PEAK

Considerations for the Use of Ionizing Radiation in Dentistry

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Considerations for the Use of Ionizing Radiation in Dentistry

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Radiology is a diagnostic test, and in dentistry, this test almost always involves the use of ionizing radiation. Therefore, oral and maxillofacial radiology should be performed thoughtfully and responsibly, minimizing radiation dose to the patient, but maximizing diagnostic benefit.

Today, dentists have a wide range of imaging modalities from which to choose. For many diagnostic dilemmas encountered in the practice of dentistry, periapical, bitewing, or panoramic radiography may be appropriate, and all that may be required to help formulate a patient diagnosis. In the past decade, dentistry, and oral and maxillofacial radiology in particular, has seen the introduction of numerous computer-based digital imaging technologies. Many practitioners have replaced film-based techniques with digital ones, and the recent introduction of three-dimensional volumetric or cone beam computed tomography (CBCT) in dentistry has generated both widespread excitement and concern as strategies are developed for incorporating this novel technology into patient care.

The radiologic examination, whether it involves one or multiple modalities, should be designed to address a particular diagnostic concern; there is no such thing as a "one size fits all" type of imaging modality. Therefore modalities such as CBCT should be seen as an addition rather than a replacement for older, more classic techniques. Understanding the scope and limitations of what the imaging modalities can bring to patient care is an important first step in ensuring that oral and maxillofacial radiology is practised in a safe and responsible way.

RADIATION SCIENCES, DOSIMETRY AND RISK

Radiation is potentially harmful. Unfortunately, the manifestation of this harm may not be realized for upwards of 10 to 20 years; this is the so-called latent period of radiation injury[1]. Therefore, it is important for dentists to have a basic understanding of x radiation so that their patients, and in particular children and adolescents, are not placed in unnecessary risk from radiologic procedures that may be performed today in their offices.

Discussions of radiation dose and risk should begin by defining the units of radiation measurement. The term "exposure" is often, but incorrectly, used as a synonym for "human exposure." Rather, the word "dose" should be used to quantify "human exposure." Radiation absorbed dose is measured in Gray (abbreviated Gy). A related unit, the Sievert (abbreviated Sv), is used to measure radiation dose equivalent, the product of absorbed dose (in Gy) and a quality factor that reflects the potency of a particular ionizing radiation. For x rays, the quality factor is 1, so for all intents and purposes, Gy and Sv may be used interchangeably when referring to doses from x radiation.

Humans are subjected to a variety of naturally occurring radiations during their lifetimes, and these cannot be controlled[1]. Cosmic rays, cosmogenic radionuclides and terrestrial sources, including radon (^{222}Rn), constitute the greatest proportion of annual human radiation doses. Less significant sources also include technologically-enhanced sources (including the burning of fossil fuels, the use of phosphate fertilizers and some building materials, and air travel), and technologically-produced sources derived from the nuclear weapons and power industries. In total, human populations are subject to between 3 milli-Sievert (mSv) and 4 mSv of background radiation per year, depending on their geographic location on the planet.

In humans, x radiation interacts primarily with water molecules, and the result of these interactions is the generation of molecular intermediaries called free radicals[1]. Free radicals are relatively unstable atoms or molecules that contain at least one unpaired electron. Their production can initiate a cascade of events throughout the cell, damaging cellular macromolecules including DNA, proteins and enzymes, lipid, and carbohydrate molecules. Although mammalian cells have a significant capacity to repair radiation damage, damage to DNA in the form of double strand breaks may be more difficult to repair. In some instances, DNA can be misrepaired, and this may result in point mutations and chromosomal aberrations, both of which have been linked to the development of cancer in cells, laboratory animals and humans[2]. Indeed, there is direct evidence from epidemiologic studies that organ doses corresponding to common medical CT studies can result in an increased risk of cancer development; evidence that is reasonably convincing for adults and very convincing for children. And as individual organ doses from some dental CBCT systems[3,4] either approach or exceed organ doses from medical CT, this is a topic of considerable significance (Table 1).

Phantoms are often used to estimate radiation absorbed dose from various

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Table 1

Selected organ doses corresponding to oral and maxillofacial radiology examinations‡

	Bone marrow	Thyroid gland	Salivary gland
Full mouth series (ANSI F speed film or PSP* with round collimation)	134 μSv	550 μSv	4110 μSv
4 Bitewing radiographs (ANSI F speed film or PSP with rectangular collimation)	4 μSv	0 μSv	156 μSv
Panoramic radiograph (assorted CCD#-based systems)	up to 20 μSv	up to 67 μSv	up to 761 μSv
Lateral cephalometric skull radiograph with a PSP sensor	5 μSv	45 μSv	80 μSv
PA cephalometric skull radiograph with a PSP sensor	11 μSv	30 μSv	55 μSv
Cone beam CT (large field)	82 to 1542 μSv	183 to 10042 μSv	956 to 11833 μSv
Imaging Sciences iCAT	105 (l) to 147 (p) μSv	183 (l) to 283 (p) μSv	1250 (l) to 1836 (p) μSv
Hitachi CB Mercuray	466 (6″) to 1542 μSv (12″)	1300 (6″) to 10042 (12″) μSv	9006 (6″) to 11833 (12″) μSv
64 slice medical spiral CT	1031 μSv	3700 μSv	15300 μSv

(p): portrait mode
(l): landscape mode
‡Adapted from Ludlow et al[3] and Ludlow and Ivanovic[4]
*photostimulatable phosphor
#charge-coupled device

radiologic examinations. One well-known radiologic phantom is the RANDO® MAN, manufactured by Alderson Research Laboratories (Salem, NY). RANDO® MAN is a human skeleton embedded into a material that absorbs radiation similar to that of soft tissue. As many as 25 organ locations may be defined within the RANDO® MAN head and neck, and data from these sites are used to calculate radiation doses to the various organs and tissues here. This methodology has been used extensively in radiation dose estimates to the oral and maxillofacial region (Table 1)[3-8].

To relate individual organ doses to the whole body, radiation scientists have defined the absorbed dose equivalent as the summed products of a weighting factor for a tissue, T, (WT), absorbed dose (derived from the RANDO® MAN phantom) to a tissue (DT) and the fraction of a tissue irradiated in the imaging volume (FT). Tissue weighting

Table 2

Effective dose corresponding to oral and maxillofacial radiology examinations‡

	Effective Dose
Full mouth series (ANSI F speed film or PSP with round collimation)	170.7 μSv 4
Bitewing radiographs (ANSI F speed film or PSP with rectangular collimation)	5.0 μSv
Panoramic radiograph (assorted CCD-based systems)	up to 24.3 μSv
Lateral cephalometric skull radiograph with a PSP sensor	5.6 μSv
PA cephalometric skull radiograph with a PSP sensor	5.1 μSv
Cone beam CT (large field) Imaging Sciences iCAT Hitachi CB Mercuray	68 to 1073 μSv 74 (l) to 87 (p) μSv 407 (6") to 1073 (12") μSv
64 slice medical spiral	CT 860 μSv

(p): portrait mode
(l): landscape mode
‡Adapted from Ludlow et al[3] and Ludlow and Ivanovic[4]

factors are numerical values that are defined by the International Commission on Radiological Protection (ICRP), and they are reviewed periodically based on current organ radiobiological information. Recently, there have been substantial increases to various tissue weighting factors, and these have lead to dramatic increases in radiation dose calculations[9]. For example, almost 20 years ago in 1992, the radiation absorbed dose equivalent calculated for a full mouth series of intra-oral radiographs using a 70 kVp and 10 mA x-ray beam, American National Standards Institute (ANSI) D speed film and round collimation was reported to be 84 μSv5. Using the most recent 2007 ICRP tissue weighting factors, the absorbed dose equivalent for this radiologic examination is now 388 μSv6; more than four times the value calculated in 1992. The absorbed dose equivalent for the same examination with ANSI F speed film decreases the dose to 170.7μSv. And when rectangular collimation is used with ANSI F speed film, the dose decreases further to 34.9 μSv. Indeed, these decreases are dramatic.

For extra-oral imaging, the current radiation absorbed dose equivalent for panoramic radiography using a charge-coupled device (CCD) digital sensor has been reported to be up to approximately 24.3 μSv, depending on the system being evaluated. For lateral cephalometric radiography using a photostimulatable phosphor (PSP) digital sensor, the radiation absorbed dose equivalent has been estimated to be approximately 5.6 μSv[6,7]. In contrast, radiation absorbed dose equivalents vary widely for CBCT examinations; 5.3 μSv for a small field of view, 5 cm in diameter by 3.7 cm in height, centred in the anterior maxilla (Ludlow, unpublished data) to 1073 μSv for a 12 inch field of view centred on the head using the maximum quality setting for this system[3,4,7] (Table 2). The very large differences can be explained on the basis of the size of the field-of-view, the tissues contained within the field-of-view, the operating kVp and mA of the x-ray tube, and whether the system delivers x radiation as a pulsed or continuous beam. Each one of these factors can substantially modify the dose calculation[8] and greatly impact the patient. Therefore, it is imperative that dentists choose appropriate exposure parameters (kVp, mA, exposure time) for all imaging examinations, whether periapical or CBCT, based on patient size (child and adult) and region of interest (i.e. anterior versus posterior, mandible versus maxilla).

Unfortunately, radiation dosimetry data is sometimes presented in overly simplistic terms by comparing various dose levels to common life experiences or other imaging modalities. The comparison of the radiation dose from a panoramic radiography to days spent in the sun is inappropriate because it assumes that the two types of radiation (x radiation and ultraviolet radiation) impart the same type of biological damage. While both forms of radiation impact on cellular macromolecules, they

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Table 3

Probability of *X* in a million fatal cancers corresponding to oral and maxillofacial radiology examinations‡

	X
Full mouth series (ANSI F speed film or PSP with round collimation)	9
4 Bitewing radiographs (ANSI F speed film or PSP with rectangular collimation)	0.3
Panoramic radiograph (assorted CCD-based systems)	up to 1.3
Lateral cephalometric skull radiograph with a PSP sensor	0.3
PA cephalometric skull radiograph with a PSP sensor	0.3
Cone beam CT (large field) Imaging Sciences iCAT Hitachi CB Mercuray	4 to 59 4 (l) to 6 (p) 22 (6″) to 59 (12″)
64 slice medical spiral CT	47

(p): portrait mode
(l): landscape mode
‡Adapted from Ludlow et al[3] and Ludlow and Ivanovic[4]

do so in very different ways. Moreover, the cellular mechanisms required to repair this damage is also different[1]. More recently, comparisons of dosimetric data from CBCT examinations have been made with radiation doses from other imaging modalities such as panoramic radiography. Since CBCT and panoramic radiography have different purposes, comparisons such as this are overly-simplistic, and potentially misleading. And as such, they should be avoided.

The effects of high radiation doses on human populations has been studied primarily in two population groups: the survivors of the atomic bombs at Hiroshima and Nagasaki, and from radiation workers in the nuclear industry[11]. These data together with new dose data from different imaging modalities[3,4,6], form the basis for the development of radiation risk injury estimates and ultimately, radiation protection guidelines worldwide[1]. The "injury" referred to here is commonly the development of a fatal cancer. Currently, risk estimates range from the development of 0.3 fatal cancers per million series of 4 bitewing radiographs made with a PSP digital sensor or American National Standards Institute (ANSI) F speed film and rectangular collimation, to 21 fatal cancers when ANSI D speed film and round collimation are used. For CBCT examinations, the calculated risks range from 4 fatal cancers per million CBCT examinations to as high as 59. Indeed, for some CBCT systems, the risks of developing a fatal cancer are comparable to contemporary medical CT machines (47), and this has many concerned (Table 3).

Although the radiation absorbed doses from some oral and maxillofacial radiologic procedures are low, they are not zero. This means that the risks are also not zero. Therefore, it is essential that dental practitioners use every available means at their disposal to ensure that radiation doses to patients, particularly children and adolescents, are kept as low as reasonably achievable, balancing patient risk with diagnostic benefit. This fundamental principle of radiation protection, abbreviated ALARA, states that radiation is potentially harmful, and therefore, human exposures should be continuously monitored and controlled. Furthermore, no exposures should be permitted without considering the benefits that may be derived from that exposure, and the relative risks of alternative approaches.

RADIOGRAPHIC SELECTION CRITERIA

Radiation doses to patients are most effectively controlled by making prudent decisions about the need and scope of radiography based on clinical need. In 1983, the United States Food and Drug Administration (USFDA) convened a panel of clinicians and radiation scientists to develop radiographic selection criteria for dental patients[12]. These criteria were developed as

Table 4[13]

Clinical situations for which radiographs may be indicated, but not limited to:

Positive historical findings	Positive clinical signs or symptoms
Previous periodontal or endodontic treatment	Clinical evidence of periodontal disease
History of pain or trauma	Large or deep restorations
Familial history of dental anomalies	Deep carious lesions
Post-operative evaluation of healing	Malposed or clinically impacted teeth
Remineralization monitoring	Swelling
Presence of implants or evaluation for implant placement	Evidence of dental/facial trauma
	Mobility of teeth
	Sinus tract ("fistula")
	Clinically suspected sinus pathology
	Growth abnormalities
	Oral involvement in known or suspected systemic disease
	Positive neurologic findings in the head and neck
	Evidence of foreign objects
	Pain and/or dysfunction of the temporomandibular joint
	Facial asymmetry
	Abutment teeth for fixed or removable partial prosthesis
	Unexplained bleeding
	Unexplained sensitivity of teeth
	Unusual eruption, spacing or migration of teeth
	Unusual tooth morphology, calcification or colour
	Unexplained absence of teeth
	Clinical erosion

guidelines rather than strict requirements or regulations, and provided practitioners with a list of historical as well as clinical signs or symptoms that when identified, indicated a possible need for radiography. The guidelines endorse the doctrine of risk versus benefit; that the potential risk of a proposed radiological procedure is justified if there is a net benefit to the patient. A new panel was convened in 2004[13] by the United States Department of Health and Human Services (the United States Public Health Service and the USFDA) and the guidelines were reviewed in light of evidence from the previous 21 years on the nature and cause of disease in the jaws. The 2004 revised guidelines now recognize 6 positive historical findings, and 22 positive clinical signs and symptoms for which radiographs may be useful. Moreover, most, if not all of these can only become known to the dentist after a patient interview and clinical examination (Table 4). Therefore, the decision to prescribe radiography without having examined a patient is not considered responsible.

Adoption of the guidelines has been alarmingly slow by both dental practitioners and academic

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institutions[14-16]. One explanation for this may be that dentists fear the threat of litigation should they fail to identify a quiescent, intra-osseous abnormality. Some dentists argue that always making a full mouth series of intra-oral radiographs or a panoramic radiograph to screen for quiescent disease is an effective way of ensuring nothing is missed. This is an unfounded fear, and unsupported in the literature. Of course, this type of approach also presupposes that the dentist is capable of interpreting any abnormality should one actually be present.

When considering the need for radiography in the absence of clinical signs or symptoms, one must consider several factors: the prevalence of such lesions in the jaws, the probability that the presence of such a lesion would fail to produce a clinically-detectable sign or symptom, and whether the presence of such a lesion would influence management (a Stafne submandibular defect is an example of an abnormality that would have no bearing on patient management)[12]. Central intra-osseous jaw lesions have an approximately 85% likelihood of occurring in the apical areas of the teeth, and are primarily odontogenic in origin. An additional 7% of these are reported to be developmental in origin, and the remaining 8% are said to form the basis of whether or not to conduct a radiographic examination[12]. As a group, odontogenic tumours are rare. Surveys of anatomic pathology services report tumour incidences ranging from 0.7% to 2.7% of all accessions[17-21]. Odontogenic cysts are more common, with an incidence of approximately 17.20%. Of these accessions, the largest percentage of cysts are radicular cysts with non-odontogenic cysts representing only 1.01% of accessions. For non-odontogenic cysts, the nasopalatine duct cyst is the most common.

A review of some 30 million health insurance records in the United States suggests that the detection of quiescent disease in asymptomatic patients given economic and radiobiological costs, and the morbidity and mortality to patients is not, in fact, justified[22]. Indeed, in the oral and maxillofacial radiology literature, where the use of selection criteria has been studied extensively, there is now a sizeable base of evidence supporting their use[23-27]. These studies suggest that when selection criteria are carefully used, only a small number of entities are missed, most of which are resorbed roots, retained primary tooth roots, hypercementoses and dense bone islands. Some of these entities require no additional management whatsoever. The guidelines also discourage radiography at predetermined, regular time intervals (i.e. the making of a panoramic radiograph every 5 years in asymptomatic patients); there is no evidence base for this practice.

The SEDENTEXCT project[28], a European consortium of oral and maxillofacial radiologists and radiation physicists have recently released their version 2.0 of their evidence-based guidelines document for CBCT use. This document has gathered evidence for the use of CBCT in a wide range of clinical scenarios in oral and maxillofacial imaging. Among the topics discussed are imaging of the developing dentition, restoring the dentition, and oral and maxillofacial surgical and orthodontic applications. Unfortunately, for many of these applications, there is little published evidence supporting the use of CBCT; more research needs to be done in this regard. The SEDENTEXCT panel has, therefore, taken a cautious, conservative approach to making recommendations for imaging. Of the recommendations that the panel has indicated to be "best practice", two general themes stand out. First, should three-dimensional imaging have been performed in the past using medical CT, the panel suggests that CBCT may be a better option for patients because of the lower radiation absorbed doses. And second, the size of the imaging field should be limited to only the area of interest, and not beyond.

After careful consideration of a patient's imaging needs following a thorough clinical examination, image acquisition can then begin. As was the case with image selection, continued consideration is required to ensure that the principles of ALARA are preserved during image acquisition.

PROJECTION RADIOGRAPHIC TECHNIQUES

For many years, film-based intra-oral radiography with its very high image resolution has been used as the gold standard for oral and maxillofacial radiography. In more recent years, the slower and less sensitive ANSI D speed emulsion film has been replaced by the faster and more sensitive ANSI F speed emulsion film. ANSI F speed emulsion is approximately 60% more sensitive to radiation than is ANSI D speed emulsion, which translates to a 60% decrease in radiograph exposure times; a considerable dose savings to the patient[29]. This decrease has not, however, impacted on image resolution, which has been reported to be at least 20 line pairs per millimetre (lp/mm). Indeed, there are

now numerous in vitro studies that have demonstrated the diagnostic quality of ANSI F speed film to be equivalent to that of ANSI D speed film[30-33].

In many practices, digital sensors are replacing radiographic film as image receptors. Three digital receptors technologies are now widely available for both intra- and extra-oral imaging; the solid state charge-coupled device (CCD), the complementary metal oxide semiconductor (CMOS), and the photostimulatable phosphor plate (PSP)[34]. There are many reasons why dentists might consider digital imaging technology in their practices. These may include ease of image manipulation following exposure, increased productivity, elimination of darkroom chemicals and environmental chemical waste, and radiation dose reduction[35]. The pros and cons of digital intra-oral radiographic systems is addressed more comprehensively elsewhere[36]. Indeed it has been reported that the mean effective radiation dose reduction when using intra-oral digital sensors is approximately 55% compared with ANSI D speed film[35,37]. It should be noted that intra-oral CCD and CMOS sensors have smaller active surface areas than film or PSP sensors, so more images may be required to cover the same anatomical area within the oral cavity, thus reducing the potential for greater dose savings.[38] In contrast, substantial dose reductions have not been found for digital panoramic imaging over film-based radiographs with rare Earth intensifying screens[6,39,40].

Image resolution is one issue that does separate film-based imaging from digital sensor technologies. As we have stated earlier, ANSI F speed film emulsions display an image resolution of at least 20 lp/mm. The median resolutions of several CCD and CMOS sensors have been reported to be as low as approximately 11 lp/mm in various in vitro studies. In contrast, PSP sensor resolutions are reported to be even lower at approximately 8 lp/mm. The newest generations of CCD and PSP sensors have recently achieved tested resolutions of greater than 20 lp/mm and 13 lp/mm, respectively, rivalling ANSI F speed film[34].

The mean resolution of film-based panoramic systems has been reported to vary between approximately 7 lp/mm to 11 lp/mm, depending on the type of intensifying screen used in the cassette. In comparison with intra-oral film-based radiography or some digital intra-oral systems, this difference is substantial. The resolution of digital panoramic systems has been reported to be less than 10 lp/mm[40]. Given the relatively poor resolution of panoramic systems in general, they should not be the first choice for depicting fine bony architecture, or the architecture of periradicular structures such as the periodontal ligament space or the lamina dura. Moreover, the production of ghost images and the superimposition of the cervical spine may obscure key areas, particularly in the anterior mandible and maxillae. The notion of panoramic imaging replacing periapical or bitewing radiography, or as a "screening tool", should be considered inappropriate given the inherent artefacts of panoramic imaging, the lower image resolution, and the discussion above, regarding the use of radiography for the detection of quiescent disease.

CONE BEAM COMPUTED TOMOGRAPHY

CBCT technology, first described in 1998 for applications in dentistry, employs a cone-shaped x-ray beam and a planar digital sensor[41]. During image acquisition, both the radiation source and sensor rotate around the stationary patient. There are two general classes of CBCT systems; ones that employ small fields of view with dimensions of 8 cm or less and large fields of view machines with dimensions of greater than 8 cm. Unlike projection radiography, a CBCT system captures the anatomy of the area being imaged as three-dimensional volume elements, or voxels. The anatomy can then be viewed as two-dimensional planar images reformatted along straight or curved planes to display the internal anatomy of the region of interest. Small field-of-view systems employ pixel dimensions as low as 0.076 mm while the larger field machines employ pixel dimensions of up to 0.40 mm.

The centre of the imaging field determines what tissues may potentially be irradiated. As we have discussed earlier, position of the imaging field may have a substantial bearing on patient radiation dose. Although radiation dose considerations are of particular concern for large field-of-view 3D imaging, they are less so for small volume CBCT. For small field systems, the effective radiation doses have been reported to range from approximately 5.3 μSv to 38.3 μSv (Ludlow, unpublished). Since radiation effective dose calculations are based on the volume and sensitivity of tissues contained within the imaging volume, regional variations in dose calculations are normal. For large field

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CBCT systems, depending on the system, the effective dose may range from 68 mSv to 1073 μSv[3,4,7]. This very large range can be attributed to the operating kVp and mA of the different machines, the field of view sizes and the mode in which the radiation is delivered (pulsed or constant output).

COLLIMATION

When an x-ray beam exits the housing of an x-ray unit, the size, shape and spread of the beam is restricted by a device called a collimator. For intra-oral x-ray systems, collimators (formerly and incorrectly referred to as "cones") of varying lengths are available. Collimator length determines the distance between the x-ray target in the x-ray tube housing and the exit point of the collimator and the degree of spread of the x-ray beam. Shorter units provide collimation of 8 inches or less, and produce x-ray beams that are more divergent at the beam periphery than collimators that provide 12 or 16 inch distances between the x-ray source and the collimator opening. The more divergent x-rays that exit the housing of shorter collimators interact with the skin to a greater degree, and impart an additional dose to the patient. Furthermore, the more divergent components of the x-ray beam produce more distortion of the image and reduce image contrast[42]. A unit that provides for longer collimation allows only the most parallel-running components of the x-ray beam to exit the collimator, absorbing many of the more divergent components in its walls. Longer collimation also generates an image that is less distorted. The most significant difference, however, between the use of long and short collimators is the observation that when short collimators are used, this increases the effective radiation dose to the patient by approximately 1.5 times[43]. Therefore, the use of long collimation is the preferred choice.

A further refinement to the concept of collimation is the replacement of the round cross sectional opening of the collimator with one that has a rectangular cross-section; an area not substantially larger than the surface area of an ANSI size 2 film. Health Canada's Safety Code 3043 dictates that the intra-oral x-ray beam should be no larger than a circle corresponding to 7 cm in diameter or a rectangle of no more than 38.5 cm^2. Indeed, the National Commission on Radiologic Protection's Report 145 has a more stringent guideline, indicating that rectangular collimation should be routinely used for periapical radiography unless patient cooperation and/or anatomy preclude the effective use of a position indicating devices[45]. The rectangular restriction has been reported to decrease patient radiation absorbed dose by a factor of between 4 to 5 times without an impacting image quality[46]. For bitewing radiography, the use of rectangular collimation may be difficult, but it is not impossible. For the larger ANSI 4 size film that is used for adult occlusal radiography, the use of rectangular collimation may not be possible.

For panoramic and skull imaging, the x-ray beams are typically determined by the manufacturers, and are not adjustable, even if the patient is small. This has the effect of increasing doses to areas of the skull such as the orbits and cervical spine for panoramic imaging, and the cranial cavity and cervical spine for skull imaging. For CBCT systems, many different field of view sizes are available on these machines, and it is the responsibility of the user to determine the field size based on the area of interest. Indeed, the SEDENTEXCT[28] guidelines for the use of CBCT suggest that the smallest field size that is compatible with the clinical investigation should be used; a best practice, in their opinion.

LEAD APRONS AND THYROID COLLARS

Lead aprons are recommended for use for radiography by Health Canada Safety Code 30, although the physical requirements for the apron are not well-described[44]. For panoramic imaging, coverage is recommended for both the front and rear of the patient, although this document does not indicate how far toward the feet this coverage should extend. Consequently, there are many different lead aprons available. These may cover the entire front of the body, the front and back of the body to the pelvis, or only to the chest, and may incorporate different thicknesses of lead. Aprons may also incorporate a thyroid collar, or this may be purchased separately from the apron.

As conventional dental x-ray beams are very highly collimated, the role of the lead apron is not to protect the patient against irradiation by the primary beam[47]. Rather, lead aprons are used to protect the gonadal tissues against scattered radiation that could potentially affect genetic material contained there. Using a lead apron incorporating 0.25 mm lead, Wood et al[47] found that for maxillary vertex occlusal and periapical exposures made with a round collimator, the dose to the gonadal tissues was the same, whether or not a lead apron was used; 0.01±0.01 mGy (10 μGy). Since control dosimeter readings were also 0.01

mGy, their results suggested that the doses were so low that they were less than the detection threshold of the dosimeter. The authors cautioned that they would still recommend the use of a lead apron incorporating 0.25 mm of lead for protection of breast tissue from scattered radiation. Extrapolating this to panoramic radiography, it would be reasonable that the apron should cover the front and the back of the patient to the level of chest.

Perhaps of greater importance than the absorption of scattered radiation to the gonadal tissues is the absorption of scattered radiation to the thyroid gland, a relatively radiosensitive organ in the head and neck. Sikorski and Taylor[48] measured this dose using a RANDO® MAN phantom, and in children and adults undergoing full mouth series and panoramic radiography in dental offices. For intra-oral and panoramic radiography, these workers reported a mean thyroid dose reduction of 24% and 60%, respectively, when a thyroid collar, incorporating 0.3 mm of lead, was used. Furthermore, in their patient study, these workers found mean dose reductions of 58% between offices that used thyroid collars and those that did not.

Although some radiation protection agencies such as the NCRP suggest that lead aprons may not be necessary if radiation protection guidelines are stringently followed[45] (i.e. the judicious use of selection criteria, digital receptors or ANSI F speed film, and 16 inch rectangular collimators), few practices are able to comply with all three requirements. One other reason, although not quantifiable, for why lead aprons should be used is for the psychological well-being of the patient. The routine use of lead aprons is considered commonplace in dental clinics. It is likely, then, that if a patient is not covered by a lead apron, that they may question the dentist why one is not being used. It is recommended, however, that thyroid collars be used whenever possible, particularly in children and adolescents, unless the region of interest becomes obscured by the collar.

IMAGE WISELY™ AND IMAGE GENTLY™ CAMPAIGNS

Good clinical decision-making, particularly, when it comes to radiation use, can sometimes be a daunting task. Two internet resources have recently been developed to help both the clinician and the patient in this regard. Image Wisely™ is the radiation use awareness campaign of the American College of Radiology, the Radiological Society of North America, the American Association of Physicists in Medicine, and the American Society of Radiologic Technologists[49]. It encourages practitioners to use the lowest, optimal radiation dose for radiologic examinations that are necessary for patients, and to avoid unnecessary examinations. Image Gently℠ is a campaign of the Alliance for Radiation Safety in Pediatric Imaging[50]. This campaign, in particular, raises awareness for imaging and safety of the pediatric population. Both campaigns provide viewable and downloadable information on their websites that guide practitioners in the careful selection of technical criteria for which to acquire images (i.e. kVp and mA). Moreover, both encourage practitioners to only scan the region of interest, and not areas peripheral to this. Although these resources are directed at physicians, they are no less relevant to dentistry since the majority of dentists act as their own oral and maxillofacial radiologist.

With the introduction of CBCT systems in dentistry, the potential to do harm is considerably greater now than ever before because of the higher effective doses imparted by this new modality. Should these examinations be directed toward children and adolescents, the most vulnerable in our population, the resources and recommendations of Image Gently℠ could not be more timely.

SUMMARY

Radiography is not a diagnostic test that should be performed routinely. Rather, radiography should be ordered only after completing a clinical examination, and when a historical finding, or a clinical sign or symptom suggests the presence of an abnormality that requires further investigation. When imaging is indicated, every effort should be made to design the examination so that the radiation dose to the patient is kept as low as reasonably achievable. The design of such an examination should consider the size, location, perceived nature and accessibility of the abnormality, x-ray receptor sensitivity, x-ray beam output area or field-of-view size, technical factors (e.g. kVp, mA and exposure time), and lead coverage, all of which have the potential to impact on patient dose. In the final analysis, responsible radiologic decision-making practices should yield a benefit to the patient and ultimately, influence their management.

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References

1. Hall EJ, Giaccia AJ. *Radiobiology for the Radiologist*. Philadelphia, PA: Lippincott, Williams & Wilkins; 2006.
2. Brenner DJ, Hall EJ. Computed tomography - an increasing source of radiation exposure. *N Eng J Med* **357**:2277-2284; 2007.
3. Ludlow JB, Brooks SL, Davies-Ludlow LE, Howerton B. Dosimetry of 3 CBCT units for oral and maxillofacial radiology. *Dentomaxillofac Radiol* **35**:219-226; 2006.
4. Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. *Oral Surg, Oral Med, Oral Pathol, Oral Radiol, Endod* **106**:106-114; 2008.
5. White SC. 1992 Assessment of radiation risk from dental radiography. *Dentomaxillofac Radiol* **21**:118-126; 1992.
6. Ludlow JB, Davies-Ludlow LE, White SC. Patient risk related to common dental radiographic examinations: The impact of the 2007 International Commission on Radiological Protection Recommendations Regarding Dose Calculations. *JADA* **139**:1237-1243; 2008.
7. Ludlow JB, Davies-Ludlow LE, Brooks SL. Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit. *Dentomaxillofac Radiol* **32**:229-234; 2003.
8. Jadu FM, Yaffe M, Lam EW. A comparative study of the effective radiation doses from cone beam computed tomography and plain radiography for sialography. *Dentomaxillofac Radiol* **39**:257-263; 2010.
9. Valentin J. *The 2007 recommendations of the International Commission on Radiological Protection*. Oxford, England: Elsevier; 2007.
10. Little MP. Cancer and non-cancer effects in Japanese atomic bomb survivors. *J Radiol Prot* **29**:A43-A59; 2009.
11. Cardis E. Epidemiology of accidental radiation exposures. *Environ Health Persp* **104** (Suppl 3):643-649; 1996.
12. Matteson SR, Joseph LP, Bottomley W, Finger HW, Frommer HH, Koch RW, Matranga LF, Nowak AJ, Rachlin JA, Schoenfeld CM, Strub D, Valachovic RW, White, SC. The report of the panel to develop radiographic selection criteria for dental patients. *Gen Dent* **39**:264-270; 1991.
13. American Dental Association Council on Scientific Affairs. The use of dental radiographs. *JADA* **137**:1304-1312; 2006.
14. Kantor ML. Trends in the prescription of radiographs for comprehensive care patients in U.S. and Canadian dental schools. *J Dent Educ* **57**:794-797; 1993.
15. Kantor ML. Use of radiology practice guidelines and compliance with accreditation standards in US and Canadian dental schools. *J Dent Educ* **79**:1532-1536; 2000.
16. Kantor ML. Longitudinal trends in the use of individualized radiographic examinations at dental schools in the United States and Canada. *J Dent Educ* **70**:160-168; 2006.
17. Daley TD, Wysocki GP, Pringle GA. Relative incidence of odontogenic tumors and oral and jaw cysts in a Canadian population. *Oral Surg, Oral Med, Oral Pathol* **77**:276-280; 1994.
18. Jing W, Xuan M, Lin Y, Wu L, Oiu L, Zheng X, Tang W, Qiao J, Tian W. Odontogenic tumours: a retrospective study of 1642 cases in a Chinese population. *Int J Oral Maxillofac Surg* **36**:20-25; 2007.
19. Osterne RLV, de Matos Brito RG, Nues Alves APV, Cavalcante RB, Sousa FB. Odontogenic tumors: a 5-year retrospective study in a Brazilian population and analysis of 3406 cases reported in the literature. *Oral Surg, Oral Med, Oral Pathol, Oral Radiol, Endod* **111**-474-481; 2011.
20. Tawfik MA, Zyada MM. Odontogenic tumors in Dakahlia, Egypt: analysis of 82 cases. *Oral Surg, Oral Med, Oral Pathol, Oral Radiol, Endod* **198**:e67-e73; 2010.
21. Gaitán-Cepeda LA, Quezada-Rivera A, Tenorio-Rocha F, Leyva-Huerta ER. Reclassification of odontogenic keratocyst as tumour. Impact on the odontogenic tumours prevalence. *Oral Dis* **16**:185-187; 2010.
22. McClean PM, Miller JW. Recommendations on administratively required radiographs. *JADA* **107**:61-63; 1983.
23. Zeichner SJ, Ruttimann, UE, Webber RL. Dental radiography: Efficacy in the assessment of intraosseous lesions of the face and jaws in asymptomatic patients. *Radiol* **162**:691-695; 1987.
24. Atchison KA, White SC, Flack VF, Hewlett ER. Assessing the FDA guidelines for ordering dental radiographs. *JADA* **126**:1372-1383; 1995.
25. Atchison KA, White SC, Flack VF, Hewlett ER, Kinder SA. Efficacy of the FDA selection criteria for radiographic assessment of the periodontium. *J Dent Res* **74**:1424-1432; 1995.
26. Flack VF, Atchison KA, Hewlett ER, White SC. Relationships between clinician variability and radiographic guidelines. *J Dent Res* **75**:775-782; 1996.
27. White SC, Atchison KA, Hewlett ER, Flack VF. Efficacy of FDA guidelines for prescribing radiographs to detect dental and intraosseous conditions. *Oral Surg, Oral Med, Oral Pathol, Oral Radiol, Endod* **80**:108-114; 1995.
28. SEDENTEXCT. Radiation protection: Cone beam CT for dental and maxillofacial Radiology. www.sedentexct.eu/files/guidelines_final.pdf
29. Ludlow JB, Platin E, Mol A. Characteristicks of Kodak Insight, an F-speed intraoral film. *Oral Surg, Oral Med, Oral Pathol, Oral Radiol, Endod* **91**:120-129; 2001.
30. Nair MK, Nair UP. An in-vitro evaluation of Kodak Insight and Ektaspeed Plus film with a CMOS detector for natural proximal caries: ROC analysis. *Caries Res* **35**:354-359; 2001.
31. Sheaffer JC, Eleazer PD, Scheetz JP, Clark SJ, Farman AG. A comparison of D-, E-, and F-speed conventional intraoral radiographic films in endodontic measurement. *Oral Surg, Oral Med, Oral Pathol, Oral Radiol, Endod* **93**:337-340; 2002.
32. Schulze RK, Nackat D, D'hoedt B. In vitro carious lesion detection on D-, E-, and F-speed radiographic films. *Oral Surg, Oral Med, Oral Pathol, Oral Radiol, Endod* **97**:529-534; 2004.
33. Woolhiser GA, Brand JW, Hoen MM, Geist JR, Pikula AA, Pink FE. Accuracy of film-based, digital, and enhanced digital images for endodontic length determination. *Oral Surg, Oral Med, Oral Pathol, Oral Radiol, Endod* **99**:499-504; 2005.
34. Farman AG, Farman TT. A comparison of 18 different x-ray detectors currently used in dentistry. *Oral Surg, Oral Med, Oral Pathol, Oral Radiol, Endod* **99**:485-489; 2005.
35. Wenzel A, Møystad A. Experience of Norwegian general dental practitioners with solid state and storage phosphor detectors. *Dentomaxillofac Radiol* **30**:203-208; 2001.
36. Wenzel A, Møystad A. Workflow with digital intraoral radiography: a systematic review. Acta Odontol Scand **68**:106-114;2010.
37. Hayakawa Y, Shibuya H, Ota Y, Kuroyanagi K. Radiation dosage reduction in general dental practice using digital intraoral radiographic systems. *Bull Tokyo Dent Coll* **38**:21-25; 1997.
38. Bahrami G, Hagstrøm C, Wenzel A. Bitewing examination with four digital receptors. *Dentomaxillofac Radiol* **32**:317-321; 2003.
39. Gijbels F, Jacobs R, Bogaerts R, Debaveye D, Verlinden S, Sanderlink G. Dosimetry of digital panoramic imaging. Part 1: patient exposure. *Dentomaxillofac Radiol* **34**:145-149; 2005.
40. Farman AG, Farman TT. Panoramic dental radiography using a charge-coupled device receptor. *J Digit Imaging* **11**(Suppl 1): 166-168; 1998.
41. Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique; preliminary results. *Eur Radiol* **8**:1558-1564; 1998.
42. Falk A, Lindhe JE, Rohlin M, Nilsson. Effects of collimator size of a dental X-ray unit on image contrast. *Dentomaxillofac Radiol* **28**:261-266; 1999.
43. Velders XL, van Aken J, van der Stelt PF. Absorbed dose to organs in the head and neck from bitewing radiography. *Dentomaxillofac Radiol* **20**:161-165; 1991.
44. Health Canada. Radiation Protection in Dentistry. *Recommended safety procedures for the use of dental x-ray equipment* (Safety Code 30). Minister of Public Works and Government Services, Canada; 1999.
45. National Council on Radiation Protection and Measurements. *Radiation Protection in Dentistry* (NCRP Report No. 145). Bethesda; 2004.
46. Rohlin M, White SC. Comparative means of dose reduction in dental radiography. *Curr Opin Dent* **2**:1-9; 1992.
47. Wood RE, Harris AMP, van der Merwe EJ, Nortjé CJ. The lead apron revisted: Does it reduce gonadal radiation dose in dental radiology? *Oral Surg, Oral Med, Oral Pathol* **171**:642-646; 1991.
48. Sikorski PA, Taylor KW. The effectiveness of the thyroid shield in dental radiology. *Oral Surg, Oral Med, Oral Pathol* **58**:225-236; 1984.
49. Image Wisely℠. www.imagewisely.org
50. Image Gently™. www.pedrad.org/associations/5364/ig/

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