Thermoluminescent dosimetry of panoramic radiography

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This study aims to calibrate a thermoluminescence dosimeter (TLD) using a diagnostic radiation device and evaluate the dose of panoramic radiography. TLD-100s were calibrated using a solid-state dosimeter (Unfors Mult-O-Meter 512L; Unfors Instruments, Billdal, Sweden) and a diagnostic radiation device (HDT-500R; Hyun Dai Medical X-ray Co., Paju, Korea). Forty eight TLDs were placed in 24 sites of a head and neck phantom of a male (ART-210; Radiology Support Devices Inc., Long Beach, CA, USA), and panoramic radiation was performed under exposure parameters of 70 kVp and 10 mA using a ProMax (Planmeca, Helsinki, Finland). Using the International Commission on Radiological Protection (ICRP) 2007 recommendation, the effective dose of panoramic radiography was calculated from the absorbed doses of the tissues of the 24 TLD sites in a head and neck phantom. The absorbed dose of the TLD site was higher in the parotid gland (right: 1854.4 μ Gy, left: 1788.9 μ Gy) and lower in the calvarium anterior (3.8 μ Gy). The effective dose was calculated at 28.4 μ Sv. The cancer and heritable risks were 1.56×10^{-6} and 5.67×10^{-8} , respectively. The TLD was calibrated using a diagnostic radiographic device, and the panoramic radiographic dose was evaluated. The findings of this study could be helpful in future dose studies.

Key Words: Radiation Dosage; Radiography, Dental; Radiography, Panoramic

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Introduction

Radiation is commonly known to be harmful. The effects of radiation are classified as deterministic and stochastic; deterministic effects are evaluated as equivalent doses (H_T) and stochastic effects as effective doses (E) [1,2]. In 1990, 2005, and 2007, the International Commission on Radiological Protection (ICRP) published the tissue weighting factors (W_T) required to calculate effective dose [3-5]. The tissue weighting factors for the ICRP 1990 recommendations are based on mortality of cancer, whereas those for

ICRP 2007 recommendations are based on cancer incidence. Notably, effective dose may vary from 23% to 224% when tissue weighting factors of the ICRP 1990 and 2007 recommendations are applied [6].

Since effective dose presents radiation hazards to the entire body, the risks of different radiographs could be directly compared. However, effective dose do not reflect individual characteristics such as age, sex, and genetic radioactivity [7].

Effective dose of panoramic radiography ranges from 3.85 to 39 μ Sv, which indicates a significant variation [8,9]. Lud-

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low and Ivanovic [6] reported that the value of the dosimeter could vary by approximately 23%, depending on the collimator adjustment, unit calibration, and phantom position in the unit. Lee et al. [8] reported that effective dose could vary depending on the gender of the phantom, the number and location of the thermoluminescent dosimeter (TLD) used, and the exposure conditions, even for a similar panoramic device.

Various methods using TLD, optically stimulated luminescence dosimeter, solid-state dosimeter, dose area product, and ionization chamber can be used for dose studies [1,7,10]. The most widely used method for measuring doses by placing TLDs into anthropomorphic phantoms requires significant time and effort, but it has been used as a basis for comparison in the study of doses in other methods [6,7].

In dosimetry using TLD, calibration of TLD is crucial for obtaining a conversion factor between the response of the dosimeter and the absorbed dose (D_T), as well as for improving the homogeneity of the TLD response. Radiation sources using radioactive isotopes, such as Co-60 and Cs-137, have been used to irradiate TLDs. Using X-rays as a radiation source is a medical linear accelerator, and the use of diagnostic radiation devices has rarely been reported [11–13].

This study aims to calibrate the TLD using a diagnostic radiation device and evaluate the dose of panoramic radiography.

Materials and Methods

Thermoluminescence dosimeter calibration

A diagnostic radiation device (HDT-500R; Hyun Dai Medical X-ray Co., Paju, Korea) was used to expose the TLDs to radiation. The focus of the HDT-500R was adjusted, and one of the quartiles based on the central guide line within the field of view of the HDT-500R was selected (Fig. 1A).

A solid-state dosimeter (Unfors Mult-O-Meter 512L; Unfors Instruments, Billdal, Sweden) was calibrated by the Korea Atomic Energy Research Institute and used to select the irradiation area where the dose decreased or increased relatively evenly between horizontal and vertical lines within the selected quartile.

The irradiation area was 7 mm from the centerline of the horizontal and vertical lines and was selected for the TLD phantom 104 mm wide and 88 mm long. The TLD phantom with 108 holes for a TLD was obtained using polymethylmethacrylate, which has no significant difference in dose calculation [10].

The exposure parameters of the HDT-500R (46.1 kVp, 200 mA, and 0.2 s) were set. Doses in the irradiation area were measured using a solid-state dosimeter at nine sites: lower right (area 1); lower middle (area 2); lower left (area 3); middle right (area 4); middle (area 5); middle left (area 6); upper right (area 7); upper middle (area 8); and upper left (area 9) (Fig. 1B).

Fig. 1. Irradiation area and irradiation method for calibrating TLD. (A) TLD phantom was located in the irradiation area within the quartile of the field of view. (B) In the irradiation area, doses were measured using a solid-state dosimeter at nine sites: lower right (area 1); lower middle (area 2); lower left (area 3); middle right (area 4); middle (area 5); middle left (area 6); upper right (area 7); upper middle (area 8); upper left (area 9). (C) The TLD phantom with TLDs in the irradiation area was exposed to radiation in the normal position and by flipping horizontally, vertically, and horizontally. TLD, thermoluminescence dosimeter.

The TLD phantom with TLDs in the irradiation area was exposed to radiation in the normal position by flipping horizontally, vertically, and horizontally (Fig. 1C).

Nine sites in the irradiation area were divided into four groups. As shown in Fig. 1, areas 1, 3, 7 and 9 (A group) are exposed in four corner positions successively; areas 2 and 8 (B group) are exposed successively; areas 4 and 6 (C group) are exposed in the same position successively; area 5 (D group) is exposed in the same position four times.

The sum dose was obtained by grouping, and its mean was the reference dose for calibrating the TLD. TLDs with an error correction coefficient between 0.77 and 1.43 were selected and used.

Harshaw TLD-100 (Thermo Electron Co., Oakwood Village, OH, USA) was used after annealing at 400°C for 1 hours. The energy of the TLD was measured using a Harshaw 3500 (Harshaw/Bicron, Solon, OH, USA).

Dosimetry of panoramic radiography

A ProMax (Planmeca, Helsinki, Finland) and the head and neck phantom of a male (ART-210; Radiology Support Devices Inc., Long Beach, CA, USA) were used to measure the absorbed dose of panoramic radiation (Fig. 2). And forty eight TLDs were placed in 24 sites of the head and neck phantom (Table 1).

Panoramic radiography was performed 10 times under

Fig. 2. Head and neck phantom.

the exposure parameters of 70 kVp and 10 mA, which are the normal settings for adult patients. Additionally, the background radiation was measured using two TLDs.

After reading the TLD and subtracting the average of the background radiation from the average absorbed dose of each site, the absorbed dose of each site was obtained by converting it to a single exposure. The absorbed dose of the tissue/organ for calculating effective dose was calculated by averaging the selected sites among the 24 TLD sites (Table 2). The bone surface dose is derived from the bone dose [14].

The equivalent dose is the absorbed dose multiplied by the radiation weighting factor, and X-rays have a radiation weighting factor of 1. Therefore, the equivalent dose was equal to the absorbed dose. Moreover, effective dose was calculated as the sum of equivalent dose multiplied by the fraction ratio of tissue/organ exposed to radiation (fraction irradiated) and tissue weighting factors, using the following

Table 1. Location of TLDs and absorbed doses in head and neck phantom

Phantom location (phantom level)	TLD ID	Absorbed dose (μ Gy)
Calvarium anterior (2)	1	3.8
Calvarium left (2)	2	16.1
Calvarium posterior (2)	3	18.4
Mid brain (2)	4	21.8
Pituitary (3)	5	28.2
Right lens of eye (3)	6	5.6
Left lens of eye (3)	7	9.4
Right orbit (4)	8	13.0
Left orbit (4)	9	14.4
Right cheek (5)	10	29.2
Right parotid (6)	11	1854.4
Left parotid (6)	12	1788.9
Right ramus (6)	13	518.2
Left ramus (6)	14	615.9
Center C spine (6)	15	566.3
Left back of neck (7)	16	339.3
Right mandible body (7)	17	117.7
Left mandible body (7)	18	157.6
Right submandibular gland (7)	19	437.5
Left submandibular gland (7)	20	409.5
Center sublingual gland (7)	21	213.0
Midline thyroid (9)	22	70.7
Thyroid surface-middle (9)	23	36.5
Esophagus (9)	24	102.7

TLD, thermoluminescence dosimeter.

Table 2. TLDs used to calculate the absorbed dose of tissue, fraction ratio of tissue/organ exposed to radiation (fraction irradiated), tissue weighting factors (W_T), and equivalent dose (H_T) used to calculate the effective dose

Tissue/organ	TLD ID	Fraction irradiated	W_T	H_T	Effective dose calculation
Bone marrow		16.5%	0.12		3.0
Mandible	13, 14, 17, 18	1.3%		352.3	
Calvaria	1, 2, 3	11.8%		12.7	
Cervical spine	15	3.4%		566.3	
Thyroid	22, 23	100.0%	0.04	53.6	2.1
Esophagus	24	10.0%	0.04	102.7	0.4
Skin	6, 7, 10, 16	11.0%	0.01	95.9	0.1
Bone surface ^a		16.5%	0.01		1.0
Mandible	13, 14, 17, 18	1.3%		1429.3	
Calvaria	1, 2, 3	11.8%		51.7	
Cervical spine	15	3.4%		2297.1	
Salivary glands		100.0%	0.01		8.2
Parotid	11, 12			1821.6	
Submandibular	19, 20			423.5	
sub-lingual	21			213.0	
Brain	4, 5	100.0%	0.01	25.0	0.2
Remainder			0.12		13.2
Lymphatic nodes	11-15, 17-22, 24	40.0%		571.0	
Muscle	11-15, 17-22, 24	5.0%		571.0	
Extrathoracic airway	8, 9, 11-15, 17-22, 24	100.0%		491.4	
Oral mucosa	11-14, 17-21	100.0%		679.2	
Effective dose					28.4

TLD, thermoluminescence dosimeter.

^aBone surface dose=bone marrow dose×bone/muscle mass energy absorption coefficient ratio (MEACR). MEACR= $-0.0618 \times 2/3$ kV peak+6.9406 using data taken from National Bureau of Standards handbook no. 85 [14].

Table 3. Tissue weighting factors (W_T) for calculation of effective dose ICRP 2007 draft recommendations

Tissue/organ	W_T	ΣW_T
Bone marrow, breast, colon, lung, stomach, Remainder tissues ^a	0.12	$0.12 \times 6 = 0.72$
Gonads	0.08	$0.08 \times 1 = 0.08$
Bladder, esophagus, liver, thyroid	0.04	$0.04 \times 4 = 0.16$
Bone surface, brain, salivary glands, skin	0.01	$0.01 \times 4 = 0.04$
Sum		1.00

ICRP, International Commission on Radiological Protection.

^aAdrenals, extrathoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus, and uterus/cervix.

formula: $E = \Sigma H_T \times W_T$ (Tables 2 and 3). The tissue weighting factors were applied by ICRP 2007 [4].

The cancer and heritable risks were calculated by multiplying effective dose by the detriment adjusted nominal risk coefficients for cancer ($5.5 \times 10^{-2}/\text{Sv}$) and heritable effects ($0.2 \times 10^{-2}/\text{Sv}$).

Results

In the irradiation area, the dose measured by the solid-state dosimeter was higher in area 7 (464.2 μGy) and lower in area 3 (402.9 μGy). The average of the doses in each area was 433.5 μGy , with a standard deviation of 20.4 and a coefficient variation of 4.7. The dose in the irradiation area increased as it moved upward from the center line and decreased as it moved to the left (Table 4).

Table 4. Doses of irradiation area

Area			Dose (μGy)		
9	8	7	434.7	453.5	464.2
6	5	4	410.9	435.7	449.7
3	2	1	402.9	417.2	432.5
Average				433.5	
Stdev				20.4	
CV				4.7	

Stdev, standard deviation; CV, coefficient of variation.

For visibility, it is arranged in order of exposure location, not number order.

The sum dose by group was higher in group D (1742.6 μGy) and lower in group C (1721.2 μGy). The average sum dose by group was 1734.9 μGy, with a standard deviation of 9.8 and a coefficient variation of 0.6 (Table 5). The reference dose for calibrating the TLD was 1734.9 μGy.

The absorbed dose of the TLD site was higher in the parotid gland (right: 1854.4 μGy, left: 1788.9 μGy), followed by that in the left ramus (615.9 μGy), cervical vertebrae (566.3 μGy), and lower in the calvarium anterior (3.8 μGy) (Table 1).

The equivalent dose of the tissue/organ required to calculate effective dose is shown in Table 2.

The effective dose was calculated at 28.4 μSv. The cancer and heritable risks were 1.56×10^{-6} and 5.67×10^{-8} , respectively.

Discussion

TLD-100 is widely used for dose research because of its excellent physical characteristics such as homogeneity, reproducibility, and linearity, although it has some disadvantages such as reading once, being sensitive to light, and being affected by moisture or dust [15,16]. For TLD calibration, Co-60, Cs-137, Ir-192, and medical linear accelerator may be used to irradiate the reference dose, and the actual radiation dose may differ from the planned doses by 0–6% depending on the irradiation method [11–13,16–18]. Because the diagnostic radiation device cannot irradiate the planned dose, the dose measured using a solid-state dosimeter was the reference dose. Additionally, to reduce the difference in dose distribution, it was irradiated repeatedly by flipping the TLD phantom horizontally and vertically (Fig. 1). Methods for irradiating TLDs uniformly using diagnostic

Table 5. Sum doses by exposure group

Group	Area	Sum dose (μGy)
A	1, 3, 7, 9	1734.2
B	2, 8	1741.4
C	4, 6	1721.2
D	5	1742.6
Average		1734.9
Stdev		9.8
CV		0.6

Stdev, standard deviation; CV, coefficient of variation.

radiation devices were devised and studied, but uncertainty verification was not performed. Considering this, follow-up research will be needed.

Analyzing the absorbed doses of the TLDs located on the face indicates that the dose decreases as it moves away from the central ray in order of cheek (29.2 μGy) at phantom level 5, orbit (right 13.0 μGy, left 14.4 μGy) at phantom level 4, lens of the eye (right 5.6 μGy, left 9.4 μGy) at phantom level 3, and calvarium anterior (3.8 μGy). However, the difference in the dose of parotid gland (right 1854.4 μGy, left 1788.9 μGy), ramus (right 518.2 μGy, left 615.9 μGy), and center of C-spine (566.3 μGy) at phantom level 6 indicates that not all areas are irradiated equally during panoramic radiography (Table 1). This is because the areas where the ghost and double images can be formed are irradiated several times, and an understanding of panoramic geometry is required to analyze the absorbed dose of panoramic radiography.

Ludlow and Ivanovic [6] calculated the skin and lymph nodes of the head and neck as 5%. However, in this study, the head and neck skin was applied as 9% by rule of nine at burn, and lymph node as 37.5%. This is because 300 of the 800 lymph nodes were located in the neck [19,20].

The effective dose in this study was 28.4 μSv , which is different from the 24.3 μSv obtained using the same equipment by Ludlow et al. [21]. The difference could be attributed to the differences in exposure parameters, the position of the phantom, the position of the TLDs, and the difference in the fraction ratio of the tissue/organ applied.

In this study, the sum of tissue weighting factors used in calculating the dose was 0.36. Tissue/organ equivalent to 0.64 is missing (Table 2). The dose will be further reduced if the measuring area is reduced. Lee et al. [8] reported that effective dose of the entire body, including the head and neck, was higher than that calculated by the head and neck alone in a study using an entire body phantom. Although dental radiation is used mainly in the head and neck areas, an entire body phantom is suitable. In addition, dentists should be able to understand dose concepts and analyze dose-related reports because they select radiation equipment and determine how and how many radiographs should be taken.

Some researchers have calculated equivalent doses by multiplying the fraction ratio of the tissue [6,8]. Equivalent dose is smaller when only a fraction of the tissue is exposed to radiation (such as bone marrow, skin, and lymph nodes). Because equivalent doses are doses to deterministic effects, doses from exposed areas should be applied as is.

The application of fraction ratios to the effective dose may also be controversial. This is because it is difficult to expect the effects of radiation-induced cancer on areas other than the fingers when radiation irradiates the fingers. In addition, the units of equivalent dose and effective dose are Sv, thus causing confusion. The concepts and methods for obtaining doses need to be studied and developed further.

Therefore, there is a limit to evaluating the harmful effects of radiography using only effective dose. Absorbed doses from the TLD location should be revealed to re-interpret the results of the study by assessing the adequacy of the study and applying dose-producing methods that may vary depending on time.

Because the method for radiation risk assessment is not perfect, dose studies should continue to develop new concepts of radiation. Further, new equipment should be introduced for dose studies, and the possibility of changes

in how the existing equipment are used should be investigated. The findings of this study could be helpful in future dose studies.

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Conflicts of Interest

The authors declare that they have no competing interests.

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