<th>Perception</th>
<th>Agree Strongly</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Disagree Strongly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teledentistry would provide adequate diagnostic information</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teledentistry would be too expensive to set up</td>
<td></td>
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<tr>
<td>Teledentistry would save time compared with a referral letter</td>
<td></td>
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<tr>
<td>Teledentistry would necessitate an extra appointment for taking photographs</td>
<td></td>
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<tr>
<td>Teledentistry would increase surgery time spent with the patient</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Teledentistry would reduce costs for the dental practice</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Teledentistry would enhance clinical training and continuing education</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

### Dental Practitioner’s Perception of Efficiency of Teledentistry System

<table>
<thead>
<tr>
<th>Perception</th>
<th>Agree Strongly</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Disagree Strongly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teledentistry would make referral of new patients more efficient</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teledentistry would improve communications between dentists (including dental therapists, GDPs and consultants)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Teledentistry would enhance guidance and advice</td>
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<tr>
<td>Teledentistry would help shorten waiting lists</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Teledentistry diagnosis is accurate via assessment of intra-oral images in traditional clinical setting</td>
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### Dental Practitioner’s Perception of Benefits of Teledentistry System for Patients

<table>
<thead>
<tr>
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<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Disagree Strongly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teledentistry would be useful for patients in distant or rural locations</td>
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<tr>
<td>Teledentistry would be convenient for patients not well received by patients</td>
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<td>Teledentistry would be helpful to monitor patient’s condition</td>
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<tr>
<td>Teledentistry would help reduce unnecessary travel to hospital</td>
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<tr>
<td>Teledentistry would help with patient information and education</td>
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<tr>
<td>Teledentistry would improve interaction and communication with patients</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Teledentistry would save money for patients</td>
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### Dental Practitioner’s Concerns about Practice-Related Use of Information Technologies

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<th>A little concerned</th>
<th>No feeling either way</th>
<th>Not particularly concerned</th>
<th>Not concerned at all</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability of equipment used in teledentistry</td>
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<td></td>
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<tr>
<td>Technical Incompatibility</td>
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<tr>
<td>Potential for tampering with computer images</td>
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<tr>
<td>Patient confidentiality when images are sent online to the hospital</td>
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<tr>
<td>Gaining patient consent for referral via online</td>
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</tr>
</tbody>
</table>

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Appendix J

Publication Arising from Chapter 2

Australia is one of the most sparsely populated countries in the world, with the majority of its population (88%) living in metropolitan cities, whilst the remainder live in outer regional or remote areas. Like many developed countries, dentistry in Australia faces significant labour force issues, particularly maldistribution. The majority of practising dentists work in private settings, mostly concentrated in metropolitan areas. A significant variation in the number of dentists between urban and rural regions does exist, with the number of dentists practising per 100,000 population highest in major cities (64.3) compared to remote/very remote areas (21.5). The unwillingness of dentists to practise in rural settings is a complex issue, with factors such as access to specialist training, low remuneration and social reasons just to name a few. As a result, many rural and remote communities are left underserved, even though people outside capital cities have poorer oral health than people living in capital cities.

In contrast, mid-level dental providers (MLDPs) such as oral health therapists, are distributed more evenly across rural and remote Australia. However, they only represent less than 7% of the dental workforce, accounting for less than 7 therapists per 100,000 population, and will 30% of these therapists working in the private sector. It is projected that shortages of this group of dental professionals in rural Australia will continue. Previous research identified a number of reasons for Australian MLDPs leaving the profession in rural settings, including family reasons, relocation, career change, poor salaries and lack of access to continuing education. Against this background it is important to continue to explore options to address the unmet oral health needs and expand access to care among underserved populations.

Labour force substitution in dentistry is not a new concept. The deployment of MLDPs to provide routine and preventive dental care has been well received in many Western countries. In Australia, the role of MLDP is well described in relation to their scope and practice. Although the practices of MLDP have been limited to under 18-year-olds, their scope of clinical practice has been extended in some Australian states to treat adult patients. Substantial evidence indicates that MLDPs are able to provide quality, safe and effective dental care at low cost, and their employment are now being considered rational and cost saving.

Developing and deploying MLDPs with the extended duties capacity from rural communities has been one way to ameliorate the maldistribution issue. Recent reports on the Alaskan workforce model demonstrate that students with a rural background are more likely to return to their villages where they had been raised, after graduation. Locally recruited students are more willing to work and live in rural areas on a long-term basis compared to most dentists who were recruited from and trained outside of rural areas. This has been seen as true in other health disciplines where the evidence is even stronger than in dentistry, with available evidence indicating that selecting applicants with rural origins and providing exposure to rural experiences during training enhance likelihood of rural practice.

James Cook University (JCU) College of Medicine and Dentistry was established with a mission to select and educate medical graduates prepared to work as doctors in rural and remote Australia. A report on the early career outcomes of JCU medical graduates in the first six cohorts shows that 46% of JCU graduates planned to work in rural towns compared with 18% of graduates from other medical schools. This has been supported by early data from JCU School of Dentistry, as well as anecdotal reports from other rural based dental schools (MT personal communications).

Given that a shortfall in the number of MLDPs in rural Australia is projected to increase, developing and recruiting rural students should contribute to increase the capacity of dental workforce in rural areas. Because many patients need first-line access to basic dental care (and if necessary triaging to higher level care), MLDPs with extended duties would be able to provide care to uncomplicated cases, and manage care pathways for more complicated cases to dentists. Similar to other health professions, the deployment of MLDPs would be expected to be more efficient and cost-effective.
Therefore, the use of MLDPs has the potential to increase care access and reduce disparities in oral health status between rural and urban regions. Providing regular training to rural practising MLDPs is essential to build their capacity to treat patients. Making use of technologies such as telemedicine to provide consultation and training would reduce the isolation of rural MLDPs and assist them in diagnosis and appropriate treatment planning. Based on reports from Alaska’s dental health aide therapist programme, the use of telemedicine has proven to be successful in connecting rural MLDPs with ‘supervisory’ dentists, and ensuring they demonstrate competency in their defined (wider) scope of practice.

Simply producing more dentists is unlikely to completely solve workforce maldistribution problems, but deploying MLDPs (with appropriate scope of practice and support to serve underserved regions) might be an approach to reduce the maldistribution issue. In the longer term, recruiting and training different members of the dental team from rural communities, offer a practical and effective way to increase the retention and recruitment in rural and remote settings. In addition, offering support, consultation and incentives to rural dental practitioners might contribute to workforce retention. These strategies can serve as beneficial tools to ensure equality in provision of oral healthcare services and bridging the gap in rural-urban oral health.

REFERENCES

MOHAMMED ESTAI
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International Research Collaborative
Oral Health and Equity
Department of Anatomy, Physiology and Human Biology
The University of Western Australia
Western Australia, Australia

(Received 5 December 2015.)
Role of telemedicine and mid-level dental providers in expanding dental-care access: potential application in rural Australia

Mohamed Estai, Estie Kruger and Marc Tennant

International Research Collaborative, Oral Health and Equity, Department of Anatomy, Physiology and Human Biology, University of Western Australia, Perth, WA, Australia.

Despite great progress in oral health over the past three decades, the rates of cavities remain high in Australia, particularly among underserved populations. The reasons for poor oral health amongst underserved populations are multiple, but rests with socio-economic determinants of health. The present review considers international workforce models that have been created to enhance the recruitment and retention of dental providers in rural areas. Several strategies have been developed to address care access problems in rural areas, including the use of telemedicine and mid-level dental providers (MLDPs). Despite ongoing opposition from dentistry organisations, the Alaska and Minnesota workforce models have proven that developing and deploying dental therapies from rural communities has the potential to address the unmet needs of underserved populations. It is more efficient and cost-effective for MLDPs to perform triage and treat simple cases and for dentists to treat complicated cases. The use of MLDPs is intended to increase the capacity of the dental workforce in areas that are too isolated to attract dentists. Telemedicine has emerged as one solution to address limited access to health care, particularly in locations where there is a lack of providers. Telemedicine not only provides access to care, but also offers support, consultations and access to continuing education for practicing dental providers in rural areas. This strategy has the potential to free up resources to increase care access and reduce oral health disparities, thereby contributing to closing the rural-urban oral health gap.

Key words: Telemedicine, dental therapist, workforce, rural, remote, oral health, disparity

INTRODUCTION

Dentistry in Australia, like in many countries, faces significant workforce issues, particularly an uneven distribution of the dental workforce. In 2013, a total of 20,000 dental practitioners were registered in Australia, with 65% of the total dental workforce being practising dentists. However, the majority of practising dentists work in the private sector, which is largely clustered in major cities. There is also a marked variation in the average dentist-to-population ratio between urban and rural regions. The reluctance of dentists to practise in rural settings probably pertains to family reasons, low reimbursements and lack of continuing education opportunities. As a result of this maldistribution in the dental workforce, many rural and remote communities in Australia are left underserved, leading to untreated oral disease. There are multiple reasons for this gap between rural and urban oral health, one of which is lack of access to dental care. Different strategies have been developed in many countries to address unmet oral health needs, including the use of telemedicine and the recruitment of mid-level dental providers (MLDPs).

Workforce shortages, sparsely populated regions, funding challenges and the decreasing cost of and advances in technology, have resulted in an increased interest in the adoption of telemedicine services. Teledentistry is a domain of telemedicine that emerges from the combination of information communication technology (ICT) and dentistry. For several decades, telemedicine has played a role in bridging gaps and overcoming barriers related to distance through expanding care access to unreachable populations. The use of MLDPs, like dental therapists (DTs), to provide preventive and routine care is long established in many countries, including Canada, the
USA, the UK, the Netherlands and New Zealand. The development and deployment of DTs has the aim of decreasing the costs and increasing the capacity of existing dental care. Although the practices of DTs have been generally limited to children, their scope of practice has been extended in some countries, also for the treatment of adults. The present review draws on insights from international experiences and opportunities that address the shortcomings in the provision of dental care in rural settings, related to the shortage of dental providers, and to suggest solutions to reduce oral health disparities.

**METHODS**

The focus of this study was to identify and review the available literature related to the use of teledentistry and MLDPs in the dental workforce. With the very limited size of the literature base, no attempt was made to conduct a weighted meta-analysis/systematic review of the published literature. The review protocol included a wide-ranging search of multiple databases (PubMed, EMBASE, the Cochrane Library and CINAHL) using a combination of key words from the following list: ‘tele-dentistry’, ‘tele-health’, ‘tele-medicine’ and ‘dentistry’, ‘dental therapist’, ‘mid-level dental providers’, ‘dental auxiliaries’, ‘tele-dentistry’, ‘school dental services’, and ‘dental workforce’. All records electronically identified were scanned, by the authors, according to title and abstract, and the full text of all studies considered potentially relevant was obtained.

**DENTAL THERAPIST PRACTICE IN AUSTRALIA**

A DT is a member of the dental team who is registered with the Dental Board of Australia and has completed an accredited bachelor programme of study in the dual streams of dental therapy and dental hygiene. Before 2006, DTs were trained in non-university vocational schools in a 2-year diploma programme. The education of DTs is now university-based with 3-year curricula at the Universities of Melbourne, La Trobe, Griffith, Sydney, Newcastle, Charles Sturt, Queensland, Adelaide, Western Australia and Curtin. At the time of writing, many universities offer dual qualifications in dental hygiene and dental therapy, and the graduates of these programmes are called an oral health therapist (OHT). As in New Zealand, Australian DTs are responsible for examining, diagnosing, and developing and providing treatment plans for children, as well as referring those in need of oral treatment that is beyond their scope of practice. A list of clinical services performed by DTs in Australia is summarised in Table 1.

**Table 1: Scope of practice for dental therapists in Australia**

<table>
<thead>
<tr>
<th>Roles</th>
<th>Procedures</th>
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<tbody>
<tr>
<td>Oral diagnosis</td>
<td>Oral examination</td>
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<tr>
<td></td>
<td>Internal dental radiography</td>
</tr>
<tr>
<td></td>
<td>External dental radiography (on prescription)</td>
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<tr>
<td></td>
<td>Impression taking (but not for prosthodontics treatment)</td>
</tr>
<tr>
<td>Prevention</td>
<td>Application of therapeutic solutions to teeth (excluding in-surgery bleaching)</td>
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<tr>
<td></td>
<td>Fissure sealants</td>
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<tr>
<td></td>
<td>Scaling</td>
</tr>
<tr>
<td></td>
<td>Dental prophylaxis, including the removal of dental calculi</td>
</tr>
<tr>
<td>Operative care</td>
<td>Administration of local anaesthesia</td>
</tr>
<tr>
<td></td>
<td>Restoration of diagnosed tooth structure (excluding indirect restorations)</td>
</tr>
<tr>
<td></td>
<td>Pulpotomy</td>
</tr>
<tr>
<td>Orthodontics</td>
<td>Orthodontic procedures, under the supervision of a dentist (excluding diagnosis, treatment planning, initial fixation of brackets, design of orthodontic appliances, and retention and adjustment of orthodontic appliances)</td>
</tr>
<tr>
<td>Oral surgery</td>
<td>Extraction of deciduous teeth</td>
</tr>
</tbody>
</table>

It is well documented that rural Australia experiences significant oral workforce recruitment and retention issues, particularly of DTs. With DTs only representing 5% of the Australian dental workforce, a significant shortfall in DTs is projected, particularly in rural and remote areas. In 2013, there were an estimated 1117 registered DTs engaged in practice, with the vast majority (88%) employed by the School Dental Service (SDS). Over the last decade, Australia’s SDS has suffered a reduction in workforce, and services remain largely concentrated in the highly populated regions; thus, it rarely provides a sustainable oral care service for all children.

Until the 2000s, employment of DTs was limited to the state-operated SDS that is responsible for providing dental care for schoolchildren in Australia. Since 2006, restrictions on the age of patients who can be treated by DTs have been extended to include adults in some Australian States. A recent study evaluated an educational bridging program to enable Australian DTs to treat patients 26+ years of age in Victoria. Following completion of 203 hours of didactic and clinical observation, participating DTs indicated that the programme was successful in developing their clinical skills and poses an effective method for extending their existing scope of practice to adults. Employing DTs to provide primary care for children has been well received throughout the world because of the inability of the current dental workforce to address unmet dental-care needs. Substantial evidence indicates that DTs can provide quality, safe and effective dental care at low cost.
TELEMEDICINE IN DENTAL PRACTICE

The rapid advances in ICT and availability of the Internet have increased the potential benefits of telemedicine to dentistry. Telemedicine has emerged as a solution to address limited access to dental care, particularly in places far from care centres. Teledentistry is a form of telemedicine that is specifically dedicated to dentistry and uses ICT for delivery of oral care, teleconsultation, continuing education and public awareness. Teledentistry application is of utmost importance in rural areas where shortages of dental workforce are apparent. It has the potential to address various shortcomings that affect the healthcare delivery system, such as poor infrastructure, shortage of practitioners and delay in the delivery of care as a result of long waiting lists or the long distance to travel to tertiary centres.

Despite the relatively slow integration of telemedicine into dentistry, the number of teledentistry programmes has rapidly increased, particularly in the USA and Europe. Although evaluation of different telemedicine applications has proven that this technology can be successfully integrated into different care settings, there is currently little active teledentistry practice in Australia. This could be pertained to practitioners' concerns with costs, surgery time and security threats of teledentistry, as well as the absence of clear guidelines and policy. With oral care services distributed very unevenly in Australia, particularly in rural areas, teledentistry poses an alternative approach for performing examinations, diagnosis and triage referrals, and supports locally based treatment.

Several areas in dentistry that are particularly appropriate for teledentistry are remote consultations for providing treatment plans or preventive care, supervising DTs practicing in remote areas and continuing education. Dental education and screening for oral disease are the most common types of teledentistry application in the literature. The teledentistry system offers efficient ways to deliver distance education and clinical training compared with face-to-face communication. For instance, Alaska's dental health aide therapists (DHATs) and their supervisory dentists utilise teledentistry to exchange clinical data, to discuss the optimal way to perform a procedure and to consult on accurate diagnosis and making treatment plans. Evidence indicates that dental providers with minimal training can successfully perform complex dental procedures under the supervision of an off-site specialist. This approach would reduce the isolation of local providers and allow them to implement treatment plans under the guidance of a dentist at a distance.

EMERGING WORKFORCE MODELS

Several US states have developed programmes that utilise MLDPs and teledentistry to address barriers contributing to the poor oral health among underserved populations. In early 2000, the Alaskan Native Tribal Health Consortium (ANTHC) developed a workforce model "DHAT" that utilises teledentistry to address oral health disparities and lack of access to oral care in Alaska. Alaska's DHAT model was developed based on the New Zealand school-based program for DTs. Before the development of the ANTHC, a total of 10 Alaskan students completed a 2-year dental therapy programme at the University of Otago in New Zealand. In 2008, ANTHC partnered with the University of Washington to develop a 2-year training programme specifically designed for Alaska's DHATs. In the first year of the programme, students received basic training held at the University of Washington DENTEX centre in Anchorage, Alaska, and the second year of the programme consisted of intensive clinical training in Bethel, Alaska. Alaska now has 24 federally certified DHATs who provide preventive and therapeutic care for 40,000 Alaska Natives.

Following completion of 3,000 hours of training during a 2-year dental therapy programme, DHATs must undergo a mandatory preceptorship lasting 400 hours, under the direct supervision of licensed dentists, before they begin to work under general supervision. DHATs are closely connected with their supervisory dentists through teledentistry, with dentists providing direct, indirect and general supervision. To retain certification, DHATs continue to work in their villages under general supervision, provided that they demonstrate competency in their full scope of practice. A recent study found that Alaskan DHATs provide high-quality and appropriate care that is within their scope of practice. The DTs have the potential to take on more substantive-type roles and be more self-reliant in treatment planning.

In 2009, the state of Minnesota passed legislation to authorise a new non-dentist member, DTs, to practice. The aim of this legislation was to address oral
health disparities and to expand access to dental care in Minnesota\textsuperscript{43}. This resulted in the creation of two new categories of practitioners (a DT with a bachelor degree and a masters-level advanced DTs), along with a framework that outlines the legal scope of practices and oversight by a licensed dentist. The advanced DTs have a broader scope of practice and can practice off-site without general supervision of a dentist, but they still need to get approval from the supervising dentist before performing restorative and surgical procedures\textsuperscript{44}. The funding of Alaska’s DHAT model is based on billing Medicaid for dental services delivered to Medicaid recipients\textsuperscript{45}. While in Minnesota, DTs are reimbursed for the services they deliver to Minnesota Health Care Plan recipients using a fee-for-service payment model\textsuperscript{46}.

Apple Tree Dental is a non-profit model dental practice and runs five dental-care access programs in urban and rural areas of Minnesota\textsuperscript{47}. The Apple Tree Dental model links mid-level providers, practicing under the supervision of off-site dentists, with Head Start Centers, schools and other community sites for people experiencing physical, financial and geographical barriers\textsuperscript{48}. The Pacific Center for Special Care at the University of the Pacific, Arthur Dugoni School of Dentistry, created a model ‘Virtual Dental Home’, in sites throughout California, which uses a Cloud-based software system that allows recording, management and retrieval of data from any location. The model is completed with a collapsible dental chair, a laptop computer, a digital camera, supplies to perform temporary fillings and a handheld X-ray machine\textsuperscript{49}. Similarly to Apple Tree Dental, Virtual Dental Home permits mid-level providers to provide preventative and simple therapeutic services to an underserved population in community settings under the supervision of a licensed dentist.

Despite the unwillingness, for years, of dentists to work in rural communities, with the majority preferring to work in major cities\textsuperscript{50}, the Alaska and Minnesota models have faced opposition by dentists who express concerns about the scope of practice of DTs and their ability to fix dental-care access problems\textsuperscript{51}. The American Dental Association also started unsuccessful legal action against the Alaska initiative\textsuperscript{52}. Despite ongoing opposition, the DHAT model has been welcomed by many in the oral health workforce who consider DTs as a viable solution for expanding oral health services for underserved populations\textsuperscript{53}.

**DISCUSSION AND CONCLUSION**

A key feature of the Minnesota model is the adoption of restrictions to ensure that DTs practice in settings that serve low-income and underserved individuals\textsuperscript{54}. An essential aspect of Alaska’s DHAT is that DTs are recruited from the rural communities where they serve. It is widely acknowledged that, after graduation, students with a rural background are more likely to return to the villages where they were raised\textsuperscript{55}. This implies that locally recruited students will be willing to work and live in rural areas on a long-term basis as opposed to most of the dentists who are recruited from and train outside rural areas. Because the shortfall in the number of DTs in rural Australia is projected to increase, recruitment of increased numbers of rural students should contribute to increasing the number of dental providers practicing in rural areas\textsuperscript{56}. The implications of telemedicine for dental-care services and oral health in rural areas are enormous\textsuperscript{7}. A previous study addressed a number of reasons why Australian DTs leave the profession in rural settings, including family reasons, career change, poor salaries, relocation and lack of continuing education opportunities\textsuperscript{58}. Aside from expanding access to dental care, telemedicine can be used to provide support, consultation and access to continuing education for dental providers practicing in rural areas. The use of telemedicine to supervise rural MLDPs remotely also offers a reliable approach to ensure competency and safe practice\textsuperscript{59}. This would support locally based treatment and allow practicing MLDPs to manage simple cases independently of a dentist but permit collaboration for complicated cases. This approach would also encourage practicing dental providers to consider working in rural areas.

There is a need for dental therapy training programs focused on providing services in rural settings with supervision of a licensed dentist through telemedicine. Particularly, more emphasis on examination, diagnosis and providing preventive and routine care, as well as public education, is required. Telemedicine consultations often need a role substitution to perform examinations and various diagnostic and treatment procedures, and a dental team member other than a dentist can be trained to take up this role. Training this type of dental provider would need significantly less time and fewer resources compared with training a dentist. Because most dental care does not need in-depth specialty consultation, MLDPs with additional training would be able to examine and provide care to simple cases, but to refer complicated cases to a dentist. Recruiting and developing MLDPs may offer a viable approach to solve shortages in the dental workforce, in addition to providing support and incentives to dentists to attract them away from major cities.

There is marked variability in how a telemedicine-based care programme can be funded. Although the implementation of telemedicine necessitates initial
investments in ICT and equipment, and in the costs of technical and administrative personnel, cost savings can be realised in the long term as teledentistry use increases.5 Savings can also be achieved through reduction in duplication of tests and examinations, and in an increased efficiency in referrals and in communications between peers.5 Additionally, use of the available ICT infrastructure in dental practices would reduce practice expenses and consultation costs. The use of MLDPs has the potential to free up human and economic resources to increase care access and reduce disparities in oral health. It is more efficient and cost-effective for MLDPs to perform triage and treat simple cases and for dentists to focus on treatment of more complicated cases.27,28 Based on evidence from recent reports on programs in Alaska and Minnesota, the use of DTs is cost-effective as their earnings account for less than 30% of the revenue generated.29,30 Given that the salaries of DTs are about half those of dentists, funding could be secured through the revenue generated by DTs.

As telecommunications technology becomes more widely available and the use of DTs gains acceptance, this is likely to impact care access, the quality of and continued education and the costs of care. This strategy can also serve as a beneficial tool to ensure equality in the provision of oral health-care services and in closing the rural-urban oral health gap.

Acknowledgement

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Conflicts of Interest

None declared.

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Appendix L

Publication Arising from Chapter 2

LETTER TO THE EDITOR

Letters may comment on articles published in the Journal and should offer constructive criticism. When appropriate, comment on the letter is sought from the author. Letters to the Editor may also address any aspect of the profession, including education, new modes of practice and concepts of disease and its management. Letters should be brief (no more than two A4 pages).

THE USE OF MOBILE HEALTH APPLICATIONS IN SCHOOL DENTAL SCREENING

The global improvements in oral health over recent decades, particularly in children, have led many to believe that most dental problems are solved. However, dental caries remains the most prevalent disease of childhood and causes serious health consequences requiring costly treatment. Less than 50% of Australian children suffer from caries by the age of 6 years. The problem is particularly severe amongst socially disadvantaged children, causing a significant burden, not only on individuals but also on the government. Caries remains the second most costly diet-related disease, ahead of cardiovascular disease and diabetes. Between 2005 and 2013, the national expenditure on dental services increased from $56 to $97 billion.

Dental services are not only unevenly available across Australia but there are inequalities in utilization of dental services. Children with the greatest needs who already have poorer oral health, have limited access to care, whilst children with the least needs, have easy access to care and consume the most expensive resources. As a result, much dental disease amongst socially disadvantaged children goes without treatment, widening the gap between the levels of their oral health and the rest of the population. The reason for oral health inequalities is varied but mainly pertains to the inequality in dental care access, often due to socioeconomic gradients and the shortage of dental workforce. Although school dental therapists have been responsible for providing most of the dental services through the School Dental Service (SDDS), this programme remains a sustainable oral care service for all children, with nearly half of the school children caried for in the SDDS suffering from poor oral health. In recent years, the SDDS has suffered a reduction in workforce participation, and services remain largely concentrated in urban regions. The decreased retention and recruitment of school dental therapists have been attributed to their preferring to work in the private sector.

Healthy behaviours established in early life are often carried into adulthood. Therefore, improving oral health in childhood is fundamental for reducing dental caries, early tooth loss and other oral diseases in adulthood. Caries appears mainly during childhood and adolescence, its impact can be reduced through shifting the emphasis of dental care from the provision of treatment towards effective prevention of dental diseases. To achieve this, a range of preventive strategies can be adopted such as oral health promotion, systemic and topical fluoride, sealants and improvements in diet. However, such strategies can be unsuccessful if not targeted at high-risk children or those with high needs. Dental screening in asymptomatic school children can provide a way to identify high-risk groups and offer a valuable strategy for more effective disease prevention and control. There are many methods for dental screening, although tactile or visual inspection remains the most common method. However, this technique has a limitation as it is inappropriate in a large-scale epidemiological setting. The cost of visual inspection can be excessively high due to the expense of travelling and the high salaries of trained personnel (dentist and dental assistant). One of the practical solutions to address the inequality in oral health and improving oral health is the use of mobile applications in screening for dental diseases in asymptomatic school children.

Mobile health or mHealth refers to the use of mobile devices to facilitate data and information exchange between patients and health care providers. mHealth applications have become increasingly popular due to improved global cellular infrastructure and the increased affordability of mobile devices. Most mHealth applications rely on mobile devices and its widespread use (the majority of the world’s population now use mobile devices). mHealth is an attractive technology due to mobile connectivity, digital photography capabilities and the computational power of modern mobile phones which allow their users to perform multiple tasks such as processing, storage and transmission of data as well as access to low-cost, secure ‘cloud’ storage. As mobile devices are constantly carried and can be used at any time,
this technology can be utilized as point-of-care devices to improve the delivery of patient-centred care. Their use in disease surveillance, particularly in the screening for skin malignancies and hearing impairment, has proven to be effective. However, the body of literature on mHealth applications in dentistry is still limited.

Until recently, the use of mobile applications in dentistry was not well received because of the poor quality of their cameras, limited storage space and data transfer failure. Their recent introduction into dental research has shown an acceptable diagnostic performance in comparison with visual inspection, particularly in the screening for dental caries and oral cancer or precancerous lesions. The use of a smartphone camera in dental photography can be useful for recording a baseline of oral health status preoperatively, which can be used to confirm the diagnosis and prepare an appropriate treatment plan. Also, it can be helpful to prioritize patients when referring to consultants and avoid delay in treatment, particularly for urgent or complicated cases.

Improving the public’s oral health is challenging, with unequal distribution of dental workforce and scarcity of resources making the transition to the prevention of diseases difficult. Dental screening could be a first step towards the implementation of long-term preventive measures and effective control of common dental diseases like dental caries. The implementation of a large-scale, economical and efficacious epidemiological oral screening requires an economical and effective screening tool that is used by trained non-health professionals (e.g., teachers or parents), with a practitioner (dentist or dental therapist) evaluating dental photography and preparing a treatment plan at a distance. The use of mHealth applications to screen for dental diseases in children are a worthwhile initiative to control dental diseases by identifying screened positive children and providing them with a quick pathway to receive appropriate treatment. Children who are considered to be at low risk do not need additional management other than to receive preventive care. This strategy can help in the allocation of scarce resources, directing specific dental care towards a population group who most need it and contribute to reducing inequalities in oral health.

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(Accepted for publication 23 April 2017.)
Appendix M

Publication Arising from Chapter 3

A systematic review of the research evidence for the benefits of teledentistry

Mohamed Estal1, Yogesan Kanagasingam2, Marc Tennant1 and Stuart Bunt1

Abstract

Objective: This review is designed to inform future decisions about the benefits of integrating teledentistry into routine health services, by presenting an overview of the evidence for the effectiveness and economic impact of teledentistry.

Methods: Two reviewers searched PubMed, EMBASE and CINAHL databases through November 2016 to identify published peer-reviewed studies in English. Teledentistry studies were included if they were: (a) controlled (randomised or non-randomised) assessment studies; and (b) compared outcomes of a teledentistry intervention in terms of clinical or economic evaluation with the outcomes of traditional clinical alternatives. The quality of the studies was evaluated using a quality appraisal tool that considered study performance and design.

Results: This review identified 385 publications, of which 217 full-text articles were retrieved for further inspection. Of these, only 11 articles met the inclusion criteria. Nine of the included articles showed some clinical outcomes; the other two were primarily economic analyses. The balance of these studies assessed the efficacy of teledentistry interventions rather than their effectiveness. Four studies (36%) achieved higher quality scores and have greater potential to influence health-care decision-making. To date, the most convincing published evidence regarding the efficacy of teledentistry was provided by studies on paediatric dentistry, orthodontics and oral medicine. The economic analysis referred only to cost-minimisation, suggesting that the use of teleconsultation in dentistry can be cost-saving when compared to a conventional consultation. However, high-quality economic studies on teledentistry are rare.

Conclusion: There is emerging evidence supporting the efficacy of teledentistry. However, there is not yet enough conclusive evidence, particularly for its effectiveness, cost-effectiveness and long-term use, to make evidence-based policy decisions on teledentistry.

Keywords

Teledentistry, oral health, future decisions, efficacy, effectiveness, cost

Data received: 3 October 2016; Data accepted: 13 December 2016

Introduction

Dental manpower shortages, remoteness, funding challenges and the decreasing cost of and advances in technology, have increased the interest in the use of telemedicine applications.1-3 Teledentistry, being a subset of telehealth, uses communications networks for delivery of healthcare services and medical education from one geographical location to another, primarily to address challenges like uneven distribution and shortage of infrastructural and human resources.2 Teledentistry is a domain of telemedicine that is specifically dedicated to dentistry, and it emerged from the combination of digital and telecommunication technology and dentistry.3 The implications of teledentistry for oral care services and oral health in rural or remote areas are significant.1-3 Teledentistry has the potential to identify high-risk populations, facilitate patients’ referrals to a dental consultant and support locally-based treatment, thus reducing waiting lists and unnecessary travel and loss of productivity.1-3

A number of areas in dentistry that are particularly appropriate for teledentistry are remote consultations for preparing treatment plans, providing preventive care and supervising practitioners working in rural settings as well as continuing education.4-5 The Dental Health Aide Therapists (DHATs) programme is a notable workforce model that makes use of role substitution (using native dental therapists) and telemedicine to address inequity in access to dental care in Alaska. In 2002, the DHATs Programme began in Alaska as an expansion of the Community Health Aide...
Programme (CHAP). The CHAP has been the basis of the health care delivery system for rural Alaskan residents, providing 350,000 patient visits annually. Alaskan Natives are trained and employed as DHATs with an expanded scope of practice to perform prophylaxes, restorations and uncomplicated extractions as well as provide preventive care in Alaska Native villages. The DHAT's scope of practice was established by supervising dentists who provided general supervision via telemedicine.

The emergence of telemedicine has led to many research studies that have evaluated teledentistry applications in different settings. Despite the heterogeneity of the studies, there is a growing body of evidence supporting the use of teledentistry, in particular, for early detection of dental diseases. A database search for systematic reviews and meta-analyses on teledentistry identified only four systematic reviews, but to date, no meta-analyses on teledentistry have been published. The systematic reviews, however, were descriptive, as none considered the quality of evidence or research rigor in the evaluation of studies, and mainly addressed the feasibility or accuracy of various teledentistry applications. This poses a difficulty in determining the impact of teledentistry on clinical outcomes, resulting cost-benefits and the implications for future decisions. This systematic review aims to inform decision-makers who are doubtful about the capability and merit of integrating teledentistry into routine health services by presenting an objective overview of good-quality evidence for the effectiveness and economic impact of teledentistry.

Methods

Data sources

Following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines for systematic reviews, literature searches for teledentistry studies were conducted through November 2016 using the PubMed, EMBASE and CINAHL databases. Research on teledentistry uses the term ‘teledentistry’ inconsistently in the literature. As a result, various queries were used in the database search to ensure no relevant studies would be missed. Database searches in this review were carried out using a combination of the following keywords: ‘dental’ and ‘real-time’; ‘dentist’ and ‘remote consultation’; ‘dentist’ and ‘remote screening’; ‘dentist’ and ‘store-and-forward’; ‘dental’ and ‘teleconsultation’; ‘dental’ and ‘tele-diagnosis’; ‘dental’ and ‘videoconferencing’; ‘tele-dentistry’ and ‘oral medicine’; ‘tele-dentistry’ and ‘oral surgery’; ‘tele-dentistry’ and ‘orthodontics’; ‘tele-dentistry’ and ‘periodontics’; ‘tele-dentistry’ and ‘preventive dentistry’; ‘tele-dentistry’ and ‘prosthodontics’ and ‘tele-dentistry’ and ‘endodontics’; ‘tele-health’ and ‘tele-medicine’ and ‘dentistry’.

Eligibility criteria

The inclusion criteria were studies: (a) published in a peer-reviewed journal; (b) controlled (randomised or non-randomised) assessment studies; and (c) compared outcomes of a teledentistry intervention in terms of clinical or economic assessment with the outcomes of traditional clinical approaches. Studies were excluded if they were: (a) without a comparison between a teledentistry and a conventional alternative; (b) limited to describing the technical feasibility of a certain application; (c) non-controlled studies (e.g., cross-sectional, case report or case series) due to their high risk of bias; (d) presented in the format of reviews, editorials or letters; (e) dissertations, books, reports or unpublished materials; (f) provided inadequate information such as abstract or conference proceedings; and (g) written in a language other than English.

Study selection and data extraction

Two authors (ME and MT) screened the titles of identified publications independently and in duplicate when titles fulfilled the eligibility criteria or were unclear, the abstracts were read. The same process was used in assessing abstracts, the selection of the relevant studies was based on the data collected from the abstracts, which gave an indication that the eligibility criteria would be met, and was agreed upon discussion among the authors. In the next stage, relevant full-text articles were obtained and independently evaluated for the eligibility criteria by the two authors, who then reached an agreement on whether an article should be included. Full-text articles meeting the eligibility criteria were selected and abstracted into the evidence table (Table 1). The first author (ME) extracted data from the full-texts, and the other reviewer (MT) independently verified the extracted data. Discrepancies between the two reviewers were resolved through discussion. Additional details of each selected paper are presented in the evidence table, in which studies are tabulated by type of specialty, application considered, problem concerned, the technology used, outcome measured and the conclusion reached. In addition, the author’s name; country; study sample; study design and type of economic analysis are also listed here.

Evaluation of study quality

The quality of each study, other than those aspects related to economic analysis, was evaluated independently by two authors using the protocol established by Hailey et al. (originally modified from the Jovell and Navarro-Rubio classification), taking into account the study performance and study design (Table 2). This protocol is a useful approach, as it can provide a quantitative measure of scientific rigor. For assessing the design of included studies, large randomised controlled trials (RCTs) were assigned a score of five. Small RCTs were assigned a score of three, prospective non-randomised controlled trials a score of two, retrospective non-randomised controlled trials a score of one and non-controlled studies a score of zero. For assessing the study performance, five criteria
<table>
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<tr>
<th>Author(s) et al.</th>
<th>Country</th>
<th>Problem</th>
<th>Specialty</th>
<th>Application</th>
<th>Modality/Equipment</th>
<th>Study design</th>
<th>Sample/Participants</th>
<th>Outcome favour</th>
<th>Outcome reached</th>
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<tbody>
<tr>
<td>Benoit et al. (2009)</td>
<td>USA</td>
<td>Training of postgraduate dental students</td>
<td>Orthodontics</td>
<td>Teleconsultation</td>
<td>Real-time videoconferencing unit (Polycom VSX 2000, Polycom)</td>
<td>Prospective, non-randomized controlled studies (category C)</td>
<td>Children age 8-11 years, n=96 (control); n=30 (case)</td>
<td>Comparable</td>
<td>Peer assessment rating index was 35.6% in the teledentistry group and 44.1% in the direct supervision group (p value &lt; 0.001).</td>
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<tr>
<td>Bru et al. (2015)</td>
<td>India</td>
<td>Screening for oral diseases</td>
<td>Oral medicine</td>
<td>Teleconsultation</td>
<td>Store-and-forward (HTC Wildfire S)</td>
<td>Prospective, non-randomized controlled studies (category C)</td>
<td>Targeted cohort, n=3800</td>
<td>Comparable</td>
<td>In the targeted cohort, most (41% of 81; 41%) interpretable images, 23 of 51 (45%) of the lesions were confirmed by specialists, while 100% concordance with the specialists (106 of 106).</td>
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<td>Kopycinska-Kedziorawski et al. (2014)</td>
<td>USA</td>
<td>Screening for caries</td>
<td>Paediatric dentistry</td>
<td>Teleconsultation</td>
<td>Store-and-forward (Dr Cariroscope Intra-oral camera)</td>
<td>Large-sample RCT, Good (category A)</td>
<td>Age 12-40 months, n=124</td>
<td>Comparable</td>
<td>The mean DFS score for the children examined by means of teledentistry was 1.73 (SD = 4.35) and for the children examined by means of teledentistry was 1.40 (SD = 4.07).</td>
</tr>
<tr>
<td>Kopycinska-Kedziorawski et al. (2018)</td>
<td>USA</td>
<td>Screening for caries</td>
<td>Paediatric dentistry</td>
<td>Teleconsultation</td>
<td>Store-and-forward (Dr Cariroscope Intra-oral camera (Somatech))</td>
<td>Large-sample RCT, Good (category A)</td>
<td>Age 12-40 months, n=124</td>
<td>Comparable</td>
<td>After follow-up examinations at 12 months, the mean DFS scores for the children examined by means of teledentistry was 3.02, and for the children examined by means of the clinical method was 1.79.</td>
</tr>
<tr>
<td>Mandell et al. (2005)</td>
<td>UK</td>
<td>Patient referrals to consultant</td>
<td>Orthodontics</td>
<td>Teleconsultation</td>
<td>Store-and-forward Camera type not reported</td>
<td>Large-sample RCT, Good (category A)</td>
<td>Patients, n=247 (control); n=80 (test)</td>
<td>Teleconsultation</td>
<td>The sensitivity and specificity of the teledentistry system were 0.89 and 0.73 respectively. The inappropriate referral rate for the teledentistry group was 8.2% and for the controls 34.3% (p value = 0.037).</td>
</tr>
<tr>
<td>Mante et al. (2014)</td>
<td>Australia</td>
<td>Screening for oral diseases</td>
<td>Other dental fields</td>
<td>Teleconsultation</td>
<td>Store-and-forward (Real-time intra-oral camera (SOPHOTERA))</td>
<td>Cost-minimization study (category D)</td>
<td>Aged care residents, n=100</td>
<td>Teleconsultation</td>
<td>The net cost of store-and-forward teleconsultation was AUD$32.33 while the total cost of real-time consultation was AUD$41.28 per resident.</td>
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<th>Outcome favour</th>
<th>Outcome reached</th>
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<td>Nickajig et al. (2009)</td>
<td>Germany</td>
<td>Pre-implant dental assessment</td>
<td>Prosthodontics</td>
<td>Teleconsultation</td>
<td>Real-time videoconferencing (category C)</td>
<td>Prospective non-randomized controlled studies</td>
<td>Adult patients n=772 (control)</td>
<td>Comparable</td>
<td>In three cases (3%), a basic change in the periodontal concept was required as compared to the telemedicine plan, in the control group the concept changed in 7% of cases.</td>
</tr>
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<td>Ojima et al. (2003)</td>
<td>Japan</td>
<td>Oral health promotion</td>
<td>Periodontics</td>
<td>Teleconsultation</td>
<td>Store-and-forward</td>
<td>Small sample RCT</td>
<td>Adult workers n=7 (test)</td>
<td>Teledentistry</td>
<td>Indices for periodontal destruction, plaque accumulation, gingival inflammation and oral hygiene between the baseline and the 3-month examination were significant in each group (p=0.046, 0.027, 0.028 and 0.018, respectively). In each of these 342 patients with PFO were assisted by telemedicine, only 13 (3%) patients presented some other PFO pathology that required multifaceted surgery. The remaining 307 (96.4%) patients received no further treatment in the primary care centre, in the mean time of 2 days (p=0.019). The mean cost of 6 non-working hospitalization (p=0.019).</td>
</tr>
<tr>
<td>Salazar-Fernandez et al. (2012)</td>
<td>Spain</td>
<td>Temporomandibular Joint disorders</td>
<td>Dentistry</td>
<td>Teleconsultation</td>
<td>Store-and-forward</td>
<td>Prospective non-randomized controlled studies</td>
<td>Patients average age = 38-61 years</td>
<td>Teleconsultation</td>
<td>Of the 342 patients with PFO, 13 (3%) presented some other PFO pathology that required multifaceted surgery. The remaining 307 (96.4%) patients received no further treatment in the primary care centre, in a mean time of 2 days (p=0.019). The mean cost of 6 non-working hospitalization (p=0.019).</td>
</tr>
<tr>
<td>Southam and Steed (2002)</td>
<td>UK</td>
<td>Consultation about dental and oral diseases</td>
<td>Restorative dentistry</td>
<td>Teleconsultation</td>
<td>Real-time videoconference (category D)</td>
<td>Cost-minimization study (category D)</td>
<td>Mean age 46 years n=25</td>
<td>Teleconsultation</td>
<td>Cost savings are greatest where the cost of travel is greatest. For Orkney (a remote island) patients.</td>
</tr>
</tbody>
</table>

(continued)
were taken into account: patient selection, description of the interventions, analysis of the study, patient disposal and outcomes reported. 20,21 Each of the five criteria of study performance received a score of zero (if relevant information was not provided or unclear), a score of one (if relevant information was provided but there were some significant shortcomings) or a score of two (if the information provided was satisfactory, with no significant shortcomings).

The maximum overall quality scores (performance plus design) for each selected study was 15. The overall quality scores for each study provide an indication of the degree of confidence that can be placed in its findings and implications for future decisions making on teledentistry. Each study was designated to one of five categories (A to E), according to the totals of the quality scores. A study that had a high degree of confidence in its result was put in category A, whilst studies provided findings of unacceptable uncertainty and had a potential for selection bias were put in category E (Table 2). 20,21

Quality of economic evaluation
The quality of studies relating to the economics of teledentistry was assessed against Drummond et al. 5,21 criteria which includes a 10-point checklist.

1. Was a well-defined question posed in an answerable form?
2. Was a comprehensive description of the competing alternatives given?
3. Was the effectiveness of the programmes or services established?
4. Were all the important and relevant costs and accurately in appropriate physical units?
5. Were costs and consequences measured accurately in appropriate physical units?
6. Were costs and consequences valued credibly?
7. Were costs and consequences adjusted for different timing?
8. Was an incremental analysis of costs and consequence of alternatives performed?
9. Was allowance made for uncertainty in the estimates of costs and consequences?
10. Did the presentation and discussion of the study results include all issues of concern to users? 20,21

For each selected paper, a score of one was assigned for each criterion that was fulfilled. Therefore, the score for the economic evaluation of each study, ranged from 1 to 10.

Results
Retrieved articles
The database search identified a total of 385 titles, of which 287 abstracts were reviewed to determine if they were relevant to the scope of the study and were retrieved in full-text.
Table 2. Study quality classification by Hailey et al. (2004) 24

<table>
<thead>
<tr>
<th>Category</th>
<th>Study design</th>
<th>Strength of evidence</th>
<th>Overall quality score</th>
<th>Potential impact on future decisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Large RCTs</td>
<td>High quality</td>
<td>11.5-15.0</td>
<td>High degree of confidence in study findings</td>
</tr>
<tr>
<td>B</td>
<td>Small RCTs</td>
<td>Good quality</td>
<td>9.5-11.0</td>
<td>Some uncertainty regarding the study findings</td>
</tr>
<tr>
<td>C</td>
<td>Prospective non-randomised controlled studies</td>
<td>Fair to good quality</td>
<td>7.5-9.0</td>
<td>Some limitations that should be considered in any implementation of study findings</td>
</tr>
<tr>
<td>D</td>
<td>Retrospective non-randomised controlled studies</td>
<td>Poor to fair quality</td>
<td>5.5-7.0</td>
<td>Substantial limitations in the study findings should be used cautiously</td>
</tr>
<tr>
<td>E</td>
<td>Non-controlled series</td>
<td>Poor quality</td>
<td>1-5.0</td>
<td>Unacceptable uncertainty for study findings</td>
</tr>
</tbody>
</table>

RCT: randomised controlled trial. *Total score for study design and study performance.

Figure 1. The preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram of included studies.

Based on a review of the abstracts, 217 full-text articles were obtained for closer inspection. Of these, 11 were considered to fail the preset inclusion criteria (Figure 1). Nine of the included articles considered some clinical outcomes. 22, 23, 26, 28, 29, 30, 31 The remaining two were mainly economic analyses. 27, 29 Some kind of economic analysis was considered in one study. 2 The Kappa statistic (a measure of inter-reviewer reliability for the process of study selection and quality assessment) ranged from 0.62-0.70. This suggests that the concordance between the two reviewers was substantial/good at all stages.

Studies were clustered into two major applications, tele-diagnosis and teleconsultation. A minority of the reviewed studies were concerned with the referral clinical training or oral health promotion. 32, 33, 34 The majority of the reviewed studies were focused on the speciality of oral medicine, 35, 36, 37, 38 orthodontics 39, 40, 41, 42, 43 and dentistry 44, 45 Two types of consultation technique were used in the studies, store-and-forward (n = 5) or real-time (n = 4). The studies included in this review were conducted in seven different countries, with the majority of studies from Europe (n = 5) and the USA (n = 3), with one
Table 3. Proportion of studies as per type of intervention, type of application, type of technology and location of study.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Number of Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intervention/speciality</td>
<td></td>
</tr>
<tr>
<td>Paediatric dentistry</td>
<td>2</td>
</tr>
<tr>
<td>Oral medicine</td>
<td>3</td>
</tr>
<tr>
<td>Orthodontics</td>
<td>2</td>
</tr>
<tr>
<td>Prosthodontics</td>
<td>1</td>
</tr>
<tr>
<td>Periodontics</td>
<td>1</td>
</tr>
<tr>
<td>Restorative dentistry</td>
<td>1</td>
</tr>
<tr>
<td>Other dental fields</td>
<td>1</td>
</tr>
<tr>
<td>Type of application</td>
<td></td>
</tr>
<tr>
<td>Teleconsultation</td>
<td>4</td>
</tr>
<tr>
<td>Tele-referral</td>
<td>1</td>
</tr>
<tr>
<td>Tele-diagnosis and teleconsultation</td>
<td>1</td>
</tr>
<tr>
<td>Tele-diagnosis, teleconsultation and tele-referral</td>
<td>1</td>
</tr>
<tr>
<td>Type of technology</td>
<td></td>
</tr>
<tr>
<td>Score-and-forward</td>
<td>5</td>
</tr>
<tr>
<td>Real-time</td>
<td>4</td>
</tr>
<tr>
<td>Both</td>
<td>2</td>
</tr>
<tr>
<td>Country of study</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>5</td>
</tr>
<tr>
<td>USA</td>
<td>3</td>
</tr>
<tr>
<td>Australia</td>
<td>1</td>
</tr>
<tr>
<td>Japan</td>
<td>1</td>
</tr>
<tr>
<td>India</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
</tr>
</tbody>
</table>

detail was provided on the randomisation procedure and patient disposals. A further report of a small RCT,24 had a very small sample size and a more limited description of the randomisation procedure. All studies reported sample size, with the majority of the included studies using convenience sampling in the recruitment. However, only three studies reported power calculations.24–26

The study design and performance were a good indication of study quality. Studies that had higher overall quality scores had high study design and performance scores. The three large RCTs24–26 achieved the highest performance scores (7.0–7.50), indicating high quality in their performance and relatively high confidence in their results. Implications for the possible impact of a study on health-care decision-making regarding teledentistry arise from the reliability of a study as indicated by the overall quality scores and the degree of confidence put in their findings. Studies with higher overall quality scores had a high degree of confidence in their findings, and therefore, greater potential to influence future decisions on teledentistry. Six studies were found to have implications for future decision-making on teledentistry.24,25,27–29 The remaining studies reported more preliminary results, which may be useful to guide decision-making. The distribution of study design and performance scores with implications for future decisions for individual studies is given in Table 4.

Economic analyses

The economic analyses in the reviewed papers were methodologically more like cost-analysis studies. Cost-minimization was said to be conducted in two studies,27,28 since the benefits were calculated as cost-savings (direct and indirect costs) compared with the non-teledentistry alternative. One study included some indirect costs estimation (mainly lost working hours).28 The effectiveness of a teledentistry intervention was reported to be established in one study27 and assumed in two studies.24,25 The perspective of the economic analysis was explicitly reported in two studies, with one being from both the patient’s and health-care perspective29 and one from only the healthcare perspective.28 Only one study applied sensitivity analyses to evaluate the robustness of the results.28 Cost-benefit, cost-effectiveness or cost-utility were not considered in the reviewed studies. None of the selected studies considered incremental economic analysis (except Scaffham and Steed).29 Of three studies that included economic evaluation, two studies satisfied five or six criteria given by Drummond et al.29 and were judged to be of fair to good quality (Table 4).

Clinical outcomes

Despite the included studies using different objectives, methods and outcome measures, all studies indicated that teledentistry interventions were comparable to, or had advantages over non-teledentistry approaches. The
overall conclusions reached in the selected studies are given in Table 1. Two of the large RCT studies considered store-and-forward telediagnosis for detection of early childhood caries (ECC), and suggested that remote screening for ECC in preschool children using teledentistry was comparable to clinical visual examinations. A further report of a large RCT which used a tele-referral system to screen new patient orthodontic referrals, indicated that teledentistry offered a valid tool for identifying appropriate new referrals and avoiding inappropriate referrals. Another report of a small RCT study considered a web-based system for promoting periodontal health in a workplace, suggesting the use of this system allowed the public to access useful health information and enabled effective intervention of oral care professionals. The non-randomised controlled studies were diverse in their quality, as evaluated by the descriptions of methods, analysis of results and outcomes. For example, Salazar-Fernandez and colleagues evaluated the effectiveness of store-and-forward teledentistry to perform diagnosis and provide treatment for patients with temporomandibular joint disorder (TMJD). The authors indicated that teledentistry can offer valid diagnosis and adequate treatment of TMJD from primary care sites. Nickenig and colleagues evaluated real-time teledentistry for pre-implant dental evaluation. Nickenig et al. suggested that teledentistry has the potential to facilitate preparative assessment of the implantation operation. Another study by Berndt and colleagues indicated that interceptive orthodontic procedures performed by supervised general dentists via teledentistry can help in reducing the severity of malocclusions among children. Another study by Birur et al. examined the effectiveness of remote oral cancer surveillance programme using the mHealth application. Birur et al. showed that the mHealth-based approach aided remote screening for oral cancer by primary care practitioners. A further report of a non-randomised trial considered teledentistry to assess lip position in children with cerebral palsy. Results indicated that lip position assessed by real-time videoconferencing and direct clinical assessment are comparable, suggesting that videoconferencing offers a more unobtrusive approach than direct clinical assessment.

The effectiveness of teledentistry interventions was reported to be assessed in four studies. However, none of the studies considered cost-effectiveness. Only a few economic analysis studies, particularly those concerning cost-minimisation, were identified and included in this review. Mariko and colleagues compared the cost and benefits of Visual examination conducted by a dentist at a residential aged-care facility in rural areas with a teledentistry approach. The authors concluded that store-and-forward teleconsultation was the lowest cost service model compared to the in-person and real-time model of care. Scuffham and Steed undertook a cost-minimisation analysis to compare the costs of teledentistry with two alternatives, outreach visits and hospital visits. Scuffham and Steed reported that cost savings could be significantly higher when teledentistry was used in remote/very remote regions and even with additional costs, teledentistry can help in reducing dental inequalities. Another cost-minimisation study by Salazar-Fernandez and colleagues suggests that the use of store-and-forward teledentistry for management of patients with TMJD can shorten the delay in treatment onset and prevent or reduce the loss of productivity by patients.

Discussion

There is a consistent trend in the literature supporting the validity and reliability of teledentistry applications in comparison to non-teledentistry alternatives. However, most of the available literature (27 full-text articles screened) is limited to technical reports or feasibility studies, and only a small number of the studies reported a controlled comparison of a teledentistry application with conventional alternatives. In many cases,
the balance of the reviewed studies was towards assessing the efficacy of teledentistry application rather than assessing its effectiveness. Controlled assessments of the clinical outcomes and costs of teledentistry applications are needed to provide scientific evidence of the appropriateness of teledentistry. Generally, RCTs remain the gold standard for assessing the effectiveness and cost-effectiveness of an intervention within biomedicine, due to their ability to reduce the chances of bias and control for the potential impact of confounding factors. However, many argue that the complexity and methodological limitations of conducting RCTs to evaluate eHealth technologies may impact the generalisability of the findings. Therefore, there is a call for alternative strategies to evaluate the effectiveness of eHealth technological interventions such as using qualitative evaluation methods that allow consideration of sociotechnical contextual issues. Nevertheless, in this review, a robust and scientific approach to evaluating the literature on teledentistry was used that focused on assessing controlled assessment studies reporting a comparison of outcomes of a teledentistry approach with non-teledentistry or conventional alternatives. This approach could provide more conclusive evidence of the performance of teledentistry than those without a comparator. This review indicates that there are only a few good-quality comparative studies of teledentistry available, especially those evaluating the efficacy of teledentistry. Apart from few studies that assess the effectiveness of teledentistry,24,25 none of the reviewed studies considered the effectiveness, cost-effectiveness or long-term outcome of teledentistry applications. A growing body of evidence supporting the efficacy of teledentistry is provided by some of the studies on paediatric dentistry, orthodontics and periodontics. The majority of the research in these areas reported that teledentistry had similar or better outcomes than the conventional alternative. To date, the most convincing published evidence regarding the economic benefits of teledentistry deals with teleconsultation and telediagnosis. However, cost-minimisation analysis was being assessed, rather than cost-effectiveness, cost-utility or cost-benefits. The absence of good-quality economic studies in teledentistry has also been cited in previous reviews. Although some useful clinical and economic outcomes have been identified in a few teledentistry applications, conclusive evidence is still rare, and therefore, the generalisability of results is difficult to ascertain.

Teledentistry is an innovative method of oral health-service delivery that can connect dental practitioners and patients with a dental consultant anywhere on the globe. This is important particularly for underserved communities that lack access to oral care due to geographical barriers, socioeconomic issues or dental workforce shortages. Despite its great potential to address the needs of rural or remote populations, our findings indicated that more than half of the reviewed studies were undertaken in urban areas rather than rural settings. This could be attributed to funding difficulties in rural or remote areas or to the fact that the majority of the trials of teledentistry are still in proof-of-concept or pilot stages. The present review also shows that the majority of reviewed studies are clustered in developed countries, in particular, the USA and Europe, and little research work has been done in developing countries. The dearth of teledentistry projects in developing countries could be attributed to the conservation of decision makers, a lack of resources, ICT infrastructure and equipment. In addition, the provision of dental care services in developing countries is based on emergency rather than preventive care.

There were several limitations in most of the reviewed studies, so that even though the present review was restricted to good quality publications on teledentistry, at present they provide an inadequate indication of the status of this technology. It is possible that a large body of literature on teledentistry assessment was not located. Since the focus of this review was only on identifying controlled assessments of teledentistry and comparative outcomes, there was no attempt to review all the relevant 'grey literature' (e.g. education, technical reports, reviews and dissertations) as it is unlikely that there would be many articles fulfilling the inclusion criteria.

Conclusion
The present review identifies a growing body of evidence supporting the efficacy of teledentistry, particularly, in some areas of dentistry. However, in many cases, the reviewed studies provide only preliminary results and considered only the feasibility and short-term use of teledentistry. Due to limited conclusive evidence and the heterogeneity of the methods used, interventions and outcomes assessed in the reviewed studies, the generalisability of the findings is limited. Well-designed research into the assessment of teledentistry, taking into account its effectiveness, cost-effectiveness and long-term use, will be required before future decisions on whether to establish teledentistry services can be made.

Declaration of Conflicting Interests
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References


Appendix N

Publication Arising from Chapter 4

FEATURE ARTICLE
DIAGNOSTIC ACCURACY OF TELEDENTISTRY IN THE DETECTION OF DENTAL CARIES: A SYSTEMATIC REVIEW

MOHAMED ESTAI, MBBS, MMSc; STUART BUNT, BSc, MA, DPhil; YOGESAN KANAGASINGAM, BSc, MSc, PhD; ESTIE KRUGER, BChD, MChD, PhD; AND MARC TENNANT, BDSc, PhD, FRACDS(GDP), FADI, FIDC

*International Research Collaborative—Oral Health and Equity School of Anatomy, Physiology and Human Biology, University of Western Australia, Perth, Western Australia, Australia

ABSTRACT
Objective
This study sought to systematically review the literature for research evidence for the diagnostic accuracy of teledentistry in the detection of dental caries.

Methods
Two reviewers searched PubMed, EMBASE, and Scopus databases through January 2016 for comparative studies that examined the diagnostic accuracy of teledentistry for detecting caries compared with nonteledentistry alternatives. Retrieved studies were screened for inclusion criteria and were evaluated for methodological quality using the quality assessment of diagnostic accuracy studies (QUADAS-2) checklist.

Results
Of 287 citations identified, 10 met the preset inclusion criteria. Sensitivity and specificity were the most common measures of diagnostic accuracy used in 10 studies. Despite very limited published evidence on the diagnostic accuracy of teledentistry, the reviewed teledentistry studies showed comparable diagnostic performance compared with nonteledentistry alternatives. The average methodological quality of the selected articles is low, since none of the selected studies satisfied all 4 QUADAS-2 domains. Only 6 articles were scored as having a low risk of bias in 3 of 4 QUADAS-2 domains. All the selected studies had low concerns regarding applicability. The main shortcoming was that in most of the selected studies, the methodology, in particular patient selection and index tests, was insufficiently described.

Conclusions
Teledentistry has an acceptable diagnostic performance in the detection of dental caries. However, due to the heterogeneity of the reviewed studies, the generalization of results may be difficult. Further well-designed research to investigate the effectiveness of the teledentistry approach to caries detection is needed to determine the capability of this technology in epidemiologic oral surveys.

INTRODUCTION
Despite considerable improvement in children’s oral health over the past decades, dental caries (tooth decay) is still the most prevalent health

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E-mail: abdalla177@gmail.com

KEYWORDS
Validity. Dental caries, Diagnosis, Photography. Telemedicine

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problem, being 5 times more common than asthma.\textsuperscript{1} Caries is a potentially preventable infectious disease, which, if left without treatment, can result in acute morbidity necessitating costly treatment.\textsuperscript{2} Among children, restorations and dental extractions are considered the leading causes for hospital separations in Australia.\textsuperscript{3} In adults, caries remains the second most costly disease-related chronic disease ahead of heart disease and diabetes mellitus.\textsuperscript{4} Regular screening and early detection of oral problems have the potential to improve oral health and save significant resources.\textsuperscript{5}

Although visual examination remains the primary technique for caries detection,\textsuperscript{6} this method has some subjective limitations (related to the examiner), such as inconsistency in the charting and inability to blind examiners to particular characteristics of the subjects.\textsuperscript{7} The visual approach to caries detection is inappropriate in large-scale epidemiologic oral surveys as it necessitates excessive and expensive travel and time. It is essential to seek cost-saving alternatives that can expedite early detection of caries and provide a comparable diagnostic performance to a visual examination. Teledentistry is an increasingly popular alternative to the traditional visual approach to screen for oral diseases at a distance. Teledentistry is a new field of telemedicine which results from the incorporation of information and communication technology and dentistry.\textsuperscript{8} Teledentistry incorporates a store-and-forward technology and dental photography into oral care services, where clinical data (e.g., radiographs and photographs) can be acquired by oral health professionals and then stored and forwarded for later evaluation by dental experts. Although the introduction of photography into dentistry has increased rapidly in recent years, it has rarely been used for diagnosis, consultation, or referrals.\textsuperscript{9}

There is an increasing interest in the use of teledentistry services in daily dental practice, but the quality of evaluation of this technology is still unclear. Teledentistry has been the subject of evaluation studies for over 15 years now, with several studies having been conducted to examine the diagnostic accuracy and reliability of the photographic method for the screening of oral diseases. Recent systematic reviews on a broad range of teledentistry applications found generally positive results concerning the conventional non-telemedicine approaches.\textsuperscript{10,11} However, these systematic reviews have to date provided qualitative reviews, rather than a quantitative synthesis. Thus, in view of the relatively frequent use of teledentistry in screening for caries, we conducted a systematic review of the literature to evaluate the diagnostic accuracy of the teledentistry approach for caries detection as compared to the traditional non-telemedicine alternatives.

METHODS

Search Strategy
A comprehensive review of the literature was conducted for peer-reviewed studies that reported the diagnostic accuracy of a teledentistry approach to the detection of caries, published until January 2016. We searched the PubMed, EMBASE, and Scopus databases. The database search strategy is described in Table 1. The systematic reviews were conducted in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (Figure 1).\textsuperscript{12}

Eligibility Criteria and Study Selection
All titles and abstracts of articles identified were first assessed against the inclusion criteria: (1) examined the accuracy of the teledentistry method in the detection of dental caries; (2) had a reference standard; (3) compared the teledentistry approach to caries detection to visual oral examination or non-telemedicine methods; (4) had some mention of a teledentistry approach for caries detection using different photography techniques (video or still photograph); and (5) examined primary or permanent human teeth, either in vivo or in vitro settings.

A 3-stage screening strategy (title, abstract, and full-text study) for identified studies was performed independently and in duplicate by 2 authors (M.E. and E.K.). All titles and abstracts were reviewed by both reviewers who selected relevant articles based on the data collected from identified abstracts, which gave an indication that the inclusion criteria would be met. In the next stage, relevant full-text articles were obtained and evaluated independently for the eligibility criteria. Discrepancies between the 2 reviewers were sorted out by discussion and consensus. Studies in languages other than English that provided inadequate information or with no abstract available were excluded. Studies that evaluated oral diseases other than dental caries

<table>
<thead>
<tr>
<th>Table 1. Database search strategy.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Search Syntax</strong></td>
</tr>
<tr>
<td>1. Dental AND (remote) OR photography OR x-ray AND (dental caries AND (caries OR carious caries OR root caries))</td>
</tr>
<tr>
<td>2. Dental AND (remote screening OR telediagnosis OR teleconsultation)</td>
</tr>
<tr>
<td>3. Teledentistry AND (abstract) OR (teledentistry AND dentistry) OR (telehealth AND dentistry)</td>
</tr>
</tbody>
</table>
Dentine or enamel reported detection performance using artificial caries were also excluded from the analysis.

Data Extraction
The first author (M.E.) collected the relevant data from the included full-text articles into an evidence table (Table 2). The extracted data included the following: author and year of publication; country; equipment used (including modality, camera type, type of images “still or video”); study setting; sample characteristics; and study design. In addition, the scoring system to classify the disease; part of tooth analyzed (per teeth and/or surface); experimental setting (in vivo or in vitro); and conclusion were considered. The second author (E.K.) checked and verified the collected data independently. Discrepancies between the 2 reviewers were settled by discussion. The strength of the evidence in each of the included studies was evaluated according to the classification scheme developed by Jowett and Navarro-Rubio,29 in which the research design is sorted in descending order of strength from level 1 to 9 (Appendix Table 1).

Quality Assessment
In an attempt to improve the quality of the present review, 2 reviewers (M.E. and E.K.) conducted a quality assessment independently and in duplicate. Disagreement on the quality assessments was sorted out by discussion. The Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) instrument established by Whiting et al.30 was used to evaluate the applicability and risk of bias of the selected studies.
Table 2. Summary of teledentistry studies included in the review.

<table>
<thead>
<tr>
<th>Author(s) &amp; Year</th>
<th>Country</th>
<th>Setting</th>
<th>Study design</th>
<th>Sample</th>
<th>Conventional sampling size</th>
<th>Technology/Type of imaging/Examiners</th>
<th>Category of experiment</th>
<th>Scoring system</th>
<th>Teeth/Tooth surface</th>
<th>Reference</th>
<th>Main outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armoore et al. (2019)</td>
<td>Portugal</td>
<td>Kindergartners</td>
<td>Cross-sectional cohort study</td>
<td>N = 66</td>
<td>age = 4+ yrs</td>
<td>Standardized forward, photograph, x-ray</td>
<td>In vivo</td>
<td>Scoring system defined by the authors</td>
<td>Per tooth</td>
<td>Visual examination (oral dental)</td>
<td>The sensitivity and specificity values for the photographic method ranged from 94% to 100% and 92% to 100%, respectively. The mean PPF and NPF were 90% and 97%.</td>
</tr>
<tr>
<td>Bayle et al. (2019)</td>
<td>United Kingdom</td>
<td>University Oral Health Unit</td>
<td>Cross-sectional cohort study</td>
<td>N = 50</td>
<td>Human permanent teeth</td>
<td>Standardized forward, photograph, dental camera (iPhone, Coolscan LS)</td>
<td>In vivo</td>
<td>SASCD</td>
<td>Per occlusal surface</td>
<td>Radiology examination</td>
<td>In comparison to the reference radiographs, the median sensitivity for the photographic and visual assessments were 91.3% and 65.5%, respectively. The Cohen’s Kappa for intraobserver agreement for the visual and photographic assessments was 3.95 and 0.74, respectively.</td>
</tr>
<tr>
<td>Bayle et al. (2019)</td>
<td>United Kingdom</td>
<td>Primary school</td>
<td>Cross-sectional cohort study</td>
<td>N = 15</td>
<td>N = 170</td>
<td>Standardized forward, photograph, dental camera (iPhone, Coolscan LS)</td>
<td>In vivo</td>
<td>IMP3D</td>
<td>Per tooth</td>
<td>Visual examination (oral dental)</td>
<td>The teledentistry method had a sensitivity of 96% to 99% in the 5-6 years and 95% to 97% in the 10-11 years. Teledentistry method had a positive predictive value of 97%-100% in the 5-6 years and 90%-99% in the 10-11 years. The median intraobserver agreement for the photographic assessment was 0.56. The intraclass correlation coefficient for the photographic assessment ranged from 0.62 to 0.83.</td>
</tr>
<tr>
<td>Elhassan et al. (2020)</td>
<td>Saudi Arabia</td>
<td>Dentists practice</td>
<td>Cross-sectional cohort study</td>
<td>N = 45</td>
<td>5-6 year old children</td>
<td>Standardized forward, photograph, dental camera (Digital Upper, PointCam)</td>
<td>In vivo</td>
<td>dfH</td>
<td>Per tooth and per face</td>
<td>Visual examination (oral dental)</td>
<td>The sensitivity and specificity values for the photographic assessment were 85% and 98%, respectively. The interrater agreement for the photographic assessment, as compared with the visual examination was 0.76. The intraclass correlation coefficient for the photographic assessment ranged from 0.62 to 0.83.</td>
</tr>
<tr>
<td>Eter et al. (2020)</td>
<td>Turkey</td>
<td>KIR</td>
<td>Cross-sectional cohort study</td>
<td>N = 50</td>
<td>Human permanent teeth</td>
<td>Standardized forward, photograph, dental camera (EndoSoft)</td>
<td>In vivo</td>
<td>UKN</td>
<td>Per occlusal surface</td>
<td>Radiology examination</td>
<td>In comparison to the reference radiographs, the sensitivity and specificity of the photographic method were 43% and 90%, respectively. The mean PPF and NPF were 40% and 85%, respectively. The median interrater agreement for the photographic method was 0.13 and 0.4.</td>
</tr>
<tr>
<td>Eter et al. (2020)</td>
<td>Australia</td>
<td>Dental practice</td>
<td>Cross-sectional cohort study</td>
<td>N = 50</td>
<td>Children and adults</td>
<td>Standardized forward, photograph, dental camera (Digital Upper, PointCam)</td>
<td>In vivo</td>
<td>Scoring system defined by the authors</td>
<td>Per tooth</td>
<td>Visual examination</td>
<td>The sensitivity and specificity of the photographic method were 43% and 90%, respectively. The mean PPF and NPF were 40% and 85%, respectively. The median interrater agreement for the photographic method was 0.13 and 0.4.</td>
</tr>
</tbody>
</table>
studies. The QUADAS-2 checklist comprised 4 domains: patient selection, index test, reference standard, and flow and timing. The 4 domains were evaluated regarding the risk of bias. The first 3 domains were additionally evaluated regarding the applicability. A detailed description of QUADAS-2 checklist including signaling questions is reported in Appendix Table 2.

RESULTS
The bibliographic databases search identified a total of 287 titles, of which 244 abstracts were reviewed to determine if they were relevant to the scope of the study and were retrieved in full text. Of these, 10 full-text articles satisfied the eligibility criteria and were included in the final analysis (Figure 1). All 10 included studies came from PubMed database.

Characteristics of the Included Studies
Teledentistry studies included in the present review were carried out in 7 different countries, with 6 studies from Europe. All the reviewed studies (n = 10) were published during 2003 to 2016, and 5 of these studies were published in the past 5 years (since 2011). Six of the studies were conducted in clinical (in vivo) and 4 studies in laboratory (in vitro) settings. Four studies used a histology examination as a reference standard and 6 studies used a visual oral examination as the reference standard. The review shows clustering of the studies in pediatric dentistry. 2 studies evaluated adult participants, and the studies that considered children had a broad range in age groups. Most of the reviewed studies did not explicitly report the setting of the study (rural or urban). Three studies were carried out in childcare centers or schools, and the remaining studies conducted in hospitals, oral health centers, or dental clinics. Different scoring systems were used to evaluate dental caries, including some established by the authors. The type of equipment used to acquire the photographs showed significant variations, most of the included studies (n = 7) used intraoral cameras as a photographic device, 2 studies used digital single-lens reflex (DSLR) cameras and 1 study used a smartphone camera. All studies used store-and-forward technology, and except for 1 study, all studies used still photographs rather than video in the analyses (Table 2).

Diagnostic Outcomes and Study Design
Sensitivity and specificity were the most common measures of diagnostic accuracy used in 10 studies. Only 4 studies reported positive and negative predictive values. Diagnostic reliability (interobserver or intraobserver kappa) of the teledentistry approach compared with the gold standard was used in 8 studies. The collected diagnostic accuracy and reliability data show contrasting results (Table 2). The sensitivity of the photographic assessments ranged from 43% to 100% and the specificity ranged from 52% to 100%. Kappa as a measure of interobserver agreement of photographic method ranged from 0.33 to 0.86. Three studies favored the photographic caries assessment to visual examination, and in the remaining 7 studies, the diagnostic accuracy for the photographic method and visual caries assessment were comparable. All 10 reviewed studies were uncontrolled descriptive studies corresponding to category VII according to the Joveil and Navarro-Fulbio criteria. Sample sizes ranged from 50 to 270 individuals, with only one study having sample size estimates and power calculations.

Risk of Bias and Applicability Assessment
The results of quality assessment for the 10 included studies are presented in Table 3. Most authors did not provide a comprehensive description of the eligibility criteria for their studies, nor did they explicitly state if the examiners independently evaluated photographs without knowledge of the results of the gold standard. In addition, it was not clear whether the gold standard was calibrated or not. All studies used convenience sampling in the recruitment. The domains of index test and patient selection contributed the most to the risk of bias, being insufficient in 30% and 40% of the studies, respectively. Ertun et al., Fergie et al., Boye et al., and Gómez et al. had a high risk of bias as a result of the lack of randomization and blindness during the sampling process. Amavel et al., Estai et al., and Morosini et al. had an unclear risk of bias because of the lack of information about the eligibility criteria of patients, sampling, and randomization procedures. Elfrink et al. and Kopycka-Kedzierska et al. had a high risk of bias because the same examiners were used to interpret both the reference standard and index test. The reference standard and flow and timing domains were considered adequate in 100% and 92%, respectively, of the studies. Figure 2. Boye et al. had the highest risk of bias because the index test was not interpreted independently from the reference standard, and the study showed no adequate time interval between the reference standard and index test. All the selected studies had good applicability (Figure 3). Due to the lack of high-quality diagnostic accuracy studies and variations of study design, it was not possible to carry out a meta-analysis.

DISCUSSION
The present review sought to assess the diagnostic accuracy of the teledentistry approach for detection of caries compared with reference visual inspection or
nontelemedicine alternatives. Ten studies were found that met the criteria for inclusion in this review, and more than half of the included studies \cite{5-10} were scored as having a low risk of bias, and all the included studies had low concerns regarding applicability (Figures 2 and 3). All the selected studies (n = 10) were dominated by uncontrolled descriptive studies and assessed the efficacy of teledentistry rather than its effectiveness, thus providing poor evidence. Randomized controlled trials are regarded as the most reliable method of evaluating the effectiveness and cost-effectiveness of an intervention in health care. However, conducting randomized controlled trials in telemedicine to evaluate the effectiveness of an intervention is often challenging, expensive, and not always

Table 3. Quality assessment outcomes of the selected studies using the QUADAS-2 checklist.

<table>
<thead>
<tr>
<th>Author (Y)</th>
<th>Risk of bias</th>
<th>Applicability concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Patient selection</td>
<td>Index test</td>
</tr>
<tr>
<td>Amsel et al. (2009)</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Boye et al. (2012)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Boye et al. (2013)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Ehrler et al. (2009)</td>
<td>?</td>
<td>No</td>
</tr>
<tr>
<td>Erton et al. (2008)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Estai et al. (2016)</td>
<td>?</td>
<td>Yes</td>
</tr>
<tr>
<td>Forgie et al. (2002)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Gomez et al. (2013)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Kopyshko-Kanisterowska et al. (2007)</td>
<td>?</td>
<td>No</td>
</tr>
<tr>
<td>Merisini et al. (2014)</td>
<td>?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Yes = Low risk, No = High risk, ? = Unclear risk.
practical, depending on local variations in administration and organization.

Sensitivity and specificity as a measure of diagnostic accuracy for the teledentistry approach ranged from moderate to high. Kappa as a measure of interobserver agreement between a teledentistry approach and the reference alternative ranged from fair to almost perfect agreement. Most of the reviewed research on photographic caries assessment showed at least equivalent diagnostic accuracy and reliability when compared to non-teledentistry alternatives. The QUADES-2 instrument established by Whiting et al. was used to evaluate the risk of bias and applicability for the included articles. The average methodological quality of the included articles is low, since none of the studies satisfied all 4 QUADES domains. Only 6 articles were scored as having a low risk of bias in 3 of 4 QUADES-2 domains (Figure 2). The major issue was that in most of the selected studies, patient selection and index tests were not very clearly described.

Dental caries is considered the fifth leading cause for admission to the hospital for preschool children in Western Australia. From 2013 to 2014, the total expenditure on dental care in Australia increased to $9 billion. Caries not only requires costly treatment, but it can impact on the quality of life of children. In the long term, if caries remain untreated, it may influence the growth and cognitive development of young children. There has been increasing interest in research into caries detection in children. This is reflected in this review which has a substantial number of the included studies that have been carried out in childcare or school settings and most studies involved preschool-aged or school-aged participants.

Less than half of the reviewed studies were conducted in in vitro settings. In vitro studies are more costly and time consuming than in vitro. However, in vitro studies have certain shortcomings in that they are inappropriate for the evaluation of the effectiveness of a new diagnostic method. The in vitro approach may also present difficulties in the generalization of findings as this approach is often conducted in a highly standardized way and under ideal conditions which are absent under normal clinical settings. Although the photographic method has the potential to maintain diagnostic performance at the level of visual oral examination, this method has certain limitations. Neither visual examination nor the photographic method can detect pre-erupted lesions. The shortcomings of the photographic method are mainly related to the inability to detect small carious lesions, difficulty in distinguishing lesions from artifact spots, quality of images, and two-dimensional view which only allows the detection of carious lesion on the occlusal surface. The quality of the photographs and equipment used to acquire the photographs may influence interpretation and analysis of images and consequently result in suboptimal sensitivity and specificity and reduced interexaminer or intraexaminer reliability.

There is increasing interest in store-and-forward technology; the store-and-forward method is more attractive than real-time consultation as it can provide good results at low cost, without the additional costs for equipment or connectivity. All 10 of the selected studies used a store-and-forward method. Store-and-forward telemedicine has the potential to prioritize new patient appointments and facilitate patient referrals to a consultant, especially in places that require lengthy travel. It has also proven to be more cost saving than real-time and in-person clinical consultation in dentistry and some clinical disciplines. The photographic method and store-and-forward telemedicine have been used widely to screen for diseases in ophthalmology, dermatology, and audiology. Traditionally, a DSLR camera is the primary photography device due to its ability to generate high-quality images even in low-light or high-magnification situation. However, this review shows variations in the type of equipment used to acquire the photographs, with most studies using intraoral cameras as the primary photographic technique. Compared with DSLR camera, the intraoral camera can be used to produce quality images with poor quality. Besides, these devices being relatively expensive and not always providing satisfactory images, intraoral cameras are also not yet readily available to rural dental providers, and even less so for patients.

More recently, mobile telemedicine is often regarded as a subdivision of teledentistry. It emerges as a combination of cellular technology and store-and-forward technology. Mobile telemedicine has been shown to improve access, in particular in teledentistry and teledermatology, as well as dentistry. Cellular technology is an attractive innovation due to its inherent digital imaging capabilities, mobile connectivity, and sharing as well as being readily available to the general population. In addition, the relatively low-cost, small weight, portability, and ability of users to provide satisfactory photographs with less training make these devices appropriate to use in epidemiologic oral surveys. Further research is required to determine the capability of smartphone technology in dental screening.

The store-and-forward teledentistry approach for assessment of oral health has advantages in rural settings, where nurses or non-licensed health care providers such as teachers or parents could be employed to obtain clinical data (photographs, radiographs, or clinical information) for a dental expert to evaluate at a distance. The photographic approach could facilitate the archiving of the photographs and allow dental experts at a hub site to assess dental photographs at their desktop quickly and easily. This can reduce the introduction of potential bias and increase the
diagnostic accuracy. As telemedicine and digital imaging technology rapidly evolve, the reduction in the size and improvement of features of the various technology-supporting equipment will reduce the cost of establishment of telemedicine services. Therefore, the use of photographic methods in large-scale epidemiologic studies becomes feasible. In epidemiologic oral surveys, this strategy offers a practical and potentially cost-saving method for screening for oral diseases among unreachable and high-risk populations, who have limited access to oral care.

CONCLUSION

Based on this systematic assessment of the literature and taking into account the limitations of photographic caries assessment, it can be concluded that the telendontistry approach has an acceptable diagnostic value in the detection of caries lesions. Despite very limited published evidence on the diagnostic accuracy of telendontistry, the reviewed studies showed at least comparable results between photographic methods and the non-teledentistry alternatives of caries assessment. However, due to the diversity in the research methodology used, the generalization of results may be difficult. Further well-designed research to investigate the effectiveness of telendontistry in the detection of dental caries is needed to determine the capability of this technology in epidemiologic oral surveys.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ejop.2016.08.003.

REFERENCES


Appendix O

Publication Arising from Chapter 5

A proof-of-concept evaluation of a cloud-based store-and-forward telemedicine app for screening for oral diseases

Mohamed Estal1, Yogesan Kanagasigam², Di Xiao3, Janardhan Vignarajan4, Boyan Huang5, Estie Kruger7 and Marc Tennant1

Abstract
Objective: It is widely considered that telemedicine can make positive contributions to dental practice. This study aimed to evaluate a cloud-based telemedicine application for screening for oral diseases.

Methods: A telemedicine system, based on a store-and-forward method, was developed to work as a platform for data storage. An Android application was developed to facilitate entering demographic details and capturing oral photos. As a proof-of-concept, six volunteers were enrolled in a trial to obtain oral images using smartphone cameras. Following an onsite oral examination, images of participants’ teeth were obtained by a trained dental assistant. Oral images were directly uploaded from the smartphone to a cloud-based server via broadband network. The assessments of oral images by offsite dentists were compared with those carried out via face-to-face oral examinations.

Results: A complete set of 30 oral images was obtained from all six participants. Out of 192 teeth reviewed, the proportion of ungradable teeth was 8%. Sensitivity and specificity of teledental screening were 57% and 100% respectively. The inter-grader agreement estimated for two examination modalities and between two teledental graders was 70% and 62% respectively. Findings indicate that the proposed system for screening of oral diseases can be implemented to provide a valid and reliable alternative to traditional oral screening.

Conclusion: This study provided evidence that a robust system for store-and-forward screening for dental problems can be developed, and leads to the need for further testing of its robustness to confirm the accuracy and reliability of the teledentistry system.

Keywords
Telemedicine, teledentistry, smartphone, cloud, carries, dental, digital imaging, remote

Due to remoteness, shortage of dentists, lack of insurance or financial burden, in Australia only half of all adults visit a dentist at least once a year.1 Thus, it is essential to seek strategies that can increase access to adequate care and avoid long waiting without compromising quality, effectiveness and safety. One of a number of growing

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solutions to address limited access to dental care is the utilization of telemedicine technologies in the screening for oral diseases, providing care, evaluation of care and referral. There are two telemedicine modalities: real-time consultation and store-and-forward. For most dental applications, the store-and-forward method provides excellent results without excessive costs for equipment or connectivity. While email remains a popular method for store-and-forward consultation with limited data security, videoconferencing is still a popular method for real-time consultation. However, video conferencing has its limitations as it needs expensive equipment and requires all parties to be online at the same time. Cloud storage represents another store-and-forward method that allows storing and retrieving data through a secured system. Despite adoption rates for email and videoconferencing within the field of dentistry increasing rapidly, adoption of cloud computing is still lagging.

With smartphone camera technology improving significantly, utilization of smartphones to obtain and transmit images for screening of dental caries has recently matured. Similar to dedicated digital oral cameras, smartphone cameras have zoom and flash features, as well as manual adjustments that allow easier capturing of intraoral or extra-oral images. The portability and accessibility features of smartphones can provide an effective means for capturing images in less time and be less intimidating for children. Recent studies reported that children were enthusiastic and cooperative during photography and recording procedures with smartphones. The process of capturing images using smartphones can therefore be noninvasive and less stressful for small children than the usual oral examination. This study was designed to develop a suite of technology harnessing the advantages of ubiquitous smartphone imaging technologies and cloud-based computing and to build an easy-to-use, accurate tool to enhance the opportunity for dental screens for patients with otherwise limited access to dental care.

Methods
System architecture
Based on a telemedicine platform "Remote-i", which was developed for ophthalmology and other medical applications, the Australian e-Health Research Centre (AeHRC) has built a store-and-forward based teledentistry system to carry out a screening programme for dental caries. Remote-i is a comprehensive data management server that has been widely used as a teledentistry platform in various screening programmes in Australia and China. The system enables uploading and storing images online either directly from a smartphone or from a computer. In addition, it is capable of image acquisition, data entry, storage and retrieval of data through a password-protected system (Figure 1).

Smartphone application (Android)
An image acquisition Android application was developed and installed on the Motorola® Moto smartphone (USA) to facilitate entering patient personal details and capturing dental photos, and then uploading data corresponding to each patient to cloud storage, using Wi-Fi hotspots or the cellular data networks (Figure 2). At this stage, the app only supports Android devices, but an app that can support other operating systems such as iOS and Windows is under consideration. The patients’ data stored on the database system are accessible via a specially designed web interface. The web interface also allows users to plug in any USB dental camera, capture images and add them to the current patient’s record without the need to import them from the mobile device. The research team can also access the server and follow up with the remote screening site for further action (Figure 1).

Technical details of the teledentistry system
The Remote-i server uses Microsoft ASP.NET server technology under the Windows 2008 server and is built using the ASP.NET MVC framework. Dental screening data is stored on the server using the Microsoft SQL Database engine. The website is built using modern web standards (HTML5, JavaScript and CSS technologies), and can be rendered in any mobile/desktop web browsers with proper size proportions. Users can log in to Remote-i using any web browser, including Chrome, Mozilla Firefox and Safari, from any location. The database is highly portable across various platforms, including Microsoft Windows, Mac OS X, and Linux. Only authorized users (investigators and teledental examiners) are allowed to access the database using individual user IDs and passwords. For security purposes, all data transmissions go over encrypted internet connections such as Secure Socket Layer (SSL) and hypertext transfer protocol over SSL. The speed of data transmission depends on the network bandwidth available at the facility, but at a maximum it may take 2–3 minutes (using the 3G network in rural areas) to transmit data from the smartphone to the server.

The phone app is developed using Java on the Android platform. The Android app uses an SSL to transfer information to and from the cloud server. The cloud server and Android app communicate using the JSON (JavaScript object notation) messaging standard to promote open interoperability within different kinds of systems. The tele-dental Android app is designed to invoke existing Android camera applications installed in the user smartphone to capture images, which provides the user with the flexibility to choose suitable camera apps for dental imaging or use the default one. The tele-dental Android app can seamlessly take control after image capture and manage the captured images using adding, deleting, clipping and reviewing functions (Figure 2).
Proof-of-concept trial protocol

All data collection was completed under ethics approval from The University of Western Australia. Six adult volunteer patients enrolled in the proof-of-concept trial. Each participant received an in-person oral examination by a registered dental practitioner (without radiographs) to record caries and existing restorations; this was used as the gold standard. The onsite dentist spent an average 10 minutes per patient for oral screening. The dentist recorded data on an oral assessment sheet aligned with World Health Organization (WHO) protocol and provided treatment recommendations or referral (Figure 3). In a separate visit, a trained teledental assistant took photographs of each participant’s oral cavity using a smartphone application. Techniques for obtaining each oral view were demonstrated during training, and each teledental assistant is provided with image photography protocol. Check retractors and intraoral mirrors were not used in the screening so as to simulate the final expected working conditions. An average of five oral images were taken per patient including: one anterior view, one upper occlusal view, one lower occlusal view, and two lateral view images. Additional views of the teeth, intraoral soft tissue or extra-oral structures were taken in some cases. The photographs were then directly transmitted from the smartphone to a secure online server (Remote-i) for evaluation by an offsite grader (Figure 3). Although the patient’s data transmitted to the server is de-identified or anonymous, it was not de-identified to the main investigator or clinicians as we used patients ID numbers in the database as a key. Techniques for obtaining each oral view were demonstrated during training, and each teledental assistant was provided with image photography protocol.

Role of the teledental assistant

Dental screening can be performed by teledental assistants (who were in the proof-of-concept environment, dental students or assistants). The teledental assistants were oriented to basic oral visualization and provided hands-on training on how to capture good quality images using a smartphone app and the camera. Each assistant had the opportunity to practice using the smartphone’s camera on adult volunteers for as long as it took for them to feel competent. The formal training was kept to a bare minimum to simulate the situation expected in the working situation.

Role of the teledental grader (offsite practitioner)

The reviewing of the dental images was carried out by an offsite dental practitioner using a separate web-based data and image-viewing app built upon the Remote-i system.
(Figure 3). In the proof-of-concept, two independent teledental graders were provided with written and oral instructions about how to log in to the Remote-i server to review the intraoral images, how to insert comments or findings on the predefined oral assessment form, and how to submit their findings into the Remote-i server. Offsite practitioners can access the database using individual user IDs and passwords. After selecting a record, a predefined dental chart appears for the reviewers to insert their comments. The chart includes an oral health assessment form based on the data from the WHO protocol (Figure 3). The assessment form is designed to facilitate the processing of results and minimize errors. Each grader reviewed the oral images and commented on the dentition status for each tooth (dental caries or existing restoration) on a predefined assessment form. A final question required to be answered is an assessment of interventional urgency, and the need for patient referral to a dental practice to receive further treatment. After completing the review, the grader could submit the report (and recommendation) into the Remote-i server for storage in the cloud-based server.

**Findings from the proof-of-concept trial**

A complete set of 30 oral images was obtained from all six participants using the smartphone's camera and uploaded to the Remote-i server (Figure 3). All uploaded files were stored in a database in an uncompressed JPEG format; the average file size was 900 KB. Participants' characteristics collected during the trial are summarized in Table 1. It took approximately one minute to register a patient (entering personal details) and five minutes to take pictures. The quality of images obtained by the teledental assistant was assessed by an independent practitioner to ensure that they were complete, colour-balanced, focused, and clear. Oral images of poor diagnostic quality were re-captured when necessary.

The proportion of the captured digital images that were gradable was 100%. Out of 192 teeth reviewed, the proportion of ungradable teeth was 8%. Statistical testing of the reliability of the two sets of oral examinations (clinical and teledental) and two graders (grader 1 and grader 2) was completed using kappa statistics. The calculation of sensitivity and specificity of teledental screening was based on the presence or absence of untreated caries; the sensitivity of the teledentistry examination was 57% and specificity was 100% versus in-person oral examination (Table 2). The inter-grader agreement between traditional oral examinations and teledentistry examinations was 70%, while inter-grader agreement between teledental grader 1 and teledental grader 2 was 62% (Table 2).

**Discussion**

Our findings suggested that the combination of a smartphone camera and store-and-forward technology for oral health screening can be adequate for screening purposes and offers a reliable alternative to traditional oral examinations. The trial showed at the level of proof-of-concept that there was a good concordance between teledental and face-to-face oral assessments. This reflects previous research which shows no statistical difference between teledentistry and clinical screening for caries, with kappa statistics for inter-grader reliability between clinical and teledentistry screenings ranging from moderate to very good agreement.11-19

Teledentistry has become a viable option to address limited access to specialist care, particularly in locations far from specialist centres. Specialists do not need to be physically present with the patient, as they can provide consultation and guidance for local practitioners at a distance. Teledentistry would expedite early diagnosis and facilitate timely treatment of oral diseases by reducing the isolation of practitioners and increasing access to specialist care.20 In addition, it has the potential to improve the quality of care for the underserved by facilitating the provision of timely information to dentists for better decision making and effectively triaging patients who require specialist consultation, thus reducing waiting lists and supporting locally based oral treatment.19 Teledentistry applications within dentistry are highly diverse, including preventive dentistry, oral medicine, oral and maxillofacial surgery, orthodontics, periodontics and education, with
preliminary evidence suggesting positive outcomes in comparison to clinical settings. The quality of images and the capability to grade images accurately are very important factors when evaluating the feasibility of telediagnosis of diseases. During testing we found that many of the oral images were blurred or over saturated when the default camera application was used. This is because the flash of the camera is too bright, and when we move the camera close to the mouth it will oversaturate the area and the resulting image will be bleached out. However, a third party camera app has a feature called ‘the torch mode’ (e.g. Camera360 Ultimate, China), which can keep the flashlight turned on during the initial focus and will not change until the capturing is finished. Using this mode, we were able to obtain high quality photos with proper focus and illumination. This is likely due to the ability of the mobile phone computer to analyse the over-exposed areas and adjust its exposure values appropriately.

The smartphone camera used in this study produces images of 10 megapixels, and is considered adequate for producing good-quality images. However, in some cases there was concern about the loss of detailed diagnostic information due to the poor quality of the images. Because graders sometimes found difficulty identifying caries spots and differentiating them from darkened defects or artefacts, some teeth were graded as unrated or not shown by teledental graders. Depending on the

\[
\begin{array}{|c|c|c|}
\hline
\text{Participant} & \text{Age (in years)} & \text{Sex} & \text{Indigenous status} \\
\hline
1 & 33 & Male & None \\
2 & 61 & Male & None \\
3 & 53 & Male & None \\
4 & 22 & Male & None \\
5 & 47 & Female & Yes \\
6 & 22 & Male & None \\
\hline
\end{array}
\]

\[
\begin{array}{|c|c|c|c|}
\hline
\text{Comparison of oral health assessments} & \text{Sensitivity (%)} & \text{Specificity (%)} & \text{Kappa} \\
\hline
\text{Gold standard vs teledental} & 57% & 100% & 0.70 \\
\text{1st grader vs 2nd grader} & 60% & 99% & 0.62 \\
\hline
\end{array}
\]

Calculation of sensitivity and specificity of teledental screening was based on the presence or absence of untreated caries. Kappa value refers to the level of inter-grader agreement between the first and second teledental graders of photographic assessment and between two modalities of oral assessment (gold standard versus teledentistry).
lighting, identifying amalgams or composites was also a challenge. Although training teledental assistants to obtain good quality oral images did not take much time, adherence to the given photography protocol was a challenge especially in the situation where patients are uncooperative or stressed, such as preschool children. In this trial, the sensitivity of the teledentistry examination was 57%, and specificity was 100%. The sensitivity value of 59% was because missing and filled teeth were not included in the analysis, as they can be easily recognized on digital images. In addition, sub-optimal sensitivity and specificity ratings are often associated with poor quality images which are likely attributed to the method, limitations of digital image acquisition (e.g. lighting, autofocus) or non-optimal image review modalities (e.g. monitors).51

The shortcomings of current policy that govern telemedicine services have been a matter of concern for many practitioners.22 Lack of remuneration, licensure and taxation guidelines as well as medico-legal and copyright issues have created a barrier to the adoption of teledentistry in practice.22 Well-defined and efficient policies and laws are essential to regulate teledentistry practice and expand the use of technology in clinical practice. Despite teledentistry being applicable in both public and private dental settings, barriers impeding the integration of teledentistry technology into dental practice exist. The increasing costs of setting up teledentistry equipment were regarded by many advocates of teledentistry as a major obstacle.22 However, almost all dental practices possess introral cameras, digital radiographs, computers and internet access, which provide the core infrastructure for teledentistry practice.22 The use of available infrastructure can reduce overall practice expenses and consultation fees. Integration of teledentistry into practice has the potential to address certain aspects of routine dental practice such as reducing consultation times and practice expenses, as well as improving practice management, referrals and patient satisfaction.24 Further well-designed efficacy and cost-effectiveness trials in rural or remote communities are needed to determine whether specific populations may benefit from the use of teledentistry.

Conclusion
In order to improve oral health for the underserved or people living in rural and remote areas we need robust and readily deployable screening tools. Simple teledentistry applications hold considerable promise in bridging the gap in oral healthcare for the remote or rural communities. This trial shows that teledental screening has the potential to be utilized as a valid and reliable screening tool to identify high-risk individuals with decay and can allow on-site practitioners to triage referrals in a timely manner and treat more patients. However, this study was only a proof-of-concept trial and a full study is needed to confirm the accuracy and reliability of the teledentistry system.

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We thank Professor Stuart Hunt from the school of Anatomy and Human Biology, UWA, for his help in drafting and editing the manuscript. We also thank the Dental School at the James Cook University and in particular Andrew Lion, Olivia Hasleton, Abhayat Dhillon and Sacri Harr for their contributions in this trial.

Declaration of Conflicting Interests
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References
Appendix P

Publication Arising from Chapter 6

Original Research
Comparison of a Smartphone-Based Photographic Method with Face-to-Face Caries Assessment: A Mobile Teledentistry Model

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Abstract
Objectives: This study sought to evaluate the efficacy of a mobile teledentistry approach using a smartphone camera for remote screening of dental caries. Materials and Methods: An image acquisition Android App was created to facilitate the acquisition and transmission of dental images to a store-and-forward based teledentistry server. One hundred participants who were attending routine checkups at dental clinics were enrolled in 2011. Following a face-to-face oral screening by a screener (dentist), images of patients’ teeth were obtained using a smartphone camera. These images, along with patient identification, were then transmitted from the Android App to the server through the Internet for later independent assessment by two charters (off-site dentists). The assessments of these charters were then compared to the benchmark face-to-face caries assessment. Results: Sensitivity values for the photographic method when compared to the benchmark face-to-face caries assessment were moderate, and ranged from 60% to 63%. Weighted kappa (κ) as a measure of intragrade agreement for the photographic assessment was estimated as almost perfect (κ = 0.84). The intergrade agreement for the photographic method compared to the face-to-face caries assessment ranged from moderate to substantial (κ = 0.54–0.66). Conclusions: Despite some limitations, the mobile teledentistry approach has shown the potential to detect occlusal caries from photographs taken by a smartphone camera with an acceptable diagnostic performance compared to traditional face-to-face screening. This study suggests that teledentistry and cellular phone technology can be combined to create an inexpensive and reliable screening tool.

Keywords: caries, dental photography, dental screening, smartphone, teledentistry

Introduction
Caries (tooth decay) is the second most costly diet-related chronic disease in Australia, behind coronary artery disease and diabetes mellitus.1 Rural or remote populations often have poorer oral health than other groups, primarily due to geographical remoteness and the uneven distribution of the dental workforce.2 Caries is often not a self-limiting disease, but its impact can be prevented or reduced through regular dental screening, access to fluoridated water, and oral health promotion.1 A shift from a “treatment” to “prevention” is the key to reducing or preventing dental caries among a population. Reaching rural/remote populations to assess their oral health status is challenging, as this necessitates lengthy travel, time, and funding. Although unaided face-to-face screening has remained the gold standard approach to routine oral examination, this method is inappropriate in large epidemiological surveys as it requires substantial economic and human resources. Searching for an inexpensive and valid alternative that can expedite diagnosis of oral diseases among rural populations, while maintaining a good level of diagnostic accuracy, is essential.

One of the potentially viable solutions to address geographical hurdles and the unavailability of dentists, is mobile teledentistry.3 Mobile teledentistry is a subset of teledentistry that incorporates cellular phone technology and store-and-forward teledentistry into oral care services. Almost all smartphones have a built-in camera and mobile connectivity and are readily accessible at a low cost. These technologies can be combined to create an effective teledentistry screening alternative. Despite dental photography becoming an integral part of daily dental practice, it has rarely been used as means of diagnosis, consultation, or referral in routine practice. Recent evidence indicates that the diagnostic performance of photographic methods in the detection of oral diseases is comparable to the traditional visual approach.4, 5 A flash-equipped digital single-lens reflex (DSLR) camera can produce high-quality images even in low illumination setting. However, its relatively high cost, large size.

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weight, and complexity makes it difficult to use. In contrast, camera-equipped smartphones are readily available, affordable, portable, easy to handle, and can produce good-quality images. The power of cellular technology enables their usage in various tasks such as processing, storing, and subsequent sharing of images. Their introduction into other health disciplines, in particular, tele-audiology and teledermatology, has been shown to be beneficial. A number of telendiety studies have been conducted using DSLR or infrared cameras to evaluate the accuracy and reliability of photographic methods in oral screening. However, evidence on the use of smartphone cameras in epidemiological dental research is rare. As an initial phase, a validation study was conducted to establish and test a robust store-and-forward teledentistry system and smartphone app for use in remote dental screening. In view of the limitations of a face-to-face screening approach and toward finding a valid and inexpensive screening solution, the purpose of this study was to evaluate the efficacy of a mobile teledentistry approach in remote screening for dental caries.

Materials and Methods

STUDY SAMPLE

Adults or parents/guardians of children visiting the dental clinic were invited to participate in dental screening, including obtaining photographs from their mouth. Information sheets and consent forms were provided to participants. This trial is an observational cross-sectional study carried out in a dental clinic in 2014, where a sample of one hundred (n = 100) participants was recruited. The inclusion criteria for the participation were patients of any age, attending a routine checkup, and providing informed consent. All captured photographs were anonymous and only showed the participant’s dentition. The research was completed under ethics approval from the Human Research Ethics Committee, the University of Western Australia (Ref No. RA/4/1/66447).

ARCHITECTURE OF THE MOBILE TELEDENTISTRY SYSTEM

A store-and-forward teledentistry server, “Remote-i,” was developed to facilitate the storage, retrieval, and management of the database. The Remote-i allows the transmission and storage of photographs online, from either a smartphone or computer through the Internet. Users can access the database from any mobile/desktop Web browser using individual user IDs and passwords. An image acquisition Android app was also created to operate the existing default camera on a Motorola MotoG smartphone. The new Android app enabled patient information to be entered, dental photographs to be captured, and then allowed subsequent transmission of these records to the server, using Wi-Fi or mobile data networks.

SCREENING (VISUAL AND PHOTOGRAPHIC) PROCEDURES

Using the screening protocol used in our previous trial, the unaided face-to-face oral screenings (without radiography) of all the participants were carried out by a registered dentist to screen for caries visually. This assessment was used as the benchmark standard. The face-to-face assessment scores were recorded on an oral screening form that followed the guidelines for oral health surveys developed by the World Health Organization (WHO), a treatment plan or referral was provided where necessary. In a separate subsequent visit, a trained teledentist assistant (dental student or dental assistant) took photographs of each participant’s mouth using a smartphone camera (Fig. 1). The teledentist assistants were provided with a photography protocol and received hands-on training on how to capture good images. They also had the opportunity to practice using a smartphone camera on volunteers. Only the room lighting and built-in flash of the smartphone camera were used during the photography. Neither cheek retractors nor intraoral mirrors were used for the dental photography. A minimum of five dental images per patient were taken, front, right lateral, left lateral, upper occlusal, and lower occlusal views (Fig. 2). Following the completion of photography and creating a record on the Android app, each participant’s set of data was then directly transmitted from the Android app to the Remote-i server through the Internet, for later evaluation by an off-site dentist (chart).

OUTCOME ASSESSMENT

The charting of the photographs was conducted independently by two dentists (charters) using a separate image-viewing app built upon the Remote-i system. Dental photographs were charted without any knowledge of the results of the benchmark standard. Both charters received instructions on how to use

Fig. 1 Illustration showing the relationship between a smartphone camera and the mouth during the dental photography.
SMARTPHONE-BASED PHOTOGRAPHIC ASSESSMENT OF CARIES

Fig. 2. Examples of smartphone camera shots showing five dental views. (a) Front view; (b) upper occlusal view; (c) lower occlusal view; (d) left lateral view; and (e) right lateral view.

the database, review photographs, insert findings, and submit their reports into the system. Charters accessed the database using user IDs and passwords. After selecting a record, each charter reviewed images and commented on the dentition status for each tooth on a predefined assessment chart. The external reviewers (screeners/charter) also had access to other personal information about the participants such as date of birth, gender, and postcode, as well as Indigenous status. These independent assessments by charters formulated the database, which was compared to the benchmark face-to-face chart assessments. Caries assessment was completed at tooth level based on a protocol developed by the WIH. This protocol has the advantage that it has been designed to be simple and easy to use in large-scale oral health surveys. At the screening level, the difficulty of detecting these carious lesions in photographs, filled and missing teeth were also excluded from the analysis. The sample size calculation was based on a two-sided 95% CI (confidence interval) for a single proportion using the Z-test approximation, an effect size of 0.1 and an expected observed proportion of 0.9. The number of participants with caries that met a power of 0.8 was estimated to be 35 \[ n \geq \frac{Z^2(1-p)\cdot p}{p^2} \] . With the prevalence of caries at 35% (1.16 x 35 = 65), 65 participants would be needed. So a sample of 100 participants was recruited.

Results

The demographic characteristics of the sample are presented in Table 1. Approximately, 500 dental photographs...
(5 photographs per subject) were obtained from the participants using the smartphone’s camera. Of 3,200 teeth scored, the percentage of untreated (not amenable to be scored) teeth was 8% (266 teeth) for chart 1 and 19% (596 teeth) for chart 2. Sensitivity and specificity values for the photographic method compared to the benchmark face-to-face caries assessment ranged from 60% to 63% and from 96% to 99%, respectively. The sensitivity value for the photographic caries assessment (chart 1 vs. chart 2) was 85%. Weighted kappa as a measure of intragrader agreement for the photographic assessments was almost perfect ($K=0.84$). The intergrader agreement between the two methods of screening (photographic vs. face-to-face) ranged from moderate to substantial ($K=0.54–0.66$). The level of intergrader agreement between chart 1 and chart 2 was substantial ($K=0.68$). The diagnostic accuracy measures and level of agreements for both photographic and face-to-face screening methods are presented in Table 2.

**Discussion**

This study shows that the combination of store-and-forward teledentistry and inexpensive smartphone camera use, offers a valid and reliable means of remote screening for dental caries. Despite the scarcity of research evidence on the use of a smartphone camera in dental screening, the present findings strengthened our previous reports that the mobile teledentistry approach has the potential to detect caries from a photograph taken by a smartphone camera with an acceptable “moderate” diagnostic validity and reliability. It is acknowledged that neither the photographic method nor a standard face-to-face screening approach can detect interproximal or preavitated carious lesions without radiography examination and the failure to use radiography could result in underestimation of caries occurrence. Therefore, at the screening level, the focus of this study was on the evaluation of efficacy of a mobile teledentistry approach for dental screening, not for the clinical estimation of caries prevalence.

Our findings showed a moderate level of concordance between the two screening approaches (photographic vs. face-to-face) and the two dentist charts, it is well-known that different dentists can reach different diagnostic outcomes. The moderate level of concordance ($K=0.64$) between the two charts was most likely due to the difference in clinical experience and training. Although both charts had a lower level of intergrader agreement relative to the benchmark face-to-face screening, the intergrader agreement for the photographic assessment was quite high, suggesting that the charts were uniform in the charting and the way they detected caries from the photographs.

Despite "unaided" face-to-face oral examination being the primary method used to assess oral health status, previous research has shown that this technique is not accurate, with a sensitivity of less than 51%. Our results indicate that photographic caries assessment maintained a relatively moderate level of sensitivity and a very high specificity, comparable to that of face-to-face caries assessment. The specificity values were higher than sensitivity values across the two charts and the two screening approaches. The higher value for the specificity could be attributed to the inability of the charts to see some carious lesions on a photograph compared to the benchmark face-to-face assessment. The sensitivity of the photographic method (chart 1 vs. chart 2) met the WHO’s reference standard of 0.85–0.90. In contrast, the sensitivity score for the
photographic method (60–69%) compared to the benchmark face-to-face assessment were lower than the WHO’s reference standard. The lower value of the sensitivity is likely to be because filled and missing teeth were not included in the analysis. Missing teeth and restorations/ Fillings are more likely to be detected on a photograph.1,4 Chapter 1 had a slightly higher level of concordance and sensitivity relative to chapter 2. This is probably explained by the potential of chapter 1 to identify carious lesions on the photographs more than the other chapter or when uncertain by rating a tooth with suspected lesion as having cavities.

Our previous research,5,6 demonstrated that some photographs taken by smartphone were of low quality; we attributed this to a failure to comply with the photography protocol or due to the presence of saliva, blood, or debris. For the purpose of facilitating the charting process, both charters were asked to score any tooth not amenable to be scored as "unscored.” The difficulty in detecting carious lesions on the photographs and distinguishing them from artifacts could justify why charters scored some teeth as "unscored.” Such drawbacks could contribute to the suboptimal sensitivity and specificity. This is consistent with previous research that reported variations in the inter-rater reliability in caries detection, mainly in the posterior teeth, attributed to failure in morphology or staining.5,6,20 It is well known that assessment of caries from photographs has a shortcoming in that a photograph can only provide a two-dimensional view, which prevents observing all tooth surfaces, particularly the interproximal surfaces of posterior teeth (molars).6,24 The photographic method is also known to have limitations for the detection of caries on root surfaces (unless they are exposed through gingival recession) or unerupted secondary caries. The two-dimensional view allows detection of carious lesions mostly on the occlusal surfaces, buccal and lingual surfaces, of the teeth. The teledentistry approach to dental screening (incomplete oral examination) used within the framework of this limitation, offers a reliable means of screening.20,21 This method can be effective when a shortened arch with a reduced number of surfaces of limited visibility is present, such as in children.

From a practical point of view, it seems reasonable to take advantage of the advances in information and communication technology and increasingly widespread global connectivity to utilize potential cost-saving solutions such as smartphone use to make oral care services more accessible. Until recently, the use of the smartphone in teledentistry was not well received because of the low quality of the built-in cameras, limited storage space, and unsuccessful data transmission.18 With many people now possessing smartphones, their use in routine dental services is projected to increase due to their inherent digital imaging capabilities, computational power, and sharing ability as well as access to low-cost, secure cloud storage.

Due to the shortage of dentists practicing in rural communities, residents in these regions may seek dental care from general medical practitioners (GPs) or emergency departments. This can result in underreferral or unselective referral of patients who need a specialist consultation, increasing the burden on rural populations through additional travel and increased waiting times. The mobile teledentistry approach to dental screening holds great promise for rural or remote communities where dental care services are limited. At the screening level, GPs, nurses, or even nonlicensed health professionals such as teachers or caregivers can obtain digital data (dental photos) for later evaluation by a dentist at a distance.22-24 A dental expert accessing the database from the desktop can access the records and determine whether cases need a referral or can be delayed. This approach provides a way to identify those for whom referral is unnecessary or prioritizing those requiring an urgent assessment by a dental specialist. This has the potential to reduce inappropriate referrals and prioritize patient assessment, thus avoiding unnecessary travel and reducing waiting times.20-23

Conclusion

Despite some limitations, this study suggests that the mobile teledentistry approach has the potential to detect occlusal caries from photographs taken by a smartphone camera with an acceptable diagnostic level. To improve the oral health of a population, ongoing monitoring of oral health status, using valid and inexpensive screening tools, is necessary. In light of the limitations of the face-to-face dental screening approach in large epidemiological studies, it is possible that a mobile teledentistry approach can offer a potential cost-saving alternative to address the problems of care access and the rising costs of dental care. Further well-designed research is required to address the existing limitations and improve the diagnostic performance of the teledentistry approach.

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Authors’ Contributions

M.E., the main author, contributed to conception, design, data acquisition, analysis, and interpretation, drafted, and critically revised the article; M.L. and E.K., contributed to design, data analysis, and critically revised the article; Y.K., contributed to development of the telemedicine system and critically reviewed the article; B.H.J., contributed to data acquisition and critically reviewed the article; J.S., contributed to data acquisition and critically revised the article. All authors gave final approval and agree to be accountable for all aspects of the work.

Disclosure Statement

No competing financial interests exist.

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Appendix Q

Publication Arising from Chapter 7

The efficacy of remote screening for dental caries by mid-level dental providers using a mobile teledentistry model


Abstract – Objectives: This study aimed to determine whether intraoral photographic assessment by mid-level dental providers (MLDPs) offers a valid and reliable means of dental caries screening. Methods: A mobile teledentistry model was developed to facilitate the acquisition of dental images, and transmission and reviewing of data. One hundred regularly attending patients at a dental clinic participated in the study: Following an on-site clinical examination by a senior dentist, photographs of participants’ teeth were taken by a teledentist assistant, using a smartphone camera. These intraoral photographs were directly uploaded from an Android App to a cloud-based server, ‘Remoce’, using an encrypted store-and-forward telemedicine technology. The photographic assessment carried out by two independent screeners (MLDPs), was compared to the visual oral examination scores of a benchmark examiner. Results: The sensitivity and specificity values for the photographic assessment method (assessed by screeners) as compared to the direct visual examination ranged from 60% to 68%, and 97% to 98%, respectively. The intra-rater reliability for the photographic assessment was almost perfect, with a kappa score of 0.89. The inter-rater reliability between the photographic and visual oral assessments ranged from moderate to substantial agreement, with kappa scores ranging from 0.57 to 0.61. Conclusion: A new smartphone-based mobile teledentistry model used by mid-level dental providers shows potential for remote screening of dental caries.

Key words: caries; digital imaging; mid-level dental providers; remote screening; smartphone; teledentistry

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Dental caries is the most prevalent disease of childhood, being five times more common than asthma. Compared to other chronic diseases, regular screening and early detection are more likely to prevent or halt the progress of many oral diseases. Mid-level dental providers (MLDPs), such as dental therapists, perform a range of clinical tasks, including screening and provision of routine dental care, in many countries, including Canada, the United States, the United Kingdom, the Netherlands, and New Zealand. Several studies have been undertaken to assess the efficacy of screening for oral diseases by different members of the dental team, and indicated that screenings by MLDPs are nearly the same as those of a clinical dentist. Substantial evidence indicates that MLDPs can provide quality, safe and effective dental care at low cost. The use of MLDPs to screen for oral diseases among the asymptomatic population has the potential to free up considerable economic and human resources.

Although clinical oral examination is regarded as the most accurate method for correct diagnosis, intra-oral photographic assessment has a good level of sensitivity and specificity for visual detection of
caries. As digital imaging becomes the cornerstone of teledentistry practice, image acquisition methods, information quality, and connectivity become essential factors in the success of a teledentistry service. There is no doubt that the digital single-lens reflex (DSLR) camera is a better device in terms of flash units, illumination, and quality of images as it can produce sharp pictures, even in low-light situations, or at high magnification. However, its relatively large size and weight make it less convenient to use. DSLR cameras also require a special flash setup for optimal intraoral illumination. DSLR cameras may not be readily accessible to rural dental providers. In contrast, the smartphone camera is readily accessible, lightweight, very easy to use, and provides satisfactory images with minimal training. The inherent inbuilt connectivity of smartphone devices simplifies the processing, storage, and transmission of images, and they have been shown to be effective in teledentistry and particularly in teleo-Dentistry. It is predicted that, as the smartphone technology continues to advance, the image quality and technical challenges will be fixed in the near future.

The utilization of teledentistry technology for telediagnosis of dental caries has had growing acceptance in recent years. More recently, mobile teledentistry, which is considered to be a subset of teledentistry, has also shown potential to serve as a valid and reliable tool in the screening for caries. However, the body of literature on mobile health applications in dentistry is limited to small clinical trials or pilot studies. This poses a difficulty in drawing conclusions about the use of a smartphone in remote screening for dental caries. Our initial development efforts have been aimed at finding an efficient and cost-effective caries screening solution using the digital imaging capabilities, mobile connectivity, and computational power of a camera-enabled smartphone to capture high-resolution digital images and perform subsequent image transmission to a cloud server for evaluation by a remote dentist. The current study aims to evaluate the use of MLDPs in the remote screening for dental caries, utilizing an inexpensive smartphone camera, and store-and-forward teledentistry technology.

Materials and methods

Study population

This is a cross-sectional study that examined a convenience sample of 100 participants of different ages in 2014. Prior to the start of the study, information sheets and consent forms were provided to adult participants and the parents or guardians of children who visited the dental clinic, inviting them to participate in a dental screening, including photographing the teeth, that would happen on the next appointed day in the dental clinic. Only adult participants and children whose parents/guardians gave informed consent were included in the study. Photographs showed only the teeth and gums, and individuals were thus not easily identifiable. All data collection was completed under ethics approval from the Human Research Ethics Committees of the University of Western Australia and James Cook University.

System and acquisition method

A telemedicine system, Remote-i, based on store-and-forward technology, was developed to serve as a platform for data storage and management. The Remote-i is a comprehensive data management system that is capable of image acquisition, data entry, storage and retrieval of patient health information. It also enables uploading and storing images online, either directly from a smartphone or from a PC. Users can log in to the Remote-i database via a secure web interface from any mobile phone or desktop computer using individual user IDs and passwords. An Image acquisition App was developed to invoke the existing camera App on the Android-based Motorola MotoG smartphone (USA). This App was used to enter patient data and capture dental photographs, and then upload the data corresponding to each patient to the Remote-i server, using Wi-Fi hotspots or mobile data networks (Fig. 1).

Examination procedures

Following the protocol used in a previous pilot study, each participant received a visual oral examination to record caries and existing restorations, according to the WHO protocol and treatment recommendations and referral were provided if necessary. This examination was used as the benchmark assessment. The onsite dentist had only 15 min per patient to complete the examination, and no radiographs were used to detect caries. In a separate room, a dental student with basic training in the use of the smartphone took photographs of each participant's oral cavity (using a smartphone camera). Five intraoral photographs per patient were obtained (anterior, right lateral, left lateral, upper occlusal, and lower
eccuutal views) (Fig. 2). Besides the room LED lighting, the built-in flash of the smartphone camera App was used during the dental photography. The smartphone camera flash was set up with 'Torch mode', which can keep the flashlight turned on during the initial focus and remain until the capturing is completed. The dental student was given a dental imaging protocol and had the opportunity to practice using the smartphone camera on adult volunteers for as long as it took to feel comfortable (Fig. 3). It is estimated that the total training took about 20 min. Records were then directly transmitted as encrypted data from the Android App to the Remote-i, for later scoring by screeners (MLDPs). The record for each participant was assigned a numeric code that was linked to the original Benchmarck charting.

Outcome measure

Doing analysis based on the International Caries Detection and Assessment System (ICDAS-II) (which is based on tooth surface) was not feasible because photographs only provide one-dimensional views. Also, to perform a comparison between visual oral examination and photographic screening, the entire tooth, rather than tooth surface, was used as a unit of analysis. At the screening level, we used a method developed by the WHO based on tooth-by-tooth assessment, which is simple and easy to use in the field in large epidemiologic surveys. The dental images were reviewed independently, by two Australian registered MLDPs who each had more than 10 experience, using a web-based data and image-viewing App built upon the Remote-i system. In this trial, the screeners were provided with written and oral instructions on how to securely access the database to review oral images and record findings. After selecting a record, a predefined dental chart appears, and the reviewers were able to insert their comments. This chart included an oral health assessment form based on the WHO protocol. Both screeners reviewed the introral photographs independently and recorded the status for each tooth on their assessment forms. These independent assessments formed the base of the data used to compare with the benchmark examiner assessment and between the screeners. After completing the scoring, the screeners submitted their report and recommendations to the Remote-i server. For clarity, the term examination (with substantial differences in the definitions of the word
Statistical analysis

version 17.0 (IBM Company, Chicago, IL, USA) was used to compute kappa statistics as a measure to test the inter-rater and intra-rater reliability of the visual examination and the photographic assessments, using the Landis and Koch measurement of rater agreement for categorical data. To test the intra-rater agreement between the two screeners, 15% of the records were scored again, at least, 4 weeks after the initial scoring of the photographs. The sensitivity, specificity, accuracy, positive predictive value (PPV), and negative predictive value (NPV) of the photographic method for each screener were calculated. For this analysis, teeth were classified as either sound or carious. All teeth having arrested caries, caries into dentine or enamel level caries, were scored as carious. Because of difficulties to detect root caries from photographs, root caries was excluded. Filled and missing teeth were excluded from the analysis. Using the sample size methods devised by Brocklehurst et al. based on a two-sided 95% confidence interval for a single proportion (sensitivity or specificity) using the Z-test approximation, an effect size of 0.1 and expected observed proportion of 0.90, the number of cases with dental caries that would satisfy a power of 0.8 was calculated to be 35 \[ n = \frac{Z^2 \times p(1 - p)}{d^2} \] With a dental caries prevalence of 35%, 65 caries-free participants were
required \((1.86 \times 35 = 65)\), so the total sample size of 100 was considered appropriate for this study.

**Results**

The demographic characteristics of the participants are summarised in Table 1. The quality of images obtained by the teledental assistants (dental students) was evaluated by an independent reviewer to ensure that the images were complete, color-balanced, focused, and clear. A complete set of 500 oral images (five images per subject) were obtained from the 100 participants using the smartphone camera and uploading the images to the RemoteHealth server. Ninety-four percent of the captured digital images were gradable. Of 3200 teeth reviewed, the proportions of teeth that were not amenable to be scored were 11% (445 teeth) for screener 1 and 15.4% (405 teeth) for screener 2. Across all assessment methods, the specificity was higher than sensitivity, ranging from 97% to 98% with the sensitivity ranging from 60% to 68%. The inter-rater reliability between the visual oral examination and photographic screening, and the two screeners (MLDPs) was calculated as a moderate-to-substantial agreement, with a kappa score ranging from 0.57 to 0.61. The intra-rater reliability for the photographic assessment was estimated as almost perfect, with a kappa score of 0.89. The accuracy and reliability measures for both visual and photographic assessments are presented in Table 2.

**Discussion**

There is no photography-based method that can detect pre-cavitated carious lesions. It is acknowledged that the screening was not a complete oral examination, and the failure to use radiography may underestimate caries diagnosis and prevalence. The purpose of this study, however, was to evaluate the applicability of using MLDPs and mobile teledentistry in the screening for dental caries. Our study suggested that the use of MLDPs offers a valid and reliable means for the remote screening for caries, using an inexpensive smartphone camera. This reflects recent research that examines the mobile teledentistry approach for the screening for dental caries by dental hygienists. Daniel and colleagues suggested that a dental hygienist’s clinical findings related to dental caries are comparable to those of the dentist. Our results are also consistent with previous research showing that photographic assessment using a DSLR camera and intraoral camera offers a valid and reliable way of remote screening for dental caries. The findings demonstrated a good level of concordance between the two assessment modalities (visual and photographic) and the two screeners. Although both screeners had a marginally lower level of agreement in comparison with the benchmark standard, the intra-rater reliability for the photographic assessment was also high, suggesting that the screeners were consistent in the scoring and the way they identified caries from the photographs.

The specificity scores were higher than the sensitivity scores across all screeners and assessment methods. In contrast, the sensitivity scores were lower than the WHO’s reference standard of 0.85–0.90. The higher value for the specificity could be explained by the inability of screeners to detect

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<td>98</td>
<td>96</td>
<td>97</td>
<td>0.61 (0.52–0.70)</td>
</tr>
<tr>
<td>Screener 1 versus Screener 2</td>
<td>68</td>
<td>97</td>
<td>97</td>
<td>98</td>
<td>0.61 (0.52–0.70)</td>
</tr>
</tbody>
</table>

PPV, Positive predictive value; NPP, negative predictive value. Benchmark refers to the visual oral examination scores of a benchmark examiner.
some carious lesions on a photograph compared to the visual oral examination. The lower value of the sensitivity is likely because filled and missing teeth were not included in the analysis. They can be easily identified on a photograph\(^{56}\). Screener 1 had a marginally higher sensitivity score and appeared to have a lower threshold for identifying lesions as carious on the photographs compared to screener 2. There was a moderate agreement (k = 0.61) between the two screeners. This could be attributed to the difference in the clinical experience and training between the two screeners. Screener 1 was more experienced, and therefore she/he was used as a reference standard when compared to screener 2.

Previous research indicated that the inter-rater reliability in detecting caries is low, particularly in the posterior teeth\(^{57-59}\). When a pilot study was conducted prior to the current study\(^{39}\), we have observed that some photographs had a poor quality, and to facilitate scoring of photographs by the screeners, they were advised to record any tooth not amenable to be scored as “unreadable”. In some cases, there was the potential for loss of detailed diagnostic information due to image quality, or the presence of saliva, blood, or debris, particularly for the posterior permanent teeth. At the screening level, it was not possible to remove stains or plaques, as the onsite dentist (visual examination) had only 15 min to screen a patient. The difficulty in detecting caries and differentiation from staining or dark artifacts could explain why up to 15% of the screened teeth were not amenable to be scored. This uncertainty could contribute to the suboptimal sensitivity and specificity, particularly for the posterior permanent teeth. Although the dental students received training to produce good-quality oral images, adherence to the photography protocol provided was difficult to achieve, especially where patients were uncooperative or stressed, such as preschool children.

Despite ongoing opposition from some sectors of the profession, recent evidence from the Alaska workforce model has proven that deploying MLDPs to provide essential dental care to remote Alaskan communities has the potential to address the unmet needs of underserved populations\(^{59}\). Australia has one of the healthiest populations in the world. As a result (unlike a few decades ago), many patients who attend for routine dental checkups will not have a disease. However, this is not the case for rural or underserved populations who often have the majority of oral diseases. MLDPs would be able to perform screening and treat simple cases, while only urgent or complicated cases are referred to dentists. MLDPs with limited training using mobile teledentistry can offer a practical and potential cost-saving means to screen for oral diseases among a population with high levels of need who have no access to care.

Mobile teledentistry has great potential to address oral health needs, particularly in rural settings and among underserved populations. It is intended to expedite early detection of oral diseases, identify high-risk groups, and provide a treatment pathway for those who require urgent intervention. It has implications for improving the quality of care by facilitating the provision of timely information to dentists for better decision-making, effectively triage patients, and reduces inappropriate referrals, thus reducing waiting lists and support locally based oral treatment where possible. It also has implications for providing consultation and guidance to local dental practitioners, thereby reducing their isolation and increase the capacity of the dental workforce in areas that are too isolated to attract dentists. In addition, nurses or non-licensed health professionals, such as teachers, can obtain clinical data (intraoral photographs or radiographs), store-and-forward to offsite dentists for review, diagnosis, and treatment planning. Therefore, this strategy has the potential to save significant economic and human resources, and contribute to reducing disparities in oral health between rural and metropolitan populations.

**Conclusion**

The main findings of this study suggest that visual and photographic assessments are comparable in the detection of dental caries. Dental providers with minimal training have the potential to detect dental caries from remotely sourced oral photographic records. Development of a method to reduce the time taken in dental photography, and to simplify transmission, processing, and reviewing of dental images that would also provide the comparable screening level to visual oral examination, would increase the adoption and acceptance of the mobile teledentistry model. This strategy has implications for supporting the use of MLDPs to perform screening for oral diseases and increasing the capacity to care for those who have limited or no access to care.
Acknowledgements
We would like to acknowledge the kind assistance of Clinical Associate Professor John Winters from the Princess Margaret Hospital and Professor Stuart Rust from the University of Western Australia for their contributions in this trial. We gratefully acknowledge the invaluable assistance of Dr. Christopher Pantin, Mrs. Debbie Williams, and Ms. Jennifer Bywaters from Absolute Dental for their efforts in data collection. We would like to thank Di Xiao and Jianzhun Vignarajah from the CSIRO Australia for their technical support. Thanks also to dental students (Andrew Liu, Olivia Housin, and Ahlayeji Dhillon) at the dental school, James Cook University, for their efforts in collecting data.

References
Appendix R

Publication Arising from Chapter 8

Validity and reliability of remote dental screening by different oral health professionals using a store-and-forward telehealth model

M. Estai, J. Winters, V. Kanagasigam, J. Shikha, H. Checker, E. Kruger and M. Tennant

Objectives This study was conducted to evaluate the validity and reliability of intraoral photographic assessments by different members of a dental team as a means for dental screening in children. Methods The intraoral photographic records of 126 children (2 to 18 years old) were obtained from routine clinical records taken before dental treatment. Intraoral photographs were obtained using a DSLR camera and then uploaded to a cloud-based server using store-and-forward telehealth technology. Images were reviewed by an expert panel to formulate a benchmark screening baseline, to which the screeners' data were compared. The photographic assessments conducted by a mid-level dental practitioner (MLDP) and dentist, were compared to the benchmark expert panel assessment. Results The screeners' assessments by means of intraoral photography, when compared to the expert panel assessment, had a sensitivity value of 82-89% and specificity value of 97%. The inter-examiner agreement between the expert panel assessment and photographic method (assessed by a dentist and MLDP), was almost perfect, with a kappa score ranging from 0.82 to 0.88. The mean DIT/diff score for the children as determined by the expert panel's review and photographic assessment ranging from 5-41 to 5.79, with mean scores between the two assessment methods not significantly different (P = 0.746). Conclusion Our results suggested that oral health professionals (other than dentists) have the potential to screen for caries from intraoral photographs with the same diagnostic accuracy and reliability as dentists. This strategy has implications for supporting the use of MLDPs such as dental therapists or hygienists to screen for oral disease using telehealth.

Introduction

Most dental care services in developed countries are funded privately, with much of it received on a fee-for-service basis. This is coupled with limited dental insurance and a tendency for the uninsured to be those who are undertreated and also experience the majority of the dental diseases. Australia, for example, has one of the healthiest populations in the world but significant healthcare inequalities still exist where patients with high needs have little access to dental care, while patients with the least needs are treated using the most expensive resources. Efficient and effective dental screening has the potential to reduce oral health inequalities and optimise the use of limited resources. Unlike many medical disorders, dental caries is relatively easy to detect in clinical settings or epidemiological studies. Early diagnosis, early intervention, and preventive treatment can prevent or reduce the progress of many dental diseases. This concept is considered the cornerstone of cost-effective delivery of dental care, with the potential to save hundreds of millions of dollars. Therefore, there is a need to shift the oral healthcare system from a care to care culture.

One of the viable solutions to address unmet oral health needs is the use of mid-level dental practitioners (MLDPs), specifically dental therapists, to screen for oral diseases and where only the more complex patients are referred to dentists, while simple cases are treated by MLDPs. Although the practices of dental therapies have been mostly limited to under-18-year-olds worldwide, dental therapists' scope of clinical practice in some places has been extended to also treat adults. Evidence suggests that dental practitioners with minimal training can successfully screen for oral diseases and perform complex dental procedures under the supervision of an off-site mentorship. A recent report on the Alaskan workforce model has provided evidence that employing MLDPs utilizing a telehealth system
has the potential to address the oral health needs of underserved populations in remote Alaska. This strategy can help in reducing the isolation of local practitioners in remote areas, and allow them to provide treatment under the guidance of a remotely-located dental expert.

The clinical oral examination has been the primary technique used for dental screening. However, this technique is inappropriate in comparative studies where dental examiners remain non-blinded to certain characteristics of participants. Also, conducting clinical examination in large epidemiological surveys is challenging, as this necessitates huge resources. Seeking approaches that can expedite early detection of dental problems, improve patient referrals and avoid treatment delay without affecting the accuracy of diagnosis is needed. The growing interest in telehealth services utilizing rapidly evolving digital imaging has provided dental providers with alternatives to traditional methods. The use of photographs in dentistry has increased rapidly over recent years and it has become an integral part of routine dental practice. Several studies have examined the use of intraoral photographs in dental epidemiology. Most studies found that telediagnosis of oral diseases based on intraoral photographs can offer a valid and reliable alternative to the traditional oral examination. Previous studies were focused on the assessment of the feasibility, validity and reliability of the photographic assessment in comparison to a visual examination as the reference standard. However, research reports on comparing the assessment of intraoral photographs by different members of the dental team are limited. Against this background, this study aimed to compare the validity and reliability of the photographic method in the screening for dental caries, between different levels of dental practitioners.

Methods

Ethical approval for this study was granted by the University of Western Australia Human Research Ethics Committee. This study was a retrospective descriptive study that examined intraoral photographic records of 126 children (2 to 18 years old), who were patients of one author (FO) between the years 2010 and 2016.

Original photograph collection

A digital single-lens reflex (DSLR) camera (Canon EOS 7D, EF 100 mm f/2.8 Macro USM Lens, Macro Ring Lite MR-14EX) was used to obtain intraoral photographs from all 126 patients undergoing dental treatment under general anesthesia. Dental photography was completed pre-operatively by a trainee specialist dental registrar (Paediatric Dentistry). A standard series of three intra-oral photographs per patient was obtained using retractors and intraoral photographic mirrors (anterior, upper occlusal and lower occlusal views), and these were uploaded to a Remote-i server at a later time (Fig. 1). The uploaded images were JPEG format to the Remote-i server.

Expert panel review

All intraoral photographs were reviewed by an expert panel to formulate a standard screening baseline, to which the examiners’ data could be compared. The panel consisted of three dental practitioners (including authors, EX and MT). A consent based on the collaborative assessment of the panel was formulated for each patient to reflect the dental status at the time the images were taken. This was at the level of screening, not a comprehensive examination. This was the benchmark against which the other examiners’ assessments were tested.

Data assessment

The evaluation of the dental photographs was carried out by two independent, off-site dental practitioners, a MLD® and an internationally-trained dentist (not registrable in the jurisdiction) using a web-based data and image-viewing app built upon the Remote-i system. The Remote-i is a comprehensive data management server that has been widely used as a telehealth platform in various screening programmes. A simple user manual and cover letter were sent to the examiners explaining the study purpose and how to use the system. The system enabled each examiner to evaluate photographs independently and input comments on the predefined oral health assessment form and submit reports or recommendations into the Remote-i server. These independent assessments by dental practitioners created the database used to compare with the benchmark panel assessment and between the scorers. We used a method developed by the WHO based on tooth-by-tooth assessment, which is simple and easy to use in large epidemiological surveys. As the photographs only provide two-dimensional views we could not use the International Caries Detection and Assessment System (ICDAS) (which is based on tooth surface) as the unit of analysis.

Statistical analysis

SPSS version 17.0 (IBM Company, Chicago) was used to compute Cohen’s kappa to test the inter-examiner reliability for the benchmark panel assessment, and the photographic assessments based on tooth-by-tooth comparisons. Fifteen percent of the intraoral photographs were re-rated to test the intra-examiner agreement, at least, four weeks after the initial scoring of the photographs. The sensitivity, specificity, accuracy, positive predictive value (PPV) and negative predictive value (NPV) of the photographic method for each examiner were calculated. For this analysis, all teeth were classified as sound or carious. Caries experience, using the DFT/dft (decay, filled teeth) index, were calculated for each case and

<p>| Table 1: Demographic characteristics of participants |</p>
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>N (%)</th>
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<tbody>
<tr>
<td><strong>Age</strong></td>
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</tr>
<tr>
<td>2-3 years</td>
<td>51 (41%)</td>
</tr>
<tr>
<td>6-7 years</td>
<td>56 (44%)</td>
</tr>
<tr>
<td>12-18 years</td>
<td>19 (15%)</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td>---</td>
</tr>
<tr>
<td>Male</td>
<td>51 (41%)</td>
</tr>
<tr>
<td>Female</td>
<td>65 (51%)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>116</td>
</tr>
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</table>
analysed through descriptive statistics. DFT/diff was used instead of DMFT/dmft, as the reasons for missing teeth (exfoliation, caries, other) could not be assessed. Statistical differences between group means were determined by one-way ANOVA. Using the sample size methods derived by Hulka et al. where the prevalence of the disease is less than 0.50. With an ideal sensitivity of 95% and a lower 95% confidence limit of 80%, the number of cases with caries required was 50. With dental caries prevalence of 40% (1.5 × 50 = 75), 75 cases are needed without caries. So the total sample size of 125 was required in this study.

Results

The demographic characteristics of the participants are summarised in Table 1. All introral photographs were gradable, however, out of 4,032 teeth reviewed, a small proportion of the individual teeth were scored as ‘unrated’ by the MDP (142 teeth, 3.5%) and dentist (75 teeth, 1.9%).

Tooth-by-tooth comparisons: The inter-examiner agreement between the benchmark panel assessment and photographic method (assessed by a dentist and MDP) was almost perfect, with the kappa score ranging from 0.82 to 0.88. The intra-examiner agreement for the photographic assessments for screeners was almost perfect, with the kappa score of 0.82. Across all the screeners and examination methods, the specificity (96% to 97%) was higher than sensitivity (81% to 89%). The level of agreement, sensitivity, specificity, accuracy, positive predictive value (PPV) and negative predictive value (NPV) for both the benchmark panel and screeners’ photographic assessments are presented in Table 2.

The mean DFT/diff score (at the screening level) for the children, as determined by the expert panel was 5.79 (4.30 ± SD), and as determined by the off-site dentist and MDP was 5.41 (3.94 ± SD) and 5.73 (4.13 ± SD), respectively. The mean DFT/diff was not significantly different between the three assessment groups (P = 0.746). Approximately 90.5% of the children were classified as having caries experience by the expert panel and 88.9% to 90.6% of the children were classified as having caries experience by the screeners (Table 3). The sample also included eight participants with genetic conditions affecting the teeth, such as dentinogenesis imperfecta and amelogenesis imperfecta. All these cases were identified by the expert panel and the screeners.

Discussion

The assessment of two screeners (dentist and MDP) was compared to the benchmark expert panel. Our results indicate that the assessment of introral photographs at a distance maintains a good level of the sensitivity and specificity. Across all examination methods and screeners, specificity values were slightly higher than the recommended threshold, falling outside of the 95% confidence interval around the WHO reference standard. In contrast, sensitivity values were slightly lower than the WHO recommended threshold, except for the dentist, whose sensitivity value was high and met the WHO’s reference standard of 0.85–0.95. The higher value for the sensitivity might be explained by the higher likelihood that the dentist scored a tooth as carious when in doubt, in order for it to be subjected to additional investigations.

Nevertheless, the MDP was not significantly different to the dentist or benchmark panel assessments. The high values of the NPV are not of concern given that the low numbers of false negatives reported by all screeners are associated with the high level of agreement across the examiners. Our findings demonstrated a substantial to almost perfect inter-examiner agreement for both screeners (dentist versus MDP) and against the benchmark expert panel. The intra-examiner reliability for the photographic assessment was also high, suggesting that screeners were consistent in the way they identify cavities from photographs. Although the MDP had a marginally lower level of agreement in comparison to the benchmark panel, the MDP had a slightly higher mean DFT/diff score compared to the dentist, suggesting that the MDP has a lower threshold of identifying lesions as carious on photographs. The results of a recent study in which introral photographs were used to screen for caries in vivo that compared photographic assessments with a visual oral examination suggests that the photographic method can be a valid and reliable way of screening for caries and can be used in large epidemiological studies with some degree of confidence. Our findings are also consistent with other studies evaluating the efficacy of dental screening by different members of the dental team in vivo, which indicated that MDPs are capable of screening for caries to a similar standard as dentists.

The quality of photographs and the capability to grade correctly are important factors when evaluating the feasibility of telediagnosis of oral diseases. The DSLR camera used in this study produces images of 18 megapixels and is considered adequate for producing

<table>
<thead>
<tr>
<th>Table 3: Proportion of children with caries-experienced and mean DFT/diff score at the level of screening</th>
</tr>
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<tbody>
<tr>
<td>Caries experience (%)</td>
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<tr>
<td>-------------------------</td>
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<tr>
<td><strong>Benchmark panel</strong></td>
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<tr>
<td>MDP</td>
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<tr>
<td>Dentist</td>
</tr>
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</table>

*The level of significance between the dentist, MDP and benchmark panel assessments is (P = 0.746).

MDP = Multidisciplinary Dental Panel

<table>
<thead>
<tr>
<th>Table 2: Accuracy and inter-examiner reliability of photographic assessment calculated on the basis of tooth-by-tooth comparisons</th>
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<tbody>
<tr>
<td>Sensitivity (%)</td>
</tr>
<tr>
<td>----------------</td>
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<tr>
<td>Benchmark panel vs MDP</td>
</tr>
<tr>
<td>Benchmark panel vs Dentist</td>
</tr>
<tr>
<td>Dentist vs MDP</td>
</tr>
</tbody>
</table>

PPV = Positive predictive value
NPV = Negative predictive value
MDP = Multidisciplinary Dental Panel

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high-quality images, even in low-light situations, or at high magnification. However, in some cases, there was uncertainty about the loss of detailed diagnostic information due to the presence of saliva, blood or debris, particularly for the posterior permanent teeth. The difficulty in detecting carious lesions and differentiating them from staining or dark artefacts could explain why some teeth were scored as "untouched" by the screeners. These limitations could contribute to the lower sensitivity in the posterior permanent teeth compared to other parts of the dentition. This reflects previous studies which have found variations in the intra-examiner reliability in detecting caries in posterior teeth largely due to the morphology of the fissures and staining.

The use of photographic methods in large-scale epidemiological studies is considered feasible. Photographic assessment utilizing stone- and forward-table health technology has been used widely to screen for diseases. The photographic method has the potential to facilitate the archiving of photographic records which can facilitate remote assessment of photographs in research studies that may require binding. This strategy also has implications for prioritizing new patient appointments, and facilitating patient referrals to a dental consultant, thus reducing waiting lists and travel, and delays in diagnosis and associated treatment. Healthcare professionals (nurse) or non-licensed healthcare professionals (teacher) could obtain intra-oral photographs from children for a later assessment by an off-site dentist. The use of dental practitioners with limited training like MOLDS can offer a practical and potential cost-saving means to screen for dental caries disease in populations. However, the population with high levels of need, who have limited access to oral care.

**Conclusion**

The sample in this study was enriched with dental caries; these sorts of cases are those that you want strong assurance will be picked up urgently in a screening programme. This study suggests that different members of the dental team, with minimal additional training, have the potential to detect caries from web-based presented photographs with a comparable diagnostic accuracy and reliability to dental experts. This approach offers the potential to free up economic and human resources as well as support the use of MOLDS to screen for oral diseases and increase the capacity to care for those who have no access to oral care because of distance or social exclusion. In the future, pattern recognition and artificial intelligence algorithms could be harnessed to detect caries from the photographs without human intervention. However, at present, this technology is still under development. Further testing of the effectiveness of different oral health professionals to screen for caries and other important oral conditions is needed.

**Acknowledgments**

We would like to thank Dr. De Zuij and Mr. Sander Hidsgaard for their valuable comments and technical support. We also thank the staff at the Dental Departement, Princess Margaret Hospital, Australia for their kind assistance. And Professor Stuart Bird from the University of Western Australia for his contributions.


Appendix S

Publication Arising from Chapter 9

End-user acceptance of a cloud-based teledentistry system and Android phone app for remote screening for oral diseases

Mohamed Estai¹, Yogesan Kanagasigam², Di Xiao³, Janardhan Vignarajan², Stuart Bunt¹, Estie Kruger¹ and Marc Tennant¹

Abstract

Objective: This study aimed to evaluate users' acceptance of a teledentistry model utilizing a smartphone camera used for dental caries screening and to identify a number of areas for improvement of the system.

Methods: A store-and-forward teledentistry platform “Remote-I” was developed to assist in the screening of oral diseases using an image acquisition Android app operated by 17 teledental assistants. A total of 465 images (five images per case) were directly transmitted from the Android app to the server. A panel of five dental practitioners (graders) assessed the images and reported their diagnosis. A user acceptance survey was sent to the graders and smartphone users following completion of the screening program.

Results: Of the 22 surveys sent out, 20 (91%) were completed. Generally, users showed optimism towards the use of the teledentistry system, and strongly positively assessed items on content and service quality. The majority of graders took less than 15 min to read the images while phone users took 5–10 min to complete the dental photography using the Android app. This study identified a number of factors that are essential for improving the current system, such as optimization of smartphone camera features, the format of the server, and the orientation of images and using oral retractors during photography.

Conclusions: Users appear to be generally satisfied with the proposed teledentistry model. However, they have specific concerns to address, many of which could be resolved through more effective training, coordination between sites and upgrading the current system.

Keywords

Attitude, dentist, dental screening, store-and-forward, smartphone, teledentistry

Date received: 8 September 2015; Date accepted: 19 November 2015

Introduction

Teledentistry, as a subspecialty of teledentistry, can be defined as “the provision of real-time and off-line dental care such as diagnosis, treatment planning, consulting and follow up via electronic transmission from different sites.”¹ (p. 399) For several decades, teledentistry has played a role in bridging gaps and overcoming barriers through spurring healthcare to previously unreachable populations.² Most teledentistry studies were at a small scale and limited to short-term outcomes,³ utilizing now superseded technologies or expensive peer-to-peer system approaches. Evidence indicates that teledentistry examinations are comparable to clinical examinations in screening for caries.⁴,⁵ However, none has demonstrated superior clinical results (i.e. validity, reliability, and effectiveness) compared to traditional settings. It is postulated that teledentistry offers a cost-effective means to help reduce some obstacles to optimal oral health, particularly for underserved populations.⁶,⁷

There are many methods for screening for oral diseases. However, the most common method is the face-to-face examination. The rapid advances in digital imaging and other technologies have provided practitioners with alternatives to traditional settings.⁸ Assessment of intra-oral photographs can maintain a good level of sensitivity and specificity of visual detection of caries.⁹ Dental photography can also be less stressful and intimidating for young children than a conventional dental examination.¹⁰

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smartphone camera technology improving significantly and widespread availability of the cellular networks, utilization of smartphone cameras in dental imaging has grown.15,16

Derived from the theory of planned behaviour (TPB), the technology acceptance model (TAM) aims to explain user acceptance and to predict the adoption of technologies.17 TAM has been widely adopted in research, due to its parsimonious nature and wealth of recent empirical support of its role in predicting the acceptance behaviour of a technology.18 TAM posits that behavioral intention is determined jointly by attitude and perceived usefulness, the latter also affects attitude directly. Meanwhile, the perceived ease of use directly influences both attitude and perceived usefulness.17 TAM works as an appropriate framework for our survey as it gives attitude a key role in predicting the potential user's behavioral intention to use a technology; a role that has been shown to be fundamental in the acceptance of telemedicine.15,16

In response to the increasing demand for oral care services, particularly in remote or rural regions, we have developed a store-and-forward teledentistry platform called "Remote-I" and a novel image acquisition Android app that can be used for screening purposes.19 The present study builds on an initial validation (proof-of-concept trial) study that tested the validity and reliability of the teledentistry approach in the screening for dental caries.19 The findings show that the proposed teledentistry model for dental screening using a smartphone camera offers a valid and reliable alternative to visual dental examination.19 Since perceived usefulness and ease of use are critical factors in the acceptance of a technology, we sought to evaluate users' acceptance of the teledentistry model and to identify the factors that contribute to the improvement of the current system.

Methods

Teledentistry system

A teledentistry system, "Remote-I," based on a store-and-forward method, was developed by the Australian E-Health Research Centre (AEHRC) to work as a platform for data storage and management.19 Remote-I is capable of image acquisition, data entry, storage and retrieval of data. An image acquisition app was built and installed on a Motorola MotoG smartphone (USA) to facilitate entering patient details and capturing dental photos, and then uploading data corresponding to each patient to Remote-I, using Wi-Fi hotspots or cellular data networks. After obtaining their informed consent, participants were enrolled in a trial to obtain oral images using smartphone cameras. Each participant received an in-person oral examination by a dentist to record caries and existing restorations, before trained teledentistry assistants took photographs from each participant’s oral cavity, using a Motorola smartphone camera. Records were then directly transmitted as encrypted data from the smartphone to the Remote-I for evaluation by a dentist at a distance. The images captured using the smartphone were deleted from the phone immediately after transmission of the images to the Remote-I system to avoid any privacy issues (Figure 1). The components of the teledentistry system are summarized in Table 1.

Participants (users)

Graders (dental practitioners). Reviewing of dental images was carried out by five independent dental practitioners using a web-based data and image-viewing app built upon the Remote-I system. Although graders did not receive any training on how to use the system, a simple user manual and cover letter were sent to graders explaining the purpose of the study and how to use the system. They were able to access the database using individual user identities (IDs) and passwords. The system enabled graders to review images and insert comments on the predefined oral assessment form and submit reports or recommendations into the Remote-I server (Figure 2).

Teledental assistants (smartphone users). Patient recruitment and dental photography were performed by 17 trained teledental assistants (dental students, dental assistants, dental practitioners) using a smartphone camera. The teledental assistants received hands-on training on how to capture good quality images using a smartphone camera. Recruitment of patients and dental photography were completed in a series of locations: a small practice, hospital, and large dental facility. Over six months, up to 100 records were uploaded to the Remote-I server; these comprised 485 images (approximately five images per case) and anonymous patient demographic data.

Questionnaire instrument

The survey questions are based on a standard, validated, and reliable instrument for end-user satisfaction modified for teledentistry.21,22 Our study has good content validity, as the survey items were vetted and revised by three dental practitioners, and the questions reflected their concerns and areas of satisfaction. The survey comprised four sections. The first section included questions about the users' demographic characteristics. The second section comprised of 11, five-point, Likert-type questionnaire (never = 1; seldom = 2; about half the time = 3; most of the time = 4; always = 5) used to assess the quality of the system which comprised five dimensions: content, format, information quality (accuracy), ease of use, service quality, and support. An additional two items were included to assess the usefulness and overall satisfaction with applications. The third section examined the average time that was spent to create a record and complete photography using the Android app and grade a record on the Remote-I server. The final section solicited free comments about whether users have suggestions to improve existing systems. Following completion of the trial, the survey was distributed by e-mail.
Figure 1. Architecture of the teledentistry system.

Table 1. The components of the teledentistry system.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
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<tbody>
<tr>
<td>Teledentistry system</td>
<td>A telemedicine platform that utilizes store-and-forward and smartphone technology to screen for oral diseases at distance.</td>
</tr>
<tr>
<td>Remote-I server</td>
<td>Cloud-based platform that enables data entry, storage, image acquisition, retrieval of large amount of data.</td>
</tr>
<tr>
<td>Android app</td>
<td>An image acquisition app “Teledent” installed on a smartphone device that enables entering patient data, taking dental images, and uploading a record to Remote-I using a 3G Internet or Wi-Fi connection.</td>
</tr>
<tr>
<td>Smartphone</td>
<td>Motorola MotoG, Android = 3.0 Lollipop.</td>
</tr>
<tr>
<td>Camera360 Ultimate</td>
<td>Third party Android camera app that is used for dental photography instead of the default Motorola camera app.</td>
</tr>
<tr>
<td>Teledental assistant</td>
<td>Obtain consent from the patient, create records, and obtain dental photographs.</td>
</tr>
<tr>
<td>Grader</td>
<td>Review and assess records stored in Remote-I.</td>
</tr>
</tbody>
</table>

with a cover letter stating the purpose of the survey. A reminder was sent to all users who did not respond to the initial correspondence. The protocol for this study was approved by the Human Research Ethics Committee of The University of Western Australia.

Results
A total of 22 requests for completion of the survey were sent to all users of either the smartphone (teledental assistant) or Remote-I (graders) users. A total of 20 completed surveys were received (91% response rate); only two smartphone users did not respond to the survey. The mean age of respondents was 34 years and the majority of respondents (80%) were women. The respondents’ professions were dentists (n = 11; 55%), dental therapists (n = 3; 15%), dental students (n = 3; 15%) and nurses (n = 3; 15%). All respondents confirmed that they used computers both at home and work, and reported good typing proficiency.

User acceptance of Remote-I system and smartphone app
The overall level of satisfaction with both the Remote-I server and Android app was positive. Generally, smartphone users had strong positive assessments on items assessing content, format and service quality (system's
stability). The answers to “How often is the content presented in the app sufficient and appropriate?,” “How often does the content meet your needs?,” “How often do you think the output is presented in a useful format?,” and “How often is the information clear?” were given as “most of the time” or “always” by more than 87% of app users. The answer to “How often is the system subject to technical problems or crashes?” was answered with “seldom” or “never” by 89% of the users.

Remote-I users had strong positive assessments on items assessing content, information quality, and service quality (system’s stability). The answers to “How often is the dental chart content appropriate for oral health assessment?”, and “How often are you satisfied with the accuracy of the system?” were given “most of the time” or “always/almost always” by 80% of respondents while the item “How often is the system subject to technical problems or crashes?” was answered with “seldom” or “never” by all users. Users were somewhat less positive towards the Android app in terms of the information quality (quality of taken images), the ease of use of camera and training received. Graders were somewhat less positive towards the Remote-I server in terms of the format and ease of use. However, both graders and smartphones users sometimes had negative assessments about whether they get the assistance they need from the research team (Table 2 and 3).

Time taken for dental photography and grading

The assessment time of records depended on the quality of the images and the severity of the oral diseases, but most graders spent less than 15 min to assess each record on the Remote-I system. On the other hand, the majority of smartphone users took 5–10 min to create a record in the Android app and complete the dental photography for a patient (Table 4).

Users’ suggestions of ways to improve the system

Users were enthusiastic about the use of the teledentistry system for screening for caries based on photographic assessments. The majority of smartphone users (67%) suggested a number of areas for improvement; in particular, in the zoom and autofocus features of the smartphone camera. Similar opinions were expressed by other users (27%) who felt that the quality of some images was not good due to lighting issues related to the built-in camera flash (Figure 3). More than half of smartphone users (53%) suggested using disposable retractors during photography to help in obtaining clear images. Few users (20%) suggested developing an app that can support other operating systems such as iPhone operating system (iOS) and Windows, and also suggested making the app available in the Google or Apple stores.
Table 2. End-user acceptance survey of the Android smartphone app.

<table>
<thead>
<tr>
<th>Items and subscale</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Negative (%)</th>
<th>Positive (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Content</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. How often is the content presented in the app</td>
<td></td>
<td></td>
<td></td>
<td>1(7%)</td>
<td>6(40%)</td>
<td>8(53%)</td>
<td>93%</td>
</tr>
<tr>
<td>2. How often does the content meet your needs!</td>
<td></td>
<td></td>
<td>1(7%)</td>
<td>2(13%)</td>
<td>8(53.5%)</td>
<td>5(33.5%)</td>
<td>87%</td>
</tr>
<tr>
<td><strong>Information quality (accuracy)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. How often are you satisfied with the accuracy of the</td>
<td></td>
<td></td>
<td></td>
<td>3(20%)</td>
<td>2(13%)</td>
<td>4(27%)</td>
<td>6(40%)</td>
</tr>
<tr>
<td>app?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. How often are the captured dental images clear?</td>
<td></td>
<td></td>
<td></td>
<td>3(20%)</td>
<td>2(13%)</td>
<td>9(60%)</td>
<td>5(33.5%)</td>
</tr>
<tr>
<td><strong>Format</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. How often do you think the output is</td>
<td></td>
<td></td>
<td></td>
<td>1(7%)</td>
<td>8(53%)</td>
<td>6(40%)</td>
<td>93%</td>
</tr>
<tr>
<td>presented in a useful format?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. How often is the information clear?</td>
<td></td>
<td></td>
<td></td>
<td>2(13%)</td>
<td>6(40%)</td>
<td>7(47%)</td>
<td>87%</td>
</tr>
<tr>
<td><strong>Ease of use</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. How often is the smartphone camera easy to use?</td>
<td></td>
<td></td>
<td>3(20%)</td>
<td>3(20%)</td>
<td>9(60%)</td>
<td>2(13%)</td>
<td>60%</td>
</tr>
<tr>
<td>8. How often is the app user-friendly?</td>
<td></td>
<td></td>
<td></td>
<td>4(27%)</td>
<td>7(44.5%)</td>
<td>4(26.5%)</td>
<td>73%</td>
</tr>
<tr>
<td><strong>Service quality (system stability)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. How often is the system subject to technical</td>
<td>5(33%)</td>
<td>7(47%)</td>
<td>1(7%)</td>
<td>2(13%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>problems or crashes?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Support</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. How often do you get the assistance you need</td>
<td></td>
<td>1(7%)</td>
<td>5(33%)</td>
<td>3(20%)</td>
<td>3(20%)</td>
<td>1(7%)</td>
<td>40%</td>
</tr>
<tr>
<td>from the research team?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. How often are you satisfied with training received?</td>
<td></td>
<td>3(20%)</td>
<td>3(20%)</td>
<td>7(47%)</td>
<td>2(13%)</td>
<td></td>
<td>60%</td>
</tr>
<tr>
<td><strong>Additional items</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Do you feel the app is useful?</td>
<td></td>
<td></td>
<td>4(27%)</td>
<td>5(33%)</td>
<td>6(40%)</td>
<td></td>
<td>73%</td>
</tr>
<tr>
<td>13. Overall, are you satisfied with the app?</td>
<td></td>
<td>2(13%)</td>
<td>3(20%)</td>
<td>6(40%)</td>
<td>4(27%)</td>
<td></td>
<td>67%</td>
</tr>
</tbody>
</table>

*Never/almost never = 1; seldom = 2; about half the time = 3; most of the time = 4; always/almost always = 5. The percentage of respondents reporting "most of the time"/"great" and "always/almost always"/"very great" (Likert scales "4" and "5") within a given scale were charted as percent positive, while the percentage reporting "never"/"bad at all" and "seldom"/"very little" (Likert scales "1" and "2").

Despite their satisfaction with the content, most dental graders asked for improvement of the format of the teleodontal system, in particular dental charting, as this would facilitate inserting comments and avoid making errors. One grader suggested improving the orientation and labeling of saved images as some labeling was incorrect. Others (two graders) suggested using oral retractors during photography for a better view of posterior teeth as some images were difficult to read because some posterior teeth (molars) were not clear or not shown (Table 5).

**Discussion**

Overall, our survey showed that users perceived the store-and-forward based teledentistry system positively as useful for screening purposes. This reflects previous research which has shown excellent levels of acceptance of real-time based teledentistry system by both patients and professionals.²²,²⁴ Although, most teledentistry systems utilize a real-time modality,²¹ the practices of asynchronous or store-and-forward teledentistry have proven to be more cost-effective and efficient compared to real-time and in-person models in some clinical disciplines.²³,²⁵-²⁷ Historically, mobile devices suffered from a low storage space and low quality of imaging, and this could be a reason for underusing smartphones in dental photography. With recent significant improvements in smartphone camera technology, utilization of smartphones in dental photography and for screening purposes has grown.²³,²⁸ Even when a teledentistry system proves to be useful, users also note room for improvement or offer suggestions. Collecting feedback on areas of satisfaction, barriers, and suggestions from users about a teledentistry program can help foster better-designed programs that can be more successfully implemented.²⁷

Despite the majority of users believing that the Remote-I system is accurate, stable, easy to use, and presented in a useful format, our findings showed that perceived accuracy, format, and ease of use could be improved. A few concerns persist among respondents, including difficulty in reviewing posterior teeth because the oral cavity was not retracted enough, system architecture such as dental chart layout and design, and orientation of images and labeling. Another matter affecting the
Table 3. End-user acceptance survey of the Remotec server.

<table>
<thead>
<tr>
<th>Items and subscale</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Content</strong></td>
<td></td>
</tr>
<tr>
<td>1. How often is the dental chart content appropriate for oral health assessment?</td>
<td>- - 1 (20%) 3 (60%) 2 (40%) 0 80%</td>
</tr>
<tr>
<td>2. How often does the content meet your needs?</td>
<td>- - 2 (40%) 3 (60%) - 0 60%</td>
</tr>
<tr>
<td><strong>Information quality (accuracy)</strong></td>
<td></td>
</tr>
<tr>
<td>3. How often are you satisfied with the accuracy of the system?</td>
<td>- - 1 (20%) 2 (40%) 2 (40%) 0 80%</td>
</tr>
<tr>
<td>4. How often are patients' images clear?</td>
<td>- - 1 (20%) 1 (20%) 3 (60%) - 20% 60%</td>
</tr>
<tr>
<td>5. How often are teeth gradable?</td>
<td>- - 2 (40%) 3 (60%) - - 60%</td>
</tr>
<tr>
<td><strong>Format</strong></td>
<td></td>
</tr>
<tr>
<td>6. How often do you think the output is presented in a useful format?</td>
<td>- - 2 (40%) 3 (60%) - 0 60%</td>
</tr>
<tr>
<td>7. How often is the information clear?</td>
<td>- - 1 (20%) 1 (20%) 3 (60%) - 20% 60%</td>
</tr>
<tr>
<td><strong>Ease of use</strong></td>
<td></td>
</tr>
<tr>
<td>8. How often is the system easy to use?</td>
<td>- - 2 (40%) 2 (40%) 1 (20%) 0 60%</td>
</tr>
<tr>
<td>9. How often is the system user-friendly?</td>
<td>- - 2 (40%) 1 (20%) 2 (40%) 0 60%</td>
</tr>
<tr>
<td><strong>Service quality (system stability)</strong></td>
<td></td>
</tr>
<tr>
<td>10. How often is the system subject to technical problems or crashes?</td>
<td>3 (60%) 2 (40%) - - - 100% 0</td>
</tr>
<tr>
<td><strong>Support</strong></td>
<td></td>
</tr>
<tr>
<td>11. How often do you get the assistance you need from the research team?</td>
<td>- - 2 (40%) 2 (40%) 1 (20%) - 40% 20%</td>
</tr>
<tr>
<td><strong>Additional items</strong></td>
<td></td>
</tr>
<tr>
<td>12. Do you feel Remotec is useful?</td>
<td>- - 1 (20%) 2 (40%) 2 (40%) - - 80%</td>
</tr>
<tr>
<td>13. Overall, are you satisfied with the server?</td>
<td>- - 1 (20%) 1 (20%) 3 (60%) - 20% 60%</td>
</tr>
</tbody>
</table>

*Never/almost never = 1; seldom = 2; about half the time = 3; most of the time = 4; always/almost always = 5. The percentage of respondents reporting "most of the time" or greater and "always/almost always" or greater (Likert scales 4 and 5) within a given scale were charted in percent positive, while the percent reporting "never" or "seldom" or "very little" (Likert scales 1 and 2).*

Table 4. Duration of dental photography and grading process.

<table>
<thead>
<tr>
<th>Time taken to review a record on the server</th>
<th>&lt;5 min</th>
<th>5–10 min</th>
<th>10–15 min</th>
<th>15–20 min</th>
<th>&gt;20 min</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time taken to create a record and for photography</td>
<td>1 9</td>
<td>4 1</td>
<td>15</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

graders' ability to review images and grade teeth is the quality of the images that the telehealth assistants send. The quality of images and the capability to grade images accurately are very important factors when evaluating the feasibility of telediagnosis of diseases. Many of the problems encountered could be overcome following further modification and optimization of the server. Despite attention to many issues (over bright or dark images) related to smartphone camera use, adjustment of photography protocols prior to starting the trial, concerns with the information quality and ease of use of smartphone camera were observed (Figure 3). Although, the majority of the smartphone users believed that the Android app was accurate and easy to use, the survey results showed that a substantial number of Android users (20%) experienced difficulty with the use of the smartphone camera and a majority of the smartphone users suggested that the quality of images and the smartphone camera need further improvement. Users' concerns with the smartphone camera mainly pertained to the difficulty of obtaining good images due to issues relating to the optimization of phone camera features, the absence of oral retractors, or lack of training.

The survey shows that the average time spent on creating a record, uploading and grading was 20 min. Although this time is longer than an in-person oral assessment...
Figure 3. Example of a smartphone camera shot. (a) An extraoral occlusal view of upper teeth with poor image quality (blurred) due to being out of focus. It is not possible to observe teeth or soft tissue in this image. (b) Shows extraoral occlusal view of upper teeth with excellent image quality. It is possible to see decayed first molars and decayed left second molar.

(10–15 min), a duration of 20 min is still considered acceptable as the only alternative is to spend hours traveling to the nearest practice or sending a practitioner to a remote site. Although training of teledental assistants to provide good quality oral images was provided and does not consume much time, adherence to the photography protocol provided was hard to achieve. Many Android users’ concerns could be resolved through more effective training and hands-on experience.

The results of this study partly support the TAM model of telemedicine acceptance. Similar to the assertion of TAM, perceived ease of use and usefulness was relatively high among users and positively associated with users’ attitudes toward using the system, and these results are consistent with previous reports. However, our data indicates that the perception of the system’s stability, content, and format have a strong influence on the attitude towards teledentistry system. The intention to use the system is not only predicted by its perceived usefulness but also determined by the system’s stability, format, and content which were rated consistently high in the survey. Perceptions of information quality and support were not found to influence the intention to use the system significantly, and the latter could be attributed to the absence of coordination between sites and lack of prior personal experience with teledentistry. Another important factor that may affect a user’s intention to use telemedicine is the need for collaboration and coordination between remote and hub sites when implementing a telemedicine system. Because the supervisory dental team at the hub site cannot do a hands-on examination, they have to rely on the assessment performed by the local practitioner at the remote site. Repeated practice, establishing confidence, and good working relationships between team members at both sites can establish a reliable and smooth teledentistry process.

This study was not designed to examine in depth the users’ perception of teledentistry, but it gives insights on its acceptance. Further investigations on how different types of factors (external or internal) operate to support or hinder the adoption of a teledentistry model are needed to be addressed. Despite the rapid growth of teledentistry, it has not yet become an integral part of mainstream oral health care. Future research is needed to determine the obstacles that delay the implementation of teledentistry as an adjunct for a comprehensive health care system. Identifying and addressing the barriers to adoption of teledentistry could motivate dental providers to adopt the use of telemedicine services in daily practice.

Conclusion

Generally, users considered the teledentistry model as useful, despite their concerns with specific aspects of the system. This study provides developers with key observations about user needs when building a teledentistry system and can form the basis for the development of a more user-friendly system. Utilization of teledentistry approaches for caries screening has steadily gained acceptance in recent years. More recently mobile teledentistry, often seen as a sub-set of telemedicine, has also emerged as a possible means of screening for oral diseases. This area is particularly attractive due to the fact that many smartphones are now equipped with digital cameras, and there is widespread penetration of smartphones and cellular network reception globally even in underserved regions. We believe that these technologies (teledentistry and smartphones) can be combined to create an inexpensive and powerful tool for screening purposes. This approach could offer a practical and potential cost-saving means to screen for oral diseases among a population with high levels of need who have no access to care.

The development of a cloud-based server and an image-acquisition Android app for screening purposes is the first of its kind in Australia and has the potential to serve rural providers to reduce inappropriate referrals and waiting lists for consultation as well as facilitating timely information to the local practitioner for better decision-making. Evaluation of users’ acceptance provides valuable insight into the factors which impact professionals’ intentions to
Table 5. Categories and frequencies of suggestion by respondents.

<table>
<thead>
<tr>
<th>Suggestions of ways to improve the system</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote-I (five users)</td>
<td></td>
</tr>
<tr>
<td>The layout of the dental chart should be further improved, e.g., making the</td>
<td>1 (20%)</td>
</tr>
<tr>
<td>layout horizontal rather than vertical. It would be more</td>
<td></td>
</tr>
<tr>
<td>likely that the server was upgraded to a system similar to the Dental Window</td>
<td></td>
</tr>
<tr>
<td>program.</td>
<td></td>
</tr>
<tr>
<td>Make sure that the orientation and labeling of images are correct.</td>
<td>3 (60%)</td>
</tr>
<tr>
<td>An image must be closed in order to use the chart. It would be</td>
<td></td>
</tr>
<tr>
<td>easier for the clinician if the image was kept open while</td>
<td></td>
</tr>
<tr>
<td>recording on the chart.</td>
<td></td>
</tr>
<tr>
<td>The headings of the columns for the dental chart are at the top, so when</td>
<td>1 (20%)</td>
</tr>
<tr>
<td>you record at bottom of the page, you need to</td>
<td></td>
</tr>
<tr>
<td>scroll back to the top every time to identify the actual headings; this may</td>
<td>2 (40%)</td>
</tr>
<tr>
<td>lead to increased errors.</td>
<td></td>
</tr>
<tr>
<td>The posterior teeth were the most difficult to review due to lack of</td>
<td>2 (40%)</td>
</tr>
<tr>
<td>buccal retraction. Simple retraction devices such as</td>
<td></td>
</tr>
<tr>
<td>tongue depressors would be useful.</td>
<td></td>
</tr>
<tr>
<td>It is impossible to edit or make corrections once a record is</td>
<td>3 (60%)</td>
</tr>
<tr>
<td>evaluated and the report submitted. It would be helpful to</td>
<td></td>
</tr>
<tr>
<td>validate and double check some records if the system supported editing</td>
<td></td>
</tr>
<tr>
<td>and corrections after submitting the records.</td>
<td></td>
</tr>
<tr>
<td>Android phone app (15 users)</td>
<td></td>
</tr>
<tr>
<td>Improve camera features such as zooming and autofocus. The quality of some</td>
<td>10 (67%)</td>
</tr>
<tr>
<td>captured photos was poor because the camera features are not optimized.</td>
<td></td>
</tr>
<tr>
<td>Improve the camera flash. Some photos were either over exposed or</td>
<td>4 (27%)</td>
</tr>
<tr>
<td>dark because the camera flash is not optimized.</td>
<td></td>
</tr>
<tr>
<td>Uploading records from the Android app to the server depends on the</td>
<td>1 (7%)</td>
</tr>
<tr>
<td>availability of the Internet connection. I would suggest improving the</td>
<td></td>
</tr>
<tr>
<td>current app to allow storage of records in the smartphone memory to</td>
<td></td>
</tr>
<tr>
<td>be uploaded into the server at a later time.</td>
<td></td>
</tr>
<tr>
<td>Photography of lateral views or posterior teeth was difficult because</td>
<td>8 (53%)</td>
</tr>
<tr>
<td>photography was done without oral retraction as per</td>
<td></td>
</tr>
<tr>
<td>image protocol. I would suggest using disposable retraction during</td>
<td></td>
</tr>
<tr>
<td>photography as this will help in obtaining good dental</td>
<td></td>
</tr>
<tr>
<td>images.</td>
<td></td>
</tr>
<tr>
<td>Make this app available free in the Google or Apple stores.</td>
<td>2 (13%)</td>
</tr>
<tr>
<td>The phone app only works on Android devices, I would suggest developing an</td>
<td>1 (7%)</td>
</tr>
<tr>
<td>application that can support iOS and Windows phones.</td>
<td></td>
</tr>
</tbody>
</table>

Adopt teledentistry services. Building on these experiences, the next step will be the implementation of multi-site, community-based, and large-scale projects that can incorporate remote dental screening and oral health promotion, and involve different members of the dental team such as dental therapists, dental hygienists, and dental nurses.

Acknowledgement

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References

Perceptions of Australian dental practitioners about using telemedicine in dental practice

M. Estai, E. Kruger, and M. Tennant

Objective: This study aimed to explore Australian dental practitioners’ perceptions of the usefulness of teledentistry in improving dental practice and patient outcomes. Methods: A descriptive cross-sectional study involving an anonymous, electronic survey of a sample of 169 Australian dental practitioners. We designed a 24-item, 5-point Likert-scale questionnaire assessing perceptions of dentists in four domains: usefulness of teledentistry for patient; usefulness of teledentistry for dentists' practice; capability of teledentistry to improve practice; and perceived concerns about the use of teledentistry. Results: Of the 144 respondents (response rate 89%), 135 completed responses that were suitable for analysis. More than 80% of respondents agreed strongly that teledentistry would improve dental practice through enhancing communication with peers, guidance and referral of new patients. The majority also felt that teledentistry is quite useful in improving patient management and increasing patient satisfaction. A substantial proportion of respondents expressed uncertainty with technical reliability, privacy, practice expenses, the cost of setting up teledentistry, surgery time, and diagnostic accuracy. Conclusion: Dental practitioners generally reported optimism and support to the concept of teledentistry and its integration into current dental practices. Addressing how teledentistry can benefit specific practice issues, would encourage more dentists to use telemedicine in routine practice.
were randomly selected from that directory (over 1,000 members) as the sample. The random sample shared common demographic and professional characteristics with the Australian dental workforce. The directory is a collective of dental practitioners, mostly general dentists, working in different settings but mainly in urban private practices across the nation. The survey was then distributed by email and was also enclosed with a definition of telemedicine and description of the benefits of telemedicine in addressing many issues in daily practice. Following the initial correspondence, a reminder was sent to all practitioners who did not respond to the first email at fortnightly intervals.

### Data analysis

Completed responses were entered into an Excel spreadsheet (Microsoft 2013) and coded for data analysis. The data were analyzed using Excel and SPSS (version 17.0). Descriptive statistics were used to summarize demographics and data. Data were expressed as frequencies and valid percentages.

### RESULTS

Of the 109 surveys mailed to dental practitioners, 144 responses were returned, indicating a response rate of 96%. Of the 144 respondents, nine provided incomplete responses. Therefore, only 135 completed responses were available for analysis.

### Demographic and professional characteristics of respondents

Demographic data found that more than half of the study population was aged above 45 years. Most respondents were practitioners general dentists or specialists (53%), males (54%) and had more than 16 years of work experience (46%). The majority of practitioners were working in major cities (77%), and the remainder were either working in regional or remote Australia. While a large proportion of respondents (42%) worked 35–49 hours per week, almost a quarter of respondents worked over 50 hours per week. Despite the majority of respondents working either in private (77%) or public (19%) practices, the proportion of practitioners who worked in both public and private sectors was just less than 23% (11%).

### Internet use and communication method preferences

Less than three-quarters of respondents spent less than four hours on the internet per day for the practice-related purpose (Table 2). With the emergence of ICT and the availability of the internet, tools traditionally used for communication, such as letters, fax or face-to-face, seem to be less preferable. For instance, a minority of respondents used in-person (52%), letters (19%) or fax (1%) as a tool of communication with others. A substantial proportion of respondents rated email (23%) and phone (14%) as a preferred medium for communication. The adoption of social media, forums or video-conferencing was still slow among practitioners (Fig. 1).

### Practitioners’ concerns relating to security and confidentiality issues

Concerns about the incompatibility of software or hardware tended to be higher than those surrounding privacy, reliability of equipment, and gaining consent, with just under 60% of respondents a little, or very concerned, about technical incompatibility. Although a slim majority of 54% expressed little or great concern with a potential violation of confidentiality, nearly a third of respondents were either a little or very concerned with gaining patient consent for telehealth consultations. On the other hand, uncertainty was observed in the practitioners’ views about the reliability of equipment and potential image forgery (Fig. 2).

### Capability of teledentistry system to improve practice

Generally, advantages of the teledentistry system in improving practice were well perceived by most practitioners. More than 80% of respondents agreed or strongly agreed that communication with colleagues, guidance and referral of new patients would be enhanced. However, respondents were unsure if teledentistry would help shorten waiting lists with more than 40% of respondents indicating uncertainty about this statement. Respondents were also unclear in their opinions about whether teledentistry can provide a valid diagnosis compared with a diagnosis within a clinical setting (Fig. 3).
Usefulness of a teledentistry system for dental practice

The majority of respondents indicated that teledentistry could be quite useful in improving dental practice by saving time when compared to conventional referrals, supplying sufficient diagnostic information, and enhancing clinical training. A slim majority of respondents (52%) felt that teledentistry would not require extra appointments for photography. In contrast, respondents were less convinced that teledentistry would reduce time spent on patients and be too expensive to set up, with over a third of respondents unsure about this statement. Similarly, more than half of respondents (54%) were doubtful as to whether teledentistry would reduce costs for their dental practice (Fig. 4).

Usefulness of a teledentistry system for patients

Generally, practitioners’ beliefs in the potential merits of teledentistry for patients were positive, and up to 20% of respondents agreed or strongly agreed with statements that highlighted the benefits of a teledentistry system. More than 50% of practitioners agreed strongly that a teledentistry system would benefit patients in remote or rural locations. The willingness of respondents to communicate with colleagues and link with their patients was also observed, and 80-90% of respondents showed that teledentistry would improve interaction with peers and patients (Fig. 5).

DISCUSSION

To our knowledge, this is the first to evaluate Australian dentists’ perceptions about the usefulness of teledentistry in dentistry. Generally, more optimism was expressed by respondents with respect to the advantages of teledentistry for patients, compared with its advantages to dental practice. Most respondents felt that teledentistry would be useful in improving dental practices, patient management, and patient satisfaction. This reflects previous studies that found that dentists are quite open to the use of teledentistry in clinical practice. A majority of respondents were wary of particular aspects of teledentistry practice. These aspects are largely attributed to practitioners’ concerns over cost, time, security, and diagnostic accuracy. For some attributes such as the cost of setting up teledentistry, practice expenses, and surgery time, the perceptions of usefulness were lower, as a larger proportion of respondents did not express strong views.

Cost, time, security, technical reservation, guidelines, lack of direct contact and comfort with technology have been identified as barriers to the integration of ICT in clinical practice.10,12 Similarly, Australian dentists were solicitous for set-up costs, practice expenses, surgery time, technical incompatibility and security issues. These findings were consistent with concerns expressed by UK GPs. However, this contrasts with those of Canadian orthodontists in a survey which have considered remuneration, security issues and lack of comfort with technology as less important.11-14 Concerns with long surgery times reflect previous reports which show that the time spent to prepare a patient for a teleconsultation is longer than conventional settings.15,16 Increased use of technologies in practice has heightened concerns such as security vulnerabilities associated with transmitting unencrypted data, transferring data via an open Wi-Fi hotspot, and inappropriate access to databases.17-19 With violation of patient privacy seeming to be easier than ever before, protecting patients’ privacy in an electronic environment becomes challenging. Therefore, practitioners of teledentistry should put maximum efforts to protect the confidentiality of information.

While increased risk of privacy violation has been cited as an initial barrier for using teledentistry, other issues such as remuneration, licensure, taxation, copyright, and medicolegal issues may become a matter of concern. Costs of teledentistry equipment and supporting technologies may also represent a burden on providers and governments. Nowadays in developed countries it is hard to imagine a dental practice without digital radiography, intraoral cameras, digital cameras, computerized patient registry, and computers with Internet access. Therefore, the use of available ICT infrastructure in practices would save the cost of teledental
equipment, and reduce practice expenses and consultation costs. Furthermore, despite its ability to make accurate diagnoses, there is a growing concern about the diagnostic validity of teledentistry compared with in-person oral examination. Uncertainty about diagnostic accuracy may arise from the inability to perform complete investigations when using teledentistry for certain clinical situations, thus, direct patient contact may still be needed to establish an accurate diagnosis. Oral diseases also vary in colour, shape, and consistency, and, therefore, a very high quality of oral images is important to allow for online consultation.

Despite reluctance to the use of digital and electronic technologies such as social media, forums or video-conferencing in communication, other tools like email and phone seem to be the favourable medium of communications. For instance, a survey of 4,000 US doctors indicated that almost two-thirds were communicating with colleagues via email. Email can provide clinicians practicing in remote locations with valuable access to the second opinion, since it allows low-cost communication of digital images. Therefore, email can offer a richness of communication compared to traditional tools. Furthermore, respondents were more likely to communicate not only with colleagues, but with their patients. This was reflected in their support of the concept that teledentistry would enhance communication, clinical training and guidance among practitioners, and improve interactions with patients. These results were inconsistent with other research showing that dentists are more open to interacting electronically with other dentists than with patients or the public.

Addressing how teledentistry can benefit specific practice aspects would motivate more dental practitioners to actively integrate this technology into daily practice. It would also be helpful to re-evaluate dental practitioners’ perceptions as new issues may emerge when teledentistry becomes more widely used. Furthermore, policy-makers must establish well-defined standards and laws that can regulate the use of teledentistry in dental practice.

CONCLUSION

The majority of respondents expressed positive views towards technology-based solutions and tools that can bring added benefits to dental practices. However, this study has identified certain barriers to the use of teledentistry, and identified where practitioners would need support to use teledentistry technology, especially in aspects related to practice expenses, equipment setup costs, time, technical incompatibility and security.
Acknowledgments

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Cost savings from a teledentistry model for school dental screening: an Australian health system perspective

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Abstract
Objective. The aim of the present study was to compare the costs of teledentistry and traditional dental screening approaches in Australian school children.

Methods. A cost-minimisation analysis was performed from the perspective of the oral health system, comparing the cost of dental screening in school children using a traditional visual examination approach with the cost of mid-level dental practitioners (MLDPs), such as dental therapists, screening the same cohort of children remotely using teledentistry. A model was developed to simulate the costs (over a 12-month period) of the two models of dental screening for all school children (2.7 million children) aged 5–14 years across all Australian states and territories. The fixed costs and the variable costs, including staff salary, travel and accommodation costs, and cost of supply were calculated. All costs are given in Australian dollars.

Results. The total estimated cost of the teledentistry model was $50 million. The fixed cost of teledentistry was $1 million and that of staff salaries (tele-assistants, charters and their supervisors), as well as information technology support was estimated to be $49 million. The estimated staff salary saved with the teledentistry model was $55 million, and the estimated travel allowance and supply expenses avoided were $16 million and $14 million respectively; an annual reduction of $85 million in total.

Conclusions. The present study shows that the teledentistry model of dental screening can minimise costs. The estimated savings were due primarily to the low salaries of dental therapists and the avoidance of travel and accommodation costs. Such savings could be redistributed to improve infrastructure and oral health services in rural or other underserved areas.

What is known about the topic? Caries is a preventable disease, which, if it remains untreated, can cause significant morbidity, requiring costly treatment. Regular dental screening and oral health education have the great potential to improve oral health and save significant resources. The use of role substitution, such as using MLDPs to provide oral care has been well acknowledged worldwide because of their ability to provide safe and effective care. The teledentistry approach for dental screening offers a comparable diagnostic performance to the traditional visual approach.

What does this paper add? The results of the present study suggest that teledentistry is a practical and economically viable approach for mass dental screening not only for isolated communities, but also for underserved urban communities. The costs of the teledentistry model were substantially lower than the costs associated with a conventional, face-to-face approach to dental screening in both remote and urban areas. The primary driver of cost savings is the low salary of MLDPs and avoidance of travel and overnight accommodation by MLDPs.

What are the implications for practitioners? The use of lower-cost MLDPs and a teledentistry model for dental screening has the potential to save significant economic and human resources that can be redirected to improve infrastructure and oral care services in underserved regions. In the absence of evidence of the economic usefulness of teledentistry, studies such as the present one can increase the acceptance of this technology among dental care providers and guide future decisions on whether or not to implement teledentistry services.
Additional keywords: caries, children, cost-analysis, smartphone.

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Introduction

In all Australian states and territories, the provision of free or low-cost dental care for school children is provided by the School Dental Service (SDS). Historically, school dental therapists have been responsible for providing most of the SDS dental services (examination, diagnosis, treatment and preventive care) under the supervision of dentists. The employment of dental therapists was limited to the state-operated SDS, but now many dental therapists are employed in the private sector. In recent years there has been a gradual reduction in workforce participation and scarcity of resources in SDS. A recent report suggested that the SDS rarely provides sustainable dental care, less than a quarter of Australian school children attended a SDS for their last dental visit. The decreased retention and recruitment of school dental therapists is attributed to the preference of school dental therapists to work in the private sector or leave the profession, as well as the establishment of a bachelor degree (3 years at university level) of Oral Health Therapy in several Australian universities. This degree is intended to replace the existing (2 years vocational level) diploma programs in Dental Therapy or Dental Hygiene. The new bachelor programme allows the oral health therapist (OHT) to incorporate the skills of both the dental hygienist and the therapist.

Despite improvements in oral health over past decades, nearly half the school children receiving dental care within the SDS do not enjoy good oral health. In 2010, 55% of children aged 6 years had experienced decay in their deciduous teeth, whereas 48% of children aged 12 years had a history of decay in their permanent teeth. Dental caries is a potentially preventable infectious disease, which, if left untreated, can lead to considerable morbidity requiring expensive treatment. In 2013–14, the total national expenditure on dental care in Australia increased from $6 to $9 billion, with 60% of this estimated to be out-of-pocket spending. Improving oral health in children is achieved through the implementation of a range of systematic preventive strategies, such as oral health promotion, systemic and topical fluorides, fissure sealants and improvements in the diet. However, these measures are often not directed towards children with the greatest needs. Dental screening using a reliable and low-cost screening tool offers a way to identify high-risk groups, and thus provides a useful approach for the effective prevention and control of dental diseases.

In 2015, dentists made up 75% (n = 15 500) of the dental workforce in Australia, compared with <10% (n = 2050) dental therapists or OHTs. However, most Australian dentists (82%) work in the private sector. In recent years, many dental therapists or OHTs have opted for private practice careers because of a lack of competitive salaries in the SDS or public sector. In the private sector, dental therapists or OHTs are often working as "hygienists" responsible for performing scaling and root planing for adult patients; thus, they have a minor role in the provision of dental care. OHTs have not been used effectively to increase the capacity of the existing dental workforce (i.e. mostly dentists) and address the inequality in access to dental care. One way to address the inequality in oral health is role substitution in dentistry, where the duties performed by expensive dentists are delegated to mid-level dental practitioners (MLDPs), such as OHTs or dental therapists. The use of MLDPs to provide dental care has received increasing acceptance worldwide because of the inability of dentists alone to address all unmet oral care needs. There is evidence that OHTs have the potential to detect oral diseases in vivo with a standard comparable to that of dentists. It could be reasonable to use OHTs to screen, diagnose and provide simple treatment while referring dentists for managing complicated cases. Using MLDPs for the dental screening of asymptomatic populations could improve oral health in underserved populations and free up significant resources.

Despite teledentistry still being in its infancy and not having been widely used as a screening tool, recent reports indicate that MLDPs have the potential to screen for dental caries using a smartphone camera, with acceptable diagnostic performance. These findings are consistent with previous research indicating that teledentistry provides a reliable and cost-saving alternative to traditional screening. Although teledentistry is becoming increasingly popular, the number of economic analyses of teledentistry, particularly those looking at cost minimisation, remains small. A comparison of the costs of teledentistry and its alternatives is of particular importance to those making future decisions about implementing a new screening service. The purpose of the present study was to model and evaluate the costs of a teledentistry approach to screen for dental caries and compare it with the modelled costs of the traditional alternatives from a national care provider's perspective.

Methods

In order to identify the least costly alternative, a cost-minimisation analysis was performed to compare the costs of two methods of dental screening that provide comparable outcomes. The analysis was conducted from the perspective of the health system and did not take into consideration costs incurred by the patients or their families. A model was developed to simulate the costs of screening all Australian school children (aged 5–14 years) using teledentistry (where therapists or OHTs performed online charting using dental photographs taken with a smartphone camera) and the traditional approach (a dentist performing a traditional visual screening). Because dental caries in children occurs rapidly and progressively, a 1-year time period was used in both screening models. All data were collected from web-based open-access sources; therefore, no ethics approval was required.

Screening procedures for teledentistry and traditional models
A cloud server, developed to facilitate the local acquisition of dental photographs, as well as the transmission and reviewing of the dental images remotely. Trained tele-assistants (teachers) acquire photographs from children’s mouths at their schools using their own mobile cameras. Dental records (including dental photographs and anonymous patient details) are then directly transmitted from the Android app to the server via the Internet (Fig. 1). The charting of dental records is performed by dental therapists (charters) under the indirect supervision of registered dentists at a distance. Charters are able to access the database using any web browser and from any location. After selecting a record from the database, a list of dental photographs and a predefined assessment chart appears for the charter to insert their findings (Fig. 2). The chart includes an oral health assessment form aligned with the World Health Organization (WHO) protocol for oral health assessment. The system enables charters to independently review dental photographs and submit reports or recommendations to the server. Detailed descriptions of the Remote1 system and screening process have been published previously. Under the traditional model, operators (registered dentists) and their dental assistants are assumed to travel across the nation to perform on-site dental screening among the same cohort of children in their own schools. Screening is performed by operators to screen for cavities and other dental issues, which are then recorded on an oral health assessment form aligned with the WHO protocol. No radiographs were used in the dental screening, but retouchers and editors were used to permit visualization of the teeth. Australia is divided into 54,000 non-overlapping statistical area level 1 (SA1). The population data of children across each of the 54,000 SA1s are distributed by age, state, and remoteness. The degree of remoteness of each SA1 was obtained from the ABS using the Australian Standard Geographical Classification (ASGC). According to the ASGC, Australia is divided into five remoteness zones: major Australian cities (R1), inner regional Australia (R2), outer regional Australia (R3), remote Australia (R4), and very remote Australia (R5). The number of school children aged 5–14 years across all states and territories of Australia, as well as over the five remoteness area groups (Fig. 3), was obtained from the ABS and entered into Microsoft Excel spreadsheet (2003). Estimation of costs In the present cost model, the majority of unit costs were derived from real data and real values. However, some assumptions were used when data were not available. The costs for both models of dental screening were further divided into fixed and variable costs. All costs are given in Australian dollars and all salaries used in the calculation are based on the Australian government pay rates. Fixed costs No fixed costs were associated with the traditional method of dental screening. For the teledentistry option, we considered establishment costs, which included the annual software licence fee, annual server host fee, marketing and training (online induction and self-practice to take good images), to be fixed costs. However, the costs of communication or the Internet and smartphone devices were not considered in the present economic evaluation because almost all schools in Australia have Internet access and most tele-assistants (local teachers) own suitable mobile devices. Variable costs Traditional model. The variable costs associated with the traditional alternative were divided into direct and indirect costs, which included staff salaries and the costs of travel and overnight accommodation at each site for operations and their assistants, as

![Diagram](https://via.placeholder.com/150)

Fig. 1. Flow diagram of the teledentistry model of school dental screening.
Fig. 2. Assessment of dental photographs by an off-site charter. (a) Snapshot of a record containing a dental chart and dental photographs. (b) Off-site charter logging-in to the database to access dental records.

well as consumable items or materials used to conduct the visual screening. The costs of consumable items (e.g., gloves, mirror, and retractors) were assumed to be $5 per patient. The cost of office space rental was not taken into consideration because the screening process was assumed to be performed in schools.

Based on a recent report, an operator would need ≤15 min for the oral examination and the assistant would spend ≤15 min on chairside charting. Typically, in Australia, a working year consists of 220 active days per year (after deducting 20 days annual leave and 10 days sick or family leave). After deducting education, administration and travel times from 220 working days, the active days per year remaining in which to perform traditional dental screening range from 99 (screening located in R4 or R5) to 162 (screening located in R1). Considering the movement between screening sites across different geographical zones, the estimated workload (number of children intended to be screened) ranged from 26 children per 5 h per day located in R4 or R5 to 39 children per 7.5 h per day located in R1 (i.e. 12 months, the number of children who could be screened would range from 4860 (located in R1) to 1860 (located in R4 or R5)). The number of full-time equivalent (FTE) operators or dental assistants was 620. The estimation of FTE for the traditional model is provided in Table 1.

Staff salaries included the salary for operators and their dental assistants. The average annual salary (base salary plus 20% on-costs, superannuation and workers compensation) of the operator (registered junior dentist) and the dental assistant would be $108 000 and $60 000 respectively. Considering the incentive allowance for the operator and assistant performing screening in R4 and R5 regions, the annual salary was augmented with a 20% remote allowance, bringing these to salaries to $126 000 and $70 000 respectively.

Because the majority of the target population and dentists or operators are clustered near cities, most screening sites would be located in R1 and R2, but dentists and their assistants would need to travel to screening sites located in R3, R4 and R5 areas to perform the on-site screening. Travel allowance expenses (transport, accommodation and incidentals) were adjusted for each remoteness zone. Flights and accommodation expenses were only considered for three geographical zones (R3, R4 and R5). Estimated costs for transport (flight, train or car) were allocated to each of the five geographical groups (R1–R5). The average transport costs (car, bus or train) plus incidentals for one operator or assistant performing screening in the R1 or R2 zones were estimated to be $75 per person. The average costs for flights, overnight accommodation and incidentals (i.e. 50% of total travel allowances) for one operator or assistant performing screening in the R3–R5 zones were estimated at $750 per person.

Teledentistry model. Variable costs for the teledentistry option include the salaries of the tele-assistants (e.g., teachers), charters and their supervising dentists, and technical experts. Based on the previous study, a charter or OIT would require an average 10 min for charting and submission of the recommendation online. After deducting education and administration days from 229 working days, the active days per year remaining to
perform charting would be 200. The patient load was estimated to be 56 per recorder 61 per day or 7200 per year. The number of FTE charters was 375. In addition, there would be IT support to respond to technical problems and the supervisory senior dentist to monitor the charter (therapists, OHTs) assessment; the FTE for IT support and the supervisory dentists was 1:20 of that for the charter (i.e. 19 FTE each). The tele-assistant (teacher) would need ≤10min to photograph a child’s mouth and, if working 6h per day, would need 455-49h to obtain intraoral photographs from all Australian children over a 1-year time horizon. It is expected that any available smartphone would be used and the data would flow through the existing Internet. The estimation of FTE for the teledentistry model is presented in Table 1.

The average annual salary (base salary plus 20% on-costs) of a charter (OHT) was $72,690. The average annual salaries of IT support and supervisory dentists were $72,000 and $144,000 respectively. The hourly tele-assistant salary was assumed to be $40.

**Statistical analysis**

The cost model was built using a spreadsheet (Microsoft Excel 2003, Redmond WA, USA) to compare the costs and savings associated with dental screening using teledentistry versus visual examination over a 1-year period. The model outputs for traditional screening included variable direct and indirect costs incurred by the operators and their assistants; for the teledentistry model, the outputs consisted of fixed costs and variable direct costs incurred by charters and their supervisory dentists, tele-assistants and IT support. Total costs were also compared for both models. A threshold analysis was performed to determine the number of children at which the total costs (sum of variable and fixed costs) in the two models was similar. A sensitivity analysis was used to determine how the uncertainty in input variables would affect the overall costs of both models under a given set of assumptions.

**Results**

The estimated number of school children (aged 5–14 years) assumed to have dental screening was 2.7 million. Children living in the R1 and R2 geographical zones (2.8 million and 0.5 million respectively) accounted for 87% of the school children population in Australia. The distribution of children across the five geographical zones is shown in Fig. 3.

**Costs of traditional screening**

The total average variable cost of the traditional model of dental screening over 1 year was up to $115 million and the fixed cost of the traditional model was zero (Table 2). In total, the direct costs of the traditional model of screening (including the salaries for the operator and assistant) were $105 million, accounting for 78% of the total costs. The total indirect cost of the traditional model (travel and accommodation costs plus incidental costs) was up to $1 million. The total cost of materials and supply needed to perform dental screening was $14 million.

**Costs of teledentistry screening**

Overall, the total cost of the teledentistry model over a 1-year period was $50 million (Table 3). The total fixed cost of the teledentistry model was $1 million, with the major part of these costs being marketing or advertisement costs. The total average variable cost of the teledentistry model was $49 million. The estimated direct costs (including salaries of the charter, IT support, supervisory dentist and tele-assistant) were up to $49 million, accounting for 98% of the total costs of the teledentistry model. The costs of salaries of the charters and tele-assistants were up to $27 million and $18 million respectively, accounting for 90% of the total cost of the teledentistry model. The estimated average travel and accommodation staff salary saved was $56, and the estimated travel allowance and materials expenses avoided were up to $16 million and $14 million respectively, which represents a net saving of $55 million. The average cost per child for teledentistry was $19.

| Table 1. Patient load assumptions for the teledentistry and traditional model |
|--------------------------------------------------|---|---|---|---|---|
| ASGC, Australian Standard Geographical Classification remunerated category: | R1, major Australian cities; R2, inner regional Australia; R3, outer regional Australia; R4, remote Australia; R5, very remote Australia; FTE, full-time equivalent |
| **Patient loads in the traditional screening (for one operator plus one assistant per operator)** |
| ASGC | R1 | R2 | R3 | R4 | R5 | Total |
| Patients screened per day | 50 | 30 | 25 | 20 | 20 | 20 |
| Working days per year | 220 | 220 | 220 | 220 | 220 | 220 |
| Education days per year | 5 | 5 | * | * | * | * |
| Administration days per year | 48 | 48 | 48 | 48 | 48 | 48 |
| Travel days per year | 5 | 5 | 48 | 48 | 48 | 48 |
| Movement (weeks per year) | 48 | 48 | 48 | 48 | 48 | 48 |
| Active days per year | 162 | 162 | 162 | 162 | 162 | 162 |
| Patients examined per year | 4800 | 4800 | 2925 | 1860 | 1860 | 1860 |
| FTE | 379 | 111 | 91 | 23 | 23 | 23 |
| **Patient loads in the teledentistry model (for one charter)** |
| Records charted per day | 30 | 30 | 30 | 30 | 30 | 30 |
| Working days per year | 220 | 220 | 220 | 220 | 220 | 220 |
| Education days per year | 10 | 10 | 10 | 10 | 10 | 10 |
| Administration days per year | 10 | 10 | 10 | 10 | 10 | 10 |
| Active days per year | 260 | 260 | 260 | 260 | 260 | 260 |
| Records charted per year | 7200 | 7200 | 7200 | 7200 | 7200 | 7200 |
| FTE | 378 | 378 | 378 | 378 | 378 | 378 |
Table 2. Estimated costs of the traditional model of dental screening according to Australian Standard Geographical Classification remoteness category.

<table>
<thead>
<tr>
<th>Remoteness category</th>
<th>Mean estimate (million AUD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1, major Australian cities</td>
<td>$2</td>
</tr>
<tr>
<td>R2</td>
<td>$2</td>
</tr>
<tr>
<td>R3</td>
<td>$7</td>
</tr>
<tr>
<td>R4</td>
<td>$3</td>
</tr>
<tr>
<td>R5</td>
<td>$2</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$16</td>
</tr>
<tr>
<td>Direct costs (base salary plus 20% on-costs) incurred by operators and assistants</td>
<td>$64</td>
</tr>
<tr>
<td>R1</td>
<td>$19</td>
</tr>
<tr>
<td>R2</td>
<td>$15</td>
</tr>
<tr>
<td>R3</td>
<td>$4</td>
</tr>
<tr>
<td>R4</td>
<td>$3</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$105</td>
</tr>
<tr>
<td>Cost of materials and disposables ($5 per child)</td>
<td>$14</td>
</tr>
<tr>
<td>Total cost</td>
<td>$125</td>
</tr>
</tbody>
</table>

*High fees applicable only to operators and assistants practicing in R3, R4 and R5.

Table 3. Estimated costs of the teledentistry model of dental screening

<table>
<thead>
<tr>
<th>Cost component</th>
<th>Estimated cost (million AUD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed costs Marketing in the media and Internet</td>
<td>$1</td>
</tr>
<tr>
<td>Software licence fee (per year)</td>
<td>$0.004</td>
</tr>
<tr>
<td>Server host fee (per year)</td>
<td>$0.008</td>
</tr>
<tr>
<td>Training (online induction course and self-practice)</td>
<td>$0.015</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$1</td>
</tr>
<tr>
<td>Variable costs (staff salaries)</td>
<td>$27</td>
</tr>
<tr>
<td>Chart (27% FTE)</td>
<td>$1</td>
</tr>
<tr>
<td>Supervisory dentist*</td>
<td>$3</td>
</tr>
<tr>
<td>Telescist</td>
<td>$18</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$49</td>
</tr>
<tr>
<td>Total cost</td>
<td>$50</td>
</tr>
</tbody>
</table>

*The FTE for the TIT team is 1:20 FTE of charters.

Table 4. Individual costs of dental screening per child in the traditional and teledentistry models

<table>
<thead>
<tr>
<th>Remoteness category</th>
<th>Mean cost estimate per child (AUD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional model</td>
<td></td>
</tr>
<tr>
<td>R1</td>
<td>$41</td>
</tr>
<tr>
<td>R2</td>
<td>$43</td>
</tr>
<tr>
<td>R3</td>
<td>$49</td>
</tr>
<tr>
<td>R4</td>
<td>$172</td>
</tr>
<tr>
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<td>Teledentistry model</td>
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Sensitivity analysis

The cost analysis showed that the threshold at which the teledentistry alternative became cheaper than traditional dental screening occurred at a workload of 22,700 children (Fig. 4). A series of scenarios were created to identify the effects of making different assumptions about the underlying variables on the total costs, as detailed below.

If a registered dentist was used to substitute a therapist or OHT as a chart, this assumption would make teledentistry costs increase from $56 to $61 million. Replacing a registered dentist or OHT with a qualified overseas-trained OHT (the average annual salary for dental therapists in New Zealand is $60,000) would lead to a reduction in the teledentistry cost by $4 million (8%) from the baseline estimated cost for teledentistry. The latter assumption would make the teledentistry model cheaper.

If a registered dentist ‘operator’ was replaced with OHTs to perform traditional screening, travel allowance expenses plus total salaries for OHT ‘operators’ and their assistants (FTE = 620) and their supervisory dentists (FTE = 1.3 operators) would be $132 million. This assumption would result in an increase of 8% from the baseline calculated cost for the traditional model.

Fig. 4. Costs of dental screening by the traditional and teledentistry models at different workloads. The threshold indicates that at a workload of 22,700 children, the costs of the teledentistry approach became lower than traditional dental screening. AUD, Australian dollars.
Assuming a charter or OHT reviews 24 records per day (rather than the proposed 36 records) and a tele-assistant recruits four children (instead of the proposed six children) per hour over 6 days (i.e. 24 children per day) results in a teledentistry model cost of $375 million, an increase of 30% from the baseline of estimated costs for teledentistry. Alternatively, if we considered a charter or OHT reviewing 48 records per day (instead of the proposed 36 records) and a tele-assistant recruiting eight children (instead of the proposed six children) per hour over 6 days (i.e. 48 children per day), the teledentistry model would cost $38 million, a decrease of 35% from the baseline calculated cost. The latter assumption would make the teledentistry model the cheapest of all the scenarios.

If we considered a charter or OHT charting 48 records per day (rather than the proposed 36 records) and a 15% reduction in the standard salary for charters was assumed in the calculation, the total costs of the teledentistry model would decline by 20% from the baseline estimated cost, resulting in a teledentistry model cost of $40 million. In contrast, if we considered charters or OHTs charting 24 records per day (instead of the proposed 36 records) and a 15% rise in the standard salary for charters in the calculation, the total costs for teledentistry would escalate from $50 to $72 million.

If an operator spent 5 min (rather than the proposed 15 min) completing a visual examination and we assumed a 15% reduction in the standard salary for the operator or assistant, combining both assumptions leads to the traditional model costing an estimated $49 million, a decrease of approximately 64% on the baseline estimated cost. This would make the teledentistry model slightly more expensive than the traditional model of dental screening. Alternatively, if an operator spent 25 min (instead of the proposed 15 min) completing a visual examination and we assumed a 15% increase in the standard salary for operator or assistant in the calculations, the total costs of the traditional model would escalate from $135 to $241 million. This assumption would make the traditional model the most expensive alternative among all scenarios.

When considering the lowest prices for travel and accommodation and a 15% drop in the standard salary for operators or assistants in the analysis, the total costs of the traditional model of screening would decrease from $135 to $114 million, giving a net saving of $21 million. In contrast, when the highest prices for travel and accommodation and a 15% increase in the standard salary for operators or assistants was taken into account, this increased the costs of the traditional model from $135 to $156 million, resulting in a net saving of $100 million with the teledentistry model.

Discussion

A cost-minimisation analysis was undertaken in the present study to identify whether dental screening using teledentistry could reduce total costs compared with the traditional approach. Like previous studies, the present study demonstrated significant savings, particularly in rural and remote areas. The analysis showed that the traditional approach used for dental screening was $85 million a year more expensive than the teledentistry model. The major contributions to the cost savings of the teledentistry model were the low cost of salaries for charters and OHTs and avoidance of travel and accommodation costs, as well as a reduction in the use of equipment or disposable supplies. Australia is the world’s sixth largest country geographically with a total population of only 23 million, with the majority living in capital cities. Conducting traditional dental screening in large geographical areas and among such sparsely distributed populations would require lengthy travelling and huge expenses. The avoidance of travel and overnight accommodation contributed to 15% of the total net savings. The fixed costs of the teledentistry model were relatively low and represented a small proportion of the overall expenses. This could be attributed to improvements in teleradiology technology. As the technology for teleradiology evolves, the cost of equipment will decrease while the quality of teleconsultation improves.

In Australia, as in many other countries, the private sector remains the primary dental health delivery system, with most dental services funded on a private basis, and oral care is delivered on a fee-for-service basis. Given that less than half of all Australians have private dental insurance, these individuals are responsible for meeting the full cost of private oral care. Recent evidence indicates that a substantial number of Australians are unable to access oral care due to financial barriers. In addition, the SDS is unevenly distributed across Australia, largely concentrated in urban areas. In addition, the SDS has been suffering from funding difficulties and chronic recruitment and retention issues that contribute to the inequity in access to dental care among school children. Through the SDS, OHTs rarely provide sustainable dental services to large numbers of school children and are unable to reach those living in underserved or remote areas. The prohibitive costs of dental care (dental care is not covered by Medicare), the uneven distribution of dental services across Australia and the scarcity of resources make providing dental care to all school children difficult.

Numerous strategies have been proposed to address unmet oral health needs, including the use of role substitution to provide dental care. MDPs, such as OHTs and dental therapists, are often ideal for playing a role in dental screening. They have the potential to provide safe and good-quality dental care at a lower cost than a dentist. Also, training and developing this type of dental workforce would require significantly less time and fewer resources than training a clinical dentist to perform clinical on-site screening. The use of a teledentistry approach to screen for dental caries could offer a means for the effective use of OHTs to remotely screen large numbers of people at a low cost. Screening could be a first step towards the implementation of preventive services and the effective control of dental caries. Dental screening in asymptomatic populations facilitates the identification of children at risk of developing the disease and allows them to receive specific dental care. Those children considered low risk do not need additional management other than to receive preventive care. This strategy can help direct specific dental care or preventive services towards a population that needs it more and allows for the optimal distribution of scarce resources, thus contributing to reducing inequalities in oral health.

The findings of the present study demonstrate that considering OHTs for the operator’s role in the traditional model is more costly than using dentists. Additional phenomena observed are related to the costs of supervising OHTs at screening locations. Under the SDS, OHTs have a limited scope of practice and
therefore need to practice under the indirect supervision of a dentist. This means that before OHTs can start providing treatment, supervisory dentists need to re-examine children in order to verify treatment plans, particularly for those with a moderate or severe disease. With just less than half of Australian children expected to be free of decay, sending dentists to review OHTs’ assessments at screening sites is costly. In contrast, the tele-dentistry model, supervisory dentists can monitor OHTs indirectly through teleconsultations and have access to the database, which allows them to verify OHTs’ treatment plans easily and quickly. In the near future, with an extended scope of practice and increasing numbers of OHTs (the Bachelor of Oral Health Therapy is now offered in eight universities), it could be possible to delegate the operator’s role to OHTs under the traditional model.

In the sensitivity analysis, the operator’s role was modified, with qualified overseas-trained MLDPs considered, to enable costs comparison with other nations. The findings suggest that the tele-dentistry approach supports or facilitates the use of overseas-trained OHTs with accredited qualifications, such as those from New Zealand, the UK, Ireland or Canada, to screen for dental diseases at a distance. When considering ethical and legal aspects, this approach is not intended to remove overseas OHTs from their existing jobs or activities. The tele-dentistry approach enables oral health professionals anywhere in the world to view and assess dental photographs at their desktops and at their convenience, without the need to be physically present at the screening locations. Using a limited number of off-site overseas OHTs with good mentorships could reduce the dependence on overseas-trained dentists from developing countries who are primarily brought in to mitigate extreme shortages in rural areas.

To our knowledge, no attempt has been made to visually screen all school children in Australia. Undertaking traditional dental screening of all Australian children by dentists or any oral health professionals is challenging due to the high costs associated with such a screening program and distribution of the dental workforce. Apart from the economic evaluation, the tele-dentistry model would provide valuable data about the extent and severity of dental diseases among all Australian children. The data collected from the tele-dentistry model can be easily linked to existing oral health databases across the states and territories (there are no universal oral health databases in Australia). In addition to its great potential to save substantial costs and improve oral health, tele-dentistry also has the potential to enhance career or employment opportunities, particularly for those practitioners suffering from physical disabilities and occupational injuries (e.g. chronic shoulder or back disorders) or those nearing retirement age who would prefer to practice without interacting with patients.

The present study has some limitations. Dental services (e.g. restoration, preventive care or oral health promotion) that are often provided by school dental therapists through the SDS were not considered in the analysis. This is due to the scope of the study, which was focused on evaluating the use of tele-dentistry in dental screening and the difficulty of assigning a monetary value to these services. Despite the large sample size (all school children in Australia) considered in our model, the findings may not be generalizable to models of other dental services or age groups other than children. In a previous study, we showed that in some situations there was a loss of diagnostic details due to the poor quality of dental photographs obtained using smartphone cameras. This may require repeating dental photography and result in a delay in the screening process. In addition, in the tele-dentistry model, the ability of charterers and their supervisors to engage about particular cases is limited compared with the traditional model, because they need to rely on local tele-assistants to obtain information. Because the supervisory dentists, charterers and tele-assistants and IT team are working at different locations, they have to rely on telecommunication for liaison. The absence of collaboration or coordination between remote and hub sites may represent a barrier to the success of tele-dentistry.

Conclusion

To our knowledge, this study presents the first national-level cost model that has been developed to estimate the potential cost savings from using tele-dentistry for school dental screening. The results of the present study suggest that tele-dentistry is a practicable and economically viable approach for mass dental screening. The cost of the tele-dentistry model was substantially lower than that associated with conventional face-to-face dental screening, not only in remote and very remote regions, but also in urban areas. The primary driver of net savings is related to the lower salaries of MLDPs and the avoidance of travel and overnight accommodation costs. The economic evaluation of tele-dentistry services is essential to ensure efficient allocation of resources and redirection of net savings to improve oral care services in underserved regions. Such studies can be helpful in guiding future decisions on implementing tele-dentistry services. Further research on the cost-effectiveness of tele-dentistry considering other dental services (not only dental screening) is warranted to improve the current model.

Competing interests

None declared.

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Appendix V

Publication Arising from Chapter 13

**Optimizing patient referrals to dental consultants: Implication of teledentistry in rural settings**

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**EDITORIAL**


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The uneven distribution of dental practitioners (particularly consultants – in Australia commonly called specialists) in Australia creates a barrier to accessing consultant level dental care. This maldistribution often results in the isolation of general dental practitioners (GDPs) practising in rural/remote settings, and the consequent lack of easy access to a second expert opinion from dental consultants. It then becomes challenging for GDPs to weigh up cases that need consultant advice. This, at times, can contribute to under-referral or unselective referral of patients that require consultant advice, furthering the burdens on rural residents through additional travel and increased waiting times.

In Australia, distances to the nearest referral centre continue to be a matter of concern for many rural and remote residents. The traditional paper-based referral pathway has historically been the key method for sharing clinical information between GDPs and specialists; however, there is a growing risk that the referral letters may lack essential clinical information (photos, radiographs or pathology results). The problem with the traditional paper-based referral is not about the quality of the referral letter, but the inability of this method to provide timely information to specialists and provide digital data. This could lead to inappropriate referrals of cases and missing cases which require referrals. Inadequate referral letters are often associated with delayed patient assessment and contribute to delayed diagnosis and treatment of even sinister lesions (e.g., oral cancer), and less favourable outcomes for the patient.

In Australia patients don’t normally have direct access to specialist care, but near universally on a referral basis from a GDP. In addition, the majority of specialist dentists in Australia are working in the private sector (in major urban centres) which can add a layer of complexity, and cost, for patients including travelling and loss of productivity. In the traditional referral pathway, a patient is referred to a specialist accompanied by a referral letter. The additional digital information (clinical photographs and radiographs), which typically is not available through the traditional referral pathway, may impact not only diagnostic validity, but also clinical outcomes. Many referred cases can be assessed through good radiographs and/or pathology test and a provisional treatment plan can be provided without the need for a hospital visit. In view of these limitations in traditional paper-based referral pathways and the absence of a central oral health record that connect GDPs to specialists, developing alternative referral models for managing and prioritising treatment for patients is an important opportunity.

Alternatively, dental consultants can provide consultation through the utilization of teledentistry technology. The use of teledentistry, (often seen as a sub-specialty of telehealth), has rapidly grown and proven beneficial recently.1 Consultation through teledentistry can take on two modes, real-time and store-and-forward. Real-time (synchronous) consultation involves a videoconferencing between a patient and his/her practitioner at a remote site, as well as another practitioner (often a consultant) at a hub site simultaneously. The real-time application is more useful for continuing education and consultation.
between GPs and consultants.3,5 With the majority of consultants working in the private sector, in the long-term, the use of the real-time modality in consultation can be inconvenient, time-consuming and costly, as compared to the store-and-forward consultation. In store-and-forward (asynchronous) consultation, clinical data (radiography, photographs and personal information) is stored, before being forwarded electronically for a consultant advice. Available evidence indicates that the store-and-forward application has the potential to prioritise new patient appointments and facilitate patient referrals particularly in certain dentistry disciplines such as orthodontics6-8, oral surgery9 and oral medicine.10 The practices of store-and-forward teleconsultancy have also proven to be more cost-saving and efficient compared to real-time and in-person consultation.11 Taking advantage of the information and communication technology and increasingly widespread global connectivity, as well as access to low-cost, secure cloud storage, has the potential to improve referrals and make oral care services more accessible. A number of asynchronous-based referral systems have been developed in other healthcare disciplines in particular telemedicine.10-12 These resulted in a reduction in the number of patient referrals and waiting time as well as improved accuracy of diagnosis and treatment outcomes.

Our initial efforts lead to the development of a cloud-based server, “Remote-i”, based on store-and-forward technology, to work as a platform for storage and management of databases.13 This system enables uploading and storing images and patient information online either directly from a smartphone or computer. Also, the system is capable of image acquisition, entry, storage and retrieval of data through a secured system. Users can access the database using a web-based data and image-viewing app built upon the Remote-i system. GDP can upload patient information along with x-ray images and intraoral photographs to the Remote-i for later evaluation by a consultant at a distance. In the teleconsultancy-based referral model, patients do not need to travel to visit a consultant, as dental specialists can access the database in their convenient time and assess records at a distance to determine whether a case needs a referral to a specialist or can be treated by a locally-based GDP. To ensure data privacy, patients’ data stored on the server are anonymous and unidentifiable, the record for each patient has an ID that corresponds to the hospital/clinic ID, and all users use username and password to access the database. The proposed tele-referral system design process is shown in Figure 1.

Many dental consultants favour direct visual examination of patients to establish a valid diagnostic decision. However, due to the inability of consultants to travel to examine patients in their hometown, a teleconsultancy-based referral system could provide an opportunity for consultants to identify those for which referral is unnecessary or could be delayed, thus help in a reduction in the number of referrals to specialists. In this way, patients with potentially malignant lesions, or those requiring urgent intervention can be prioritised for assessment by a consultant. This in time, could result in a reduction in time from referral date to the date treatment commenced, thus providing a quick pathway to a consultant. Thus, teleconsultancy has implications for validation of referrals (and thus by corollary the optimization of waiting times based on risk). From dentists’ perspective, teleconsultancy has the potential to reduce inappropriate referrals, in certain disciplines like orthodontics, oral medicine, oral surgery and paediatric dentistry, through providing a second opinion and timely information to GDPs for better decision-making and supporting locally-based treatment. Teleconsultancy could increase the integration of remote dental experts by reducing dental consultants’ need for travel and facilitate interactivity (consultations and sharing of patient health information) between rural practitioners and dental consultants. Reductions in travel time would also result in an increased availability of the dental consultant services at their residence clinics. In the long term, the Remote-i system can be used as a starting point for establishing a wider electronic oral health record. It would also allow dental practitioners to incorporate dentistry into the larger health-care delivery system by enhancing collaboration with other healthcare disciplines.

Teleconsultancy has the capability to connect dental experts anywhere in the world. This is particularly important to the sparsely populated and isolated communities that do not have access to specialist dental care. This technology is particularly attractive because almost all dental practices (in developed countries) are now equipped with a computer, digital camera, radiography, and internet access, even in underserved regions. From a practical approach, it seems reasonable to use technical equipment that is readily available in dental practices, which automatically provide the infrastructure for teleconsultancy solutions. Store-and-forward teleconsultancy can be incorporated into the oral health system to create an efficient and reliable screening system to optimize referrals and prioritize patients’ assessments, and thus offers an alternative (or, at least, an augmentation) to the traditional referral pathway. Historically, teleconsultancy services have been underutilized due to privacy
vulnerability, costs and lack of clear guidelines to regulate teledentistry practice. It is expected that as the technology continues to advance, these issues will not be critical in the near future. Further research is needed to evaluate the effectiveness of the proposed system in improving referrals and prioritizing patients’ assessments.

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PEER REVIEW
Peer reviewed.

CONFLICTS OF INTEREST
The authors declare that they have no competing interests.

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Figure 1: Flow diagram of the proposed tele-referral system

A GDP uploads records of referred cases to the cloud server for a later evaluation by a consultant at a distance.

A dental expert accesses the database to assess the records to determine whether it can be released or deleted at a managed site.

Dental expert at the hub site.