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Attribution of the rise in radiation dose to the relaxed panoramic radiography diagnostic reference level in Korea

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► ***Technical Note***

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***Keywords:** Diagnostic reference level, dental panoramic radiographic, public health, radiation dose, dose area product.*

ABSTRACT

***Background**:* In Korea, the adoption of dental panoramic radiography devices is steadily growing, and diagnostic reference level (DRL) continues to increase in parallel with this phenomenon relative to that in other countries. Moreover, radiation dose is a risk factor for public health; however, to our knowledge, no study has investigated the cause of this rise in DRL. This study therefore sought to discern why the proposed DRL is high by measuring the use status and the dose area product (DAP) of panoramic devices. ***Materials and Methods**:* DAP was measured under standard adult exposure conditions to 41 panoramic devices in use at dental clinics in Incheon, and the differences between the groups were analyzed by stratifying them into below-the-DRL group and exceeding-the-DRL group. ***Results**:* Ultimately, the most significant cause of the increase in DRL in dental panoramic radiography was that patients were irradiated by the system in a high-definition mode using high tube voltage or were subjected to long exposure time. ***Conclusions**:* To protect public health from excessive radiation dose, dentists or radiologists must attempt to use the lowest possible radiation dose according to the "as low as reasonably achievable" principle while ensuring that sufficient image quality is attained for diagnostic and treatment purposes. In addition, the Korea Disease Control and Prevention Agency needs to revise the current DRL, which is a third quartile value of the measured dose distribution, to an appropriate value by referring to the opinions of expert groups.

INTRODUCTION

According to data from the Ministry of Food and Drug Safety, the annual exposure amount and the frequency of diagnostic radiation in the Korean population increased by approximately 51% (from 0.93 mSv to 1.4 mSv) and 35%, respectively, between 2007 and 2011. Although the radiation dose from dental X-ray imaging only accounts for approximately 0.3% of the total radiation dose from diagnostic imaging, dental X-ray imaging is the second most frequent diagnostic imaging assessment (~11%) performed after general X-ray imaging [(1)]. Further, dental X-ray imaging is frequently conducted in patients of all age groups—thus, exploring measures to minimize the radiation dose during this procedure is essential. The increasing aging population has resulted in the growth of the dental implant market. The increased demand for orthodontic treatments stems from a higher national income level, resulting in the increased use of panoramic radiography in dental clinics [(2)]. Among dental X-ray systems, the number of panoramic dental computed tomography scanners increased annually from 18,227 in 2015 to 19,616 in 2017 and 20,597 in 2019 [(3-5)]. To safely monitor the increasing adoption of diagnostic radiography in Korea, the Rules on Safety Management for Diagnostic X-ray Units were implemented in 1995, which require the functional testing of diagnostic radiographic units every three years [(6)].

In Korea, the diagnostic reference level (DRL) of panoramic radiography was first recommended in 2009 (110.9 mGy*cm²) and then modified in 2014 (151 mGy*cm²) and 2019 (227.0 mGy*cm²) [(7-9)]. However, in a previous study by Kang *et al.* [(10)] assessing the awareness level of radiation safety management in dental clinics, only 4.8% of subjects responded "yes" to the question, "do you know the exposure dose of the radiographic units used in your clinic in comparison with the DRL?," suggesting that a low level of awareness of DRL continues to be pervasive. In addition, the latest DRL recommended in 2019 for panoramic radiography was 227.0 mGy*cm². Despite its higher value in comparison with the DRL of other countries (e.g., 81 mGy*cm² in the United Kingdom, 100 mGy*cm² in the United States, and 120 mGy*cm² in Finland) [(11-13)], few studies have investigated the cause of the increase in DRL. Furthermore, a study that investigated 125 (1.4%) of 8,772 units (as of March 2019) said to exist in Korea may not be a representative cohort [(9)].

This study investigated the use of panoramic radiography at dental clinics within a district in Korea, measuring the dose area product (DAP) and comparing the recommended values with the 2019

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DRL revision. Thus, this study aimed to present basic data for lowering the DRL by identifying the cause of the unnecessary increase in radiation dose due to the increase in DRL. Results are intended to help in selecting an appropriate imaging method that can reduce the radiation exposure dose in hospitals.

MATERIALS AND METHODS

Between December 2019 and February 2020, 41 panoramic radiographic units from 37 dental clinics located in Incheon City (ranked 6th with respect to the use of diagnostic radiographic units among 17 cities and provinces in Korea [5] were randomly selected. The usage status of each unit for exposure conditions on a standard adult subject was assessed, focusing on parameters such as X-ray tube voltage (tube voltage), X-ray tube current (tube current), exposure time, usage period (through the manufacturing date of the unit), inspection period of the safety management regulations for diagnostic X-ray units, and detector type. In addition, a DAP meter (KermaX Plus, IBA Dosimetry, Schwarzenbruck, Germany), which can measure down to 0.01 μGy*cm^2, was applied after calibration. For each panoramic radiographic unit, triplicate measurements were collected, and their average value was compared with the DRL value recommended in 2019 (227.0 mGy cm^2).

Furthermore, the units were dichotomized into two groups containing units where the DAP was below-the-DRL and where the DAP was exceeding-the-DRL. Considering the characteristics that can affect DAP, the usage period, inspection period of the safety management regulations for diagnostic X-ray units, X-ray tube voltage/current, and exposure time were comparatively analyzed to identify what element(s) most likely facilitated the increase in DAP. The patient entrance surface dose (ESD) according to the change in DAP was measured by using optically stimulated luminescence dosimeters (nanoDots, Landauer Co. Ltd., USA), and head phantom's (PUB-50, Kyoto Kagaku Co., Ltd) oral mucosa, eyeball, and thyroid doses were measured (figure 1). After measuring the dose three times each, ESDs were calculated in the shooting conditions at the lowest DAP value (64 kV, 6 mA, 13.2 s), highest value (90 kV, 10 mA, 14 s), and third quartile value (75 kV, 10 mA, 14.1 s).

Statistical analyses were performed using SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA), and $P < 0.05$ was considered significant. For the comparative analysis of differences based on values exceeding-the-DRL, the nonparametric Mann–Whitney U test was performed. Data for variables were represented using mean and standard deviation values.

Figure 1. ESD measurement using optically stimulated luminescence dosimeters.

RESULTS

Usage status of panoramic radiographic units

All 41 panoramic radiographic units assessed in this study had a flat panel detector (FPD), with a mean usage period of 5.4 ± 4.09 (maximum usage period, 15.9) years. All units had undergone their last inspection regarding safety management regulations for diagnostic X-ray units within the three-year period, exhibiting a mean length of 1.0 ± 0.86 years from the time of the last assessment. For standard adult exposure conditions, the mean tube voltage was 75.6 ± 7.47 kVp, and the mean exposure time was 13.7 ± 1.78 s. The tube current ranged from 6.0 to 15.0 mA, and there was a big gap (a 2.5-fold difference) between the minimum and maximum current values. In addition, the minimum and maximum DAP values were 35.3 mGy*cm^2 and 293.3 mGy*cm^2, respectively (an 8.3-fold difference), and the third quartile value was 210.7 mGy*cm^2 (table 1).

Comparison of characteristics between the below-the-DRL and exceeding-the-DRL groups

As mentioned previously, using the modified DRL suggested in 2019 (227.0 mGy*cm^2) as a standard, the units were dichotomized into two groups according to whether the DAP was below or exceeded the DRL. A comparison of the usage period between the two groups revealed that those units in the exceeding-the-DRL group showed a significantly shorter usage period (mean, 2.62 years) than those in the below-the-DRL group (mean, 6.30 years) (P = 0.010) (table 2).

No significant differences were found between the two groups in terms of the inspection period for safety management regulations for diagnostic X-ray units (P > 0.05) (table 3).

When assessing the exposure conditions, the exceeding-the-DRL group presented a significantly higher tube voltage (84.4 kVp) than the below-the-DRL group (P = 0.003), while all units using a high tube voltage (90 kVp) demonstrated a DAP that was higher than the DRL (figure 2). In addition, the

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exceeding-the-DRL group showed a significantly longer exposure time (14.9 s) than the below-the-DRL group (13.3 s) (P = 0.003). However, no significant difference was found in the tube current between the two groups (table 4). The ESD according to DAP was 46.3-152.2 μGy in the oral mucosa, 49.0-199.8 in the eyeball, and 45.5-182.3 μGy in the thyroid. The ESDs at the third quartile value of DAP were 73.2, 106.7, and 99.3 μGy for the oral mucosa, eyeball, and thyroid, respectively.

Table 1. Usage status of the surveyed panoramic radiographic units (n = 41).

	Min.	Max.	Third quartile value	Mean ± SD
Usage period (years)	0.2	15.9	7.6	5.4 ± 4.09
Last inspection for the safety management regulations (years)	0.0	2.9	1.8	1.0 ± 0.86
X-ray tube voltage (kVp)	64.0	90.0	75.0	75.6 ± 7.47
X-ray tube current (mA)	6.0	15.0	10.0	9.9 ± 1.80
Exposure time (sec)	9.7	17.0	14.1	13.7 ± 1.78
DAP (mGy*cm^2)	35.3	293.3	210.7	120.1±85.97

Table 2. Relationship between DRL and usage period.

		N	Mean ± SD	*P*-value
Usage period (years)	Below-the-DRL group	31	6.3 ± 4.19	0.010
	Exceeding-the-DRL group	10	2.6 ± 2.10	

P-values were obtained through the Mann–Whitney U test

Table 3. Relationship between the DRL and inspection period of the safety management regulations for diagnostic X-ray units.

		N	Mean±SD	*P*-value
Last inspection for the safety management regulations (years)	Below-the-DRL group	31	1.2±0.80	0.075
	Exceeding-the-DRL group	10	0.7±0.98	

P-values were obtained through the Mann–Whitney U test

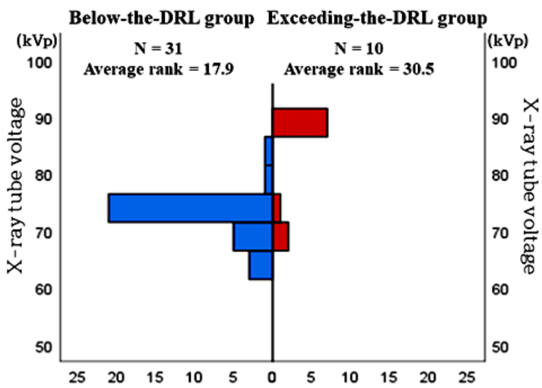

Figure 2. Frequency of tube voltage between the two DRL groups.

Table 4. Relationship between DRL and exposure conditions.

		N	Mean±SD	*P*-value
X-ray tube voltage (kVp)	Below-the-DRL group	31	72.7±3.93	0.003
	Exceeding-the-DRL group	10	84.4±9.08	
X-ray tube current (mA)	Below-the-DRL group	31	9.9±2.08	0.777
	Exceeding-the-DRL group	10	10.0±0.00	
Exposure time (sec)	Below-the-DRL group	31	13.3±1.72	0.003
	Exceeding-the-DRL group	10	14.9±1.45	
DAP (mGy*cm^2)	Below-the-DRL group	31	76.9±42.29	0.001
	Exceeding-the-DRL group	10	254.1±22.41	

P-values were obtained through the Mann–Whitney U test.

DISCUSSION

When assessing the usage period of the units in the below-the-DRL and exceeding-the-DRL group, the units in the latter group were found to have been manufactured more recently. A total of 23 (56.1%) units were manufactured within the past five years, and among them, eight (34.8%) units had DAP measurements exceeding the 2019 DRL revision. These findings are in agreement with the 2019 report from the Korea Disease Control and Prevention Agency (KDCA) [9]. In a 2009 study, 66.7% of units boasted FPD as their detector type. However, the proportion of FPD units increased to 90.5% in 2014 and to 97% in 2019, suggesting the rapid technological shift in favor of this type of system. In addition, recently manufactured panoramic radiographic units often offered a high-definition (HD) mode, likely because dental clinics often use this mode as their standard exposure condition setting [8,9].

In a previous study by Jang *et al.* [14], a longer inspection period regarding adherence to the safety management regulations for diagnostic X-ray units can leave space for a change in the functionality of the unit. However, in this study, no significant difference was found in the safety inspection period between the two groups.

For the tube voltage, the mean value of the exceeding-the-DRL group (84.4 kVp) was higher than that of the below-the-DRL group (72.7 kVp) by 11.7 kVp. These findings are also higher than the values reported in recent studies from other countries, which have reported a mean tube voltage of 68.1–71.3 kVp [15-18]. All seven units (17%) with a tube voltage exceeding 90 kVp in this study were being used with their HD mode engaged as standard exposure conditions, and all were in the exceeding-the-DRL group. The exposure time in the exceeding-the-DRL group was significantly longer (1.6 seconds on average) than that in the below-the-DRL group, with the probable cause being the standard exposure conditions set by the manufacturer used in the actual exposure conditions. ESD value was up to 3.3 times greater in the oral mucosa when the DAP was at the maximum than at the minimum. Moreover, similar to the study by Zamani *et al.* [18,19], since the eyeball dose was high as that of the oral mucosa or thyroid dose, an appropriate method for eyeball dose reduction was particularly necessary.

Barot *et al.* [20] reported that shortening the exposure time from that highlighted in the manufacturer's suggested exposure conditions enabled a reduction in DAP (36%) without significantly affecting the image quality. Elsewhere, Dannewitz *et al.* [21] reported that radiographs obtained at reduced mA had inferior subjective image quality, but no difference was observed in the

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diagnostic performance. Thus, a reduction in tube current of approximately 50% is recommended. Similarly, several studies have sought to minimize the exposure dose without affecting image quality by exploring the potential for lowering the exposure conditions stated in the manufacturer's guidelines (22).

The most important cause of the persistent increase in the DRL for panoramic radiography in Korea is the high tube voltage or long exposure time necessary for the HD mode in recently manufactured units. Since these are key causes of the excessive radiation dose to patients, dentists or radiologists must try to minimize the radiation dose for each patient without severely affecting the image quality according to the "as low as reasonably achievable" principle.

One limitation of this study is that we could not perform an in-depth investigation of the relationship between image qualities and DAP with altered exposure conditions since the included radiographic units are currently being used in dental clinics to examine patients. In addition, only adult shooting conditions were studied.

CONCLUSIONS

Dentists or radiologists must try to minimize the radiation dose for each patient without severely affecting the image quality. In addition, the KDCA needs to revise the current DRL to an appropriate value by referring to the opinions of expert groups.

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