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Review

An Urgent Need for Radiation Protection Education and Dose Assessment in the Dental Field

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Concern and anxiety over medical radiation exposure have increased in Japan following the Tokyo Electric Power Company nuclear plant accident in Fukushima triggered by the Great East Japan Earthquake in March 2011. In June 2015, based on domestic fact-finding surveys by various academic societies and organizations connected with the Japan Network for Research and Information on Medical Exposure, a diagnosis reference level (DRL) "Diagnostic Reference Levels Based on Latest Surveys in Japan—Japan DRLs 2015—" was made public for the first time in Japan. Although X-ray photography is routinely used in the dental field for diagnosis and treatment, inspection and review of devices are insufficient because dentists' awareness of radiation protection is low. This low awareness may be because the effective dose per unit exposure in dental devices is very small compared with that in medical devices, thus dentists do not perceive a high risk of radiation exposure. However, it is important for dentists to understand the contents of DRLs and pay careful attention to radiation protection from a public health standpoint. The objective of this paper is to overview the radiation protection in the dental field.

Key words: diagnostic reference levels, radiation protection, optimization, dental education, oral radiology

1. Introduction

Radiation is widely used in various medical situations. The use of radiation for diagnosis and treatment in tandem with equipment development and subsequent introduction of new methods has made a great contribution to public health. However, radiation exposure is increasing with improved medical diagnostic methods. In the dental field, X-ray examination has increased with the recent advance of computed tomography (CT) and dental cone beam CT (CBCT), in addition to intraoral radiography, panoramic radiography, and cephalometric radiography. Therefore, the concept of radiation protection has become critical as medical radiation exposure increases. Concern and anxiety over medical radiation exposure have increased throughout Japan in the aftermath of the Tokyo Electric Power Company nuclear plant accident in Fukushima triggered by the Great East Japan Great Earthquake in March 2011. These feelings stem from not only increased medical radiation exposure, but also limited knowledge and education of healthcare professionals about radiation protection. Dentists receive basic education about radiation in educational curriculum as healthcare professionals, however, this curriculum

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focuses on knowledge and use of imaging techniques for diagnosis and treatment. In particular, the time devoted to education on radiation protection and safety is far from sufficient and protection education is in much need of improvement.

The principle of "Dose Limits" is not applicable for radiation protection in medical practice, while "Justification of Practice" and "Optimization of Protection" are pillars of protection. The ICRP recommends the introduction of diagnostic reference levels (DRLs), the focus of this paper, to optimize patient protection[1, 2]. DRL is defined as an easily measured dose, usual the absorbed dose in air or tissue-equivalent material at the surface of a simple standard phantom or standard patient, to judge the level of radiation exposure[3]. DRL is an essential concept in radiation protection systems and closely connected to optimization[3].

In June 2015, based on domestic fact-finding surveys by various academic societies and organizations associated with the Japan Network for Research and Information on Medical Exposure, "Diagnostic Reference Levels Based on Latest Surveys in Japan—Japan DRLs 2015—" were made public for the first time in Japan[4]. The media has reported on Japan DRLs 2015 since its release, and it has become clear that medical radiation exposure is a serious concern for the public. The Japan DRLs 2015 defines DRLs for CT, general radiography, mammography, intraoral radiography, interventional radiology (IVR), and nuclear medicine.

X-ray photography is routinely used in dentistry as the target of intraoral radiography dental therapy is hard tissues. Because the effective dose per unit exposure from intraoral radiography is considered to be very small compared with that in the medical field and digitized image receiving systems have reduced exposure doses compared with conventional systems, dentists feel comfortable using the equipment without sufficient inspection and review of the equipment. Moreover, the concept of DRL is not well known to dentists who are not radiation specialists, suggesting that most dentists are not unaware of the importance of radiation protection. As we dentists are in the position to judge the application of radiographic examination, it is important for us to understand the concept of DRL and pay greater attention to radiation protection. At the same time, it seems that the approach of radiation protection underscores the need for multidisciplinary cooperation involving fields not limited to dentistry, similar to that observed with other professions and regional alliances. Here, we discuss radiation protection in the dental field from a specialist standpoint.

2. Dental X-ray examination

A dental X-ray examination mainly consists of intraoral radiography and dental panoramic radiography, both of which are indispensable in dental clinical practice. Intraoral radiography is a photographic technique that consists of placing an image receptor system, such as radiography films or an X-ray detector, within the patient's mouth and is used to diagnosis dental diseases such as dental caries and periodontitis syndrome. Article 30 of the Medical Care Act enforcement regulations stipulates that intraoral radiography equipment should have a diameter of ≤ 6 cm in the X-ray field at the edge of the treatment cone. Although obtaining a digital X-ray image in the dental field is delayed compared with computed radiography (CR) in the medical field, its use has become widespread since the announcement of a digital X-ray image diagnosis system corresponding to intraoral technique in 1987[5].

Intraoral X-ray radiography is divided into two systems, charge-coupled device (CCD) method and image plate (IP) method, according to the X-ray detector used. The CCD method uses a CCD sensor coupled to a digital camera as a photo detector, while the IP method uses an IP made of photostimulable phosphor similar to CR. Extraoral radiography is a photographic technique that consists of an X-ray detector placed outside the patient's mouth.

Panoramic radiography is a form of tomography used to scan the jaw, allowing visualization of surrounding tissues such as the upper and lower jaw, nasal cavity, and temporomandibular joints, in addition to the tooth. Cephalometric radiography is used to analyze facial symmetry and occlusal status in orthodontic and oral surgery treatment. To follow up the patient's condition, a cephalostat is used to take pictures under a constant geometric condition. The construction of a digital system corresponding to extraoral radiography has advanced enough to be used, along with the introduction of an electronic clinical record system. Additionally, filmless operation and equipment that uses flat panel detectors has recently increased[6, 7].

In addition to this equipment, inspection via medical CT and dental CBCT is more likely to be used in university/medical school hospitals. Medical CT, which is applied for conditions such bone fractures, inflammation, and benign and malignant tumors, is used for accurate evaluation for surgical intervention in the dental field[8-12]. State-of-the-art CT equipment embedded with new imaging modalities plays an active role in the dental field. For example, dual energy or dual source CT can reduce beam-hardening artifacts and assess bone surrounding the dental implant[13, 14]. Moreover, CT equipped with iterative model reconstruction, an image reconstruction method

Table 1. Japan DRLs 2015 for dental intraoral radiography (from Diagnostic Reference Levels Based on Latest Surveys in Japan 2015)

Examination site		PED (mGy)[a]	
		Adult[b]	Child[c]
Maxilla	Incisor	1.3	0.9
	Canine	1.6	1
	Premolar	1.7	1.1
	Molar	2.3	1.3
Mandible	Incisor	1.1	0.7
	Canine	1.1	0.9
	Premolar	1.2	0.9
	Molar	1.8	1.1

[a]Patient entrance dose (PED) calculated as air kerma in cone-tip free air, not including the patient's backscattering.
[b]Adult patient with normal build.
[c]10-year-old pediatric patient.

Table 2. Summary of two local DRL studies (from Izawa et al. 2016 and Sakaino 2016)

Examination site		PED (mGy)	
		Izawa et al.	Sakaino
Maxilla	Incisor	1.56 ± 0.27	1.27 ± 0.25
	Premolar	1.92 ± 0.38	–
	Molar	2.42 ± 0.33	–
Mandible	Incisor	1.09 ± 0.31	1.16 ± 0.24
	Premolar	1.27 ± 0.22	–
	Molar	1.59 ± 0.20	–

PED: patient entrance dose.

using iteration, substantially reduces background noise compared with the conventional filtered back projection method and is used to evaluate soft tissues in the dental field[15, 16]. CT equipped with 320 rows (area detector) enables one to take motion photography pictures from within the range of 16 cm on the caudal side without moving the bed, does not require swallowing images, and has decreased scanning time, making it suitable for young children[17]. Dental CBCT comprises an X-ray tube and a two-dimensional sensor, which rotates 180 or 360° around the patient's head and composes cross-sectional images by collecting projection data. The pixel size varies, ranging from 0.08 mm to 0.4 mm on a side. The field of view (FOV) also varies, ranging from 4 cm to 20 cm in diameter and from 3 cm to 20 cm in height. Due to superior isotropic nature and resolution, dental CBCT can visualize minute structures of hard tissues of teeth and jaw, particularly the periodontal ligament space, lamina dura, bone trabeculae, and root canals. Therefore, it could become the ideal tool for delicate and technical dental treatment[18-25].

Further advances in imaging modalities and examination are expected with the expansion of national insurance coverage for dental CBCT and introduction of equipment to dental clinics due to downsizing and development of equipment with composite function. However, indicators for the evaluation of radiation dose and image quality performance have not been set for dental CBCT, which has been significantly delayed in terms of examination optimization and quality assurance/control (QA/QC). Therefore, DRLs are urgently needed. The following sections discuss consideration of DRLs for intraoral radiography and dental CBCT.

3. DRL in intraoral radiography

Intraoral radiography exposure is evaluated using the patient entrance dose (PED). Standard intraoral radiography using the bisecting or paralleling technique has been evaluated in past studies. The Radiation Protection Committee of the Japanese Society for Oral and Maxillofacial Radiology conducted a survey including 29 university dentistry departments and dental college hospitals. The survey evaluated radiation exposure from intraoral radiography in the maxillary and mandibular incisors, canines, premolars, and molars in adult patients of normal build and 10-year-old children. PED was calculated by the air kerma (mGy) in cone-tip free air, excluding the patient's backscattering, measured via a solid-state dosimeter, ThinX Rad (Unfors RaySafe AB, Billdal, Sweden) (Table 1)[4]. The survey found that the dose used to irradiate the same site differed by 4–14-fold according to the maximum/minimum PED ratio. Moreover, facilities introducing a digital system performed radiography at different sites under the same exposure conditions. These findings demonstrate the necessity of standardized conditions across institutions to reduce the amount of radiation exposure.

DRLs are values to which the condition of radiodiagnosis is appropriately set. Therefore, each medical facility must select appropriate imaging conditions and QC measurements so that DRLs will not be exceeded[1, 2]. In response to the release of Japan DRLs 2015, each university developed a new approach for radiation protection. Izawa *et al*. and Sakaino reported the local DRLs as baseline values of QC according to an investigation of intraoral radiographic conditions in an analog system for facilities (Table 2)[26, 27]. In addition, Sakaino's study investigated factors to establish a QC program, particularly those that influence films. As 24 out of 29 university departments of dentistry and dental college hospitals have already introduced digital systems, we can use information from these facilities to optimize intraoral radiography.

4. DRL in dental CBCT

Since the SEDENTEXCT project recommended that

Table 3. Dose-area product (DAP) and air kerma (Kc) for dental CBCT in university hospitals (from Sato 2016)

Patients	DAP (mGy cm^2)/Kc[a] (mGy)					
	Min	Max	Max/Min	Mean	Median	Third quartile
>15 years	204/9.26	7,134/79.7	35.0/8.60	1,011/24.2	795/21.2	1,541/28.2
≤ 15 years	204/7.41	3,980/79.7	19.5/10.8	1.092/21.2	795/16.8	1,565/24.1
Total	204/7.41	7,134/79.7	35.0/10.8	1.026/23.6	795/18.7	1.546/27.6

[a] Kc = DAP/Ac, where Ac is the nominal field of area of the section (cm^2).

the DRL dose in dental CBCT should be the Dose-Area Product (DAP) of 250 mGy/cm^2, the DAP has become a surrogate for DRL in dental CBCT[28]. DRL dose for medical CT is currently determined by the weighted CT Dose Index (CTDI) and Dose-Length Product (DLP). However, previous studies in dental CBCT rarely used CTDI and DLP as DRL dose for medical CT[29, 30]. Conversely, DRLs are not currently available for dental CBCT. The IEC defines the dose measured by CTDI as air kerma in the CTDI Phantom and stipulates that DAP and air kerma on the surface of the detector should be used on dental CBCT[31]. The Radiological Protection Committee of the Japanese Society for Oral and Maxillofacial Radiology recently conducted a nationwide survey with the aim to set DRLs for dental CBCT. Sato investigated dental CBCT, including 12 models by four manufacturers in a total of 32 units used by 25 medical school hospitals, for the maximum exposure conditions and number of examinations between January and December 2012[32]. Patients were divided into two groups according to age (< =15 years and >15 years) with the adoption of DAP and air kerma (Kc) at the rotation center on the surface of the detector as DRL dose. Air kerma The Kc, which was the value of DAP divided by the nominal field of area (Ac) of the section (i.e., Kc = DAP /Ac), was reported to be about 30 mGy for patients >15 years and 20 mGy for patients < =15 years. Further investigation is currently underway as baseline data in Japan (Table 3)[32].

Setting DRLs for dental CBCT is challenging. First, DAP has not been validated as a surrogate for DRL dose, therefore it must be confirmed for use together with CTDI, DLP, and air kerma. Area detector CT, which is currently in the completion stage of development, is conceptually similar to dental CBCT and uses CTDI as DRL dose[33]. Considering the increased use of CT technology in medical and dental fields, it is necessary to determine DRLs for such modalities. Second, as PED of dental CBCT greatly varies according to imaging conditions, selection of a FOV with a large diameter can increase the exposure dose to more than that of multi-detector CT under low-dose conditions. Thus, it is necessary to select as small a FOV as possible according to the purpose of the examination. However, when the dose is too low, image quality worsens, decreasing diagnostic ability. Therefore, it is critical to reduce the dose while maintaining diagnostic ability. Lastly, some devices also have high-speed (half rotation) and off-center scanning modes. Therefore, setting one DRL for all diagnostic methods is difficult in dental CBCT, and imaging conditions such as imaging site and diagnostic purpose must be considered[34]. Nevertheless, the report of DRL in dental CBCT following DRL in intraoral radiography provides a good opportunity for dentists to consider optimization to protect patients. However, it is important to note that DRLs will need to be constantly revised to reflect changes in imaging devices. Although no revisions have yet been made, various academic societies and organizations have started actions for DRL revision. We dentists need to understand the currently recommended measurement methods and values and pay attention to future revisions to maintain a high level of patient care.

5. Radiation protection education

The final area to consider is proper education of radiation protection in the dental field. In February 2016, the “Safety Use of Medical Radiation” Forum at the 37th Japan Association on Radiological Protection in Medicine opened at the Arakawa campus of Tokyo Metropolitan University. The forum's theme was “Use and Protection of Medical Treatment Radiation” in the dental field and the panel discussed the subject of safe radiation in dentistry, including radiation protection education for dental students. Each university prepares dental student education curriculum in reference to “Japanese model core curriculum for dental education”, which aims to impart indispensable practical ability (knowledge, skill, and attitude) that students should acquire before graduation or beginning clinical practice. However, the method of education and order of course curriculum are at the discretion of each university[35]. Additionally, “Japanese model core curriculum for dental education” has been influenced by social condition changes and revised to reflect environmental changes surrounding dental and medical education. In accordance with the proposal to “Train doctors and dentists in response to various needs,” a revision is currently underway for the first time in 6 years. The most current “Japanese model core curriculum for dental education” revision

Table 4. Questions along with correct answers (taken from Furmaniak et al., 2016)

1. Background radiation comes from (among others) radioactive isotopes in the Earth's crust, cosmic radiation emitted by the Sun and radioactive elements contained in materials used for buildings' construction.	TRUE
2. Ionizing radiation used in radiological diagnosis has similar properties to natural background radiation.	TRUE
3. The average dose from periapical radiography is lower or comparable with daily background radiation dose.	TRUE
4. Radiation dose associated with one periapical radiograph is absolutely safe and has no impact on health.	FALSE
5. Risk involved with radiation should be lower than benefits from diagnostic information.	TRUE
6. Every radiation exposure brings possibility of occurrence of harmful effects, e.g., leukemia.	TRUE
7. Statistically, 1 in 1,000 people, who have undergone one periapical examination, will die due to cancer induced by radiation.	FALSE
8. Children and fetuses are more vulnerable to radiation.	TRUE
9. Performing radiological examination in pregnant women is forbidden.	FALSE
10. Number of radiographs prescribed to patients in 1 year is not limited by law.	TRUE
11. A patient must have a prescription from a dentist to undergo periapical radiography.	FALSE
12. A patient must have a prescription from dentist to undergo an orthopantomogram.	TRUE
13. In all X-ray devices, there is a radioactive stone which emits X-rays.	FALSE

(2010) aimed at "understanding of the combination of the radiation influence on human body and way of protection from it" as a general aim and included the acquisition of ability of "explanation of standard and measures for radiation protection" as an attainment target. However, it is clear that amount of time spent on protection education is limited compared to that for radiation quality, radiography, diagnosis, and treatment. For example, our institution offers "Radiology introduction" for second and third year transfer students and "Dental radiology" for fourth year students as dental courses. "Radiation physics" and "Radiation biological protection" are also available to second and third year transfer students and only require several hours to complete. The students then advance to preclinical and clinical practical training without any additional courses on radiation protection. It is necessary to guide preliminary clinical practice while devising the contents.

Reports related to dental radiation education have mainly focused on scanning techniques and diagnostic imaging[36-39], while few reports in Japan have focused on radiation protection in the dental field. Additionally, to our knowledge, only one report has evaluated clinical radiation protection education through role play[40]. Moreover, we searched PubMed for reports of "awareness of radiation protection" and identified studies including doctors, radiological technologists, residents, and medical students[41-43]. However, few reports included dentists and dental students, suggesting decreased awareness and delay of education of radiation protection in the dental field. Furmaniak *et al.*[44] conducted a questionnaire survey on "awareness of radiation protection" intended for dentists, radiological technologists, and students. The questionnaire consisted of 13 items concerning basic knowledge and legal problems with responses of "TRUE," "FALSE," and "I DO NOT KNOW" (Table 4).[44] The authors found that "awareness of radiation protection" was insufficient among dentists, radiological technologists, dental students, and radiological technology students, without significant differences between the main groups surveyed. As dentists who went through radiation protection training showed high awareness of radiation protection, both programs for dentists and radiological technologists should emphasize curriculum on dental radiation. Moreover, Nakayama *et al.* conducted a questionnaire survey in dentists after clinical training and focused on the response "I couldn't answer the question about radiation exposure by a patient". The reason why clinically trained dentists lack sufficient knowledge about radiation exposure and protection might stem from the fact that educational training programs only teach by lectures[39]. It is important that similar to radiography technique and diagnosis, education increase student interest in radiation protection, including safety control of radiation, and emphasize the importance of such knowledge. Education programs from undergraduate studies to clinical training and clinical practice must be revised to provide sufficient learning time and continuity.

6. Conclusion

Radiation protection, optimization, and DRL have become buzzwords, appearing in the national dentistry examinations and dental association. Thus, the general public has gained an interest in these words since they have frequently appeared in the media in the aftermath of the Great East Japan Earthquake. However, many issues in the dental field must be addressed such as increased awareness of radiation protection, establishment of dose evaluation in dental CBCT, and image performance evaluation. With further advancements in radiographic equipment in dentistry, there is no doubt that understanding of radiation protection and control of radiographic devices will become increasingly important.

We must actively address these issues in the dental field to improve patient care.

Conflict of Interest Disclosure

The authors declare that they have no conflicts of interest.

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