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Equivalent Dose Measurements from Digital Intra- and Extra-Oral Imaging Examinations

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ABSTRACT

The aims of this study are to estimate the equivalent dose to the skin, eyes and thyroid in intra- and extra-oral imaging examination and to compare the dose-area product (DAP) derived from the calculation method with Diagnostic Reference Levels (DRL) that has been provided by the Malaysian Ministry of Health (MOH). Dose equivalent is measured by placing Thermoluminescence Dosimeter (TLD-100H) in the anthropomorphic RANDO phantom. Exposure is performed using intra-oral X-ray machine *ActeonSatelec X-Mind*® and extra-oral X-ray machine *Instrumentarium*OP300®, and the value is compared to the equivalent dose of the International Commission on Radiological Protection (ICRP) dose limit. DAP value for both examinations was obtained by using formula and comparing them with the DRL from MOH. The average dose equivalent of intra- and extra-oral radiographic examination is lower than the ICRP dose limit. The doses derived from both examinations did not exceed the prescribed levels when compared with DRL. The doses calculated for intra-oral examination of molar maxillary, molar mandibular and interproximal (bitewing) was 0.880 mGy while periapical examination of the anterior maxillary and mandibular was 0.688 mGy and occlusal examination was 1.100 mGy. For the panoramic examination the dose was 0.011 mGy.m^2 while lateral cephalometric examination was 0.0054 mGy.m^2. The doses obtained from this study were within the dose limit and predetermined level. This shows that a patient receives the minimum dose for both dental radiographic examinations with the optimum level of safety which meets the ALARA concept.

Keywords: Dental imaging, diagnostic reference levels, dose-area product, equivalent dose

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INTRODUCTION

Dental imaging is used as a diagnostic tool for detecting oral diseases. Its advantages in providing diagnostic information are dependent on the type of examination, whether intra-oral or extra-oral dental imaging. Unlike other radiographic examinations, dental imaging uses low exposure factors. However, some X-ray effects cannot be entirely avoided. As these effects are cumulative over time, frequent use of dental radiography on the same individual may not be absolutely risk free. In addition, the proximity of the patient to the X-ray tube means that the risks associated with dental imaging should not be underestimated.

Sensitive organs close to the X-ray tube, such as the skin, eyes, salivary glands, meninges and thyroid, can be subjected to scattered radiation. Two types of cellular damage, deterministic and stochastic effects are produced by radiation in the absence of adequate repair. Deterministic effects occur above a threshold dose and are characterized by a dose-related increasing risk and associated severity of outcome. A long-recognized adverse deterministic effect is radiation-induced dermatitis. (Hymes, Strom, & Fife, 2006). Stochastic effects, including cancer and hereditary effects are caused by a mutation or other permanent change in which the cell remains viable. The probability of a stochastic effect increases with dose (probably with no threshold, an assumption based on molecular knowledge of carcinogenesis: a very small X-ray dose can cause a base change in DNA), but the severity of the outcome is not related to the dose (Linet et al., 2012). Epidemiologic literature on low-dose and low-dose rate effects is hindered by limited statistical power at cumulative lifetime radiation levels of less than 100 millisieverts (mSv), even for very large studies. Despite wide confidence limits, the results of individual large and pooled studies of radiation workers reveal modest exposure-related increases in risk of solid tumours at low-dose levels (Cardis et al., 2007; Muirhead et al., 2009). The highest risks from dental radiography are leukaemia and thyroid cancer and incidents of these have been recorded at doses as low as 500 mSv (Sheikh, Bhoweer, Arya, & Arora, 2010). One study states that every one million full-mouth examinations may produce about 100 fatal cancers (Mortazavi et al., 2004). Dentists should take this, and the patient's age, into consideration before requesting repeated imaging examinations.

In any imaging examination, the principle of as low as reasonably achievable (ALARA) is an important concept to be practiced after considering the justification for radiographic examination when the benefits outweigh any risks that may be present (Alcaraz et al., 2011). In dental imaging examination, ALARA should be used to reduce the radiation dose on patients without compromising the image and resulting diagnostic information. The exposure time has been reported to be significantly reduced in digital sensor as compared to the conventional D-speed film and therefore reducing the radiation exposure (Anissi & Geibel, 2014). However, the use of radiation in an examination must always be justified and optimized as proposed by the International Commission on Radiological Protection (ICRP).

The aim of this study is threefold: (i) to evaluate and measure the equivalent dose to the skin, eyes and thyroid in digital intra- and extra-oral dental imaging; (ii) to assess the dose-area product (DAP) derived from the intra- and extra-oral dental imaging; and (iii) to compare the values of derived DAP with the diagnostic reference levels (DRL) as prescribed by the Malaysian Ministry of Health (MOH).

MATERIALS AND METHOD

Prior to the start of the study, the calibration factor (CF) for each TLD-100H chip was obtained by running a calibration process. A total of 40 TLD-100H chips were first irradiated freely in air with gamma rays from a radionuclide Cs-137 source at a distance of 1 m from the source. Gamma ray irradiation time was over 1.30 minutes with a dose of 1 mGy. Next, for the data of response reading per chip, TLD Harshaw reader with WinREMS software (version PL-26732.8.0.0.0, BICRON/Harshaw, 6801 Cochran Road, Solon, OH 44139, USA) was used. The CF value of each TLD-100H chip was obtained using formula as follows (Ali, 2016):

$$Calibration\ Factor\ (CF) = \frac{1\ (mGy)}{TLD\ response\ reading\ (nC)}$$

where 1 mGy is the total of gamma ray irradiation dose imposed on the TLD-100H chips and is divided by the response reading of each TLD-100H chip that is recorded in electrical charge, nanoCoulomb (nC).

Two TLD-100H chips were placed at each location of the skin, eyes and thyroid (Figure 1). For radiation dose collection on the thyroid, the chips were inserted into the holes on the anthropomorphic phantom segments (thyroid), while for the skin and eyes, the chips were pasted onto the surface of the phantom. Before being pasted, each chip was wrapped in a sealed plastic container and labelled with the location to avoid doubt and data inaccuracies. After a certain chip was placed neatly and correctly onto the phantom, the phantom was positioned onto the intra-oral X-ray machine *ActeonSatelec X-Mind*® and extra-oral X-ray machine *Instrumentarium*OP300®.

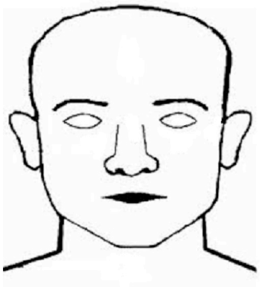

Figure 1. TLD-100H chips location on phantom

After the phantom and TLD-100H chips were placed in a position appropriate for each examination, the exposure was performed using parameters that have been set for each examination. The scanning parameters shown in Table 1 are routinely applied in intra- and extra-oral radiographic examinations at the Faculty of Dentistry, Universiti Teknologi MARA Sungai Buloh Campus, Malaysia. Exposure was performed in the total of three times to get an accurate reading of the values from each examination and the chips were then read. Radiation dose values were recorded in the electricity charging unit, nC. Table 1 shows the scanning parameters for each examination involved in this study. The flow chart in Figure 2 shows briefly the method of data collection for this study.

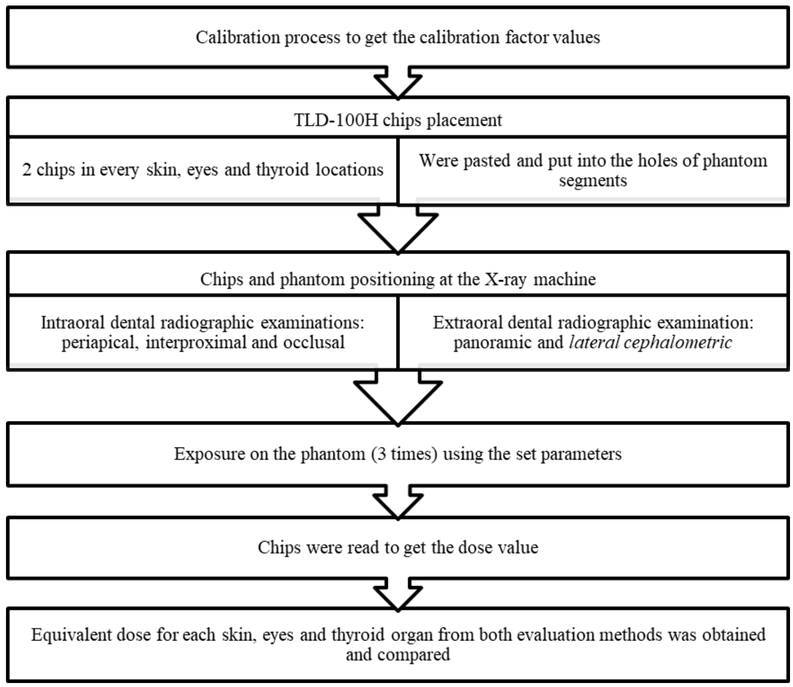

Figure 2. Flow chart of data collection method

The selection of kV and mA for intra-oral examination is based on the standard mode set by the machine manufacturer with a selection voltage of 60 kV and 70 kV and a current value of 4 mA and 8 mA with changeable exposure time. Extra-oral panoramic examination automatically determines parameter values contingent on the anatomy of the patient's head, with a voltage range of 57–90 kV and a maximum current of 16 mA. In extra-oral lateral cephalometric examination, the parameters are set at 90 kV, 13 mA and 16 s.

Table 1
Scanning parameters and DAP of involved examinations

Examinations	Voltage (kV)	Current (mA)	Exposure time (s)	Dose in air (mGy)	DAP (mGy.cm^2)
Intra-oral					
Periapical Anterior Maxillary	70	8	0.125	0.688	0.688
Periapical Anterior Mandibular	70	8	0.125	0.688	0.688
Periapical Molar Maxillary	70	8	0.160	0.880	0.880
Periapical Molar Mandibular	70	8	0.160	0.880	0.880
Interproximal (Bitewing)	70	8	0.160	0.880	0.880
Occlusal (Maxillary and Mandibular)	70	8	0.200	1.100	1.100
Extra-oral					
Panoramic	66	11.667	16.4	0.417	109.237
Lateral Cephalometric	90	13	16	0.131	54.000

Data Analysis

The radiation dose was obtained by using two methods, one with experimental method using the phantom and the other one is the method of formula calculation. In determining the radiation dose to the skin, eyes and thyroid, the reading of the dose value from the reader was used to be then calculated by using the following formula (Ali, 2016):

$$Equivalent\ dose, H_T\ (mSv) = q\ (nC)\ .CF\ (mGy/nC)\ .Q\ (Sv/Gy)$$

Where q is the response reading in nC

CF is the calibration factor in mGy/nC, and

Q is the quality factor or radiation weighting factor in Sv/Gy.

In the second method of determining the dose, scanning parameters for each examination such as mAs, kVp, focus to skin distance, focus to sensor distance, size of the collimator and the X-ray machine output was recorded and were used in the following formula (Akinlade, Farai, & Okunade, 2012):

$$DAP\ (mGy.cm^2) = L\ (mAs)\ D_o\ (mGy/\ mAs)\ A\ (cm^2)_{\ (FSD)}$$

Where L is the tube loading, expressed in mAs

Do is the normalized beam output in mGy / mAs at 1 meter

FSD is the focus to skin distance, and

$A_{(FSD)}$ is the cross-sectional area of the beam on the skin of the patient.

Because DAP is a determinant of the absorbed dose to the area receiving radiation, equivalent dose can also be obtained by performing a conversion unit to mSv. The results of the two calculation methods were further evaluated and compared with the limits and levels that have been recommended by the ICRP and DRL from MOH to determine the level of radiation dose received by the skin, eyes and thyroid organs.

RESULTS

Figure 3 shows the distribution of the CF values for each TLD-100H chip used in this study. Most TLD-100H chips have uniform CF values ranging from 3.681 for number 12 to 0.486 for number 5.

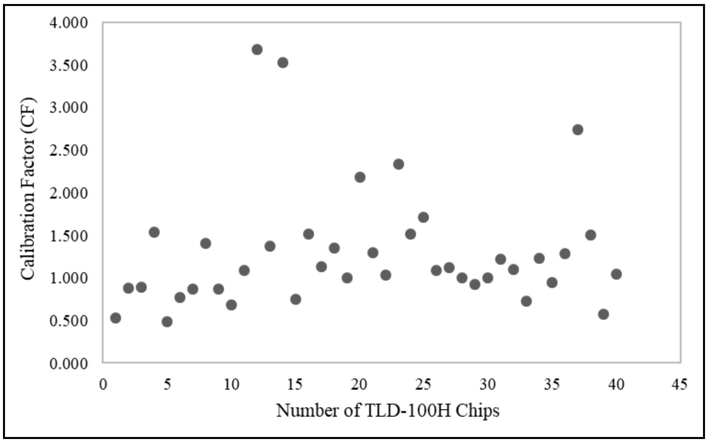

Figure 3. Distribution of calibration factor values for each TLD-100H Chips

Intra-Oral Imaging

Anterior maxillary and mandibular examinations gave the highest dose value to the left skin compared to other organs of study. The mean value of equivalent dose to the skin is 2.770 ± 2.459 mSv for anterior maxillary examination and 2.085 ± 1.624 mSv for anterior mandibular examination (Table 2). In the left molar maxillary periapical examination, the mean value of equivalent dose to the left skin is 1.227 ± 0.958 mSv. For the right molar maxillary periapical examination, the mean value of equivalent dose is 2.943 ± 2.434 mSv, also to the left skin. This is a higher dose than in the left molar maxillary examination. On the left mandibular molar examination, the left eye received a higher mean equivalent dose than any other organ (4.335 ± 3.960 mSv). Meanwhile, examination of the right mandibular molar exhibited the highest means in equivalent dose in the right thyroid (0.952 ± 0.361 mSv).

In the interproximal (bitewing) examination, the mean values of equivalent dose to the skin, eyes and thyroid differed in left and right cases. The left bitewing examination showed the highest mean value of equivalent dose to the left skin (2.890 ± 2.999 mSv), while the right bitewing examination showed the highest mean value of equivalent dose to the right thyroid (2.038 ± 0.327 mSv).

Occlusal examination unveiled a slightly higher exposure time as compared to other intra-oral examination. The mean values of equivalent dose from the maxillary occlusal and mandibular occlusal examinations revealed the highest amount of doses in the left thyroid organ (3.189 ± 2.014 mSv) and the organ of left eye (2.612 ± 0.336 mSv), respectively.

Table 2
Mean values of equivalent dose and standard deviation

	Equivalent dose for posterior maxillary periapical imaging (Mean ± SD)					
	Right organ (mSv)			Left organ (mSv)		
	Skin	Eyes	Thyroid	Skin	Eyes	Thyroid
Left maxillary molar	0.651±0.441	0.635±0.402	0.460±0.175	1.227±0.958	0.819±0.515	0.382±0.176
Right maxillary molar	1.734±1.138	1.573±0.746	1.199±0.473	2.943±2.434	1.181±0.483	2.516±1.634
	Equivalent dose for posterior mandibular periapical radiograph (Mean±SD)					
Left mandibular molar	2.599±0.867	2.363±1.726	4.023±0.106	3.657±1.674	4.335±3.960	1.901±0.445
Right mandibular molar	0.579±0.078	0.483±0.145	0.952±0.361	0.837±0.268	0.664±0.297	0.618±0.427
	Equivalent dose for anterior maxillary and mandibular periapical radiograph (Mean ± SD)					
Anterior maxillary	1.280±0.382	1.777±1.418	0.875±0.406	2.770±2.459	1.329±0.379	2.056±0.439
Anterior mandibular	1.531±0.590	0.769±0.523	1.677±0.505	2.085±1.624	1.710±0.648	1.554±0.456
	Equivalent dose for interproximal bitewing radiograph (Mean ± SD)					
Left bitewing	1.180±0.564	1.464±0.708	1.266±0.764	2.890±2.999	1.076±0.151	1.855±1.511
Right bitewing	1.428±0.525	0.873±0.135	2.038±0.327	1.744±0.828	1.219±0.171	1.201±0.318
	Equivalent dose for occlusal radiograph (Mean ± SD)					
Maxillary occlusal	1.289±0.534	1.582±0.636	1.405±0.745	2.384±2.341	1.290±0.632	3.189±2.014
Mandibular occlusal	1.690±0.734	1.240±0.305	2.255±0.404	2.362±1.745	2.612±0.336	1.546±1.200
	Equivalent dose for extra-oral radiograph (Mean ± SD)					
Panoramic	0.435±0.165	0.404±0.215	0.570±0.184	0.794±0.731	0.425±0.213	1.125±0.999
Lateral cephalometric	0.636±0.348	1.041±0.953	0.670±0.182	1.273±1.041	0.784±0.320	2.361±1.789

Extra-Oral Imaging

Table 2 shows the mean values of equivalent dose and standard deviation (in mSv) obtained in the skin, eyes and thyroid in the panoramic and lateral cephalometric examinations. Based on this finding, the organ which received the highest dose is the left thyroid with mean equivalent dose of 1.125 ± 0.999 mSv for panoramic examination and 2.361 ± 1.789 mSv for lateral cephalometric examination. Due to the higher exposure factor used in lateral cephalometric examination, equivalent doses to each organ under study were slightly higher in lateral cephalometric examination than in panoramic examination.

Dose-Area Product from Formula Calculation

The scanning parameters for intra-oral radiographic examination were set at 70 kV and 8 mA, with different exposure time depending on the type of examination according to the recommendation by the manufacturer. In periapical examination of maxillary and mandibular molar, the exposure time was set at 0.160 s, similar to the interproximal (bitewing) examination. Periapical examination of the anterior maxillary and anterior mandibular used a shorter exposure time of 0.125 s, while occlusal examination used an exposure time of 0.200 s for both maxillary and mandibular examination. The area in which the dose is received is estimated at 1 cm^2.

DAP for occlusal examination was higher (1.100 mGy.cm^2) than the other examinations due to the longer exposure time (0.200 s) (Table 1). By estimating the radiation dose received in the 1 cm^2 area, the DAP value is equivalent to the entrance surface dose (mGy) for the intra-oral examination. The exposure factors in panoramic examination are determined automatically depending on the anatomy of the patient's head. This study uses 66 kV and 16.4 s exposure time with a mean current of 11.667 mA. Area exposed to the radiation was 261.96 cm^2. For lateral cephalometric examination the parameters were set at 90 kV, 13 mA and 16 s, with an exposure area of 412.16 cm2. Table 1 shows the DAP for both extra-oral examinations.

According to Table 1, the DAP value is higher for panoramic examination (109.237 ± 24.440 mGy.cm^2) even though the mA used is lower than lateral cephalometric examination. This is because the exposure time for panoramic examination is slightly higher (16.4 s) than that for lateral cephalometric examination, which will affect the absorbed dose value in the area exposed. DAP value for lateral cephalometric examination was 54.000 ± 0.872 mGy.cm^2.

DISCUSSION

From the overall examination of intra- and extra-oral imaging, it was found that the mean values of the equivalent dose to the skin and thyroid are higher than for the eyes and this can be attributed to the sensitivity level of tissues to the radiation. The mean values of equivalent dose obtained from this study are in line with the results of another that has proven that the equivalent dose values to the eyes are lower when compared with the thyroid (Morant et al., 2013). Besides that, other factors may also affect the values of radiation dose received by each organ in this study, such as X-ray tube positioning, placement of TLD chips and the accuracy of the dosimetric system. The values of equivalent dose derived from this in vivo method are subsequently compared with the limit set by ICRP (Table 3).

Table 3
Comparison of equivalent dose values

Equivalent dose	Values from ICRP (mSv)	Mean values of equivalent dose from in-vivo method (mSv)
Eyes	15	Intra-oral examination: 1.450±0.873
		Extra-oral examination: 0.664±0.306
Skin	50	Intra-oral examination: 1.843±0.841
		Extra-oral examination: 0.784±0.357
Thyroid	50	Intra-oral examination: 1.648±0.899
		Extra-oral examination: 1.182±0.823

According to the annual dose limit prescribed by ICRP, the dosimetric data of TLD-100H as a whole is still within the allowed limit. Equivalent dose in a year prescribed by ICRP is 15 mSv for eyes and 50 mSv for skin and thyroid. For the intra-oral examination that has been conducted, the equivalent dose is lower than the limit prescribed, with mean values of 1.450 ± 0.873 mSv for the eyes, 1.843 ± 0.841 mSv for the skin and 1.648 ± 0.899 mSvf or the thyroid.

For the extra-oral examination, the equivalent dose on average is also low (0.664 ± 0.306 mSv for eyes, 0.784 ± 0.357 mSv for skin, 1.182 ± 0.823 mSv for thyroid).

The DRL set by MOH was referred to when assessing the DAP data obtained from this study to ensure that the radiation exposure was not excessive. Proposed DRL for intra-oral radiographic examination based on entrance surface dose is 3.18 mGy, and for extra-oral radiographic examination based on kerma-area was is 0.016 mGy.m^2. Based on the findings of the current study, the overall dose values obtained from formula calculation meet the benchmarks prescribed by MOH.

According to Table 1, the values of dose obtained for intra-oral examination of molar maxillary, molar mandibular and interproximal (bitewing) is 0.880 mGy, while for periapical examination of the anterior maxillary and anterior mandibular it is 0.688 mGy. The dose for occlusal examination is slightly higher than for other intra-oral examinations (1.100 mGy), but still within the levels prescribed. The values of dose obtained were compared with the values given by MOH (Figure 4).

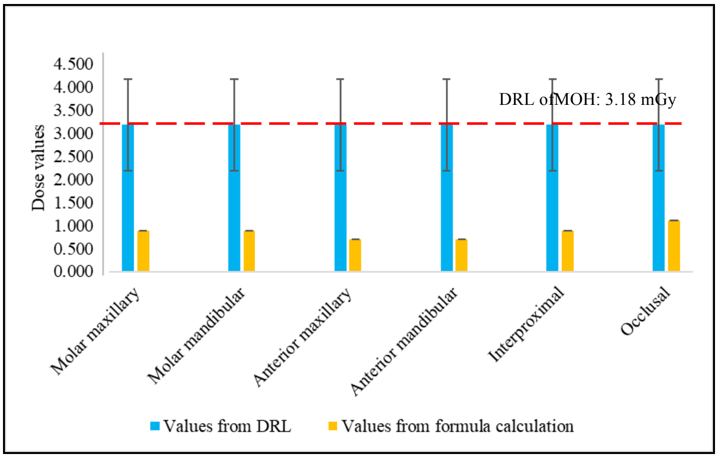

Figure 4. Comparison of dose values from formula calculation with DRL that has been prescribed by MOH for intra-oral examinations

There are significant differences between the DRL of MOH and the values obtained from the formula calculation. For intra-oral examination of molar maxillary, molar mandibular and interproximal (bitewing), the difference is 72%, while the values of periapical examination of the anterior maxillary and anterior mandibular vary by 78% and occlusal examination vary as much as 65% from the DRL. This shows that the dose applied to patients is as low as is reasonable to achieve a high-quality image.

When compared with the DRLs from various international organizations such as the National Radiological Protection Board (NRPB), the American Association of Physicists in Medicine (AAPM) and the Conference of Radiation Control Program Directors (CRCPD), the values of dose derived from this study for intra-oral examination are still low and within the prescribed limits (NRPB1.80 mGy, AAPM3.50 mGy, CRCPD 2.10–3.10 mGy).

The values of dose from extra-oral examinations also comply with the levels set by the MOH. Based on Table 1, the values obtained from the formula calculation are 109.237 mGy.cm^2 and 54.000 mGy.cm^2 for panoramic and lateral cephalometric examinations, respectively. Since the DRL from MOH is given in mGy.m^2, unit conversion is made to ease the comparison. Therefore, the value obtained for panoramic examination is 0.011 mGy.m^2 and for lateral cephalometric examination is 0.0054 mGy.m^2 (Figure 5).

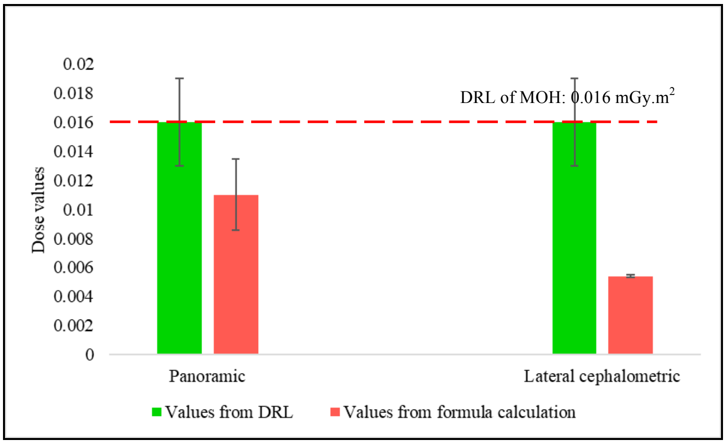

Figure 5. Comparison of dose values from formula calculation with DRL that has been prescribed by MOH for extra-oral examinations

The difference between the values prescribed by the DRL of MOH and the derived values from the formula calculation is 31% for panoramic examination and 66% for lateral cephalometric examination. Lateral cephalometric examination shows that the radiation dose applied to patients to get an image of the head, teeth and jaws is lower than that for the panoramic examination, where higher doses of radiation were applied even if only to get an image of the teeth and jaws.

No DRLs have been set by relevant international organizations for extra-oral dental radiographic examination, thus comparison of DRL is done based on studies that have been conducted and published by the related authors. These studies have proposed DRLs for DAP of 0.0071 mGy.m^2 (Chu, Lam, & Liang, 2007), 0.0073 mGy.m^2 (Helmrot & Alm Carlsson, 2005) and 0.0113 mGy.m^2 (Williams & Montgomery, 2000). These values are comparable with the DRLs prescribed by the MOH.

CONCLUSION

Dental imaging examination is the most common diagnostic tool used in dentistry. However, the principle of justification should be very closely followed due to the fact that the best way to protect patients is to avoid examination that is deemed unnecessary. If all criteria are used preferably, cumulative dose to the patient can be reduced. Each level of radiation dose should be considered potentially dangerous to humans, even at low doses, it may cause tissue damage.

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