Aperito Publications

Pediatrics and Neonatal Care
Open Access

Received: September 24, 2013
Accepted: October 23, 2013
Published: October 27, 2013

http://dx.doi.org/10.14437/pncoa.104 *Research* *Aps, Pediatr Neonatal Care 2013, 1:1*

Theoretical Assessment of the Thyroid Gland's Radiation Dose from Radiographs taken in Dento-Alveolar Trauma Cases in Pediatric Patients

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Abstract

Introduction: Dento-alveolar trauma to the maxillary incisors often requires combined clinical and radiographical follow-up. The number of radiographs can add up substantially in particular cases, which subsequently results in a higher patient's absorbed radiation dose. As a consequence from the X-ray beam's downward angulation, the thyroid gland potentially receives a substantial amount of radiation, both from the primary beam as from the scattered radiation.

Aim: Assess the absorbed radiation dose by the patient's thyroid gland by means of Personal Computer X-ray Monte Carlo calculations (PCXMC® 2.0 software), taking into account voltage, milli-Ampères, exposure time, vertical projection angle, beam collimation and age of the patient.

Results: The use of a longer focus-to-skin distance and a rectangular collimator resulted in a significant lower radiation dose to the thyroid gland. The latter was irrespective of the patient's age. The dose to the thyroid gland was significantly higher in younger subjects. The impact of the vertical projection angle was not similar for all age categories.

Conclusion: The dose to the thyroid gland seems to be mostly affected by the size of radiated surface, the focus-to-skin distance and the milli-Ampère exposure time product. The study assessed only the absorbed radiation dose by the thyroid gland under different radiographic exposures, mimicking real clinical circumstances and did not did not assess image quality. Therefore the results should be interpreted with care.

Keywords: Dento-alveolar trauma; Radiographs; PCXMC®; Children; Thyroid glands radiation

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Introduction

Dento-alveolar trauma is a very common accident in pediatric patients. It occurs both in the primary as well as in the permanent dentition and the number of dental radiographs taken in an individual depends on the type of trauma, the severity and the age of the patient. Severe traumas in the primary dentition often require tooth extraction to minimize the risk of injury to the permanent successor. Subsequently, a minimal exposure to ionizing radiation should be the rule of thumb. In the permanent dentition it is different, because either the tooth's root is not fully maturated or the trauma is so complicated, multiple radiographs are needed during the often long treatment period and multi-step procedure [1]. The different types of dento-alveolar traumas are not the purpose of this paper and as such it will not be further mentioned here.

However the radiation doses to which pediatric patients are exposed to in the dental office are more of a concern, because of the high numbers and not because of the high X-ray energies used. Classical intraoral dental radiographs are taken at 60, 65 or 70 kilovolts (kV), at 4 to 10 milli-Ampères (mA) and at an exposure time of about 0.10 to 0.40 seconds. The reason for this variety is the different brands of machines on the market. Most dentists use a circular collimator instead of a rectangular (standard spacer cones, beam indicating devices or projection indicating devices provided by manufacturers are usually cylinder shaped), which results in about 50% extra surface being exposed to ionizing radiation. The latter is disturbing because this 50% does only result in additional radiation dose and not in extra diagnostic information.

The maxillary incisors are the teeth that are most often involved in a dento-alveolar trauma. Consequently the projection angle to obtain a radiograph is aiming downwards to where the thyroid gland is located in the patient's neck. Figure 1 illustrates three different vertical projection angles (65°, 45° and 30°) in a 10 year old child. From this figure it is obvious that the thyroid gland may be in the path of the primary beam. The thyroid gland is a very radiosensitive organ and subsequently demands extra protection. The latter is even more paramount in young individuals. Memon et al. [2] described the impact of dental radiography on the development of thyroid cancer and they reported that the number of dental radiographs and the age at which these are taken seemed to be crucial.

Mathematical theoretical models, such as "personal computer X-ray Monte Carlo calculations" (PCXMC®, STUK, – Radiation and Nuclear Safety Authority, Helsinki, Finland – www.stuk.fi/pcxmc) are a convenient tool to investigate the effect of exposure parameters on the absorbed radiation dose of particular organs. They are an ideal way to investigate the absorbed radiation dose without having to purchase expensive phantoms, thermo-luminescent dosimeters and reading equipment. This mathematical approach, which takes into account the photoelectric effect and Compton scattering for every exposure parameter, beam size and projection angle entered into the software, enables one to investigate the impact of a variety of horizontal and vertical angulations of the X-ray beam as well as different exposure settings and beam sizes.

Aim

The aim of this study was to theoretically assess by PCXMC® the radiation dose absorbed by the thyroid gland from intraoral radiographs of the maxillary incisors under different vertical angulations and

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exposure settings, as they are made under clinical conditions in children who suffered a dento-alveolar trauma.

Material and Methods

PCXMC® software (version 2.0) was loaded with the following exposure parameter variations: 3 vertical downward angulations (30°, 45° and 65°), 2 voltage settings (60 and 70 kV, continuous X-ray exposure as is custom in dental X-ray machines for intraoral radiography), 3 milli-Ampère exposure time product settings (10 mA x 0.1s, 10 mA x 0.2s, 10mA x 0.4s), 3 collimation configurations (horizontal rectangular (3.5 cm x 4.5 cm, about the size of an intraoral film or image receptor), vertical rectangular (3.5 cm x 4.5 cm) and circular (diameter of 6 cm), 2 focus-to-skin distances (20 and 25 cm) and the age of the patient (1 year, 5 years, 10 years, 15 years, adult person). The patient's age cannot be narrowed down, as the software only allows for the aforementioned increments. Figure 2 shows an example of the program's lay-out. The exposure settings mirror real dental clinical circumstances. The results were immediately transferred into Medcalc® (Mariakerke, Belgium) medical statistical software and checked by a medical statistician.

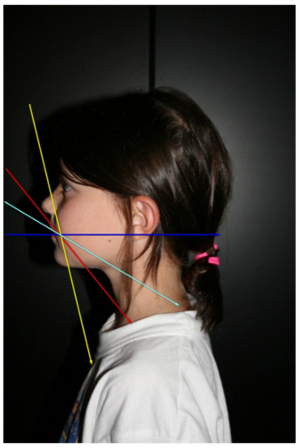

Figure 1: Visualization of three different vertical projection angles to make a radiographic image of the maxillary incisors (yellow arrow is at 65° with the occlusal plane, red is at 45° and light blue is at 30° with the occlusal plane - the dark blue line represents the occlusal plane, which is parallel to the floor)

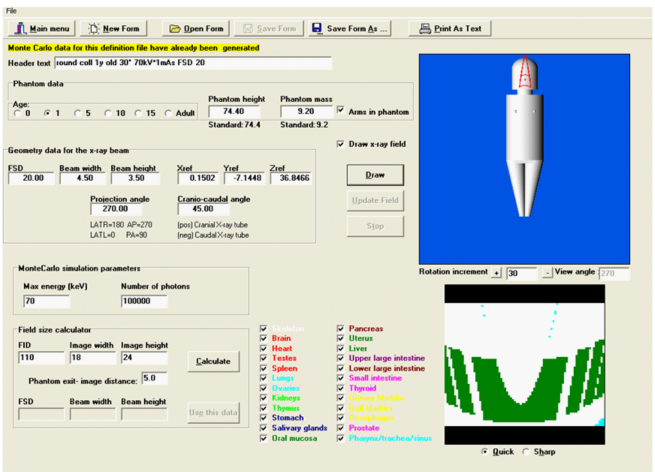

Figure 2: Example of the lay-out of PCXMC 2.0® software for exposure and patient settings (here a 1 year old).

Because the study was a mathematical and theoretical approach and was not performed in vivo, no ethics committee approval was needed.

Results

A multiple regression analysis with the thyroid glands absorbed radiation dose as a response variable, showed that all independent variables included in this study had a statistical significant influence ($P < 0.0001$). The zero order correlation coefficients (Table 1) for age of the patient, collimation size and focus-to-skin distance were negative, while they were positive for voltage, mAs (mA multiplied by the exposure time in seconds) and vertical angulation. The lowest correlation coefficient was seen for voltage ($r = 0.085$). Single regression analysis with all independent variables, showed that voltages of either 60 or 70 kV had no statistical influence on the thyroid glands absorbed radiation dose. Subsequent two-way analysis of variance (2-way ANOVA) was performed with all independent variables alternating, in order to obtain an idea of what measures one could take in clinical practice to reduce the thyroid glands absorbed radiation dose in upper occlusal and periapical radiographs of the maxillary incisors. The results showed that only age of the patient combined with collimation size or with vertical angulation of the x-ray beam had a significant influence ($P = 0.032$ and $P < 0.001$ respectively). Table 2 shows the summary statistics of the calculated absorbed doses for the different variables included in this study. It also shows the respective significant differences per variable. Table 3 summarizes the impact of the collimation on the absorbed radiation dose by the thyroid gland with regard to age of the patient. Circular collimation resulted always in a significant higher radiation dose. This table also illustrates the decrease in absorbed radiation dose with age. Table 4 illustrates the impact of the focus-to-skin distance for the different ages. At 25 cm focus-to-skin distance, it was found that there is a significant lower radiation dose to the thyroid gland in 1 to 10 year olds.

Regarding the thyroid glands absorbed radiation dose, pair wise comparisons (Student-Newman-Keuls test) between the independent variables showed that there was a significant difference in dose between all age categories involved ($P < 0.001$), except between 10 and 15 year olds. It was also found that a circular collimation resulted in a significant higher dose than any of the two rectangular collimations ($P < 0.001$). A shorter focus-to-skin distance resulted in a significant higher dose to the thyroid gland compared to a larger distance ($P = 0.004$). It was also observed that there was a significant difference in dose between all three "mA x exposure time settings" ($P < 0.001$) as well as between all three vertical projection angles chosen in the study ($P < 0.001$). Table 5 shows the results for the different projection angles. There does not seem to be an ideal vertical projection angle for all ages.

Discussion

It was interesting to find that changing the voltage from 60 to 70

Independent variable	r
Age of the patient	-0.722
Collimation	-0.209
Focus-to-Skin Distance (FSD)	-0.135
Voltage	0.085
mAs (mA x exposure time in seconds)	0.264
Vertical angulation of the X-ray beam	0.122

Table 1: Zero order correlation coefficients (r) of the independent variables calculated from the multiple regression analysis with absorbed radiation dose by the thyroid gland as a response variable

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Independent variable		Mean absorbed radiation dose (thyroid) in mGy	Median absorbed radiation dose (thyroid) in mGy	95% CI to the mean	2.5th and 97.5th percentile	Number of calculations
Age (years)	1	0.183	0.138	0.154 - 0.213	0.029 - 0.567	90
	5	0.057	0.042	0.047 - 0.068	0.009 - 0.190	90
	10	0.027[1]	0.019	0.081 - 0.032	0.003 - 0.105	90
	15	0.035[1]	0.019	0.025 - 0.046	0.002 - 0.211	90
	adult	0.009	0.005	0.006 - 0.011	0.001 - 0.039	90
Collimation	circular	0.087	0.047	0.069 - 0.105	0.004 - 0.434	150
	rectangular horizontal	0.046[2]	0.017	0.033 - 0.060	0.001 - 0.279	150
	rectangular vertical	0.054[2]	0.022	0.040 - 0.067	0.001 - 0.349	150
Focus-to-Skin Distance	200mm	0.073	0.034	0.059 - 0.087	0.001 - 0.377	225
	250mm	0.052	0.022	0.041 - 0.063	0.001 - 0.271	225
Voltage	60 kV	0.062[3]	0.024	0.050 - 0.074	0.001 - 0.360	270
	70 kV	0.063[3]	0.031	0.051 - 0.076	0.002 - 0.302	180
mAs (mA x exposure time in seconds)	10 mA x 0.1s	0.038	0.016	0.028 - 0.047	0.001 - 0.180	180
	10 mA x 0.2s	0.067	0.031	0.054 - 0.080	0.002 - 0.338	180
	10 mA x 0.4s	0.102	0.045	0.074 - 0.130	0.003 - 0.486	90
Vertical angulation of X-ray beam	30°	0.066	0.011	0.047 - 0.085	0.001 - 0.440	150
	45°	0.085	0.048	0.069 - 0.100	0.002 - 0.361	150
	65°	0.036	0.025	0.030 - 0.041	0.005 - 0.137	150

[1]No significant difference in absorbed radiation dose by the thyroid gland between a 10 and 15 year old
[2]No significant difference in absorbed radiation dose by the thyroid gland between horizontal and vertical rectangular collimation
[3]No significant difference in absorbed radiation dose by the thyroid gland between 60 and 70 kV

Table 2: Summary statistics of the PCXMC 2.0® calculated thyroid glands absorbed radiation doses, with respect to all the individual independent variables included in this study. Significant differences in thyroid glands absorbed radiation dose were found between all of the independent parameter settings, except for those marked with a superscript.

Independent variables age of the patient and type of collimation used		Mean absorbed radiation dose (thyroid) in mGy	Median absorbed radiation dose (thyroid) in mGy	95% CI to the mean	2.5th and 97.5th percentile	Number of calculations
1 year old	circular	0.221	0.177	0.161 – 0.281	0.035 – 0.642	30
	rectangular horizontal	0.157	0.125	0.108 – 0.205	0.027 – 0.582	30
	rectangular vertical	0.172	0.133	0.126 – 0.218	0.027 – 0.492	30
5 year old	circular	0.085[1]	0.066	0.063 – 0.107	0.015 – 0.242	30
	rectangular horizontal	0.041	0.029	0.028 – 0.054	0.007 – 0.143	30
	rectangular vertical	0.047	0.034	0.033 – 0.060	0.009 – 0.147	30
10 year old	circular	0.043[2]	0.033	0.031 – 0.055	0.007 – 0.133	30
	rectangular horizontal	0.016	0.012	0.011 – 0.020	0.002 – 0.043	30
	rectangular vertical	0.022	0.017	0.015 – 0.029	0.003 – 0.075	30
15 year old	circular	0.069[3]	0.036	0.041 – 0.098	0.006 – 0.296	30
	rectangular horizontal	0.015	0.011	0.010 – 0.019	0.001 – 0.045	30
	rectangular vertical	0.022	0.018	0.015 – 0.029	0.002 – 0.073	30
Adult	circular	0.017[4]	0.012	0.011 – 0.023	0.001 – 0.069	30
	rectangular horizontal	0.005	0.003	0.003 – 0.006	0.0004 – 0.018	30
	rectangular vertical	0.005	0.003	0.003 – 0.007	0.0006 – 0.020	30

[1,2,3,4] The absorbed dose by the thyroid gland is significantly higher when a circular collimation is used in a 5, a 10, a 15 year old child and an adult individual, compared to a rectangular collimation.

Table 3: Tabulation of the summary statistics regarding the thyroid glands absorbed radiation dose, with age and collimation as independent variables. Statistical significant differences are indicated with superscript and explained at the bottom of the table.

kV did not seem to alter the thyroid glands absorbed radiation dose significantly. Similar findings were also reported by Käppler et al. [3], who concluded that it was more important to reduce the mA than to increase kV, which is exactly what was also shown in the present study.

Peculiar is the fact that for one year old children the size of the collimator did not seem to make a significant difference with regard to the thyroid glands absorbed radiation dose. This can be explained by the fact that the surface covered by the X-rays with either a spacer cone with a circular opening or one with a rectangular opening is relatively large enough to have the thyroid gland exposed to the primary beam. The position of the thyroid gland, relative to the maxilla, is very closeby. For all other age groups, it was found that a circular collimator causes

Independent variables age of the patient and Focus-to-Skin Distance (FSD) in cm		Mean absorbed radiation dose (thyroid) in mGy	Median absorbed radiation dose (thyroid) in mGy	95% CI to the mean	2.5th and 97.5th percentile	Number of calculations
1 year old	FSD = 20	0.210[1]	0.163	0.165 – 0.254	0.036 – 0.590	45
	FSD = 25	0.157	0.114	0.118 – 0.195	0.024 – 0.533	45
5 year old	FSD = 20	0.070[2]	0.052	0.053 – 0.086	0.012 – 0.220	45
	FSD = 25	0.045	0.033	0.034 – 0.056	0.007 – 0.137	45
10 year old	FSD = 20	0.032[3]	0.022	0.024 – 0.040	0.004 – 0.124	45
	FSD = 25	0.021	0.013	0.015 – 0.028	0.003 – 0.093	45
15 year old	FSD = 20	0.043	0.023	0.025 – 0.034	0.003 – 0.271	45
	FSD = 25	0.028	0.016	0.016 – 0.039	0.002 – 0.173	45
Adult	FSD = 20	0.010	0.005	0.007 – 0.013	0.001 – 0.039	45
	FSD = 25	0.008	0.004	0.004 – 0.012	0.0004 – 0.047	45

[1,2,3] The absorbed radiation dose by the thyroid gland is significantly higher at FSD = 20 cm than at FSD = 25 cm in 1,5 and 10 year old children

Table 4: Tabulation of the summary statistics regarding the thyroid glands radiation absorbed dose, with age and focus-to-skin distance as independent variables. Statistical significant differences are indicated in superscript and explained at the bottom of the table.

Independent variables age of the patient and vertical angulation of the X-ray beam		Mean absorbed radiation dose (thyroid) in mGy	Median absorbed radiation dose (thyroid) in mGy	95% CI to the mean	2.5th and 97.5th percentile	Number of calculations
1 year old	30°	0.249	0.201	0.191 – 0.306	0.058 – 0.642	30
	45°	0.221	0.186	0.172 – 0.271	0.070 – 0.614	30
	65°	0.080[1]	0.071	0.064 – 0.096	0.024 – 0.182	30
5 year old	30°	0.057	0.034	0.035 – 0.079	0.007 – 0.242	30
	45°	0.085[2]	0.076	0.068 – 0.101	0.026 – 0.181	30
	65°	0.031	0.027	0.025 – 0.038	0.008 – 0.074	30
10 year old	30°	0.012[3]	0.008	0.008 – 0.016	0.002 – 0.046	30
	45°	0.044[3]	0.037	0.032 – 0.057	0.008 – 0.133	30
	65°	0.024[3]	0.020	0.018 – 0.029	0.006 – 0.059	30
15 year old	30°	0.009[4]	0.007	0.006 – 0.012	0.001 – 0.032	30
	45°	0.067	0.035	0.038 – 0.096	0.005 – 0.0296	30
	65°	0.030	0.026	0.023 – 0.036	0.008 – 0.075	30
Adult	30°	0.003[5]	0.002	0.002 – 0.003	0.0004 – 0.009	30
	45°	0.010[5]	0.004	0.004 – 0.015	0.001 – 0.067	30
	65°	0.014[5]	0.013	0.011 – 0.018	0.003 – 0.040	30

[1] The absorbed radiation dose by the thyroid gland in 1 year old children is significantly lower when the vertical angulation of the X-ray beam is 65°

[2] The absorbed radiation dose by the thyroid gland in 5 year old children is significantly higher when the vertical angulation of the X-ray beam is 45°, there is no significant difference between 30 and 65° angles

[3] The absorbed radiation dose by the thyroid gland in 10 year old children is significantly different for all vertical angulations (highest dose at 45° vertical angle)

[4] The absorbed radiation dose by the thyroid gland in 15 year old children is significantly lower when the vertical angulation of the X-ray beam is 30°

[5] The absorbed radiation dose by the thyroid gland in adults is significantly different for all vertical angulations (dose increases with increasing vertical angulation)

Table 5: Tabulation of the summary statistics regarding the thyroid glands absorbed radiation dose with age and X-ray beam angulations as independent variables. Significant differences are indicated in superscript and explained at the bottom of the table.

a significant higher absorbed radiation dose than a rectangular one. This is logical as the size of the surface being irradiated is almost 50% larger when a circular collimator is used. This emphasizes the need to use collimators that come as close to the size of the image receptor that is being used. Manufacturers provide rectangular collimators already, but the author's personal experience from asking dentists at lectures, learns that most dental practitioners never use them. The impression of experiencing more difficulties to aim correctly is the most reported reason.

There did not seem to be an ideal vertical projection angle of the X-ray beam which results in the lowest absorbed radiation dose by the thyroid gland. For individuals of at least 10 years old, the lowest absorbed radiation dose for the thyroid corresponds with a vertical projection angle of the X-ray beam of 30°. This can be explained by the fact that with using this less steep vertical angle in this age categories, the thyroid gland, which is located considerably lower in the neck compared to a child younger than 10, will be missed by the primary beam. It should be emphasized that this pure theoretical approach, in which image quality is not considered. Therefore these figures should be interpreted with care, as the theoretical ideal upper standard occlusal should be made at a 65° vertical angle to the patient's occlusal plane [4]. However, clinical limitations or circumstances may force the clinician to alter the ideal vertical projection angle. The latter was the reason for choosing the three specific projection angles in this study. This study did not include thyroid lead shielding either, which would probably result in slightly different findings with regard to the absorbed radiation dose by the thyroid gland. The reason for not implementing the thyroid shielding is because most dental practitioners do not use proper thyroid lead shielding. If the thyroid collar does not really fit well around the patient's neck, the impact on the radiation dose to the thyroid gland is negligible. In order to have a significant reduction in the absorbed dose by the thyroid gland, the thyroid collar should be adjusted meticulously around the neck of every patient individually [5].

A Focus-to-Skin Distance (FSD) of 25 cm resulted in a significant lower radiation dose to the thyroid gland in individuals younger than 15 years. This finding is supported by the earlier report by Stenström et al. [6], which showed that the use of a rectangular collimator and a larger FSD resulted in a lower absorbed radiation dose. It should be emphasized once more that this is a theoretical calculation, without considering the image quality.

One could argue that the X-ray energy used in intraoral dental imaging is very low, compared to the ones used in medicine. The effective dose of a periapical radiograph is about 3 micro Sieverts, while the effective dose of a lateral skull radiograph corresponds to 10 micro Sieverts and a CT of the thorax to 8000 micro Sieverts. These figures are averages for the entire population and do not take patient's age into account. The effective doses should be put in perspective with the annual natural background radiation, which is approximately 2000 micro Sieverts in Europe and 3000 micro Sieverts in the USA. The latter is subjective to alterations, depending on the elevation and the nature of the soil [7]. However, the number of dental radiographs can be considerably higher. Therefore, the cumulative effect of being exposed to ionizing radiation, which in dentistry can eventually be substantial, should not be forgotten [8]. Ludlow et al. [9] calculated with the most recent tissue weighting factors of 2007 that, depending upon different exposure parameters of course, the risk associated with dental radiography is 32 to 422 percent higher than was estimated with the ICRP 1990 guidelines. The latter study did not even take age of the patient into account, but encourages the use of rectangular collimation and fast-speed films or digital detectors for intra-oral radiography, to decrease the patient's absorbed radiation dose. The same study encouraged the use of mathematical risk models (*e.g.* PCXMC®) to calculate the absorbed radiation doses.

Conclusion

A smaller irradiated skin surface (by means of a rectangular collimator which sizes down the X-ray beam surface to the rectangular image receptors used in dentistry), reduction of the milli-Ampère exposure time product, using a longer focus-to-skin distance and changing the vertical angulation in relation to the age of the patient seem to play a significant role in reducing the absorbed radiation dose by the thyroid gland in case of periapical radiographs of the maxillary incisors. Changing the voltage from 60kV to 70kV, however, did not have a significant impact on the absorbed radiation dose. The limitations of this study are that it did not assess the image quality or the use of thyroid gland lead shielding. This study is a theoretical approach to assess the impact of exposure parameters, beam surface sizes and beam angulations, in relation to the patient's age, of the radiation dose to the thyroid gland.

References

1. Cohenca N, Simon JH, Roges R, Morag Y, Malfaz JM (2007) Clinical indications for digital imaging in dento-alveolar trauma. Part 1: traumatic injuries. Dent Traumatol 23: 95-104.
2. Memon A, Godward S, Williams D, Siddique I, Al-Saleh K (2010) Dental x-rays and the risk of thyroid cancer: a case-control study. Acta Oncol 49: 447-453.
3. Kaeppler G, Dietz K, Herz K, Reinert S (2007) Factors influencing the absorbed dose in intraoral radiography. Dentomaxillofac Radiol 36: 506-513.
4. Whaites E (2007) Occlusal Radiagraphy. In: Essential of dental radiography and radiology. Churchill Livingstone, London, UK 135-140.
5. Qu XM, Li G, Sanderink GC, Zhang ZY, Ma XC (2012) Dose reduction of cone beam CT scanning for the entire oral and maxillofacial regions with thyroid collars. Dentomaxillofac Radiol 41: 373-378.
6. Stenström B (1986) Dose contributions to the Swedish population from oral radiography. Swed Dent J 40: 1-62.
7. Whaites E (2007a) Dose units and dosimetry. In: Essentials of dental radiography and radiology (4th Edn.) Churchill Livingstone Elsevier, London, UK 25.
8. Regulla DF, Eder H (2005) Patient exposure in medical X-ray imaging in Europe. Radiat Prot Dosimetry 114: 11-25.
9. Ludlow JB, Davies-Ludlow LE, White SC (2008) Patient risk related to common dental radiographic examinations: the impact of 2007 International Commission on Radiological Protection recommendations regarding dose calculation. J Am Dent Assoc 139: 1237-1243.