

Safety Reports Series

No. 108

Radiation Protection in Dental Radiology



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IN DENTAL RADIOLOGY

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INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, establishes basic requirements for radiation protection and safety in medical exposures. IAEA Safety Standards Series No. SSG-46, Radiation Protection and Safety in Medical Uses of Ionizing Radiation, provides recommendations and guidance on fulfilling the requirements of GSR Part 3 with respect to medical uses of ionizing radiation, including dentistry. However, SSG-46 does not provide detailed guidelines specific to different modalities and techniques used in dental radiology.

Dentistry is an independent health care specialty and dental X ray equipment can be used in a variety of settings. Often dentists undertake X ray procedures for patients on the basis of their own clinical assessments. Therefore, dentists have a responsibility to justify medical exposure and optimize radiation protection for patients, and need specific and detailed guidelines. The available international guidelines for radiation protection in dental radiology are either outdated or only partly cover existing dental techniques, such as the use of cone beam computed tomography.

Participants in an IAEA meeting of experts held in February 2016 in Vienna, including representatives of leading international organizations and professional societies, concluded that there was a need for guidance on the justification and appropriateness of dental radiology imaging and the optimization of radiation protection and safety for patients, staff and the public, including details on safety aspects of dental facilities and equipment. The meeting participants requested that the IAEA consider leading the development of such a publication and approaching the international organizations represented at the meeting of experts to contribute to the development of this publication and endorse it.

The purpose of this Safety Report is to provide guidance on meeting the requirements for radiation protection and safety in the use of ionizing radiation in dentistry established in GSR Part 3. This guidance is intended for those using X rays to examine dental, maxillofacial and adjacent structures, including dental practitioners, referring medical practitioners, medical radiation technologists and other dental health professionals, as well as medical physicists, radiation protection experts and manufacturers of dental imaging equipment. Regulatory bodies may also use it for reviewing applications for the authorization and inspection of dental radiology facilities. This Safety Report is expected to be of use to experts participating in IAEA missions to advise on implementation of the requirements established in GSR Part 3 for the practice of dental radiology.

This Safety Report has been endorsed by the FDI World Dental Federation, the Image Gently Alliance, the International Association of DentoMaxilloFacial Radiology and the International Organization for Medical Physics.

The IAEA expresses its appreciation to all those who assisted in the drafting and review of this publication. The IAEA officer responsible for this publication was J. Vassileva of the Division of Radiation, Transport and Waste Safety.

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1. INTRODUCTION

1.1. BACKGROUND

X ray imaging is used extensively in dentistry to diagnose, plan and monitor treatments and to follow up pathoses. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)¹, approximately 13% of all diagnostic radiological examinations are performed in dentistry globally, with the annual frequency estimated to be 74 dental examinations per 1000 population globally, and 275 per 1000 population in health care level I countries² [1]. A report by the European Commission [2] estimates that dental X ray procedures make up 32% of all plain radiography procedures in Europe, with a mean value of 352 dental procedures per 1000 population per year. The 2014–2015 Nationwide Evaluation of X-Ray Trends survey in the United States of America (USA) [3] estimated that approximately 500 million intraoral radiographs and almost 4 million dental cone beam computed tomography (CBCT) examinations were performed in the USA yearly. These data suggest that globally at least 1.5 billion dental radiographic examinations are performed annually.

The imaging techniques used in dentistry can be categorized as intraoral radiography (i.e. bitewing, periapical and occlusal), panoramic radiography, cephalometric radiography and CBCT, with CBCT being the newest modality and associated with relatively high patient doses. Medical computed tomography (CT) imaging is also needed in some patients. Although the individual doses from dental procedures are small, because of the increasing frequency of dental imaging procedures, particularly of CBCT and CT, their contribution to collective dose is increasing and raises the need for more attention to be paid to radiation protection of patients. An important consideration is that dental radiological procedures are performed more frequently on younger individuals, who are generally at higher risk for radiation induced cancer than adults, and additional attention is needed regarding the justification and optimization of dental imaging procedures.

Dentistry is an independent health care specialty. Dental X ray equipment is often owned by dentists, who refer patients for X ray procedures performed by themselves. Therefore, dentists have a responsibility to justify medical exposure

¹ A list of abbreviations is provided at the end of this publication.

² Level I countries were defined by UNSCEAR as those in which there was at least one physician for every 1000 people in the general population [1].

and to optimize radiation protection of patients, and thus require specific and detailed guidance.

1.2. OBJECTIVE

IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [4], establishes basic requirements for radiation protection and safety in the medical use of ionizing radiation. IAEA Safety Standards Series No. SSG-46 , Radiation Protection and Safety in Medical Uses of Ionizing Radiation [5], provides specific recommendations on the diagnostic use of X rays but does not include specific guidance on dental radiology.

The purpose of this publication is to provide guidance on meeting the requirements of GSR Part 3 [4] for radiation protection and safety in the use of ionizing radiation in dental radiology, complementing and detailing the recommendations of SSG-46 [5]. It is important to note that, although this publication provides information on the key requirements of GSR Part 3 and the recommendations of SSG-46 related to dental radiology, the reader needs to refer to the original publications for a complete explanation.

The intended audience for this Safety Report is dentists, dental specialists, other dental professionals, referring medical practitioners (e.g. physicians, dentists), medical radiation technologists (e.g. radiographers), medical physicists, radiation protection experts, manufacturers and regulatory bodies. In addition to these professional groups, patients and the public might also find this publication a useful source of information.

1.3. SCOPE

This Safety Report includes guidelines for the justification of medical exposure, the appropriateness of dental radiological procedures and the optimization of radiation protection and safety for patients, carers and comforters, as well as for dental staff, with special attention paid to children and pregnant women. It also provides guidelines for dental radiological equipment, including considerations of quality assurance, dosimetry and operation.

The term ‘dental radiology’ as used in this publication includes all applications of X ray imaging in dentistry for examining dental, maxillofacial and adjacent structures.

1.4. STRUCTURE

Section 2 outlines the X ray imaging modalities and techniques used in dental radiology, namely intraoral, panoramic and cephalometric radiography, CBCT and conventional multidetector CT. Section 3 summarizes the main elements of the framework of radiation protection in dental radiology, including information on current knowledge about radiation risk and dose, basic principles of radiation protection, roles and responsibilities, education and training, and quality assurance and quality audit. Section 4 provides guidance on applying the principle of justification in dental radiology, with special consideration for children, women of reproductive age, carers and comforters. Section 5 describes the principle of optimization of radiation protection and safety as applied to medical exposure (i.e. exposure of patients, carers and comforters, and volunteers as part of a programme of biomedical research). Section 6 outlines the elements of radiation protection related to occupational and public exposure.

Appendix I to this publication describes and defines radiation dose quantities applicable to dental radiology, and Appendix II gives a summary of education and training objectives for different roles applicable to dentistry. The Annex presents a non-exhaustive selection of clinical indications for dental radiological imaging, derived from existing professional guidelines.

2. IMAGING MODALITIES AND TECHNIQUES USED IN DENTAL RADIOLOGY

2.1. INTRAORAL RADIOGRAPHY

Intraoral radiographs, in which the image receptor is placed in the patient's oral cavity, are the most common type of radiograph used in dentistry. They are divided into the following categories:

- (a) Bitewing radiographs, which show the crown of a tooth and the adjacent alveolar crests;
- (b) Periapical radiographs, which show the entire tooth and surrounding bone;
- (c) Occlusal radiographs, which cover a larger area of maxilla or mandible.

All intraoral radiographs are produced with the same dental X ray unit, which can be fixed, mobile or portable. Different types of image receptor can be used, such as film, photostimulable phosphor and solid state receptors.

2.1.1. Dental X ray units

2.1.1.1. Fixed units

Fixed dental X ray units consist of a tube head attached to an adjustable arm mounted to a wall, ceiling or floor. Adjustment of the arm and of the angulation of the tube head allows for exposures for any type of projection geometry used in intraoral radiography.

2.1.1.2. Mobile units

Mobile dental X ray units consist of a tube head attached to an adjustable arm mounted to a mobile unit. Adjustment of the arm and of the angulation of the tube head allows for exposures for any type of projection geometry used in intraoral radiography.

2.1.1.3. Portable (handheld) units

Portable dental X ray units were introduced in the early 1990s for specific situations in which this mobile function is needed (see Section 5). Owing to the proximity of the operator³, special considerations for occupational protection apply, including the need for backscatter shielding (see Section 6).

2.1.2. Intraoral image receptors

2.1.2.1. Film receptors

Intraoral films come in various sizes, according to the size of the region of interest (Table 1). For adults, size 2 is usually used, with size 1 often used for periapical radiographs of the anterior teeth. For children, sizes 1 and 0 can be used. For an extended bitewing radiograph, size 3 is used. Size 4 is specifically available for occlusal radiographs.

X ray films are characterized by their radiographic speed, which is determined by their sensitivity to radiation. Intraoral films are available in D and E/F speeds, with the former falling out of clinical use because of the higher patient exposure needed (see Section 5). Intensifying screens are not used in intraoral radiography owing to the loss in spatial resolution and the non availability of suitable cassettes.

³ The term ‘operator’ is used in a general sense in this publication. The operator is usually a medical radiation technologist, but may sometimes be a dentist, dental specialist or other dental professional who is authorized to operate dental X ray equipment.

TABLE 1. INTRAORAL FILM SIZES

Size 0	22 mm × 35 mm
Size 1	24 mm × 40 mm
Size 2	30.5 mm × 40.5 mm
Size 3	27 mm × 54 mm
Size 4	57 mm × 76 mm

Intraoral films are placed in the patient's mouth using a generic holding or beam aiming device to ensure proper exposure of the film and avoid beam misalignment ('cone cut'). Failure to place the film correctly might necessitate the exposure to be repeated.

After exposure, films are developed and fixed, and can be mounted for viewing. Film processing can be manual or automatic.

2.1.2.2. *Digital receptors*

Different types of digital image receptor are used in intraoral radiography. Although their spatial resolution is lower than that of film, they exhibit wider latitude (i.e. range of detectable exposures). Furthermore, solid state receptors can provide a diagnostic image at a shorter exposure time than photostimulable phosphor and film receptors.

Another advantage of digital images is that different types of software based image processing can be applied, and images can be transferred, stored and backed up.

2.1.2.2.1. Photostimulable phosphor receptors

Photostimulable phosphor receptors, also referred to as image plates, form a latent image after X ray exposure. This latent image can be read out and digitized using laser light stimulation, after which the plate can be reused. The use of photostimulable phosphor receptors is also known as computed radiography.

Generally, receptor holders used for films can also be used for photostimulable phosphor receptors. However, whereas films can be gently bent in the patient's mouth when needed, bending a photostimulable phosphor receptor may damage it.

2.1.2.2.2. Solid state receptors

At present, two types of solid state receptor are used in intraoral radiography: the charge coupled device (CCD) and the complementary metal oxide semiconductor (CMOS) receptor. A CCD consists of a silicon wafer arranged in a matrix of pixels. Exposure to X rays induces local charges within the matrix, which can be read out and digitized. CMOS receptors are also silicon based, but each pixel is individually connected to a transistor. The use of solid state receptors is referred to as digital radiography.

Compared with film and photostimulable phosphor receptors, solid state receptors can be bulky and they are always inflexible. In addition, they require an active computer connection using a cable, although wireless systems have become more prevalent recently.

2.1.3. Bitewing radiography

Bitewing or interproximal radiographs are primarily used in early detection of caries, and in the detection of secondary caries below restorations. Furthermore, they can be used for evaluation of the periodontal bone.

Bitewing radiographs are acquired with the X ray beam parallel to the occlusal plane (usually angled around 10° downwards to avoid overlap of upper and lower cusps). Image receptors are usually oriented horizontally, unless the patient has extensive alveolar bone loss, in which case vertical receptors can be used.

2.1.4. Periapical radiography

Two projection techniques are used in periapical radiography. The preferred technique is the paralleling technique. When proper placement of the image receptor for the paralleling technique is not possible (e.g. owing to rigidity of the receptor in combination with anatomical limitations), the rectangular technique can be used.

2.1.4.1. *Paralleling technique*

In this technique (also referred to as the right angle or long cone technique), the image receptor is parallel to the long axis of the teeth. The X ray beam is perpendicular to both the teeth and the image receptor. As a result, geometric distortion is minimal.

2.1.4.2. *Rectangular technique*

For solid state receptors, a parallel position to the tooth's main axis in the maxilla is usually not feasible [6]; therefore, a 'rectangular technique' is a good compromise. The image receptor is oriented perpendicular to the central X ray by means of an aiming device, without any specifications regarding the angle between tooth and receptor.

2.1.4.3. *Bisecting angle technique*

In this technique, the image receptor is placed as close to the lingual aspect of the teeth as possible, thereby forming an angle with the long axis of the teeth. The X ray beam is aimed perpendicularly to the bisector between the tooth axis and image receptor. The exact amount of X ray beam angulation needed depends on the tooth being imaged.

2.1.5. Occlusal radiography

In occlusal radiography, the image receptor is placed between the occlusal surfaces of the teeth, and the X ray beam is directed at a steep angle through the (upper or lower) jaw. Occlusal radiographs can be divided into maxillary occlusals or mandibular occlusals. Partial occlusal radiographs displaying only one side of the respective jaw are also applied.

2.2. PANORAMIC RADIOGRAPHY

A panoramic radiograph provides an overview of the complete mandible and maxilla, and of the supporting structures, including the temporomandibular joints. During panoramic image formation, the X ray tube and image receptor rotate around the patient, usually with a continuously varying centre of rotation. Owing to the combined movement of the image receptor — which undergoes both a rotational movement and a translation in the opposite direction, effectively acquiring one vertical line of the image at a time — a small curved area within the patient is projected sharply; this is referred to as the focal trough. In the case of a solid state receptor, the readout speed is matched to that at which the vertical fan beam traverses the objects inside the focal trough. The focal trough follows the dental arch, ensuring that the teeth and surrounding bone are well defined on the panoramic radiograph. Structures outside the focal trough are blurred and, depending on their distance from the focal trough, can be magnified or otherwise distorted beyond recognition.

Before panoramic image acquisition, the patient is positioned using proper head positioning and orientation. Positioning protocols vary between panoramic units; accurate patient positioning is essential given the limited width of the focal trough, especially in the anterior region.

The image receptor in panoramic radiography can be film, a photostimulable phosphor receptor or a solid state receptor. In the case of film, intensifying screens are used to increase the sensitivity of the film to X rays, thereby reducing the required exposure.

2.3. CEPHALOMETRIC RADIOGRAPHY

Cephalometric radiographs are two dimensional (2-D) extraoral radiographs acquired with a cephalostat, which is a head positioning device that enables a standardized orientation of the X ray beam, patient head and image receptor. Both lateral cephalometric radiographs and posteroanterior cephalometric radiographs are used in dentistry, with the former being used far more frequently.

Cephalometric radiographs are acquired using a relatively long focus to skin distance (150–200 cm). Typically, cephalometric radiographic units are incorporated into panoramic radiography units (as well as some hybrid CBCT–panoramic units), using either a separate image receptor (film, photostimulable phosphor or solid state receptors) or the same receptor that is used for panoramic imaging (which can then be moved between panoramic and cephalometric ‘slots’). When the latter is a line detector, it is moved in an either vertical or horizontal linear trajectory in coordination with the fan beam so that the image is captured sequentially.

2.3.1. Lateral cephalometric radiography

For lateral cephalometric radiograph acquisition, the X ray beam is directed perpendicular to both the midsagittal plane and the image receptor, with the left side of the patient’s head usually placed toward the receptor. A wedge filter can be placed over the anterior side of the X ray beam to act as an additional X ray absorber; this allows visualization of the soft tissues of the face.

A dedicated analysis of cephalometric landmarks is usually applied to these radiographs (e.g. during orthodontic treatment). On the basis of skeletal (e.g. porion, sella, nasion), dental (e.g. root tips, incisal edges) and soft tissue (e.g. glabella, tip of nose) landmarks, the relationship between anatomic structures can be evaluated both before and during treatment.

2.3.2. Posteroanterior cephalometric radiography

Posteroanterior cephalometric radiographs are acquired with the X ray tube at the back (posterior) side of the patient, using the same equipment as lateral cephalometric radiographs. The X ray beam is perpendicular to both the coronal plane and the image receptor. The patient's head is in a natural position, oriented so that the Frankfort plane⁴ is horizontal and perpendicular to the image receptor.

Posteroanterior cephalometric radiographs can be used to evaluate facial symmetry in the coronal plane, for example before, during or after orthognathic surgery (also known as 'corrective surgery').

2.4. CONE BEAM COMPUTED TOMOGRAPHY

CBCT is a CT imaging technique that uses a 2-D detector array instead of (rows of) arched detectors. Early generation CBCT devices used image intensifier detectors with a circular active area; as a result, the X ray beam was cone shaped. Currently, rectangular flat panel detectors are used in CBCT, so the X ray beam is actually pyramid shaped. Whereas alternative names have been proposed to overcome this inherent terminological flaw (e.g. digital volume tomography, flat panel CT), CBCT is generally accepted.

2.4.1. Image acquisition

A CBCT unit consists of an X ray tube and a flat panel detector connected via a rigid arm, which can be rotated in the axial plane using a step motor. Almost all CBCTs allow for the patient to be standing or seated, with a few units having the patient in a supine position.

The acquired images used for CBCT reconstruction consist of a series of 2-D radiographic projections, produced during a rotation of 360° or less of the X ray tube and flat panel detector. The volume of the patient that is reconstructed, referred to as the field of view (FOV), consists of a three dimensional (3-D) image based on the combined information from the 2-D projections.

The FOV in CBCT is usually cylindrical in shape, and its size can therefore be expressed by its diameter and height. The X ray beam collimation depends on the CBCT unit, resulting in FOVs ranging from a few centimetres in height and diameter, e.g. covering only one or two teeth, to FOVs covering (most of) the

⁴ The Frankfort plane corresponds to a line connecting the superior edge of the external auditory meatus and the most inferior point of the infraorbital margin.

head. Most CBCT units allow for different selectable FOV options, depending on the clinical application (see Section 5).

Usually, a few hundred projections are acquired during a CBCT acquisition. Owing to the limited temporal resolution of CBCT detectors, the acquisition of the projections (scan time) is typically 10–20 s, although shorter and longer scan times are used as well. The majority of CBCT units use a pulsed X ray exposure, resulting in exposure times of a few seconds.

2.4.2. Image reconstruction

Before image reconstruction, different types of correction are applied to the 2-D projections. Detector offset is corrected by a series of ‘dark’ projections, acquired without X ray exposure. Gain calibration is performed by acquiring a series of homogeneous exposures with no object between the X ray source and detector. In addition, values for defective pixels can be interpolated, and residual signals (‘afterglow’) can be corrected.

At the time of writing, the reconstruction technique used in CBCT is almost exclusively based on the modified filter backprojection principle, also referred to as the Feldkamp–Davis–Kress algorithm [7]. The 3-D FOV is sectioned into cubic voxels with a predetermined voxel size (expressed as the length of any side of the voxel). For each projection, the inverse of the signal at each detector pixel is assigned to each voxel along a line connecting the focal spot with that detector pixel. The resulting backprojections are then averaged. Seeing that the result of backprojection is blurry, a filter is applied to the images during reconstruction in order to retain sharpness. The choice of filter affects the sharpness and noise of the reconstructed image.

CBCT reconstruction using filter backprojection can be performed in a few minutes. Iterative reconstruction techniques, in which a ‘best fit’ reconstruction is produced in several repetitive steps involving forward and backprojections, are not common in clinical CBCT yet owing to the increased computational time required.

Recently, certain CBCT units have incorporated metal artefact reduction during reconstruction. Owing to the ubiquity of high density metal objects in the patient’s mouth, such as fillings, crowns and dental implants, CBCT images can contain metal artefacts that may affect diagnostic image quality. The use of metal artefact reduction can reduce the appearance of these artefacts, but the processing of the CBCT image during metal artefact reduction can interfere with its diagnostic capability. The validity of metal artefact reduction in CBCT is yet to be demonstrated on a clinical level.

2.4.3. Image visualization

A panoramic view can be generated based on a manually, semiautomatically or automatically drawn curve along the dental arch. A series of slices cross sectional to this curve can also be generated, allowing the user to browse along the dental arch while showing the buccal/labial and lingual/palatal aspects of the jaw bones in each slice.

For all types of 2-D slice, the slice thickness and slice interval can be selected. The former is defined as the thickness of a slice in the direction perpendicular to it, whereas the latter is the distance between consecutive slices in a stack. While the native slice thickness is equal to the voxel size in CBCT, higher slice thickness values can be selected, essentially resulting in consecutive slices being averaged. Although noise is decreased at an increased slice thickness, spatial resolution is reduced as well. The slice interval does not affect the noise or spatial resolution within a given slice, but might affect the visualization of small structures and pathosis, which may be hidden between slices if the slice interval is too large.

The 3-D FOV can be visualized in different ways. A multiplanar reformatting consists of three perpendicular slices along the coronal, sagittal and axial planes, allowing the user to navigate along each plane. It is also possible to produce slices at other ('oblique') angles.

Different types of 3-D visualizations can aid the user. Volume and surface renderings are based on a (pre-set or manually selected) threshold, determining which tissues are displayed on the rendered image; typically, only the bone and teeth are shown by choosing a threshold value in between the grey value ranges for soft tissue and bone. Maximum and minimum intensity projections provide a projectional view of the FOV in which, for each projection line, only the voxel with the highest or lowest grey value is shown, respectively.

2.5. CONVENTIONAL MULTIDETECTOR COMPUTED TOMOGRAPHY

Whereas CT is widely used in medical imaging, its use in dentistry has gradually declined since the introduction of CBCT. It is now primarily used for 3-D imaging when CBCT is not available, or for specific applications for which it provides superior diagnostic capability compared with CBCT (see Section 4).

While reconstructed CT and CBCT images look largely similar, there are a few essential differences between the two techniques. In CT, the patient is always in a supine position, lying on a table that is controlled by the CT unit. Modern CT equipment has several adjacent detector rows, and is thus capable

of acquiring several slices in a single rotation of tube and detectors; therefore, CT units are referred to as multidetector CT (MDCT) units. MDCT units with 64 and 128 detector rows have become common, but scanners acquiring 512 slices and beyond are currently in use as well. The increased width of the X ray beam for the MDCT scanners, which results in a shape that resembles a pyramid rather than a fan, has led to renewed comparisons with CBCT. However, there are still several distinctive properties, and these are summarized in Table 2.

TABLE 2. OVERVIEW OF DIFFERENCES BETWEEN CURRENT GENERATION CBCT AND MDCT SYSTEMS

	CBCT	MDCT
X ray tube	Single X ray source, with a single beam energy being used almost exclusively	Dual energy/dual source and spectral CT currently in clinical use (but not commonly used for dental applications)
X ray beam	X ray beam collimated along every aspect to as small as a few centimetres in height or width	Wider X ray beam, which fully covers the head; only the scan length is variable
Detector	Flat panel detector with small detector elements (pixels), but limited detector sensitivity and speed No detector side collimation, resulting in large amounts of scatter	High speed detectors and detector elements are larger Scatter reduction along longitudinal axis possible through the use of collimation between adjacent rows of detectors
Exposure	Automatic exposure control not commonly used Relatively long scan time (typically 10–20 s) Typically, low tube current settings (≤ 10 mA)	Tube current modulation, both angular and longitudinal, is almost ubiquitous Subsecond scans possible for modern equipment
Reconstruction	Usually based on filtered backprojection	Iterative reconstruction techniques commonly used for dose reduction and improved image quality

TABLE 2. OVERVIEW OF DIFFERENCES BETWEEN CURRENT GENERATION CBCT AND MDCT SYSTEMS (cont.)

	CBCT	MDCT
Image quality	Relatively noisy images, with limited contrast in the soft tissue density range No reliable conversion between greyscale values and attenuation/density (i.e. Hounsfield units are not applicable)	High bone and soft tissue contrast possible; noise typically lower than in CBCT, even for sharp reconstruction kernels Greyscale values calibrated as Hounsfield units according to X ray attenuation
Other	Relatively low cost and smaller physical footprint	Relatively high cost; requires a larger room and more stringent radiation protection measures

Note: CBCT — cone beam computed tomography; MDCT — mutidetector computed tomography.

3. FRAMEWORK FOR RADIATION PROTECTION IN DENTAL RADIOLOGY

3.1. RADIATION RISK

There are two main biological effects of radiation: stochastic effects, which relate to the potential for future harm to the tissue and the body, and tissue reactions (deterministic effects) with a more immediate suprathreshold dose related severity [8].

Somatic stochastic effects refer to the potential for cancer occurrence and owe their name to the random (stochastic) nature of the interaction of radiation with matter. Apart from somatic effects, ionizing radiation has the potential to cause another type of stochastic effect called genetic effects (‘hereditary anomalies’). However, such effects have so far not been observed in humans, although they have been documented in non-human species. In dental radiology, somatic stochastic effects are possible. Stochastic effects are thought to have no dose threshold for occurrence (the ‘linear, non-threshold theory’). Theoretically, a single mutation of the DNA might cause a carcinogenic effect. However, it is important to understand that many cells might undergo mutation and yet no cancer

will result. In reality, cellular repair mechanisms greatly reduce this possibility. However, the probability of occurrence of stochastic effects is considered to be proportional to the imparted dose, no matter how low the dose might be. The probability of occurrence of stochastic effects is assumed to be additive and is proportional to the dose, whereas the severity of the cancer does not depend on the amount of imparted dose.

Tissue reactions happen when the dose exceeds a specific threshold. Cataract formation, hair loss or skin injuries are examples of such tissue reactions. The severity of tissue reactions, rather than their probability of occurrence, is proportional to the dose imparted to the tissue. In dental radiology, tissue reactions are very unlikely to happen except in specific situations, for example related to accidents due to equipment malfunction or personnel error, or potentially cataract formation due to high dose exposures.

The effects of radiation on the developing fetus depend on the stage of pregnancy and the amount of absorbed dose [9]. Radiation risks are most significant during organogenesis and the early fetal period, are somewhat reduced in the second trimester, and are at their lowest level in the third trimester [9]. Relatively high exposure in the first two weeks following conception is most likely to result in failure to implant or to an undetectable miscarriage; malformations are unlikely or very rare. During the period of major organogenesis starting from the third week after conception, doses above some threshold might cause tissue reactions (e.g. mental retardation, organ malformation), especially in the organs under development at the time of exposure, with a maximal radiosensitivity of the developing central nervous system during weeks 8–15. This threshold is considered to be higher than what is reached in most diagnostic X ray imaging procedures [9].

3.2. RADIATION DOSE

Special dosimetric quantities have been developed for radiation protection purposes.

3.2.1. Fundamental dose quantities

The fundamental quantities for radiation protection purposes, recommended by the International Commission on Radiation Units and Measurements (ICRU) and the International Commission on Radiological Protection (ICRP), and adopted in IAEA publications are the following:

- (a) Absorbed dose, D , with unit gray (Gy);

- (b) Kerma, K , with unit gray;
- (c) Equivalent dose in an organ or tissue, with unit sievert (Sv);
- (d) Effective dose, with unit sievert.

The definitions and additional explanations provided in Appendix I are based on Refs [8, 10–13].

3.2.2. Specific quantities for patient dose estimation

It is imperative to have a well defined, accurate and easy to use method for patient dose estimation. Different types of X ray equipment can be used for imaging in dental radiology. Each of these systems has different modes of operation and means of image production. Therefore, different dosimetric quantities have to be used to measure patient dose. The quantity used in practice depends on the imaging modality (Table 3). The definitions and explanations of the quantities listed in Table 3 are given in Appendix I [11, 14, 15].

TABLE 3. OVERVIEW OF SPECIFIC QUANTITIES FOR PATIENT DOSE ESTIMATION IN DENTAL RADIOLOGY

Dose quantity	Modality	Symbol	Common abbreviation	Unit
Incident air kerma	Intraoral radiography	K_i	IAK	mGy
Entrance surface air kerma	Intraoral radiography	K_e	ESAK, ESD	mGy
Air kerma–area product	Panoramic radiography, cephalometric radiography, CBCT	P_{KA}	KAP, DAP	mGy·cm ²
Air kerma–length product ^a	CT, panoramic radiography	P_{KL}	DLP	mGy·mm
CT air kerma index	CT, CBCT	C	CTDI	mGy

^a Also termed ‘dose width product’ for dental panoramic radiography.

Note: CBCT — cone beam computed tomography; CT — computed tomography.

3.3. BASIC PRINCIPLES OF RADIATION PROTECTION

This section provides a brief summary of the basic principles of radiation protection as defined by the ICRP [8] and the IAEA (in IAEA Safety Standards Series Nos SF-1 [16] and GSR Part 3 [4]), and detailed with respect to the use of ionizing radiation in medicine in Refs [17, 18] and in SSG-46 [5].

The three general principles of radiation protection are justification, optimization and the application of dose limits. The application of radiation protection principles and the requirements for radiation protection and safety differ according to the category of exposure, so it is important that the exposure of persons is categorized correctly.

As defined in GSR Part 3 [4], medical uses of ionizing radiation involve the following three categories of exposure:

- (a) Medical exposure: “[e]xposure incurred by patients for the purposes of medical or dental diagnosis or treatment; by carers and comforters; and by volunteers subject to exposure as part of a programme of biomedical research”.
- (b) Occupational exposure: “[e]xposure of workers incurred in the course of their work”.
- (c) Public exposure: exposure of members of the public, such as in waiting rooms of radiological facilities.

For example, a dentist performing a dental X ray would be considered to be occupationally exposed, whereas a dentist or other staff member working in the same dental clinic but not involved in performing X rays would be considered to be subject to public exposure.

The term ‘carer and comforter’ is defined in GSR Part 3 [4] as “[p]ersons who willingly and voluntarily help (other than in their occupation) in the care, support and comfort of patients undergoing radiological procedures for medical diagnosis or medical treatment.” Carers and comforters are subject to medical exposure — for example, a parent supporting a child during a dental X ray — whereas a person accompanying a patient but waiting outside the X ray room would be considered a member of the public and hence subject to public exposure.

3.3.1. Justification

Justification of medical uses of ionizing radiation involves consideration of all three categories of exposure — medical exposure, occupational exposure and public exposure.

Paragraph 2.10 of SSG-46 [5] states:

“From an occupational exposure and public exposure perspective, the practice should be justified. This aspect of justification is the process of determining whether the use of the given radiological procedure is expected to yield benefits to the individuals who undergo the procedure and to society that outweigh the harm (including radiation detriment) resulting from the procedure. In almost all cases, the occupational exposure and public exposure considerations in justification are overshadowed by the justification of medical exposure (see para. 2.11). While a medical radiological procedure is expected to do more good than harm to the patient, account should also be taken of the radiation detriment from the exposure of the staff of the medical radiation facility and of other individuals.”

The comparison of detriments and benefits often goes beyond the consideration of protection and safety, and involves economic, societal and environmental factors. For medical exposure, a special approach to justification is applied, considering that individuals (primarily patients) are deliberately, directly and knowingly exposed to radiation for their benefit.

Paragraph 2.11 of SSG-46 [5] states:

“The application of the justification principle to medical exposure requires a special approach, using three levels (the three-level approach). As an overarching justification of medical exposure, it is accepted that the proper use of radiation in medicine does more good than harm (level 1). At the next level (level 2), generic justification of a given radiological procedure should be carried out by the health authority in conjunction with appropriate professional bodies. This applies to the justification of current technologies and techniques and new technologies and techniques as they evolve. The decisions should be reviewed from time to time, as more information becomes available about the risks and effectiveness of the existing procedure and about new procedures. Those radiological procedures that are no longer justified should be removed from medical practice. The possibility of accidental or unintended exposure should also be considered at level 2. For the final level of justification (level 3), the application of the radiological procedure to a given individual patient should be considered. The specific objectives of the exposure, the clinical circumstances and the characteristics of the individual involved should be taken into account. National or international referral guidelines, developed by professional bodies together with health authorities, are required to be used (para. 3.158 of GSR Part 3...).”

Specific guidance on applying the principle of justification in dentistry is provided in Section 4.

3.3.2. Optimization

Paragraph 1.15 of GSR Part 3 [4] requires the following:

“The optimization of protection and safety, when applied to the exposure of workers and members of the public, and carers and comforters of patients undergoing radiological procedures, is a process for ensuring that the likelihood and magnitude of exposures and the number of individuals exposed are as low as reasonably achievable, with economic, societal and environmental factors taken into account. This means that the level of protection would be the best possible under the prevailing circumstances. Optimization is a prospective and iterative process that requires both qualitative and quantitative judgements to be made.”

As defined in GSR Part 3 [4], “[f]or medical exposures of patients, the optimization of protection and safety is the management of the radiation dose to the patient commensurate with the medical purpose.” In diagnostic medical exposure, this means “keeping the exposure of patients to the minimum necessary to achieve the desired diagnostic...objective” [5].

According to para. 1.16 of GSR Part 3 [4], “[t]oo low a radiation dose could be as bad as too high a radiation dose, in that the consequence could be that...the images obtained are not of suitable diagnostic quality.”

Specific guidance on optimization in dental radiology is provided in Section 5 for medical exposure and in Section 6 for occupational and public exposure.

3.3.3. Dose limits

A dose limit is defined as “[t]he value of the effective dose or the equivalent dose to individuals in planned exposure situations that is not to be exceeded” [4]. Dose limits apply to occupational exposure and public exposure. More details are given in Section 6. Dose limits do not apply to medical exposure (i.e. exposure of patients, carers or comforters and volunteers as part of a programme of biomedical research).

3.4. ROLES AND RESPONSIBILITIES FOR RADIATION PROTECTION

There are various levels of roles and responsibilities when the issue of radiation protection in dental radiology is addressed, starting from the government and coming down to the level of end users and patients. More detailed guidance on the roles and responsibilities of different stakeholders based on the requirements in GSR Part 3 [4] is provided in SSG-46 [5]. The information here summarizes the main points applicable to dental radiology.

3.4.1. Government

Paragraph 2.30 of SSG-46 [5] states:

“The government has a responsibility to facilitate and ensure that the health authority, the relevant professional bodies and the radiation protection regulatory body communicate and cooperate in working towards establishing the infrastructure necessary for radiation protection and safety in medical uses of ionizing radiation.”

3.4.2. Health authority

The roles and responsibilities of the health authority for radiation protection are stated in paras 2.52 and 2.53 of SSG-46 [5]:

“All medical facilities should be authorized by the health authority to ensure that the facility meets the applicable requirements for quality of medical services. When the medical facility uses ionizing radiation, authorization for medical practice and health care should be granted by the health authority only if the radiation safety requirements are met.... Coordination and collaboration between the health authority and the radiation protection regulatory body should ensure radiation protection and overall safety of the medical facility.”

“Radiation protection and safety in medical uses of ionizing radiation should be assured by the proper specialization of health professionals, namely that only health professionals with the appropriate competencies can take on roles that include specific responsibilities for radiation protection and safety. The health authority has responsibilities in providing policy and guidance with respect to health profession specialties and their subspecialties, including on the scope of practice, and requirements for competence.”

The health authority has a particular role in the application of the radiation protection requirements for justification. Paragraphs 2.59 and 2.60 of SSG-46 [5] state:

“National or international referral guidelines should be used as an important tool in the application of the process of justification of medical exposure for an individual patient. The health authority should support the relevant professional bodies in developing and implementing evidence based referral guidelines.”

“The health authority should also encourage the development of, and promote the implementation of, practice guidelines and technical standards developed by professional bodies.”

These issues related to dental radiology are discussed in more detail in Section 4.

3.4.3. Regulatory body

The regulatory functions of the regulatory body include establishing requirements and guidelines, authorizing and inspecting facilities and activities, and enforcing legislative and regulatory provisions. Requirement 6 of GSR Part 3 [4] for a graded approach has particular significance for medical radiation facilities because of the wide variation in their complexity. Paragraph 2.71 of SSG-46 [5] recommends that “[r]egulatory bodies should consider which form of authorization is appropriate for a given type of medical radiation facility.” In accordance with the requirements of GSR Part 3 [4], authorization can be granted through either registration — that is, “[a] form of authorization for practices of low or moderate risks whereby the person or organization responsible for the practice has, as appropriate, prepared and submitted a safety assessment of the facilities and equipment to the regulatory body” — or a licence — that is, “[a] legal document issued by the regulatory body granting authorization to perform specified activities relating to a facility or activity” [4].

SSG-46 [5] further stipulates the typical practices that are amenable to registration and recommends that for facilities performing dental radiography (without CBCT), authorization through registration may be acceptable without the need for licensing. According to para. 2.73 of SSG-46 [5]:

“No matter which form of authorization is used for a medical radiation facility, a crucial step prior to the granting of it is that the regulatory body ascertains the credentials of key personnel with responsibilities for radiation

protection and safety, including radiological medical practitioners, medical radiation technologists, medical physicists and RPOs [radiation protection officers]. This step cannot be overemphasized, as all aspects of radiation protection and safety in medical uses of ionizing radiation depend ultimately on the competence of the personnel involved”⁵.

3.4.4. Professional bodies

In the case of dental radiology, examples of professional bodies that could play a role in radiation protection include dentists, dental radiologists, medical physicists and medical radiation technologists.

Paragraph 2.62 of SSG-46 [5] states:

“Professional bodies...represent the collective expertise of the given health profession and specialty and, as such, they should also play a role in contributing to radiation protection and safety in medical uses of ionizing radiation. This includes setting standards for education, training, qualifications and competence for a given specialty, and setting technical standards and giving guidance on practice.”

Paragraph 2.65 of SSG-46 [5] further recommends:

“Professional bodies should take the lead in the development of referral guidelines (also called appropriateness criteria in some States) for use in justification of medical exposure for an individual patient... It might not be possible for every State to develop its own referral guidelines. The significant work of a number of professional bodies around the world could be utilized by many other States through adoption or adaptation by the local professional bodies”.

Furthermore, professional bodies, in partnership with the health authority and the radiation protection regulatory body, have a role with respect to the establishment of a comprehensive quality assurance programme for medical exposure (see Sections 3.6 and 5.2) and diagnostic reference levels (DRLs) (see Section 5.3). They also have a role in disseminating information on standards and guidance relevant to radiation protection and safety in dental radiology [4, 5].

⁵ A radiation protection officer is a person technically competent in radiation protection matters relevant for a given type of practice who is designated by the registrant, licensee or employer to oversee the application of regulatory requirements [4].

3.4.5. Medical radiation facility

As defined in GSR Part 3 [4], a medical radiation facility is “[a] medical facility in which radiological procedures are performed.” This term covers all possible settings in which medical uses of ionizing radiation take place, including dental practices.

Paragraphs 2.89 and 2.90 of SSG-46 [5] state:

“In medical uses of ionizing radiation, the prime responsibility for radiation protection and safety rests with the person or organization responsible for the medical radiation facility, normally referred to as the registrant or licensee. Almost all the requirements of GSR Part 3...applicable to a medical radiation facility for ensuring radiation protection and safety in medical uses of ionizing radiation place the responsibility on the registrant or licensee (and on the employer, in the case of occupational radiation protection).”

“However, medical uses of ionizing radiation involve a multidisciplinary team led by a health professional who often is not the registrant or licensee of the authorized medical radiation facility. Because of the medical setting in which such exposures occur, primary responsibility for radiation protection and safety for patients lies with the health professional responsible for the radiological procedure, who is referred to in GSR Part 3...and in this Safety Guide as the radiological medical practitioner. The term ‘radiological medical practitioner’ is the generic term that GSR Part 3...uses to refer to a health professional with specialist education and training in medical uses of radiation, who is competent to perform independently or to oversee procedures involving medical exposure in a given specialty.”

A dentist or other dental health care professional, such as an oral hygienist or dental therapist, might act as a radiological medical practitioner, subject to training and competence. Other specialists with specific roles for radiation protection are medical radiation technologists and medical physicists. For more guidance see Section 3.5 and Ref. [5].

3.4.6. Suppliers of equipment and software, maintenance and servicing organizations

Suppliers of dental radiological equipment and developers of software that could influence the delivery of the medical exposure have responsibilities with respect to design and performance. Maintenance and servicing of dental radiological equipment are usually performed by an engineer or technician

employed either by a company offering such services (who may also be the manufacturer or the vendor) or by the medical facility itself (e.g. as part of an engineering, biomedical or clinical engineering, or service department).

More guidance is provided in Ref. [5].

3.4.7. Patients

Paragraph 2.117 of SSG-46 [5] states:

“Patients are increasingly being involved in the decision making processes concerning their own health care, and this includes medical uses of ionizing radiation. Paragraph 3.151(d) of GSR Part 3...requires that the registrant or licensee for the medical radiation facility ensure that the patient be informed, as appropriate, of both the potential benefit of the radiological procedure and the radiation risks. Information should be provided in an understandable format (e.g. verbally, leaflets, posters and web sites) and in a timely manner. The level of information should be commensurate with the complexity, dose and associated risks; and for some radiological procedures, informed consent may be required, either written or verbal. Female patients of reproductive capacity should be informed about the risk to the embryo or fetus from radiological procedures for either diagnosis or therapy.”

3.4.8. Management system for radiation protection and safety

The use of X ray imaging is just one aspect of dental practice, and radiation risk is just one of the risks for patients and staff to be considered in planning, implementing and managing dental facilities, and in particular dental radiological facilities. As recommended in paras 2.138 and 2.139 of SSG-46 [5], “[t]he application of the radiation protection and safety requirements of GSR Part 3... should complement the wider set of requirements that ensure good medical practice”, and should be “effectively integrated into the overall management system of a given organization.” IAEA Safety Standards Series No. GSR Part 2 [19] and GSR Part 3 [4] establish detailed requirements for the protection and safety elements of the management system, for promoting a safety culture and for taking human factors into account. SSG-46 [5] emphasizes that “effective management for radiation protection and safety requires commitment from the highest level of management in the medical radiation facility, including the provision of all the required resources.” This also applies to dental practice.

3.5. EDUCATION AND TRAINING

Safe use of ionizing radiation in dentistry depends strongly on the skills and expertise of the health professionals involved, as the patient is necessarily and deliberately exposed to radiation. Therefore, the education, training, qualification and competence of the health professionals involved are of the utmost importance in this respect. Paragraph 2.21 of GSR Part 3 [4] states that “[t]he government shall ensure that requirements are established for:...Education, training, qualification and competence in protection and safety of all persons engaged in activities relevant to protection and safety”. Paragraph 2.22 of GSR Part 3 [4] continues that “[t]he government shall ensure that arrangements are in place for the provision of the education and training services required for building and maintaining the competence of persons and organizations that have responsibilities relating to protection and safety.”

GSR Part 3 requires that the health professionals involved in medical exposure have specialist education and training in the particular discipline (including radiation protection and safety), and have been assessed as being competent to carry out that particular role (see the definitions in GSR Part 3 [4] for complete descriptions). The competence of a person is normally assessed by the State through a formal mechanism for registration, accreditation or certification of the particular specialized health professional. Involvement of the regulatory body in the accreditation and review of training programmes for dentists and other dental health care professionals would embed good practice in radiation protection during the training period, when it is most likely to have a lasting effect.

3.5.1. Referring medical practitioners

The referring medical practitioner is defined as “[a] health professional who, in accordance with national requirements, may refer individuals to a radiological medical practitioner for medical exposure” [4]. In dentistry, a dentist or other dental health care professional, such as an oral hygienist or dental therapist, may act in the role of the referring medical practitioner, if he or she refers a patient to an independent imaging centre or a hospital radiology department for an X ray examination.

The referring medical practitioner is involved in the justification process for the application of the radiological procedure to a given individual patient and needs to have an understanding of radiation risks. This can be achieved by promoting education and training in radiation protection and safety as part of the general degree curriculum, or as part of the corresponding specialty education and training programme [5].

3.5.2. Radiological medical practitioners

‘Radiological medical practitioner’ is the term that GSR Part 3 uses to refer to “[a] health professional with specialist education and training in the medical uses of radiation, who is competent to perform independently or to oversee radiological procedures in a given specialty” [4]. In dentistry, a dentist or other dental health care professional, such as an oral hygienist or dental therapist, might act as a radiological medical practitioner, subject to training and competence.

As described in para. 2.124 of SSG-46 [5]:

“In States where there are well established processes in place for education, training, qualification and competence in these specialties, such education, training, qualification and competence includes subjects not only in the specialty itself but also with respect to radiation protection (patient protection and occupational protection). Radiological medical practitioners would typically become registered with the national medical or dental registration board (or a body with a similar function), and competence in the specialty should include competence in radiation protection and safety. The regulatory body and the relevant professional body should periodically review the radiation protection and safety aspects of the education and training to ensure that it is still up to date and relevant. In States where there is a lack of infrastructure for education and training in these specialties, a prospective radiological medical practitioner should gain the necessary education, training and qualification outside the State, both in the specialty itself and in radiation protection and safety. The competence of radiological medical practitioners trained outside the State should be assessed. In this situation the regulatory body should seek advice from the health authority and the relevant professional body (if it exists) with respect to the adequacy of the specialization of the individual and assessment of the individual’s competence with respect to radiation protection and safety may need to be performed by the regulatory body. In time, this approach should develop into a standardized process for dealing with competence assessments.”

3.5.3. Medical radiation technologists

GSR Part 3 defines a ‘medical radiation technologist’ as “[a] health professional with specialist education and training in medical radiation technology, competent to perform radiological procedures, on delegation from the radiological medical practitioner” [4]. This definition includes a medical radiation technologist performing dental radiology procedures.

Paragraph 2.92 of SSG-46 further explains:

“A wide variety of terms are used throughout the world for such health professionals, such as radiographer, radiological technologist, nuclear medicine technologist and radiation therapist.... The medical radiation technologist is usually the interface between the radiological medical practitioner and the patient, and his or her skill and care in the choice of techniques and parameters determines to a large extent the practical realization of the optimization of radiation protection and safety for a given patient’s exposure in many modalities.”

In accordance with paras 2.126 and 2.127 of SSG-46 [5]:

“The programme of education and training in medical radiation technology usually includes significant components of radiation protection (patient protection and occupational protection). On completion of the programme, the medical radiation technologist would typically become registered with the national registration board (or a body with a similar function), and his or her competence in medical radiation technology should include competence in radiation protection and safety.”

“Medical radiation technologists may be specialized in various fields and subfields. The approach to specialties and subspecialties vary significantly among States.”

3.5.4. Medical physicists

Paragraph 2.93 of SSG-46 [5] states:

“a medical physicist is a health professional with specialist education and training in the concepts and techniques of applying physics in medicine and competent to practise independently in one or more of the subfields (specialties) of medical physics (e.g. diagnostic radiology, radiation therapy and nuclear medicine). The medical physicist provides specialist expertise with respect to radiation protection of the patient. The medical physicist has responsibilities in the optimization of radiation protection and safety in medical exposures, including source calibration, clinical dosimetry, image quality and patient dose assessment, and physical aspects of the programme of quality assurance, including medical radiological equipment acceptance and commissioning. The medical physicist is also likely to have responsibilities in providing radiation protection and safety training for

health professionals. In addition, he or she may also perform the role of the RPO [radiation protection officer], whose responsibilities are primarily in occupational and public radiation protection.”

More details on the education, training, qualification and competence of medical physicists can be found in Refs [5, 20–24].

3.5.5. Suppliers, installation, maintenance and servicing personnel

Paragraph 2.135 of SSG-46 [5] states:

“Persons who work as engineers or technicians for the supply, installation, maintenance and servicing of radiological medical equipment and software should be qualified and competent in such work. Often, they will have been trained by their employer specifically for this role. Another aspect of their training should be in the area of radiation protection and safety, not only for their own occupational radiation protection and radiation protection of the staff of the medical radiation facility where they are working, but they should also have a good working knowledge of patient radiation protection in the context of the types of medical radiological equipment and software they are servicing. For the latter, this particularly includes understanding the radiation protection and safety implications of the various features of the equipment or software, and how that changes when the features undergo adjustments or revisions. Regulatory control of servicing engineers and technicians varies around the world. In some States, a licence may be required to perform servicing and a prerequisite to obtaining such a licence should be that such engineers or technicians have had appropriate radiation protection and safety training.”

More guidance is provided in Ref. [5].

3.5.6. Considerations for dental radiology

In dentistry, the above defined roles of the professionals involved are not so clearly specified. The dentist or dental health care professional can hold the role of a radiological medical practitioner but can also act as a referring medical practitioner or, in some cases, act as an operator of the X ray equipment.

The training and education need to be appropriate to these roles. Guidance on the content of education and training of dentists and dental health care professionals, along with proposed numbers of training hours, has been developed by several authorities [25–28]. This guidance can be used depending

on national requirements. In view of the growing availability and use of CBCT, Member States could consider further increasing the number of training hours that are suggested in Ref. [25].

Appendix II gives a summary of the education and training objectives for the three roles applicable to dentistry. Training material on radiation protection in dental radiology has been developed by the IAEA in collaboration with the FDI World Dental Federation, the Image Gently Alliance, the International Association of DentoMaxilloFacial Radiology, the International Organization for Medical Physics and the World Health Organization (WHO).⁶ The IAEA also provides an on-line course on radiation protection for dentists and other dental professionals in different languages.⁷

3.6. QUALITY ASSURANCE AND QUALITY AUDIT

3.6.1. Quality assurance

GSR Part 3 [4] defines quality assurance as “[t]he function of a management system that provides confidence that specified requirements will be fulfilled.” In para. 3.170, GSR Part 3 [4] states:

“Registrants and licensees, in applying the requirements of these Standards in respect of management systems, shall establish a comprehensive programme of quality assurance for medical exposures with the active participation of medical physicists, radiological medical practitioners, medical radiation technologists and, for complex nuclear medicine facilities, radiopharmacists and radiochemists, and in conjunction with other health professionals as appropriate. Principles established by the World Health Organization, the Pan American Health Organization and relevant professional bodies shall be taken into account.”

A quality assurance programme in diagnostic radiology, as defined by the WHO [29], is “an organized effort by the staff operating a facility to ensure that the diagnostic images produced by the facility are of sufficiently high quality so that they consistently provide adequate diagnostic information at the lowest possible cost and with the least possible exposure of the patient to radiation”.

⁶ Available at <https://www.iaea.org/resources/rpop/resources/training-material>

⁷ Available at <https://www.iaea.org/resources/rpop/resources/online-training#6>

Quality assurance programmes in dental radiology include the following elements, outlined in para. 3.171 of GSR Part 3 [4]:

“Registrants and licensees shall ensure that programmes of quality assurance for medical exposure include, as appropriate to the medical radiation facility:

- (a) Measurements of the physical parameters of medical radiological equipment made by, or under the supervision of, a medical physicist:
 - (i) At the time of acceptance and commissioning of the equipment prior to its clinical use on patients;
 - (ii) Periodically thereafter;
 - (iii) After any major maintenance procedure that could affect protection and safety of patients;
 - (iv) After any installation of new software or modification of existing software that could affect protection and safety of patients.
- (b) Implementation of corrective actions if measured values of the physical parameters mentioned in (a) above are outside established tolerance limits.
- (c) Verification of the appropriate physical and clinical factors used in radiological procedures.
- (d) Maintaining records of relevant procedures and results.
- (e) Periodic checks of the calibration and conditions of operation of dosimetry equipment and monitoring equipment.”

The complexity of the programme of quality assurance will depend on the type of facility. A dental practice that performs only intraoral radiography will have a simpler programme compared with a facility that offers all dental imaging modalities. Nonetheless, most of the elements of the programme are common, and differences exist mainly in the degree of application. Common elements for the testing of equipment performance at regular intervals include X ray tube and generator performance, image receptor (film or digital) performance, image quality (via quantitative assessment), display system performance and patient dose assessment. In addition, the quality assurance programme includes clinical image quality assessment. Written records of these tests have to be maintained by staff to ensure adherence to the programme and increase recognition of its importance among them.

3.6.2. Quality audits

GSR Part 3 [4] requires that “radiological reviews are performed periodically at medical radiation facilities and that records are maintained.” The radiological reviews could be part of the wider clinical audit, as described in Ref. [30]:

“Clinical audits are intended as an independent assessment of how actual clinical practice compares with good practice, and of how well the systems in place are achieving the set quality standards, with the primary aim of improving patient care.”

Furthermore, Ref. [30] describes the scope of the clinical audit that also applies to dental radiology as follows:

“A comprehensive clinical audit of diagnostic radiology practices consists of a review and evaluation of the quality of all elements involved in the practices, including staff, equipment and procedures, patient protection and safety, and overall performance of the diagnostic radiology facility, as well as its interaction with external service providers. Any gaps in technology, human resources and procedures should be identified so that the institution will be able to plan for improvement.”

Reference [30] states:

“Clinical audit involves evaluation of data, documents and resources to check performance against standards. It is essentially a process of fact finding and interpretation and, as such, provides an efficient tool for improvement of quality. The purpose of a multidisciplinary clinical audit can be generally summarized as:

- To improve the quality of patient care;
- To promote the effective use of resources;
- To enhance the provision and organization of clinical services;
- To further professional education and training.”

4. JUSTIFICATION AND IMAGING GUIDELINES

According to the published data discussed in Section 1.1, dental examinations are the most frequent type of radiological procedure. The radiation dose from 2-D dental radiography is usually very low [1, 2]. Doses from dental CBCT are generally higher, with median effective doses in the order of 100 μ Sv for large volume scans, yet with a huge variation in both directions [31]. Another important factor in dental radiography is the larger share of paediatric patients exposed to dental radiography [1, 2, 32]. The fraction of patients exposed to dental radiographs below the age of 15 years may range between 6% and 21% [1, 32]. In light of the increasing average dose from dental radiology due to the growing use of CBCT, its generally high frequency and the comparatively young age group in which these images are typically acquired, a clear need for thorough justification criteria is evident. This is of particular importance, as in many countries the dentist undertakes the radiological procedure for patients as a result of justification on the basis of his or her own clinical assessment, generally termed ‘self-referral’ [5]. Although dentistry has been cited as an example of “acceptable self-referral practice” [5], self-referral leads to potential weaknesses in the justification process due to a lack of objectiveness, possibly also driven by economic considerations. In particular, the purchase of high cost equipment (e.g. CBCT machines) might increase the pressure to overuse the equipment to pay off the costs.

The clinical conditions that lead to the use of dental radiography are very rarely life threatening. Many procedures (e.g. implantology, endodontology, restorative procedures) are elective in nature. In addition, the benefit of radiographic information in dentistry is often lower than for many other medical procedures.

Justification for dental radiography is generally determined by a need to obtain specific information not available from other sources [33]. The ultimate responsibility for justification is specified in national regulations.

4.1. GENERAL APPROACHES FOR JUSTIFICATION IN DENTAL RADIOGRAPHY

GSR Part 3 [4] requires in para. 3.157 that the justification of medical exposure for an individual patient take into account several factors, including the characteristics of the individual patient and the relevant information from the patient’s previous radiological procedures.

Regarding justification in dental radiography, Ref. [34] recommends:

“In order for the justification process to be carried out properly, it is essential that selection of dental radiographs is based on the individual patient’s history and a clinical examination. The routine use of x-rays for diagnosis based on a generalised approach rather than individual prescription is unacceptable. A ‘routine’ (or ‘screening’) examination is one in which a radiograph is taken regardless of the presence or absence of clinical signs and symptoms.”

GSR Part 3 [4] requires that relevant national or international referral guidelines be taken into account for the justification of the medical exposure of an individual patient. As defined in Ref. [35], “guidelines are systematically developed statements to assist practitioner and patient decisions about appropriate health care for specific clinical circumstances”.

Furthermore, Ref. [34] explains that “In radiology, guidelines assist the process of selecting the appropriate imaging pathway. Such guidelines, called ‘selection criteria’, or ‘referral criteria’, exist for both medical and dental imaging.” Radiographic referral criteria have been defined in Ref. [36] as “descriptions of clinical conditions derived from patient signs, symptoms and history that identify patients who are likely to benefit from a particular radiographic technique.”

In dental practice, self-referral is very common. In some cases, however, a dental practitioner may refer a patient to a colleague, an imaging centre or a hospital X ray department for imaging, for example for panoramic radiography or CBCT.

In line with the requirements established in GSR Part 3, Ref. [34] advises that when referring patients, it needs to be ensured that adequate clinical information and sufficient patient history are provided to the person taking responsibility for the exposure. A request to undertake, for example, “CBCT, please!” would not be considered adequate clinical information.

General approaches for justification can be summarized as follows:

- (a) Ensure that no X ray imaging is selected unless a history and examination have been performed.
- (b) Select radiographs for every patient based on their individual clinical needs, not because of ‘routine’ practices.
- (c) Always take into account the radiation dose implications when selecting radiographs.
- (d) Consult available professional guidelines to help in selecting X ray examinations.

- (e) Take into account the different imaging needs and the radiation risks of paediatric patients when selecting X ray examinations.
- (f) Use CBCT when it is appropriate to do so, not just because the equipment is available.

4.2. JUSTIFICATION IN TWO DIMENSIONAL DENTAL RADIOGRAPHY

4.2.1. Intraoral radiography

Intraoral radiography is used, for example, to identify carious lesions or the consequences of trauma and periapical pathosis; for periodontal assessment, endodontic and implant treatment planning and post-treatment review; and for other tasks involving pathosis of the dental hard tissue or of the body of the mandible and maxilla.

4.2.1.1. *Bitewing radiography*

Bitewing radiography for the detection of early caries represents a special situation in dental radiography, as paediatric patients may undergo repeated bitewing examinations during their childhood and adolescence. Prescription of bitewing radiographs for caries diagnosis has to be based on caries risk assessment [34–39]. Risk assessment is based on clinical examination, patient history and socio-behavioural risk factors [34, 40]. Intervals between subsequent bitewing radiographic examinations have to be based on the actual current risk situation, which has to be reassessed regularly [34, 36, 41].

4.2.1.2. *Periapical radiography*

Periapical radiography is mainly indicated for assessment of the dental root or the surrounding alveolar bone. To represent the entire dentition using intraoral radiography, a full mouth survey consisting of several (more than ten) periapical radiographs would be needed. However, as other techniques are available with lower radiation dose (e.g. panoramic radiography), full mouth surveys are generally no longer indicated [36].

4.2.1.3. *Occlusal radiography*

Occlusal radiography has some benefits, for example, it complements other radiographs (e.g. panoramic radiography) to localize structures of interest

(e.g. teeth, foreign bodies). This might be justified in cases where 3-D localization by means of 3-D techniques (e.g. CT, CBCT) appears not to be appropriate, for instance owing to dose considerations or patient conditions. Mandibular occlusal radiographs can be used to visualize fractures in the axial plane or to diagnose radiodense sialoliths if ultrasonography is not sufficient or available.

4.2.2. Panoramic radiography

Panoramic radiography is an imaging technique that enables an overview of the entire dentition, as well as the mandible and maxilla, plus adjacent anatomical structures (e.g. maxillary sinus, nasal cavities). Panoramic radiography provides lower spatial resolution than intraoral radiography. In addition, it is prone to specific variable magnification and distortion characteristics. The literature indicates that panoramic radiography in general has lower diagnostic accuracy than intraoral radiography for common dental radiographic diagnostic tasks (e.g. caries diagnosis, periapical diagnosis) [34, 36, 38, 42]. It is typically used for orthodontic assessment, for diagnosis of unerupted or supernumerary teeth and trauma conditions, before surgical removal of lower and upper wisdom teeth, and for acquisition of a crude overview of the lower part of the maxillary sinus or the temporomandibular joint plus the ascending ramus of the mandible. Panoramic radiographs are used for treatment planning (e.g. in dental implantology, for planning of prosthetic dentures, for surgical removal of retained roots or for orthodontic procedures). Panoramic radiography is also frequently used for post-treatment review in situations where such review is likely to be beneficial for the patient. Modern panoramic radiography devices allow for collimated panoramic radiographs of parts of the dentition. These can be used when only local information is needed (e.g. for third molars).

4.2.3. Cephalometric radiography

Cephalometric radiography is widely used in orthodontic diagnosis and treatment planning to determine specific angles and distances between well defined landmarks ('cephalometry'). The lateral cephalometric radiograph is mainly used to assess distances and angles in the sagittal dimension. However, the posteroanterior cephalogram is also sometimes applied to assess dimensions in the transversal plane, in particular when there is significant facial asymmetry.

4.2.4. Other extraoral projection radiography

Extraoral projection radiography is rarely conducted in dental offices and is mostly restricted to specialized environments such as hospitals. It is likely to

decline in use as the availability of 3-D imaging (e.g. CT, CBCT) increases. In special circumstances it may still be indicated, since its radiation dose is very low compared with these 3-D techniques. The overall cumulative dose from these radiographs is considered to be negligible.

Table 4 summarizes the typical indications for common dental radiographic procedures, based on information from Refs [34, 36, 43].

TABLE 4. TYPICAL INDICATIONS FOR COMMON DENTAL RADIOGRAPHIC PROCEDURES [34, 36, 43]

Dental imaging procedure	Typical indications
Intraoral radiography	
Bitewing radiography	Detection of caries, particularly approximal carious lesions Assessment of periodontal bone levels Identification of restoration marginal integrity or deficiency
Periapical radiography	Evaluation of dento-alveolar trauma Identification of root canal anatomy in endodontics Evaluation of pulp pathosis (sclerosis, internal resorption) Assessment of periodontal bone level Evaluation of dental development Assessment of periapical and alveolar bone pathosis
Occlusal radiography	<i>Maxillary</i> — Identification of abnormalities of the bony palate — Localization of ectopic teeth in the bony palate — Evaluation of dento-alveolar trauma <i>Mandibular</i> — Trauma (dento-alveolar and complete jaw fractures) — Localization of ectopic teeth — Evaluation of bony pathosis — Identification of radiodense sialoliths in the floor of the mouth
Panoramic radiography	Assessment of bony pathosis in the maxilla/mandible Identification of supernumerary/missing teeth Identification of developing dentition Assessment of bone height and quality during implant planning Pre-surgical assessment for oral surgery/tooth extraction Evaluation of dento-alveolar and facial trauma Localization of (radio-opaque) foreign bodies

TABLE 4. TYPICAL INDICATIONS FOR COMMON DENTAL RADIOGRAPHIC PROCEDURES [34, 36, 43] (cont.)

Dental imaging procedure	Typical indications
Panoramic radiography (cont.)	Assessment of a grossly neglected dentition prior to multiple extractions Assessment of the bony structures in the temporomandibular joint Crude overview of the lower part of the maxillary sinus
Cephalometric radiography	
Lateral cephalometric radiography (evaluation of the sagittal plane)	Maxillary and mandibular growth assessment Assessment of skeletal pattern and labial segment angulation Assessment of unerupted teeth Implant planning (in combination with periapical or panoramic radiograph)
Posteroanterior cephalometric radiography (evaluation of the coronal plane)	Assessment of facial asymmetry

4.3. JUSTIFICATION IN THREE DIMENSIONAL DENTAL IMAGING

The following considerations mainly concern the use of CBCT, although CT may also be accessible to some dentists. Moreover, these considerations only refer to the acquisition of high contrast slice images without the use of intravenous contrast media.

Dental CBCT has been adopted from radiotherapy, where it was initially used for therapy guidance. The first CBCT devices surfaced in 1996, and broader use of this kind of equipment can be seen especially in industrialized countries, where CBCT devices have become increasingly affordable.

Because of its relatively high dose, the justification for a CBCT examination has to follow scientifically generated evidence. The benefit from the additional information provided by CBCT has to outweigh the radiation detriment. Numerous guidelines and position statements regarding the use of dental CBCT have been developed by a number of scientific societies [44–46].

Currently, dental CBCT is mainly used for the evaluation of the alveolar process in upper and lower jaws prior to implant placement. Besides the measurements of bone dimensions — the most frequently demanded application — any osseous pathosis can be revealed within the capabilities of high contrast imaging. It is also commonly used for endodontic applications. Furthermore, it can be applied for pre- and post-operative assessment of tumours of the jaws; for the evaluation of osteomyelitis or similar osseous changes; prior to the extraction or mobilization of ectopic and supernumerary teeth, especially in paediatric patients; for the evaluation of periodontal disease, especially regarding the molars in the upper jaw; and for the assessment of pathologies in the maxillary sinuses. Furthermore, it is a suitable tool for pre-operative assessment regarding midfacial trauma when neurological symptoms are ruled out. It is used for pre-operative planning in cleft patients or other patients with comparable disorders and for pre-operative planning in orthognathic surgery.

Table 5 gives an overview of situations in which the use of CBCT might be justified for different anatomical structures. CBCT could be appropriate for situations in which conventional radiography cannot provide an adequate answer to the diagnostic question and when CBCT offers greater diagnostic efficiency. The selection of radiographic imaging for patients is made where there is a prospect that the results are likely to affect patient management or prognosis.

TABLE 5. EXAMPLES WHERE THE USE OF CBCT COULD BE CONSIDERED TO BE JUSTIFIED

Individual teeth ^a	<p><i>Trauma</i></p> <p>— Detection of root fracture</p> <p><i>Endodontic management</i></p> <p>— Examples include anomalous or complex root canal anatomy; suspected perforations; location of extensively obliterated canals; image guided endodontics; assessment of internal or external resorption</p>
Jaws and alveolar processes	<p><i>Trauma</i></p> <p>— Trauma to the dentition and jaw bones when conventional imaging fails to provide adequate detail</p>

TABLE 5. EXAMPLES WHERE THE USE OF CBCT COULD BE CONSIDERED TO BE JUSTIFIED (cont.)

Jaws and alveolar processes (cont.)	<p><i>Inflammation</i></p> <ul style="list-style-type: none"> — Periodontal and periapical inflammation when conventional imaging fails to provide adequate information — Evaluation of osteomyelitis <p><i>Tumours within the jaw bones</i></p> <ul style="list-style-type: none"> — Suspected neoplastic growths — Lesions manifesting with jaw expansion <p><i>Others</i></p> <ul style="list-style-type: none"> — Congenital disorders and clefts — Pre-operative assessment prior to orthognathic surgery — Localization of ectopic and impacted teeth <p><i>Others</i></p> <ul style="list-style-type: none"> — Orientation of roots close to the inferior alveolar canal — Localization of foreign bodies — Implant planning and bone augmentation
Temporomandibular joint	<p><i>Trauma</i></p> <ul style="list-style-type: none"> — Suspected inflammatory arthritis <p><i>Ankylosis</i></p> <ul style="list-style-type: none"> — Swellings and neoplastic disease
Midface	<p><i>Trauma</i></p> <ul style="list-style-type: none"> — Swellings and (non-malignant) neoplastic disease <p><i>Planning of zygomatic implant insertion</i></p> <ul style="list-style-type: none"> — Pre-operative assessment for navigational surgery
Paranasal sinuses	<ul style="list-style-type: none"> — Inflammation and fluid retention — Evaluation of the ostiomeatal complex — Swellings and (non-malignant) neoplastic disease — Localization of foreign bodies — Planning of sinus floor augmentation

^a CBCT for single tooth uses, particularly endodontics, requires higher spatial resolution and a small field of view.

Note: CBCT — cone beam computed tomography.

Despite this large number of potential indications, there are some pathoses for which CBCT might be useful; for example, the evaluation of pharyngeal and supralaryngeal soft tissues in cases with sleep apnea. Moreover, although CBCT acquisitions are performed almost routinely as part of orthodontic planning, there are no studies about the potential benefit for the patient. Specifically, the

acquisition of a CBCT image solely to synthesize a panoramic or cephalometric view is inappropriate.

4.4. JUSTIFICATION IN PAEDIATRIC PATIENTS

Dental radiology is unique in terms of its high frequency of use in paediatric patients, including infants, children and adolescents [1, 32]. This is because of the greater prevalence of dental caries, of developmental anomalies of the teeth and jaws requiring orthodontic intervention, and of dental trauma in children. Furthermore, paediatric patients may undergo repeated dental X ray examinations as part of continuing care. As the risk of radiation induced stochastic effects has an inverse relationship with age, the risks to children associated with dental radiology at a population level are greater than might be suggested by the individual dose levels of most dental X ray examinations [47, 48]. Thus, for paediatric examinations special consideration has to be given to the justification process [4, 5, 49].

As is the case with adult patients, most dental X rays of children are performed in the primary dental health care settings. In these settings, self-referral by the dentist is the usual situation, and the dentist is both the referrer and the radiological practitioner. Furthermore, in some cases dentists work as independent practitioners, without immediate peer support. In the primary health care setting, dentists lack the support of an establishment of specialist radiologists, radiographers and medical physicists and usually do not have a robust structure for clinical governance.

Because of the potential problems of self-referral, the role of imaging guidelines (i.e. selection criteria, referral criteria and appropriateness criteria) in the imaging of children in dentistry is especially important. Such criteria have been developed nationally and internationally by professional bodies or through dedicated projects, some specifically aimed at the paediatric age group [36, 43, 44, 50–55].

It is important to involve paediatric patients in the justification process, as appropriate for their age, so that it becomes a partnership between the patient, the parent (or responsible adult) and the dentist. The dentist has to be prepared to answer questions about a proposed X ray examination and the parent (or responsible adult) and patient have to be encouraged to ask those questions. It might be useful for the dentist to offer information in the form of leaflets or posters, along with links to available web sites such as that established by the Alliance for Radiation Safety in Pediatric Imaging (the Image Gently Alliance)⁸

⁸ See <https://www.imagegently.org/Procedures/Dental>

or the IAEA's Radiation Protection of Patients web site⁹. Reference [56] provides advice on communicating radiation risk in paediatric imaging.

Dental radiography in children is sometimes performed for the early detection of disease, but not as part of an approved health screening programme, for example in the detection of dental caries or as part of assessment of dental development. The health authority, together with relevant professional bodies, has a role in providing guidance on the applicability and appropriateness of such procedures [5]. In many cases, dentists are independent practitioners with limited or no involvement of others, so professional association guidelines play an important role in justification.

X ray imaging of children in dentistry is often limited to intraoral and panoramic radiography. CBCT usually has a higher radiation dose than intraoral and panoramic radiography, and justification demands special attention. CBCT has to be selected according to specific criteria and cannot be treated as a routine examination [45–47, 57]. Low dose protocols are more appropriate when they provide adequate image quality for diagnostic purposes (see Section 5).

4.5. JUSTIFICATION IN PREGNANT PATIENTS

In dental exposures of pregnant patients, radiation doses to the fetus are low owing to the relatively long distance between the source of scattered radiation (i.e. the head of the patient) and the fetus. Studies on fetal dose from dental exposures are scarce, and Table 6 [58–61] provides a summary of reported uterus doses without the use of shielding. Doses to the fetus are comparable to the dose from a day or less of background radiation. Therefore, if the examination is justified, there is no need to postpone a dental radiographic examination until after pregnancy. Clinicians, however, need to be sensitive to the concerns of the patient. Because most dental radiography is non-urgent, examinations can often be delayed if the patient prefers it.

4.6. GUIDELINES ON THE USE OF IMAGING IN DENTISTRY

References [42, 62] present recent published reviews on the topic of guidelines containing referral criteria for radiological examinations in dentistry. It is beyond the scope of this publication to devise referral criteria. As an example, the Annex presents a non exhaustive selection of clinical indications for dental radiological imaging, derived from existing professional guidelines.

⁹ See <https://rpop.iaea.org>

TABLE 6. ABSORBED DOSE TO THE UTERUS FOR DENTAL RADIOGRAPHY

Imaging modality	Absorbed dose to uterus (μGy)	References
Intraoral	0.009–2.66	[58, 59]
Panoramic	0.11–7.97	[58, 59]
CBCT	0.05–6.93	[59–61]

Note: CBCT — cone beam computed tomography.

4.7. JUSTIFICATION OF MEDICAL EXPOSURE FOR CARERS AND COMFORTERS

Some dental X ray procedures can be performed better with the assistance of a carer or comforter, for example a relative in the case of a paediatric patient, or a relative or friend for a disabled, very elderly or very ill patient. In these circumstances, the carer or comforter will be exposed, usually to a low dose.

For dental radiology, the following guidance, provided in para. 3.153 of SSG-46 [5], applies:

“The three-level approach to justification is not applicable for carers and comforters. Instead, para. 3.155 of GSR Part 3...establishes the requirement to ensure that there be some net benefit arising from the exposure, for example the successful performance of a diagnostic procedure on a child. The crucial component in the justification of medical exposure of carers and comforters is their knowledge and understanding about radiation protection and the radiation risks for the procedure being considered. To this end, the radiological medical practitioner or medical radiation technologist involved in the radiological procedure, prior to the performance of the procedure, has the responsibility to ensure that the carer or comforter is correctly informed about radiation protection and the radiation risks involved, and that the carer or comforter understands this”.

5. OPTIMIZATION OF RADIATION PROTECTION OF INDIVIDUALS UNDERGOING MEDICAL EXPOSURE

5.1. EQUIPMENT SELECTION

5.1.1. General considerations

The selection of equipment in dental radiology can have a pronounced effect on protection of the patients, workers and the public. For each imaging modality commonly used in dental imaging, there are a number of specific factors to consider. If the equipment will be used on children, special design features may be needed that both facilitate successful radiological procedures on patients who may be uncooperative and suit the imaging of very small patients (see also Section 5.5).

Paragraph 3.40 of SSG-46 [5] states:

“All digital medical radiological equipment should have the following additional features:

- (a) Real time dose display and end-of-case dose report (radiation dose structured report, DICOM object), including export of dose metrics for the purpose of DRLs and individual patient dose calculation;
- (b) Connectivity to RIS and to PACS.”¹⁰

5.1.2. Intraoral radiography

5.1.2.1. Intraoral radiographic units

In accordance with para. 3.35 of SSG-46 [5], a minimum tube voltage of 60 kV should be used, produced by a direct current (DC) or alternating current (AC) generator.

The nominal focal spot values of current intraoral radiographic units range between 0.4 and 0.7. Smaller focal spots increase image sharpness because of their smaller penumbra. Focal length (source–skin distance) has to be at least 20 cm [5, 63], but longer distances (e.g. 30 cm) are preferred. The higher the focal length, the lower the local absorbed dose at the skin is, and the smaller the penumbra caused by the focal spot is. However, correct aiming at the target will

¹⁰ DICOM: Digital Imaging and Communications in Medicine; RIS: radiology information system; PACS: picture archiving and communication system.

become increasingly difficult if the focal length is increased beyond a meaningful distance (e.g. 30 cm).

The total filtration has to be such as to ensure that the measured half-value layer is equal to or greater than 1.5 mm aluminium equivalent for units operating at or below 70 kV, and 2.1 mm aluminium for units operating at 71 kV or higher [63]. If the amount of filtration is insufficient, skin doses will be relatively high.

The tube current is usually 3.5 to 8 mA, and the exposure time can be set depending on the image receptor, patient age and anatomical area. The selectable range of exposure times for contemporary fixed/mobile intraoral X ray units is between 0.01 and 4 s, although sub-second exposure times are normal nowadays. The current–exposure time product needed for a diagnostic image is affected by the choice of image receptor.

X ray beam collimators in intraoral tubes can be circular or rectangular. The use of rectangular collimation is strongly preferred, as it results in a much lower patient radiation dose and can also improve image quality owing to reduced X ray scatter. X ray beam dimensions at the collimator end have to be no more than 4 cm × 5 cm, if rectangular, or 6 cm in diameter, if cylindrical [5, 63].

The technical specifications of portable (handheld) intraoral units are largely similar compared with fixed/mobile units, although portable units tend to operate at a longer exposure time owing to their relative low tube current. Portable intraoral X ray units are to be selected only in specific situations [64–66] and special consideration is needed to ensure that these units adhere to the same quality and safety standards as fixed units (further discussed in Section 6).

5.1.2.2. Intraoral image receptors

A brief description of film, photostimulable phosphor receptors, CCD and CMOS receptors used in intraoral imaging is provided in Section 2.1.2. Whereas the spatial resolution is highest for film, diagnostic image quality is considered to be similar for the different receptors [67–69]. The choice is therefore determined by other factors, including the versatility and convenience of digital imaging in terms of exposure latitude, image readout, post-processing and storage. If using film, preference will be given to E/F speed films rather than to obsolete D speed films [65, 70].

5.1.3. Panoramic and cephalometric radiography

The same considerations as for intraoral imaging apply in terms of X ray tube specifications and dose display. Although currently the same image receptors are used as in intraoral radiography, the use of photostimulable phosphor

receptors is discouraged because of inferior image quality [71]. A high speed acquisition mode, as well as a collimated small area option, for both panoramic and cephalometric modes have to be available for paediatric patients. If the machine will be used for specific evaluation of isolated regions (e.g. third molars, temporomandibular joints), a collimated mode that does not expose the structures outside this region has to be available.

5.1.4. Cone beam computed tomography

5.1.4.1. Field of view options

An important consideration when selecting a CBCT unit is the range of available FOV options. The FOV size is one of the most important determinants of patient dose [72] and is also connected to image quality through its effect on X ray scatter and its relationship with voxel size (see Section 5.4.5). The FOV has to be adapted to the clinical indication, ensuring that a region of interest can be covered with a reasonable margin of error, without exposing areas that are not needed for diagnostics [45]. Considering the fact that the majority of clinical applications of CBCT involve a small region of interest (e.g. a single implant site, a single tooth requiring endodontic treatment), CBCT units have to offer at least a small FOV option (not larger than 6 cm × 6 cm) but do not necessarily require a large FOV option.

In accordance with para. 3.159 of SSG-46 [5], to obtain different FOV sizes, only physical collimation at the tube side should be performed; software based cropping of the FOV after exposure is not considered to be good practice.

For small FOVs, an appropriate aiming device, such as a laser beam plus scout views available in the device, can help to avoid retakes due to incorrect or partially missed target areas.

5.1.4.2. Technical specifications

In terms of the technical specifications of the X ray tube, a wide range can be seen between CBCT units in terms of tube voltage (typically 70–120 kV) and tube current–exposure time product (generally 10–150 mA·s), whereas the nominal focal spot size is typically 0.5 mm (range: 0.3–0.6 mm) [73]. A few CBCT scanners can operate at tube voltages below 70 kV, but such low tube voltages are not suitable for clinical scans from a radiation protection point of view. While the specification of appropriate values or ranges for these parameters is not possible, because image quality and patient dose are determined by a multitude of other factors, it is important that units provide at least a few options

in terms of current–exposure time product, whereas the tube potential could be fixed or variable.

Specifically, high, medium and low tube current settings have to be available to optimize scans for patients with different head sizes [74]. This can be achieved through manual selection of the tube current, although pre-set values have to be available for regular and large adult males, adult females and adolescents, and children. Pre-set values have to be modifiable by the user.

If a form of automatic exposure control (AEC) is used, the specifications of the previous paragraph do not apply. The AEC system has to either allow continuous current adaptation or to have at least five discrete current options. Furthermore, at least three AEC levels have to be available to cope with high or low image quality specifications. If the tube current is assigned automatically based on the scan projection radiograph (i.e. scout, topogram), this has to be determined by both the lateral and frontal scout images, as the use of only one scout could lead to over- or underestimation of the optimal tube current. Furthermore, if the current is determined by the scout, it has to be based on the part of the scout corresponding to the eventual FOV of the CBCT scan, if this FOV is considerably different in size or position compared with the anatomical coverage of the scout image.

Regarding scan/exposure time, a high speed scan option (10 s scan time or faster, regardless of the exposure time) has to be available for patients at risk for movement (e.g. small children, elderly persons), and low, standard and high resolution options have to be available (with short, medium and long exposure times and large, medium and small voxel sizes, respectively) to optimize scans for clinical applications with different needs in terms of image sharpness (see Section 5.4.5).

Users are advised to be aware that voxel size is one of many parameters determining image sharpness, and not to compare units based on this parameter. While smaller voxel sizes do not always yield a diagnostic benefit [75, 76], it is proposed that CBCT units have a high resolution mode with a voxel size below 0.2 mm to properly visualize trabecular bone [77], as well as other anatomical details and small pathologies [78, 79].

Regarding the extent of the rotation of the X ray tube and detector ($180^{\circ 11}$, 360° or in between), and given the extensive evidence regarding the diagnostic efficacy of 180° scan modes [80–84] as well as the benefit of having a shorter acquisition time for these modes, it is advised that CBCT units have at least an optional 180° rotation mode. The use of an off-axis detector geometry, in which only a part of the FOV (~55–60%) is exposed to the X ray beam at any point

¹¹ The minimum rotation arc in CBCT is actually slightly above 180° and depends on the beam angle.

during the scan, has limited relevance, although it can be noted that off-axis geometries do not allow for 180° scan modes.

5.1.4.3. Patient immobilization

Considering the relatively long acquisition time in CBCT, proper immobilization of the patient's head has to be ensured, to avoid excessive blurring and artefacts due to motion [85]. At the least, a support of the temporal area can be provided to avoid rotation and sideways tilting of the head. For CBCT units in which the patient is seated or standing, a support for the forehead and/or back of the head can be used in addition to avoid forward/backward tilting. As there is no rigid connection between the mandible and the rest of the skull, a chin rest can be used to avoid micromovements of the lower jaw. A bite block can be used if separation of the lower and upper teeth is necessary for radiological purposes, but might not be optimal in terms of lower jaw immobilization owing to muscular tremors.

For CBCT units in which the patient is supine, the use of only a temporal support could provide sufficient immobilization, although additional immobilization might have to be considered for children, patients with physical or mental disorders causing involuntary movement (e.g. Parkinson's disease) and any other patient considered to be at risk for movement.

It is important to ensure that immobilization mechanisms can be applied to small children (minimum three years old) just as well as to adults.

5.1.4.4. Hounsfield unit calibration

At present, it is not advised to use CBCT units for absolute or relative density estimations based on grey values, owing to the considerable instability of grey values between CBCT units, for different protocols of a given CBCT unit and within the FOV of a given CBCT image [72]. In other words, CBCT does not, and is not expected to, yield Hounsfield units (HUs). In the absence of specific criteria for grey value stability in CBCT, manufacturers cannot claim that their product yields HUs, unless HU stability equal to existing MDCT quality assurance standards can be demonstrated (see Section 5.2).

5.1.4.5. Metal artefact reduction

Owing to the limited evidence available concerning the efficacy of metal artefact reduction algorithms used in current CBCT units [75, 86–90], the presence or absence of a metal artefact reduction option is not a criterion for equipment selection at present.

5.1.4.6. *First and third party viewer software*

Viewers used for radiological reporting have to display the CBCT image at its native resolution and to have at least a multiplanar reformatting view. The left and right sides of the patient have to be unequivocally indicated on the axial and coronal slices, preferably through the use of L/R indicators rather than diagrams. Adherence to the attribute ‘patient position’ in DICOM PS 3.3 is advised. The availability of curved (‘panoramic’) reformatting is not essential but advised.

Users have to be able to adapt image display through window/level adjustment. Manufacturers have to ensure that the initial display of the reconstructed image is already suitable for radiological evaluation of the hard tissues by automatically applying pre-set or adaptive window/level values after image reconstruction, while emphasizing to users that window/level values always have to be fine-tuned before radiological viewing.

Viewers have to be able to display CBCT images with at least a 1:1 ratio between image voxels and monitor pixels. The ability to zoom up to 400% or more is proposed, especially when relatively small monitors, small voxel sizes or large FOVs are used. In addition, the availability of a ‘zoom reconstruction’ mode, in which a small sub-volume of a large FOV can be reconstructed at a smaller voxel size, would be preferred. On the other hand, the availability of such a zoom reconstruction mode is not meant to lead to the routine use of large FOVs; considerations regarding physical versus software collimation (see Section 5.4.5) and indication oriented FOV selection (see Section 5.1.4.1) apply.

Linear, angular, area and volume measurements have to be possible, and the accuracy of these measurements has to be ensured (see Section 5.2). If it is possible to measure grey values (either of individual voxels, or within a linear, 2-D or 3-D region of interest), these grey values will not be referred to as HUs unless the CBCT unit adheres to the stipulations presented in Section 5.2.4.2.3.

Export of CBCT images to third party viewers has to be possible as an axial stack at native resolution and bit depth, in accordance with DICOM PS 3.6, to avoid quality loss during coronal/sagittal reformatting [91].

5.1.5. Image viewing conditions

Image viewing conditions, including monitors, viewing boxes and ambient light, have a strong influence on the accuracy of the image interpretation. Ideally, images should be interpreted in a dedicated room with a low level of ambient light [5]. However, in a dental office, such optimal conditions are found infrequently. For film based intraoral radiographs, magnification improves diagnostic yield. The viewing monitors used for digital radiographs would have to meet the applicable standards [44, 63, 92].

5.2. QUALITY CONTROL

5.2.1. Basic principles

Quality control deals with the performance of the equipment after installation. An appropriate quality control programme is essential to ensure that patients do not receive an excessive radiation dose, and to verify compliance of the X ray unit's performance with the manufacturer's specifications and with regulatory requirements. A quality control programme follows a regular timetable, consisting of a check of performance before clinical use (acceptance), providing baseline comparative metrics (commissioning) and routine (periodic) testing. Usually, a medical physics expert is involved in performing quality control procedures.

The following subsections provide a summary of existing quality control specifications. Users of this Safety Report, medical physicists and policy makers will always refer to local regulations and guidelines, if available.

5.2.2. Quality control in intraoral radiography

The following tests can be performed for quality control in intraoral radiology. More details regarding these tests, acceptability criteria, action levels and practical procedures can be found in Refs [70, 93, 94]:

- (a) Stability of the tube head after it is released by the operator.
- (b) Visual inspection of the tube housing, and measurement of leakage radiation if damage to the tube's shielding is suspected.
- (c) X ray field size (i.e. collimation) and source–skin distance have to be in accordance with regulations and relevant recommendations.
- (d) Focal spot dimensions.
- (e) Beam quality by means of half-value layer.
- (f) Kilovoltage and exposure time: correspondence with nominal value.
- (g) Reproducibility of the exposure.
- (h) Linearity of tube current or current–exposure time product.
- (i) Quality control of the darkroom or film processors (if film is used) to avoid film fogging due to exposure to light.
- (j) Quality control of film processing (if film is used).
- (k) Evaluation of uniformity, spatial resolution and contrast resolution (if digital image receptors are used). Apart from periodic quality control testing, receptor performance will be evaluated if any damage is suspected (e.g. due to dropping the sensor). Different dedicated phantoms are available for this purpose.

- (l) Evaluation of the display used for image evaluation (if digital image receptors or digitized films are used) [95, 96].
- (m) Entrance surface dose (equal to the entrance surface air kerma), compared with available DRLs and achievable doses.
- (n) Scattered radiation (during acceptance testing).

5.2.3. Quality control in extraoral radiography (including panoramic radiography)

Tests for tube leakage, tube potential accuracy, reproducibility, darkroom quality control and digital receptor quality control can be performed using the procedures used in quality control for intraoral radiography. For beam quality measurements, the specifications for half-value layer values may be different from those in intraoral radiography (depending on the tube potential). Further, different DRL measurement methodologies and DRL values apply (see Section 5.3).

A specific test for panoramic radiography and ‘scanning based’ cephalometric radiography involves the measurement of the vertical and horizontal dimensions of the X ray beam, ensuring that it coincides with the slit at the image receptor. For broad beam cephalometric radiography, the X ray field size has to be verified and compared with nominal values, as well as light fields [70].

5.2.4. Quality control in cone beam computed tomography

At the time of writing, the most recent dedicated guidelines on quality control in dental CBCT are the guidelines published by the European Commission (also known as the SEDENTEXCT guidelines) [44] and the UK Health Protection Agency [92], and Germany’s DIN 6868-161 [97] and DIN 6868-15 [98] Standards. Guidelines by the American Association of Physicists in Medicine on dental CBCT are in preparation¹². In addition, a unified protocol for quality control in CBCT (not exclusively for dental applications) has been prepared by the European Federation of Organisations for Medical Physics (EFOMP) in collaboration with the European Society for Radiotherapy and Oncology (ESTRO) and the IAEA [99].

5.2.4.1. Standard tests

Standard tests (i.e. not specific to CBCT) can be performed, according to manufacturers’ specifications, recent guidelines or superseding national

¹² https://www.aapm.org/org/structure/?committee_code=TG261

regulations. More details regarding these tests, acceptability criteria, action levels and practical procedures can be found in the EFOMP–ESTRO–IAEA protocol [99]. Some of the parameters to be tested are as follows:

- (a) X ray tube potential;
- (b) X ray tube leakage;
- (c) Total filtration or half-value layer;
- (d) Repeatability of radiation output;
- (e) Reproducibility of radiation output;
- (f) Beam collimation;
- (g) Image slice thickness (or spatial resolution along the z axis);
- (h) Image display;
- (i) Image artefacts not included in Section 5.2.4.2 (through visual inspection);
- (j) Operator protection.

If the manufacturer has identified other specific tests, they have to be checked during acceptance/commissioning and during quality control.

5.2.4.2. *Specific image quality tests*

5.2.4.2.1. Uniformity

Uniformity refers to the stability of grey values throughout the FOV for an image of a homogeneous object. Uniformity is not a crucial image quality parameter in dental CBCT, and a lack of uniformity due to the heel effect, beam hardening and FOV truncation can be acceptable. However, poor uniformity may indicate issues related to detector performance and reconstruction, which might indicate that maintenance is necessary.

Uniformity measurements can be performed using a homogeneous (section of) a cylindrical head equivalent phantom, for example a polymethyl methacrylate (PMMA) cylinder with a 16 cm diameter or a slightly larger water container. While uniformity issues primarily manifest in axial slices, uniformity along the z axis (i.e. between axial slices) could also be evaluated.

5.2.4.2.2. Geometric accuracy

Geometric accuracy (or precision) refers to the proper 3-D representation of different (anatomical or other) components on the image. It is of particular importance for clinical applications that rely on visualization and/or measurement of spatial relationships (e.g. bone dimensions and distance to mandibular canal

or maxillary sinus floor for implant planning, root canal length for endodontic treatment planning).

The geometric accuracy of CBCT can be affected by unwanted motion of the tube–detector arm during image acquisition, improper geometric calibration or the inherent limitations of the Feldkamp reconstruction technique used in CBCT at the present time. Geometric accuracy has to be checked with respect to both the raw projection data (allowing for the detection of mechanical movement of the equipment during image acquisition) and the reconstructed data (to check the accuracy of linear and angular measurements), using dedicated phantoms with known dimensions.

5.2.4.2.3. Grey value stability

Grey values (also known as pixel/voxel intensity values) in CBCT are related to the attenuation, and therefore the radiodensity, of the materials or tissues in the image. While the ability to distinguish between densities is determined by the contrast resolution (see Section 5.2.4.2.5), the stability of grey values is directly related to image contrast. In CBCT, the following factors are known to affect grey value stability in the reconstructed image:

- (a) Scattered radiation received by the detector. This can lead to a local increase or decrease in grey values in the image. The relatively wide X ray beam, short patient–detector distance and absence of scatter grids or other detector side collimation result in a high amount of detected scatter in CBCT.
- (b) Beam hardening. This is the effect of low energy X rays being absorbed to a greater degree than high energy X rays. Central parts of the FOV, or high density objects therein, are subject to X rays with a higher average energy (i.e. ‘harder’ X rays) than peripheral parts. As a result, central areas may appear less radiodense (cupping artefact).
- (c) Metal artefacts. This can arise owing to the presence of high density materials in or near the FOV. These artefacts are very common in CBCT because of the presence of metal restorations, dental implants and other objects. The marked attenuation of the X ray beam due to these metals is expressed as dark and bright streaks on the reconstructed image.
- (d) ‘Local tomography’ or ‘exomass’ effect. This effect arises because part of the patient is outside the FOV. Because current image reconstruction algorithms assume that the entire scanned object is contained within the FOV, and considering the asymmetry of the amount, density and distribution of tissues outside the FOV, grey values in the FOV are affected by posteroanterior and left–right ‘shading’.

Grey values on CT images can be calibrated as HUs. HU values are connected to the linear attenuation coefficient of a material. Materials are assigned a HU value based on the following formula:

$$\text{HU} = 1000 \frac{\mu_x - \mu_{\text{water}}}{\mu_{\text{water}}}$$

where μ_x is the linear attenuation coefficient of the material in question and μ_{water} is the linear attenuation coefficient of water at a specific energy spectrum (usually at 120 kV). The HU scale is defined by water, with HU = 0, and air, with HU = -1000, whereas for other materials or tissues the HU value depends on X ray absorption.

As many dental CBCT manufacturers do not claim to provide HU, the evaluation of grey value stability for these units is limited to a reproducibility check, in which grey values for a number of materials are compared over time, using a standardized measurement set-up and relatively lenient action levels.

If CBCT units claim to provide HU, more dedicated measurements are needed to ensure that grey values measured for low, medium and high density materials correspond to their theoretical HUs within acceptable margins [99, 100]. Owing to the local tomography effect mentioned above, HU accuracy has to be verified using different FOVs (if available) and phantom positions.

5.2.4.2.4. Noise

Image noise refers to variations of grey values at the level of the individual pixel or voxel (as opposed to uniformity, which refers to variations between different areas of pixels in an image). There are different sources of noise, mainly electronic noise (induced by the detector), quantum noise (due to the stochastic nature of X ray interactions) and structural/anatomical noise (objects or structures that interfere with a region of interest), the latter of which is not considered in a typical quality control programme.

In CBCT, noise tends to be relatively high because of the low current–exposure time product and high scatter to primary ratio of X rays at the detector, among other factors. Considering that CBCT is primarily used for the visualization of high contrast structures (i.e. bone, teeth and air cavities), a moderate amount of noise does not interfere with diagnostic image quality. Nonetheless, excessive noise and increases in noise over time have to be evaluated during quality control. Noise could be measured as such using a homogeneous (section of a) phantom, or in combination with contrast as the contrast to noise ratio (see Section 5.2.4.2.5).

5.2.4.2.5. Contrast resolution

Contrast resolution refers to the ability to distinguish differences in signal (in this case, difference in radiodensity). Subjective evaluation of contrast resolution has been performed traditionally, but these methods are prone to subjectivity and different factors resulting in variability (e.g. image display, viewing software, conditions). Objective methods that do not rely on visual image interpretation are therefore preferred, although it is essential to evaluate the viewing conditions separately [99].

Contrast is strongly connected to noise and is often quantified using the contrast to noise ratio, which is defined as the ratio of the difference in grey values between objects with different densities and the standard deviation (i.e. noise) of grey values within these objects. While materials with high contrast between them are of most interest in dental CBCT (e.g. a bone equivalent material versus a soft tissue equivalent material or air), the contrast to noise ratio in the low contrast range could be measured as well.

5.2.4.2.6. Spatial resolution

Spatial resolution (or sharpness) refers to the ability to resolve small details in an image. CBCT has a relatively high spatial resolution, which is of essence for a multitude of clinical applications requiring the visualization of small anatomical details and pathosis.

Spatial resolution in CBCT is often mistakenly expressed by the voxel size of the reconstructed image, which is connected to image sharpness but does not uniquely define it. The actual spatial resolution is determined by several other factors such as focal spot size, detector pixel size and binning, number of projections, and filtering during reconstruction.

When evaluating spatial resolution in CBCT, objective measurements (e.g. point spread function, modulation transfer function) are preferred over visual evaluation for the reasons explained in Section 5.2.4.2.5. The measurement methodology ideally measures the spatial resolution in each plane; whereas voxels in CBCT are isotropic, spatial resolution in the axial and coronal/sagittal planes has been shown to vary [101]. Further, potential differences in spatial resolution, depending on the location in the FOV, have to be taken into account [102] by placing the phantom in a standardized position or by measuring the spatial resolution at central and peripheral locations and at different axial levels. As in dental applications fine details often need to be visualized, a minimum spatial resolution of one line pair per millimetre in high resolution mode has been suggested [63].

5.2.4.3. *Radiation dose*

As noted in Ref. [103], “standardisation in CBCT dosimetry remains largely unresolved.” This is highlighted by the comprehensive overview of different dose metrics provided in the EFOMP–ESTRO–IAEA protocol for quality control in CBCT [99]. In the absence of a standardized approach for phantom based dosimetry in dental CBCT, the air kerma–area product, most often referred to as dose–area product (DAP) in dental applications, is the most reasonable dose metric for quality control purposes, as it takes the primary factors affecting patient dose into account (i.e. FOV size, beam energy and current–exposure time product).

DAP measurements are performed using a calibrated large area ionization chamber (a ‘DAP meter’), which is mounted on the X ray tube. An exposure is then made (without the presence of a phantom in the FOV), and DAP is recorded and corrected for air temperature and pressure.

If, instead of a direct DAP measurement, a point measurement is performed at the isocentre or at the detector (as per the German Standard DIN 6868-161 [97]), it is strongly advised that a DAP value is derived from this measurement based on the nominal or measured beam area, and that head supports or other elements of the unit that absorb radiation are removed.

If the CBCT unit uses automatic exposure control, exposure parameters have to be entered manually when performing phantomless dosimetry.

5.2.4.4. *Clinical image quality assessment*

Apart from technical checks, quality assurance also includes clinical image quality evaluation. This can be performed in three ways. First, a comparison with standard reference images (which may be specific to each type of equipment and to different diagnostic tasks) can be performed. Second, a reject analysis can be performed by maintaining a record of the examinations that were rejected, along with the reason for rejection. The European Commission has proposed that no more than 10% of radiographs can be of unacceptable quality [36]; for CBCT, it has adopted the UK Health Protection Agency’s maximal reject rate of 5% [44, 92]. The proportion of unacceptable images is expected to reduce at each successive audit cycle. A third approach is to audit against established clinical image quality criteria, through visual grading of anatomical features.

5.2.5. Acceptance testing and quality control of protective apparel

Any protective apparel used (either by patients or workers) for dental X ray exposures has to be tested. Before first use, the lead equivalence is to be evaluated and compared with the manufacturer’s specifications using a tolerance

level of 5% [104, 105]. All protective apparel is to be checked for defects before first use and at regular intervals, by means of visual inspection, palpation and radiographic/fluoroscopic evaluation of suspicious regions.

5.3. PATIENT DOSIMETRY AND DIAGNOSTIC REFERENCE LEVELS

GSR Part 3 [4] requires DRLs to be established and used as a tool for optimization of medical exposure, and periodic local assessments of typical doses to patients to be performed in X ray facilities for those procedures for which DRLs have been established. This requirement also applies to all dental radiology facilities. Paragraph 2.19 of SSG-46 [5] describes how DRLs and local assessment are used:

“If comparison with established DRLs shows that the typical doses or activities to patients are either unusually high or unusually low, a local review is required to be initiated to ascertain whether protection and safety has been optimized and whether any corrective action is required. DRLs are not dose limits”.

5.3.1. Establishment and use of diagnostic reference levels

GSR Part 3 [4] assigns the responsibility to the government to establish DRLs, through a consultation between the health authority, the relevant professional bodies and the regulatory body. It is essential that the dental professional bodies be involved in defining the dental X ray examinations, considering the clinical indications for which DRLs are to be established. Relevant advice on the establishment, use and periodic review of DRLs is given in paras 2.34–2.45 and 3.224–3.231 of SSG-46 [5], as well as in Refs [106–108].

5.3.2. Diagnostic reference levels in dental radiography

5.3.2.1. *Two dimensional radiography*

Detailed descriptions of the dose metrics used for setting DRLs for dental radiography can be found in Section 3.2. Proposed DRLs for intraoral radiography published after 2004 are shown in Table 7 [109–118], where DRLs based on the dose quantities entrance surface air kerma (dose) and air kerma–area product (often displayed as DAP on dental units) are reported. DRLs for lateral cephalometric radiography, based on air kerma–area product, are listed in Table 8 [111, 115, 118, 119]. DRLs for panoramic radiography published after 2000 are shown in Table 9, with values based on entrance surface air kerma, air kerma–area product and air kerma–width product [109, 111, 115, 116, 118, 120–124].

TABLE 7. PROPOSED DIAGNOSTIC REFERENCE LEVELS FOR INTRAORAL RADIOGRAPHY

Dose index, unit	Country	Protocol	Diagnostic reference level	Reference
Air kerma–area product, mGy·cm ²	Germany	Maxillary molar	61.5	[110]
		Maxillary premolar	44.1	
		Maxillary canine	36.2	
		Maxillary incisor	37.9	
		Mandibular molar	41.2	
		Mandibular premolar	31.8	
		Mandibular canine	31.8	
		Mandibular incisor	26.2	
		Bitewing (front)	46.1	
		Bitewing (back)	47.3	
	Occlusal (maxilla)	87		
	Occlusal (mandible)	71.2		
	Republic of Korea	Maxillary molar	55.5	[111]
		Maxillary premolar	46	
Maxillary incisor		36.5		
Mandibular molar		87.4	[112]	
Entrance surface air kerma, mGy	Greece	Maxillary molar	1.2 (digital)	[113]

TABLE 7. PROPOSED DIAGNOSTIC REFERENCE LEVELS FOR INTRAORAL RADIOGRAPHY (cont.)

Dose index, unit	Country	Protocol	Diagnostic reference level	Reference
Entrance surface air kerma, mGy (cont.)	Greece	Maxillary molar	3.7 (film)	
		Incisor	0.65 (digital)	
		Incisor	2.35 (film)	
	Ireland	Incisor	2.3 (2.5 proposed)	[114]
		Mandibular molar	2.4	[115]
	Republic of Korea	Mandibular molar	3.1	[116]
	Spain	Maxillary molar	2.8	[117]
	UK	Mandibular molar, adult	1.2	[118]
		Mandibular molar, child	0.7	
	USA	Bitewing/periapical	1.6	[109]

TABLE 8. PROPOSED DIAGNOSTIC REFERENCE LEVELS FOR LATERAL CEPHALOMETRIC RADIOGRAPHY

Dose index, unit	Country	Protocol	Diagnostic reference level	Reference
Air kerma–area product, mGy·cm ²	Germany	Adult	33	[119] ^a
		Child	26	
	Republic of Korea	Adult	146	[115]
		Child	121	[111]

TABLE 8. PROPOSED DIAGNOSTIC REFERENCE LEVELS FOR LATERAL CEPHALOMETRIC RADIOGRAPHY (cont.)

Dose index, unit	Country	Protocol	Diagnostic reference level	Reference
Air kerma–area product, mGy·cm ² (cont.)	UK	Adult	35	[118]
		Child	24	

^a Adopted by the USA [109].

TABLE 9. PROPOSED DIAGNOSTIC REFERENCE LEVELS FOR PANORAMIC RADIOGRAPHY

Dose index, unit	Country	Protocol	Image receptor	Diagnostic reference level	Reference
Entrance surface air kerma, mGy	Greece	Adult	All	4.1	[120]
		Small adult/female	Digital radiography	3.5	
		Child	Computed radiography	4.2	
			Film	3.7	
			All	3.3	
			All	2.2	
		Spain		All	0.66
Air kerma–width product, mGy·mm	Ireland	Adult	N/A	60	[115]
			All	60.1	[122]
	Republic of Korea	Child	All	95.9	[116]
		Adult	All	120.3	[111]

TABLE 9. PROPOSED DIAGNOSTIC REFERENCE LEVELS FOR PANORAMIC RADIOGRAPHY (cont.)

Dose index, unit	Country	Protocol	Image receptor	Diagnostic reference level	Reference
	Greece	Male	All	117	[123]
		Female	All	97	
		Child	All	77	
	UK	Adult	All	81	[118]
		Child	All	60	
	Germany	Large adult	All	101	[124]
		Adult male	All	87	
		Adult female	All	84	
		Child	All	75	
	USA		All	100	[109]

5.3.2.2. *Cone beam computed tomography*

At the time of writing, national DRLs for CBCT are available from Finland and the UK [118, 125]. They are listed in Table 10.

Given the various clinical indications, each with their own specifications in terms of diagnostic image quality and FOV coverage, it is essential that separate CBCT DRLs be determined for each (common) clinical application, including the indications shown in Table 11.

TABLE 10. PROPOSED DIAGNOSTIC REFERENCE LEVELS FOR CBCT OF ADULTS

Dose index, unit	Country	Clinical indication	Diagnostic reference level	Reference
Air kerma–area product, mGy·cm ²	Finland	Presurgical imaging of implant treatments (one tooth)	360	[125]
		Assessment of the relationship between wisdom tooth and mandibular canal	380	
		Assessment of tooth’s periapical region and root canal morphology	550	
		Imaging of paranasal sinuses (excluding trauma imaging)	1150	
	UK	Adult (imaging prior to placement of a maxillary molar implant)	265	[118]
		Child (imaging of an impacted maxillary canine of a 12 year old child)	170	

TABLE 11. OVERVIEW OF CLINICAL INDICATIONS REQUIRING DIAGNOSTIC REFERENCE LEVELS IN CBCT

	Image quality needs	Field of view ^a		
		Small	Medium	Large
Adult	Low	Ectopic teeth Single implant Multiple implants Periapical pathosis Bony pathosis Sinus assessment	Airway analysis	Facial trauma Orthognathic surgery

TABLE 11. OVERVIEW OF CLINICAL INDICATIONS REQUIRING DIAGNOSTIC REFERENCE LEVELS IN CBCT (cont.)

	Image quality needs	Field of view ^a		
		Small	Medium	Large
Adult (cont.)	High	Endodontics Dental trauma		
Paediatric patients	Low	Ectopic teeth Periapical pathosis Cleft surgery ^b Bony pathosis		Orthognathic surgery
	High	Endodontics Dental trauma (permanent dentition)		

^a Small: less than 10 cm height; medium: 10–15 cm height; large: more than 15 cm height [13].

^b A local typical dose at a higher level may be used if segmentation of the data is planned and a low noise level is needed.

5.4. PROCEDURAL ASPECTS

5.4.1. General recommendations and considerations

Following justification, dental radiological procedures have to be performed in such a way as to optimize patient protection. The level of image quality that is sufficient for diagnosis is determined by the radiological medical practitioner (which in dental radiology is the dentist) and is based on the clinical question posed and the anatomical structures imaged.

The following points from para. 3.157 of SSG-46 [5] apply to all types of X ray equipment used in dentistry:

- “(a) There should be an effective system for correct identification of patients, with at least two, preferably three, forms of verification, for example name, date of birth, address and medical record number.

- (b) Patient details should be correctly recorded, such as age, sex, body mass...
- (c) The clinical history of the patient should be reviewed.”

Other considerations for optimization, adapted from paras 3.158–3.164 of SSG-46 [5], include the following:

- (a) The first step in operational considerations of optimization is the selection of the appropriate dental radiological equipment. This is discussed extensively in Section 5.1.
- (b) The volume or area of the patient that is exposed has to be strictly limited to that of clinical interest. This is very important in CBCT, and therefore an appropriate FOV is always to be selected with great caution.
- (c) The cooperation of the patient ought to be ensured to achieve an image of diagnostic quality. This is particularly relevant when imaging children. Good communication helps to achieve this. Verbal interaction between the medical radiological technologist or the medical radiological practitioner and the patient can take place before, during and after the procedure.
- (d) Optimization of protection for a woman undergoing a dental radiological procedure during pregnancy has to take into account the woman and the embryo or fetus. More details and guidance are provided in Section 5.6.
- (e) Shielding of radiosensitive organs such as the gonads, the lens of the eye, the breast and the thyroid is to be used when appropriate and according to national regulations. Care is to be taken in the anatomical placement of such shields, the impact of shielding on image quality (artefacts), and the use of automatic exposure control devices and the consequences for patient dose. According to Ref. [126], “[t]here is no justification for the routine use of protective aprons for patients undergoing any form of dental radiography or dental CBCT imaging as the main X-ray beam should never be directed towards the abdomen. Doses to the patient or the foetus from scattered X rays and leakage will then be negligible as will the associated risk”. The American Academy of Oral and Maxillofacial Radiology [127] points out that the value of leaded aprons is minimal compared with the benefits of the use of E/F speed films (or digital image receptors) and rectangular collimation. Finally, Ref. [36] states that there is no evidence to justify routine use of abdominal (gonadal) lead protection for dental radiography. As far as the thyroid gland is concerned, Refs [36, 44] state that lead shielding of the particular organ has to be used in those cases where the thyroid is in line of, or very close to, the primary beam (e.g. maxillary occlusal radiographs, lateral cephalometric radiographs, mandibular CBCT scans). The Image Gently Alliance advises that thyroid collars always be

used for children, whereas the American Thyroid Association proposes that they be used routinely for adults as well [128]. The US National Council on Radiation Protection and Measurements' (NCRP) report 177 [129] recommends that “thyroid collars shall be used when it will not interfere with the examination”. The UK consensus guidance [130] advocates the use of appropriate equipment, exposure factors, technique and collimation as the primary approach to reduce the dose to the thyroid, with thyroid shielding having a potential benefit for specific procedures. As there is no current consensus on the use of shielding as part of patient protection, further investigation on this subject is strongly advised.

- (f) Written protocols that specify the operating parameters to be used have to be developed, adopted and applied in each radiology facility. Such protocol ‘technique charts’ would have to be posted adjacent to all X ray generators and be specific for each piece of equipment. The protocols have to be developed using guidelines from national or international professional bodies, and hence would reflect current best practices. For modern digital equipment many of the factors are automated through the menu driven selection of options on the console. Nevertheless, in setting up these options, significant scope exists for optimization of protection through the appropriate selection of values for the various technical parameters, thereby effectively creating an electronic ‘technique chart’.
- (g) Size specific written protocols have to be developed for children and have to include additional operational considerations. More details and guidance are provided in Section 5.5.

5.4.2. Intraoral radiography

Paragraph 3.187 of SSG-46 [5] recommends the following with regard to the intraoral radiology:

“In developing protocols for conventional intraoral radiography, factors that can influence the image quality and the patient dose include: tube potential; current; exposure time; collimation; focus to skin distance; and, for analogue systems, film speed and processing development time and temperature.”

Detailed information on appropriate choices for those factors is provided in the guidelines on radiation protection in dental radiology issued by the European Commission [36] and the UK [126].

5.4.3. Panoramic radiography

In addition to the above factors, when developing protocols specifically for panoramic imaging, patient positioning (e.g. jaw open or closed) and collimation (e.g. for examinations of the third molars, only those areas are to be included) have to be considered. According to Ref. [36], limitation of field size to the area needed for diagnosis has to be used for panoramic radiography, if available. For analogue systems, film speed or screen speed and processing development time and temperature also need to be considered. The European and UK guidelines mentioned in the previous paragraph provide detailed guidance to facilitate the development of panoramic protocols.

5.4.4. Cephalometric radiography

Although cephalometric radiography traditionally produces images of the entire head and much of the cervical spine, the area of interest to orthodontists can be limited inferiorly at the level of the base of the skull, although some orthodontists wish to see the upper cervical spine. For this reason, and in an attempt to optimize radiation dose, Ref. [36] states that, where possible, lateral cephalograms can be collimated to limit the field to the area needed for diagnosis. Furthermore, the report proposes that manufacturers incorporate this feature into the design of the equipment.

5.4.5. Cone beam computed tomography

The most important factor in CBCT optimization is the selection of an appropriate FOV according to the clinical indication. Appropriate technical means could be incorporated to ensure proper aiming to the selected FOV to avoid retakes. In addition, the tube output could be adapted according to the image quality specifications for the diagnostic task (i.e. high/low resolution modes) and patient size. When high image quality is needed, an increase in current is preferred over a commensurate increase in exposure time, because the latter could lead to motion blurring and/or artefacts. The user is advised not to rely on exposure settings predetermined by the manufacturer, but actively explore the use of low dose protocols [131–133]. Table 11 provides a generic description of the proposed FOV and resolution for a list of clinical indications.

As mentioned in Section 5.1.4, the use of motion correction algorithms and appropriate patient immobilization is advised. Metal artefact reduction algorithms are to be used with caution, as they might result in areas of diagnostic interest being obscured.

The use of thyroid shields can be advocated, especially when the inferior edge of the FOV extends below the lower border of the mandible, with dose reductions of 35–44% to the thyroid reported in the literature [132, 134–136]. A recent publication reviewed the latest literature and proposed that thyroid shielding has to be routinely used for children undergoing CBCT scanning and could be used for adults up to the age of 50. It also advised on using a collar with a lead equivalent thickness of at least 0.25 mm, tightly fitted to the neck below the chin. Thyroid shielding is not to be used when visualization of tissue below, or slightly above, the axial level of the top of the shielding is needed [137].

The literature on the use of protective eye shielding shows a dose reduction to the eye lens [136], although tissue reactions due to dental exposures do not occur (see Section 3.1). Instead of shielding, collimation of the FOV could be considered as the primary dose reduction mechanism. Shielding of the female breast region has been shown to result in significant reduction of skin entry dose in this radiation sensitive region [138].

It has to be assured that image quality is not affected by the use of shielding. For equipment using automatic exposure control based on a scout radiograph, the shield has to be placed after acquiring the scout. If tube current modulation is used (i.e. the adaptation of tube current during the scan based on real time feedback from the projection data), the use of shielding is contraindicated [137].

Metal objects have to be removed, if possible (e.g. earrings, hearing aids). If metal objects are present in or outside the FOV, the patient's head has to be orientated in a way that minimizes the intrusion of artefacts from these metals into the region of interest (e.g. aligning the occlusal plane with the scan axial plane in order to minimize the spread of artefacts from crowns and bridges).

5.5. PAEDIATRIC PATIENTS

5.5.1. General considerations

It is estimated that 12% of intraoral and panoramic radiographs in developed countries are performed on children of up to 15 years [1]. Dental examinations are therefore particularly frequent in children, including periodic bitewing examinations in children with high caries risk, cephalometric radiographs before and during orthodontic treatment, and CBCT and CT examinations for surgical planning (e.g. trauma, cleft palate treatment).

Paediatric exposures need special consideration for three reasons:

- (a) Higher radiation sensitivity due to more active tissue proliferation;

- (b) Longer life expectancy, leading to an increased probability for the (late) manifestation of radiation induced cancers;
- (c) Higher effective dose than adults for an identical set of exposure parameters, owing to smaller size.

Justification of paediatric dental exposures is covered in Section 4, and optimization aspects are particularly important for children [4]. In accordance with para. 3.164 of SSG-46 [5], “[s]ize specific written protocols should be developed for children, from neonates to teenagers, and should include additional operational considerations”.

All considerations regarding equipment selection, quality assurance and quality control apply to both adult and paediatric exposures. As mentioned in Section 5.3, separate DRLs have to be established for paediatric patients. Personal shielding (see Section 5.4) has to be considered more strongly for children than for adults. Owing to the strong age dependence of radiation induced cancer risk to the thyroid gland, thyroid shielding has to be used at all times, except under the conditions mentioned in Section 5.4.1.

5.5.2. Specific considerations for dental radiography

5.5.2.1. Intraoral radiography

Smaller films or digital receptors tend to be used in children, but this is currently done only for practical reasons (smaller oral cavity), as the X ray beam collimation cannot be adapted to the size of the image receptor in intraoral radiography. This kind of consistent overexposure is unique to intraoral radiography and is in direct conflict with the principle of optimization. Manufacturers of intraoral X ray units have to consider the implementation of adaptable beam collimation in their products. Furthermore, as in adults, the use of rectangular collimation is strongly advised.

While the exposure time is dictated by the region being exposed, as well as the image receptor being used, it has to be ensured that the exposure times used for children are lower than the corresponding exposure times for adults. While a reduced current has an equivalent effect, a reduced exposure time is preferred for children, who are more prone to move during the exposure than adults.

5.5.2.2. Panoramic and cephalometric radiography

Panoramic radiography of children has to be performed by adapting the exposed area through the use of a collimated paediatric acquisition mode (when available), and by using a high speed exposure mode (usually <10 s acquisition

time). The current can be adapted either manually or through the use of (modifiable) pre-set values.

Cephalometric radiography is advised to be performed using a suitably adapted smaller area for children. A high speed mode is to be used if applicable, and the current has to be adapted to the size of the patient.

5.5.2.3. *Cone beam computed tomography*

The FOV has to be collimated to the diagnostic region of interest. Separate FOV size criteria are to be implemented for small children, taking the difference in relative anatomical coverage for a given FOV into account (see Table 11). For example, a scan of the dentoalveolar area of the upper and lower jaw can be performed with an FOV of approximately 10 cm × 8 cm for an adult male, whereas the same region of interest can be captured with an FOV of approximately 8 cm × 6 cm for a child (values are illustrative).

High speed and 180° scan modes are advised to be used. The use of scan times higher than 20 s is to be avoided unless the diagnostic image quality criteria are especially high, and the required image quality cannot be reached through the adaptation of other scan parameters.

The tube output has to be adapted to the head size. Although data have shown that a reduction in current for paediatric CBCT exposures is more dose efficient than a reduction in tube potential [74], further confirmation of this finding is needed. Prior research has indicated that in CBCT the current can be reduced by as much as 50% for paediatric patients [77, 132].

5.6. PREGNANT PATIENTS

If a pregnant patient is exposed, lead shielding can be used to further reduce the dose to the fetus. Even if the reduction in absolute dose is negligible, there is no contraindication to the use of shielding, as long as the considerations in Section 5.4 are taken into account (i.e. avoiding overlap between shielding and diagnostic region of interest, avoiding the effect of the shield on automatic exposure control). For CBCT and panoramic radiography, the use of a lead apron consistently reduced the fetal dose, with dose reductions of 61–72%. For intraoral radiography, a thyroid shield reduced the fetal dose by 96% for an upper occlusal examination (with the addition of a lead apron providing a slightly higher dose reduction), and by 39–57% for other examinations. For cephalometric radiography, a dose reduction of only 3% was found for the use of a lead apron [59].

5.7. CARERS AND COMFORTERS AND VOLUNTEERS IN BIOMEDICAL RESEARCH

For carers and comforters, as well as for volunteers in programmes of biomedical research, optimization of protection is achieved through applying dose constraints and proper optimization measures [4, 5]. GSR Part 3 [4] requires that a biomedical research programme involving volunteers be approved by an ethics committee in accordance with provisions of international and national guidelines [139–141]. The role of the ethics committee is described in para. 2.99 of SSG-46 [5].

5.7.1. Dose constraints

As defined in GSR Part 3 [4], “the dose constraint is a source related value used in optimizing the protection of carers and comforters of patients undergoing radiological procedures, and the protection of volunteers subject to exposure as part of a programme of biomedical research.” According to paras 3.149 and 3.173 of GSR Part 3 [4], the government is responsible for ensuring that dose constraints are established, as a result of consultation between the health authority, relevant professional bodies and the regulatory body, and that the registrants and licensees are responsible for ensuring that the established dose constraints are used in practice. In addition, for volunteers subject to exposure as part of a programme of biomedical research, GSR Part 3 (footnote 40) [4] further requires that “[t]he selection of constraints for carers and comforters is a complex process in which a number of factors have to be taken into account, such as the age of the individual and for a woman the possibility of her being pregnant.”

Further guidance on dose constraints is provided in paras 2.46–2.50 of SSG-46 [5].

5.7.2. Optimization of protection

For carers and comforters, similar considerations as for occupational and public protections apply (see Section 6). Specifically, adequate distance and (room and personal) shielding have to be ensured, taking into account the specific situation and the role of the carer/comforter in ensuring patient compliance. For CBCT exposures in particular, a ‘dry run’ (i.e. a rotation of the tube and detector with no X ray exposure) can be performed first, in order to familiarize the patient with the scanning process, and to judge the need of the carer or comforter to be in (close) vicinity of the patient during the exposure.

For volunteers in biomedical research, similar considerations as for optimization of protection to patients apply (see Section 5.4). It has to be ensured

that the radiation dose to the volunteer is as low as reasonably achievable, taking the image information and quality needed for the particular research study into account.

5.8. UNINTENDED AND ACCIDENTAL MEDICAL EXPOSURES

Unintended and accidental medical exposures may occur in any imaging procedure, including dental ones, and GSR Part 3 [4] sets out the requirements for their prevention and investigation. In dental radiology, unintended and accidental medical exposure can include exposure of the wrong patient, or performance of the wrong examination, as well as any failure of dental X ray equipment while in operation, failures and errors in the software controlling or influencing the delivery of the radiation, and human error.

SSG-46 [5] recommends that the general strategies for addressing these problems include the regular maintenance of equipment and software, a comprehensive quality assurance programme, continuing education and training of staff, and the promotion of a safety culture. Procedures have to be put in place that consist of several independent methods of patient identification, and verification of requisition of the examination and of the orientation of the patient. All unintended and accidental medical exposure has to be investigated and records have to be kept.

Further guidance on the prevention, investigation and reporting of unintended medical exposure is provided in Ref. [5].

6. OCCUPATIONAL AND PUBLIC PROTECTION

In dental imaging procedures, the occupationally exposed individuals are usually medical radiation technologists, radiological medical practitioners such as dentists or dental radiologists, medical physicists, biomedical, clinical or service engineers, and some contractors, depending on their role.

6.1. DOSE LIMITS

The dose limits for occupational and public exposure are determined and updated by the ICRP and are subsequently adopted into national legislation. Table 12 lists the dose limits from GSR Part 3 [4].

TABLE 12. DOSE LIMITS FOR OCCUPATIONAL AND PUBLIC EXPOSURE, ACCORDING TO GSR PART 3 [4]

Type of limit	Occupational	Public
Annual effective dose	20 mSv ^{a,b}	1 mSv ^c
Annual equivalent dose to:		
Eye lens	20 mSv ^a	15 mSv
Skin ^d	500 mSv	50 mSv
Hands and feet	500 mSv	—

^a Averaged over five consecutive years (100 mSv in five years), with no single year exceeding 50 mSv.

^b Additional restrictions apply for pregnant women.

^c Similar to the occupational dose, a higher annual dose could be allowed in a single year in special circumstances, providing that the average over five consecutive years does not exceed 1 mSv in a year.

^d Averaged over 1 cm², regardless of the area exposed.

6.2. CLASSIFICATION OF AREAS

In a dental office, X ray equipment can be found in the treatment areas and in dedicated areas for radiology. In accordance with para. 3.56 of SSG-46 [5], these rooms, or areas within them, should be classified as controlled areas or supervised areas. The classification can be made according to the estimated dose rate. All other rooms and areas are considered as being in the public domain and levels of radiation in these areas should be low enough to ensure compliance with the dose limits for public exposure. However, handheld equipment is also used in dentistry, which complicates this situation. General guidance is provided in the next few paragraphs. However, final decisions would be based on the expert advice of the medical physicist, a qualified expert in radiation protection or the radiation protection officer. National regulatory requirements will need to be followed.

6.2.1. Controlled areas

In accordance with para. 3.57 of SSG-46 [5], all X ray rooms should be designated and marked as controlled areas. Rooms where mobile or handheld intraoral X ray units are used, including external premises such as care homes or patients' private residences, can also be categorized as controlled areas during the time in which radiological procedures are being carried out. Areas without fixed walls, where curtains or similar are used to create cubicles, with either

fixed, mobile or handheld X ray units, can also be categorized as controlled areas during the time in which radiological procedures are being carried out. To avoid uncertainties about the extent of controlled areas, the boundaries should, when possible, be walls and doors.

6.2.2. Supervised areas

Supervised areas may involve areas surrounding X ray rooms. Paragraph 3.59 of SSG-46 [5] states:

“The control console may be inside the X ray room, separated by structural shielding, or outside the X ray room in the staff area, with visual control of the X ray room and with patient communication. Access of unauthorized individuals to control console areas should be restricted to avoid the distraction of the operator, which might lead to unnecessary or repeated exposures. Control panel areas are not in the public domain and therefore should be classified as either controlled areas or supervised areas.”

6.3. DESIGN OF X RAY ROOM

As far as the design of dental practices is concerned, and because dental imaging includes a number of different X ray machines, para. 3.9 of SSG-46 [5] states that “[t]he siting and layout should take into account the types of radiological procedure, workload and patient flow”. This should also take any adjacent occupied areas into account, such as residential accommodation, medical centres and shops.

In accordance with para. 3.10 of SSG-46 [5], the three factors relevant to dose reduction (i.e. time, distance and shielding) should be combined in the design to optimize occupational radiation protection and public radiation protection. Furthermore, para. 3.11 of SSG-46 [5] states:

“Shielding requirements should be tailored to meet any national requirements and to suit the practice requirements based on the intended patient workload and the types of examination to be performed. Further assessments should be undertaken when the intended use of a room changes, X ray equipment is upgraded, underlying procedures or patient workload changes, or the surrounding room occupancy is altered.”

The following guidance, adapted from paras 3.12–3.15 of SSG-46 [5], applies to dental radiology. Any doors and viewing windows in walls or doors

should have at least the same lead equivalence as the minimum shielding specifications for the shielded wall or barrier in which they are located. Due consideration should be given to the provision of floor and ceiling shielding when rooms immediately below and above the X ray installation, respectively, are occupied. All penetrations and joints in shielding should be arranged so that they are equally effective in shielding radiation.

General safety features include the following:

- (a) A barrier should be placed at the control console to shield staff to the extent that they do not need to wear protective clothing while at the console.
- (b) All possible intended directions of the X ray beam should be taken into consideration in the room design so that the X ray beam cannot be directed at any area that is not shielded and cannot lead to potentially unacceptable doses being received in this area.
- (c) The doors should provide protective shielding for secondary radiation and should be shut when the X ray beam is on.
- (d) The operator should be able to clearly observe and communicate with the patient at all times during an X ray diagnostic procedure.

Signs and warning lights, preferably positioned at eye level, should be used at the entrances of controlled areas and supervised areas to prevent inadvertent entry. The signs should be clear and easily understandable. Warning lights, such as illuminated or flashing signs, as appropriate, should be activated when radiation is being produced inside the controlled area or supervised area. Door interlocks are not appropriate in X ray diagnostic radiological procedures, because if the X ray beam is stopped, the medical procedure may have to be repeated.

A stable power supply should be available. An uninterruptible power supply or battery backup systems should be installed to capture the active information at the time of the outage and to power down all software in a controlled manner. Servers should be programmed to automatically shut down when the power supply is interrupted.

6.4. PROTECTION FOR ADJACENT AREAS

As specifically stated in Ref. [129], shielding does not necessarily mean lead lined X ray rooms. Normal building materials may be sufficient in most cases. However, a qualified expert has to be involved for all new and remodelled dental facilities in advance of construction [5, 142]. If a conventional building structure does not provide adequate shielding, the shielding can be applied either

by providing greater thickness of the building material or by adding lead, gypsum wallboard or another suitable material.

Two widely used methods for shielding calculations are given in Refs [143, 144]. Other methods are also available and used (see Refs [145–148]). More advice on shielding is given in paras 3.18–3.24 of SSG-46 [5].

6.5. LOCAL RULES AND PROCEDURES

6.5.1. General considerations

As established in para. 3.94 of GSR Part 3 [4], local rules and procedures are required to be established in writing in any radiology facility, including dental ones. Their purpose is to ensure protection and safety for workers and other persons.

The following guidance is from para. 3.60 of SSG-46 [5]:

“local rules and procedures should include measures to minimize occupational radiation exposure both for normal work and in unusual events. The local rules and procedures should also cover the wearing, handling and storing of personal dosimeters, and should specify investigation levels and ensuing follow up actions”.

Since all personnel involved in using radiation in a dental radiology facility need to know and follow the local rules and procedures, the development and review of these local rules and procedures should involve a qualified expert and representatives of all health professionals involved in dental radiology procedures.

Dental equipment (both hardware and software) should be operated in a manner that ensures satisfactory performance at all times with respect to both the tasks to be accomplished and radiation protection and safety. The manufacturer’s operating manual is an important resource in this respect, but additional procedures are likely to be needed. The final documented set of operational procedures should be subject to approval by the licensee of the radiology facility, and should be incorporated into the facility’s management system, as required by GSR Part 2 and GSR Part 3 [5, 19].

Radiology facility staff should understand the documented procedures for their work with radiation and for the operation of the equipment with which they are working, including the safety features. They should be trained, with periodic refresher training, in what to do if things go wrong. Additional training should be

conducted when new medical radiological equipment is brought into use in the radiology facility.

Many local rules and procedures address some or all aspects of occupational radiation protection, patient radiation protection and public radiation protection, either directly or indirectly, as well as providing for a successful dental radiology procedure.

For those radiological procedures where there is no need for staff to be in the room during an exposure, all attending staff should position themselves in the appropriately shielded areas.

In general, there should be no need for occupationally exposed staff to hold, or have close contact with, patients during a dental radiological procedure. If such holding or contact is indeed necessary, then the person to be used in that role should be considered a carer or comforter of the patient and should be afforded the appropriate radiation protection.

Immobilization devices, as used for example in CBCT, should be used whenever possible and as appropriate to minimize exposure of the patient, the staff member or the carer or comforter. Immobilization of patients should not be performed by staff and, if possible, not by any person. If immobilization requires the use of a person, then this should be someone, such as a relative of the patient, who has agreed to be a carer or comforter, and is afforded radiation protection accordingly.

6.5.2. Dental facilities with intraoral and panoramic equipment

Paragraph 3.75 of SSG-46 [5] recommends the following specific measures for dental facilities with intraoral and panoramic equipment:

“For dental facilities with intraoral and panoramic equipment, the following measures should be taken:

- (a) Personal protective equipment is not usually needed. Radiation protection is afforded through the use of distance from the patient. Typically, a distance of at least 2 m is recommended.
- (b) The operator should not hold the image receptor during the exposure.
- (c) Handheld portable X ray equipment for intraoral radiography should be used only for examinations where it is impractical or not medically acceptable to transfer patients to a fixed unit or to use a mobile unit (e.g. in nursing homes, residential care facilities or homes for persons with disabilities; in forensic odontology; or for military operations abroad without dental facilities)”.

In situations when the operator of intraoral equipment has to be in the room during the exposure, a minimum distance of 2 m (preferably 3 m) and a proper position have to be maintained with respect to the X ray source, generally at an angle of 90 to 135 degrees from the central X ray [129].

When the use of a handheld portable X ray unit is justified, devices with an integrated scatter shield are preferable to protect the operator [129]. Measures have to be in place to ensure that only an authorised person with adequate training will use the device.

6.5.3. Dental facilities with cone beam computed tomography equipment

Paragraph 3.76 of SSG-46 [5] recommends that when a dental facility uses CBCT, it “should be housed in a room that has been designed and shielded accordingly. Staff should be positioned behind the protective barrier at the control console when exposures are made.”

6.6. INDIVIDUAL MONITORING AND ASSESSMENT OF OCCUPATIONAL EXPOSURE

With respect to the assessment of occupational exposure and individual monitoring, the requirements set by the national regulatory body should be followed. Routine personal dosimetry is not universally required across States [39, 142].

The purpose of monitoring and dose assessment is, inter alia, to provide information about the exposure of workers and to confirm good working practices and regulatory compliance. In accordance with para. 3.100 of GSR Part 3 [4]:

“For any worker who usually works in a controlled area, or who occasionally works in a controlled area and may receive a significant dose from occupational exposure, individual monitoring shall be undertaken where appropriate, adequate and feasible.”

To ensure compliance, it is desirable to seek the advice of a qualified expert. A risk based approach to occupational radiation monitoring has to be adopted in order to avoid unnecessary monitoring [4, 5, 141, 142]. For CBCT, owing to the higher radiation dose levels, the need for personal monitoring has to be carefully investigated [149].

If the analysis concludes that personal dosimetry is required, then one of the widely accepted methods of individual monitoring can be used, such as film

dosimeters, thermoluminescence dosimeters, optically stimulated luminescence badges or other appropriate devices.

For cases in which personal dosimetry is required, para. 3.106 of SSG-46 [5] provides advice that also applies to dental radiology:

“Each dosimeter should be used for monitoring only the person to whom it is issued, for work performed at that radiology facility, and it should not be taken to other facilities where that person may also work. For example, if a person is issued with a dosimeter at hospital A, it should be worn only at hospital A and not at any other hospitals or medical centres where he or she also works. Monitoring results can then be interpreted for the person working in a specific radiology facility, and this will allow appropriate review of the effectiveness of the optimization of protection and safety for that individual in that facility. However, national regulatory requirements may differ from this advice, and they would need to be followed in those jurisdictions in which they apply (see also paras 3.123–3.125).”

In accordance with para. 3.107 of SSG-46 [5], the monitoring period (period of dosimeter deployment) specified by regulatory bodies in most States is typically in the range of one to three months. In dental radiology, a longer monitoring period (i.e. two or three months) could be applied, as personnel are generally exposed to lower doses. In this way (applying a longer monitoring cycle), it is more likely that a reading can be obtained. Dosimeters should be sent from the radiological facility to the dosimetry service provider, which should then process the dosimeters and return the dose reports, all in a timely manner. Some regulatory bodies may specify a performance criterion for timely reporting.

More guidance on the assessment of occupational exposure is provided in Refs [5, 142].

Appendix I

RADIATION DOSE QUANTITIES APPLICABLE TO DENTAL RADIOLOGY

This appendix summarizes the fundamental quantities used for the assessment of doses from radiation exposures, and the specific quantities used in diagnostic radiology for the estimation of patient dose, as recommended by the ICRP and ICRU [8, 10]. The recommended methods for their estimation are given in Refs [11, 15].

I.1. FUNDAMENTAL DOSE QUANTITIES

The absorbed dose, D , is the fundamental dosimetric quantity that is generally utilized for all types of ionizing radiation. D is defined as the mean energy per unit mass imparted by ionizing radiation to matter. The SI unit of D is the gray, defined as one joule per kilogram.

Kerma, K , can be described as the sum of the initial kinetic energies of all charged particles liberated by uncharged particles (e.g. X ray photons) per unit mass. The kerma value for air is termed 'air kerma'. Air kerma and the absorbed dose in air are numerically equal in the range of X ray photon energies used in dental radiology. This explains why in many circumstances 'dose' is used instead of the more correct term 'air kerma'.

The equivalent dose in an organ or tissue, H_T , is defined as follows:

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

where $D_{T,R}$ is the absorbed dose delivered by radiation of type R averaged over a tissue or organ T, and w_R is the radiation weighting factor for radiation type R [8]. The radiation weighting factor w_R varies from 1 for photon radiation to 20 for heavy particles to reflect the relative biological effectiveness of the radiation in inducing stochastic effects at low doses. The SI unit of equivalent dose is the sievert, defined as one joule per kilogram. Since the value of w_R for X ray radiation is 1, in dental radiology, an absorbed dose of 1 Gy always equals an equivalent dose of 1 Sv in an organ or tissue.

To assess the probability of health detriment from stochastic effects due to ionizing radiation, the quantity effective dose, E , is introduced. E is defined as the weighted sum of tissue equivalent doses as follows:

$$E = \sum_T w_T H_T$$

where w_T is the tissue weighting factor for tissue or organ T . The unit of effective dose is the sievert. The summation is performed over all organs or tissues considered to be sensitive to the induction of stochastic effects comprising cancer and heritable effects. The w_T values are chosen to represent the contributions of individual organs and tissues to the overall radiation detriment from stochastic effects (Table 13). Their values, as well as the list of organs and tissues, were defined in Ref. [12] and revised in Ref. [8]. It has to be noted that, owing to the latest inclusion of the salivary gland, oral mucosa, muscle, lymphatic nodes and extrathoracic airway in the list of radiosensitive tissues in Ref. [8], the effective doses in dental radiology have increased significantly [13].

I.2. SPECIFIC QUANTITIES FOR PATIENT DOSE ESTIMATION

I.2.1. Incident air kerma

The incident air kerma, K_i , is the air kerma from an incident X ray beam measured on the central beam axis at the position of the patient or phantom

TABLE 13. TISSUE WEIGHTING FACTORS

Tissue	w_T	Σw_T
Bone marrow (red), colon, lung, stomach, breast, remainder tissues ^a	0.12	0.72
Gonads	0.08	0.08
Bladder, oesophagus, liver, thyroid	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04
Total		1.00

^a Remainder tissues: adrenals, extrathoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus and uterus/cervix.

surface. Only the radiation incident on the patient or phantom, and not the backscattered radiation, is included [11, 14].

I.2.2. Entrance surface air kerma

The entrance surface air kerma, K_e , is the air kerma measured on the central beam axis at the position of the patient or phantom surface. The radiation incident on the patient or phantom and the backscattered radiation are included. The unit of entrance surface air kerma is the gray, and in dental radiology the dose levels are usually in the order of milligray or microgray. Entrance surface air kerma can be calculated by multiplying the incident air kerma by the backscatter factor [11, 14]. The entrance surface air kerma is frequently reported as ‘entrance surface dose’ in dental radiology.

I.2.3. Air kerma–area product

The air kerma–area product, P_{KA} , is the integral of the air kerma over the area of the X ray beam in a plane perpendicular to the beam axis. It is approximately invariant with distance from the X ray tube focus, as long as the planes of measurement and calculation are far enough from the patient or phantom to avoid a significant contribution from backscattered radiation. The unit of air kerma–area product is $\text{mGy}\cdot\text{cm}^2$. The air kerma–area product is frequently reported as DAP in dental X ray units.

I.2.4. Air kerma–length product

The air kerma–length product, P_{KL} , is the integral of the air kerma over a line of length L , and the unit is $\text{mGy}\cdot\text{cm}$. In CT, air kerma–length product is defined as the CT air kerma index multiplied by the scan length. This quantity is analogous to the dose–length product, which is accepted by the ICRU [15]. In dental panoramic dosimetry, this quantity has been termed the dose–width product [11, 14].

I.2.5. Computed tomography air kerma index

The CT air kerma index, $C_{a,100}$, measured in air for a single rotation of a CT scanner, is the integral of the kerma along a line parallel to the axis of rotation of the scanner over a length of 100 mm, divided by the nominal slice thickness. It corresponds to the term ‘computed tomography dose index’, which is accepted by the ICRU and frequently used in dose reports [15]. The CT air kerma index is expressed in milligrays.

The weighted computed tomography dose index, C_w , also measured in milligrays, is the computed tomography dose index calculated from measurements at the centre and periphery of a standard PMMA head or body phantom.

The volume computed tomography dose index, C_{vol} , is equal to the weighted computed tomography dose index divided by the pitch of the helical CT scanner [11].

Appendix II

EDUCATION AND TRAINING OBJECTIVES APPLICABLE TO DENTISTRY

Table 14 provides a summary of the education and training objectives for the three roles applicable to dentistry: referring medical practitioner, radiological medical practitioner and operator of the X ray equipment, whose roles are described in Section 3.5. Depending on their role, health professionals are expected to have sufficient knowledge, skill and competences with respect to radiation protection, obtained through education and training.

TABLE 14. EDUCATION AND TRAINING OBJECTIVES FOR THE KEY HEALTH PROFESSIONALS INVOLVED IN DENTAL RADIOLOGY

	Knowledge and understanding	Skills and abilities	Competences
Referring medical practitioner	<ul style="list-style-type: none"> • Radiation dose and associated risk • Principles of radiation protection • Selection criteria for dental X ray imaging • Alternative diagnostic methods not using ionizing radiation • Aspects of optimization relevant to referral • Information needed for appropriate referral • Radiological anatomy • Radiological interpretation of pathosis 	<ul style="list-style-type: none"> • Ability to prepare an appropriate referral note • Ability to analyse normal anatomical structures of the teeth, jaws and facial skeleton in dental X ray images • Ability to recognize the anatomy and disease of teeth and their supporting structures in dental X ray images • Ability to search and identify adequate scientific literature • Ability to prepare a radiological report • Ability to understand a radiological report received from another practitioner 	<ul style="list-style-type: none"> • Strive for a minimal radiation dose to patients • Make referrals that are reasonable and likely to be justified • Take responsibility for own competence development in the field of dentomaxillofacial radiology

TABLE 14. EDUCATION AND TRAINING OBJECTIVES FOR THE KEY HEALTH PROFESSIONALS INVOLVED IN DENTAL RADIOLOGY (cont.)

	Knowledge and understanding	Skills and abilities	Competences
Radiological medical practitioner	<ul style="list-style-type: none"> • Radiation dose and associated risk • Principles of radiation protection • Selection criteria for dental X ray imaging 	<ul style="list-style-type: none"> • Ability to recognize malfunctioning of dental X ray equipment • Ability to apply a quality control programme for dental X ray equipment 	<ul style="list-style-type: none"> • Strive for a minimal radiation dose to patients and staff • Take responsibility for own competence development in the field of dentomaxillofacial radiology
Radiological medical practitioner (cont.)	<ul style="list-style-type: none"> • Alternative diagnostic methods not using ionizing radiation • Knowledge and understanding of how X ray equipment works • Theoretical and practical aspects of optimization • Radiological anatomy • Radiological interpretation of pathosis 	<ul style="list-style-type: none"> • Skills in practical use of software and other tools • Ability to differentiate between findings indicative of normal anatomical structures and those indicative of diseased teeth, jaws and facial skeleton • Ability to analyse disease and create a report of dental X ray images • Ability to identify and critically review adequate scientific literature 	<ul style="list-style-type: none"> • Take responsibility for staff development in the field of dentomaxillofacial radiology • Identify when to refer for a second opinion

TABLE 14. EDUCATION AND TRAINING OBJECTIVES FOR THE KEY HEALTH PROFESSIONALS INVOLVED IN DENTAL RADIOLOGY (cont.)

	Knowledge and understanding	Skills and abilities	Competences
Operator	<ul style="list-style-type: none"> • Radiation dose and associated risk • Principles of radiation protection • Selection criteria for dental X ray imaging • Practical aspects of optimization • Understanding of the information needed for appropriate referral • Radiological anatomy • Occupational protection 	<ul style="list-style-type: none"> • Ability to recognize malfunctioning of dental X ray equipment • Ability to apply a quality control programme for dental X ray equipment • Skills in practical use of software and other tools 	<ul style="list-style-type: none"> • Strive for a minimal radiation dose to patients and staff • Take responsibility for own competence development in the field of dentomaxillofacial radiology

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Annex

CLINICAL INDICATIONS FOR DENTAL RADIOLOGICAL IMAGING

This annex presents a non-exhaustive list of clinical indications (clinical tasks) for dental radiological imaging, which was assembled from existing professional guidelines [A-1 to A-13].

For each clinical task, Table A-1 includes suggestions for the type of examination, including some alternative diagnostic examinations not using ionizing radiation, associated dose levels per examination and additional comments for consideration.

Three levels of suggestions are used:

- (a) Indicated: normally an imaging method of choice.
- (b) Indicated only in specific circumstances: limited to specific clinical situations; particular care over justification is necessary.
- (c) Specialized investigation: indicated but may not be easily accessed by dentists or may need specialized training.

‘Indicated’ does not mean compulsory. X ray examinations have to be justified individually for each patient on each occasion. For some applications, several imaging options are classified as indicated; this does not mean that all have to be used for the same patient, but indicates that there is a clinical judgement to be made between the options available. Radiological examinations are only to be performed when the outcome can be reasonably expected to influence patient management.

‘Dose level’ gives the level of exposure to radiation:




- (a) None — techniques using no ionizing radiation;
- (b)  — effective dose typically <25 μSv ;
- (c)  — effective dose typically <100 μSv ;
- (d)  — effective dose typically <500 μSv .

TABLE A-1. NON EXHAUSTIVE LIST OF CLINICAL INDICATIONS (CLINICAL TASKS) FOR DENTAL IMAGING, ASSEMBLED FROM EXISTING PROFESSIONAL GUIDELINES [A-1 to A-13]




Clinical task	Type of examination	Dose level	Suggestion	Comment
Caries diagnosis: initial visit	Clinical examination	None	Indicated	Clinical examination of dried tooth surfaces with good lighting is essential as first step in caries detection
	Intraoral bitewing radiographs		Indicated	For high and moderate caries risk patients, there is a significant addition to diagnostic yield of clinical examination alone. For low caries risk patients, there is less strong evidence
	Fibre optic transillumination	None	Indicated	Useful adjunct to radiography for detection of approximal lesions
	Laser fluorescence methods	None	Specialized investigation	Adjunct to radiography, but with significant false positive rates
Caries diagnosis: monitoring	Clinical examination	None	Indicated	Clinical examination of dried tooth surfaces with good lighting is essential at all stages of monitoring and review in caries detection
	Intraoral bitewing radiographs		Indicated	Intervals between radiographic examinations depend on clinically assessed caries risk status
Periodontal bone assessment	Clinical examination	None	Indicated	The primary diagnostic method is clinical examination using a periodontal probe, with full pocket charting if needed
Periodontal bone assessment (cont.)	Intraoral bitewing radiographs		Indicated	Provides good geometrical perspective for crestal bone attachment. These may have already been taken for caries diagnosis. Vertical bitewings may be considered where bone loss is already present and when it might be excluded from the conventional bitewing image

TABLE A-1. NON EXHAUSTIVE LIST OF CLINICAL INDICATIONS (CLINICAL TASKS) FOR DENTAL IMAGING, ASSEMBLED FROM EXISTING PROFESSIONAL GUIDELINES [A-1 to A-13] (cont.)









Clinical task	Type of examination	Dose level	Suggestion	Comment
	Intraoral periapical radiographs		Indicated	Provides an image of the whole tooth. Consider when there is advanced bone loss
	Panoramic radiograph		Indicated	Provides an alternative to multiple intraoral radiographs but with inferior image detail
	CBCT	 or 	Indicated only in specific circumstances	May have value in assessment of complex bone defects if surgery planned, or for perio-endo lesions
Periapical inflammatory pathosis diagnosis	Intraoral periapical radiograph		Indicated	Increased likelihood of identifying periapical inflammatory lesions for teeth that have clinical signs or symptoms, gross caries, deep restorations, crowns or bridge abutments and previously endodontically treated teeth
	CBCT	 or 	Indicated only in specific circumstances	There is evidence of higher diagnostic accuracy for some CBCT systems
Endodontic therapy: working length estimation	Intraoral periapical radiograph		Indicated	More than one radiograph may be needed in multirrooted teeth to avoid superimpositions and allow parallax localization of roots and canals
	Electronic apex locator	None	Indicated	Normally need confirmation of measurement by radiography, although some guidelines suggest that apex locators may be used alone in selected cases when the operator has confidence in the reading

TABLE A-1. NON EXHAUSTIVE LIST OF CLINICAL INDICATIONS (CLINICAL TASKS) FOR DENTAL IMAGING, ASSEMBLED FROM EXISTING PROFESSIONAL GUIDELINES [A-1 to A-13] (cont.)








Clinical task	Type of examination	Dose level	Suggestion	Comment
	CBCT	 or 	Indicated only in specific circumstances	If high resolution CBCT is already available, then this may allow measurement of working length, but CBCT does not have to be used as the normal method of working length estimation
Endodontic therapy: mid-fill ('master point')	Intraoral periapical radiograph		Indicated	Radiograph of tooth with master gutta percha cone in position may be indicated, depending on clinical judgement
Endodontic therapy: end of treatment	Intraoral periapical radiograph		Indicated	End of treatment radiograph needed for confirmation of adequate obturation and as a baseline for future image comparison
Endodontic therapy: review	Intraoral periapical radiograph		Indicated	Suggestions on the timing of review radiography are inconsistent between guidelines and lack an evidence base. A review 12 months after treatment completion has some evidence to support it. Review after this point depends on clinical judgement
Planning crown	Intraoral periapical radiograph		Indicated	Most teeth requiring full coronal coverage restoration will be heavily restored and/or root filled. These criteria are also both good predictors of periapical inflammatory pathosis
Planning bridge (tooth supported fixed prosthesis)	Intraoral periapical radiograph		Indicated	For abutment teeth that are heavily restored or root filled, the same justification exists as for planning a crown. For unrestored or minimally restored abutments and where an adhesive bridge is planned, a radiograph might not be needed

TABLE A-1. NON EXHAUSTIVE LIST OF CLINICAL INDICATIONS (CLINICAL TASKS) FOR DENTAL IMAGING, ASSEMBLED FROM EXISTING PROFESSIONAL GUIDELINES [A-1 to A-13] (cont.)













Clinical task	Type of examination	Dose level	Suggestion	Comment
Implant therapy: planning	Intraoral periapical radiograph		Indicated	Various combinations of imaging can be justified for implant planning, depending on clinical complexity and the surgeon's judgement. CBCT may offer lower dose than MDCT, although low dose protocols for MDCT may overcome this. CBCT usually has advantages for dose over MDCT when a small FOV can be used. Magnetic resonance imaging for implant planning is currently limited to a few specialist centres.
	Panoramic radiograph		Indicated	
	CBCT	 or 	Indicated	
	MDCT	 to  	Indicated	
	Magnetic resonance imaging	None	Specialized investigation	
Implant therapy: intra-operative	Intraoral periapical radiograph		Indicated	May be needed during preparation of implant site
Implant therapy: end of treatment	Intraoral periapical radiograph		Indicated	Combinations of either intraoral or panoramic radiographs, or both, are appropriate, depending on the specific clinical situation
	Panoramic radiograph		Indicated	
	CBCT	 or 	Indicated only in specific circumstances	Indicated in cases where there is suspected misplacement or damage to adjacent structures (e.g. mandibular canal)

TABLE A-1. NON EXHAUSTIVE LIST OF CLINICAL INDICATIONS (CLINICAL TASKS) FOR DENTAL IMAGING, ASSEMBLED FROM EXISTING PROFESSIONAL GUIDELINES [A-1 to A-13] (cont.)











Clinical task	Type of examination	Dose level	Suggestion	Comment	
Implant therapy: review	Intraoral periapical radiograph		Indicated	Combinations of either intraoral or panoramic radiographs, or both, is appropriate, depending on the specific clinical situation. Intraoral radiographs give greater detail of the crestal bone and implant-bone junction, but the technique can be challenging where there is much alveolar ridge resorption	
	Panoramic radiograph		Indicated		
	CBCT	 or 	Indicated only in specific circumstances		Artefacts around implants reduce the value of images in examining the implant-bone junction. CBCT is useful in selected cases (e.g. suspected incorrect placement, for evaluation of bony defects)
Trauma (teeth and alveolar bone)	Intraoral periapical radiograph		Indicated	Combinations of intraoral radiographs using different perspectives provide fine detail and are usually sufficient for dental trauma	
	Intraoral occlusal radiograph		Indicated		
	Panoramic radiograph		Indicated		Provide more extensive coverage of bone for suspected dento-alveolar fracture
	CBCT	 or 	Indicated only in specific circumstances		Localized high resolution CBCT appears to have higher diagnostic accuracy for root fracture detection, but is indicated only when conventional radiographs have proved to be inadequate for patient management. Patient cooperation has to be excellent, as movement artefact will reduce fracture detection
Trauma (maxillofacial)	Panoramic radiograph		Indicated	Combinations of panoramic and facial bone radiographs are the traditional methods of detecting bone injuries. CBCT and MDCT are increasingly replacing these	

TABLE A-1. NON EXHAUSTIVE LIST OF CLINICAL INDICATIONS (CLINICAL TASKS) FOR DENTAL IMAGING, ASSEMBLED FROM EXISTING PROFESSIONAL GUIDELINES [A-1 to A-13] (cont.)
















Clinical task	Type of examination	Dose level	Suggestion	Comment
	Facial/skull radiographs		Indicated	
	CBCT	 or 	Indicated	
	MDCT	 or  	Indicated	
Orthodontic treatment	Intraoral periapical radiograph		Indicated	Taken to determine the presence and position of unerupted teeth, the presence or absence of apical disease or root form. Periapical views can form part of a parallax technique for localization of teeth
	Intraoral occlusal radiograph		Indicated	The most common use for an occlusal image is to help in assessing the position of misplaced and unerupted canines. With the parallax technique used in conjunction with a periapical or panoramic radiograph, the position of unerupted teeth can be determined
	Panoramic radiograph		Indicated	To confirm the presence, position and morphology of unerupted teeth when there are clinical indications of a disturbance of normal dental development. Routine radiographic screening of children cannot be justified

TABLE A-1. NON EXHAUSTIVE LIST OF CLINICAL INDICATIONS (CLINICAL TASKS) FOR DENTAL IMAGING, ASSEMBLED FROM EXISTING PROFESSIONAL GUIDELINES [A-1 to A-13] (cont.)

Clinical task	Type of examination	Dose level	Suggestion	Comment
	Cephalometric radiographs		Indicated	To assess skeletal pattern and labial segment angulation. To monitor the effects of treatment Patients who may need lateral cephalometry include those with a skeletal discrepancy when functional or fixed appliances are to be used for labio-lingual movement of the incisors. Posteroanterior cephalograms may be of use in patients who present with facial asymmetry
	CBCT	 or 	Indicated only in specific circumstances	Used in selected cases to localize impacted teeth, with particular reference to the position of adjacent teeth and possible resorption To assess dental structural anomalies, e.g. gemination, fusion, supernumerary teeth For some complex cases of skeletal abnormality and for orthognathic surgery treatment planning Cleft palate cases
	MDCT	 or  or 	Indicated only in specific circumstances	For some complex cases of skeletal abnormality and for orthognathic surgery treatment planning Where possible, CBCT has to be substituted where this involves a lower radiation dose and adequate images
Internal derangement of the temporomandibular joint	Clinical examination	None	Indicated	Usually provides the information needed from diagnosis
	Magnetic resonance imaging	None	Indicated only in specific circumstances	In cases where there is uncertainty about the origin of the symptoms, e.g. potentially juvenile rheumatoid arthritis

Note: CBCT — cone beam computed tomography; MDCT — multidetector computed tomography.

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ABBREVIATIONS

AEC	automatic exposure control
CBCT	cone beam computed tomography
CCD	charge coupled device
CMOS	complementary metal oxide semiconductor
CT	computed tomography
DAP	dose–area product
DICOM	Digital Imaging and Communications in Medicine
DRL	diagnostic reference level
EFOMP	European Federation of Organisations for Medical Physics
ESTRO	European Society for Radiotherapy and Oncology
FOV	field of view
HU	Hounsfield unit
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
MDCT	multidetector computed tomography
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organization

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