RESEARCH ARTICLE

Evaluation of the radiation dose in the thyroid gland using different protective collars in panoramic imaging

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Background: The value for the use of thyroid shield is one of the issues in radiation protection of patients in dental panoramic imaging.

Objectives: The objective of this research is to investigate the attenuation characteristics of some models of thyroid shielding in dental panoramic examinations.

Methods: The effects of five different types of lead and lead-free (Pb-equivalent) shields on dose reduction of thyroid gland were investigated using implanted Thermoluminescence Dosimeters (TLDs) in head-neck parts of a Rando phantom.

Results: The results show that frontal lead and Pb-equivalent shields can reduce the thyroid dose around 50% and 19%, respectively.

Conclusions: It can be concluded that the effective shielding area is an important parameter in thyroid gland dose reduction. Lead frontal collars with large effective shielding areas ($>300\text{ cm}^2$ but not necessarily very large) are appropriate for an optimized thyroid gland dose reduction particularly for the critical patients in dental panoramic imaging. Regardless of the shape and thickness, using the Pb-equivalent shields is not justifiable in dental panoramic imaging.

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Introduction

Thyroid gland is one of the critical organs in human body that may be exposed by primary and/or scattered X-ray in various dental imaging methods such as panoramic, CBCT, intraoral etc. Irradiation of thyroid gland by any type of diagnostic imaging may lead to thyroid carcinoma so that a 13% increase in thyroid cancer risk for every 10 reported dental radiographs has been already estimated via statistical investigations.^{1,2} Thus, according to some guidelines, thyroid shielding are being mandatory for all patients under the age of 20,³ or below 30 (in Europe).⁴ Also, the American Thyroid Association recommends thyroid shields for all dental imaging examinations when they do not interfere with the examination.⁵

Panoramic is one of the imaging methods that are frequently used in mandibular and maxillary imaging.⁶ The effective dose from a panoramic has been reported to be 19–75 μSv , depending on the equipment used.⁷ Although some investigations state that there is no evidence justifying the routine use of thyroid shields in panoramic imaging particularly when it is located outside the primary beam,⁷ whereas some others indicate a dose reduction up to 30% for the thyroid gland.⁸ Obviously, the model of panoramic machine, attenuation material and design of shield do influence on the dose reduction in this regard.

Although lead is the best material for shielding of organs against the ionizing radiations, the related scattered rays may interfere with the primary beam and cause artefacts or obscure anatomical structures thus, need for a repeat exposure.⁷ Recently, lead-free collars (so called Pb-equivalent) have been commercially produced, and

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Figure 1 Head-neck part of a male anthropomorphic Rando phantom along with slice numbers.

used for thyroid protection in dental imaging.⁹ This shield is consisting of some metals such as aluminum, bismuth, tin and so on in composite form.

In this research, the impact of various designs of protective collars was investigated on dose reduction of superior and inferior parts of the thyroid gland in panoramic imaging using Rando phantom and thermoluminescence dosimeters.

Methods and materials

Rando phantom

The head-neck part of an adult male Rando phantom was used for the experiments (Figure 1). This phantom is made of both soft and hard tissues equivalent materials of a human which can simulate the real tissues in terms

of effective atomic number. Thyroid gland is extended approximately to the slice numbers of 9 and 10, so the superior and inferior parts of thyroid can separately be assessed in the experiment. The thyroid doses resulting from the primary beam, which is produced by dental panoramic imaging machine and the scattered rays produced by the collision of the beam to these tissues inside of the head and neck region, can be estimated by placing the dosimeter in this phantom.

Dosimetry method

LiF: Mg, Cu, P (GR-200®, China) TLD pellets (0.9 mm thickness and 4 mm diameter) were implanted inside the phantom holes at the six points (three dosimeters in superior and the same number in inferior parts of thyroid) (Figure 2). Also, one dosimeter was located on the skin surface of this region (Position 7).

All the Thermoluminescence Dosimeters (TLDs) were calibrated to standard field of a ¹³⁷Cs calibration source. A TLD reader (Harshaw-4000®, USA) was used for the TLDs readout. The dose at each point *i* (*Dose_i*) was calculated as:^{10,11}

$$Dose_i = TL_i \times ECC_i \times CF \times \left(\frac{\mu_{en}}{\rho} \right)_{Air[660 \text{ kev}] }^{LiF} \times \left(\frac{\mu_{en}}{\rho} \right)_{LiF[30 \text{ kev}]}^{PMMA} \quad (1)$$

where, *TL* is the thermoluminescence read-out, *ECC*

is the elementary correction coefficient of the TLD pellet, *CF* is the calibration factor of TLDs, and the

Figure 2 Measurement points in corresponding parts of superior and inferior thyroid gland, dosimeters from 1 to 6 are placed internally, while Number 7 is placed on the outside of the phantom.

Figure 3 Typical experimental set up in dental panoramic imaging.

μ_{en}/ρ ratios are the mass energy absorption coefficients of the corresponding media; polymethyl methacrylate (phantom material), LiF (dosemeter) and air. Then, the weighting dose of these seven points was considered as the average thyroid dose. In order to improve the accuracy of the measurement, irradiation was performed

Figure 4 Five types of protective collars (Table 1).

10 times in each experiment, and the experiment was repeated 3 times to calculate the standard deviation as the precision of measurement.

Exposure parameters and experimental set up

A two-dimensional/three-dimensional dental imaging system (NewTom GO GiANO®, Italy) was used in the panoramic two-dimensional mode for the phantom irradiation. The tube setting of 90 kV/10 mA was selected with an average exposure time of 13 s for adults. In all the experiments, the TLDs were implanted in corresponding locations of 9 and 10 slices number of phantom. First, the head phantom was adjusted inside the system based upon the general protocol and the correct position of guide lines (*i.e.* adjusting the system’s light localizer on the midsagittal of skull, and placing the side light localizers on the maxillary canine areas). Since the location of phantom is fixed for all the tests, any possible geometrical error does not impact on the total results. Then, the thyroid collar was fastened on the neck part of phantom, irradiated and simultaneously checked for the artefact effects. Figure 3 shows the scanning system along with a typical setting of phantom and thyroid collar in one experiment.

Protective collars

Figure 4 shows the five types of protective collars (Navid Parto Nama Co., Iran) used in this investigation. The physical characteristics of these shields are presented in Table 1 which includes material type, effective shielding area, nominal thickness, and shielding region on the thyroid. All the collars (except Type A) protect just the front part of thyroid gland. Although, Type A can protect the posterior, interior and lateral sides of thyroid, its artefact effects on the image makes it unusable in panoramic dental imaging. So, this collar was used merely as a control sample in this study.

Statistical test

In order to study the statistical significance of dosimetry results, Pearson tests were conducted to indicate the correlation between the dose at test points (the seven dosimetry points in Figure 2) and total average thyroid dose.

Table 1 Characteristics of the used thyroid protective collars (Figure 4)

Type of shield	Material	Effective shielding area (cm ²)/ nominal thickness (mm)	Area of shielding
A	Lead	460/0.5	All around the neck
B	Lead	300/0.5	Frontal
C	Lead	2250/0.25	Frontal
D	Pb-equivalent	70/0.25	Frontal
E	Pb-equivalent	180/0.5	Frontal

Table 2 Doses of superior, inferior and total thyroid gland with and without protective collars

Type of shield	Dose (μGy)/scan			Percentage of reduction (%)
	Superior	Inferior	Total	
No-shield	87.5 $\pm$ 5.2	27.7 $\pm$ 1.7	55.7 $\pm$ 3.3	NA
A	21.1 $\pm$ 1.3	9.7 $\pm$ 0.6	14.8 $\pm$ 0.9	73
B	40.3 $\pm$ 2.4	14.7 $\pm$ 0.9	24.6 $\pm$ 1.5	56
C	42.9 $\pm$ 2.6	14.5 $\pm$ 0.8	28.5 $\pm$ 1.7	49
D	73.2 $\pm$ 4.4	24.2 $\pm$ 1.5	42.1 $\pm$ 2.5	24
E	70.4 $\pm$ 4.2	25.5 $\pm$ 1.5	47.9 $\pm$ 2.3	14

Results and discussion

No artefacts were observed on the images after using all of the frontal thyroid collars during the exposing phantom. Table 2 presents the results of doses on superior, inferior and whole part of thyroid gland with and without protective collars. The precision of measurements was calculated to be 6% in average.

In comparison with the thyroid of no-shield, the lead collars of Type B and C could reduce the dose about 50% in average, whereas the value for Pb-equivalent shields (*i.e.* Type D and E) was obtained to be 19% approximately. In both Type B and C, the shielding material is made of lead and also the effective shielding areas are considerably large, whereas the types of D and E are made of Pb-equivalent materials and the effective shielding area are rather smaller than the other protective collars. The *p*-value of -0.9 in a Pearson test between effective shielding area of A, B, D and E types, and the total thyroid dose, indicate that there is a negative strong correlation between the shielding size and thyroid dose reduction. Therefore, the effective shielding area is one of the most effective parameters in dose reduction of thyroid. Nevertheless, considering very large area of the Type C (Poncho shape) and the approximate equal dose reduction percentage with Type B indicate that there is probably a limit in the area size of the frontal protective collars above which the dose would not be more reduced with increasing the size. Also, the data in Table 2 indicate that the nominal thickness of shield is not so effective parameter in dose reduction, because a considerable part of thyroid dose is due to the internal scattering of primary beam inside of the head and neck regions of a patient. Moreover, no one can be confident about the uniformity of thickness and/or homogeneity of composite material in all parts of one protective collar. The relative independence of the attenuation value from the thickness of protective collar, and also the 50% dose reduction by lead shields are in accordance with those of similar results investigated by Hidalgo *et al*⁹ in CBCT. Furthermore, regardless of collar type, the superior part of thyroid is received more value of doses in comparison with those of inferior due to its proximity to the X-ray tube window. Since the Type A can protect the thyroid gland from the scattered rays in all directions, obviously

the maximum reduction was achieved by this protective collar.

A Pearson test was performed on doses at the seven dosimetry points (Figure 2) and total average thyroid doses. As shown in Table 3, the *p*-values obtained from this test are greater than 0.8, indicating that there is a rather strong positive correlation between the dose at each TLD points and the total thyroid dose. That is, in general, there are little dispersions in the results of the dose assessed via implanted TLDs at these seven points. Moreover, the greater *p*-value for superior part means that the dose assessment on this part is performed with higher degree of reliability than the inferior part. This is probably due to the lesser distance of measuring points from the X-ray tube window as well as better geometrical condition in exposing the dosimeters.

Conclusions

In this work, various designs of thyroid protective shields were assessed for radiological protection of thyroid gland. Although any reduction in patient dose is beneficial according to as low as reasonably achievable principle, however, Pb-equivalent shields indicated that they do not have much value for use as thyroid protection in this regard. Effective shielding area and material composition are the most important factors in the organ dose reduction. Nominal thickness of shield should not be considered as a reliable criterion selecting a specific protective collar. It can be concluded that lead frontal

Table 3 *p*-Values of the Pearson test on the dose of TLDs (Figure 2) and total thyroid dose

TLD location	TLD point no.	<i>p</i> -value
Superior part (slice no. 9)	#1	0.90
	#2	0.96
	#3	0.95
Inferior part (slice no. 10)	#4	0.80
	#5	0.89
	#6	0.84
Surface area	#7	0.91

TLDs, thermoluminescence dosimeters.

collars with large effective shielding areas ($>300\text{ cm}^2$ but not necessarily very large) are appropriate for an

optimized thyroid gland dose reduction particularly for the critical patients in dental panoramic imaging.

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