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Review article

Radiation dose and protection in dentistry

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Summary Radiographic examinations play an essential part of dental practice. Because a certain amount of radiation is inevitably delivered to patients, it should be as low as reasonably achievable. The purposes of this article are to review the definition of the dose, the concept of the radiation protection, the measurement of the dose in dental radiography, and means to reduce dose through effective selection of patients and the management of radiographic equipment. The effective dose from some dental radiographic examinations is high enough to warrant reconsideration of means to reduce patient exposure. By using digital sensors or F-speed film, instead of D-speed film, combined with rectangular collimation instead of round collimation, dentists can reduce patient's exposure by a factor of 10 for bitewing and full-mouth radiographs. Justification and optimization of a procedure along with dose limitations are essential in clinical practice. It is prudent to establish diagnostic reference levels for dental radiography in Japan. In addition, dentists should remain informed about safety updates and availability of new equipment, supplies and techniques that would further improve the diagnostic ability of radiographs and simultaneously decrease patient exposure.

Contents

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1. Introduction

Radiation is indispensable in modern medicine. The radiographic examination is one of the principal diagnostic methods used in all fields of medical services and contributes to the promotion of the health, both individually and nationally. Accordingly, a certain amount of radiation is inevitably delivered to patients and populations. In Japan the average dose to the population from diagnostic radiology may be equivalent or even more than from the natural background exposure [1,2]. The adverse effects to humans, such as radiation carcinogenesis, can be considered on the basis of a hypothesis so-called a linear no-threshold (LNT) model, which was scientifically presumed from the epidemiological studies including atomic bomb survivors of Hiroshima and Nagasaki [3]. On this assumption, the risk associated with low-level diagnostic exposures could be expected to be low but greater than zero. For this reason it is prerequisite to measure the dose to the patients in the diagnostic radiology precisely. In addition, the radiation dose to the patients should be as low as reasonably achievable, a principle known as ALARA [4]. The number of diagnostic examinations should also be taken into consideration because the risk is directly proportional to the frequency of X-ray exposure.

Dental radiographic examinations are one of the most frequently performed radiological studies in Japan. A survey in 1999 estimated that dentists were making 82 million intraoral radiographs and more than 12 million panoramic radiographs each year [5]. The effective dose delivered to patients per radiograph is low but the collective dose is significant because of the large number of radiographs made.

A unique aspect of radiological protection in medicine, which differs somewhat from other types of radiation exposure, is that the details of a medical radiographic examination are up to the discretion of the clinician. Such decisions are made on the basis of the anticipated health benefit to the patient. The decision is always made based on the professional judgment of the doctor in charge of the patient, with informed consent, which includes not only the expected benefit but also the potential risk [6]. In the case of low risk procedures such as dental and chest radiography, the degree of informed consent may be low, even where the cultural or societal factors have to be considered. The benefit of a particular examination in medical practice is qualified by consideration of evidence-based medical literature [7]. The effective usage of radiation in dental practice has been studied for many years and several guidelines have been proposed [8—11]. Dentists and other dental health care personnel should use these well-thought-out and research-proven guidelines, which benefits patients by reducing not only the radiation dose but also the cost [12].

Another aspect of protection in medicine is to consider optimization of radiographic procedures. Reduction in exposure dose to patients may be attained by proper management of equipment and the accomplishment of a quality assurance program [13]. The goal of optimization is to keep the dose ''ALARA, economic and societal factors being taken into account,'' and is best described in medical practice as: management of the radiation dose to the patient to be commensurate with the medical purpose [6].

The purposes of this article are to review definitions of dose, the concept of radiation protection, the measurement of dose in dental radiography, and ways to reduce dose through effective use of X-ray and the management of equipment.

2. Radiation dose and effects

2.1. Definitions of dose used in radiation protection

The absorbed dose, D, is the basic physical dose quantity, and it is used for all types of ionizing radiation. It is defined as the mean energy imparted to matter of mass by ionizing radiation [14]. The SI unit of absorbed dose is J/kg and its special name is gray (Gy). The protection quantity equivalent dose in an organ or tissue, H_T, is defined by

$$H_T = \sum_R w_R D_{T,R}$$

where $D_{T,R}$ is the average absorbed dose in the volume of a specified organ or tissue T, and w_R is the radiation weighting factor for radiation R [14]. The values of w_R are defined largely on the basis of the relative biological effectiveness of the different radiations. The sum is performed over all types of radiations involved if an individual is exposed to more than one type of radiation. The unit of equivalent dose is J/kg and has the special name sievert (Sv). As w_R of X-ray is 1, so 1 Gy in dental radiology corresponds to 1 Sv.

To assess the probability of health detriment from low doses of ionizing radiation, the International Commission of Radiation Protection (ICRP) proposed a theoretic quantity in 1977 [4] as effective dose equivalent and finally it is known as effective dose in 1990 [15]. The effective dose, E, is defined by a weighted sum of tissue equivalent doses as:

$$E = \sum_T w_T \sum_R w_R D_{T,R}$$

where w_T is the tissue weighting factor for tissue T and $\Sigma w_T = 1$ [14]. The sum is performed over all organs or tissues considered to be sensitive to the induction of stochastic effects including cancer and heritable effects. These w_T values are chosen to represent the contributions of individual organs and tissues to overall radiation detriment from stochastic effects. The unit of effective dose is J/kg with the special name sievert (Sv). Both w_R and w_T values and the list of organs or tissues were reconsidered in ICRP 60, 1990 and were further revised in ICRP 103, 2007 Publication. As a result of the revisions the effective dose in dental radiology are estimated to be 32—422% higher because of the recent inclusion of the salivary gland as well as oral mucosa, muscle, lymphatic nodes and extrathoracic airway in the list of radiosensitive tissues [12,16].

2.2. Radiation effects to human

Adverse effects of radiation are grouped into two categories: deterministic effects and stochastic effects [4,15]. Deterministic effects are based on cell killing and are characterized by a threshold dose. Below the threshold dose there is no clinical effect. With exposures above the threshold dose the severity of the injury increases with dose.

On the other hand, stochastic effects, including cancer and heritable effects are based on damage to DNA. In this incidence the frequency of the response, but not the severity, is proportional to dose. Further, there is no-threshold or "safe" dose with stochastic effects. In the low dose range, below about 100 mSv, the ICRP adopted a scope that "it is scientifically plausible to assume that the incidence of cancer or heritable effects will rise in direct proportion to an increase in the equivalent dose in the relevant organs and tissues" [6]. They recommended as a practical system of radiological protection that it is reasonable to assume that "at doses below about 100 mSv a given increment in dose will produce a directly proportionate increment in the probability of incurring cancer or heritable effects attributable to radiation" [14] and is generally known as "linear no-threshold" or LNT model [3,17]. A study of the estimated excess risk of cancer among groups of atomic bomb survivors showed that a group receiving 5—100 mSv had significantly increased incidence of solid cancer compared with a group exposed to less than 5 mSv. The authors suggested that acute exposures above 10—50 mSv increases the risk of some cancers. However, a cancer risk in human population could not be demonstrated at doses below 10 mSv. Below this level, the risk remains hypothetic and the linear no-threshold relationship between dose and risk is considered the best practical criterion [3].

3. Measurement of dose of dental radiographic procedures

3.1. Dosimetry and its applications

Measurements of the dose absorbed in organs or tissues can be attained by using dosimeters embedded in a RANDO phantom (Alderson Research Laboratories), which is especially fabricated for radiation dosimetry *in vitro* [18]. The locations of dosimeters typically correspond to the organs or tissues used to estimate effective dose. In a typical measurement several dosimeters are placed in each organ or tissue, and the measured exposure values for each organ or tissue are then averaged. Several types of dosimeters including the thermoluminescence dosimeter (TLD), photoluminescence glass dosimeter, or optical stimulated luminescence (OSL) dosimeter could be used to measure the exposure [19,20]. The readings obtained by any dosimeters are compared with the "exposure" (air kerma in free air) measured by an ionization chamber. The values obtained are converted into absorbed dose in air by the use of a correction factor. From the air dose, the dose absorbed by tissues or organs is then calculated by multiplying by a factor estimated as the ratio of the mass energy absorption coefficients of air to the tissues. The mean bone marrow or skin dose was estimated in considering the distribution of bone marrow or skin in the body. With these modifications the equivalent dose can be estimated. The effective dose for each examination is then calculated using the equation previously shown, considering the tissue weighting factors listed in the ICRP Publications [4,14,15]

Another way to estimate absorbed dose and effective dose is to apply a computer model. A Monte Carlo system has been developed to compute dose distribution in heterogenous phantoms from external, divergent, polyenergetic photon beams in the diagnostic energy range [21,22] from the data of entrance surface dose (ESD) or dose area product (DAP) by applying conversion coefficients [23]. The estimated results of the effective dose from the measurement and the computer model were comparable [24]. Both methods can be used for estimating dose depending on available equipment. A Monte Carlo system has already used for patient dosimetry for dental radiology [25], although such method has not been widely applied to estimate effective dose [26].

Diagnostic reference levels (DRL) are exposure values that serve as standards to guide clinicians in knowing if they are overexposing their patients. DRL is a term that is defined from the third quartile (75th percentile) of the relevant dose-related quantities for a specific radiographic examination derived from large scale surveys of X-ray equipment in a country or a region [15,27]. Entrance surface dose (ESD), dose area product (DAP), dose-width product (DWP) are commonly used to establish DRL in dental radiography [28—31]. In CT study, $CTDI_w$, computed tomography dose index (weighted) and DLP, dose length product, which are used to represent dosimetric quantities for determining relative performance of the equipment and technique using an ionizing chamber in the standard phantom [32], can be applied to assess the effective dose and DRL [27,33,34].

3.2. Effective dose in diagnostic radiology

The goal of measuring effective dose for various radiographic examinations is to compare the radiologic risk of different modalities for a standard patient with optimal image quality. Reported effective doses for intraoral radiography are shown in Table 1. Similar data has been collected for panoramic

Table 1 Effective dose in intraoral radiography (μSv).

Author/source	Parameters	ICRP 60 (ave./film)
Gibbs [26]	70 kV, short round cone, E-speed, 18 films	100 (5.5)
	70 kV, long rectangular cone, E-speed, 21 films	14 (0.66)
	Long round cone, E-speed, 4 bitewings	12 (3)
UNSCEAR 2000 [35] (Health-care level I)		(13)
	70 kV, Short round cone, E-speed, 2 bitewing films	4 (2)
European Commission Issue 136 [8]		(1–8.3)
Iwai et al. [5]	60 kV, 24 cm round collimation	(9.3)
White and Pharoah [36]	Long round cone, D-speed, FMX	388 (18.47)[a]
	Long round collimation, PSP or F-speed film, FMX	171 (8.14)[a]
	Long rectangular collimation, PSP or F-speed film, FMX	35 (1.6)[a]

[a]ICRP 103, 2007.

radiography (Table 2), cone-beam dental CT (Table 3a), dental implants/jaw study using Computed Tomography (Table 3b), and medical routine conventional radiography and CT (Table 4).

The effective dose from intraoral radiography is shown for a full-mouth survey, for two or four bitewings films, or for per exposure for periapical radiography. Depending on the targeted region, the resulting dose can vary. However the 'averaged' dose for intraoral radiography can be assessed from such data, which were ranged from less than 1 to around 20 μSv [5,8,26,35,36], depending on the film/digital sensors used, collimation, focus skin distance and tube voltage. In the routine conditions used in Japan including E-speed film or digital sensor, short round cone, 20 cm FSD, and 60 kV in intraoral radiography, the effective dose could be around 10 μSv.

On the other hand, the effective dose reported in panoramic radiography is more consistent and were ranged from 4 to 30 μSv [5,8,35,37–41]. A value of 15 μSv may be the best estimate in the case of using a contemporary machine with digital sensor. This is equivalent to 2–3 days of background radiation.

For dental cone-beam CT the effective dose varied widely among the products and the size of the field of view (FOV). When a limited area is exposed, the effective dose is less than 100 μSv [42–44]. When the whole face is imaged or large FOV is selected, the effective dose ranges from 500 to 700 μSv [39,45]. These exposures are almost equivalent to the dose in the implant and the jaw study using a conventional multi-detector CT [45–48] as shown in Table 3b. In comparison with general radiography [32,49], the effective dose in dental radiography is relatively low as shown in Table 4. From this

Table 2 Effective dose in panoramic radiography (μSv).

Author/source	Apparatus/parameters	ICRP 60
Danforth et al. [37]	Planmeca PM 2002®: 60 kV, 4 mA, 18 s	3.85
UNSCEAR 2000 [35] Health-care level I		7–14
European Commission Issue 136 [8]		3.85–30
Iwai et al. [5]	Veraview®: 75 kV, 8 mA	10.3
Gijbels et al. [38]	Cranex tome®: 70 kV, 4 mA, 15 s	8.1
	Cranex Excel®: 65 kV, 6 mA, 19 s	12.3
	Veraviewepocs 5D®: 70 kV, 4 mA, 8.2 s	5.5
	EC Proline®: 64 kV, 7 mA, 18.3 s	14.9
	Orthoralix 9200 DDE®: 74 kV, 4 mA, 12 s	4.7
Ludlow et al. [39]	Sirona Orthophos XG® (CCD)	14.2[a]
	Planmeca Promax® (CCD)	24.3[a]
Gavala et al. [40]	Planmeca Promax®: 66 kV, 6 mA, 16 s	17
	Planmeca PM 2002®: 66 kV, 8 mA, 18 s	23
	Planmeca PM 2002®: 60 kV,4 mA, 18 s	12
Matsuda et al. [41]	Asahi Hyper X®: 78 kV, 10 mA	12.76[b]
	PanoACT-1000®: 80 kV, 6 mA	6.66[b]
	OP 200®: 66 kV, 10 mA	8.89[b]

[a] ICRP 103, 2007.
[b] ICRP 103, 2007 excluding reminder tissues.

Table 3a Effective dose in cone beam dental CT (μSv).

Author/source	Apparatus/parameters	ICRP 60	ICRP 103
Tsiklakis et al. [42]	NewTom QRDVT 9000®: 110 kV, 3.4 mA	35	
Ludlow et al. [39]	NewTom 3G®: large FOV, 110 kV, 1.1–2.0 mA	42	68
	CB MercuRay®: large FOV, 100 kV, 10 mA	464	569
	Illuma®: large FOV, 120 kV, 3.4 mA	50	98
	Galileos®: medium FOV, 85 kV, 5 mA	28	70
	Promax 3D®: small FOV, 84 kV, 16 mA	203	652
	PreXion 3D®: small FOV, 90 kV, 4 mA	66	189
Hirsch et al. [43]	3D Accuitomo®: 6 × 6 cm, 80 kV, 4 mA		43.27[a]
	3D Accuitomo®: 4 × 4 cm, 80 kV, 4 mA		20.02[a]
	Veraviewepocs 3D®: 8 × 4 cm, 80 kV, 4 mA		39.92[a]
	Veraviewepocs 3D®: 4 × 4 cm, 80 kV, 4 mA		30.24[a]
Okano et al. [45]	3D Accuitomo®: 6 × 6 cm, 80 kV, 5 mA	66.08	101.46[b]
	3D Accuitomo®: 4 × 4 cm, 80 kV, 5 mA	31.05	49.92[b]
	CB MercuRay®: FOV: 102.4 mm in diameter, 120 kV, 15 mA	454	510.6[b]
Roberts et al. [44]	i-CAT®, 120 kV, 3–8 mA:		
	Full FOV (head)	92.8	182.1
	13 cm mandible and maxilla	39.5	110.5
	6 cm mandible	23.9	75.3
	6 cm maxilla	9.7	36.5
	6 cm mandible (high resolution)	47.2	148.5
	6 cm maxilla (high resolution)	18.5	68.3

[a] ICRP 2005 draft.
[b] ICRP 2007 excluding reminder tissues.

data the individual risks in dental radiography can be considered to be low.

Young children are more sensitive to ionizing radiation than the adults [8,23]. The age-at-exposure effect is shown by a 20% decrease in attained-age-specific excess relative risks (ERRs) per decade increase in age at exposure [50,51]. Also the risk for females is always relatively higher than for males because of differences in size and position of radiosensitive organs [8,23].

4. Radiation protection in dental radiographic procedures

4.1. Effective use of radiographic examination

Guidelines for selecting patients for dental radiographic examinations have been developed to serve as an adjunct to the dentist's professional judgment of how to best use diagnostic imaging for their patients. Such guidelines are usually intended to serve as a resource for practitioner, because an individual dentist is in the best position to make a individual judgment because of their knowledge of the patient [6]. The concept of radiographic justification and the effective use of X-ray in dental practice has well described in European guidelines [8], and American Dental Association guidelines [9]. These guidelines mainly suggest that

(1) All X-ray examinations must be justified on an individual patient basis by demonstrating that the benefits to the patient outweigh the potential detriment. The anticipated benefits are that the X-ray examination is likely to add new information to aid the patient's management,

Table 3b Effective dose in CT for dental implant/jaw study (μSv).

Author/source	Apparatus/parameters	ICRP 60	ICRP 103
Ludlow et al. [39]	Somatom Sensation 64 MDCT®: 120 kV, 90 mA, 120 mm[a]	453	860
Ohman et al. [46]	Somatom Plus 4 Volume Zoom®: 120 kV, 100 mA, 52 mm[a]		250[b]
Silva et al. [47]	Somatom Sensation 16®: 120 kV, 90 mA, 100 mm[a]		429.7[b]
Loubele et al. [48]	Somatom Sensation 16®: 120 kV, 90 mA, 63 mm[a]		474
	Philips Mx8000IDT®: 120 kV, 140 mA, 60 mm[a]		541
Okano et al. [45]	HiSpeed QX/i®: 120 kV, 100 mA, 77 mm[a]	595.65	768.88[c]

[a] Scan length.
[b] ICRP 2005 draft.
[c] ICRP 2007 excluding reminder tissues.

Table 4 Typical effective dose (E) of routine conventional radiography and computed tomography (mSv).

Diagnostic procedure	Effective dose	
	ICRP 87 [32]	Mettler et al. [49]
Conventional X-ray procedure		
Skull	0.07	0.1 (0.03–0.22)
Chest (single PA film)	0.02	0.02 (0.007–0.50)
Abdomen	1	0.7 (0.04–1.1)
Barium enema	7	8[a] (2.0–18.0)
Computed tomography		
Head	2	2 (0.9–4.0)
Chest	8	7 (4.0–18.0)
Abdomen	10	8 (3.5–25)
Pelvis	10	6 (3.3–10)

[a] Includes fluoroscopy.

(2) No radiographs should be made until a history and clinical examination has been performed. 'Routine radiography' is unacceptable practice, and
(3) When referring a patient for a radiographic examination, the dentist should supply sufficient clinical information (based upon a history and clinical examination) to allow the practitioner taking clinical responsibility for the X-ray exposure to perform the justification process.

As the development and progress of many oral diseases are associated with the patient's age or development stage, such factors should be taken in consideration in regular dental practice. The development stage is categorized into five in the US guideline [9]; child with primary dentition; child with transitional dentition; adolescent with permanent dentition, adults with dentate, or partially edentulous, and totally edentulous adult. Additionally the time of the visit such as new or recall should also be considered.

These guidelines should be used by dentists after an evaluation of the patient's needs that includes a health history review, a clinical dental history assessment, a clinical examination and an evaluation of susceptibility to dental diseases [9]. Studies have shown that 43% periapical radiographs and 42% panoramic radiographs are practiced as 'routine screening' of new patients without any clinical findings to support such radiographic examinations [9,52] and thereby the collective dose can be reduced from medical radiography by 30% by avoiding self-referrals or self-defensive medicine [53,54].

4.1.1. Dental caries

Similar guidelines are proposed by both the US and EC [8,9]. "Recommendations" shown in the EC are as follows:

(1) Prescription of bitewing radiographs for caries diagnosis should be based on caries risk assessment. Intervals between subsequent bitewing radiographic examinations must be reassessed for each new period, as individuals can move in and out of caries risk categories with time.
(2) It is recommended that when children are designated as high caries risk, they should have 6-monthly posterior bitewing radiographs taken, and when children are designated as moderate caries risk, they should have annual posterior bitewing radiographs. These should continue until no new or active lesions are apparent and the individual has entered a lower risk category. In addition radiography for caries diagnosis in low caries risk children should take into account population prevalence of caries, and intervals of 12–18 months (deciduous dentition) or 24 months (permanent dentition) may be used, although longer intervals may be appropriate where there is continuing low caries risk.
(3) It is recommended that adults designated as high caries risk have posterior bitewing radiographs made at 6-month intervals, and adults designated as moderate caries risk have annual posterior bitewing radiographs made until no new or active lesions are apparent and the individual has entered another risk category. In addition, it is recommended that adults designated as low caries risk have posterior bitewing radiographs made at approximately 24-month intervals. More extended intervals may be used where there is continuing low caries risk.

Cone-beam CT (CBCT) has a similar accuracy to conventional radiography for the detection of caries in posterior teeth *in vitro* [55]. In addition, the artifacts in CBCT from existing metallic restorations could reduce the accuracy of caries diagnosis. Therefore, CBCT is not recommended in detection of caries at this moment.

4.1.2. Periodontal disease

Periodontal diseases can be diagnosed by a clinical examination. Radiographs may be a useful supplement to further determine and document the extent of alveolar bone loss. The EC guidelines [8] suggested the following recommendations.

(1) Radiographs should be used in the management of periodontal disease if they are likely to provide additional information that could potentially change patient management and prognosis.
(2) There is insufficient evidence to propose robust guidelines on choice of radiography for periodontal diagnosis and treatment, but existing radiographs e.g. bitewing radiographs taken for caries diagnosis should be used in the first instance.

Although, CBCT accurately depict infra-bony defects and furcation [56], such benefits on management and treatment outcome has not been analyzed quantitatively [10].

4.1.3. Periapical lesions/endodontics

A periapical radiograph can provide essential information about pulp and root canal anatomy which cannot be obtained in any other way [8]. It also provides information around root apex that may influence the selection of treatment options. The radiographs play an important role in working length estimation and post-operative assessment in root filling and periapical condition.

CBCT may have several valuable applications in identifying periapical pathosis [57] thus CBCT may be considered for periapical assessment, in selected cases, when conventional radiographs give a negative finding and when there are contradictory positive clinical signs and symptoms [10].

4.1.4. Developing dentition/orthodontic therapy

The use of cephalometric radiography coupled with panoramic radiography has been a routine practice in orthodontics. The cephalometric radiography is also requested for selected patients in certain periods during the treatment.

In addition the effect of radiographs on changing orthodontic diagnosis and treatment plans is ranging from 16% to 37% [8]. On the EC guidelines the recommendation is as follows, "Specialist guidelines on orthodontic radiography should be consulted as an aid to justification in the management of the developing dentition in children" can be followed by the clinician.

An unknown percentage of cephalograms may be obtained by orthodontists in Japan for defensive medicine. Because the figures could not be estimated, further study is required.

A large volume CBCT can be utilized in orthodontics to evaluate the shape and function of the maxillofacial complex. A robust guidance on clinical selection for large volume CBCT in orthodontics, based upon quantification of benefits to patient outcome [10].

4.1.5. Tooth extraction dental implant

Panoramic radiography is most appropriate radiographic examination for most tooth removal because it can reveal the relationship of third molars to important anatomical structures such as the mandibular canal or maxillary sinus. Where conventional radiographs suggest a close relationship between a mandibular third molar and the inferior alveolar canal, and when a decision to perform surgical removal has been made, CBCT is justified [10].

CBCT may also be justified for pre-surgical assessment of an impacted tooth in selected cases where conventional radiographs fail to provide the information required [10].

The goal of selection criteria in implant radiography is to identify the most appropriate imaging procedure for each stage of patient care. A radiologic guideline for implant was proposed by the Japanese Society for Oral and Maxillofacial Radiology in 2007 and was accepted by Japan Council for Quality Health Care [58]. For maxillofacial implant planning, where cross-sectional imaging is judged to be necessary, CBCT can be used as an alternative imaging modalities to conventional CT [10].

4.2. Equipment factors

4.2.1. Image receptor

In conventional intraoral radiography, the fastest available films consistent with satisfactory diagnostic results should be used [8]. Intraoral films of ISO speed groups E or F are recommended because they significantly reduce patient dose by more than 50% compared with D-speed films [8,9,59,60].

Regarding conventional extra-oral radiography, the fastest available rare-earth intensifying screen/film combination consistent with satisfactory diagnostic results should be used [8]. The speed of the system should be at least 400 [8,61], as it requires only half the dose of a 200-speed system [62,63]. Modern rare-earth screens up to 600-speed may further reduce the dose substantially.

Digital image receptors encompass a number of different technologies and come in many different sizes and shapes. Currently, the most useful distinction is that between two main technologies: solid-state technology i.e. charged-coupled device based sensor (CCD) and photostimulable phosphor technology (PSP). In intraoral CCD radiography, the radiation dose is almost reduced by 50% when compared with E-speed film [60,61]. According to a recent study by Farrier et al., the mean exposure time and radiation surface dose for the PSP is greater than that for the CCD system by a factor of 2.45 [64] and thus is comparable to E/F-speed film. Studies reported a dose reduction of about 43% in digital panoramic sensor with the conventional panoramic system [65].

CBCT employed three types of imaging receptors namely image intensifiers tube (IIT), charged-coupled device (CCD) and Flat Panel Detectors (FPD). According to Baba et al., at a given equal detector pitch, reconstructed images obtained with a FPD exhibit less noise than those obtained with the IIT at a constant dose levels [66]. The image quality from different image receptors and radiation dose of CBCT scanners has not yet been reported.

4.2.2. Collimation

Reducing the size of the X-ray beam to the minimum size needed to image the object of interest is an obvious means of limiting dose to patients [8] and improves image quality [36] by reducing scatter radiation. Traditionally, round collimation is used for intraoral radiography. A circular collimation of 6 cm of diameter is approximately 135% larger in area than a conventional periapical dental film of size No. 2, indicating considerable scope for further collimation [67]. As rectangular collimator decreases the radiation dose by up to fivefold as compared with a short circular one [68—70], so radiographic equipment should equipped with rectangular collimation for periapical and bitewing radiographs [61]. As an X-ray beam is divergent, increasing this distance reduces the divergence within the patient and therefore reduces the volume irradiated. Two standard focal source-to-skin distance are used for intraoral radiography are 20 cm (8 inch) and 40 cm (16 inch). The use of rectangular long collimation results in 29% reduction to the lens of the eye [68] and 38—45% reduction in thyroid exposure [36].

Panoramic system with automatic selection of beam limitation or field size program especially for children can reduce the exposed area of X-ray by 27—45% [70].

CBCT equipment should offer a choice of volume sizes i.e. FOV and examinations must use the smallest FOV that is compatible with the clinical situation if this provides less radiation dose to the patient [11].

4.2.3. Tube voltage and filtration

An important consideration with dental radiography is the X-ray spectral sensitivity of dental X-ray film and the image quality at different kilovoltages [8]. Increasing the kilovoltage much beyond 70 kVp results in a spectrum ill matched to the optimal sensitivity of dental film [70]. Use of 60—70 kVp for intraoral radiography is considered to be a reasonable choice in terms of limiting dose and diagnostic efficacy [8].

X-ray beam filters preferentially remove lower energy X-ray photons from the beam. As low-energy photons have little penetrating power, they are absorbed mainly by the patient and contribute nothing to the information on the image. Thus filtration is invaluable as a mean of reducing skin doses to patients. Filtration using aluminum is an established component of dental X-ray equipment [8]. Practically, 1.5 mm Al total filtration for X-ray equipment operating at 60—70 kVp and with 2.5 mm Al total filtration when operating above 70 kVp is advised [36] and is usually followed by the manufacturers.

4.2.4. Lead shielding

The thyroid gland, one of the most radiosensitive organs in the head and neck region, is frequently exposed to scattered radiation and occasionally to primary beam during dental radiography [69]. Thyroid skin exposure can be reduced by 33—84% in adults and 63—92% in children by using thyroid shield [70]. Therefore, thyroid shielding can be applied to patients especially children as an adjunct to the use of rectangular collimation and paralleling technique. As the gonadal doses and even to embryo are not significant in dental radiography, the use of lead aprons has been recommended on the grounds of patient reassurance [61,71,72].

4.2.5. Diagnostic reference levels (DRL)

The term DRL was first introduced by ICRP in 1996 [15]. The objective of DRL is to control of medical radiation exposure to a level commensurate with the clinical purpose of a medical imaging task [73]. The use of DRLs is part of the optimization process of radiation protection, in that it identifies practices that are in need of corrective action, resulting in dose reduction. In diagnostic radiology, reference levels usually have been derived from distributions of dosimetric quantities for patients observed in practice in the relevant region or country. DRLs should be used by regional, national and local authorized bodies [27,33]. Such reference values provide a means for radiologists and medical physicists in the imaging community to compare radiation exposure levels at their facilities with those at facilities across the nation, while bearing in mind that the comparative data are the state-of-the practice data as opposed to state-of-the-art data [74]. Having an average dose below a relevant DRL gives some confirmation that patient doses in a particular facility are reasonable in line with other facilities. However, doses consistently above a DRL would definitely indicate that patient dose is not in line with the ALARA principle and effective action should be taken to reduce the dose. Therefore, implementation and use of DRL is recognized as an efficient and powerful tool in optimization of diagnostic radiology.

In 1999 the National Radiation Protection Board (NRPB) in the UK recommended the adoption of reference doses of 4 mGy (patient entrance dose) for an adult mandibular molar intraoral radiograph and 65 mGy mm (dose-width product) for an adult panoramic radiograph [28]. In Germany DRL for intraoral radiography is calculated by DAP (dose area product) measurements and is ranged between 26.2 and 87 mGy cm^2 [29] whereas DRLs for panoramic imaging based on DAP calculations for 4 different settings are 101, 87, 84 and 75 mGy cm^2 for 'large adult', 'adult male', 'adult female' and 'child' respectively [30]. According to a preliminary study in Japan, the DRLs in 54% and 57% of the 28 surveyed dental offices for intraoral and panoramic radiography respectively were within the recommended limit when compared to the DRLs set in UK [75].

Further work needs to be carried out to establish a measurement protocol (most probably DAP) for CBCT and to undertake further field measurements so that DRL can be established [10]. Manufactures of CBCT equipment should provide a DAP measurement after each exposure [10].

4.3. Protection of dental professionals

Though dental professionals receive low exposure to X-radiation, operator protection measures are essential to minimize occupational exposure to ionizing radiation. Operator protection measures include the implementation of a radiation protection program, recommendations for personal dosimeters and the use of barrier shielding [9,76].

5. Summary

Radiation dose reduction in dental radiography continues to be a clinical and ethical concern. Dental radiographic selection criteria and guidelines have been in place for more than two decades, yet compliance has been historically low. Although dental radiography contributes enormous diagnostic benefit to patients, the increased effective doses, especially from CBCT examinations, are high enough to warrant reconsideration of means to reduce patient's exposure. By using digital sensors or F-speed film instead of D-speed film, combined with rectangular collimation instead of round collimation, dentists can reduce patient's exposure by a factor of 10 for bitewing and full-mouth radiographs. Justification and optimization of a procedure along with dose limitations are absolutely essential in clinical practice. It is prudent to establish diagnostic reference levels for dental radiography in Japan. In addition, dentists should remain informed about safety updates and availability of new equipment, supplies and techniques that would further improve the diagnostic ability of radiographs and decrease exposure to patients.

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