Teleophthalmology: Feasibility Study in Western Australia

Kamala Raghavan Sajeesh Kumar

This thesis is presented for the degree of Doctor of Philosophy

THE UNIVERSITY OF WESTERN AUSTRALIA

Centre for Ophthalmology and Visual Science
June 2006
Preface

This thesis consists of a series of published and intended to publish papers for refereed, international scientific journals. Whilst the journal papers have multiple authors, only the work, where I am the primary author has been included in this thesis. In these papers, the first author performed conceptualization, design, development, clinical trial, fieldwork, data collection, analysis, writing and presentation, while other authors provided supervision, assistances and review of the work.
Declaration

The work presented in this thesis is the original work of the author, and none of the material in this thesis has been submitted either in full, or in part, for a degree at this or any other university. The design and planning of the study and the preparation of this manuscript were carried out by me after discussion with my supervisors, Prof. Yogesan Kanagasingam (Centre of Excellence in e-Medicine) and Prof. Ian J Constable (Lions Eye Institute).

Kamala Raghavan Sajeesh Kumar
June 2006
Abstract

The issues relating to feasibility of telemedicine based eye care (teleophthalmology) to the rural and remote regions in Western Australia has not been established.

For the first time, these issues are investigated in this thesis by presenting original techniques. Towards this goal, an extensive review of economic studies concerning teleophthalmology service was carried out. Further, a dedicated teleophthalmology service in rural Western Australia was evaluated exhaustively. Apart from comprehensive economic analysis, the rural and remote patients’ and clinicians’ perception of this novel healthcare intervention was also analyzed.

Feasibility of the teleophthalmology service was further augmented with the development of novel, computerized visual function tests. Towards an effective, feasible teleophthalmology based eye disease screening strategy, the thesis also accomplished an extensive review of protocols for a major, blinding disease-glaucoma- in Western Australia. Furthering the research towards teleophthalmology service feasibility, this thesis evaluated the usefulness of various telemedicine-friendly digital devices.

This thesis demonstrates that the teleophthalmology services could be feasible and successful in remote eye care. Further potential enhancements to the teleophthalmology service feasibility and sustainability are outlined in this thesis through original contributions are made to the body of knowledge in each area. The thesis identified effective procedures towards potentially useful teleophthalmology screening protocol, computerized visual function tests and telemedicine friendly devices for remote eye care.

In summary, the research techniques, developments, trials, and results presented in this thesis leads to an improved understanding of the feasibility of telemedicine in rural and remote eyecare in Western Australia.
Acknowledgments

My humble and sincere thanks and praises to God Almighty who helps and inspires me. To Him I dedicate this effort.

On a personal note, my biggest thank you to my beloved parents and lovely sisters whose unlimited love and support throughout my life made this undertaking so pleasant and rewarding.

I am indebted to my supervisors Prof. Yogesan Kanagasingam (Centre of Excellence in e-Medicine) and Prof. Ian J Constable (Lions Eye Institute) for their guidance, challenge, encouragement and most importantly for their valuable and wholehearted support, unselfishly sharing their expertise, time and material in my work and also in the preparation of this thesis. My special thanks to Prof. Yogesan who is not only an excellent supervisor but also a champion and companion who while trusting me and allowing me to feel confident to do my work, inspired me a lot. I will always remember your warm welcome when I first arrived in Perth.

I would like to express my thanks for the financial support from Government of Australia through International Post Graduate Scholarship (IPRS), University of Western Australia through University Post Graduate Award (UPA-IS) and Lions Save Sight Foundation (LSSF) through Dr Jack Hoffman Post graduate Scholarship.

Part of the work in this thesis was completed with collaboration and the helpful data from Department of Health, Western Australia. I am grateful to Francisco Chaves, Eric Dillon and Robyn Fary from Telehealth Development Unit, Department of Health, Western Australia for their support for the study.

This thesis is my own work except where stated otherwise but here I would also like to acknowledge staff at the Lions Eye Institute. Thanks to Francis Dao who helped me with technical assistances for developing visual function tests. Thanks to Barry van der Vyuer, Judy Pilbeam, and Julie Robson for their assistances with the clinical trials of computerized vision tests. I would also like to acknowledge the assistances from Dr. Antonio Guibilato,
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I am most grateful to the patients and clinical and administrative staff at Carnarvon Regional Hospital and Lions Eye Institute, Perth for their co-operation with this study. Without you this thesis would not be possible. Big thanks go to Beth Hudson, Telehealth Coordinator at Carnarvon. I would also like to thank Dr. Catherine Middlemiss, School of Medicine, University of Aberdeen, United Kingdom for her timely assistance for evaluation of telemedicine friendly tonometers for glaucoma screening. And special thanks to Brian King MBE (Ex Chairman of Lions Eye Institute), all LSSF officials Lorraine Strikland, Gail Mason, Geoff Moore and the dedicated team of rural and remote glaucoma screening program who introduced me to the real life in the outback of this vast, magnificent continent. Each journey to a new territory was like a new chapter. Thank you all for making my stay in Western Australia so memorable.

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My thanks also to the American Academy of Optometry (AAO) and All Japan Optometric and Optical Association for the travel grants to attend the conferences in Hawaii and Tokyo respectively. Also, my sincere thanks to my friends, fellow students and numerous persons in the Western Australian community for making my stay in Perth most enjoyable.
Publications Relating to this Thesis

The following publications contain work from this thesis.

A. Refereed Journal Publications:


B. Book Chapter Publication:


C. Book Publication:


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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACD</td>
<td>Anterior Chamber Depth</td>
</tr>
<tr>
<td>CCT</td>
<td>Central Corneal Thickness</td>
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<tr>
<td>CMBS</td>
<td>Commonwealth Medicare Benefit Schedule</td>
</tr>
<tr>
<td>CRH</td>
<td>Carnarvon Regional Hospital</td>
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<tr>
<td>CVFT</td>
<td>Computerized Visual Function Test</td>
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<tr>
<td>DOHWA</td>
<td>Department of Health, Western Australia</td>
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<tr>
<td>DR</td>
<td>Diabetic Retinopathy</td>
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<td>ETDR</td>
<td>Early Treatment Diabetic Retinopathy study</td>
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<tr>
<td>FDT</td>
<td>Frequency Doubling Technology</td>
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<tr>
<td>GAT</td>
<td>Goldmann Appplanation Tonometer</td>
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<tr>
<td>GP</td>
<td>General Practitioner</td>
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<tr>
<td>IOP</td>
<td>Intra Ocular Pressure</td>
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<tr>
<td>Kbps</td>
<td>Kilo Bytes Per Second</td>
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<tr>
<td>LEI</td>
<td>Lions Eye Institute</td>
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<td>PATS</td>
<td>Patient Assisted Travel Scheme</td>
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<td>POAG</td>
<td>Primary Open Angle Glaucoma</td>
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<td>RANZCO</td>
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<td>RFDS</td>
<td>Royal Flying Doctor Service</td>
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<td>WA</td>
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<td>WHO</td>
<td>World Health Organization</td>
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Chapter 1

Introduction

1.1 Thesis Structure and Overview
The main body of this thesis is presented as a series of published and intended to publish papers for high impact scientific journals and papers presented at international scientific conferences. In Part 1 of this thesis, a general overview of the thesis is given. The issues of feasibility of teleophthalmology in Western Australia are dealt in the subsequent chapters in two parts (Part 2 and Part 3). This is followed by a general discussion and conclusion (Part 4).

Following this introduction is Chapter 2, which comprise the published version of an introduction to teleophthalmology.¹

Part 2 of the thesis consist of chapters 3, 4 and 5. In chapter 3, a published version of extensive literature review of cost-benefit analysis of teleophthalmology is detailed.² Chapter 4 essentially is a comprehensive evaluation of a teleophthalmology service. This chapter incorporates 3 published papers on feasibility of teleophthalmology service.³,⁴,⁵ The published paper representing Chapter 5, reports patient perspective analyses on the efficacy of teleophthalmology service.⁶

Part 3 of this thesis deals with clinical issues relating to feasibility of teleophthalmology and consist of chapters 6, 7, 8 and 9. Chapter 6 reviews existing glaucoma screening
Chapter 1. Introduction

protocols towards a novel teleophthalmology screening protocol for glaucoma. Towards this goal, Chapter 7 analyses telemedicine friendly, portable tonometers. The Chapter 8 further analyses the conventional and telemedicine friendly devices. The research and development of computerized visual function tests for increasing the efficacy of teleophthalmology service is outlined in Chapter 9.

A general discussion and conclusion is given in Part 4. Chapter 10 in this section discusses issues that influence the feasibility of teleophthalmology. This chapter essentially comprises 3 published manuscripts. Conclusion of the study is presented in Chapter 11. This is followed by the significance of the study and the suggestions for future work in Chapter 12. A Bibliography containing the complete literature database referenced for this thesis work follows in Chapter 13.

Chapter 14 contains a number of appendices. Appendixes 1-7 are some of the published articles relating to this thesis. Appendix 8 is a teleophthalmology protocol which was developed and used for teleophthalmology project in Carnarvon, Western Australia. Appendix 9 is a sample of patient questionnaire. Appendix 10 is a clinician perception evaluation form. Appendix 11 is a teleophthalmology log sheet.

1.2 Need of the Study

Teleophthalmology research is about the investigation of the feasibility, implementation, acceptability and limitations of such processes. The Western Australian (WA) Health Reform Committee 2004, states as recommendation 22 that: ‘Opportunities for Telehealth to be a component of the integrated care system should continue to be explored’. It is reported that, without extra interventions, the global number of blind individuals would increase from 44 million in the year 2000 to 76 million in 2020. In Australia, without intervention the number of people with vision impairment will double over the next 20 years from 400,000 to 800,000. 80% of those people will lose vision or go blind unnecessarily. In year 2004 alone, blindness and other vision problems cost Australia more than $9.8 billion in treatment and lost income, prompting calls for more research funding aimed at preventing eye disease.
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About 490,000 in a total population of Western Australia of 1.8 million live in rural and regional areas. The table below (Table 1) shows that in some areas in WA a high percentage of the population was found to have a sight-threatening eye condition, which in most cases is treatable (In the table below, "Total" = number of people affected by blinding eye diseases in each area, "%" = Percentage of population affected by eye disease).

**Table 1:** Number of people with sight-threatening eye condition in WA.

<table>
<thead>
<tr>
<th>Centre</th>
<th>Diabetes</th>
<th>Glaucoma</th>
<th>Cataract</th>
<th>Trachoma</th>
<th>Total</th>
<th>Total population</th>
<th>%</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Aborigine</td>
<td>non-Aborigine</td>
<td>Aborigine</td>
<td>non-Aborigine</td>
<td>Aborigine</td>
<td>Total</td>
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<td>33</td>
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<td>618</td>
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<td>205</td>
<td>10</td>
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<td>2142</td>
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The provision of ophthalmic services to Aboriginals and Torres Strait Islanders was extensively reported in 1997 by Prof. Taylor H. Significant points of his report are:

- the provision of specialist eye services in remote areas are inadequate
- the ocular problems in which the aboriginal population is over represented are
  - cataract (3.6% compared to 0.8% of non-Aboriginals)
  - diabetic retinopathy with up to 35% affected
  - trachoma, affecting 13% of the population, and in one region affecting over half the children.
- 1.49% of Aboriginals are blind (≤ 6/60) compared to 0.16% in the non-aboriginal population.

In the state of Western Australia, with a land area approximately ten times larger than United Kingdom, ophthalmologists practice mostly in the Perth city area. Regular specialist visits to 15 regional hospitals in the state happen only once or twice a year. When specialist ophthalmic care is required for people in remote areas, this need may remain unfulfilled for some time, or the patient must be sent to Perth. Moreover, detailed, specialist examination of the eye cannot be performed in regional hospitals due to the absence of appropriate equipment. Considering this scenario, teleophthalmology may be an alternate mode of service to identify and manage the preventable and treatable causes of blindness and visual impairment in remote regions of Western Australia.
Chapter 1. Introduction

While the use of teleophthalmology is limited but growing, evidence of its clinical and economic feasibility is incomplete. Most of the available literature refers to pilot projects, and in many publications the descriptive status of the application only was reported.

In Western Australia, few rural and remote communities are already receiving a small number of telemedicine services. There is thus growing local experience, which needs to be monitored carefully and evaluated for its ability to affect health outcomes. There are also limited overseas data emerging on implementing and utilising teleophthalmology services. However, from a review of the literature and direct visits to overseas systems, it is apparent that there are yet little data available on the feasibility of teleophthalmology service.

Cost analysis is one of the techniques of economic evaluation designed to compare the feasibility of a healthcare intervention to assess whether it is worth doing before they can be considered for routine use on a large scale. A published, international literature review carried out for this thesis work shows that although a number of services are in progress, there is a lack of data on the cost effectiveness of telemedicine in ophthalmology. Hence, a systematic analysis of the costs of teleophthalmology and its alternatives is vital need for decision-makers to opt for or against new teleophthalmology services. Based on this critical need, the present study aims to evaluate the cost of an established, ongoing teleophthalmology service from a healthcare service provider’s perspective.

Before adoption into routine use, such new medical technology has to be proved to be acceptable to the patients and clinicians. At present, much is assumed and little is known about the patient and clinician acceptance of a telemedicine based eye care service. Given this vital need of data, the current research aims to study the patient and clinician satisfaction and attitudes towards teleophthalmology services in Carnarvon, a rural and remote region in Western Australia.

The feasibility of teleophthalmology service in a community based ophthalmic screening setting involves the usage of appropriate protocol. Glaucoma is a leading cause of irreversible blindness in the world, and it will become a larger problem as the populations of various countries age. In the absence of specialists, glaucoma screening in rural and remote regions, is a difficult proposition, which further indicate that, there is a dire
need of teleophthalmology specific glaucoma screening protocol. This necessitates verifying existing screening protocols and analyzing the accuracy of medical devices for teleophthalmology screenings.

Meanwhile, despite the availability of technological, financial and human resources, a significant number of people face unnecessary vision impairment and vision loss in Australia. Almost 50% of legal blindness and 70% of vision impairment in Australia are caused by conditions that are preventable or treatable.\textsuperscript{14} Non-availability of specialist ophthalmologists in remote and rural regions has been the major obstacle in screening and data collection for blindness and vision impairment.\textsuperscript{9} This situation indicated an urgent need of teleophthalmology based visual function screening tests, which will provide access to complex visual function tests and early diagnosis to the remote regions of Australia and enhance the feasibility of teleophthalmology service.

1.3 Aims of the Study
The aim of the study is to analyze and report issues relating to clinical and economical feasibility of teleophthalmology service in the state of Western Australia.

1.4 Objectives of the Study
The objective of the current study is to answer the following questions:

- Is teleophthalmology service cost effective than the existing eye care delivery options?
- Are the patients and clinicians satisfied with teleophthalmology service?
- Are the digital, portable devices feasible for glaucoma screening?
- Is the computerized visual function test feasible towards screening visual impairment?

1.5 Study Methods
Cost information relating to the teleophthalmology service to the Gascoyne regional population in Western Australia was gathered and compared with alternative options available. Data on service provision costs was gathered from the Department of Health of Western Australia (DOHWA), the Carnarvon Regional Hospital (CRH) and the Lions Eye
Institute (LEI). Data from the Commonwealth Medical Benefits Schedule (CMBS) was used to quantify standard and specialist consultation costs.

Effectiveness of existing protocols for glaucoma screenings was reviewed. Evaluations of telemedicine friendly devices were also carried out towards feasibility of teleophthalmology service. Innovative computerized visual function tests were designed and developed to optimize visual impairment data collection from rural and remote regions through teleophthalmology. These tests were trialed at the Lions Eye Institute’s Eye clinic for comparison with existing manual tests. All statistical analysis was done using Stata version 8 (*Stata Statistical Software: Release 8.0 (2003) College Station, TX: Stata Corporation*). Ethical approval was obtained from the University of Western Australia Human Ethics Committee and the Western Australia Aboriginal Health Information Ethics Committee.

### 1.6 Results in brief

- Teleophthalmology consultations are economically feasible from a health service provider perspective.
- Patients are satisfied with the teleophthalmology service.
- Clinicians are satisfied and expressed positive outlook towards teleophthalmology.
- Portable, digital devices are identified towards effective glaucoma detection.
- Computerized visual function tests contribute towards effective implementation of teleophthalmology in rural and remote regions.

### 1.7 Conclusions

Teleophthalmology services are cost efficient in relation to the alternatives available in Western Australia. However, better coordination of services is required in order to deliver increased benefits at a lower cost to the system. Potential early identification of visual impairment is achievable by computerized visual function tests which will be useful in preventing severe vision loss. By employing appropriate digital devices, blinding diseases like Glaucoma could be identified and managed at the earliest in remote regions.
Chapter 1. Introduction

1.8 Contributions to the Field of Eye Care in the Remote Regions

This thesis has led to an improved understanding of the clinical and economical feasibility of telemedicine in remote eye care. This thesis has identified some potentially useful strategies for rural and remote teleophthalmology service feasibility, including the teleophthalmology based glaucoma screening devices and computerized vision function tests for remote eye care. Immediate outcomes of this thesis are outlined as follows:

- Awareness of issues relating to feasibility and implementation of teleophthalmology through publications in high impact, refereed international scientific journals.
- Recognition, approval and adoption of teleophthalmology as a reliable service by Royal Australian and New Zealand College of Ophthalmologists (RANZCO). RANZCO also advocates reimbursement of teleophthalmology consultations by allocating a CMBS item code.
- Result of this study has been utilized by Department of Health, Western Australia in the Telehealth Strategic Planning (TSP 2005).
- Result of this study has been utilized by Department of Health and Ageing, Australian Federal Government, Canberra towards a National Eye Health Plan for Australia 2005-2010. This is a national framework for action to promote eye health and prevent avoidable blindness and vision loss (National Eye Health Plan 2005-2010).
Chapter 2

Background: Research Scenario

2.1 World Health Organization on Prevention of Blindness
The World Health Organization estimates that an estimated 180 million people worldwide are visually impaired, and of these, between 40 and 45 million persons are blind (WHO 2004).\textsuperscript{22} It also estimates that about 80% of blindness around the world is avoidable, either resulting from conditions that could have been prevented or controlled if the available knowledge and interventions had been applied earlier (e.g. glaucoma), or successfully treated by restoring sight (e.g. cataract, short sightedness).\textsuperscript{22}

In May 2003 the 56\textsuperscript{th} World Health Assembly passed resolution WHA56.26 on the elimination of avoidable blindness in recognition of the fact that 45 million people in the world today are blind and that a further 135 million people are visually impaired.\textsuperscript{23} The resolution urged member states to develop a national Vision 2020 plan in collaboration with non-governmental organisations and the private sector to prevent avoidable blindness.\textsuperscript{9, 23}

2.2 Overview of Eye Health Scenario in Australia
Loss of vision impacts on the lives of many Australians. Some of the most prevalent causes of blindness and vision loss in Australia are conditions that are potentially preventable or for which effective treatments exist.\textsuperscript{23}
Chapter 2. Background: Research Scenario

In Australia the main causes of blindness and vision loss are uncorrected or under-corrected refractive error, diabetic retinopathy, glaucoma, macular degeneration, cataract, retinitis pigmentosa, eye injuries and trachoma which is present in some remote regions of Australia.9,23

2.2.1 The Prevalence of Eye Disease in Australia

Based on the results of the 2001 National Health Survey, 9.7 million Australians or 51% of the population had at least one sight problem.24 The most commonly reported eye disorders were refractive errors, such as long-sightedness, short-sightedness, presbyopia and astigmatism. Cataract was reported by 2% of respondents and glaucoma by 1%. The prevalence of sight problems increases rapidly with age, reaching 87% by ages 45-54 and 96% by ages 75 and over, and is more common in females (55%) than males (47%).9,23 Refractive errors are optical defects that result in light not being properly focused on the eye’s retina. The most common are myopia (short-sightedness), hypermetropia (long-sightedness), astigmatism (uneven focus) and presbyopia (an age-related problem with near focus).22

The prevalence rate for glaucoma in 2004 was estimated to be 2.3% (109,300) for the Australian population aged 55 years or more.25 It is estimated that about 133,900 Australians aged 55 or more had diabetic retinopathy (DR) in 2004, which represents 2.8% of that population.25 The prevalence of DR was greater in the older age groups. Published results from the Diabetes, Obesity and Lifestyle Study reported that the prevalence of DR was similar in men and women.26 Also, any form of DR was 22% in those with known type 2 diabetes and 6% in those who had not previously been diagnosed.26

The prevalence of proliferate retinopathy was 2.1% in those with known type 2 diabetes and there were no cases identified among those who had not been previously diagnosed.26 DR is the primary vision-threatening condition for Aboriginal and Torres Strait Islander people.27

It is estimated that in Australia 116,000 people attend to hospitals or general practitioners each year with unintentional eye injuries.28 Many people do not wear eye protection when
Chapter 2. Background: Research Scenario

performing high risk activities, such as welding and grinding, particularly in the rural and home environment. Injuries also occur when eye protection is ill-fitting or not worn at appropriate times.28

2.2.2 Groups at Particular Risk of Blindness

Certain population groups are at particular risk of developing eye disease, including older people, people with a family history of eye disease, people with diabetes and Aboriginal and Torres Strait Islander people.

In Australia, although the number of children at risk of blindness is small, prevention of avoidable childhood blindness and vision loss is particularly important, because of the years of sight loss that ensue and the severity of implications for child development.

People with diabetes are at increased risk of developing eye disease, particularly diabetic retinopathy, cataract and glaucoma. It is estimated that as many as one million Australians have diabetes, though many are unaware of it.29 Age at onset and duration of diabetes are key factors influencing the prevalence of eye disease in people with diabetes. For example, in young people with diabetes (aged less than 30 years at diagnosis) the prevalence of diabetic retinopathy is 25 percent during the first 5 years after diagnosis, rising to 50 percent after 15 years since diagnosis.29

After the age of 40 the amount of visual impairment and blindness increases threefold with each decade of age.30 It is estimated that as the population ages, vision impairment will emerge as the most prevalent health condition amongst older people.30 Blindness and vision loss restrict mobility and increase morbidity amongst older people leading to a greater risk of depression, falls and hip fractures with an associated rise in hospital admissions and demand on community health and welfare services.

As with many other health conditions, Aboriginal and Torres Strait Islander people are potentially at increased risk of developing avoidable blindness and vision loss and are less likely to access eye health care practitioners than other Australians. Uncorrected refractive error, correctable with spectacles, is a leading cause of visual impairment in aboriginal
Chapter 2. Background: Research Scenario

communities, followed by cataract, diabetic retinopathy and trachoma. Australia is the only
developed country with trachoma that persists in some regions.

2.3 The Social and Economical Impact of Blindness and Vision Loss in Australia

Recent independent economic analysis undertaken by Access Economics (2004) for the
Centre for Eye Research Australia estimated the total cost of vision disorders in Australia to
be $9.85 billion. 31

Diseases of the visual system, and possible subsequent vision loss, represent substantial
social and economic concerns to the Australian public. Based on the results of the 2001
National Health Survey, 9.7 million Australians had at least one sight problem.32

Vision loss is among the major causes of disability. According to the 1998 Survey of
Disability, Ageing and Carers ‘loss of sight’ was the reason or part of the reason for
disability given by 2% of the total population (349,800 people).28 It was the principal cause
of disability in 113,200 people and about 39,600 people had a severe or profound ‘core
activity restriction’ due to loss of sight.28

Direct health costs of visual impairment include health system costs, including
pharmaceuticals, imaging and pathology, optometry and medical services, in patient and
outpatient procedures and aged care costs.30

Indirect costs of visual impairment include financial costs, such as earnings and taxation
forfeited and premature mortality rates, as well as the costs of carers, aids and building
modifications.30 Non-financial indirect costs are difficult to measure and include the pain,
suffering and loss of life quality that may result from visual impairment.

It has been estimated that the burden of disease for visual disorders was over 40,000
disability adjusted life years (DALYs) in 2004.31 This represents 2.7% of the total disease
burden.
2.4 Provision of Eye Health Care in Australia

Responsibility for eye health programs and services in Australia is currently spread across governments, the private sector, health care professions and non-government organisations.\textsuperscript{32}

Private health insurance is an important component in the funding of eye health care in Australia. Costs incurred by patients receiving private doctors' services and some optometry services, whether in or out of hospital, are generally reimbursed either fully or in part by means of Medicare benefits. Private insurance may also assist with meeting the costs of private sector services such as corrective eyewear.

Numerous non-government organisations provide community based services to promote eye health and assist people with low vision.\textsuperscript{33}

2.4.1 Medicare Benefits Schedule

The Australian government expends approximately $410 million per year for the full range of ophthalmology consultation, diagnostic and procedural items through the Medicare Benefits Schedule (MBS), as well as a range of items performed by participating optometrists under the Optometry Schedule of the MBS.\textsuperscript{34}

The Medicare Benefits Schedule lists a wide range of consultations, procedures and tests, and the Schedule fee applicable for each of these items.\textsuperscript{34} Proposed listings of new medical procedures and new technologies (example: Teleophthalmology) are assessed by the Medical Services Advisory Committee on the basis of evidence of safety, feasibility and cost-effectiveness.

2.4.2 The Specialist Eye Health Care Workforce

Specialist professions engaged in the delivery of eye care include ophthalmologists, optometrists, orthoptists, ophthalmic nurses and optical dispensers. The services they provide include prevention, education, research, treatment, rehabilitation and palliation. There is some overlap across the roles of the various eye health care practitioners.
2.4.3 The Generalist Eye Health Care Workforce

Generalist health professionals such as general practitioners (GPs), nurses, ambulance workers, pharmacists, Aboriginal and Torres Strait Islander health workers and the Royal Flying Doctor Service (RFDS) often provide basic services and advice relating to eye health. Nurses in many different settings may be called upon to provide eye care. These include occupational health nurses, community nurses and hospital nurses who work in emergency departments.

It is estimated that 1.8% of reasons for visits to GPs relate specifically to eye conditions, with removal of foreign bodies in the eye one of the most common services provided by GPs. GPs also play an important role in indirect eye care, through their care of patients whose conditions or medication can affect eye health, such as diabetes.

2.4.4 Eye Care Referral Pathways

No referral is needed for consultations with GPs, optometrists or ophthalmologists. However, medicare benefits are only payable for an initial consultation with an ophthalmologist if there is a referral from a GP, optometrist or current specialist. In general, referrals from GPs and optometrists are valid for 6-12 months, and for 3 months from other specialists. Eye health professionals may also refer people to non-government support groups.

2.5 Provision of Eye Health Care in Western Australia (WA)

2.5.1 General Eye Health Services

The WA Government funds regular visits to all regional areas of WA with a single ophthalmologist responsible for each separate area on a long term basis.

2.5.2 Patient Assisted Travel Scheme (PATS)

The PATS scheme in WA has run for decades and provides free travel and accommodation for patients, and their relatives if necessary, attending hospitals or private specialists in Perth.
2.5.3 Rural Eye Screenings in Western Australia

The advent of portable, easy to operate ophthalmic devices has revitalized Lions Glaucoma Screening programs throughout Western Australia on a free, voluntary basis. These programs are targeted at communities at risk as described in section 2.2.2.

2.6 Overview of Teleophthalmology

Teleophthalmology is a method by which patients’ eye-related problems can be examined, investigated, monitored and treated, with the patient and the eye care specialist located in different places. Tele is a Greek word meaning *distance*, and ophthalmology is the branch of medicine that deals with the anatomy, functions, pathology, and treatment of the eye. A major goal of teleophthalmology is to eliminate unnecessary traveling for patients and their escorts. Image acquisition, image storage, image display and processing, and image transfer represent the basis of teleophthalmology.

Telemedicine has been defined as the use of medical information exchanged from one site to another via electronic communications for the health and education of the patient or healthcare provider and for the purpose of improving patient care.¹

Teleophthalmology could be defined as the use of Information and Communications Technology (ICT) to provide eye care services to individuals who live some distance from the service provider.¹,¹⁷

Ophthalmology is a field of medicine that relies heavily on images of the eye to make a diagnosis and provide appropriate management of disease processes. With the advent of telecommunications technologies like internet and videoconferencing, the transmission of images of the eye for remote diagnostic and management purposes was conceived.

Although the use of older approaches (telephone, fax, photo screening) is commonplace, teleophthalmology applications increasingly use internet and videoconferencing technologies.¹ Teleophthalmology service includes medical diagnoses, treatment, prevention, education and research.¹
Teleophthalmology customarily uses two methods to transmit images, data and sound – either *live*, real-time transmission where the consulting professional participates in the examination of the patient while diagnostic information is collected and transmitted, or *store-and-forward* transmission, where the consulting professional reviews data asynchronous with its collection.

Digital still/video cameras are used for conducting the external portion of the general eye exam in store-and-forward or real-time mode.\(^1\) For reporting the refractive status of the eyes, auto refractors are used. At remote telemedicine sites visual field testing is done through automated perimeters.

Non-mydriatic digital fundus cameras are widely used to assess posterior segment pathology via teleophthalmology. The Heidelberg Retina Tomograph II, Panoramic200TM scanning laser ophthalmoscope and the TopSS Topographic Scanning System are also used in teleophthalmology. Refractive surgery patients are followed up teleophthalmologically with the use of a slit lamp video imaging system and a corneal topography unit. Intraocular pressure is measured using non-contact tonometer, assuming appropriately trained personnel are present at the remote site.

### 2.6.1 Structure of the Eye in Relation to Imaging

The eye is a complex optical system - very similar to a camera. Vision begins when light enters the eye through the cornea, a powerful focusing surface. From there, it travels through clear aqueous fluid, and passes through a small aperture called the pupil. As muscles in the iris relax or constrict, the pupil changes size to adjust the amount of light entering the eye. Light rays are focused through the lens, and proceed through a clear jelly-like substance in the centre of the eye called vitreous, which gives it form and shape. When light rays finally land on the retina, the part of the eye similar to film in a camera, they form an upside-down image (Fig 2.1). The retina converts the image into an electrical impulse that travels along the optic nerve to the brain, where it is interpreted as an upright image.
2.6.2 Digital Imaging in Eye Care

Development of technologies in telecommunication is supported equally by impressive advances in digital imaging and computing. Digital image processing and analysis techniques are an important adjunct to teleophthalmology on many levels. The role of newer technology in the form of digital computerised imaging offers the prospect of immediate high quality images that can be easily and quickly transferred from screening camera to a central reading centre through telecommunication systems. The advantages of digital ophthalmic photography and therefore teleophthalmology are:

- The ease of image acquisition and storage.
- Low running costs compared to film.
- Patients find the lower flash intensity of digital camera systems more comfortable.
- The ability to review images is popular with patients and carries potential for education.
- Image quality can be assessed immediately and, if needed, better quality images can be retaken.
- Digital images can be archived, stored, manipulated and transmitted to another location for review.
PART 2. FEASIBILITY OF TELEOPHTHALMOLOGY SERVICE IN WESTERN AUSTRALIA- ECONOMIC ASPECTS

Introduction to Part 2

The assessment of the feasibility of any telemedical intervention encompasses the study of costs involved and diffusion conditions for patients and providers. As the use of teleophthalmology service grows, provider and patient perspective evaluations merit greater attention. Part 2 of the thesis leads to a better understanding of teleophthalmology economic strategies, which will be used to deal with intertwined and complex issues related to teleophthalmology practices, health care service utilization as well as economic challenges.

Description of the Layout

The main body of this feasibility study is presented as a set of published papers.2-6 An extensive literature review is given in the chapter 3. Following this, chapter 4 is an economic evaluation of teleophthalmology service in WA. Chapter 5 presents an evaluation of patient and clinician satisfaction and attitudes towards web-based eye care services.
Chapter 3

Review of Economic Analyses in Teleophthalmology

3.1 Introduction to Cost Analysis Studies in General Healthcare

A systematic comparison of the costs of teleophthalmology and its alternatives are vital for decision-makers to opt for or against such new services. Cost analysis is one of the techniques of economic evaluation designed to compare the costs of a healthcare intervention to assess whether it is worth doing before they can be considered for routine use on a large scale.38

There are essentially four types of economic analyses performed in the health care arena.39 These include: 1) cost-benefit analysis, 2) cost-effectiveness analysis, 3) cost-minimization analysis, and 4) cost-utility analysis. Synopses of the four types are given as follows:

3.1.1 Cost-effectiveness Analysis

Cost-effectiveness analysis measures the costs expended upon an intervention and compares them with a single outcome, often the number of life-years gained.40,41 Other outcomes, such as disability avoided or cost per diagnosis, can be used as well. As an example of cost-effectiveness analysis, a comparison of the cost of life-years (years of life) saved by kidney transplantation, as versus dialysis, can be ascertained. The results are expressed in dollars per life-year (or other parameter) gained.
3.1.2 Cost-minimization Analysis

Cost-minimization analysis compares two events that have similar outcomes and ascertains which is less costly. This type of analysis is rarely undertaken, the major reason being that two interventions typically not comparable in all aspects. For example, although the visual outcomes obtained following repair of retinal detachment by scleral buckling versus pneumatic retinopexy may seem similar in some series, in reality they often differ in regard to important factors such as complication rate, incidence of re-detachment, postoperative discomfort and time lost from work. The results of cost-minimization analysis are expressed in dollars expended for each outcome.

3.1.3 Cost-utility Analysis

Cost-utility analysis objectively measures the value received from a health care intervention for the dollars expended. Cost-utility analysis is more complex than pure cost-effectiveness analysis in that it includes evaluation of both quality of life and length of life. It incorporates patient (or surrogate responder) preferences for a particular health state to assess the value conferred from an intervention in terms of improvement of the quality of life component. The results are typically expressed using cost per quality-adjusted life-year ($/QALY) gained.

3.1.4 Cost-benefit Analysis

Cost-benefit analysis measures both the costs and the outcomes of alternative interventions in terms of dollars. It compares the resources expended upon a health care intervention to those created as a result of the intervention. As an example, a vision-impaired patient who undergoes cataract surgery is able to return to work after the surgery. The monetary costs of the surgery are then compared to the monetary gain due to income from employment and not having to rely upon others for assistance with the daily activities of life. The results are typically expressed in dollars expended for dollars gained. Relatively few cost-benefit analyses have been performed in general ophthalmology or teleophthalmology, hence the emphasis of this thesis will be partly on cost-benefit analysis.
3.2 Issues of Cost in Health Care Interventions

Controversy exists concerning what costs to include in health economic analyses. Some studies include only direct costs, such as those for hospital care, physician services and pharmaceuticals. Others have also included indirect costs, such as lost wages and the time saved or consumed by patients, their families and other caregivers. There are also intangible costs, such as the improvement in worker productivity conferred by a health care intervention and opportunity costs, or the cost of investing dollars in health care when they could have been used for an alternative investment. In view of the lack of consensus regarding costs, in this thesis, cost analyses are performed using the direct cost (both fixed and variable) of health care services.

3.3 Methods

An electronic search was done using MedLine (Pubmed) databases for peer-reviewed articles published until December 2003. This included all studies of electronic transmission of ocular images and comparison reports of digital images, which was a precursor to teleophthalmology. The search strategy was as follows: ((teleophthalmology [All Fields] OR ("Telemedicine [All Fields]) AND ("Eye Diseases"[MESH] OR "ophthalmology"[MESH] OR "Diagnostic Techniques, Ophthalmological"[MESH]))) AND English [Lang]). From the result of this search, we excluded 3 publications which were identical. Studies reporting economic activities of teleophthalmology were identified. Original descriptions by the authors were mainly used in the review results.

3.4 Results

The electronic search reported 118 peer-reviewed articles. Based on a review of the abstracts, six articles were deemed to represent cost assessment studies and were inspected closely. The analyses mainly measured cost savings in terms of transportation costs. The costs of devices included varied significantly among studies, so that comparison of the cost estimates may not be feasible in many cases.
Table 3.1 Review of Teleophthalmology economic studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Year of Publication</th>
<th>Country of Study</th>
<th>Type of study</th>
<th>Number of patients</th>
<th>Main Aims</th>
<th>Cost related findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamminen H, Uusitalo et al (^{45})</td>
<td>1999</td>
<td>Finland</td>
<td>Video-conferencing</td>
<td>24</td>
<td>Tele-consultations between general practitioners and ophthalmologists</td>
<td>Reduced referrals</td>
</tr>
<tr>
<td>Yogesan, K, Henderson C, et al (^{46})</td>
<td>2001</td>
<td>Australia</td>
<td>Pilot study-prison based</td>
<td>11</td>
<td>Tele-ophthalmic system for use in maximum-security prisons</td>
<td>cost savings with the attendant increase in community safety</td>
</tr>
<tr>
<td>Tuulonen A, T. Ohinmaa, et al (^{47})</td>
<td>2001</td>
<td>Finland</td>
<td>Pilot study</td>
<td>41</td>
<td>Feasibility of teleophthalmology applications in examining patients with glaucoma</td>
<td>Costs of the telemedicine and conventional visits equal, but decreased traveling saved $55 per visit</td>
</tr>
<tr>
<td>Blackwell N.A, Kelly GJ, et al (^{48})</td>
<td>1997</td>
<td>Australia</td>
<td>Emergency department</td>
<td>24</td>
<td>Telemedicine in emergency department</td>
<td>Number of patients transferred reduced</td>
</tr>
<tr>
<td>Lamminen H, et al. (^{49})</td>
<td>2001</td>
<td>Finland</td>
<td>Small health centre</td>
<td>42</td>
<td>Cost study of teleconsultation for primary-care ophthalmology and dermatology</td>
<td>The cost decreased as the number of patients increased. Break Even at 110 patients per annum</td>
</tr>
<tr>
<td>Bjorvig S, Johansen MA, Fossen K (^{50})</td>
<td>2002</td>
<td>Norway</td>
<td>Screening</td>
<td>42</td>
<td>Economic analysis of screening for diabetic retinopathy</td>
<td>At higher workloads, telemedicine was cheaper.</td>
</tr>
</tbody>
</table>

The benefits and savings achieved through teleophthalmology were mainly consisted of reduced transportation costs for the patient in comparison with the conventional system.\(^{45}\) Pilot studies showed that there were considerable cost savings made by screening process.\(^{46,47}\) While, Tuulonen, et al \(^{47}\) reported the costs of the telemedicine and conventional visits were equal, Lamminen, et al.\(^{45}\)& Yogesan, et al\(^{46}\) reported significant reduction in the number of patients transferred for general ophthalmic assessment, following teleophthalmology consultations.
Chapter 3. Review of Economic Analyses in Teleophthalmology

Indirect benefits and savings achieved through teleophthalmology mainly consisted of time savings for the patient. There were indirect savings to the provider, by means of attendant increase in community safety (by avoiding transfer of prisoners) and reduced paperwork. Meanwhile, Blackwell, et al. reported reduction in number of patients transferred for emergency assessment.

A cost-minimization analysis by Bjorvig et al. showed that at low workloads, telemedicine was more expensive than conventional examination. However, at higher workloads, telemedicine was cheaper. The break-even point for teleophthalmology consultation occurred at a patient workload of 110 per annum (year 2001).

3.5 Discussion

This review shows that there is a lack of coherent methodology for evaluation and lack of critical mass of data to determine the cost-benefit of teleophthalmology. Of the 118 articles surveyed, most were reports about the clinical acceptance of teleophthalmology, and only a few of the studies reported a cost comparison of a teleophthalmology application with conventional means of providing services. Most of these reports where based on pilot or short-term projects for specific ocular diseases like diabetic retinopathy. Assessment of established, routine teleophthalmology is still scarce.

3.6 Teleophthalmology Economic Studies in Australia

There has been no comprehensive economic study of teleophthalmology in Australia. Of the studies that have examined the costs of teleophthalmology service in patients in Australia, the most relevant ones are Ivan et al. (2006) and Blackwell et al. (1997). In both these studies tele-ophthalmic diabetic eye screening programs are reported to be cost-effective. A sensitivity analysis by Ivan et al concluded that capital cost fluctuations of up to 230% would not affect the cost-effectiveness of the program. However, like most other international studies, these Australian studies also compared only one alternative option to teleophthalmology and were specific...
Chapter 3. Review of Economic Analyses in Teleophthalmology

to diabetic retinopathy screening only. Also, these studies assessed short term pilot projects, instead of an established routine teleophthalmology service.

3.7 Conclusions

To examine the current status of teleophthalmology in terms of costs and benefits, a review of the literature was indicated. This review noted that studies were typically small scale and short-term, lacked comparisons of all available alternate options or used hypothetical data. A systematic comparison of the costs and the effects of the alternatives should be done in the future.
Chapter 4

Economic Analysis of Teleophthalmology in Western Australia

4.1 Need of the study
Review of economic analyses in teleophthalmology (Chapter 3) indicates cost-comparison analysis to be the core study activity for the feasibility of teleophthalmology. This is appropriate for comparing the different health outcomes in terms of the claim teleophthalmology makes on and the gains it provide to the health service provider. This method will provide information on whether the outcomes achieved justify the resources used, relative to all other alternative options. As far as possible a provider view of costs should be taken. This method is expected to provide information on how the teleophthalmology service could be improved and will aid future decision-making about the allocation of resources.

Hence the aim of the current study is to demonstrate, from a health provider perspective, the cost analysis of teleophthalmology service in relation to alternative eye care service options.

This study examines the overall economic benefits of teleophthalmology consultations. From a health care service provider perspective, its objective is to answer the following question: Is teleophthalmology service cost effective comparing with the existing alternate options?
4.2 Background and Current Eye care Scenario at Carnarvon
Like many large countries, Australia has a large landmass with a low population density, and providing the population with specialist eye care services is a major problem outside the major cities.

The state of Western Australia (WA) has a land area of 2.5 million square kilometers and has a population of two million (Fig 4.1). Of this, 70% of people live in and around the capital city of Perth. Thirty percent of the population lives in rural and remote WA. When specialist ophthalmic care is required for people in remote areas, this need may remain unfulfilled for some time, or the patient must be sent to Perth. Internet-based eye care services have been proposed in WA as a means of improving access to specialist eye care. A web-based teleophthalmology service (www.e-icare.com) has been developed at the Centre of Excellence in e-Medicine (e-Med), Lions Eye Institute (LEI) in Perth (Fig.4.2).
Fig 4.2 Image of the web-based teleophthalmology system (www.e-icare.com) used at Carnarvon Regional Hospital (2003).

This system stores and transmits multimedia data to a secure, central database. The data include patients’ demographic information, medical history, images, videos and audio files (Fig 4.3).

With the assistances of the Department of Health, Western Australia (DOHWA), LEI commenced a teleophthalmology project in July 2002. This project is based at Carnarvon Regional Hospital (CRH) covering the whole Gascoyne health region. LEI has provided training to a non-medical officer (teleophthalmology coordinator) and organized eye-specialists in Perth to diagnose images sent through its internet based system.

Carnarvon Regional Hospital (CRH), is located in the heart of the Gascoyne Region of WA. Carnarvon is connected to the rest of Australia by the North West Coastal Highway and, to a lesser extent, by its airport. It takes about two hours to fly or 11 hours to drive from the nearest city of Perth (940 km). It has a population of 6622 (Australian Bureau of Statistics- 2003) of which about 15% is Aboriginal. There are no eye specialist services available in the Gascoyne region on a full-time basis. The current practice is for an eye-specialist and a registrar to visit the region for a week, two times per year for consultations. In cases of emergencies, patients are airlifted to a hospital in the city by the Royal Flying Doctor Service (RFDS). Also,
once a year, two specialists visit the region for a week to perform low complexity eye surgery, basically cataract cases.

4.3 Method

The study was based on two existing clinics. The rural clinic was located at Carnarvon Regional Hospital (CRH). The specialist who reviewed the images and provided feedback was located at the Lions Eye Institute (LEI) in Perth.

An Internet-based eye care system (http://www.e-icare.com), needed to transmit patient medical data to a secure database. All the consultations were conducted asynchronously ("store-and-forward"). A digital, portable slit lamp, developed by LEI, and a handheld digital fundus camera (Canon CR4-45NM), were used for the telemedicine
Chapter 4. Economic Analysis of Teleophthalmology in Western Australia

service. These devices were connected directly to the online eye care system (www.e-icare.com) to transmit multimedia information (58kbps) to specialists in Perth. Each time a patient was screened at CRH, an automatic e-mail was sent to alert the specialist in Perth. The specialist reviewed the data, recorded image quality, diagnosed eye disease and made recommendations for disease management and subsequent care (Fig 4.3). Specialist advice was returned to CRH within 24 hours.

<table>
<thead>
<tr>
<th>Specialist's notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rang her GP 23/9. Changes of cystoid macula edema seen previously. Suspect this may be the cause of the central smudge she is seeing. Asked her GP to prescribe Voltaren or Auralac eyedrops and to keep me informed of her condition.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Images (Part 1)</th>
<th>Date: Sep 23 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Eye:</td>
<td>Left Eye:</td>
</tr>
</tbody>
</table>

**Fig 4.4** The teleophthalmology system (www.e-icare.com) with the retinal images and specialist comments.
The Lions Eye Institute (LEI), Perth provided training to a rural non-medical officer and organized eye-specialists in Perth to diagnose images sent through this internet system (Fig 4.4 and Fig 4.5). Apart from emergency consultations, the program also conducted diagnosis and management of general eye-related diseases including glaucoma, diabetic retinopathy and trachoma.

Local media announcement was made about the telemedicine service. Teleophthalmology service was available for one half-day per week. Another half-day per week was used for administrative and other related tasks. Consultations lasted an average of 30 minutes per patient.

Cost information relating to the different ways of providing specialist eye-related diagnosis and treatment to the Gascoyne regional population was gathered and analyzed. The cost of tele-ophthalmology was compared with the costs of the following alternatives, which were available at the CRH:

- Option 1: Teleconsultation using slit lamp, retinal camera and tonometer
- Option 2: Patient travels to a hospital in Perth after referral by a local medical officer
Chapter 4. Economic Analysis of Teleophthalmology in Western Australia

- Option 3: Patient waits for few months, to be seen by a visiting specialist at CRH
- Option 4: Patient waits for few months, to be seen by a visiting specialist. The patient then travels to Perth for a full eye examination since some of the testing devices are not available in the regional hospital.

Data relating to the costs was gathered from the Department of Health in Western Australia (DOHWA), the Commonwealth Medicare Benefits Schedule (CMBS), the CRH and the LEI.

4.4 Results

During the 12-month study period (Jan-Dec 2003) 118 persons took part in teleophthalmology consultations (42% men, 58% women. Their mean age was 42 years, range 4-73). For the 2003 calendar year, 118 persons were screened for eye-related disease at CRH as part of the Teleophthalmology service. No screenings were done during the month of January as the coordinator was on annual leave. Moreover, the number of screenings fluctuated significantly during the year with March being the highest (22) and May the lowest (4). The tables 4.1, 4.2 and Fig 4.6 below show the number of attendance for screenings per month from January to December 2003.

Table 4.1: Teleophthalmology Project – Number of patients seen at Carnarvon Regional Hospital (Jan-Dec 2003)

<table>
<thead>
<tr>
<th>Month</th>
<th>Number of Patients seen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>0</td>
</tr>
<tr>
<td>Feb</td>
<td>17</td>
</tr>
<tr>
<td>Mar</td>
<td>22</td>
</tr>
<tr>
<td>Apr</td>
<td>12</td>
</tr>
<tr>
<td>May</td>
<td>4</td>
</tr>
<tr>
<td>Jun</td>
<td>13</td>
</tr>
<tr>
<td>Jul</td>
<td>18</td>
</tr>
<tr>
<td>Aug</td>
<td>5</td>
</tr>
<tr>
<td>Sep</td>
<td>7</td>
</tr>
<tr>
<td>Oct</td>
<td>5</td>
</tr>
<tr>
<td>Nov</td>
<td>5</td>
</tr>
<tr>
<td>Dec</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>118</td>
</tr>
</tbody>
</table>
A variety of ophthalmic conditions were dealt with during the study period (Table 4.2).

Table 4.2: Carnarvon Regional Hospital – list of ophthalmologic conditions consulted using teleophthalmology service in year 2003.

<table>
<thead>
<tr>
<th>Ophthalmic Conditions</th>
<th>Number of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabetic Retinopathy</td>
<td>43</td>
</tr>
<tr>
<td>Glaucoma</td>
<td>57</td>
</tr>
<tr>
<td>Cataract</td>
<td>6</td>
</tr>
<tr>
<td>Trachoma</td>
<td>0</td>
</tr>
<tr>
<td>Trauma</td>
<td>4</td>
</tr>
<tr>
<td>Other</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>118</strong></td>
</tr>
</tbody>
</table>

4.4.1 Cost analysis

Costs for each item are given below. All costs are actual costs and are expressed in Australian dollars (valued for the year 2003).

The fixed costs of tele-ophthalmology were:

- **Marketing** ($M$). The tele-ophthalmology project was marketed by way of local newspaper advertising for three months. The total cost was $320.

- **Training** ($T$). Training the coordinator involved staff travelling from Perth to Carnarvon. The cost of training was based on travel cost and the opportunity cost of the staff time and amounted to $3200.
Chapter 4. Economic Analysis of Teleophthalmology in Western Australia

- **Equipment** ($E$). The equipment costs amounted to $50,000. The lifetime of the equipment was assumed to be seven years and the depreciation rate was assumed to be 6% (Australian Taxation Department).

- **Transmission Cost** ($TC$). A monthly fee of $100 was paid for the data connection. Transmission from Carnarvon was Internet based and there were no separate call charges.

- **Software** ($L$). An annual license of $900 was paid for the e-icare software.

- **Set up** ($S$). Minor works, such as cabling, had to be carried out at the CRH in order to set-up equipment there. Their cost was $150. Equipment maintenance and repair costs were nil for year 2003.

The variable costs of tele-ophthalmology were:

- **Coordinator** ($C$). Coordinator costs were calculated at 20% of a full time equivalent (FTE) salary plus 25% to account for associated benefits.

- **Office** ($O$). Clerical assistance for the coordinator was provided for one hour per week (based on a level 4 FTE salary).

- **Specialist Diagnostic Service** ($SD$). A specialist ophthalmologist in Perth charged one-third of the conventional face-to-face consultation fee (CMBS item 104) for a digital image diagnosis. Hence, the unit cost for the specialist telediagnostic service was $23.11.

The variable costs for Options 2, 3 and 4 were:

- **Referrals** ($R$). Every patient needed to be referred by a medical officer in order to see a specialist. The scheduled fee for medical officer consultation during normal hours in rural Western Australia was $52.
Chapter 4. Economic Analysis of Teleophthalmology in Western Australia

- **Visiting Specialist (and registrar) (V).** There were costs involved in sending a specialist and a registrar from a Perth metropolitan public hospital to the CRH for a period of one week, four times per year. The total cost include airfares, accommodation, meals, professional fees, nursing/admin assistance, regional travel and the opportunity cost of not working in Perth while at the CRH for both the specialist and the registrar. The total cost was $77,256 which divided by the 352 consultations performed during the year gave a cost per consultation of $219.48 (Dept of Health, WA).

- **Specialist Consultation and Eye Tests in Perth (SC).** The scheduled fee for a consultation with ophthalmologist was $69.35. Fees for related eye-tests were $68.86.

- **Travel Assistance (TA).** Patients referred for tests in Perth received travel assistance from the Patient Assistance Travel Scheme amounting to $255.75 each.

The table 4.3C shows all four service delivery modalities and costs for comparison. It can be seen that the unit cost of providing a Teleophthalmology consultation (Option 1 at $279.95) is only marginally higher than the cost of an outpatient consultation by a visiting specialist to Carnarvon (Option 3 at $271.48). The cost per patient for consultations where travel to Perth is required is considerably higher (Option 2 at $445.96 and Option 4 at $665.44).

<table>
<thead>
<tr>
<th>Costs</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
<th>Option 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Programme marketing (M)</td>
<td>320.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training (T)</td>
<td>3200.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment (E)</td>
<td>7570.80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmission (TC)</td>
<td>1200.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software license (L)</td>
<td>900.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Setup (S)</td>
<td>150.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Fixed Cost</td>
<td>13,340.80</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total Fixed Cost/patient</strong></td>
<td>113.06</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
4.3 B. Variable costs ($ per patient)

<table>
<thead>
<tr>
<th>Costs</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
<th>Option 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tele-ophthalmology coordinator (C)</td>
<td>133.47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office clerical support (O)</td>
<td>10.31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical specialist fees for tele consultation (SD)</td>
<td>23.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP fees- referral to see specialist (R)</td>
<td></td>
<td>52.00</td>
<td>52.00</td>
<td>52.00</td>
</tr>
<tr>
<td>Visiting specialist (V)</td>
<td></td>
<td></td>
<td>219.48</td>
<td>219.48</td>
</tr>
<tr>
<td>Specialist consultation (SC)</td>
<td></td>
<td>138.21</td>
<td></td>
<td>138.21</td>
</tr>
<tr>
<td>Patient travel (TA)</td>
<td></td>
<td></td>
<td>255.75</td>
<td>255.75</td>
</tr>
<tr>
<td><strong>Total variable cost</strong></td>
<td>166.89</td>
<td>445.96</td>
<td>271.48</td>
<td>665.44</td>
</tr>
</tbody>
</table>

4.3C. Total cost (Variable and Fixed)

<table>
<thead>
<tr>
<th>Costs</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
<th>Option 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total of Fixed and Variable costs</td>
<td>279.95</td>
<td>445.96</td>
<td>271.48</td>
<td>665.44</td>
</tr>
</tbody>
</table>

Option 1: Teleophthalmology; Option 2: Patient travels to city hospital with referral letter from GP
Option 3: Patient waits for and consults a specialist visiting CRH
Option 4: Patient travels to city hospital with referral letter from visiting specialist

4.4.2 Sensitivity Analysis

Four hypotheses were examined in order to estimate cost savings due to factors such as increased coordinator’s efficiency in image taking, decreasing equipment costs, increased coordinator’s dedicated time, and finally a combination of the first three options. These assumptions are better described below.

Hypothesis 1 – Patient throughput increases due to increased program coordinator efficiency in the process of taking eye images and better program management. All other factors remain constant. It assumes the trial’s best initial monthly throughput (March 03 = 22) over 11 months, which allows for a holiday month. Total 242 screened patients (coordinator’s dedicated time still 1/2 day per week).
Hypothesis 2 – It assumes that only the cost of the equipment used to take eye images decreases. LEI are finalizing a new portable camera, which can take the functions of both slit lamp and fundus camera, at a fraction of current equipment cost. All other factors such as initial throughput remain constant.

Hypothesis 3 – Patient throughput increases due to increased program coordinator’s efficiency (as in hypothesis 1) and increased time dedicated to screening activity (twice as much or two half-days). All other factors remain constant.

Hypothesis 4 – Allows for increased officer efficiency (as in hypothesis 1), decreasing equipment costs (as in hypothesis 2) and increased officer dedicated time (as in hypothesis 3). All remaining factors are constant.

Applying the assumptions related to the above hypotheses tested would generate the following:

H1 - Cost per patient decreases to only $143.33, about 20% of the cost for option 4, a third of the cost of option 2 and half of options 1 and 3 calculated unit cost.

H2 - Cost per patient decreases to $215.11 from the current $279.95 (throughput remains 118/year).

H3 - Cost per patient decreases from $279.95 to only $115.76. Total number of screenings = 484/year

H4 - Cost per patient decreases to $103.40, about 37% of initial calculated teleconsultation, a quarter of the cost of option 2, 39% of option 3 and only 16% of option 4.

4.4.3 Break Even Point
The break-even point is the number of patients for which the cost of a teleophthalmology service is the same as the cost of a alternate consultation option. In other words break even point determines the minimum number of patients required to make teleophthalmology services economically feasible.
Fig 4.7 Cost of delivering eye care services via tele-ophthalmology and three alternatives, at different workloads

Assuming that:

\[ F_1 = \text{unit cost of a single Teleconsultation}; \]

\[ F_2 = \text{unit cost of a conventional consultation where the patient travels to Perth after being seen by a GP or local medical officer at CRH}. \]

\[ F_3 = \text{unit cost of a conventional outpatient consultation where the patient is seen by a visiting specialist at CRH but no full eye examination and diagnosis takes place}. \]

\[ F_4 = \text{unit cost of a conventional consultation where the patient travels to Perth after being seen by a visiting specialist at CRH}. \]

Break-even will occur when \( F_1 = F_2 \), or \( F_1 = F_3 \) or \( F_1 = F_4 \)

The minimum patient workloads will therefore be 71, 126 and 48 respectively (Fig 4.7).

4.4.4 Cost-Neutral Analysis

An estimation of the number of patients that could be assessed through Teleophthalmology services by using the same amount of monetary resources currently spent on conventional specialist visits to Carnarvon was done. Specialists visit the Carnarvon Regional Hospital 4 times per year, each time a weekly visit.
These are intended for outpatient consultations. The number of patient consultations by visiting specialists at CRH for 2003 was 352. Total cost for these visits was calculated at $91,760.

<table>
<thead>
<tr>
<th></th>
<th>Digital Image CRH</th>
<th>Specialist Visit CRH outpatient clinics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>850</td>
<td>352</td>
</tr>
<tr>
<td>Fixed Costs</td>
<td>13,451.69</td>
<td>-</td>
</tr>
<tr>
<td>Fixed cost per client</td>
<td>15.75</td>
<td>-</td>
</tr>
<tr>
<td>Variable Costs</td>
<td>78,170.76</td>
<td>91,759.36</td>
</tr>
<tr>
<td>Variable cost per client</td>
<td>91.97</td>
<td>260.68</td>
</tr>
<tr>
<td>Total Annual Program Costs</td>
<td>91,560.00</td>
<td>91,760.13</td>
</tr>
<tr>
<td>Total cost per client</td>
<td>107.72</td>
<td>260.68</td>
</tr>
</tbody>
</table>

The above table (Table 4.4) demonstrates that, at this level of expenditure, Teleophthalmology services would consult and provide specialist diagnostic to approximately 850 patients per year and increase of 141% in current outpatient service throughput. Moreover, these patients would each have a full eye assessment done through the eicare system already in place. Cost per patient would therefore decrease approximately 60% to $107.72.

### 4.4.5 Service-Neutral Analysis

If Teleophthalmology services were to provide for the 352 outpatient consultations, it would cost only $45,309 compared to the current $91,760 expenditure, a decrease of approximately 51% in program costs, or just over $46,000 as shown in the table below. Extrapolated to 10 regional hospitals, it would save the health system approximately half a million dollars. Moreover, it would greatly enhance access to specialist services and would free up resources to remain working in the Perth metropolitan area.
Table 4.5: Service Neutral Representation for Carnarvon Region – Ophthalmology Services 2003.

<table>
<thead>
<tr>
<th></th>
<th>Teleophthalmology</th>
<th>Specialist visit CRH outpatient clinic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Patients</td>
<td>352</td>
<td>352</td>
</tr>
<tr>
<td>Total Annual Program Costs</td>
<td>45309.44</td>
<td>91760.13</td>
</tr>
<tr>
<td>Total cost per patient</td>
<td>128.72</td>
<td>260.68</td>
</tr>
</tbody>
</table>

4.4.6 Emergency Evacuation and Teleophthalmology

There was no emergency air evacuation during the study period (Jan-Dec 2003). For the same period in the previous year (2002), there were 7 evacuations (inter-hospital air transfers) from the Gascoyne region to City of Perth (Table 4.6).

Table 4.6: Eye related emergency evacuations from Carnarvon in 2002

<table>
<thead>
<tr>
<th>Initial Diagnosis</th>
<th>Number of Cases</th>
<th>Priority Status †</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye injury</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Glaucoma</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Foreign Body</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Corneal Ulcer</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Traumatic Hyphema</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Orbital Cellulitis</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Acute Infection</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Total number of evacuations</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

† Priority code status 1 = Urgent take off, 2 = Take-off within 4 hours or so 3 = take off within 24 to 48 hours.

Six of these seven evacuations had a priority status of 3, that is, take-off within 1 to 2 days, the lowest priority code for evacuations (Table 4.6). The minimum cost of an air evacuation trip from the Gascoyne region to Perth is $7,300 (travel with a nurse). If hypothetically, these six priority 3 evacuations were avoided, savings to the system would amount to $40,600, assuming every trip was accompanied by a nurse only. I.e., Cost of avoiding 6 evacuations ($40,600) = (Evacuation average cost ($7,300) – Teleconsultation cost ($277) – Patient Assistance Travel Scheme: PATS average cost ($255)) * 6.
4.4.7 Teleophthalmology Service from Other Remote Regions

Information from two other health regions (East Pilbara and the Western Wheatbelt region) of the State of Western Australia was sought for comparison with the Gascoyne data (table 4.7).

Table 4.7: Comparison of Gascoyne region with Pilbara and Western Wheatbelt region (year 2003)

<table>
<thead>
<tr>
<th>Gascoyne Region- Options Studied</th>
<th>Teleophthalmology</th>
<th>Option 2 Patient travel with GP referral letter to Perth</th>
<th>Option 3 Specialist Visit CRH outpatient clinic</th>
<th>Option 4 Specialist visit CRH and then refer to Perth</th>
<th>Other Health Regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput</td>
<td>118</td>
<td>352</td>
<td>120</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>Cost per Patient</td>
<td>277.38</td>
<td>445.96</td>
<td>260.68</td>
<td>654.64</td>
<td>360.92</td>
</tr>
<tr>
<td>Total Cost of Program</td>
<td>32,731</td>
<td>91,760</td>
<td>43,310</td>
<td>67,041</td>
<td></td>
</tr>
</tbody>
</table>

The information above for East Pilbara and the Western Wheatbelt should be considered with a certain degree of caution. For instance, travel, meals and accommodation costs are more than likely underestimated for East Pilbara and overestimated for the Western Wheatbelt. On the other hand, it was not possible, in the Western Wheatbelt case, to properly differentiate between outpatient and surgical cases, which may be the reason for the high unit cost found.

In the case of East Pilbara, an eye specialist visits the region 4 times per year for two days each time. Hence, only 8 days per year of face-to-face specialist consultation are provided in the region. Moreover, full eye examinations cannot be provided, as comparative equipment to that used by the Teleophthalmology service in Carnarvon is not available.

For the Western Wheatbelt location, two specialists visit the region approximately 36 times per year for a full day each time. It is obviously not ideal and probably difficult and time consuming to schedule visits for each time a specialist comes
Moreover, missed appointments by scheduled patients are notorious and well documented in regional areas. A Teleophthalmology service not only would provide the opportunity for full eye examinations but also for services to be available at any time. It would also be more cost effective, as cost per patient is less expensive with Teleophthalmology than with current conventional services.

If it is assumed that costs related to the setting up of a Teleophthalmology service would be similar to Gascoyne then, based on the cost estimates above, current expenditure on eye specialist outpatient clinics exceeds observed costs for a Teleophthalmology program, which has the potential to attend more patients, at a lower cost, providing services which at current are not offered.

4.4.8 Program Direct Benefits

A large number of people could benefit from teleophthalmology service (Fig 4.8) at a relatively low cost without the need to travel long distances (economical), and be away from family and work (sociological). Moreover, the health service provider benefits by not having to assist patients traveling to Perth. For each patient the PATS value amounts to $255.75 (average cost for 2003 CRH eye related travel assistance support). The Table 4.8 compares each mode of service delivery in relation to type of service provision and its perceived benefits or shortcomings.

Table 4.8: Benefit comparison for four modes of service delivery

<table>
<thead>
<tr>
<th>Type of Service Provided - Comparison of benefits</th>
<th>Complete assessment of patient eye (front &amp; back)</th>
<th>Eye-specialist diagnostic.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Digital Image CRH - Teleophthalmology</strong></td>
<td>Yes. Image taken with cameras provide complete assessment of patient's eye.</td>
<td>Yes. Specialist can make diagnostic by analysing image forwarded through website.</td>
</tr>
<tr>
<td><strong>Patient Travel - GP Referral to Perth</strong></td>
<td>Assessment to be made in Perth after patient obtain referral (from GP of local sesional doctor at CRH) and travel.</td>
<td>Diagnostic after full assessment in Perth.</td>
</tr>
<tr>
<td><strong>Specialist Visit CRH - Outpatient Clinics</strong></td>
<td>Eye-specialist visual assessment only during outpatient clinic. For full assessment (if deemed necessary) patient needs referral then travel to Perth.</td>
<td>Diagnostic after full assessment in Perth.</td>
</tr>
<tr>
<td><strong>Specialist Visit &amp; Referral to Perth</strong></td>
<td>Eye-specialist visual assessment only during outpatient clinic. For full assessment (if deemed necessary) patient needs referral then travel to Perth.</td>
<td>Diagnostic after full assessment in Perth.</td>
</tr>
</tbody>
</table>
Teleconsultation also offers the added benefit of the opportunity of storing images for later comparison, enabling the eye condition to be evaluated over time. This is an invaluable tool not available through the other 3 options available. Not only do patients benefit from it but also doctors, as they can further their knowledge by studying varied patterns of time-related developments on eye conditions observed.

4.4.9 Healthcare Service Utilization

The implementation of teleophthalmology services has an impact on current health service utilization both at a regional level (in and outpatient) and in services delivered to Gascoyne residents in Perth hospitals (Fig 4.9).

Fig 4.8 Clinical Outcome of the CRH teleophthalmology service (2003)

Fig 4.9 Outcome of specialist review of CRH patients through teleophthalmology system (2003)
Statistics for Carnarvon Regional Hospital for eye-related Outpatient services shown below, exhibit a decline in the number of occasions of service from 2002 to 2003 of approximately 15% (Table 4.9). This may be related to a substitution of services, a number of people presenting themselves directly for the teleophthalmology program without the need to go through an earlier referral appointment.

Table 4.9: Carnarvon Regional Hospital – eye related consultations at outpatient clinic 2001-2003.

<table>
<thead>
<tr>
<th>Year</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>455</td>
<td>485</td>
<td>412</td>
</tr>
<tr>
<td>% Change</td>
<td>-</td>
<td>6.6</td>
<td>-15.1</td>
</tr>
</tbody>
</table>

On the other hand, as shown in the table 4.10 below, eye-specialist visits to Carnarvon (four weeks per year - excludes week dedicated to surgery cases) in the last three financial years show a steady number of cases due to unchanged specialist efficiency levels and frequency of visits.

Table 4.10: Visiting Eye Specialist outpatient services at Carnarvon

<table>
<thead>
<tr>
<th>Year</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>379</td>
<td>385</td>
<td>381</td>
</tr>
<tr>
<td>% Change</td>
<td>-</td>
<td>1.6</td>
<td>-1.1</td>
</tr>
</tbody>
</table>

Teleophthalmology services could offer a change of service substitution for these conventionally provided services. Although acknowledging that face-to-face consultations with a specialist doctor are beneficial, its cost is high as seen in the analysis earlier.

In terms of cost, a one-week visit by a specialist and a registrar would consume approximately 56% of the annual Teleophthalmology program budget. It can be assumed therefore that halving the number of annual weekly visits by specialists to Carnarvon (from 4 to 2 weeks per year) would generate more than enough resources to fund the Teleophthalmology program.

Moreover, because patients have the opportunity to have a full eye examination and diagnosis by means of a teleconsultation, one or more of the week(s) used for
outpatient clinics could be substituted for additional eye surgery cases at Carnarvon Regional Hospital. This would eliminate the need for a patient to be away from family and work, and do away with travel expenses, as well as save the health provider travel assistance costs (PATS) for patients.

Furthermore, these additional surgical cases would be funded by a resource shift from a metropolitan hospital (where they are currently being done) to CRH, excluding the teaching component of its cost. Regional doctors would gain increased expertise from additional exposure to a rising number of eye surgery cases at CRH. The above analysis clearly indicates better use of current resources by providing a different service mix and at the same time delivering teleophthalmology services to a larger number of people in the community.

### 4.4.10 Summary of Key Findings

- In the Gascoyne health region, during 2003 calendar year, the health system spent $91,760 to see 352 patients by alternative service delivery (specialist visits) at an average of $260 per outpatient consultation. The current analysis indicates that for the same dollar amount 850 patients could be fully diagnosed using teleophthalmology services at a cost of approximately $107 per consultation.

- Based on the 2003 calendar year throughput (118 occasions of service), the unit cost of a teleconsultation ($279.95 including fixed cost) was similar to the unit cost of a visiting specialist to CRH ($271.48 without fixed cost).

- Start-up programs such as teleophthalmology often show a lower than expected utilization which can be attributed to a lack of co-ordination from a provider perspective and poor awareness of the program. It was found that, at expected minimum efficiency levels (242 occasions of service per year for 1 half-day consultation per week), the unit cost of a teleconsultation (all other factors constant) would decrease to $143.33.

- Outpatient numbers for eye-related conditions at CRH have decreased 15% from 2002 to 2003 as a consequence of the availability of teleophthalmology services. It is expected that further decreases in conventional outpatient clinics will be achieved if teleophthalmology services are running at
4.5 Discussion

There have been few previous cost comparison studies of tele-ophthalmology services. The results of this research study demonstrates teleophthalmology to be cost efficient in relation to the alternatives available. However, better coordination of services is required in order to deliver increased benefits at a lower cost to the system. User fees of telecommunication networks are relatively low at this point in time and therefore the transfer of information via networks is a relatively insignificant cost item.

While acknowledging that face-to-face consultations with ophthalmologists are unique, its costs are enormous in remote health centers. The project led to direct potential benefits for patients in terms of improved outcomes. However, current assessment brought to light the importance of redefining utilisation criteria in order to achieve efficiency. For example, 126 patients per annum are required for a cost effective teleophthalmology service while the current efficiency rate is 118 per annum (2.2 patients per week). Better coordination between local health care workforce and CRH may increase the number of teleophthalmology consultations, which in turn will help to achieve break even or even establish net savings.

The transaction cost theory presented by Williamson is based on the idea that all transactions (exchange-related operations) are arranged with a view to minimising transaction costs. This refers to any expenditure, starting with the production of the goods or service and extending to its delivery to the customer. Services may be produced, for instance, by setting up a telemedicine network where each unit of the network concentrates on those tasks in which it holds a comparative or acquired advantage. This allows the overall logic of the operations to be appreciated and the specific expertise of each unit to be effectively manifested. The costs of telemedicine at the primary health care centre are crucially dependent on the degree of utilisation of the equipment. For instance, if the CRH is able to use telemedicine for many types of consultations, the share of the purchase cost of the
equipment (fixed costs) in the total costs will be considerably reduced. In principle, a high degree of equipment utilization (e.g. links with several primary health care centers or a large number of applications) at a hospital offering teleophthalmology services should also reduce the costs. Much depends, however, on the number of patients required to produce the service cost effective and on the effective implementation of the service through protocols.

The implementation of telemedicine is partly aimed at ensuring that health care services be produced at an optimum location from the viewpoint of both patients and financiers. Thus, visits to hospital outpatient clinics would be unnecessary when the treatment can be provided at the teleophthalmology centre. Teleophthalmology projects have a bearing on the population of the region and the distribution of specialized health care in the region. This requires that geographical distances and the unique characteristics of the WA health care system be taken into account both in the planning of projects and in their assessment. However, long distances are not a prerequisite for using telemedical applications; on the contrary, they can be used even over short distances, such as within one hospital or in the same town among different units of health care.65-67

Changes in health-related quality of life can only be monitored in some of the specialities like teledermatology. For ophthalmology, the aim is not to study quality of life, as retinal changes are so slow that the patient may not even be aware of a gradual deterioration of vision. In many instances, feasibility will have to be measured using variables related to the patient's clinical condition or to a change in diagnosis instead of health-related quality of life.

Before/after comparisons within a single primary health care centre (CRH) was carried out in this evaluation. In teleophthalmology, before/after comparisons are justified since the patients invited for teleconsultations in fact comprise the same study population of Carnarvon.

Much of the practical interpretation of the results revolves around sensitivity analysis in which cost and outcome factors are simulated under various basic
There is a real need for ophthalmic emergency services in rural regional hospitals. The cheapest and most efficient way to diagnose these emergencies appears to be through internet service. A variety of emergency complaints were managed effectively using relatively low-cost internet-based telemedicine technology, thereby eliminating the need for transportation of the patient to the emergency department in the city. A decline (15%) in the number of eye related cases in CRH may be related to a number of people presenting themselves directly for the teleconsultation service. This evaluation study also demonstrates the potential value of telemedicine use in rural eye care emergency.

Moreover, a substitution of current service arrangements for visiting eye specialists in East Pilbara and in the Western Wheatbelt would not only deliver more cost effective services but also generate enough savings to the health system to pay for a whole new teleophthalmology program. Overall, this assessment indicates, teleophthalmology’s feasibility will be enhanced by identifying the local requirements of the service and using appropriate technology and protocols.

Economic assessments of health care technologies are needed to produce information for decision-making concerning the allocation of public resources. Meagre resources may prevent society from optimising the welfare effects of its decisions. Should the health care market operate "perfectly", no cost-benefit or cost-effectiveness analyses would be needed since the market would be self-optimising. This is not the case in reality, however, because health care services are often influenced by external factors, and both competition and information are imperfect in the health care market. Health care assessment is one way of estimating these market-related problems. It also provides decision-makers with more reliable information about the relevant technologies than would be obtainable through simple surveillance of the market.38
Chapter 4. Economic Analysis of Teleophthalmology in Western Australia

4.6 Conclusion

This evaluation paper demonstrates the feasibility of teleophthalmology services in terms of its cost effectiveness and also its advantages over alternate arrangements, specifically where distance is a factor affecting service provision and patient access. The study has the advantage of taking into account the price level and the characteristics of the health care system in WA. The findings of the study have practical significance to local governments, people, central hospitals, health care districts and other public corporations. The findings are used in recommendations on the preconditions for starting telemedical operations within the eyecare speciality in any healthcare region in Western Australia. Given the evaluation from a provider perspective, further assessment of patient and clinician satisfaction is greatly indicated.
Chapter 5

Patient and Clinician Perception of Teleophthalmology Service

5.1 Introduction
As the use of teleophthalmology service grows, patient and clinician perspective evaluations merit greater attention. At the same time, much is assumed and little is known about the patient acceptance of teleophthalmology services. The current research presents an evaluation of patient satisfaction and attitudes towards web-based eye care services.

The evaluation of patient satisfaction is a common constituent of telemedicine research. It is a wholly subjective assessment of the quality of eye care service and, as such, is not a measure of final outcome of teleophthalmology. While there is speculation regarding the neutrality of patient responses and debate around the lack of understanding of how patients evaluate services, it continues to be a mechanism through which consumer attitudes can be usefully obtained.

5.2 Method
A trained teleophthalmology nurse coordinator took retinal photos and external eye pictures of patients at CRH with the equipment and technology developed at LEI.\textsuperscript{44,59,71,72} The equipment included are a portable slit lamp (e-Med), portable air-puff tonometer (Keeler Pulsair 3000, Japan) and a non-mydriatic digital fundus camera (Canon CR4-45NM, Japan).
These devices were connected directly to the online eye care system (www.e-icare.com) to transmit multimedia information to specialists in Perth. Each time a patient was screened at CRH, an automatic e-mail was sent to alert the specialist in Perth. The specialist reviewed the data, recorded image quality, diagnosed eye disease and made recommendations for disease management and subsequent care (Fig 5.1). Specialist advice was returned to CRH within 24 hours.

The service was made available to patients referred from local general practitioners and walk-in patients. Patient participation was entirely on a voluntary basis. No fee was charged. Emergency cases were also seen. Media announcement through local radio and news services were also done. A teleophthalmology protocol was primed for service. The protocol detailed the consultation criteria, technical and training requirements for people involved. It also specified the rights and responsibilities of the patients, prepared the patient for consultation, privacy and confidentiality issues, screening, referral or consultation procedures and other relevant information.
Questionnaires were used to collect patient perceptions towards teleophthalmology. These were sent along with a stamped, self-addressed envelope to all patients after consultation. The responses were collected and analyzed. The questionnaire consisted of four closed-ended questions and nine questions on rating of the service. The closed-ended questions were on service satisfaction, lack of direct physical contact with a distant clinician, privacy concerns and future use of the teleophthalmology service. The questionnaire asked the patient to rate various aspects of the teleophthalmology service such as: physical comfort, psychological comfort, convenience, duration and timeliness of consultation, skills and attitude of consultant, skills and attitude of attending health care personnel and overall satisfaction with the Internet-based service. Samples of teleophthalmology protocol, patient information sheets, patient consent forms, patient evaluation forms, clinician perception forms, and the teleophthalmology service log sheet are attached as Appendices 10-12.

5.3 Result

During the study period (January–December 2003), 118 patients were presented via Internet-based teleophthalmology. Completed questionnaires were received from 45 patients (41%), of which 42% were from men and 58% from women (mean age 42 years, range 9–73 years). More than half of these patients (53%) came to the teleophthalmology centre by awareness through local media announcements, while 36% were referred by health professionals in Carnarvon (Fig 5.2). Few of the patients (7%) became aware of the telemedicine service through their family or friends.
How Patient Became Aware of Teleophthalmology Service

- 36% from Family or Friend
- 7% from Advertising
- 53% from Health Professionals
- 2% from Other
- 2% from Another Patient

Fig 5.2. How patient become aware of teleophthalmology service at Carnarvon

Four percent of the patients used the service for consultations for eye disease treatment or care. Most of the patients (94%) used the Internet-based service for screening for eye diseases like glaucoma and diabetic retinopathy, while, 2% of the cases were for other purposes, including expert second opinion and post-operative follow up (Fig 5.3).

Fig 5.3. Utilization of teleophthalmology service at Carnarvon
A majority of patients (98%) expressed satisfaction with Internet-based consultation and observed it as convenient form of service (Fig 5.4).

![Satisfaction with quality of teleophthalmology service](image)

**Fig 5.4.** Satisfaction with quality of teleophthalmology service

Lack of physical contact with the ophthalmologist was not a major concern to 74% of the patients (Fig 5.5).

![Was the lack of physical contact with the distant clinician acceptable?](image)

**Fig 5.5.** Attitude towards lack of physical contact with diagnosing clinician in teleophthalmology service.

Eventhough 7% patients were apprehensive about privacy issues coupled with a web-based consultation, given an opportunity, 98% patients would prefer to go for teleophthalmology in the future (Fig 5.6).
Chapter 5. Patient and Clinician Perception of Teleophthalmology Service

**Fig 5.6.** Attitude towards reusing teleophthalmology service in future

88% of the patients were not apprehensive about privacy issues associated with teleophthalmology services (Fig.5.7).

**Fig 5.7.** Attitude towards privacy issues related to internet based teleophthalmology service

Timeliness of each consultation was another factor in patient’s satisfaction. 93% patients found it quicker than a traditional consultation (Fig5.8).
This Telehealth Service has given me access to health care faster than a traditional service

---

**Fig 5.8** Perception about the access to health care service.

The comfort level in the rural teleophthalmology centre was rated poor to satisfactory by majority of patients, while the skills and attitude of the personnel at the telecenter were rated highly (Fig 5.9). The results of the evaluation also showed that trust between patients and treatment providers was of major importance in engendering positive attitudes. (Table 5.1, Fig 5.9)

**Table 5.1.** Patient comments regarding teleophthalmology service in Carnarvon- year 2003

<table>
<thead>
<tr>
<th>PATIENT COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• I am pleased to be provided with this service and would be happy for re-</td>
</tr>
<tr>
<td>imaging my eyes in January</td>
</tr>
<tr>
<td>• A small room, rather than a curtained-off area would have been more</td>
</tr>
<tr>
<td>suitable – mainly due to the light requirement</td>
</tr>
<tr>
<td>• I was very happy to see the ad (advertisement) in the paper, as I would have</td>
</tr>
<tr>
<td>to book in and wait for a GP referral otherwise</td>
</tr>
<tr>
<td>• Was convenient and great use of technology, but still did not change</td>
</tr>
<tr>
<td>anything in terms of treatment, as specialist was unable to offer a conclusive</td>
</tr>
<tr>
<td>diagnosis, so chose to travel to Perth</td>
</tr>
<tr>
<td>• The whole procedure was excellent and very friendly</td>
</tr>
<tr>
<td>• Poor clinic area</td>
</tr>
<tr>
<td>• Personnel very helpful</td>
</tr>
<tr>
<td>• Quite happy with the service I received. Should be more of them</td>
</tr>
<tr>
<td>• Very friendly, convenient and helpful service</td>
</tr>
<tr>
<td>• Excellent service – saved us having to go to an Eye Specialist in Geraldton</td>
</tr>
<tr>
<td>or Perth</td>
</tr>
<tr>
<td>• Unable to ask direct questions, as this was not a direct Telehealth service.</td>
</tr>
<tr>
<td>Results took a week to come back</td>
</tr>
</tbody>
</table>
Chapter 5. Patient and Clinician Perception of Teleophthalmology Service

![Bar chart showing patient ratings](image)

**Fig 5.9** Teleophthalmology patient rating with regard to service delivery

Clinical acceptance of a teleophthalmology service may depend on the degree of confidence the clinician has in his or her clinical findings (e.g., diagnosis) when using the application as well as the clinician’s satisfaction with the encounter in the absence of proximate, tactile interaction with the patient. If clinicians are not comfortable with the new technology, or judge that the technology decreases their control over patient care, they may avoid using it, thereby, precluding other benefits of teleophthalmology. The general practitioner and other health care workers in Carnarvon spoke favorably of using teleophthalmology in that they were able to get advice from colleagues and discuss alternative management strategies. Practitioners at Lions Eye Institute (Fig 5.10) found the experience informative and challenging. Supporting the success of this trial, given below are statements of specialists involved in diagnosing images sent through the e-icare system.

“As ophthalmologists visits to the Gascoyne area is only few times a year, this screening process is useful for a number of reasons. It allows a database to be created with storage of ocular images. These images may be used for follow up purposes. Whilst not ideal, it is the next best thing for glaucoma care, as the region does not have the tools and equipment necessary for the monitoring of glaucoma progression”.
“I believe Teleophthalmology is here to stay as it complements the overall health care delivered to a patient in rural Australia. General practitioners and optometrists practicing in remote areas should be encouraged to make use of this facility more often and should become part of their armamentarium in health care delivery”

5.3.1 Clinicians perception of the Quality of Images

For eye-related diseases, accuracy of image diagnosis is very important. The efficacy of digital image equipments used in teleophthalmology is well known and has been well documented in the literature.44,59,71,72

During the period studied, approximately 5% of the screenings had minor technical difficulty associated with the service, a small number, especially when considering the early stages of the Teleophthalmology project. Moreover, records relating to assessment of image quality were analyzed (Appendix 10). Because the program was new and the CRH teleophthalmology officer had just been trained, records were assessed for the first and then the second six months of the calendar year of 2003. Imaging quality codes ranged from very poor to excellent. The table 5.2 below demonstrates the increased image quality as a function of time.
Chapter 5. Patient and Clinician Perception of Teleophthalmology Service

Table 5.2: Image quality in two semesters in year 2003

<table>
<thead>
<tr>
<th>Codes</th>
<th>1st semester</th>
<th>2nd semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>1=Very Poor</td>
<td>2%</td>
<td>1%</td>
</tr>
<tr>
<td>2=Poor</td>
<td>40%</td>
<td>19%</td>
</tr>
<tr>
<td>3=Good</td>
<td>53%</td>
<td>68%</td>
</tr>
<tr>
<td>4=Excellent</td>
<td>5%</td>
<td>12%</td>
</tr>
<tr>
<td>All images</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

From the first semester to the second, ‘poor’ and ‘very poor’ images decreased by more than half whereas a substantial increase was seen on ‘good’ images coded. Images coded ‘excellent’ more than double as a percentage of the total images taken for the period, attesting to the increased confidence and ability of the coordinator in using the available equipment. It further demonstrates the effectiveness of the portable camera service delivered to the Gascoyne community.

5.4 Discussion

The evaluation of patient satisfaction is a common constituent of any health care service.\(^4\) While there is speculation regarding the neutrality of patient responses and debate around the lack of understanding of how patients evaluate services, it is a mechanism through which consumer attitudes can be usefully obtained. It is a wholly subjective assessment of the quality of service and, as such, is not a measure of final outcome of the technology used.

Earlier evidence has suggested that patient dissatisfaction is mostly associated with non-compliance with instructions, delay in seeking further care and poor understanding and retention of medical information.\(^73\) This survey found at least 2% of the patients were not satisfied and may choose to refrain from future services. Apart from others, a possible reason for this dissatisfaction may be, as one patient put in the following words, “convenient and great use of technology, but still did not change anything in terms of treatment”. The Internet-based consultation was mainly used to provide diagnostic options, and not as a new treatment modality.
Few of the patients (5%) found the store-and-forward Internet-based service more time consuming than the conventional face-to-face method. It must be noted that, except in the case of emergency cases, an outcome report of the Internet-consultation was sent by post to all patients within 24 hours. Perneger et al., after comparing patient satisfaction in three treatment settings, suggested that satisfaction also reflects patients’ characteristics and expectations, which are not related to quality of care.74 At Carnarvon, patients had an opportunity to see the distant specialist in person on occasions of their regional visits once or twice a year. The Internet-based service was used mainly for monitoring or screening, post-operative follow-up, trauma and expert second opinion services. In this survey, at least one patient expressed concern about the inability to ask direct questions to the specialist, and 23% of the patients still preferred physical contact with the distant clinician. Data security over the Internet represents another aspect of the process, which is often overlooked. Seven percent of patients were concerned about the privacy issues associated with the security of information in an Internet environment.

The Internet-based eye care system was deployed in Carnarvon Regional Hospital by accommodating the staff and equipment in the scarce space available within the hospital. In the absence of a dedicated room for telemedicine, a corridor area was curtained off to use as a teleophthalmology clinic. While this set-up was not comfortable for many patients, convenience in receiving eye care services in their familiar surroundings was perceived as a positive aspect of teleophthalmology (98%). Along with the convenience and cost savings associated with avoided travel to Perth, there were also indirect benefits to the family, which included: increased access to clinical support, reduced risk associated with travel, and reduced disruption to family life.

The patients’ response rate could have been higher in this study. This highlights the importance of finding other ways of working and organizing the communication network in order to increase the volume of response and follow up from isolated, rural and remote patients. It was observed that a fair number of patients (7%)
became aware of the telemedicine service through their family or friends, while a greater number of patients (36%) became aware through health care professionals in the locality, such as their general practitioners. Hence, general practitioners, family and friends, and other patients could be informed and encouraged towards optimizing the number of patients using telemedicine facilities and achieving better response rates. Overall, the patients valued improved access to specialist services but had clear views as to the limitations of such a service.

5.5 Conclusion

Despite a low volume of response from the patients, we may conclude that patients approve of Internet-based services, which is in compliance with protocols, as a feasible eye care modality in remote, rural areas. Patients and clinicians surveyed during this study show no negative general attitudes towards Internet-based teleophthalmology services. From the patient perspective, the success of teleophthalmology has been overwhelmingly associated with time and cost savings associated with travel, convenience and increased access to services. The implementation of teleophthalmology projects may therefore have a positive effect within patient and clinician communities. As the use of Internet-based eye care service grows, patient and clinician perspective evaluations merit greater attention.
SECTION SUMMARY OF PART 2

The cost analysis compiled from the Carnarvon teleophthalmology service demonstrates potential cost savings to the service providers with the use of the technology and more importantly, enhanced care and service access for the community. This is achieved initially at a higher cost but will potentially reduce over the time, as the service mainstreams and increases the volume of service. The benefit to the community is evident both in health service utilization, convenience and general support. The important issue is that setting realistic targets to increase the number of service events should in time, lead to the attainment of cost and service sustainability.

Feedback from patients and clinicians has been positive as this technology has begun to reduce the inequity and difficulty experienced by rural communities in accessing high quality eye care services.

Feasibility depends on several factors including clinician and patient acceptance, the yield of cases, and the program’s cost and effectiveness. Clearly, targeting teleophthalmology programs to rural populations will identify a larger number of eye diseases and increase the feasibility of teleophthalmology service.
PART 3. FEASIBILITY OF TELEOPHTHALMOLOGY SERVICE IN WESTERN AUSTRALIA - CLINICAL ASPECTS

Introduction to Part 3

A feasibility analysis of any medical intervention also involves identifying appropriate devices, tests and protocols. As the use of teleophthalmology service grows, an analysis of diffusion conditions for devices and tests and protocol demands greater merits. Part 3 of this thesis leads to a better understanding of protocols, digital devices and tests which are extensively used in teleophthalmology. Since Glaucoma is a leading cause of blindness in the Australia and other countries, telemedicine friendly glaucoma screening devices and protocols are identified to deal with intertwined and complex issues related to teleophthalmology practices as well as clinical challenges for early detection of glaucoma. The many new developments and advancements in glaucoma detection, combined with the possible increasing prevalence of glaucoma, necessitate process towards a teleophthalmology specific protocol for glaucoma detection.

Due to the high prevalence of visual impairment and blindness in the remote and regional Australian population, development of telemedicine specific vision tests are highly indicated towards the successful implementation of teleophthalmology. Hence, Part 3 of the thesis examines the development and clinical trials of unique computerized visual function tests (CVFT). These tests are expected to pioneer the use of telemedicine in diagnosing blindness and visual impairment in rural and remote regions of Western Australia and hence enhance teleophthalmology service feasibility.

Description of the Layout

Chapter 6 examines existing glaucoma screening protocols towards the process for a teleophthalmology specific screening protocol for glaucoma. Also, towards this goal, Chapter 7 analyses telemedicine friendly, portable tonometers which could be used for telemedicine based glaucoma screenings. Furthering the analyses towards a protocol, Chapter 8 evaluates conventional and telemedicine friendly glaucoma detection techniques including visual field tests, vertical cup disc ratio and intra ocular pressure measurements. The research, development and clinical trials of computerized visual function tests for increasing the efficacy of teleophthalmology service is outlined in Chapter 9.
Chapter 6

Review of Glaucoma Screening Tests and Protocols

6.1 Need of the Study

Feasibility of new health care interventions like teleophthalmology involves the investment of public resources; hence it is heavily weighted by the degree of its effectiveness for early detection of blinding diseases like glaucoma. The many new developments and advancements in recent years for diagnosis and treatment, combined with the increasing prevalence of primary open angle glaucoma (POAG), necessitate a re-evaluation of screening strategies for POAG especially from a teleophthalmology viewpoint.

Widespread screening is critical for early diagnosis, treatment and limiting the incidence of glaucoma-associated blindness. Meanwhile, individuals living in rural or remote areas have limited access to glaucoma tests. However, recent advances in compact, portable, easy to train, automated ophthalmic diagnostic devices and increasing spread of internet based telecommunications offer novel opportunities for telemedicine based glaucoma screening and monitoring. Semi-skilled, rural, ancillary health care workers could easily be trained to connect these devices to teleophthalmology system, perform screenings and send the results electronically to specialists in urban centers for second opinion and management Fig (8.1). Meanwhile, deciding about effective teleophthalmology glaucoma screening can be complex. Unlike diabetic retinopathy, teleophthalmology screening for glaucoma is scarcely documented in the literature. Conventional, non-telemedicine based glaucoma screening itself is a controversial issue since no single screening test has shown an adequate
Several factors have underlined the necessity of reevaluating screening for POAG. These include technological advances in the understanding, diagnosis, and treatment of POAG, and evidence of the possible increasing prevalence of the disease. When deciding if a disease merits screening, Wilson and Jungner elaborate on several criteria that must be met. These are based on the following characteristics: (1) the disease (a known natural history, a preclinical phase that can be identified, and a progressive clinical course in which later stages lead to worsening of symptoms), (2) the different tests used (their validity, reproducibility, acceptability, ease of performance, sensitivity, specificity, high positive predictive value, and appreciable cost–benefit), and (3) the treatment (its availability, and effectiveness). Glaucoma meets many of these criteria, which are addressed in the following review.

6.3 Introduction

Glaucoma is a disease that leads to damage of the optic nerve and subsequent vision loss or blindness (Fig 6.1). Most cases of glaucoma are primary open-angle glaucoma (POAG), also called chronic glaucoma. Primary closed-angle glaucoma (PCAG) is less common and usually occurs in an acute form, which presents with the sudden onset of symptoms such as decreased vision, extreme eye pain, headache, nausea and vomiting, and glare and light sensitivity. POAG usually begins with the loss of peripheral vision, which is often unnoticeable. As permanent nerve damage occurs, symptoms become obvious. Tunnel vision might develop, and only objects that are straight ahead can be seen. Other symptoms include headache, blurred vision, light sensitivity or haloes around lights.

POAG is one of the leading causes of blindness in the western world. 50% to 90% of glaucoma in the developed world remain undetected. Because the future prevalence of POAG is likely to increase in developed countries, open-angle glaucoma will become an even greater public health concern, and screening may become crucial to decrease
morbidity. Effective screening can be achieved by targeting high-risk populations, such as older people or first degree relatives of glaucoma patients.  

![Image of normal optic nerve head (Optic Disc) and cupping](image1)

**Fig 6.1 (a)** Image of normal optic nerve head (Optic Disc) and cupping **(b)** Advanced cupping in primary open angle glaucoma- POAG.

### Prevalence of Glaucoma

The prevalence rate for glaucoma in 2004 was estimated to be 2.3% (109,300) for the Australian population aged 55 years or more. Investigators in the Blue Mountains Eye Study, examining POAG prevalence in Australia, found an even higher prevalence in the same over-80 age group (8.17%). There is no statistically significant difference in prevalence rates between men and women.

### Risk Factors for Glaucoma

Major risk factors include a raised intraocular pressure, age and a positive family history for glaucoma. Other minor risk factors include high myopia and hypertension in the elderly. Migraine, nocturnal hypotension, and diabetes mellitus are also associated with glaucoma. Although high intra-ocular pressure is often associated with glaucoma, it is now considered a risk factor rather than a diagnostic criterion for the condition.

### Interventions for Glaucoma

There are a range of treatments that have been shown to be effective in slowing down or halting the progress of glaucoma, including the use of medications such as prostaglandins, or surgical techniques, including laser surgery.
6.4 Method
The current study reviewed new developments that have occurred since the early 1990s in the field of glaucoma screening. Medline (PubMed) and internet search engines were used to obtain published materials. Changes that could positively influence the implementation of teleophthalmology glaucoma screening programs were identified. The accuracy of testing devices and protocols was investigated individually and compared based on sensitivity and specificity.

6.5 Results:

6.5.1 Tests used for Glaucoma detection

Intraocular Pressure Measurement
During screenings, intraocular pressure (IOP) readings is taken by various methods (Fig 6.2). When portability is important, the Tono-Pen or the Perkins tonometer may be employed. Some have argued that despite less accurate measurements, pulse-air tonometers should be used to minimize risk of corneal damage.\(^9^6\) In general, however, measurement of IOP in glaucoma screenings has been shown to be of poor predictive value. In one study, the Schiotz tonometer was shown to achieve the most uniform assessment of IOP compared with the Tono-Pen or the Perkins tonometer, but even when measured optimally, increased IOP alone was a poor predictor of glaucoma.\(^9^7\) Guidelines for IOP measurement have also been evolving, especially with respect to central corneal thickness (CCT).\(^9^8\) Studies of patients who underwent photorefractive keratoplasty (PRK) and laser in-situ keratomileusis (LASIK) demonstrated that thinner postoperative CCT underestimates real IOP.\(^9^8\) More importantly, a recent, large, multicentre, randomized controlled trial with subjects who had ocular hypertension has demonstrated that thinner central corneas are an independent risk factor for converting to glaucoma.\(^9^9\) Consequently, investigators have advocated measuring both IOP and central corneal thickness in glaucoma screenings.\(^1^0^0\) Intra Ocular Pressures above 21mmHg are generally considered bench marks for glaucoma suspected cases. However, high IOP’s is also attributed to ocular hypertension.\(^7^8\)
Glaucoma damages the optic fibre of the eye. Excessive pressure erodes the optic disc and develops central depression, otherwise known as cupping. Such phenomena can be detected upon optic disc imaging analysis. The following parameters are helpful:

- **Cup Disc Ratio (CDR)**
  - In order to find the CDR, it is necessary to locate the scleral rim (whitish colour, most noticeable on the nasal and temporal sides). Location of the horizontal and vertical (with respect to macula) outer cup limits and inner scleral rim points permit calculation of either the horizontal or vertical CDR.
  - CDR greater than 0.6 may be indicate towards further tests for glaucoma.
Neural Retinal Rim (NRR)
- Better indicator than CDR at differentiating normal and glaucomatous optic cup.
- 95% of normal > 1.09 mm$^2$, 73% of glaucoma <1.09 mm$^2$, indicating considerable overlap between normal eyes and glaucomatous eyes.$^{101}$

ISNT Sign
- Determined from the NRR. In a normal eye, the inferior margin is the thickest followed by the superior, nasal and temporal margins
- Glaucoma is suspect when the temporal margin approaches or exceeds the same value as the vertical margins (i.e. when I=S=T).$^{102}$

Blood Vessel Changes
- Flame and splinter hemorrhages around the optic disc border are good indicators, particularly in low tension glaucoma. Since it is a transient characteristic evident in the early to moderate stages of the disease, it yields a sensitivity of only 10%.$^{102}$

**Visual field tests**
Visual field defects, detected with standard achromatic perimetry (SAP), are the mainstay of demonstrating functional glaucomatous damage (Fig 6.4, 6.5). It is now suggested that up to 35% of nerve fibre axons may already be damaged before SAP detects any functional visual field loss.$^{103}$ Frequency doubling technology perimetry (FDP) may offer certain advantages for early glaucoma detection, in part due to its short patient-examination time.$^{104}$ FDP is thought to detect functional loss up to 4 years earlier than SAP by stimulating the specific My ganglion cells of the magnocellular pathway which is damaged in early glaucoma.$^{105,106}$ Several investigators have found that FDP has both sensitivity and specificity in the 90$^{th}$ percentile range, making it an excellent screening tool.$^{107-110}$ Sponsel et al believe that FDP may prove capable of detecting both glaucoma and its progression earlier than SAP.$^{112}$ Short wavelength automated perimetry (SWAP), or blue-on-yellow perimetry, is another visual field testing technique that may also detect glaucomatous damage earlier than SAP.$^{113}$ However, FDP is a faster test and a study comparing all three methods (SAP, SWAP, FDP) found it able to detect glaucomatous visual field defects the earliest of all.$^{114}$
Other existing tools have been studied with regard to visual field testing. The Damato campimeter has been found to have a sensitivity of 50% and a specificity of 90%.\textsuperscript{108} Oculokinetic perimetry has been found to have different sensitivities (75%,\textsuperscript{115} and 86%,\textsuperscript{116}) and specificities (56.1%,\textsuperscript{116} 65%,\textsuperscript{115} and 94%\textsuperscript{117}) depending on the study. These values indicate that neither is sufficient for use by itself in a glaucoma screening program.\textsuperscript{117}

**Patient Questionnaire**

Glaucoma detection can be greatly improved by asking a series of questions related to family history, ethnicity, age, head injuries etc.\textsuperscript{118} The following points need to be considered:

- **Family History**
  - If first degree relatives have glaucoma, the risk of developing the disease
increases and typically ranges from 4%-40%. In fact, approximately one third of all patients with glaucoma have a first degree relative with the disease.119

- Race/Ethnicity
  - Black Africans and Chinese have a risk factor 4 times that of Caucasians.119

- Age
  - Advancing age is a strong risk factor. Glaucoma is prevalent in 0.5%-2% of those over the age of 40; this increases to 7% for those over the age of 80.119

- Medical History
  - A myopia value greater than 5 diopters increases the risk of glaucoma fivefold
  - Diabetes increases the risk of glaucoma twofold
  - Other risk factors include chronic steroid use, a history of eye trauma and past treatment for high eye pressure or glaucoma.119

**Confocal Scanning Laser Ophthalmoscopy**

Subjective examination of the optic disc and retinal nerve fibre layer (RNFL) remains one of the most important steps in diagnosing glaucoma. Recent technological advances, however, have produced many new instruments that can objectively quantify the optic nerve head and the RNFL. Confocal scanning laser ophthalmoscopy (CSLO), optical coherence tomography (OCT), and scanning laser polarimetry (SLP) may in some cases permit earlier glaucoma diagnosis. Therefore their role in screening, especially when coupled with telemedicine, appears promising and remains to be studied. A brief summary of 3 instruments, one from each of these different technologies, is provided.

The HRT II (Heidelberg Engineering, Heidelberg, Germany) is a confocal scanning laser ophthalmoscope that provides 3-dimensional topographic images of the optic nerve head and adjacent nerve fibre layer. It is a highly reproducible exam that is considered very useful for following topographic change over time.120-122 The instrument’s potential for detecting early structural damage makes the HRT II an important tool to consider when devising a glaucoma screening program123,124 Several studies have reported sensitivity ranging from 64% to 85% and specificity from 68% to 88%,125-127 but little has been studied in actual screening scenarios.
Optical Coherence Tomography

The OCT III (Carl Zeiss Meditec Inc., Dublin, Calif.) is a computer-assisted optical instrument that produces transverse sections of the retina with an axial resolution of 10 to 20 µm (Fig 6.6). It uses an optical measuring technique called low coherence interferometry that enables examination of the posterior ocular segments including the retinal nerve fibre layer, the optic nerve head (ONH), and the macula. Studies have shown that it facilitates the diagnosis and management of retinopathies and glaucoma. 128-130 Additionally, its capacity to measure any anomalies in thickness of the retinal nerve fiber layer permits the OCT to give an objective evaluation of the RNFL. 131 Sensitivity and specificity for the linear discriminant function (LDF) between patients with glaucoma and those without, based on the Fourier analysis of the normative data of the instruments, were 76% and 90%, respectively. 132

Fig 6.6 Optical Coherence Tomography (Image: lightlabimaging)

Scanning Laser Polarimetry

The GDx (Laser Diagnostic Technologies Ltd., San Diego, Calif.) is another imaging system that analyzes the nerve fibre layer of the optic nerve using polarimetry. It has been
Chapter 6. Review of Glaucoma Screening Tests and Protocols

shown to be useful in glaucoma screening, although when patients suspected of having glaucoma are considered, results may vary.\textsuperscript{132,134} The sensitivity (74\%) and specificity (74\% and 92\%) vary depending on the study.\textsuperscript{134,135} A more recent innovation in the GDx is variable corneal compensation (VCC) technology. This newer version of the GDx compensates for possible errors due to corneal refraction differences in measurements of RNFL thickness and has shown promising results in glaucoma diagnosis and screening.\textsuperscript{136}

6.4.2 Results: Glaucoma Screening Protocols Adopted by Various Clinics

\textit{Office of Quality and Performance, U.S.A.}

The Office of Quality and Performance\textsuperscript{137} investigated the best procedure for assessing who should attend a screening exam and when they should attend one. The selection procedure was based on factors such as age, ethnicity and family history. Those who are at high risk (i.e. an African American aged greater than 65 with a family history of glaucoma) should be scheduled within 3 months whereas those at low risk (i.e. a Caucasian younger than 65 with no family history) do not need a screening test until they reach 65. It is expected that such a selection criteria will significantly reduce the number of unnecessary screenings and thereby improve cost-effectiveness.

\textit{University of Melbourne, Australia.}

The screening protocol was recommended as follows\textsuperscript{102}:

1. Shadow Test. The shadow test can be used to assess the depth of the anterior chamber. Light is shone parallel to the iris and a shadow is cast by its curvature; a shadow greater than 0.33\text{mm} is cause for failure (in which case, a gonioscopic evaluation is needed).

2. IOP Measurement. A consistent IOP value greater than 21\text{mmHg} corresponds to test failure. The threshold for patients older than 75 years drops to 18\text{mmHg}.

3. CDR Evaluation. A large (greater than 0.5) or asymmetric CDR in a normal disc is cause for failure. Large or small discs must be evaluated with signs other than the CDR, such as NRR, ISNT or retinal nerve fibre loss (RNFL).

If the patient fails any of the above 3 tests, a visual field screening test needs to be conducted. Patients with repeatable field test abnormalities should be fully evaluated for glaucoma (i.e. referred to an ophthalmologist). This screening test is recommended for all
those over the age of 40, at regular intervals of 5 years up to the age of 60. Those over the age of 60 should be screened every year. If all the tests are performed, the sensitivity approaches 94% at a moderate specificity of 69%.

University of Maryland, USA.

The University of Maryland has adopted the following protocol: 138

1. Fill out a patient history form. Risk factors such as ethnicity, age, family history, and hypertension are required.
2. Use a near card to assess visual acuity. Glasses and contacts must be left on during the exam but details are documented.
3. Test peripheral vision using the FDT.
4. Based on FDT results AND risk factors, measure IOP using tonopen.
5. Discuss results with patient.

The patient’s physician performs the dilated-pupil fundus exam.

Lions Eye Institute, Western Australia.

The Lions Eye Institute (LEI) performs up to three tests at glaucoma screenings, namely, IOP, VCDR and FDT. The referral flow chart looks as follows (Fig.6.7):

**Fig 6.7**: Schematic representation of Glaucoma Screening Protocol of Lions Eye Institute, WA.

VCDR: Vertical Cup Disc Ratio
DA: Disk Asymmetry
Chapter 6. Review of Glaucoma Screening Tests and Protocols

Aside from these tests, the Lions Eye Institute also collects patient history data relevant to glaucoma risk. These risk factors include age, family history of glaucoma, heart disease, diabetes, high blood pressure and stroke.

6.4.3 Glaucoma Screening Statistics

The following table (Table 6.1) accumulates sensitivity and specificity results from a variety of case studies. It is evident from Table 6.1 that field tests yield the highest sensitivity and specificity, followed by ophthalmoscopy and tonometry.

**Table 6.1: Screening Statistics – Sensitivity and Specificity of Screening Tools**

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>TONOMETRY</th>
<th>OPHTHALMOSCOPY</th>
<th>FIELD TESTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NOTES SE SP</td>
<td>NOTES SE SP</td>
<td>NOTES SE SP</td>
</tr>
<tr>
<td>USPSTF</td>
<td>IOP&gt;18mmHg 65 65</td>
<td>- -</td>
<td>Automated Perimetry 90 70</td>
</tr>
<tr>
<td></td>
<td>IOP&gt;21mmHg 44 92</td>
<td>- -</td>
<td>Automated Perimetry in Mass Screening 92 46</td>
</tr>
<tr>
<td>Power et. al. 139</td>
<td>IOP&gt;21mmHg 72 30</td>
<td>Mass Screening 72 64</td>
<td>Expert Examiners 84 97</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Automated Perimetry 93 88</td>
</tr>
<tr>
<td>Development &amp; Evaluation Committee 119</td>
<td>IOP&gt;21mmHg 47 92</td>
<td>CDR &gt; 0.5 48 89</td>
<td>Henson Field Screener – Untrained Staff 25 92</td>
</tr>
<tr>
<td></td>
<td>NCT 4 Puffs 92 96</td>
<td>Disc Assessment 58 99</td>
<td>Perimetry – Most Sophisticated 90 90</td>
</tr>
<tr>
<td>Ieong et. al. 140</td>
<td>- - -</td>
<td>HRT II 69 94</td>
<td>SFVA 71 94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HRT II – Early POAG 52 -</td>
<td>SFVA – Early POAG 53 -</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HRT II – Late POAG 90 -</td>
<td>SFVA – Late POAG 94 -</td>
</tr>
<tr>
<td>Fabre et. al. 141</td>
<td>- - -</td>
<td>- - -</td>
<td>TOP 94 75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- - -</td>
<td>FDP 72 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- - -</td>
<td>GDx 78 60</td>
</tr>
<tr>
<td>Kalaboukhova et. al. 142</td>
<td>- - -</td>
<td>- - -</td>
<td>FDT 92 88</td>
</tr>
<tr>
<td>Trible et. al. 143</td>
<td>- - -</td>
<td>- - -</td>
<td>FDP Screening Test – Early POAG 39 95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- - -</td>
<td>FDP Screening Test – Mod. POAG 86 95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- - -</td>
<td>FDP Screening Test – Late POAG 100 95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- - -</td>
<td>FDP Full Test – Early POAG 35 91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- - -</td>
<td>FDP Full Test – Mod. POAG 88 91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- - -</td>
<td>FDP Full Test – Late POAG 100 91</td>
</tr>
<tr>
<td>Tatemichi et. al. 144</td>
<td>- - -</td>
<td>- - -</td>
<td>FDT, Left Eye 91 45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- - -</td>
<td>FDT, Right Eye 91 55</td>
</tr>
</tbody>
</table>

Table 6.1 also suggests that it is very difficult to attain a suitable balance between sensitivity and specificity; both need to be very high, but in the cases of tonometry and ophthalmoscopy, only one or the other can be forced high (by adjusting the cutoff points) but never both. It may be possible to attain mutually high sensitivity and specificity values by using screening tool combinations, as the following table 6.2 illustrates. Note that the first reference is low because it does not include the field tests; it is highly likely that inclusion of the FDT would yield particularly good results.

Table 6.2: Sensitivity and Specificity of Screening Tool Combinations

<table>
<thead>
<tr>
<th>Reference</th>
<th>Combination of Tests</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>USPSTF 78</td>
<td>Tonometry, Direct Ophthalmoscopy and Patient History</td>
<td>49 - 66</td>
<td>79 - 87</td>
</tr>
<tr>
<td>Development &amp; Evaluation Committee</td>
<td>Henson Field Screener and Non-Contact Tonometry</td>
<td>91.7</td>
<td>92.5</td>
</tr>
</tbody>
</table>

6.5.4 Results: Glaucoma Screening Recommendations

U.S. Preventive Services Task Force

The U.S. Preventive Services Task Force\(^{78}\) states that 'There is insufficient evidence to recommend for or against routine screening for intraocular hypertension or glaucoma by primary care clinicians'. The USPSTF accumulated screening data from a wide variety of screening sources, most commonly, The Baltimore Eye Survey.

Development and Evaluation Committee, Bristol

The Development and Evaluation Committee\(^{119}\) recommendations concerning screening were divided into the categories of strongly recommended, recommended, beneficial but high cost, not recommended and not proven. Glaucoma screening fell into the category of beneficial but high cost for a screening programme.

Worldwide Glaucoma Conference 2000 (Co-sponsored by WHO)

In Baltimore, year 2000, a group of academic and practicing eye care professionals participated in a 2 day worldwide conference to evaluate the present status of glaucoma treatment and diagnosis.\(^{144}\) Working in 5 different groups, they dealt with the diagnosis and treatment of both open and closed angle glaucoma as well as evaluate the importance of
glaucoma in overall eye care. The conference provided the following glaucoma screening recommendations:

- Glaucoma screening is not viable if treatment cannot provide better long-term visual function.
- Communities with limited resources should be screened for more advanced cases of the disease (i.e. moderate to severe glaucoma).
- Glaucoma screening should be conducted as part of a comprehensive effort to diagnose all treatable eye diseases (i.e. screen for diabetic retinopathy, macula degeneration etc at the same time).

### 6.5 Discussion

In order to fulfill the WHO criteria for screening viability\(^\text{82}\), the protocol package must yield adequate sensitivity and specificity values. It is evident from Table 6.1 that this can only be attained if the following hardware is available (in order of importance):

1. FDT or other low cost field test
2. Optic disc imaging device
3. Tonometer

The HRT II/OCTIII/GDx-VCC instruments and the psychophysical tests, such as FDT, are capable of detecting glaucomatous visual damage earlier. It should be noted that although these tests may have less-than-ideal sensitivities and specificities, these can be increased by combining diagnostic modalities in parallel, thereby providing a more reliable screening program.\(^\text{145,146}\) While Age and positive family history has a greater influence on glaucoma, according to the review conducted, developing an effective teleophthalmology screening protocol also needs to be based on further evaluation of:

1) The effective combination of positive history of glaucoma, visual field analysis, optic disc analysis and IOP measurements according to their predictive powers.

2) Evaluation of IOP measurements, preferably from different tonometers, including telemedicine-friendly tonometers.
6. 6 Conclusion

Although the glaucoma screening tests reviewed here suggests less-than-ideal sensitivities and specificities, they may be still useful for early detection of Glaucoma to certain extent. It may be possible that, when combined together in parallel, these tests may provide higher sensitivities and specificities, which may assist for the increased understanding of the diagnosis and monitoring of POAG. This indicates, there is an urgent need to establish the sensitivity and specificity of various combinations of these devices and tests. Such an evaluation will positively influence the design of teleophthalmology based glaucoma screening protocols. Applying knowledge concerning the digital devices will augment the feasibility of teleophthalmology service. Consequently, an evaluation of telemedicine-friendly, portable, digital devices will be another vital contribution towards achieving this goal.
Chapter 7

Evaluation of Portable Tonometers

7.1 Introduction: Telemedicine - friendly, Portable Tonometers
Recent advances in compact, portable, easy to train, automated ophthalmic diagnostic devices and increasing spread of internet based telecommunications offer novel opportunities for telemedicine based glaucoma screening and monitoring. Semi-skilled, rural, ancillary health care workers could easily be trained to connect these devices to a teleophthalmology system, perform screenings and send the results electronically to specialists in urban centers for second opinion and management (Fig. 8.1). Currently very little is known about the effectiveness of telemedicine friendly devices especially for IOP recording and monitoring.

IOP is generally measured from the surface of the cornea with dedicated instruments, called tonometers. Traditional \textit{applanation} tonometers (Eg: Goldmann Applanation Tonometer) touch the cornea, needs anaesthetics, slit-lamp and trained professionals whereas portable \textit{air-puff} tonometers produce the measurement value without a physical contact and do not require any anesthetics. Its IOP readings are displayed digitally. Meanwhile, the current gold standard device for measuring IOP is the Goldmann Applanation Tonometer (GAT), however it is not ideal for remote regional glaucoma screenings as it requires the use of local anesthetic, and must be used by an ophthalmologist along with a slit-lamp.

The Goldmann applanation tonometer (Haag Streit AG, Bern, Switzerland) is currently the most widely used tonometer by ophthalmologists in their consulting
Chapter 7. Evaluation of Portable Tonometers
rooms (Fig 6.2), and is considered to be the gold standard for measuring intraocular pressure (IOP).\textsuperscript{147,148} The Goldmann tonometer, however, cannot be used for bedridden patients, for younger children, in the operating room, and in other situations outside the consulting room.

Although there is a portable Goldmann applanation tonometer (Perkins; Clement-Clarke Inc., Columbus, OH, USA), it is not always suitable. Other portable tonometers have been developed, such as the Tonopen (Mentor, Santa Barbara, CA, USA), the TGDc-01 (Ryazan State Instrument-making Enterprise, Ryazan, Russia), and the ICARE tonometer (TA01; Tiolat Oy, Helsinki, Finland).

The Tonopen is the oldest of these portable devices. It is a handheld device that uses the same physical principle as the Goldmann applanation tonometer.\textsuperscript{149,150} As well as the IOP, the variability of a series of measurements is also determined. An earlier version of the Tonopen was the Oculab Tonopen and the latest version is the Tonopen XL.

Recently, a new portable tonometer has been developed: the i-Care tonometer (Fig 7.1). The i-Care tonometer uses the impact rebound principle as described by Dekking and Coster (1967).\textsuperscript{151} A small probe is propelled against the cornea, impacts with it and rebounds from the eye. The movement of the probe induces a small induction current enabling the impact duration to be measured. It is a handheld tonometer measuring $23 \times 8 \times 3$ cm with single-use probes that can be used without anesthesia. Individual measurements are digitally displayed, and after six consecutive measurements the average result is given as well as a variability measure. Articles published about the i-Care tonometer are all from the same source (Kontiola).\textsuperscript{152-154}

7.2 Need of the Study
Although several studies have been published about portable tonometers, no studies have been published comparing these tonometers directly to each other, except for a comparison between i-Care and Tonopen in the rat eye by Goldblum, Kontiola et al. (2002).\textsuperscript{155} Hence towards an effective implementation of teleophthalmology service
there is a vital need to compare the PAT, ICT portable tonometers with each other and to the gold standard, Goldmann applanation tonometry (GAT), in one and the same group of subjects in a clinical setting.

In order to determine efficiency of telemedicine friendly devices for glaucoma screening, this study compared two portable tonometers- the i-Care rebound tonometer- ICT (Tiolat Oy, Helsinki, Finland) and Pulsair- Easy Eye -PAT (Pulsair-Easy Eye, Keeler, PA, USA) - with Goldmann applanation tonometer –GAT (Haag Streit AT 900, Ohio, USA). The IOP readings of both ICT and PAT are digitally displayed and could be easily integrated to a telemedicine system to transfer the data to an urban diagnosing centre. Also, both ICT and PAT do not require anesthetics. The measuring probe of ICT tonometer touches the eye gently and is reported to be comfortable.\textsuperscript{154}

![Fig 7.1. Images of the tonometers studied a) i-Care rebound tonometer- ICT b) Pulsair-Easy Eye -PAT and c) Goldmann applanation tonometer –GAT](image)

With regard to increasing awareness on the effect of corneal thickness and anterior chamber depth on IOP readings,\textsuperscript{156,157} and the increasing number of patients with a history of corneal refractive surgery, analysis was also done on the effects of central corneal thickness (CCT), anterior chamber depth (ACD) and refractive status on IOP measurement by all tonometers.
7.3 Method
The study included informed, consenting patients attending the Eye Clinic at Lions Eye Institute, University of Western Australia. Patients were excluded from the study if they recently had any eye surgery. The refractive status of the eyes was determined with an auto refractor (AutoKerato Refractometer KR 8100, Topcon, Tokyo, Japan). Myopia was defined as a spherical equivalent of -0.50 diopters (D) or less, hypermetropia as +0.50 D or more. Those subjects with either irregular astigmatism or regular astigmatism >3 D were excluded. The ACD and CCT were measured with Orbscan (Orbscan11, version 3.12, Bauch & Lomb, NY, USA).

All the tonometers were calibrated for optimal performance as recommended by the manufacturers. The i-Care tonometer (ICT) takes six consecutive readings and calculates an average. Being a relatively new instrument, ICT measurements were carried out twice (ie, 6*2=12 times in total) in each eye to assess the repeatability of the measurements. IOP readings was taken from each eye with the “Puff-Air” tonometer (PAT) but was not tested for repeatability. Topical anesthesia was used only for GAT method. All the measurements were taken in sitting position. To reduce the risk of observer bias, the GAT measurements were taken at random by three ophthalmologists (AG, MTK, WM) and the portable tonometry readings were recorded at random by allied health staffs (SK,CM).

Bland and Altman method of measuring test agreement using plots of differences against means was used as the best way to compare measurements with different instruments measuring the same thing. To examine the relationship formally we used the spearman rank correlation coefficient(r) between the absolute difference and the average. Repeatability of IOP estimates by ICT was determined by the mean difference between two consecutive IOP readings. To explore the relationship between IOP and clinical variables (CCT, ACD and refractive errors) a generalized linear model was used. In order to calculate the sensitivity and specificity, IOP by GAT was considered as gold standard and 21mmHg as the threshold for suspected glaucoma. Positive and Negative Predictive Values (PPV & NPV) were calculated using 3.13% prevalence of glaucoma. All statistical analysis was done using Stata version 8 (Stata Statistical Software: Release 8.0).
Chapter 7. Evaluation of Portable Tonometers (2003) College Station, TX: Stata Corporation). This study conformed to the standards of the Human Research Ethics Committee of the University of Western Australia.

7.4 Result

The study included 213 eyes of 107 consenting patients. There were 66 females (average age: 62.8 years, min: 24yrs and max: 88yrs) and 42 males (average age: 63.0 years, min: 26yrs and max: 88yrs). 30 patients had myopia, and 63 patients had hypermetropia. The CCT measurements ranged from 412 to 676 µm and the ACD measurements ranged between 1.58 and 4.67mm.

Fig 7.2. Differences between Goldmann Applanation Tonometry (GAT) & Puff Air Tonometry (PAT) against their mean

Fig 7.2 indicates a difference between GAT and PAT readings. The mean value represents the bias (the mean difference between two methods) and the limits of agreement represented by +/- 2 standard deviations of the mean difference. The mean bias was 2.22, sd=4.17 and r=0.18. Fig 7.3 demonstrates the differences between IOP by GAT & ICT against their mean. The mean bias was 2.24, sd=3.06 and r =0.33.

Fig 7.3. Differences between Goldmann Applanation Tonometry (GAT) & i-Care tonometry (ICT) against their mean
Both the digital tonometers had a sensitivity of 34.8% and specificity of > 95% for suspected glaucoma (Table 7.1).

**Table 7.1.** Sensitivity and Specificity (95% CI) for both Puff Air and i-Care tonometry, using 21mmHG as the threshold for Glaucoma suspect. PPV=positive predictive value and NPV=negative predictive values calculated with glaucoma prevalence = 3.13%

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity (%) (95% Conf. Interval)</th>
<th>Specificity (%) (95% Conf. Interval)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Puff Air</td>
<td>38.1 (31.5-44.7)</td>
<td>96.4 (93.9- 98.9)</td>
<td>25.5</td>
<td>97.9</td>
</tr>
<tr>
<td>i-Care</td>
<td>38.1 (31.5-44.7)</td>
<td>98.8 (97.3-100.0)</td>
<td>50.7</td>
<td>98</td>
</tr>
</tbody>
</table>

The ROC analysis (Fig 7.4) indicates minimal difference between PAT and ICT (p=0.015). The mean difference between two consecutive IOP readings by ICT in the same eye was 0.01 (SD= 1.77, coefficient of repeatability r = 3.1).

![Fig 7.4](image.png)

**Fig 7.4.** Comparison of ROC Analysis for both Puff- Air & i-Care tonometry. i-Care tonometry-ICT has a significantly higher area under the ROC curve compared to Puff-air tonometry -PAT (p=0.015).

The linear model corrected for cluster (left and right eye from same patient giving a robust estimate of the standard errors) and adjusted for age and sex shows that there was a non-significant relationship between PAT readings and ACD (Table 7.2). For each unit (0.01 mm) increase in ACD, the IOP by PAT decreased by 1.45 mmHg (p=0.027). Where as for each unit increase in ACD, the ICT readings decreased by 1.55 mmHg (p=0.088) and similarly for GAT, the IOP decreased by 1.42 mmHg (p=0.124).
Chapter 7. Evaluation of Portable Tonometers

Table 7.2. Relationship between anterior chamber depth (ACD) and Intraocular pressure (IOP) by all the tonometers. Adjusted for Age and Sex.

<table>
<thead>
<tr>
<th></th>
<th>Coef (r)</th>
<th>P-Value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Puff-Air/ACD</td>
<td>-1.45</td>
<td>0.027</td>
<td>-2.74</td>
</tr>
<tr>
<td>i-Care/ACD</td>
<td>-1.55</td>
<td>0.088</td>
<td>-3.33</td>
</tr>
<tr>
<td>Goldman AT/ACD</td>
<td>-1.42</td>
<td>0.124</td>
<td>-3.23</td>
</tr>
</tbody>
</table>

Further analysis shows significant relationship between central corneal thickness (CCT) and IOP by all the tonometers (Table 7.3). For each unit (1 µm) increase in CCT, IOP readings by PAT increased by 0.029 mmHg (p<0.0001) and IOP by ICT increased by 0.037 mmHg (p<0.0001) and by GAT increased by 0.035 mmHg (p<0.0001).

Table 7.3. Relationship between central corneal thickness (CCT) and intraocular pressure (IOP) by all the tonometers. Adjusted for Age and Sex.

<table>
<thead>
<tr>
<th></th>
<th>Coef</th>
<th>P-Value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Puff-Air/CCT</td>
<td>0.03</td>
<td>&lt;0.0001</td>
<td>0.01</td>
</tr>
<tr>
<td>i-Care/CCT</td>
<td>0.04</td>
<td>&lt;0.0001</td>
<td>0.02</td>
</tr>
<tr>
<td>Goldman AT/CCT</td>
<td>0.03</td>
<td>&lt;0.0001</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Analysis given below (Table 7.4) specify no significant relationship between myopia and IOP by ICT (p<0.634), PAT (p<0.632) or by GAT (p<0.254).

Table 7.4. Relationship between Myopia and intraocular pressure (IOP) by all the tonometers. Adjusted for Age and Sex.

<table>
<thead>
<tr>
<th></th>
<th>Coef</th>
<th>P-Value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Puff-Air/Myopia</td>
<td>0.37</td>
<td>0.632</td>
<td>-1.13</td>
</tr>
<tr>
<td>i-Care/Myopia</td>
<td>0.36</td>
<td>0.634</td>
<td>-1.14</td>
</tr>
<tr>
<td>Goldman AT/Myopia</td>
<td>1.00</td>
<td>0.254</td>
<td>-0.72</td>
</tr>
</tbody>
</table>

Analysis in Table 7.5 illustrate no significant relationship between hypermetropia and IOP by ICT (p<0.571) or PAT (p<0.375) or by GAT (p<0.371).

Table 7.5. Relationship between Hypermetropia and intraocular pressure (IOP) by all the tonometers. Adjusted for Age and Sex.

<table>
<thead>
<tr>
<th></th>
<th>Coef</th>
<th>P-Value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Puff-Air/Hypermetropia</td>
<td>-0.65</td>
<td>0.375</td>
<td>-2.08</td>
</tr>
<tr>
<td>i-Care/Hypermetropia</td>
<td>-0.44</td>
<td>0.571</td>
<td>-1.95</td>
</tr>
<tr>
<td>Goldman AT/</td>
<td>-0.77</td>
<td>0.371</td>
<td>-2.45</td>
</tr>
</tbody>
</table>
7.5 Discussion

Deciding about effective glaucoma screening can be complex. In March 2005, the U.S. Preventive Services Task Force (USPSTF) found insufficient evidence to recommend for or against screening adults for glaucoma. The USPSTF study reported that while visual field testing and ophthalmoscopy accurately identifies persons with primary open-angle glaucoma, the measurement of intraocular pressure is not a good screening tool for glaucoma. Meanwhile, Maier et al presented a meta-analysis of the glaucoma trials, which concluded that lowering intraocular pressure in patients with ocular hypertension or manifest glaucoma is beneficial in reducing the risk of visual field loss in the long term.

Despite its apparent limitations as a screening test, intraocular pressure measurement by tonometers remains the mainstay of glaucoma monitoring. The ICT and PAT tonometers have the advantage of being easily transportable from site to site for IOP examinations and do not require the patient to be positioned on a chin rest in front of a slit lamp. It doesn't transmit infectious illnesses, and it isn't necessary to use anesthetic or staining eye drops. Hence, these type of tonometers are widely and increasingly being used in optometric practice. Also, their noninvasive character allows screening to be delegated to ancillary staff. The aim of this study was to compare the effectiveness of these tonometers with that of conventional Goldmann applanation tonometer.

The analysis indicates a difference of ±2mmHg between GAT and the two portable tonometers. Earlier, investigators have found that many variables affect the measurement of IOP, including respiration, accommodation, heart rate, and rhythm. They determined an error margin of ±3 mm Hg as acceptable. In a recent report, within a study population of 46 patients, statistically significant differences were found when comparing the ICT with GAT ($p < 0.05$). The mean difference between the two tonometers was $1.34 \pm 2.03$ mmHg (mean ± S.D.) and the 95% limits of agreement were $\pm 3.98$ mmHg.
Chapter 7. Evaluation of Portable Tonometers

Adopting a screening criterion of greater than or equal to 21 mmHg (GAT) has resulted in a sensitivity of 38% and a specificity of >95% for both PAT & ICT. While higher test specificity ensures the exclusion of patients without the condition, the analysis indicates, that, although both the digital tonometers may be useful for screening patients presumed to have normal IOP, their influence in detecting the incidence of glaucoma could be negligible. ICT has a higher positive predictive value (PPV = 51%) than PAT (26%). This indicates that if a person has IOP > 21 mmHg with an ICT, there is 51% probability that he or she has glaucoma. The Negative predictive value (NPV) indicates that, if a person tests negative what is the probability that he or she does not have glaucoma. In this study, NPV was identical (98%) for both the portable tonometers. These results indicate portable tonometers may be useful for glaucoma population study.

As mentioned earlier, results of this study indicate that the portable tonometer readings differ minimally with the GAT. Corneal thickness (CCT) could be the reason for some part of these differences. As the differences in corneal thickness might explain differences between an IOP measured \(^{171,172}\) we also studied the influence of corneal thickness on the IOP measured with these tonometers. Because CCT varies greatly from one person to another, it is reasonable to assume the resistance to indentation of applanation to vary as well.\(^ {169}\) In fact, Goldmann IOP readings have been reported to be directly influenced by CCT.\(^ {173}\) as are the non-contact tonometry.\(^ {171}\) The results of current study indicate that the CCT value has significant influence on tonometry readings. However, the extent of this effect does not provide confirmation that pachymetry (measurement of CCT) needs to be routinely performed in glaucoma screening protocols based on tonometry. Albeit, the finding of higher than expected tonometry values may be further investigated, by pachymetry.\(^ {157}\)

In this study the statistical analysis of the collected data doesn't establish a significant relation between the variation of ACD and the measurements of IOP by any tonometers. Explicitly, this study confirms IOP readings by both the portable tonometers and GAT are not influenced by ACD.\(^ {156}\)
Also this study reports that the IOP readings by all the tonometers are independent of myopic or hypermetropic refractive errors. A strong relationship between myopia and glaucoma, while not dependent of IOP was reported earlier.\textsuperscript{174}

As it was not the main objective of the study, the inter & intra observer variability when measuring IOP in the same eye was not conducted during this study. Also repeatability of PAT and GAT measurements were not conducted. A potential problem of such studies is that repetitive IOP measurements over a short period, in the same eye, which are necessary to calculate the observer variability and repeatability, often influence IOP between the first and the subsequent sets of measurements.\textsuperscript{175}

Nevertheless, the ICT and PAT may be helpful as a screening tool when GAT is not applicable or not recommended, as it is able to estimate IOP within a range of \(\pm 3.00\) mmHg. Both the portable devices are also preferred for telemedicine based remote assessment of IOP for their portability and non-anesthetic reasons. However, further study is needed to examine these devices’s long-term drift in accuracy with use. Also the role of IOP tests in detecting glaucoma in combination with other tests such as perimetry and cup-disc ratio analysis needs to be examined.

\section*{7.6 Conclusion}

This study concludes that the IOP readings made by Puls-Air and I-Care techniques match well with each other and were within clinically acceptable range from GAT. In the subjects studied, except for CCT, refractive errors and ACD had no significant influence on IOP measurements with any tonometry. Portable, digitally recordable tonometry could be an effective method for intraocular pressure measurement and a supportive tool for teleophthalmology based glaucoma screening. The role of IOP tests in glaucoma detection in combination with other tests such as visual field (perimetry) and cup-disc ratio analysis needs to be examined.
Chapter 8

Evaluation of Conventional and Telemedicine-friendly Devices

8.1 Introduction
Conventional, hospital based glaucoma testing itself is a controversial issue since no single test has shown an adequate balance of sensitivity, specificity and positive predictive value. The three most common screening tests for glaucoma are tonometry (for Intra Ocular Pressure -IOP), ophthalmoscopy (for Vertical Cup Disc Ratio-VCDR), and perimetry (for Visual Field- VF). Currently very little is known about the effective combination of these devices and especially for telemedicine based glaucoma screening. Hence, the present study aims to specify effective combination of telemedicine friendly devices for effective implementation of glaucoma screening. These are portable, screening friendly devices which take less time, could be performed in a rural telemedicine centre with less specialized personnel and could be easily integrated to telemedicine screening systems (Fig 8.1).

8.2 Methods
The study included informed, consenting patients attending the general eye examination clinic at Lions Eye Institute, University of Western Australia. While all patients were recruited consecutively and offered the chance to participate, patients were excluded from the study if they recently had an eye surgery or been already diagnosed with glaucoma. Patients had both eyes tested. VCDR was observed through images taken with a digital, portable, non-mydriatic retinal camera (NM-200D, Nidek, Tokyo, Japan). Image acquisition process was repeated when the original image quality was unsatisfactory. The
better digital image was stored in the built-in memory of the camera and later down loaded to a personal computer. Conventional evaluation of VCDR was done by glaucoma specialists (AG, WM, and LJ) using direct ophthalmoscope (Keeler Instruments, PA, USA) after pupilary dilation. Asymmetries in VCDR between both eyes were noted. If it was > 0.2 VCDR it was recorded as abnormal.

Intraocular pressure (IOP) was measured in all the eyes with the telemedicine friendly non contact tonometer (Pulsair- Easy Eye, Keeler, PA, USA) and with the conventional, clinic based, Goldmann applanation tonometer-GAT (Haag Streit AT 900, Ohio, USA) (Fig. 6.2). In both the methods, three measurements of IOP in each eye of all the patients were taken and the arithmetic average was made. All the measurements were taken in sitting position.

Telemedicine friendly perimetry was done with Humphrey FDT (Frequency Doubling Technology) Visual Field Instrument (Carl Zeiss Meditech, Dublin, CA, USA) using the C-20-5 screening protocol. Conventional hospital based perimetry was done with Humphrey Automated Field Analyzer II (Carl Zeiss Meditech, Dublin, CA, USA) using 24-2 threshold (Fig 6.4 and Fig 6.5).

![Fig 8.1: Usage of telemedicine friendly portable devices – a) FDT Perimeter, b) Pulsair tonometry and c) Non mydriatic Fundus Camera- for Glaucoma screening in remote rural regions in Western Australia. Data collected by rural, ancillary health care workers are sent electronically to specialists in urban centers for second opinion and management.](image)

All devices were calibrated for optimal performance as recommended by the manufacturers. To reduce the risk of observer bias, the order of both conventional and telemedicine friendly tests were conducted at random. The sensitivity and specificity rates for each testing mode were calculated for conventional and telemedicine friendly devices.
Specialists determined the presence or absence of glaucoma in accordance with specific glaucoma screening protocol of Lions Eye Institute which acknowledged glaucoma presence as VCDR>0.5, IOP>21mmHg, abnormal visual field related to glaucoma and or disk asymmetry>0.2. Identification of glaucoma by the specialists, using conventional hospital based method was taken as gold standard.

To investigate the agreement between the tests a plot of the differences between the methods against their mean was carried out as described by Bland and Altman.\textsuperscript{160,161} To examine the relationship formally we used the spearman rank correlation coefficient\((r)\) between the absolute difference and the average. 21mmHg of IOP was used as the threshold for glaucoma.\textsuperscript{163} Multivariate logistic regression (after controlling for age, sex and family history) was used to obtain area under the curve, sensitivities and specificities. Positive and negative predictive values (PPV & NPV) was calculated using 3.13% prevalence of glaucoma in Australia.\textsuperscript{165} All statistical analysis was done using Stata version 8 (\textit{Stata Statistical Software: Release 9.0} (2005) College Station, TX: Stata Corporation).

8.3 Results
Altogether, 402 eyes of 201 consenting patients were screened (111 women, 90 men, mean age 61.04 years). Two eyes had cataract and one eye had miosis and was excluded from the study. Thus total eyes studied were 399. While 50 participants (25\%) reported family history of glaucoma, none had previously been diagnosed with glaucoma. Ophthalmologists identified glaucoma in 45 people (Table 8.1).

<table>
<thead>
<tr>
<th>Glaucoma</th>
<th>Gender</th>
<th>Family History Of Glaucoma</th>
<th>Freq</th>
<th>Mean Age (sd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>Female</td>
<td>No</td>
<td>63</td>
<td>59.3 (12.9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>21</td>
<td>60.9 (12.2)</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>No</td>
<td>64</td>
<td>56.1 (11.6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>8</td>
<td>58.0 (14.5)</td>
</tr>
<tr>
<td>Yes</td>
<td>Female</td>
<td>No</td>
<td>10</td>
<td>75.2 (11.9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>17</td>
<td>71.8 (11.1)</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>No</td>
<td>14</td>
<td>67.3 (12.2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>4</td>
<td>72.3 (11.7)</td>
</tr>
</tbody>
</table>
Analysis indicates good agreement between VCDR by ophthalmoscopy and digital image reading (Fig 8.2). There was no significant difference between the proportion of patients who had FDT compared to proportion who had HVF (p=0.832, using McNemar’s test).

**Fig 8.2**: Plot of the differences between the conventional VCDR by ophthalmoscopy and VCDR by digital photograph reading. The mean bias=-0.008 and sd=0.0577. The Spearman Rank correlation coefficient between the absolute difference (r) =0.21.

**Fig 8.3**: Plot of the differences between the conventional IOP readings by Applanation Tonometry and IOP by telemedicine friendly digital tonometer. The mean bias=1.508 and sd=2.7164. The Spearman Rank correlation coefficient between the absolute difference (r) =0.17.
A plot of the differences between the conventional clinic based IOP readings by GAT and telemedicine friendly Pulsair tonometer is shown in Fig 8.3. Table 8.2 below indicates, age and family history of glaucoma alone has a sensitivity of 35.6 % (Specificity 94.2%, Area under the Curve- AUC 0.81, Correctly Classified-CC 81.1%) and an addition of HVF test optimizes the screening sensitivity to 91.1% (Specificity 92.2%, AUC 0.94, CC 92 %).

**Table 8.2:** Comparison of different combination of tests with conventional, hospital based devices for glaucoma detection. (AUC=ROC Area under the Curve, Sen= Sensitivity, Spec=Specificity, CC= Correctly Classified, Disk Asy= Disk Asymmetry, HVF= Humphrey Visual Field Test)

<table>
<thead>
<tr>
<th>Variables</th>
<th>AUC</th>
<th>Sen%</th>
<th>Spec%</th>
<th>CC%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age+Sex+ Family History</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ VCDR</td>
<td>0.94</td>
<td>69.8</td>
<td>94.2</td>
<td>88.9</td>
</tr>
<tr>
<td>+ IOP</td>
<td>0.83</td>
<td>42.2</td>
<td>93.6</td>
<td>82.1</td>
</tr>
<tr>
<td>+ Disk Asy</td>
<td>0.87</td>
<td>51.1</td>
<td>96.2</td>
<td>86.1</td>
</tr>
<tr>
<td>+ HVF</td>
<td>0.94</td>
<td>91.1</td>
<td>92.2</td>
<td>92.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age+Sex+ Family History + VCDR</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>+ IOP</td>
<td>0.95</td>
<td>67.4</td>
<td>94.2</td>
<td>88.4</td>
</tr>
<tr>
<td>+ Disk Asy</td>
<td>0.96</td>
<td>76.7</td>
<td>94.8</td>
<td>90.9</td>
</tr>
<tr>
<td>+ HVF</td>
<td>0.97</td>
<td>86.1</td>
<td>94.1</td>
<td>92.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age+Sex+ Family History + IOP</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Disk Asy</td>
<td>0.88</td>
<td>53.3</td>
<td>93.6</td>
<td>84.6</td>
</tr>
<tr>
<td>+ HVF</td>
<td>0.95</td>
<td>88.9</td>
<td>92.9</td>
<td>92.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age+Sex+ Family History + VCDR+Disk Asy</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>+ IOP</td>
<td>0.95</td>
<td>79.1</td>
<td>94.2</td>
<td>90.9</td>
</tr>
<tr>
<td>+ HVF</td>
<td>0.98</td>
<td>88.4</td>
<td>96.1</td>
<td>94.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age+Sex+ Family History + IOP+Disk Asy</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>+ HVF</td>
<td>0.96</td>
<td>88.9</td>
<td>94.2</td>
<td>93.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age+Sex+ Family History + VCDR+IOP+Disk Asy</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>+ HVF</td>
<td>0.98</td>
<td>83.7</td>
<td>96.1</td>
<td>93.4</td>
</tr>
</tbody>
</table>
Correspondingly, analysis in Table 8.3 indicates age, family history and telemedicine friendly FDT tests will optimize the sensitivity to 91.1% (Spec 93.6%, AUC 0.95, CC 93%). An addition of IOP test does not change sensitivity (35.6%) and specificity (94.2%).

**Table 8.3**: Comparison of different combination of tests with telemedicine friendly devices for glaucoma detection.

<table>
<thead>
<tr>
<th>Variables</th>
<th>AUC</th>
<th>Sen %</th>
<th>Spec %</th>
<th>CC%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age+Sex+ Family History</td>
<td>0.81</td>
<td>35.6</td>
<td>94.2</td>
<td>81.1</td>
</tr>
<tr>
<td>+ VCDR</td>
<td>0.94</td>
<td>67.4</td>
<td>93.6</td>
<td>87.9</td>
</tr>
<tr>
<td>+ IOP</td>
<td>0.81</td>
<td>35.6</td>
<td>94.2</td>
<td>81.1</td>
</tr>
<tr>
<td>+ Disk Asy</td>
<td>0.83</td>
<td>45.5</td>
<td>96.8</td>
<td>85.5</td>
</tr>
<tr>
<td>+ FDT</td>
<td>0.95</td>
<td>91.1</td>
<td>93.6</td>
<td>93.0</td>
</tr>
</tbody>
</table>

| Age+Sex+ Family History + VCDR     | 0.94 | 67.4  | 93.6   | 87.9 |
| + Disk Asy                         | 0.95 | 64.3  | 93.6   | 87.3 |
| + FDT                              | 0.98 | 83.7  | 96.8   | 93.9 |

| Age+Sex+ Family History + IOP      | 0.95 | 93.2  | 93.6   | 93.5 |
| + Disk Asy                         | 0.98 | 85.7  | 96.8   | 94.4 |

| Age+Sex+ Family History + VCDR+IOP | + FDT | 0.95 | 93.2  | 93.6   | 93.5 |
|                                   |       |      |       |        |
| Age+Sex+ Family History + Disk Asy | + FDT | 0.95 | 93.2  | 93.6   | 93.5 |

| Age+Sex+ Family History + VCDR+IOP+Disk Asy | + FDT | 0.98 | 85.7  | 96.8   | 94.4 |

AUC=ROC Area under the Curve; Sen = Sensitivity; Spec=Specificity; CC= Correctly Classified; VCDR= Digitally measured Vertical Cup Disc Ratio; IOP= Digitally measured Intra ocular Pressure; Disk Asy= Optic Disk Asymmetry; FDT = Frequency Doubling Technology Visual Field Test.
Chapter 8. Evaluation of Conventional and Telemedicine-friendly Devices

Analysis further indicates telemedicine friendly FDT (Sen 83.7 %, Spec 96.8%, AUC 0.98, CC 93.9%) is favorable in place of ophthalmoscopy –VCDR ( Sen 67.4% ,Spec 93.6%, AUC 0.94, CC 87.9%) to determine glaucoma.

If the practitioner already has all the above mentioned devices, the test for disk asymmetry will be ideal (Sen 93.2%, Spec 93.6%, AUC 0.95, CC 93.5%) than the test for VCDR (Sen 83.7 %, Spec 96.8%, AUC 0.98, CC 93.9%). Both HVF and FDT perimetry exhibited identical positive predictive value of 99.7% (Table 8.4).

Table 8.4. Sensitivity, specificity, negative predictive value (NPV), positive predictive value (PPV) of both conventional and telemedicine friendly devices. Calculated with 3.13 % prevalence of glaucoma.

<table>
<thead>
<tr>
<th>Devices</th>
<th>Sensitivity%</th>
<th>Specificity%</th>
<th>NPV%</th>
<th>PPV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>IOP</td>
<td>42.2</td>
<td>93.6</td>
<td>15.6</td>
</tr>
<tr>
<td>VCDR</td>
<td>69.8</td>
<td>94.2</td>
<td>28.0</td>
<td>99.0</td>
</tr>
<tr>
<td>VF</td>
<td>91.1</td>
<td>92.2</td>
<td>27.4</td>
<td>99.7</td>
</tr>
<tr>
<td>Telemedicine-friendy</td>
<td>IOP</td>
<td>35.6</td>
<td>94.2</td>
<td>16.6</td>
</tr>
<tr>
<td>VCDR</td>
<td>67.4</td>
<td>93.6</td>
<td>25.3</td>
<td>98.9</td>
</tr>
<tr>
<td>VF</td>
<td>91.1</td>
<td>93.6</td>
<td>31.5</td>
<td>99.7</td>
</tr>
</tbody>
</table>

VCDR= Vertical Cup Disc Ratio, IOP= Intra ocular Pressure; VF = Visual Field Test

8.4 Discussion
With the ageing population in the world, glaucoma will be more prevalent. Because of glaucoma’s generally long preclinical phase, reproducible, patient-friendly diagnostic techniques may permit earlier detection of glaucomatous damage, which can then offer patients earlier treatment possibilities and better outcomes. Telemedicine reportedly offers an economic method for glaucoma screening with portable equipment operated by less expensive and mid-level health workers in the rural regions.4 It should be noted that although individual tests may have less-than-ideal sensitivities and specificities, these can be increased by combining diagnostic devices in parallel, thereby providing a more reliable screening program.100,176 In the absence of any single test for screening of glaucoma, the current study evaluated diverse combinations of devices and tests towards an effective screening strategy.

A dilated eye examination with direct ophthalmoscopy by an ophthalmologist has a reported sensitivity of 59% and a specificity of 73% for detecting and classifying optic disc changes associated with glaucoma.79 Qualitative evaluation of digital images of the optic
disk is more sensitive, which also allows for precise measures of disk parameters (e.g., vertical and horizontal cup-disc ratios, neuroretinal rim width). In this study, VCDR observation using telemedicine friendly non-mydriatic camera was sensitive to glaucoma detection (Table 2). Eliminating dilation and electronically archiving and transmitting retinal images are striking features of these telemedicine friendly devices. While, conventional, subjective, dilated ophthalmoscopy by specialists often encounters difficulty in detecting glaucomatous optic disc progression\textsuperscript{79}, the archiving of retinal images by telemedicine devices assists in identifying optic disc progression. Recent technological advances, however, have produced new instruments that can objectively quantify the optic nerve head and the RNFL. Confocal scanning laser ophthalmoscopy (CSLO), optical coherence tomography (OCT), and scanning laser polarimetry (SLP) may in some cases permit earlier glaucoma diagnosis.\textsuperscript{177} Therefore their role in screening, especially when coupled with telemedicine, appears promising and remains to be studied.

Glaucoma (POAG) also leads to characteristic patterns of visual field defects which is valuable for glaucoma detection, but diagnostic testing with conventional hospital based perimetry (HVF) is time consuming, hence not feasible for mass screening.\textsuperscript{178} However, portable FDT perimetry in the current setting proved sensitive\textsuperscript{(91.1\%)} for glaucoma detection. Both HVF and FDT perimetry exhibited identical positive predictive value of 99.7\% (Table 4). Several investigators have found that FDT has both sensitivity and specificity in the 90\textsuperscript{th} percentile range, making it an excellent screening tool.\textsuperscript{108-111} While, Cioffi et al suggests repeat testing to be beneficial, FDT offers definite advantages for early glaucoma detection.\textsuperscript{105-114,179,180}

Pulsair tonometry is a user friendly device and its IOP readings are digitally displayed which could be easily integrated to a telemedicine system to transfer the data to an urban diagnosing centre. However, this study indicates that the effectiveness of IOP measurement as a screening tool for POAG appears to be limited. There is no single cutoff value of IOP that provides an acceptable balance of sensitivity and specificity for screening.\textsuperscript{176,178} IOP measurements above the usual cutoff point (greater than 21 mg Hg) have a reported sensitivity of 47\% and specificity of 92\% for diagnosing POAG, and IOP measurement does not appear to perform better in high-risk groups defined by age, race, sex, or family
Moreover, high intraocular pressure can also be seen in patients with ocular hypertension, the majority of whom may never develop glaucoma. In the current study, the telemedicine friendly Pulsair tonometer was relatively less sensitive for glaucoma detection (Sen 35.6%, Spec 94.2%, NPV 16.6%, PPV 97.8%). And it is suggested that even if measured optimally, increased intraocular pressure alone is a poor predictor of glaucoma although it remains the most important risk factor.

Meanwhile, deciding about effective glaucoma screening can be complex. In March 2005, the U.S. Preventive Services Task Force (USPSTF) found insufficient evidence to recommend for or against screening adults for glaucoma. Recently, Maier et al presented a meta-analysis of the glaucoma trials. POAG reportedly had an "effective" population attributable risk percentage (PAR), a measure that reflects the public health importance of a disease of 16%, perhaps high enough to be considered a public health problem and justify inclusion as a target disease in the Vision 2020 program. However the logistics and opportunity costs of diagnosis and treatment would probably prevent inclusion of POAG in public health budgets of most developing countries. In this scenario, telemedicine promises both cost and clinically effective solution for global eye care While acknowledging that the current study sample was from an hospital based population, the results could be generalized to a community based screening with caution. Clearly, targeting screening programs to populations at higher risk for glaucoma will identify a larger number of new cases, and increase the screening test’s positive predictive value. In accordance with the USPSTF report on conventional screening, the current study, reports that screening with telemedicine friendly visual field testing and ophthalmoscopy identifies primary open-angle glaucoma patients with greater accuracy, whereas measurement of intraocular pressure is not a good screening tool for glaucoma.

8.5 Conclusion
The results of this study indicate that evaluations of visual field and cup-to-disc ratio, using portable, telemedicine friendly digital devices are most useful tool in screening for glaucoma. When used together, these devices may become an alternative for conventional glaucoma screenings. Country specific guidelines for telemedicine based glaucoma screening by rural health workers need to be established.
Feasibility of teleophthalmology based glaucoma screening service could be augmented if it is able to obtain high sensitivity and specificity results; this means that the teleophthalmology screening centre must have access to an FDT, an optic disc imaging device and a tonometer (probably not essential if the other two devices are available).
9.1 Introduction: Refractive Error in Australian Context

Refractive errors are optical defects that result in light not being properly focused on the eye’s retina. The most common are hypermetropia (long-sightedness), myopia (short-sightedness), astigmatism (uneven focus) and presbyopia (an age-related problem with near focus). It is estimated that nearly 300,000 Australians may have visual impairment because of under-corrected refractive error.\textsuperscript{25}

Based on the results of the 2001 National Health Survey, 9.7 million Australians or 51\% of the population had at least one sight problem.\textsuperscript{25} The most commonly reported eye disorders were refractive errors, such as long-sightedness, short-sightedness, presbyopia and astigmatism.\textsuperscript{25}

With the exception of presbyopia, refractive errors usually develop during childhood, when the eyes are growing. The exact causes of refractive errors are still being studied, but it is known that both hereditary and environmental influences can affect their development.

Although long-sightedness and short-sightedness are not specifically age-related, they remain common conditions in later life. Long-sightedness, short-sightedness and presbyopia were included among the five most common long-term medical conditions reported by people aged 55 years or more in the 2001 National Health Survey (Australia).\textsuperscript{25}
As refractive error is the most common cause of visual impairment in Australia, access (both cost and physical) to affordable corrective devices such as spectacles is an important issue. Spectacles (glasses) and contact lenses are commonly provided through optical dispensers at market prices. Some private health insurance schemes provide a subsidy for the cost of the appliances. State and Territory governments have schemes to provide spectacles at low cost for people on low incomes.

9.1.1 Visual Acuity Chart
Visual acuity (VA) is by far the most commonly performed measurement of visual function in clinical practice. It is used to determine the presence of refractive error, the adequacy of spectacle corrections, whether a person is fit to drive or enter into some professions such as the police force, whether a person could be registered as partially sighted or blind and also is a key indicator of ocular health.

9.1.2 Review of Computerized Vision Tests

Table 9.1. List of the online vision testing web-links

<table>
<thead>
<tr>
<th>Web-Links</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="http://members.aol.com/protanope/colorblindtest2.html">http://members.aol.com/protanope/colorblindtest2.html</a></td>
<td>Free, Demonstration purpose, Colour Vision Testing only - Ishihara Test, 5 plates presented online</td>
</tr>
<tr>
<td><a href="http://www.testvision.org/">http://www.testvision.org/</a></td>
<td>Free, Interactive, Demonstration purpose, Visual Field Testing - Three Levels of testing where Advanced incorporates contrast sensitivity to create a more sensitive test to be take after the standard, Results are presented on graphs as well as an analysis of the results</td>
</tr>
<tr>
<td><a href="http://www.visiontests.com/Tests/index.html">http://www.visiontests.com/Tests/index.html</a> or <a href="http://www.medqui.com/Tests/index.html">http://www.medqui.com/Tests/index.html</a></td>
<td>Free, Interactive, 18 Screening Tests available for Adults while 2 tests are especially for children, Results are given after each test</td>
</tr>
<tr>
<td><a href="http://www.wellesleyeye.com/eye_tests.htm">http://www.wellesleyeye.com/eye_tests.htm</a></td>
<td>Free</td>
</tr>
</tbody>
</table>

Chapter 9. Computerised Visual Function Tests

99
Chapter 9. Computerised Visual Function Tests

- Visual Acuity (Big ‘E’ Chart)
- Macular Function – White on Black Amsler Grid

http://www2.umist.ac.uk/optometry/UES/COLOUR0.HTM
- Free
- Interactive
- Simulates Colour Vision Testing
- Feedback to the subject on error type when it occurs i.e. Protanomaly/Deuteroanomaly/Tritanomaly

All the above tests can be done online. These are mostly for free of charge, demonstration purposes and made available online by optical dispensers. The results are often represented as scores but further testing by an Optometrist or Ophthalmologist is required.

9.2 Need for Innovative Online Computerized Visual Function Test

Visual Impairment is tested by measuring the visual acuity of the eyes. Adequately trained optometrists, ophthalmic assistants are often required to conduct these tests. In the rural and remote regions, due to the absence of eye care specialists, there is a vital need of easy to use, user friendly visual acuity measuring system. For testing the visual acuity, a wall mounted chart, chart projector or personal computer is commonly used in the eye clinics. In the meantime an increasing number of internet based VA tests are potentially available for millions of Internet users. The variability of the tests ranges from a simple presentation of graphic elements to a laboriously programmed interactive input by the user to specify the test result. Most of these tests are presented by opticians and the optical industry. These tests allow for a considerable inconsistency of the test conditions. Because of the test deficits determined, the results of visual acuity tests on the Internet are classified as doubtful. The newly developed CVFT Chart incorporates unique online techniques to overcome the limitations of the currently available online tests (Table 9.2). The chart also incorporates novel design principles in terms of optotype presentation and online test administration.

Currently there are two common formats of VA test charts – Snellen and logMAR - used in the eye clinics. The Snellen chart, although being the commonest tool for the measurement of visual acuity in ophthalmic practice, exhibits certain well-documented design flaws which may compromise its usefulness. Snellen measurements are very variable and impractical for clinical research. These
Chapter 9. Computerised Visual Function Tests

Theoretical design problems were addressed with the development of logMAR acuity charts, which are now employed in clinical research.\textsuperscript{186,190,191} LogMAR charts, however, have not been widely adopted into routine clinical practice. This may be due to the unfamiliar scoring system, the large size and number of letters on each chart, and the perception of a log MAR measurement as being time consuming\textsuperscript{8}. A new design of log MAR chart is incorporated in CVFT Chart, taking advantages of the computer environment on which it operates.

Fig 9.1: Images of a) Snellen Chart, b) Reduced LogMAR chart, and c) ETDRS chart.

9.3 Computerised Visual Function Test

The newly developed CVFT Chart for teleophthalmology as well as general visual acuity screening offers the format of an existing log MAR chart with the ease of use, lower testing time of the Snellen chart, improved sensitivity, specificity and is securely administered online.

The designers hypothesise that CVFT chart with reduced number of letters per line would allow measurements to be made in a clinically acceptable period of time, and with greater precision and reliability than is possible with Snellen charts. It has fewer letters per line than conventional logMAR charts.

9.3.1 Design: Computerised Visual Function Test

The CVFT Chart is designed to optimize visual acuity data collection in population-based surveys. The chart utilizes those design principles currently advocated for the measurement of visual acuity in clinical research. The test is designed to be
performed at 3m or 6m testing distance and incorporates design features, which include: logarithmic letter size progression, interletter spacing, interline spacing, and employs Tumbling E and Landolts ‘C’ optotypes. It also has equal number of letters per line and a screening phase to determine initial level of acuity. The test is quick and easy to perform and is aimed to provide a means for detecting change in letter acuity, with increased confidence.

Four different orientations (up, down, right, left) of the tumbling E optotype were constructed on a 5 x 5 unit format and graded according to log MAR principle of acuity scaling, hence the size of letters in the rows progresses in a uniform step of 0.1 logarithm unit (Fig 9.2) Each central letter is flanked with surrounding letters to simulate visual crowding.192 To provide flexibility, the chart is designed for use at 3 or 6 meters testing distances. Inorder to be used with a mirror in the smaller clinic testing rooms, the chart display can be reversed. The logMAR acuity data is readily converted to snellen acuity notation for those unfamiliar with logMAR notation.

Fig 9.2: Image of the telemedicine-friendly computerized visual function test.

9.4 Method
Consenting subjects undergoing the study were drawn from the Lions Eye Institute (LEI) outpatient clinic population. Inclusion criteria: subjects not participating in any other studies, able to understand and comply with the testing protocol and age: 4-65 years. The subjects used refractive correction for best corrected visual acuity for distance vision. For each patient, all measurements were conducted at random order by a trained clinical assistant.
Chapter 9. Computerised Visual Function Tests

Subjects had their vision tested in the right eye using both the CVFT and the ETDRS chart 1 (Lighthouse International, USA). The ETDRS measurements were done as specified in its manual of operations. For the CVFT method, subjects read a single letter at a time that was appeared on the computer screen. After reading each letter, a new letter was presented that is either bigger or smaller in size. The CVFT was done on a lap top computer with an LCD screen.

The examination was carried out meticulously without hurrying the subject. The examiner urged and encouraged the subjects to keep trying to read each smaller line on the ETDR and CVFT chart to ensure that the subject makes maximal effort. Patient and examiner only were present in the testing room avoiding any distractions. With the lightmeter measurement, consistent lighting conditions of 15 foot – candles of light was maintained on the centre of the charts. The ETDR chart was mounted at a height such that the top of the third row of letters (0.8 logMAR) was 124.46 cm from the floor. The centre point of the laptop computer was also positioned at the same height.

CVFT acuity scores were compared, with the ETDRS score serving as the reference standard. Bland and Altmann described a method of measuring test agreement using plots of differences against means as the best way to compare measurements with different instruments when actual measurement is unknown.\textsuperscript{160,161} To examine the relationship formally we used the spearman rank correlation coefficient(r) between the absolute difference and the average. For the purpose to assess whether a relationship exists between the difference between the two tests and their mean (i.e. acuity-related bias), we also used linear regression to test null hypothesis of zero slope. Repeatability of visual acuity scores by CVFT was analysed based on the method described by Bland & Altman.\textsuperscript{161} All statistical analysis was done using Stata version 8 (\textit{Stata Statistical Software: Release 8.0} (2003) College Station, TX: \textit{Stata Corporation}).
9.5 Result

Study subjects included 104, patients with or without eye disease. There were 59 females (average age: 48.4±12.3 years) and 45 males (average age: 49.2±11.6 years).

The average CVFT value is 0.159 (sd=0.217, min=-0.10 and Max=1.40). The average ETDRS value is 0.146 (sd=0.212, min=-0.20 and Max=0.80). The mean difference between CVFT and ETDRS was -0.013 logMAR (sd=0.109, 95% confidence intervals of 0.05 log MAR) (Fig 9.3). The spearman rank correlation coefficient(r) between the absolute difference and the average was 0.35. In the linear regression line, beta was -0.025, which was not significantly different from zero (p=0.634). There does appear to be one patient whose CVFT value seems overly large (1.4 logMAR compared to 0.6 logMAR by ETDR).

![Figure 9.3](image.png)

**Fig 9.3** The plot illustrating the differences between ETDR and CVFT methods against their mean. The mean value represents the bias (the mean difference between two methods) and the limits of agreement represented by +/- 2standard deviations of the mean difference. The mean bias was -0.013 logMAR (sd=0.109 logMAR).

The mean difference between two consecutive, repeated CVFT tests in the same eye was 0.015 (sd= 0.073, paired t-test p= 0.046) (Fig 9.4). The coefficient of repeatability is 0.146 and only 5 (4.8%) observations fall outside this coefficient.
The average time for testing one eye using CVFT was 54.7±11.89 seconds (min: 36 sec; max: 98 sec).

**Fig 9.4:** The mean difference between CVFT at first and second time is 0.015 logMAR (Sd= 0.073 logMAR, paired t-test p=0.046)

### 9.6 Discussion

CVFT chart produced acuity data which agreed well with those of the ETDRS chart. The mean difference between CVFT and ETDRS acuity data was 0.005 log MAR indicating that CVFT acuities agreed well with those of the ETDRS chart. The CVFT differ significantly from other automated and non automated charts (Table 9.2).

Taking advantage of the computer environment on which it operates, the CVFT chart optimizes visual acuity data collection in population-based vision screenings by semi-skilled ancillary staff, especially in remote and rural areas where there is a lack of expert personnel and where time and resources may be limited to train them(Table 9.3). While testing time for ETDRS chart has been widely reported earlier, the current study reported CVFT chart measurements were completed in less than one minute per eyes tested.
CVFT also proves to be suitable for the use in daily routine of vision examination in the clinics with the advantage, that unlike the manual tests, the investigator has less influence on the outcome of the test. The chart and its method of use was readily accepted by the ancillary staff at Lions Eye Institute who required only minimal training before automated acuity measurement could be delegated to them. The patient whose CVFT value seems overly large was further diagnosed with central retinal vein occlusion (CRVO) with peri-macular involvement, which apparently reduced the vision in straight ahead gaze. In the ETDRs chart the patient was able to read the peripheral letters, avoiding the letters in the straight ahead gaze. Meanwhile, lack of standardisation for chart construction, as well as measurement methods and conditions of measurement, invalidate comparisons of different visual acuity tests. Hence, the interpretation of the test results should consider the

<table>
<thead>
<tr>
<th></th>
<th>CVFT Chart</th>
<th>ETDR Chart (Gold standard)</th>
<th>Snellen Chart</th>
<th>Compact Reduced logMAR chart</th>
<th>Internet based Vision tests</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visible Area</strong></td>
<td>Standard PC Monitor width</td>
<td>64*59 cm</td>
<td>20*48cm</td>
<td>36*45cm</td>
<td>Standard PC Monitor width</td>
</tr>
<tr>
<td><strong>Testing Distance</strong></td>
<td>Variable</td>
<td>4 meters</td>
<td>Variable</td>
<td>Variable</td>
<td>Variable</td>
</tr>
<tr>
<td><strong>Lines</strong></td>
<td>14 lines</td>
<td>14 lines</td>
<td>Variable</td>
<td>14 lines</td>
<td>Variable</td>
</tr>
<tr>
<td><strong>Line Progression</strong></td>
<td>0.1 log MAR size</td>
<td>0.1 log MAR size</td>
<td>Variable</td>
<td>0.1 log MAR size</td>
<td>Variable</td>
</tr>
<tr>
<td><strong>Display of Letters</strong></td>
<td>Random</td>
<td>Fixed</td>
<td>Fixed</td>
<td>Fixed</td>
<td>Fixed</td>
</tr>
<tr>
<td><strong>Test Retest Variability</strong></td>
<td>0.015</td>
<td>0.14</td>
<td>0.29</td>
<td>0.17</td>
<td>Variable</td>
</tr>
<tr>
<td><strong>Scoring Method</strong></td>
<td>Repetition and averaging after a screening threshold</td>
<td>Single letter scoring algorithm</td>
<td>Line assignment</td>
<td>Single letter scoring algorithm</td>
<td>Line assignment</td>
</tr>
<tr>
<td><strong>Testing Time (median)</strong></td>
<td>54 seconds</td>
<td>60 seconds</td>
<td>30 seconds</td>
<td>40 seconds</td>
<td>Variable</td>
</tr>
</tbody>
</table>
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presence of heterogeneity of the different testing hardware, even though there was
good agreement between the results of the CVFT and those of ETDR.

Table 9.3: Features and Advantages of CVFT chart

<table>
<thead>
<tr>
<th>Features of CVFT chart</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Online VA Chart for telemedicine technology</td>
<td>Accessible from anywhere.</td>
</tr>
<tr>
<td>2 Log MAR chart</td>
<td>More accurate and reliable for Clinical and research (In comparison with standard Snellen chart)</td>
</tr>
<tr>
<td>3 Use of log MAR E / Landots C</td>
<td>User friendly. Especially for school going age children, and illiterate. Also reduces risk of user errors in entry of responses</td>
</tr>
<tr>
<td>4 Crowding bars</td>
<td>For Amblyopic and crowding phenomenon</td>
</tr>
<tr>
<td>5 Crowding letters</td>
<td>For real life – reading/crowding phenomenon</td>
</tr>
<tr>
<td>6 Repeated tests</td>
<td>For Moderate to high sensitivity and specificity of VA tests.</td>
</tr>
<tr>
<td>7 Less number of letters than standard ETDR.</td>
<td>Less timing for completion of test. No chart -reading fatigue.</td>
</tr>
<tr>
<td>8 Computerised averaging</td>
<td>Saves time on manual calculations and increases accuracy</td>
</tr>
<tr>
<td>9 Results displayed in different Visual Acuity notations</td>
<td>Easy to use in all clinics since, the notations used are different in different countries.</td>
</tr>
<tr>
<td>10 Greater range of letter sizes</td>
<td>Allows wider range of Visual Acuity to be measured</td>
</tr>
</tbody>
</table>

Certain features of the CVFT chart promises to be particularly relevant to the measurement of vision by internet-based teleophthalmology systems which can be employed in the remote testing of visual acuity. Further studies should be followed to check the effectiveness of CVFT for internet based vision screening examinations.

9.7 Conclusion

This thesis provides design protocols involved for a novel, automated visual acuity testing application. The test has advantages over the existing printed, manual chart and supports its role as an alternative tool for measuring visual acuity either in the clinic or at a remote location by a nurse or an allied healthcare person. It is expected that this automated system will be a useful tool for screening visual impairment with its ease of use, by semi-skilled ancillary staff, especially in remote and rural regions.
SECTION SUMMARY OF PART 3

The increasing incidence of glaucoma and a rapidly aging population are significant indicators that the problems and health complications caused by glaucoma may increase significantly in the near future. Many changes have taken place in the field of glaucoma in recent years, as outlined in chapter 6 of Part 3.

New instruments for glaucoma diagnosis and monitoring are now available. These advances positively influence the design of future teleophthalmology glaucoma screening programs and should now permit the development of specific protocol.

Telemedicine friendly devices and methods for early detection of glaucoma are identified as outlined in the chapters in part 3. Collaboration among diverse specialists, including ophthalmologists, community health care experts and optometrists also will be integral in organizing and implementing an effective glaucoma screening strategy.

Part 3 also provides design protocols involved for a novel, computerised visual acuity testing application. The test has advantages over the existing charts and supports its role as an alternative tool for measuring visual acuity by telemedicine technology. This computerized system is clinically proven to be a useful tool for testing visual impairment in the remote and rural regions with its accuracy, ease of use, and shorter testing time. These tests are expected to pioneer the use of telemedicine in diagnosing blindness and visual impairment and hence enhance feasibility of teleophthalmology service.
PART 4
Chapter 10

General Discussion

10.1 Discussion

Advances in health technologies are proceeding at an unprecedented rate, placing new demands on the health sector in Australia and elsewhere. The management of many eye diseases is expected to change substantially through the introduction of nanotechnologies, gene therapies and teleophthalmology. These new technologies are also making greater demands on studies of feasibility analyses than previously, with people requiring greater access to healthcare in today’s complex information society.

Ophthalmology centers in Western Australia are pioneering teleophthalmology service aimed at using information technology to promote eye care. One important facility of teleophthalmology is its ability to expand the range of ophthalmic services to remote locations. Feasibility analyses are crucial for teleophthalmology’s future success and sustainability (Fig10.1). This thesis explores the feasibility of teleophthalmology in the Australian health care context, particularly on eye health system at the state of Western Australia. It proves the feasibility of teleophthalmology service in Western Australian context by evaluating the cost efficiency of the service. This thesis also proves that teleophthalmology covers all medical activities, including making diagnoses, treatment, prevention and research.
Health technologies have been assessed since the early 1970s. Continuing advances in telecommunication and information technology are readily deployed in teleophthalmology, which in turn contributes to the service feasibility. The legal and service reimbursement issues are being discussed recently. This thesis investigated factors related to the adoption and diffusion of teleophthalmology by producing, reorganizing and synthesizing data collected from an ongoing teleophthalmology project. The assessments also provided health technology developers with information about wider aspects of the teleophthalmology service.

Technology assessments aim at identifying the best approach among the various alternatives. The economic success of health care operations depends on the efficiency of production and the fairness and equality of the distribution of services. Although efficiency is often emphasized in health care assessments, attention should also be paid to the distribution of the services. "Feasibility" should be construed broadly in this context. It also covers the social aspects of the application of a technology, such as customer-perceived accessibility and acceptability of the services.

10.2 Western Australian Teleophthalmology Service Evaluation

The purpose of this study was to determine the efficiency and efficacy of teleophthalmology service in Western Australia and compare it with the alternate service options. An extensive review of screening protocols and economic analysis were made. Telemedicine friendly digital devices were evaluated against conventional options and innovative computerized visual function tests were introduced.

A population-based study was undertaken to calculate the health system costs. The population included patients who presented to a remote, rural teleophthalmology
centre at Carnarvon Regional Hospital. The overall health system costs of teleophthalmology service were estimated. With the future ageing of the population, the demand for teleophthalmology service in the absence of effective prevention and lower treatment costs is highlighted.

The challenge of feasibility study was to evaluate marginal cost savings in comparison with alternate options of eye care service delivery. Strength of this study was it was rural, remote, population-based, with true costs identified from WA Department of Health and CRH hospital morbidity records. Eventhough, the individual follow-up of subjects after discharge from the CRH was beyond the scope of this study, best possible known sources were used as the basis for determining utilization of health system resources by rural patients.

Few studies have evaluated the efficacy of teleophthalmology service programs, and very few economic evaluations of teleophthalmology programs have been conducted. Of the studies that have examined the costs of teleophthalmology service in patients in Australia, the most significant ones are Ivan & Verma (2006) and Blackwell et al (1997).\textsuperscript{51,48} Meanwhile, the current study, presented in this thesis offers for the first time in Australia, a comprehensive economic evaluation for an established routine teleophthalmology service for a spectrum of eye related problems including emergency eye services. This study provided population-based figures of health system costs and is more useful for comparison purposes. This study provided useful information on the potential cost savings that can be obtained if teleophthalmology service programs are successfully implemented. Because of the perspective of the study, the cost to the health care service provider was widely covered. However, this study has not included the non-monetary cost of loss of quality of life (QALY) associated with visual impairment in patients. Ho & Verma (2006) have calculated diabetic incidence-based or lifetime costs in the state of Northern Territory in Australia. However both these studies reported only on costs of diabetic retinopathy screening.\textsuperscript{51,48}

In order to obtain a better understanding of the teleophthalmology service feasibility and its resource implications the current study also has addressed the geographical
distribution of teleophthalmology service in other regional areas of Western Australia. In the early stages of implementation the overhead costs are usually high and the numbers of services are low. If emphasis is placed on using the system for activities that will generate a substantial marginal cost saving then achieving breakeven or even savings is almost assured by increasing the number of services provided by teleophthalmology.

According to the Department of Health, Western Australia (DOHWA), the objectives of the Telehealth Strategic Planning (TSP) are as follows. Telehealth aims to improve health services to Western Australians, particularly those living in regional, rural and remote areas, through:

- **Increased accessibility of services through increased local availability of an extended range of Telehealth services;**
- **Increased acceptability of services by patients, clinicians, health care providers and the general community due to an increase in the range and quality of services provided in the local area; and**
- **Increased affordability of services due to an increase in the efficiency distribution, a reduction in service duplication and the provision of services in the remote and rural areas.**

The results demonstrated through this thesis support the stated aims of the Telehealth Strategic Planning. Teleophthalmology services increase access to services not previously provided to a large part of the Gascoyne population. Moreover, there is minimal travel for patients. Teleophthalmology services have shown to be acceptable by patients and clinicians. Teleophthalmology services are shown to be cost efficient in relation to the alternatives available. However, better coordination of services is required in order to deliver increased benefits at a lower cost to the system.

It was demonstrated that there is ample scope for some service substitution and better use of the specialist’s time. For instance, at current cost levels, a substitution of two weekly specialist visits for outpatient clinics (decrease visits from four to
two weeks per year) would generate enough savings to pay for the whole teleophthalmology program for the Gascoyne region over the course of a year.

Moreover, a substitution of current service arrangements for visiting eye specialists in East Pilbara and in the Western Wheatbelt would not only deliver more cost effective services but also generate enough savings to the health system to pay for a whole new teleophthalmology program in a location where no eye specialist services are available, hence generating increased access to service for the community as well as improving its health status by early identification of eye disease.

Furthermore, there is an opportunity cost in sending eye-specialists to rural and remote areas as during this time they are not available to provide services in their metropolitan location or where Teleophthalmology services are not yet available. Other benefits relate to earlier diagnosis of eye diseases leading to better health and savings to the health system and the local community, increased local knowledge and a greater number of people examined by an eye-specialist.

Results from the Visual Impairment Project conducted from 1991 to 1999 by the Centre for Eye Research Australia (CERA) estimates the total annual direct cost of visual impairment (reduced visual acuity) to the government at nearly $2.1 billion. Researchers suggested that, in order to remedy this situation we need to:

- Promote awareness among those with diabetes of the need for regular eye exams;
- Provide regular eye examinations every 2 years;
- Develop, evaluate and report sustainable local and regional models of screening.

Early identification and treatment of eye disease can prevent up to 98% of severe vision loss. The Teleophthalmology program offers a cost effective solution to the WA health system to prevent eye related disease in the rural and remote communities, improve quality of life and generate potential sizeable savings in public eye related expenditure for the near future. The feasibility analysis of teleophthalmology involves the assessment of advantages, disadvantages, costs, as
well as the protocols and telemedicine friendly devices. Population based data of visual impairment, which are needed to set priorities and plan strategies to reduce visual impairment, are limited worldwide including in Australia. In the absence of population-based data on visual impairment and blindness that includes complete visual function examination of all the remote and regional population, unique computerized visual function tests (CVFT) are essentially needed. These tests were developed and tested. Trials indicated CVFT to be easy to operate with minimal training. These tests are expected to pioneer the use of web-based visual function tests in diagnosing blindness and visual impairment. Since teleophthalmology uses novel devices, the assessment should include an evaluation of the properties of the equipment. An evaluation of telemedicine friendly devices was extensively carried out during this study. Tests and devices towards effective glaucoma screening have been identified. Apart from others the general lessons learned from the current study also include:

- Teleophthalmology services should be integrated as much as possible into the regular healthcare service at the rural / remote location. This involves teams of people at rural / remote facility to work together in order to integrate teleophthalmology into the existing health delivery system for patient encounters. This may take more than a year to accomplish.

- "Build a teleophthalmology service and patient will come" does not work. Teleophthalmology requires building external relationships among rural health service providers, administrators and other clinical staff.

- Teleophthalmology service requires skilled human resources to run successfully. Hence, ‘if you can't staff it then don't build it.’

- Physicians adapt well to teleophthalmology service that help them do their job more efficiently. From the clinician's point of view, teleophthalmology must be just as easy as providing in-person care.
This thesis proves teleophthalmology as one solution by which necessary eye care services can be provided to everybody at a reasonable cost. This thesis and accompanied published research firmly establishes the feasibility of teleophthalmology. Research undertaken during this thesis has also demonstrated that the available technology is considered suitable by most patients and clinicians. The capacity of telecommunication channels increases faster. This allows for very fast technology development with low equipment costs. Teleophthalmology is expected to grow even more in the coming years, for the following additional reasons: 9-11

- Private health practitioners embracing this currently public-dominated arena
- The equipment and transmission options becoming economical and more widespread.

The information presented in this study is also useful for policy and planning purposes - in the short term to identify the volume of services to be provided to treat patients and the costs of providing these services. And in the longer term, for preparing projections of future resource utilization and budgetary costs.

Early identification and treatment of eye disease can prevent up to 98% of severe vision loss. The Teleophthalmology program offers a cost effective solution to the WA health system to prevent eye related disease in the rural and remote communities, improve quality of life and generate potential sizeable savings in public eye related expenditure for the near future.
Chapter 11

Conclusion

Teleophthalmology has been talked about for more than 20 years, without it entering daily use with any success. Based on service costs economics, this thesis highlights certain characteristics of the feasibility and effective implementation which also demonstrates that teleophthalmology shifts the costs associated with service from patients to health-care providers themselves.

Australia’s special challenges of vast distances and the lack of eye care practitioners in rural areas are obvious incentives for experimenting and expanding teleophthalmology services. Other drivers behind these Australian teleophthalmology developments will include the realization of the clinical benefits of using combinations of information and telecommunication technologies to provide improved or new eye care services; the mounting pressure from rural patients that the clinical world takes advantage of the digital revolution; and the ubiquitous growth of the Internet.

The purpose of this thesis was to determine the feasibility of teleophthalmology service in Western Australia. An extensive review and economic analysis were made. Telemedicine friendly digital devices were evaluated against conventional options and innovative computerized visual function tests were introduced.
Chapter 11. Conclusion

11.1 Conclusion

The foundations for teleophthalmology are in place and create potential for an explosive growth. The feasible and effectively implemented ones will be built around a sustainable competitive business case, cost, quality, local demand and coordination.

The findings of the study has great practical significance to local governments, people, central hospitals, health care districts and other public corporations. The findings can be used to give recommendations on the preconditions for starting teleophthalmology operations within a particular locality. The study has the advantage of taking into account the price level and the characteristics of the health care system in WA. Since the subjects of study (eg: glaucoma, visual impairment) have a relevance to major public-health problems, substantial societal benefits are expected from the findings.

Since teleophthalmology is in the process of becoming a permanent feature, the greatest future changes in factors affecting decision-making can be assumed to be related to investment and operating expenditures. In this context, the findings of the study can be used to calculate the effects of different investment and operation alternatives.

This thesis acknowledges that successful implementation of teleophthalmology will rest upon the development of effective devices, tests, protocols, partnerships across and between all levels of government, health professions, including the specialist eye health workforce, the generalist medical and allied health workforce, non-government organisations, communities, families and individuals.
Chapter 12

Future Directions

12.1 Significance of this Study

This thesis demonstrates that, if implemented well, with protocols, teleophthalmology is feasible and will change the delivery and efficiency of eye care service. There will be a major impact on patients and ophthalmologists. Patients will be more informed. It may revolutionize vision care from the present provider-driven model to a truly point-of-care model, where citizens will be truly active parties. Ophthalmology service will be more consistent due to new policies and guidelines. It will be increasingly dematerialized, i.e., delivered electronically through kiosks rather than face-to-face. The structure of services will also be radically changed, with regional and national eye care structures replaced by global eye care services, delivered through dynamically formed grids of professionals. These visions and their realizations are achievable in near future, depending on effective implementation and optimal utilization of teleophthalmology as demonstrated by this thesis. In addition, this thesis envisages a drastic paradigm change in eyecare practices, requiring decisive policy choices.

In July 2004 the Australian Health Ministers Conference agreed on the need to develop a National Eye Health Plan for Australia 2005-2010 to promote eye health and reduce the incidence of preventable blindness and vision loss. The Plan represents Australia’s response to World Health Assembly resolution WHA56.26 on the elimination of avoidable blindness in member countries.
The Consultation Paper for this National Eye Health Plan 2005-2010 recognizes works done in this thesis. Telemedicine has also enhanced the communication between regional health workers and especially optometrists with ophthalmologists. The research programs in the North West of Western Australia (Carnarvon) have clearly demonstrated economic benefits from the use of telemedicine in providing ophthalmic surveillance in these areas particularly for the prevention of blindness from diabetic retinopathy and glaucoma” (National Eye Health Plan, Canberra 2005).

The National Eye Health Plan 2005-2010 also proposes five key action areas that have the potential to utilize teleophthalmology to lead the prevention of avoidable blindness and low vision in rural and remote Australia. They are:

- reducing the risk of developing eye disease;
- improving early detection;
- improving access to eye health care services;
- improving the systems and quality of care; and
- improving the underlying evidence base.

The significance of the work that has been presented in this thesis can not be understated since these are the first steps toward the evolution of a new model for patient care delivery. The infrastructure that has been formed for the execution of the projects in this thesis will continue to form the basis for the realization of further work in remote eyecare delivery as we remove the extraneous layers of traditional practice to arrive at the true nature of the health care encounter.

### 12.1 Future Directions

World Health Organization (WHO) estimates that there are approximately 1.5 million blind children in the world. Almost 70% of vision impairment in Australia is caused by conditions which are preventable or treatable. In Australia, Glaucoma is another major cause of permanent, yet preventable, blindness. Approximately 50% of individuals with glaucoma are unaware of their condition, and greater access to glaucoma testing would be beneficial for these individuals. In the absence of expert eye care specialists, the rural and remote regions do not have adequate
facility for early detection of childhood blindness and glaucoma. The existing school based vision screening methods are inadequate and often debatable for early detection of children’s blinding vision problems.

Hence, based on the results of the current research works, further research studies are proposed in WA. This proposed research project will serve as an important step towards detection and elimination of preventable and treatable causes of childhood visual impairment and glaucoma in remote regions of Australia. For the first time, the study will develop a) computerized, telemedicine friendly tests to detect amblyopia (lazy eye), a major condition prevalent in children b) develop innovative telemedicine friendly tests for night blindness, color blindness and double vision c) develop computerized early glaucoma detection protocol.

These computerized tests being developed could be easily integrated to test senior citizens at aged care facilities, and also to test driver’s vision requirements in Australia. Establishing a protocol and other developments will possibly lead to futuristic, automated, and self operated eye health–kiosks, which could be, used in the shopping malls and rural internet kiosks. The proposed further studies will be potential to significantly reduce health-care costs by avoiding patient travel to city, making it useful for community clinics throughout Australia and in many other countries.
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“Watson, come here. I want you,” said Alexander Graham Bell on 10 March 1876, when he accidentally spilled battery acid on himself while making the world’s first telephone call [1]. Little did Bell realize at the time that he was transmitting the world’s first telemedical consultation. The field of telemedical communications has come a long way since then; not only is telesurgery commonplace, telemedicine has made it possible to bring state-of-the-art ophthalmic care to patients in rural and other hard-to-reach areas.

Prior to the development of telemedical communications, ophthalmic expertise was not available in several areas of the world. This was due to the higher concentration of eye care specialists in large, urban cities, with fewer in suburban and rural areas. To compensate, patients often were referred elsewhere at considerable expense – even though, in many cases, treatment could have been carried out by a local physician had advice been available from a specialist. All this has changed with the development of technology ranging from personal computers and digital cameras to appropriate software and telecommunications. Locale is no longer a limitation in receiving quality eye care, for the emerging field of teleophthalmology has made it possible to transfer clinical data from any part of the world to any other part.

1.2 What is Teleophthalmology?

Tele is an Greek word meaning “distance,” and ophthalmology is the branch of medicine that deals with the anatomy, functions, pathology, and treatment of the eye.

Teleophthalmology is a method by which patients’ eye-related problems can be examined, investigated, monitored, and treated, even though the eye care specialist and patient are located in different geographical areas. Though initially considered futuristic and experimental, teleoph-
One of the first applications of telemedicine to ophthalmology was tested in 1987 as part of a project to monitor retinal vessels during space flights. To ascertain its efficacy, the Johnson Space Center in Houston, Texas, developed a system for real-time transmission of retinal images that were acquired by a portable video funduscope. Tested on the space shuttle Columbia during mission STS-50 [2], the device used state-of-the-art telecommunication tools to provide ophthalmic advice remotely; today, such technology is an integral part of eye care services in several parts of the world. Image acquisition, image storage, image display and processing, and image transfer represent the basis of teleophthalmology. Such technology is making it possible to bring high quality eye care services to patients in hard-to-reach areas, rather than having to transport patients to a distant eye care center. Because of this application, two major goals of teleophthalmology are to (1) eliminate unnecessary traveling for patients and their caretakers, and (2) enable eye hospitals to treat patients from all over the world without concern about geographical limitations.

1.2.1 Scope of Teleophthalmology

Teleophthalmology covers a wide range of activities: the transferring of high-resolution ophthalmic images, ultrasound, electrooculography and electroretinography results. Today, the applications of teleophthalmology encompass:

- Access to eye specialists for patients in rural or remote areas
- Ophthalmic disease screening, diagnosis, monitoring, and management
- Linking and sharing of diverse medical resources
- Research and clinical trial collaborations
- Distant learning and continuing education

Because of the high prevalence of eye disease in South Africa and the country could not afford the level of ophthalmic specialization achieved in the United Kingdom, a dedicated Internet site was set up by the UK’s Moorfields Eye Hospital. This system offers teleophthalmology service to African countries including Ghana, Gambia, Tanzania and South Africa [3].

The Middle East Ophthalmology Network (MEON) is a unique network among ophthalmologists working in major ophthalmology centers in Israel, Jordan, Morocco, Tunisia and the Palestinian Authority [4], because the project offered some 50 physicians across the Middle East the opportunity to benefit from sharing clinical consultation for diagnosis and management decisions beyond physical and political boundaries. The system also overcame some of the constraints imposed by the uneven distribution of medical resources and expertise in the region, reduced professional isolation, encouraged more collaboration between physicians, and offered peace dividends based on cooperation between physicians across the political divide [4].

In the Azerbaijan Republic, the quickest and most cost-effective way to improve medical care was reported to be through telemedicine [5]. The first Internet and telemedicine station in Azerbaijan was started in 1997. Since then, ophthalmology- and surgery-based telemedicine consultations have been carried out with clinics in Moscow.

In 1998, using an integrated services digital network (ISDN) line conveying information at a rate of 128 kb/s, an endoscopic laser-assisted dacryocystorhinostomy procedure was transmitted in real time from the Saint Francis Medical Center in Honolulu, Hawaii, to ophthalmologists at the Makati Medical Center in Manila, Philippines, more than 5000 miles away [6]. Live surgical and endoscopic images were sent in real time with explanations by the surgeon and with interactive questions and answers during and after the procedure. It was the first time telemedicine technology was used to support real-time surgical telementoring to remove an orbital tumor, and it opened the door to further use and
development of telementoring technology to disseminate surgical skills to distant sites.

1.4 Anatomy of a Teleophthalmology Consultation

Specific teleophthalmology and communication devices all are key components of the teleophthalmology infrastructure. They include specialized application software, data storage devices, database management software, medical devices capable of electronic data collection, and storage and transmission. In turn, these devices are enhanced through the use of telecommunications technology, network computing, video conferencing systems, and modems.

Teleophthalmology customarily uses two methods to transmit images data and sound – either live, real-time transmission wherein the consulting health care professional participates in the examination of the patient while diagnostic information is collected and transmitted; or store-and-forward transmission is used, wherein the consulting professional reviews data simultaneously with its collection. Ideally, the real-time assessment should be coupled with high-resolution, digitally still images for documentation purposes and ongoing follow-up care.

1.5 Equipment Used for Teleophthalmology Consultations

Digitally still and video cameras are used for conducting the external portion of the general eye exam in store-and-forward or real-time mode. The image quality of these cameras are usually sufficient to adequately detect gross ocular adnexal pathology, ocular motility, and alignment abnormalities (i.e. esotropia, exotropia, hypertropias, head-tilts, etc.). However, the pupillary assessment, which is usually obtained from the recorded findings of a trained examiner, utilizes sophisticated video camera systems.

For reporting the refractive status of the eyes, autorefractors are used in teleophthalmology. Many of these autorefractors have high levels of accuracy and require minimal training to use. Any of the ancillary health care personnel at remote sites can use this equipment.

The portability of devices are ideal for teleophthalmology. For instance, at remote telemedicine sites visual field testing is done through portable automated perimeters. The Humphrey Frequency Doubling Technology (HFDT) Perimeter and Dicon FieldView Perimeter are two examples of user-friendly visual field testers. They require only a short testing time, while at the same time they produce field reports in digital format that can be easily forwarded to the consulting ophthalmologist.

Intraocular pressure is measured using Keeler’s non-contact, air-puff tonometer, assuming appropriately trained personnel are present at the remote site. Hand-held tonometers, such as the Tono-Pen XL or the Clarke/Perkins tonometer, are also ideal for telemedicine applications, since they are portable and require minimal training.

Non-mydriatic digital fundus cameras are widely used to assess posterior segment pathology via teleophthalmology. The Heidelberg Retina Tomograph II, Panoramic200TM scanning laser ophthalmoscope and the Topographic Scanning System (TopSS) are also used in teleophthalmology. Refractive surgery patients are followed up teleophthalmologically, with the use of a slit lamp video imaging system and a corneal topography unit.

High magnification images of the optic nerve and fovea can be obtained by direct video ophthalmoscope, however it allows a very limited view of the fundus. Currently available digital indirect ophthalmoscopes may not be a practical device for most teleophthalmology applications, since they require someone who is well-trained in indirect ophthalmoscopy at the remote site. Additionally, two people are generally required to capture images using this device: an observer who watches the video monitor, while at the same time, the examiner is attempting to bring the retina into focus. Once the image is in focus on the monitor, the observer needs to instruct the examiner to capture the image.
1.6 Teleophthalmology Considerations

In an ideal world, everyone would have immediate access to the appropriate specialist for medical consultation. However, the current status of health services is such that total primary medical care cannot be provided in many rural areas. Even secondary and tertiary medical care is not uniformly available in suburban and urban areas. Incentives to entice specialists to practice in suburban or rural areas have failed in many nations.

For decades, research has revealed that communities most likely to benefit from teleophthalmology are those least likely to afford it, or to have the requisite communication infrastructure. However, this may no longer be accurate. In contrast to the challenge of providing quality care to patients in rural and hard-to-reach areas, Internet connections and computer literacy are becoming more affordable, and therefore, easier to obtain and utilize [7] for healthcare and other purposes.

Theoretically, it is far easier to set up an excellent telecommunication infrastructure in suburban and rural areas than to place hundreds of medical specialists in these places. The world has realized that the future of telecommunications lies in satellite-based technology and fiber-optic cables. More and more, providing health care in remote areas through the use of high technology is manifesting; for instance, there has been a phenomenal explosion in the use of computers in Indian villages [7].

1.6.1 Challenges

Immediate or widespread implementation of teleophthalmology often is hindered by many factors [8]: lack of a telecommunication infrastructure; affordability of programs; cost of equipment; accuracy of the medical and non-medical devices used; training of appropriate personnel; lack of guidelines and protocols; sustaining projects; reimbursement for teleophthalmology consultations; regulations regarding sharing of information; legal liability; privacy; and security.

To expedite the use of teleophthalmology, financial planning for it should include the costs of creating and sustaining a telecommunication and information technology infrastructure and medical devices, as well as costs such as personnel training, monthly network access fees, maintenance, telephone bills, and other operational expenses [9].

Once the objectives of a program are identified, technology support personnel should be consulted to clarify technical equipment specifications and facility requirements. Protocols and guidelines must be developed to provide clear direction for how to utilize teleophthalmology most effectively. The training of remote operators is especially critical in telediagnosis of eye conditions that require hands-on examination [8]. The reliability of a program is also related to the consulting ophthalmologists’ experience with telemedicine technology, and their awareness of both its strengths and limitations.

Another challenge is many nations do not have explicit policies to pay for teleophthalmology services therefore, establishing a teleophthalmology payment policy is crucial [10]. In this regard, several telemedicine services are being integrated into regular health care systems in the United States and the Scandinavian countries that include reimbursement and payment options [11, 12].

Additionally, studies need to be conducted about implementing, monitoring, evaluating, and refining the teleophthalmology payment process. In this regard, it should be noted that teleophthalmology licensure and indemnity laws may also need to be formulated. This issue however, remains a cloudy region for health care strategists and has implications for consulting ophthalmologists and rural/remote practitioners who practice across state or country lines.

It has been observed that successful teleophthalmology programs are often the product of careful planning, sound management, dedicated professionals and support staff, and a commitment to appropriate funding to support capital purchases and on-going operations. Clearly, implementing an effective system reflects a commitment to teamwork, and to linking technical and operational complexities into a fully integrated and efficiently functioning program. Teleoph-
Overview of Teleophthalmology

Chapter 1

7

Teleophthalmology service providers, health insurance agencies, and all concerned institutions should convene to create a workable model for teleophthalmology service improvements. The eye care professional communities would also benefit by creating teleophthalmology service guidelines, which would pave the way for consensus on several challenging issues, such as technical and clinical service standardization for teleophthalmology.

1.6.2 Rewards

Worldwide, there is difficulty in retaining eye care and other specialists in non-urban areas. Once the virtual presence of a specialist is acknowledged through teleophthalmology, a patient can access resources in a tertiary eye care center without being limited by distance. Teleophthalmology also ensures maximum utilization of suburban or rural hospitals. General practitioners in rural and suburban areas often feel that they may lose their patients to a city consultant. With teleophthalmology, the community doctor continues to primarily treat the patient, under the guidance of a specialist. Teleophthalmology also avoids unnecessary travel and expense for patients, their families and caregivers; and it improves health outcomes.

It is also personally and professionally rewarding for health practitioners to know they have played a role in increasing access to eye care services and to improving quality of care. Few moments are as rewarding as receiving an anxious look from a patient in need, and giving reassurances that access to the best medical care is only a moment away.

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Abstract
Teleophthalmology in the Asia-Pacific region is in an embryonic stage, and the barriers to its further development are substantial. To examine the current status of teleophthalmology in terms of cost-benefit, a review of the literature is indicated. A systematic electronic search was done for peer-reviewed articles published until December 2003. This review indicates scientific data concerning the cost-benefit of teleophthalmology remains limited.

Introduction
Teleophthalmology is the use of information and communication technology to provide eye care services to individuals who live some distance from the service provider. The technologies currently used include video-conferencing; data and image transfer through the Internet, fax and the telephone. In the Asia-Pacific countries, teleophthalmology is expected to increase the fairness and equality of the distribution of services because the accessibility of telecommunication services, especially in remote areas, is improving. Currently, tele-ophthalmology can provide secondary specialist advice in the diagnosis and treatment of difficult ophthalmology cases. It supports the use of real time surgical telementoring to teach complex ophthalmology procedures. In short, teleophthalmology covers many medical activities, including making diagnoses, treatment, prevention, education and research.

Cost-benefit analysis is one of the
techniques of economic evaluation designed to compare the costs and benefits of a healthcare intervention to assess whether it is worth doing before they can be considered for routine use on a large scale. In this review paper, we examine the cost-benefit of teleophthalmology as reported in the published literature.

Methods
Using a systematic search strategy, an electronic search was done in MedLine (Pubmed) for peer-reviewed articles published until December 2003. This included all studies of electronic transmission of ocular images and comparison reports of digital images, which was a precursor to teleophthalmology.

Results
The search strategy reported 118 peer-reviewed articles. Based on a review of the abstracts, six articles were deemed to represent cost-assessment studies and were inspected closely (Table 1). The analyses mainly measured cost-saving in term of transportation costs. The costs of devices varied significantly among the studies, so a comparison of the cost-estimates may not be feasible in many cases.

The benefits and savings achieved through teleophthalmology consisted mainly of reduced transportation costs for the patient in comparison with the conventional system.\(^4\) Pilot studies showed that there were considerable cost-saving made by screening process.\(^4\) While, Tuulonen, et al\(^5\) and Yogesan, et al\(^6\) reported significant reduction in the number of patients transferred for general ophthalmic assessment, following teleophthalmology consultations. Meanwhile, Blackwell, et al\(^7\) reported reduction in the number of patients transferred for emergency assessment.

Indirect benefits and savings achieved through teleophthalmology mainly consisted of timesavings for the patient.\(^8\) There were indirect savings to the provider, by means of attendant increase in community safety (by avoiding transfer of prisoners) and reduced paperwork.\(^5\)\(^8\)

A cost-minimization analysis by Bjorvig et al\(^9\) showed that at low workloads, telemedicine was more expensive than conventional examination. However, at higher workloads, telemedicine was cheaper. The break-even point for teleophthalmology consultation occurred at a patient workload of 110 per annum.\(^8\)\(^9\)

Discussion
Eye care system in the Asia-Pacific countries faces new challenges as their ageing populations need more medical care services and their eye care is more demanding. Teleophthalmology has been regarded as one solution by which necessary eye care services can be provided to everybody at a reasonable cost. In the Asia-Pacific, some outstanding teleophthalmology networks with high levels of use have been presented.\(^7\)\(^10\)\(^11\) An Internet Based Multimedia Database System (www.e-icare.com) developed at Centre for e-Health, Lions Eye Institute is now being used in Western Australia on a regular basis. The system has also been evaluated for teleconsultation from Indonesia and also on the prison population in Western Australia.\(^12\)\(^13\)

Although a number of such detailed studies are in progress in several Asia-Pacific countries, the literature has yet to address the cost-benefit of teleophthalmology applications as they move into routine use.

This review shows that there is a lack of coherent methodology for evaluation and a lack of a critical mass of data to determine the cost-benefit of teleophthalmology. Of the 118 articles surveyed, most were reports about the clinical acceptance of teleophthalmology, and only a few were reports on cost comparison of teleophthalmology application with the conventional means of providing services. Most of these reports were based on pilot or short-term projects for ocular diseases. Assessment of established, routine teleophthalmology is still scarce. When economic evaluations of teleophthalmology are being carried out, all economic parameters, including indirect effects, should ideally be taken into consideration. A large proportion of the financial savings associated with teleophthalmology are not necessarily directly visible in the health care system itself; significant economic impact may be made by, for example, time-savings and travel expenses, thereby contributing to society indirectly.

A systematic comparison on the costs and more work on the effects of the alternatives should be done in the
<table>
<thead>
<tr>
<th>Study</th>
<th>Year of Publication</th>
<th>Country of Study</th>
<th>Type of study</th>
<th>Number of participants</th>
<th>Main Aims</th>
<th>Cost related findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamminen, H., L. Alminen, and H. Uusitalo</td>
<td>1999</td>
<td>Finland</td>
<td>Video-Conferencing</td>
<td>24</td>
<td>Tele-consultations between general practitioners and ophthalmologists</td>
<td>Reduced referrals</td>
</tr>
<tr>
<td>Yogesan, K., C. Henderson, et al.</td>
<td>2001</td>
<td>Australia</td>
<td>Pilot study</td>
<td>11</td>
<td>Tele-ophthalmic system for use in maximum-security prisons</td>
<td>cost savings with the attendant increase in community safety</td>
</tr>
<tr>
<td>Tuulonen, A., T. Ohinmaa, et al.</td>
<td>2001</td>
<td>Finland</td>
<td>Pilot study</td>
<td>41</td>
<td>Feasibility of tele-ophthalmology applications in examining patients with glaucoma</td>
<td>Costs of the telemedicine and conventional visits were equal, but decreased traveling saved $55 per visit</td>
</tr>
<tr>
<td>Lamminen, H., et al.</td>
<td>2001</td>
<td>Finland</td>
<td>Small health centre</td>
<td>42</td>
<td>Cost study of teleconsultation for primary-care ophthalmology and dermatology</td>
<td>The cost decreased as the number of patients increased. Break even point occurred at a patient workload of 110 per annum</td>
</tr>
<tr>
<td>Bjorvig, S., M.A. Johansen, and K. Fossen</td>
<td>2002</td>
<td>Norway</td>
<td>Screening</td>
<td>42</td>
<td>Economic analysis of screening for diabetic retinopathy</td>
<td>At higher workloads, telemedicine was cheaper. The break-even point occurred at a patient workload of 110 per annum</td>
</tr>
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</table>
future. The benefits (and sometimes costs) were assumed to be established for teleophthalmology without any scientific evidence. As a result, decision-makers must be cautious regarding the degree to which they can apply the results of such assessments to their own circumstances. Decision-makers in the Asia-Pacific who are planning to start new teleophthalmology services should link the implementation of new and, in many instances, costly technology to realistic development of a business case.

Conclusion
In the Asia-Pacific region, the foundations for teleophthalmology are in place with potential for an explosive growth. Assessment of established, routine teleophthalmology is still scarce. We conclude that further cost-benefit studies in the field of teleophthalmology are still clearly needed.

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Internet based ophthalmology service: impact assessment

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In 2003, the Department of Health, Western Australia, commenced a teleophthalmology service between Carnarvon Regional Hospital (CRH) and Lions Eye Institute (LEI) at City of Perth (at 940 km), pioneering the use of remote, interactive consultations in ophthalmology. This assessment (a) reports the impact of teleophthalmology service on patient diagnosis, management, outcomes, and satisfaction; and (b) estimates the costs of teleophthalmology service.

Case report

An internet based system (www.e-icare.com) developed and evaluated at LEI, was used to store and transmit multimedia data to a secure, central database. Practitioners at CRH collected these data, which included patients’ demographic details, medical history, and ocular images. A portable slit lamp developed at LEI, a tonometer (Keeler Pulsair 3000, Japan), and digital retinal camera (Canon CR4-45NM, Japan) were also used. A questionnaire and interview approach assessed the satisfaction of the patients and practitioners. Estimation of costs analysed additional activity data and associated costs.

During the 12 month study period, there were 118 teleophthalmology consultations (42% men, 58% women, mean age 42 years, range 4–73 years). Most patients (53%) became aware of the service through local media, while health professionals in Carnarvon referred 36% for teleophthalmology consultation. Of the 118 cases, 3% of the patients used teleophthalmology for emergency consultation, 94% for testing for glaucoma and diabetic retinopathy; 3% of the cases were for expert second opinion and postoperative follow up.

Teleophthalmology proved to have impact on all the patients, by improving the eye care facility at CRH itself, instead of the need to travel 940 km to the city. Following teleconsultation, only 3% of patients were referred to a city hospital. While 55% of
patients had no abnormalities detected, 3% of patients received treatment at CRH itself. The ophthalmologist recommended regular follow up for 36% of patients seen by telemedicine.

The teleophthalmology consultation cost per patient, at current efficiency level, is $279.96 including fixed cost. A cost neutral analysis estimated, at optimal efficiency of 352 patients per annum, cost per patient would decrease to $107.72. In the remote area, without teleophthalmology, the cost to the service provider for a face to face consultation with an ophthalmologist is as high as $665.44 per patient. The minimum number of patients needed to make a cost effective teleophthalmology consultation is 126 per annum.

The majority of patients (98%) expressed satisfaction with the internet based consultation and observed it as convenient. Lack of physical contact with ophthalmologist was not a major concern to many patients (74%). CRH practitioners spoke favourably of using teleophthalmology, in that they were able to get advice from colleagues and discuss alternative management strategies. Practitioners at LEI found the experience informative and challenging.

**Comment**
While acknowledging that face to face consultations with ophthalmologists are unique, its costs are enormous in remote health centres. The project is a technical and clinical success and one that led to direct potential benefits for patients in terms of improved outcomes, as well as considerable educational experience for the participating medical practitioners. However, current assessment brought to light the importance of redefining utilisation criteria in order to achieve efficiency. For example, 126 patients per annum are required for a cost effective teleophthalmology service while the current efficiency rate is 118 per annum (2.2 patients per week). Better coordination between the local healthcare workforce and CRH may increase the number of teleophthalmology consultations, which in turn will help to achieve breakeven or even establish net savings. Overall, this assessment indicates that the success of teleophthalmology will be based upon identifying the requirements of the service and using appropriate technology.

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**FOOTNOTES**
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References


Remote ophthalmology services: cost comparison of telemedicine and alternative service delivery options

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Summary
We calculated the cost of an established tele-ophthalmology service, from a health-provider’s perspective, and compared this with the cost of three other existing eye-care service delivery options. During a 12-month study period, 118 persons took part in the tele-ophthalmology consultations between a rural clinic located approximately 900 km from the Lions Eye Institute in Perth. The variable costs of tele-ophthalmology were $166.89 (Australian dollars) per patient, and the alternatives cost $445.96, $271.48 and $665.44 per patient. Tele-ophthalmology incurred a set-up cost of $13,340. The threshold at which tele-ophthalmology became cheaper than any of the alternative options occurred at a workload of 128 patients. Tele-ophthalmology offers a viable alternative to conventional eye-care service in rural and remote areas.

Introduction
Tele-ophthalmology has been used to maintain contact with patients in rural and remote areas. In the state of Western Australia, which is an area approximately 10 times larger than the UK, ophthalmologists practise mostly in the Perth metropolitan area. Their visits to 15 regional health centres in the state take place only once or twice a year. Even then, a detailed eye examination cannot be performed due to the lack of appropriate equipment. Often the patient is sent to Perth with a referral letter from a general practitioner or visiting ophthalmologist.

A review of the literature indicated a lack of cost analysis data for tele-ophthalmology. A comparison of the costs of tele-ophthalmology and alternative options is important for those making decisions about new services. The purpose of the present study was to evaluate the cost of a tele-ophthalmology service from a health-care service provider’s perspective and compare it with the cost of alternatives.

Methods
The study was based on two existing clinics. The rural clinic was located at the Carnarvon Regional Hospital (CRH). The specialist who reviewed the images and provided feedback was located 940 km away at the Lions Eye Institute (LEI) in Perth. Ethics approval was obtained from appropriate committees.

An Internet-based eye-care system (http://www.e-icare.com) was used to transmit patient medical data to a secure database. All the consultations were conducted asynchronously (‘store and forward’). A portable slit-lamp, developed at the LEI, a tonometer (Pulsair 3000, Keeler, Japan) and a digital fundus camera (CR4-45NM, Canon, Japan) were also used.

A telehealth coordinator was trained to operate the equipment. A media announcement was made about the telemedicine service, which was available for one half-day per week. Another half-day per week was
used for administrative and other related tasks. Consultations lasted an average of 30 min per patient.

Data compilation

Data relating to the costs were gathered from the Department of Health in Western Australia (DOHWA), the Commonwealth Medicare Benefits Schedule (CMBS), the CRH and the LEI. During the 12-month study period (2003), 118 persons took part in tele-ophthalmology consultations (42% men, 58% women). Their mean age was 42 years (range 4–73).

The cost of tele-ophthalmology was compared with the costs of the following alternatives, which were available at the CRH:

1. Teleconsultation using slit-lamp, retinal camera and tonometer.
2. Patient travels to a hospital in Perth after referral by a local medical officer.
3. Patient waits for a few months, to be seen by a visiting specialist at the CRH.
4. Patient waits for a few months, to be seen by a visiting specialist. The patient then travels to Perth for a full eye examination, since some of the testing devices are not available in the regional hospital.

Cost analysis

The costs for each item are given below. All costs are actual costs and are expressed in Australian dollars (valued for the year 2003).

The fixed costs of tele-ophthalmology were:

- Marketing (M). The tele-ophthalmology project was marketed by way of local newspaper advertising for three months. The total cost was $320.
- Training (T). Training the coordinator involved staff travelling from Perth to Carnarvon. The cost of training was based on travel cost and the opportunity cost of the staff time, and amounted to $3200.
- Equipment (E). The equipment costs amounted to $50,000. The lifetime of the equipment was assumed to be seven years, and the depreciation rate was assumed to be 6% (Australian Taxation Department).
- Transmission cost (TC). A monthly fee of $100 was paid for the data connection. Transmission from Carnarvon was Internet based and there were no separate call charges.
- Software (L). An annual licence fee of $900 was paid for the e-care software.
- Set-up (S). Minor works, such as cabling, had to be carried out at the CRH in order to set up equipment there. Their cost was $150. Equipment maintenance and repair costs were nil for the year 2003.

The variable costs of tele-ophthalmology were:

- Coordinator (C). Coordinator costs were calculated at 20% of a full-time equivalent (FTE) salary plus 25% to account for associated benefits.
- Office (O). Clerical assistance for the coordinator was provided for 1 h per week (based on a level-four FTE salary).
- Specialist diagnostic service (SD). A specialist ophthalmologist in Perth charged one-third of the conventional face-to-face consultation fee (CMBS item 104) for a digital image diagnosis. Hence, the unit cost for the specialist telediagnostic service was $23.11.

The variable costs for alternatives 2, 3 and 4 were:

- Referrals (R). Every patient needed to be referred by a medical officer in order to see a specialist. The scheduled fee for medical officer consultation during normal hours in rural Western Australia was $52.
- Visiting specialist and registrar (V). There were costs involved in sending a specialist and a registrar from a Perth metropolitan public hospital to the CRH for a period of one week, four times per year. The total cost included airfares, accommodation, meals, professional fees, nursing/administrative assistance, regional travel and the opportunity cost of not working in Perth while at the CRH for both the specialist and the registrar. The total cost was $77,256, which divided by the 352 consultations performed during the year gave a cost per consultation of $219.48 (Department of Health, WA).
- Specialist consultation and eye tests in Perth (SC). The scheduled fee for a consultation with an ophthalmologist was $69.35. Fees for related eye-tests were $68.86.
- Travel assistance (TA). Patients referred for tests in Perth received travel assistance from the Patient Assistance Travel Scheme amounting to $255.75 each.

Results

The total fixed cost of tele-ophthalmology was $13,340.80, and the total fixed costs of the three
alternative options were zero (see Table 1). The variable costs of tele-ophthalmology were $166.89 per patient, and the alternatives were $445.96, $271.48 and $665.44 (Table 1). The threshold at which tele-ophthalmology became cheaper than any of the alternative options occurred at a workload of 128 patients (Figure 1).

Following teleconsultation, only 3% of patients were referred to a city hospital. In 55% of patients, no abnormalities were detected; 6% of patients received treatment at the CRH itself. The ophthalmologist recommended follow-up for 36% of patients seen by telemedicine.

Sensitivity analysis
An ideal efficiency level involves approximately 60% of seven consultations per week or 336 consultations/year, assuming 48 weeks (i.e. 60% of projected maximum efficient use of time and consultation numbers per week). Hence, four consultations per week or 192 consultations/year represent an ideal workload. At this level, with all other things constant, the tele-ophthalmology cost decreases from $279.96 to $180.97. However, during the study period only 2.5 consultations were performed per week.

Reducing the cost of equipment by 30% to acknowledge progress in the industry and increased price competitiveness resulted in a 7% decrease in tele-ophthalmology costs.

Combining the above two assumptions resulted in a tele-ophthalmology cost of $169.14, a decrease of approximately 40% on the baseline calculated cost.

On the other hand, if the equipment depreciation time is shortened, from seven to five years, the tele-ophthalmology cost increases to $305.63. However, when combined with the ideal efficiency level of 192 consultations/year, the tele-ophthalmology cost declines to $196.74.

Discussion
There have been few previous cost comparison studies of tele-ophthalmology services.\textsuperscript{3,6,7} The present study

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**Table 1** Provider costs per patient for four modalities of service provisions, Carnarvon, WA (2003)

<table>
<thead>
<tr>
<th>Costs</th>
<th>Option 1: Tele-ophthalmology (n=118)</th>
<th>Option 2: Patient travels to city hospital with referral letter from GP</th>
<th>Option 3: Patient waits for and consults a specialist visiting CRH (n=352)</th>
<th>Option 4: Patient travels to city hospital with referral letter from visiting specialist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed costs ($)</td>
<td>320.00</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Programme marketing (M)</td>
<td>3200.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training (T)</td>
<td>7570.80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set-up (S)</td>
<td>1200.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software licence (L)</td>
<td>900.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total fixed cost</td>
<td>13,340.80</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total fixed cost/patient</td>
<td>113.06</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Variable costs ($ per patient)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tele-ophthalmology coordinator (C)</td>
<td>133.47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office clerical support (O)</td>
<td>10.31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical specialist fees for tele consultation (SC)</td>
<td>23.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP fees-referral to see specialist (R)</td>
<td>255.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visiting specialist (V)</td>
<td>219.48</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specialist consultation (SC)</td>
<td>138.21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient travel (TA)</td>
<td>255.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total variable cost</td>
<td>166.89</td>
<td>445.96</td>
<td>271.48</td>
<td>665.44</td>
</tr>
</tbody>
</table>

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Figure 1 Cost of delivering eye-care services via tele-ophthalmology and three alternatives, at different workloads
identified the potential savings for the provider resulting from the use of tele-ophthalmology. It also showed the improved return on investment resulting from the higher service efficiency. Better coordination between the local health-care workforce and the CRH might increase the number of tele-ophthalmology consultations, which would also increase savings. Both the equipment used and the telecommunications can be expected to become cheaper in future. This will also improve the economics of tele-ophthalmology.

While tele-ophthalmology appears to represent a cost-effective alternative to conventional eye care in rural and remote regions, its success will be based upon identifying the requirements of the service, and the use of appropriate technology. For greater efficiency, any tele-ophthalmology services must be fully utilized, preferably by integrating them into the existing health-care system.

Acknowledgements: This study was supported by an IPRS Scholarship from the University of Western Australia and a Jack Hoffman Scholarship from the Lions Save Sight Foundation. We are grateful to the patients and staff at the Carnarvon Regional Hospital and the Lions Eye Institute for their cooperation. We also thank Beth Hudson, Eric Dillon and Robyn Fary from the Telehealth Development Unit, Department of Health, Western Australia for their support.

References
Emergency eye care in rural Australia: role of internet

Abstract

Purpose  Significant differences exist in the utilization of emergency eye care services in rural and urban Australia. Meanwhile, influence of internet-based technology in emergency eye care service utilization has not been established. This study aims to demonstrate, from a health provider perspective, an internet-based service’s impact on emergency eye care in rural Australia.

Methods  The teleophthalmology service was initiated in the Carnarvon Regional Hospital (CRH) of the Gascoyne region in Western Australia. A digital, slit lamp and fundus camera were used for the service. Economic data was gathered from the Department of Health of Western Australia (DOHWA), the CRH and the Lions Eye Institute.

Results  During the study period (January–December, 2003) 118 persons took part in teleophthalmology consultations. Emergency cases constituted 3% of these consultations. Previous year, there were seven eye-related emergency evacuations (inter-hospital air transfers) from the Gascoyne region to City of Perth.

Conclusions  Analysis demonstrates implementation of internet-based health services has a marked impact on rural emergency eye care delivery. Internet is well suited to ophthalmology for the diagnosis and management of acute conditions in remote areas. Integration of such services to mainstream health care is recommended.

Keywords: Healthcare evaluation; eye care; telemedicine

Introduction

Ophthalmologic accidents and emergencies are an important component of a hospital workload, constituting 5% of all emergencies. The commonest diagnoses are corneal foreign bodies (20%), corneal abrasions (12%), and conjunctivitis (8%). The male to female ratio is 1:88, the excess being explained by the higher risk of injury in men (professional and domestic). Provision of emergency eye care for children is also important, although the apparent incidence is low. In rural areas, these patients are usually seen by general practitioners, who often lack confidence in the management of eye emergencies. The broad range of presenting cases often confronts for training and the organization of effective referral chains.

Analysis reveals that 50–70% of these referrals did not constitute accidents or urgent conditions and conditions could have been more properly assessed. Given this scenario, an internet-based system for eye care (teleophthalmology) may have potential for use in emergency eye care in rural and remote regions.

Teleophthalmology is one of the fastest-evolving new technologies, providing the means for undertaking sophisticated eye care, and for keeping contact with patients in rural and remote areas. Despite the similarity in prevalence of eye disease in urban and rural areas, significant differences exist in the utilisation of eye care services in Australia. In the state of Western Australia, with a land area ten times larger than UK, ophthalmologists practice mostly in the capital city of Perth. Regular specialist visits to 15 rural and regional centers in the state happen only once or twice a year. When specialist eye care is required for people in the remote regions, often the patient must be transported to Perth.

It is suggested that telemedicine service may enhance health service delivery in rural areas. However, an internet-based service’s influence on emergency eye care has not been established. Hence, this evaluation aims to demonstrate, from a health provider perspective, an internet-based service’s impact on emergency eye care in rural Australia.
Methods

An internet–based (www.e-icare.com) eye care service was initiated in the Carnarvon Regional Hospital (CRH) of the Gascoyne region in Western Australia. The Lions Eye Institute (LEI), Perth provided training to a rural nonmedical officer and organized eye-specialists in Perth to diagnose images sent through this internet system. Apart from emergency consultations, the program also conducted diagnosis and management of general eye-related diseases including glaucoma, diabetic retinopathy and trachoma. A digital, portable slit lamp, developed by LEI10 and a hand-held fundus camera (Canon CR4-45NM), were used for the telemedicine service.

Data relating to eye-related cost of care diagnostic to the Gascoyne population was gathered from the Department of Health of Western Australia (DOHWA), the CRH and the LEI. Ethical approval was obtained from the University of Western Australia Human Ethics Committee and the Western Australia Aboriginal Health Information Ethics Committee.

Population and Setting

The total Gascoyne population for 2001 was 10 753. It takes at least 2 h to fly or 11 h to drive from the nearest city of Perth (940 km). There are no eye-specialist services available in this region on a full-year basis. The current practice is for an eye specialist to visit the region for a week two times per year for consultations. Also, once a year, two specialists visit the region for a week to perform low complexity eye surgery, basically cataract cases.

Results

During the study period (Janaunary–December, 2003) 118 persons took part in teleophthalmology consultations (42% men, 58% women, Mean age 42 years, range 4–73 years). Average time of telemedicine consultation was 30 min per patient. Teleophthalmology service was utilized for primary eye care (86%), secondary and follow-up care (11%) and for emergency cases (3%). A variety of ophthalmic conditions were dealt with during the study period (Table 1). Statistics for Carnarvon Regional Hospital for eye-related services (Table 2), exhibit a decline of approximately 15% in the number of occasions of service from 2002 to 2003.

There was no emergency air evacuation during the study period. For the same period in the previous year (2002), there were seven evacuations (inter-hospital air transfers) from the Gascoyne region to City of Perth (Table 3). Six of these seven evacuations had a priority status of three, that is, take-off within 1 to 2 days, the lowest priority code for evacuations (Table 3).

The minimum cost of an air evacuation trip from the Gascoyne region to Perth is $7300 (travel with a nurse). If hypothetically, these six priority three evacuations were avoided, savings to the system would amount to $40 600, assuming every trip was accompanied by a nurse only, that is, cost of avoiding six evacuations ($40 602) = (evacuation average cost ($7300) – teleconsultation cost ($277) – Patient Assistance Travel Scheme: PATS average cost ($255)) × 6.

Discussion

Access to emergency treatment in rural areas can often mean the difference between life and death. Internet-based technologies have the potential to provide earlier

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Carnarvon Regional Hospital—list of ophthalmologic conditions consulted using teleophthalmology service in year 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ophthalmic conditions</td>
<td>Number of cases</td>
</tr>
<tr>
<td>Diabetic retinopathy</td>
<td>43</td>
</tr>
<tr>
<td>Glaucoma</td>
<td>57</td>
</tr>
<tr>
<td>Cataract</td>
<td>6</td>
</tr>
<tr>
<td>Trachoma</td>
<td>0</td>
</tr>
<tr>
<td>Trauma</td>
<td>4</td>
</tr>
<tr>
<td>Other</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>118</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Carnarvon Regional Hospital—eye-related consultations at outpatient clinic 2001–2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>2001</td>
</tr>
<tr>
<td>Number of patients</td>
<td>455</td>
</tr>
<tr>
<td>% Change</td>
<td>—</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Eye-related emergency evacuations from Carnarvon in 2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial diagnosis</td>
<td>Number of cases</td>
</tr>
<tr>
<td>Eye injury</td>
<td>1</td>
</tr>
<tr>
<td>Glaucoma</td>
<td>1</td>
</tr>
<tr>
<td>Foreign body</td>
<td>1</td>
</tr>
<tr>
<td>Corneal ulcer</td>
<td>1</td>
</tr>
<tr>
<td>Traumatic hyphema</td>
<td>1</td>
</tr>
<tr>
<td>Orbital cellulitis</td>
<td>1</td>
</tr>
<tr>
<td>Acute infection</td>
<td>1</td>
</tr>
<tr>
<td>Total number of evacuations</td>
<td>7</td>
</tr>
</tbody>
</table>

*Priority code status 1 = urgent take-off, 2 = take-off within 4 h or so, 3 = take-off within 24–48 h.
diagnosis and intervention, save lives and avoid unnecessary transfers from rural hospital emergency departments to urban hospitals. Benefits for rural healthcare staff in skills acquisition and education are also evident. This evaluation study demonstrates the potential value of telemedicine use in rural eye care emergency.

There is a real need for ophthalmic emergency services in rural regional hospitals. The cheapest and most efficient way to diagnose these emergencies appears to be through internet service. A decline (15%) in the number of eye related cases in CRH may be related to a number of people presenting themselves directly for the teleconsultation service.

While acknowledging that the time comparisons need to be more appropriate by comparing ‘like-for-like’, at CRH, the average time of an internet consultation was 30 min against a 2-h and 45-min turnaround time for an emergency department evaluation. A variety of emergency complaints were managed effectively using relatively low-cost internet-based telemedicine technology, thereby eliminating the need for transportation of the patient to the emergency department in the city.

Specialist diagnostics is readily available and a better assessment of patient’s evacuation urgency is made using the internet service available at CRH. Other benefits included earlier diagnosis and intervention, a shorter stay in hospital (if hospitalization is deemed necessary) and avoided traveling for the patient.

Although acknowledging that conventional, face-to-face consultation with a specialist doctor is beneficial; its cost is great in the remote regions. Internet services offer a substitution for conventionally provided emergency services in rural and remote regions. Furthermore, specialists are satisfied with this arrangement as it enhances their potential income, skill and practice, without disrupting conventional consultations at their urban hospital.

Conclusion

Internet is well suited to ophthalmology for the diagnosis and management of acute conditions in remote areas. It offers considerable potential benefits to the patients, and enhances the skills of local practitioners. The implementation and integration of teleophthalmology services to the existing services will have an impact on current emergency eye care service utilization delivered for regional residents in Australia.

Acknowledgements

This work was supported by IPRS Scholarship from University of Western Australia. Authors are most grateful to the patients and clinical and administrative staff at Carnarvon Regional Hospital, Carnarvon for their cooperation with this study. We are also grateful to Francisco Chaves, Eric Dillon and Robyn Fary from Department of Health, Western Australia for their support during the study.

References

17.1 Introduction

As is typical in many large countries, Australia has a large landmass with a low population density, and providing the population with specialist eye care services is a major problem outside the major cities. The state of Western Australia (WA) (Fig. 17.1) has a land area of 2.5 million square kilometers, which is equivalent to one-third of the land mass of the United States (approximately two million kilometers).

Even though WA has a large land mass, 70% of people live in and around the capital city of Perth; the remaining 30% of the population lives in rural and remote WA. Therefore, when specialist ophthalmic care is required for people in remote areas, this need may remain unfulfilled for some time.

The fees for a single patient’s eye care can run into thousands of dollars, when travel and accommodation for the patient (and usually a family member) is included; in addition, there is the intangible cost of taking people away from familiar surroundings, work, and community [1].
Internet-based eye care services have been proposed in WA as a means of improving access to specialist eye care [2]. A Web-based teleophthalmology service (www.e-icare.com) has been developed at the Center of Excellence in e-Medicine, and the Lions Eye Institute (LEI) in Perth [3]. This system, which stores and transmits multimedia data to a secure, central database, includes patients’ data, such as demographic information, medical history, images, videos and audio files.

Before adoption into routine use, any new medical technology must be proved to be secure and acceptable to patients. Much is assumed and little is known about patients’ acceptance of Internet-based eye care settings. Given the lack of data, e-Medicine undertook a study of patient satisfaction, using a trained health care worker-led Internet-based service in Carnarvon Regional Hospital (CRH) (Fig. 17.2), which is located in the heart of the Gascoyne Region of WA. Carnarvon is connected to the rest of Australia by the North West Coastal Highway and, to a lesser extent, by its airport. It takes about 2 h to fly or 11 h to drive from the nearest city of Perth (940 km). It has a population of 6,357 (1996). There are no eye specialist services available in the Gascoyne region on a full-time basis. The current practice is for an eye-specialist and a registrar to visit the region for a week, two times per year for consultations. In cases of emergencies, patients are airlifted to a hospital in the city by the Royal Flying Doctor Service (RFDS).

17.2 The Study

A trained teleophthalmology nurse-coordinator takes retinal photos and external eye pictures of patients at CRH with the equipment and technology developed at e-Medicine [3–6]. The equipment included (1) a portable slit lamp (e-Med), (2) a portable air-puff tonometer (Keeler Pulsair 3000, Japan), and a non-mydriatic digital fundus camera (Canon CR4-45NM, Japan).

These devices were connected directly to the online eye care system (www.e-icare.com) to transmit multimedia information to specialists in Perth. Each time a patient was screened at CRH, an automatic e-mail was sent to alert the specialist in Perth. The specialist reviewed the data, recorded image quality, diagnosed eye disease, and made recommendations for disease management and subsequent care. Specialist advice was returned to CRH within 24 h.

Fig. 17.2. Image from Carnarvon Center
17.2.1 Recruitment

The service was made available to patients referred from local general practitioners (GPs), as well as and walk-in patients. Patient participation was entirely on a voluntary basis. No fee was charged, and emergency cases were also seen. Media announcements on local radio stations and news services were also done.

In the meantime, a teleophthalmology protocol, which was primed for service, detailed the consultation criteria, and the technical and training requirements for people involved. It also specified the rights and responsibilities of the patients, prepared the patient for consultation, privacy and confidentiality issues, screening, referral and consultation procedures and other relevant information.

17.2.2 Questionnaires and Forms

Questionnaires were used to collect patient perceptions toward teleophthalmology. These were sent along with a stamped, self-addressed envelope to all patients after consultation. The responses were collected and analyzed. The questionnaire consisted of four closed-ended questions and nine questions on rating of the service (Fig. 17.3). The closed-ended questions were on service satisfaction, lack of direct physical contact with a distant clinician, privacy concerns and future use of the teleophthalmology service. The questionnaire asked the patient to rate various aspects of the teleophthalmology service such as physical comfort, psychological comfort, convenience, duration and timeliness of consultation, skills and attitude of consultant, skills and attitude of attending health care personnel and overall satisfaction with the Internet-based service. Samples of teleophthalmology protocol, patient information sheets, patient consent forms, patient evaluation forms, clinician perception forms, and the teleophthalmology service log sheet are attached as Appendices 2–7.

17.3 Results

During the study period (February–November 2003), 110 patients were presented via Internet-based teleophthalmology. Completed questionnaires were received from 45 patients (41%), of which 42% were from men and 58% from women (mean age 42 years, range 9–73 years). More than half of these patients (53%) came to the teleophthalmology center through local media announcements, while 36% were referred by health professionals in Carnarvon. A few of the patients (7%) became aware of the telemedicine service through their family or friends. Four percent of the patients used the service for consultations for eye disease treatment or care. Most of the patients (94%) used the Internet-based service for screening for eye diseases like glaucoma and diabetic retinopathy, while, 2% of the cases were for other purposes, including expert second opinion and post-operative follow up.

A majority of patients (98%) expressed satisfaction (Table 17.1) with Internet-based consultation and observed it as a convenient form of service. Lack of physical contact with the ophthalmologist was not a major concern to many patients (74%). While 88% were not apprehensive about privacy issues associated with teleophthalmology services, 98% of patients would
prefer to use teleophthalmology in the future. Overall, the patients valued improved access to specialist services but had clear views as to the limitations of such a service.

The comfort level in the rural teleophthalmology center was rated poor to satisfactory by majority of patients, while the skills and attitude of the personnel at the telecenter were rated highly. The results of the evaluation also showed that trust between patients and treatment providers was of major importance in engendering positive attitudes.

GPs and other health care personnel in Carnarvon spoke favorably about using teleophthalmology, because they were able to get advice from colleagues and discuss alternative management strategies. Practitioners at e-Medicine found the experience informative and challenging.

17.4 Discussion

The evaluation of patient satisfaction is a common constituent of any health care service [1]. While there is speculation regarding the neutrality of patient responses and debate around the lack of understanding of how patients evaluate services, it is a mechanism through which attitudes of medical consumers can be usefully obtained. It is a wholly subjective assessment of the quality of service and, as such, is not a measure of final outcome of the technology used.

17.4.1 Patient Satisfaction Issues

Earlier evidence has suggested that patient dissatisfaction is mostly associated with non-compliance with instructions, delay in seeking further care, and poor understanding and retention of medical information [7]. This survey found at least 2% of the patients were not satisfied and may choose to refrain from future services. Another possible reason for dissatisfaction may be, as one patient stated, “convenient and great use of technology, but still did not change anything in terms of treatment.” The Internet-based consultation was mainly used to provide diagnostic options, and not as a new treatment modality.

Few of the patients (5%) found the store-and-forward Internet-based service more time consuming than the conventional face-to-face method. It must be noted that, except in the emergency cases, the outcome reports of the Internet-consultation are sent by post to all patients within 24 h. Perneger et al., after comparing patient satisfaction in three treatment settings, suggested that satisfaction also reflects patients’ characteristics and expectations, which are not related to quality of care [8].

Table 17.1. Sample of patient comments about Internet-based teleophthalmology service

<table>
<thead>
<tr>
<th>PATIENT COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>I am pleased to be provided with this service and would be happy for re-imagingmy eyes in January.</td>
</tr>
<tr>
<td>A small room, rather than a curtained-off area would have been more suitable—mainly due to the light requirement.</td>
</tr>
<tr>
<td>I was very happy to see the ad (advertisement) in the paper, as I would have to book in and wait for a GP referral otherwise.</td>
</tr>
<tr>
<td>Was convenient and great use of technology, but still did not change anything in terms of treatment, as specialist was unable to offer a conclusive diagnosis, so chose to travel to Perth.</td>
</tr>
<tr>
<td>The whole procedure was excellent and very friendly.</td>
</tr>
<tr>
<td>Poor clinic area</td>
</tr>
<tr>
<td>Personnel very helpful</td>
</tr>
<tr>
<td>Quite happy with the service I received. Should be more of them</td>
</tr>
<tr>
<td>Very friendly, convenient and helpful service</td>
</tr>
<tr>
<td>Excellent service, saved us having to go to an Eye Specialist in Geraldton or Perth</td>
</tr>
<tr>
<td>Unable to ask direct questions, as this was not a direct Telehealth service. Results took a week to come back.</td>
</tr>
</tbody>
</table>
17.4.2 Provider-Patient Communication Issues

In Carnarvon, patients had an opportunity to see the distant specialist in person on occasions of their regional visits once or twice a year. The Internet-based service was used mainly for monitoring or screening, post-operative follow-up, trauma and expert second opinion services. In this survey, at least one patient expressed concern about the inability to ask direct questions to a specialist, and 23% of the patients still preferred physical contact with the distant clinician. Data security over the Internet represents another aspect of the process, which is often overlooked. Seven percent of patients were concerned about the privacy issues associated with the security of information in an Internet environment.

17.4.3 Space Considerations

The Internet-based eye care system was deployed in Carnarvon Regional Hospital by accommodating the staff and equipment in the scarce space available within the hospital. In the absence of a dedicated room for telemedicine, a corridor area was curtained off to use as a teleophthalmology clinic. While this set-up was not comfortable for many patients, convenience in receiving eye care services in their familiar surroundings was perceived as a positive aspect of teleophthalmology (98%).

17.4.4 Perceived Benefits

Along with the convenience and cost savings associated with avoided travel to Perth, there were also indirect benefits to the family, which included increased access to clinical support, reduced risk associated with travel, and reduced disruption to family life. The patients’ response rate could have been higher in this study. This highlights the importance of finding other ways of working and organizing the communication network in order to increase the volume of response and follow-up from isolated, rural and remote patients. It was observed that a fair number of patients (7%) became aware of the telemedicine service through their family or friends, while a greater number of patients (36%) became aware through health care professionals in the locality, such as their general practitioners. Hence, general practitioners, family and friends, and other patients could be informed and encouraged to optimize the number of patients using telemedicine facilities and achieving better response rates. Despite a low volume of response from the patients, we may conclude that patients approve of Internet-based services, which is in compliance with protocols, as a feasible eye care modality in remote, rural areas. Patients surveyed during this study show no negative general attitudes toward Internet-based teleophthalmology services. From the patient perspective, the success of teleophthalmology has been overwhelmingly associated with time and cost savings associated with travel, convenience and increased access to services. The implementation of teleophthalmology projects may therefore have a positive effect within patient communities. As the use of Internet-based eye care service grows, patient perspective evaluations merit greater attention.

References

Internet-based eye care: VISION 2020

World Sight Day (Oct 13, 2005) is an annual event, which focuses attention on the problem of global blindness: “every 5 seconds one person in our world goes blind and a child goes blind every minute”. It is coordinated by VISION 2020: The Right to Sight, a joint initiative of WHO and the International Agency for the Prevention of Blindness, which aims to eliminate avoidable blindness by 2020. World Sight Day tries to raise awareness that 80% of blindness could be prevented or cured, and to encourage governments, corporations, and other funding sources to invest in global blindness prevention. At least US$102 billion in lost productivity will be saved if VISION 2020 is successfully implemented.

Meanwhile, the eye-care system in many countries faces several new challenges. Ageing populations need more eye-care services and specialist eye care is lacking for most of the rural and remote populations. Without extra interventions, the global number of blind individuals is expected to increase from 44 million in 2000 to 76 million in 2020. Internet-based eye care (tele-ophthalmology) has been regarded as one solution by which necessary eye-care services can be provided to everybody at a reasonable cost.

Tele-ophthalmology is the use of electronic communication and information technologies to provide or support a diverse group of activities related to eye care. Tele-ophthalmology is reliable and is likely to be valuable in rural areas, where the distance to an eye-care specialist can be a significant obstacle to satisfactory diagnosis and management. In many parts of the world, tele-ophthalmology has been used and found to be reliable by its technical, clinical, and economic feasibility. As the burden of eye disease in South Africa is high and the country could not afford the level of ophthalmic specialisation in the UK, a dedicated internet site was set up by Moorfields Eye Hospital, London. This system offers tele-ophthalmology service to African countries, including Ghana, The Gambia, Tanzania, and South Africa. The Middle East Ophthalmology Network is a unique network among ophthalmologists working in major ophthalmology centres in Israel, Jordan, Morocco, Tunisia, and the Palestinian Authority. The project offered some 50 physicians across the middle east the opportunity to benefit from sharing clinical consultation for diagnosis and management decisions beyond physical and political boundaries. The first internet and telemedicine station in Azerbaijan Republic started in 1997. Since then telemedicine consultations are being done with Moscow clinics in the specialties of ophthalmology and surgery. In 1998, using an internet line conveying information at a rate of 128 kb/s, an endoscopic laser-assisted dacryocystorhinostomy procedure was transmitted in real-time from the Saint Francis Medical Center in Honolulu, Hawaii, to ophthalmologists at the Makati Medical Centre in Manila, Philippines. Live surgical and endoscopic images were sent in real-time with explanations by the surgeon and with interactive questions and answers during and after the procedure. It was the first time telemedicine technology was used to support real-time surgical telementoring to remove an orbital tumour. ORBIS—a DC10 flying eye hospital based in the USA does tele-ophthalmology programmes in developing countries.

Tele-ophthalmology provides secondary specialist advice in the diagnosis and management of difficult cases. It also supports real-time surgical telementoring, by which complex eye-care procedures are taught

Comment

7 Matschinger T, Fruehwald S, Frottier P. Suicide behind bars—an international review. Psychiatr Prax (in press) [in German].
Tele-ophthalmology covers many medical activities, including making diagnoses, treatment, prevention, education, and research. Tele-ophthalmology makes the practice of eye care independent of location or time. Internet-based consultations are often secure and done at the specialist’s own time, even from home. Specialists are satisfied with this arrangement because it enhances their potential income, skill, and practice, without disrupting conventional consultations at their urban hospital.11

The cost-efficiency of tele-ophthalmology has been established.13 Significant savings in time and travel expenses are made by tele-ophthalmology, thereby contributing to society indirectly.11 Tele-ophthalmology services with high levels of use have been reported.13–16 However, tele-ophthalmology in many countries is still in a budding stage, and the barriers for its integration to the existing health-care system are substantial.17 Because the capacity of telecommunication channels is increasing, and the equipment costs are becoming affordable, the main obstacle in adopting tele-ophthalmology is organisational rather than technological. Apart from organisational issues, substantial financial and legal barriers also delay the adoption of tele-ophthalmology as a routine service.18

Despite these barriers, wider implementation of tele-ophthalmology services and its future success and sustainability is vital for preventing and managing blinding eye diseases globally. This wider implementation involves proving the value of emerging technologies to concerned people, promoting use of technology, and resolving the barriers.18

Both VISION 2020 and tele-ophthalmology share the same hope of creating adequate eye-care facilities, particularly in remote, rural, indigenous, and under-privileged communities. Effective use of tele-ophthal-

mology, along with reimbursement of the service, will have a greater effect in realising the goal of VISION 2020. Tele-ophthalmology is expected to grow and contribute to VISION 2020 even more in the coming years (panel).

If implemented and used optimally, tele-ophthalmology will change the delivery and efficiency of eye-care services by 2020. Patients and health-care workers will be more informed. By 2020, internet-based eye care might become an essential service: it will be an integral part of the health-care system and will create more value for the patient and their ophthalmologist, strengthening their relationships.

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sajeesh@cyllene.uwa.edu.au

The Centre of Excellence in e-Medicine is a unit of Lions Eye Institute which has been supported by Lions Club International Foundation, a member of the VISION 2020 programme. We declare that we have no conflict of interest.

Teleophthalmology Protocol V.01

The Centre of Excellence in e-Medicine
Lions Eye Institute
University of Western Australia

I. Introduction

This protocol gives the medical officers, coordinating health care professionals and nurses clear direction on how to make use of the teleophthalmology service provided by the Centre of Excellence in e-Medicine at Lions Eye Institute.

II. Aim

To provide specialist advice and a second opinion to health care providers in remote and rural areas.

III. Definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teleophthalmology</td>
<td>Store-and-forward or interactive, real time television for eye care purposes</td>
</tr>
<tr>
<td>Teleconsultant</td>
<td>Ophthalmologist whose expertise is requested via a teleophthalmology transaction</td>
</tr>
<tr>
<td>Teleconsultation</td>
<td>Remote patient evaluation and consultation via a telecommunications system</td>
</tr>
<tr>
<td>Originating Site/Remote Site</td>
<td>Site where the patient is located at the time of the teleconsultation. A medical officer and/or a co-ordinating nurse also present here</td>
</tr>
<tr>
<td>Consulting Site</td>
<td>Site where teleconsultant providing the teleconsultation is located at the time the service is provided via a telecommunications system</td>
</tr>
<tr>
<td>Site Coordinator</td>
<td>Person designated to coordinate teleophthalmology activities</td>
</tr>
</tbody>
</table>

IV. Teleophthalmology consultation criteria

The main service will be provided via store-and-forward techniques using a web-based system. However, videoconferencing is also available for any emergency or acute ophthalmic conditions.
V. Requirements

A. Technical requirements:

Slit lamp
Fundus camera
Desktop personal computer or laptop
Internet connection
Access to www.e-icare.com
E-icare software CD for image capture and advance imaging
Video conferencing
Video conferencing equipment
ISDN connection (128 kbps for face to face interview and 384 kbps for image reviewing from a slit lamp)

B. Training requirements:

Training to operate the imaging device
Training on disease grading and image quality
Training to use the e-icare software package
Training to use the video conferencing equipment

C. Other requirements:

Medical officers at the remote/originating site should be informed of the teleophthalmology and its benefits

VI. Responsibilities of the originating/remote site coordinating nurse

A. Prior to teleconsultation

1. Scheduling teleconsultation and connection time
2. Determining special needs or room arrangements
3. Contacting patient and referring provider with teleconsultation appointment time and location
4. Training users in the use of telemedicine equipment
5. Preparing patients for teleconsultation

B. During teleconsultation

1. Setting up and operating telemedicine equipment
2. Ensuring privacy and confidentiality of the patient
3. Ensuring comfort and safety of the patient
C. After teleconsultation

1. Distributing and collecting telemedicine evaluation forms
2. Logging telemedicine activities
3. Reporting telemedicine activity to the LEI

VII. Responsibilities of teleconsultant(s)

A. Prior to teleconsultation

1. Communicating special peripherals or room arrangements needed during teleconsultation to consulting site coordinator
2. Obtaining signed consent forms or medical records if applicable
3. Determining if interactive video teleconsultation is an appropriate means for providing the necessary services

B. During teleconsultation

1. Ensuring privacy and confidentiality of the patient
2. Ensuring comfort and safety of the patient
3. Determining if the teleconsultation is of sufficient quality to diagnose or evaluate the patient appropriately
4. Determining if the teleconsultation is of sufficient quality to adequately convey necessary information to the patient and the referring Medical Officer

C. After teleconsultation

1. Document teleconsultation and process resulting records appropriately

VIII. Rights and responsibilities of patients

A. Before teleconsultation

1. Right to informed consent to use telemedicine
2. Responsibility to arrive on time for the teleconsultation
3. Responsibility to have identity information available

B. During teleconsultation

1. Right to terminate teleconsultation and request other mode of consultation
2. Right to have additional family members present during teleconsultation
3. Right to privacy and confidentiality
C. After teleconsultation

1. Right to have medical records or stored images maintained in a confidential manner

IX. Referral and scheduling process

1. Scheduling of video consultation – by originating site coordinating nurse
2. Scheduling information is recorded – by manual entry in a logbook
3. Information to be recorded in the logbook – beginning and ending time of teleconsultation, date, description of teleconsultation, individuals participating in teleconsultation
4. Hours during which video consultations scheduled – to be determined by coordinators at both locations
5. Contacting the consulting site at Perth – originating site coordinating nurse

X. Type of referrals/consultations

A. Ophthalmic accident and emergency

1. Coordinating nurse to collect relevant history from the patient or accompanying persons.
2. Use video conferencing to consult an ophthalmologist or an ophthalmic registrar (on call) at Royal Perth Hospital before sending the patient to Perth
3. Or coordinating nurse can image the eye and send the high resolution images to an ophthalmologist via the web-based system. Then the specialist can be called for diagnostic advice and first aid based on the images/videos and history

B. Patient referrals to go to Perth for any ophthalmic conditions

1. Medical officers to send the patients to the coordinating nurse for imaging
2. The coordinating nurse will image the eye and send the high resolution images to an ophthalmologist via the web-based system
3. Diagnostic advice/second opinion will be received within 24 hours
4. Coordinating nurse to inform the patient and medical officer regarding the advice/second opinion received

C. Post-operative reviews, e.g. cataract and trabeculectomy

1. Medical officers to send the patients to coordinating nurse for imaging
2. Coordinating nurse will image the eye and send the high resolution images/videos to an ophthalmologist via the web-based system
3. Diagnostic advice/second opinion will be received within 24 hours
4. Coordinating nurse to inform the patient and medical officer regarding the advice/second opinion received

D. All diabetic retinopathy, glaucoma and other eye screenings

1. Coordinating nurse to image the eyes and send the high resolution images/videos to an ophthalmologist via web-based system
2. Diagnostic advice will be received within 24 hours
3. Coordinating nurse to inform the patient regarding the diagnostic opinion received

XI. Preparation of the patient

Originating site coordinating nurse is responsible for preparing the patient for the teleconsultation. Preparation includes:

1. Informing patient, participating family member(s), or their legal guardians, about the teleophthalmology technology, capabilities, risks, benefits, and confidentiality issues
2. Reviewing patient rights and responsibilities, including informing participants that they may terminate the teleconsultation at any time

XII. Privacy and confidentiality

1. Introduce all persons present at the originating and consulting sites during consultation
2. Ensure privacy for patients by providing a private room for the teleconsultation and putting a “session in progress” sign on the door to the room
3. Obtaining patient consent form
4. Obtaining patient records if applicable
5. Archiving/protecting patient records or stored images if applicable

XIII. Documentation

1. Patient consent forms
2. Patient medical record
3. Teleconsultation logbook

XIV. Quality control/evaluation

Periodic review and evaluation of this protocol and teleconsultation for quality control.
Teleophthalmology, Western Australia
Patient Questionnaire

Please fill out this form for any single Telehealth session.

Patient participation in this evaluation is completely voluntary.
If you need more space, please use the back of the questionnaire to continue.

Part A: GENERAL INFORMATION

1. **Site name (please circle):** Carnarvon / Exmouth / Onslow / Burringurrah / Shark Bay

2. **Date of Telehealth session:** ______ / ______ / ______ (dd/mm/yy)

3. **Starting time:** ______ : ______ am/pm (estimate if not sure)

4. **Ending time:** ______ : ______ am/pm (estimate if not sure)

5. **Person filling out questionnaire** (1 = individual, 2 = health care provider, 3 = family)

6. **Demographic data** (please tick)
   a. **Sex:** [ ] male [ ] female
   b. **Age:** [ ] < 1-year [ ] child [ ] adolescent [ ] adult [ ] elderly

7. a. **Type of service:** [ ] screening [ ] treatment/care [ ] other
   b. If “other”, please specify: ______________________________________________

8. **Individual became aware of this Telehealth service from (** Tick as many as apply):**
   [ ] Advertising (TV, Radio, Newspaper) [ ] Health professionals (GP, nurse, midwife etc)
   [ ] Another patient [ ] Family or Friend
   [ ] Other ___________________________
Part B. SATISFACTION INFORMATION:

<table>
<thead>
<tr>
<th>Self assessment having completed a Telehealth session</th>
<th>Yes</th>
<th>No</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>This Telehealth service has given me access to health care faster than a traditional service</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>This Telehealth service has provided a more convenient method for receiving this health service</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am satisfied with the quality of service received for this Telehealth session compared to the alternatives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would choose to use Telehealth for future health services</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Did you have privacy concerns?</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Was the lack of direct physical contact with the distant clinician acceptable? (for videoconferencing only)</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

*If “No”, please explain why in space provided below

________________________________________________________________________
________________________________________________________________________

<table>
<thead>
<tr>
<th>Patient rating of the following with regard to the service:</th>
<th>Poor</th>
<th>Satisfactory</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>The comfort in the Eye Clinic area was</td>
<td></td>
<td></td>
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<tr>
<td>The convenience of this service was</td>
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<tr>
<td>The duration &amp; timeliness of the consultation was</td>
<td></td>
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<tr>
<td>The skills &amp; attitude of attending personnel was</td>
<td></td>
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<tr>
<td>The information provided was explained in a way that was</td>
<td></td>
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</tr>
<tr>
<td>The feedback I received about the consultation was</td>
<td></td>
<td></td>
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<tr>
<td>The overall satisfaction I feel with the telemedicine session is</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Comments / explanations:

________________________________________________________________________
________________________________________________________________________

Thank you for your participation in this survey - your comments will help improve our service.

Please place this questionnaire in the envelope provided (no stamp required) and return to the nominated address.
CLINICIAN PERCEPTION EVALUATION

1. Clinician rating of the following with regard to the application:

<table>
<thead>
<tr>
<th></th>
<th>Excellent</th>
<th>Satisfactory</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Level of comfort with equipment &amp; procedures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) Scheduling convenience</td>
<td></td>
<td></td>
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<tr>
<td>c) Physical arrangements</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>d) Location</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>e) Timeliness of consultation results</td>
<td></td>
<td></td>
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<tr>
<td>f) Technical quality of service</td>
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<tr>
<td>g) Patient/consultant communication level</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>h) Functionality of equipment</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>i) Overall satisfaction with the telemedicine session</td>
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<td></td>
</tr>
</tbody>
</table>

2. Was the clinician satisfied with the telemedicine application compared to the alternatives? [ ] Yes  [ ] No

3. Did the clinician have patient privacy concerns? [ ] Yes  [ ] No

4. Did the clinician believe the application made a positive contribution to patient care? [ ] Yes  [ ] No

5. Was visual contact with the other site essential? [ ] Yes  [ ] No

6. During the session was it more useful to have:
   a) Full motion video [ ] Yes  [ ] No
   b) Still images [ ] Yes  [ ] No

7. Would the clinician use the telemedicine service again? [ ] Yes  [ ] No

8. What was the alternative to the use of the telemedicine service?

9. Outline future care for the patient eg. Referral, admission…

The Lions Eye Institute is an independent, non-profit organisation established for the investigation, prevention and cure of eye disease.
## WEEKLY LOGSHEET

**TELEOPHTHALMOLOGY Project Evaluation**  
**WEEKLY LOGSHEET**

Use this sheet for *Each Service Provision*. This logform is to be completed *during or immediately following* the telehealth service provision.

<table>
<thead>
<tr>
<th>#</th>
<th>Pt. Identity Number</th>
<th>Date</th>
<th>Instrument used¹</th>
<th>Consult Time start</th>
<th>Consult Time finish</th>
<th>Reason Review Requested²</th>
<th>Technical difficulties? (Y – N) (see other side)</th>
<th>Service³</th>
<th>Outcome Coding⁴</th>
<th>Image Quality Coding⁵</th>
<th>Follow-up⁶</th>
<th>Clinician ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Post Specialist Review</td>
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<td>2</td>
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</tr>
</tbody>
</table>

### ¹ INSTRUMENT CODING

- Videoconference: VDO
- Email (Store and Forward): WWW
- Telephony: T
- Slit Lamp: SL
- Handheld Fundus Camera: FC
- Tonometer: TN
- Other: O

### ² REASON FOR REVIEW REQUESTED

- Diabetic Retinopathy: DR
- Glaucoma: G
- Keratitis: K
- Cataracts: C
- Trachoma: T
- Trauma: A&E
- Other: O

### ³ SERVICE CODING

- Primary / Preventative Care: 1
- Secondary Care: 2
- Emergency: 3
- Follow-up: 4
- Other: 5

### ⁴ OUTCOME CODING

- No abnormality detected: N
- Patient Transferred: T
- Treatment at Receiving Site: R
- Further follow-up: F
- Other: O

### ⁵ IMAGE QUALITY CODING

- Very Poor: 1
- Poor: 2
- Good: 3
- Excellent: 4

### ⁶ FOLLOW-UP CODING

- None Required: 0
- Referral to local GP: 1
- Referral for diabetes coordinator services: 2
- Referral for visiting specialist (next available): 3
- Referral to Perth or metropolitan-based Specialist: 4
- Routine repeat screening: 5
- Other: 6
TECHNICAL DIFFICULTIES – please provide a brief explanation of the difficulty experienced and action, if any taken

1) ____________________________________________
   ____________________________________________
   ____________________________________________

2) ____________________________________________
   ____________________________________________
   ____________________________________________

3) ____________________________________________
   ____________________________________________
   ____________________________________________

4) ____________________________________________
   ____________________________________________
   ____________________________________________
Appendix 7

Should telemedicine in eye care be funded in Australia?

Appendix 1

Introduction to Teleophthalmology

Appendix 2

Teleophthalmology: Is it Cost Beneficial?

Literature Review

Appendix 3

Impact Assessment of Internet Based Ophthalmology Service

Appendix 4

Remote Ophthalmology Services: Cost Comparison of Telemedicine and Alternate Scenarios

Appendix 5

Emergency Eye Care in Rural Australia: Role of Internet

Appendix 6

Internet-based Electronic Eye Care Consultations: Patient Perspective

Appendix 7

Internet-based Eye Care: Vision 2020

Appendix 8

Teleophthalmology Protocol
Appendix 9

Patient Questionnaire
Appendix 10

Clinician Perception Evaluation
Appendix 11

Teleophthalmology Log Sheet