

## Radiation Protection in Dentistry: Fundamental Concepts and Practical Approach

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### Abstract

Radiographic imaging is an important diagnostic tool in dentistry. It offers useful information and data for proper diagnosis, treatment planning and treatment follow-up. Despite the low level of ionizing radiation used, radiation protection is necessary as evidence still suggests possible adverse effects that might be triggered by the low level radiation. This review will discuss the fundamental concepts of the radiation protection specifically in dentistry: justification, optimization and dose limits. Some practical approaches will be discussed and recommended for the benefits of the dental society and patients. With the continuous development of imaging technology such as cone-beam computed tomography and new digital sensors launched each year, evidence based approach is highly recommended to develop clinical guidelines and recommendations. One must always keep in mind the fundamental radiation protection principles and the As Low as Reasonably Achievable – ALARA principle.

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### Introduction

#### Fundamental principles of radiation protection

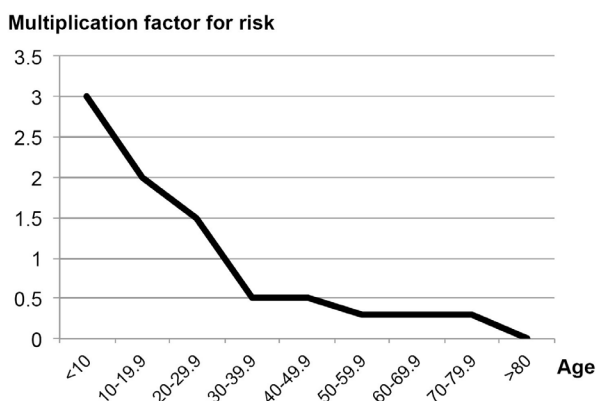
X-rays have been used in the medical field since their discovery by Wilhelm Conrad Röntgen in 1895. However, the damaging effect of radiation on human tissues and organs has been revealed in the first half of the 20th century, eventually leading to the concept of radiation protection. This article describes the three main principles of basic standards of radiation protection in dental practice. These comprise justification,

optimization and dose limits.<sup>1</sup> The justification phase starts with perceiving the information of the patient complaint, history, clinical findings and prior radiographs. After obtaining this data, dentists have to make a decision whether further radiographic examination is needed in order to acquire sufficient information for diagnosis, treatment planning and treatment follow-up. Justification of medical exposures implies that the benefits have to outweigh the cost and possible risks. Such benefits can

be an improved diagnostic accuracy and confidence, and/or an improved treatment planning and outcome. The main cost from the point of view of radiation protection is the health detriment caused by the radiation.<sup>2</sup> In practice, others costs such as financial expenses and transport may need to be taken into account.

### Biological effects of ionizing radiation

The health detriment can be categorized into deterministic effects or tissue reactions and stochastic effects. Tissue reactions may occur either shortly after the radiation exposure, including skin erythema or mucositis in the oral and maxillofacial region, or months to years after exposure, including osteoradionecrosis. However, because these effects only occur at doses which are several magnitudes higher than those of dental exposures. They are not considered in the framework of dental radiation protection.<sup>1</sup> Stochastic effects comprise cancer induction and heritable or genetic effects. The International Commission on Radiological Protection (ICRP) suggested a probability of developing a fatal cancer of approximately 1 in 20,000 per 1 mSv of effective dose.<sup>2</sup> The broad estimate of risk of a fatal radiation-induced malignancy from dental and medical radiographic examinations in a standard 30 years old patient was published in Whaites & Drage, 2013.<sup>3</sup> The age of the patient also affects the tissue sensitivity to the radiation. Figure 1 shows the multiplication factor for risk according to the age group.<sup>1,4</sup>



**Figure 1** Multiplication factor for risk of radiation-induced malignancy relative to age group based upon ICRP Publication 60.4 The risk is negligible when the age is more than 80 years old.

Heritable or genetic effects can occur when the DNA of the sperm or egg cells is damaged by x-rays reaching the reproductive organs. This may result in a congenital abnormality in the descendants. Radiation used in dental radiography does not usually reach the gonads or ovaries.<sup>5</sup> Therefore, heritable effects are of extremely limited probability to occur. Cancer induction in the head and neck region is the main concern when dental radiation is used.<sup>6</sup>

### Guidelines and recommendations in dental radiology

Recommendations for patient selection in dental radiographic examination have been proposed.<sup>7</sup> The selection of the radiographic techniques and frequency of the radiographic examination are related to patient treatment status (e.g. first examination or follow-up) and individual diagnostic task. Other guidelines or selection criteria for dental radiographic examination of particular specialties such as orthodontics, oral and maxillofacial surgery, implantology, periodontology, endodontics, pedodontics, have been presented in the literature and textbooks.<sup>8-15</sup> Two basic approaches are used to develop such guidelines.<sup>8-16</sup> The first is through judgment by an expert panel and experts' consensus. The second is to utilize an evidence-based developing method. Each approach has its own advantages and disadvantages. The most important aspect is to minimize the individual bias. Therefore, guidelines developed by an evidence-based approach are the most appropriate since it uses defined and objective ways to assess the quality of the evidence and to grade the recommendations through a systematic review of the literature. Particular guidelines in imaging, sometimes called "referral criteria", "selection criteria" or "appropriateness criteria" are thus obtained.<sup>16-18</sup>

After choosing the most appropriate radiographic technique, every effort should be exercised to ensure that the patient receives a radiation dose as low as reasonably achievable or as low as diagnostically achievable, adhering to the principle of optimization.<sup>2</sup> This can be achieved by setting suitable radiographic parameters in

accordance with image quality requirements, which are specific to the radiographic technique and the clinical indication. Exposure settings should be adapted in order to yield acceptable levels of sharpness, contrast and noise. Furthermore, adjustment of exposure settings according to patient size should always be considered. As the interplay between image quality and radiation dose varies according to the radiographic modality and manufacturer, exposure protocols should be determined on an individual basis after installation of the equipment; involvement of a medical physicist in this process is highly recommended. Shielding should be used when appropriate, and if the shielded area does not overlap with the diagnostic region of interest.

#### **Intraoral radiography**

For intraoral radiography, a kilovoltage of 60-70 kV is recommended when direct current generated by constant potential is used and a kilovoltage of 65-70 kV is recommended when alternating current produced by pulsating potential.<sup>1</sup> A kilovoltage lower than 60 kV gives absorbed dose to the skin without any benefits for the radiographic examination. On the other hand, little benefit is gained when kilovoltage higher than 70 kV is used. Direct current is preferred to alternating current since the former renders less low energy radiation resulting in lower skin dose to the patient. When using the same kilovoltage, the mean radiation energy produced by direct current is higher than that by alternating current. Rectangular collimation is recommended as the effective dose is 3.5 to 5 times less than when using round collimation.<sup>19</sup> An image receptor holder with beam alignment guide is required to avoid cone-cut when a rectangular positioning indicating device is used. Although care must be taken in order to assemble this equipment correctly to avoid any undesirable retakes from such errors. The focus-to-skin distance should be at least 20 cm to reduce the radiated area of the patient.

Image receptors should be of the fastest speed available. For direct exposure x-ray films, films with E-speed or faster should be used. An approximately

50 % reduction of radiation dose could be achieved when using E-speed films instead of D-speed films.<sup>20</sup> F-speed films need about 20-25 % less radiation exposure than E-speed films.<sup>21-23</sup>

Intraoral digital image receptors e.g. charge-coupled device (CCD), complementary metal-oxide semiconductor (CMOS) technology and photostimulable storage phosphor plate (PSP), have several advantages compared to film system. Digital image receptors require approximately half the exposure time of conventional film receptors.<sup>24</sup> Darkroom and chemical processing are not needed for digital systems. Storage of the image information does not need much physical space compared with film systems. Retrieval and transmission of the radiographic images are easy and feasible electronically. With the aid of software, measurements are possible. The disadvantage of intraoral digital image receptors is a tendency of having more retakes due to several causes. First, the rigidity of the CCD or CMOS sensors makes the positioning of the sensor in the right location difficult. Second, the working area on the CCD sensors is smaller than that of conventional film. Third, it is faster to obtain the radiographic image after exposure when using digital receptor compared to the conventional film. Therefore, it is easier for the clinician to make a decision of retaking the radiographic examination.

#### **Panoramic and cephalometric radiography**

For panoramic radiography, the height of the beam should be limited to the size of the target area, if it is feasible. Lead aprons can be worn although not necessary according to several published evidence.<sup>25,26</sup> The use of thyroid collar should be avoided as it may cause superimposition at the lower anterior region, thus hinders the visualization of the area.

For lateral cephalograms, if possible, the area of exposure in cephalometric radiography should be limited by shielding the structures above the cranial base.<sup>27</sup>

For extraoral radiography, screen-film system with at least 400 speed should be used.<sup>21</sup> Rare-earth

intensifying screen-film combination requires approximately 50 % less radiation exposure than calcium tungsten screen-film combination.<sup>28,29</sup> The types of rare-earth intensifying screen should be selected to match with the type of screen film system.<sup>21</sup> Digital panoramic and cephalometric radiography might not require lower radiation exposure than a conventional screen-film system. Based on White and Pharoah, 2014, the panoramic dose, both conventional and digital system, ranged between 9-24  $\mu\text{Sv}$ .<sup>30</sup> The radiation dose of panoramic radiograph depends on the machines and the parameter settings. In 2009, Gavala *et al.*, showed that the effective dose of digital panoramic radiography can be achieved when the lowest parameter setting was used.<sup>31</sup> Another study by Garcia Silva *et al.*, evaluated conventional and digital panoramic radiographic machines from the same company. The results showed that conventional panoramic radiograph (5.2  $\mu\text{Sv}$ ) gave more effective dose than digital panoramic radiograph (2.7  $\mu\text{Sv}$ ).<sup>32</sup> Moreover, several new panoramic radiographic machines in the market may have a fast scan mode which might reduce the exposure time in half and as a result might lower the radiation dose to patients.

### **Cone-beam computed tomography**

Effective dose from cone-beam computed tomography (CBCT) varies according to field of view (FOV) size, kV, mA, exposure time and machine specificity.<sup>33-35</sup> A detailed description of every aspect of CBCT was published in 2012 by the European Commission.<sup>17</sup> The guidelines were written under an evidence-based method, best reducing individual bias among the three methods of guideline development. However, it was noted that evidence regarding the appropriate use of CBCT was often inappropriate.

The most essential strategy for optimization of CBCT scans is the reduction (i.e. collimation) of the FOV size to the diagnostic region of interest. Not only does this lead to a considerable reduction of the effective dose,<sup>35</sup> it also has two benefits in terms of image quality. First, X-ray scatter is reduced for smaller FOVs,<sup>36</sup> which

can result in improved overall image quality. Second, small FOVs can be reconstructed at small voxel sizes, which typically results in improved sharpness.<sup>37</sup>

The optimal kV for dental CBCT imaging, and its dependence on the diagnostic task and patient characteristics, are still somewhat unclear. It has been demonstrated that, within the 60-90 kV range, 90 kV produced the best image quality when the same radiation dose was used.<sup>38</sup> Thus, the actual optimal tube voltage for CBCT imaging is likely to be above 90 kV. Slight or moderate reduction of mA compared with the manufacturer's default settings has been found to be possible depending on the diagnostic task.<sup>39-41</sup>

Image quality and dose reduction must be at balance, according to the abovementioned ALARA principle. For CBCT in particular, the operator should take the clinical indication into account to determine the required image quality level for individual patient scans; the routine use of fixed exposure settings should be avoided. When fine structures such as lamina dura and root canal are the diagnostic targets, the mA setting suggested by the manufacturer may be suitable for producing sufficient image quality. When higher contrast structures such as cortical bone, trabeculae and enamel are to be radiographically examined, the mA could be lowered as the increased noise will not interfere with image interpretation. Image quality obtained by using 180° and 360° rotation has been reported to be comparable in an *in vitro* study of detecting arthritic changes of temporomandibular joints.<sup>42</sup> An *in vivo* study evaluating bone height and bone width using various protocols used for CBCT imaging, 180° rotation was clinically acceptable.<sup>43</sup> The main effect on image quality of a 180° scan is an increase in noise compared with a 360° scan, very similar to an equivalent difference in mA. Furthermore, the reduced scan time of a 180° protocol has the additional benefit of reducing the probability of patient motion; however, should temporary motion still occur, the effect may be more severe due to the larger relative fraction of projections that will be affected compared with a 360° scan.

## Radiation shielding

Shielding equipment such as lead apron and thyroid shield have been used to protect different organs of the irradiated patients.<sup>1</sup> When a dental radiographic examination is correctly performed, the scattered radiation to the patient's abdomen is negligible.<sup>44</sup> Radiation doses to the gonads during dental radiographic examination in the situation with and without lead apron do not differ significantly.<sup>45,46</sup> UK Guidance notes for dental practitioners on the safe use of x-ray equipment state that routine use of lead aprons during dental radiographic procedures is not necessary.<sup>47</sup> The American Academy of Oral and Maxillofacial Radiology stated that the value of using lead aprons is minimal compared to the benefits of employing E-speed films and rectangular collimation.<sup>48</sup> If all the recommendations for minimizing radiation exposure, especially fastest image receptor and rectangular collimation, are followed, the use of lead aprons could be optional<sup>1</sup> or may not be necessary,<sup>7</sup> except when required by law.

A critical organ in dental radiography, especially in children is the thyroid gland.<sup>2</sup> Since the frequent scattered radiation and occasional primary x-rays expose this radiosensitive organ in dental radiography, protective thyroid collars should be employed whenever feasible. Thyroid shielding and beam collimation substantially decrease the radiation dose to the thyroid gland during dental radiographic procedures.<sup>49,50</sup> A 45 % reduction of radiation exposure could be achieved when thyroid collars are implemented during CBCT examinations. Therefore, thyroid shielding is highly recommended, particularly in young patients.<sup>51</sup>

Diagnostic reference levels (DRLs), the third quartile of the distribution of doses measured in various types of hospitals, clinics, and practices that represent the typical practice in the country or region, have been employed.<sup>52</sup> Diagnostic reference levels (DRLs) are a tool for optimization, required by the International Atomic Energy Agency (IAEA).<sup>53</sup> The intention of this metric is to urge the facilities that use the radiation dose

over the DRL to reduce the doses. X-ray facilities should compare their own dose estimates with corresponding DRL values, and review their optimization process if unusual deviations are found. Therefore, DRL values are expected to change over time according to the advancement of the image receptors and radiographic procedures.

## Occupational dose

The principle of dose limits is to assure that no radiological workers and public will receive excessive radiation exposure. The ICRP recommends a dose limit for occupational persons of 20 mSv of effective dose per year which was averaged over defined periods of 5 years with a maximum of 50 mSv in any single year. For public person, a limit of 1 mSv per year was recommended.<sup>2</sup> If the patient dose is reduced, the dose to the radiological workers and public will consequently decrease. Occupational protection could be attained by educating the radiological workers, using appropriate distance and shielding as well as limiting the time spent in the vicinity of the radiation source.

Prior to radiographic practice, personnel must be educated regarding the principles of radiation protection, how to implement the radiological equipment safely and efficiently, ensuring that the patients receive a radiation dose that is as low as reasonably achievable. Pregnant occupational personnel should use a personal dosimeter, irrespective of anticipated exposure levels.<sup>46,51</sup> If worker and public protection through maintaining of an adequate distance to the radiation source is not feasible, barrier and/or personal shielding should be employed; this is particularly recommended for CBCT.<sup>17</sup> The layout of the radiographic room and the thickness of the barrier walls should be determined with the input of a radiation physicist. The barrier shielding factors that must be taken into account include maximum kV used, anticipated maximum workload per week (mAs per week), primary or secondary barrier based on the orientation of the primary beam, controlled or uncontrolled area, distance between x-ray tube and shielded area, occupancy factor and orientation or use factors.<sup>51</sup>

The goals of shielding design for controlled areas and uncontrolled areas are recommended by NCRP<sup>52</sup> to be (in kerma) 0.1 mGy per week and 0.02 mGy per week, respectively. The radiographer should stand at least 2 meters away from the x-ray tube head and at an angle of 90 to 135 degree to the primary beam.<sup>54,55</sup> If the distance and direction of the primary beam is properly employed, utilization of barrier shielding is not necessary.

### **Handheld portable dental x-ray devices**

Handheld portable dental x-ray devices are increasingly used. Several studies have been conducted on this kind of devices, including evaluation of their physical performance.<sup>56-58</sup> Utilizing these devices does require a separate approach towards radiation protection compared with fixed or mobile intraoral dental radiographic devices. Because the operator must be close to the handheld x-ray tube head during exposure, the hands holding the tube head and the operator's body must be protected from the leakage radiation from the tube head and (more importantly) the scattered radiation from the radiated organs of the patient.<sup>56</sup> Especially when used frequently, lead protective gloves and lead apron should be worn. Furthermore, an internal sufficiently shielded tube head with a backscatter shield permanently fixed at the end of the position-indicating device is required. The x-ray devices should be approved by the reliable organizations such as FDA (Food and Drug Administration) or CE (Conformité Européenne). The approval of the devices is not adequate for the safe use of the devices. The devices must be utilized in the proper context.<sup>7</sup> The operators should hold the devices at mid-torso height and direct the position-indicating device horizontally. The backscatter shield at the end of the position-indicating device should be placed as close to the patient's skin as practicable. This device should be employed when the fixed or semi-mobile devices is impractical to be used. Handheld devices may be applied in forensic odontology for identification purpose.<sup>56,59</sup>

### **Clinical applications**

New technologies have arisen in the digital

dentistry world with higher quality of digital x-ray images and 3D imaging, the fundamental concepts of the radiation protection specifically in dentistry: justification, optimization and dose limits should still be strictly practiced.

For those responsible in regulating the use of dental x-ray, national guidelines and recommendations should be proposed and made available to the public. For clinicians, optimal radiation protection should be given to all patients and also to the x-ray operators. Before prescribing the radiographs, indications and justifications should be thoroughly reviewed. The clinicians should always be updated to knowledge related to the use of x-ray for dental practice. All x-ray devices should be chosen and purchased carefully to be suitable for the clinicians' specific tasks. The quality of the machines should be checked regularly by responsible personnel. Faster image receptors should be selected. Handheld portable dental x-ray devices should be kept out from the routine dental practice and should only be used when necessary. CBCT scans are advised when 3D information is useful to the patients. The CBCT scanning parameters, although varied among machines available in the market, should be adapted to fit the imaging purposes. Less than perfect image quality should be considered when the acquired information is enough for proper diagnosis and treatment planning. One must always keep in mind the fundamental radiation protection concepts and the ALARA principle.

## **Conclusions**

The major principles of radiation protection consist of justification, optimization and dose limits. This review has discussed these fundamental principles and recommend how to bring them to the practice. The review also gathered the available knowledge on radiation protection as well as related knowledge on dental radiographic techniques, thus it can be used as a guide for all dentists.

In summary, it is recommended that dentists should follow published clinical recommendations and

guidelines for the use of radiographs and continuing education should always be pursued. Second, it is recommended to use the fastest image receptors available. Third, proper protective shielding for both patients and personnels should be applied. Fourth, handheld portable dental x-ray devices should be used only for specific indications. Finally, an evidence-based approach is highly recommended to develop new updated clinical guidelines.

### Conflict of interests

The authors declare that there is no conflict of interest.

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