CLINICAL ORAL IMPLANTS RESEARCH

Review

E.A.O. guidelines for the use of diagnostic imaging in implant dentistry 2011. A consensus workshop organized by the European Association for Osseointegration at the Medical University of Warsaw

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Abstract

Diagnostics imaging is an essential component of patient selection and treatment planning in oral rehabilitation by means of osseointegrated implants. In 2002, the EAO produced and published guidelines on the use of diagnostic imaging in implant dentistry. Since that time, there have been significant developments in both the application of cone beam computed tomography as well as in the range of surgical and prosthetic applications that can potentially benefit from its use. However, medical exposure to ionizing radiation must always be justified and result in a net benefit to the patient. The as low a dose as is reasonably achievable principle must also be applied taking into account any alternative techniques that might achieve the same objectives. This paper reports on current EAO recommendations arising from a consensus meeting held at the Medical University of Warsaw (2011) to update these guidelines. Radiological considerations are detailed, including justification and optimization, with a special emphasis on the obligations that arise for those who prescribe or undertake such investigations. The paper pays special attention to clinical indications and radiographic diagnostic considerations as well as to future developments and trends.

Diagnostic imaging is an essential component of treatment planning in oral rehabilitation by means of osseointegrated implants. The "EAO guidelines for the use of diagnostic imaging in implant dentistry" was published in the *Journal of Clinical Oral Implant Research* in 2002 (Harris et al. 2002). These arose from the proceedings of a consensus workshop held at Trinity College Dublin in 2000 under the auspices of the EAO. The project was originally initiated because of concern about the commercialization and growing use of multislice computed tomography (CT) scans for the assessment of patients in the need of implants. The absence of any guidelines as to when or how these images should be used instead of conventional radiographic investigations was a major concern of the EAO.

Since the publication of the EAO Guidelines in 2002, cone beam computed tomography (CBCT) has become available offering cross-sectional imaging and 3D reconstructions at potentially lower radiation doses when compared with medical multislice CT and with high diagnostic capability. Furthermore, the relative low cost of CBCT equipments means that it is economically viable for purchase by clinicians and hence more likely to be used. Developments in CBCT technology continue apace as do the many potential applications for its use in implant dentistry.

The European Commission Council Directive on health protection of individuals against the dangers of ionizing radiation in relation to medical exposure (European Commission 1997) makes extensive recommendations about the responsible use of ionizing radiation in medicine. Article 3 of the Directive, dealing with justification of medical exposures, states that "Medical exposure ··· shall show a sufficient net benefit, weighing the total potential diagnostic or therapeutic benefits it produces ··· against the individual detriment that the exposure might cause, taking into account the efficacy, benefits and risks of available alternative techniques having the same objective but involving no or less exposure to ionizing radiation."

The SEDENTEXCT project (2008–2011) undertook a comprehensive and evidence-based review on radiation protection and the use of CBCT in dental and maxillofacial radiology. Provisional guidelines were published in 2009 and the final guidelines in 2011 (SEDENTEXCT 2011; European Commission 2012). In the section dealing with dental implants, the SEDENTEXCT panel recommended that the EAO reviewed its 2002 consensus guidelines on the use of imaging in implant dentistry to take into account the availability of CBCT. The Board of EAO approved this review and a 2-day closed workshop was held at the Medical University of Warsaw, Poland, in May 2011.

Experts in both clinical practice and radiology were invited on the basis of their established scientific contributions to the field, specialist knowledge, significant clinical experience and relevant activities in their academic institutions. Participants were required to review and update the original EAO guidelines and to formulate and reach a consensus on a series of relevant questions.

The aim of these guidelines is to provide recommendations applicable to various clinical situations that will ensure that essential diagnostic information is obtained with as low as reasonably achievable (ALARA principle) radiation exposure. They also draw attention to the special responsibilities, training, and knowledge that are considered a prerequisite for the application of CBCT as well as conventional radiographic techniques.

David Harris & Marc Quirynen (Chairmen).

Radiological considerations

What are the biological risks?

The biologic effects of ionizing radiation may be divided into two categories: tissue reactions (previously called deterministic effects) and stochastic effects (ICRP 103, 2007). *Tissue reactions* are proportional to the dose and occur in all individuals when the dose is large enough. They result in cell death or cell malfunction, and the severity of the effects increases with the dose. Tissue reactions, such as cataract formation, skin erythema, and effects on fertility, occur only above threshold doses that are far greater than those given in dental radiology. In contrast, *stochastic effects* are believed not to have dose thresholds. They can be considered "chance" (stochastic) effects, where the magnitude of the risk is proportional to the radiation dose. They include the detriment-adjusted nominal risk of cancer and hereditable effects owing to mutation of reproductive cells. The detriment-adjusted risk factor for the whole population is 5% per Sv (Sievert). In case of cancer, epidemiological and experimental studies provide evidence of radiation risk albeit with uncertainties at low doses (<100 mSv). The risk is age-dependent, being highest for the young and least for the elderly. The risk for small children is three times the risk for an adult at 30 years of age.

The first step in assessing the risk for a group of patients or the medical/dental staff is to estimate the effective dose (Sv). In this calculation, the relative risk of a specific type of radiation (for X-ray radiation this factor is 1), and which organs that have been irradiated are taken into account by radiation weighting factors. The organ weighting factors are given in the International Commission on Radiological Protection (ICRP 2007). In the next step, the risk can be estimated by using the ICRP statement that the approximated overall fatal risk coefficient is 5% per Sv. For example, at a dose of 1 mSv, the risk of fatal cancer is 0.00005, which implies that if 1 million people receive 1 mSv, 50 of them might get a fatal cancer.

Among the many risks to which we are prone is the normal background radiation with a world average of about 2.4 mSv per individual and year. Medical exposures now contribute with around 20% of the average annual per head effective dose to the global population. Diagnostic X-ray examinations result in per head effective dose of 0.66 mSv of which dental radiology contributes to a small fraction (UNSCEAR 2008 report 2010). The figures, however, vary from country to country. New X-ray technologies and techniques, in particular CT scanning including CBCT scanning (also known as digital volume tomography), can provide useful clinical information, not achievable by other means. As a consequence, a marked increase in effective dose per head in relation to the natural background radiation is noted and more are to be expected. The impact of CBCT will have to be closely monitored (UNSCEAR 2008 report 2010).

How do we limit the risks?

Limitation of the radiation risks to the patients and the staff is done in three steps: justification, optimization, and dose limits.

Justification

Any radiation exposure entails a risk to the patient. Under normal circumstances, however, the risk from dental radiography is very low. Nonetheless, it is essential that every radiographic examination should show a net benefit to the patient. The use of radiation is accepted when it is expected to do more good than harm, weighing the total potential diagnostic benefits it produces against the individual detriment that the exposure might cause. The efficacy, benefits, and risks of available alternative techniques having the same objective but involving no or less exposure to radiation should be taken into consideration. It is essential to select an appropriate radiographic technique based on the individual patient history and the clinical examination. When choosing the radiographic technique the prevalence of a disease, its progression rate and the diagnostic accuracy of the imaging technique in question have to be considered. Further, the possibility of accidental or unintended exposures should also be taken into account.

The decisions should be reviewed from time to time as more information becomes available about risks and effectiveness of the existing procedure, and about new procedures. Some dentists may have to refer his/her patients for a radiographic examination to hospitals or dental colleagues when not having the adequate equipment in their own offices. It will often be possible to speed up the justification process by defining referral criteria and patient categories in advance. When acting as a referrer, the dentist should ensure that adequate clinical information about the patient is provided to the person taking responsibility for the radiographic examination.

Optimization and dose limits

Optimization of radiographic procedures includes equipment selection, consistent production of necessary diagnostic information, regular quality controls and measurements, as well as evaluations of patient doses with account taken of economic and social factors.

Several strategies can be used to reduce radiation dose: implementation of diagnostic reference levels, the use of a dose indicator to measure, e.g. the dose-area-product (DAP) value, adjustment of exposure factors such as the amount of X-rays (mAs), energy of the X-rays (kV, filtration), by avoiding unnecessary exposure of radiosensitive organs and tissues outside the area of interest by limiting the exposed area and the use of appropriate shielding such as thyroid shielding.

Optimization of the radiation dose shall follow the ALARA principle (ICRP 26, 1977), which states that the radiation dose should be kept as low as reasonably achievable. A medical physics expert might be consulted to achieve an optimized dose reduction.

The optimization process also includes radiation protection of the staff by following the dose limits given by ICRP (ICRP 2007), creating dose maps depicting the amount of scattered radiation at various locations around the different devices used, and by the use of adequate barriers, of known equivalent thickness of lead, between the patient and the staff or the public.

What imaging modalities are available for implant dentistry and what information can each provide?

Intraoral and panoramic radiography still remain the dominant imaging modalities in dentistry. With careful attention to detector positioning, the intraoral technique provides high spatial resolution imaging of teeth and potential associated pathology. In addition to mesio-distal (horizontal) and crestal-apical (vertical) measurements, it will provide useful information on bone structure and density. When the alveolar crest is considerably reduced in height due to ridge resorption, a small size of detector should be used to reduce the risk of distortion.

Panoramic radiography may seem easy to perform, but is a technique where many mistakes are made, not least in patient positioning. The reason is that the panoramic image only displays a curved layer, corresponding to the shape of the jawbones. This layer is considerably thinner in the anterior region than the posterior regions. The layer is fixed relative to the X-ray tube and the detector and one must make certain that the jaws are positioned accurately within this layer, the so-called focal trough. Both frontal and posterior regions can become distorted and thus not represent the jaw dimensions correctly. This particularly affects measurements made in a horizontal direction, but panoramic radiographs can still be used to provide a quick estimate of the bone height by taking the magnification into account. The magnification varies between different types of panoramic machines, and some units permit various types of panoramic images to be taken that differ in magnification. It is thus important that one makes certain of the actual magnification in the image to be evaluated. The spatial resolution is sufficient for many purposes but inferior to that obtained by intraoral radiography.

Digital technology may offer lower patient dose for intraoral radiography, although this advantage can be lost through an increased retake rate. For both intraoral and panoramic radiography, digital technology will offer an ability to adjust brightness and contrast and the ability to store and share images easily.

Where cross-sectional imaging is not easily accessed, lateral (profile) radiography may be useful for providing an assessment of the relation between the upper and lower jaw, for obtaining an estimate of the angulation of the frontal parts of the jaws and of the widths of the jawbones in their mid-sagittal regions. The magnification of the lateral radiograph has to be compensated for when performing measurements.

Tomography can be used to obtain cross-sectional images, that is, images which are perpendicular to the curvature of the jawbones in the intended implant site. The equipment for tomography shows much more variation than that for panoramic and intraoral radiography. Three main groups of tomographic techniques can be used for preimplant tomography: motion (conventional) tomography, CT, and CBCT. For simplicity, in this document the term "computed tomography" will be used to encompass first generation CT scanners, spiral (helical) CT scanners, and multislice CT scanners. Tomography is the only method by which reliable estimates of the bone width in intended implant sites can be obtained. Tomography also displays the angulation and shape of the jawbone and the alveolar process.

Although now largely superseded by CBCT, conventional tomography is still available. Computer-controlled multimodality machines like the Scanora and Cranex Tome units (Soredex, Tuusula, Finland) can produce cross-sectional tomographic images from many areas of the jawbones. Due to spiral movement and a relatively large tomographic angle, quite sharp images can be produced, relatively free from disturbing ghost shadows from anatomical structures adjacent to those in the layer of interest.

Depending upon the specification of the unit, CBCT for dental radiology will generally offer higher spatial resolution, at a considerably lower dose, than that available from CT due to the smaller FOV, flat panel detector, and specific image processing. CBCT is a medical imaging modality, which has been applied in different fields of medicine (e.g. cardiac imaging, radiotherapy). For dentomaxillofacial use, CBCT scanners were developed in the late 1990s, and since then the technique has gained great popularity in dentistry. Today, CBCT is a "catch-all" term for a technology comprising a variety of machines differing from each other in many respects. The principle behind the technique, as its name implies, is a cone-shaped X-ray beam with the X-ray source and detector (image intensifier or flat panel detector) rotating around a point of interest in the patient. By the acquisition of multiple two-dimensional projections, a three-dimensional dataset is produced by the computer into volumetric data (primary reconstruction). This can then be visualized as two-dimensional multiplanar reformatted scans or in three-dimensional format by segmentation of the dataset and surface reconstruction (or "volume rendering").

Depending on the CBCT brand, the patient is in a seating, standing, or supine position during the examination. The approach taken by different CBCT manufactures in setting exposure factors is quite different. The simplest method to choose is the one where tube voltage (kV) and tube current (mA) are established by the manufacturers and, hence, not to be varied from patient to patient. Since these values must be sufficient for adults they will result in unnecessarily high exposures for children and in most cases also for women. Further, as pointed out by Lofthag-Hansen et al. (2011), the exposure settings have to be optimized depending on the diagnostic task. Consequently, equipment allowing, at least, adjustment of mA is recommended.

The X-ray exposure and radiation dose to the patient varies between machines, depending on type of generator (continuous or pulsed), kV-setting and filtration, number of basis-projections used to acquire the volume data set, image processing, and irradiated volume so-called field of view (FOV). In general, CBCT units can be categorized into large, medium, and small volume units based on the size of FOV. Some units allow the FOV to be selected to suit the purpose of the examination, ranging from small fields for dental imaging to large fields for maxillofacial examinations. Consequently, as shown recently, the radiation dose varies significantly (Pauwels et al. 2012).

Depending upon the type of CBCT unit and exposure optimization, the technique has the potential to clearly identify anatomic structures and boundaries, shape of the jawbone, bone structure, and density and jaw pathology, including small periapical inflammatory lesions. A complete review of the diagnostic capabilities of CBCT in dentistry is beyond the scope of this article, and readers are referred to the comprehensive literature review included within recent guidelines (SEDENTEXCT 2011; European Commission 2012).

Computed tomography has also evolved to become faster, more sensitive, more accessible, and adjustable for dental diagnostic tasks. Although data were previously captured with a narrow fan-like beam, they are now captured in multiple "slices" simultaneously with one rotation of the gantry. Newer CT units are different from their predecessors and are capable of scanning a whole jaw with one swift rotation of the gantry. Reduced dose hard tissue protocols are available for CT.

Cone beam CT and CT both suffer from beam hardening and photon depletion artifacts in the presence of highly radiopaque restorations and implants. Relatively long exposure times from CBCT and older CT scanners will also contribute to motion artifacts.

Cone beam CT and CT offer the potential to reformat the image data, create virtual models of the jaws, and the distinct advantage of accurate measurement in any dimension or along a curved line. The use of CT might be considered when higher speed imaging is required or when patient positioning in a CBCT unit is not practical, as may be the case for an elderly, kyphotic patient.

Export of CBCT and CT data to dedicated implant planning and CAD-CAM software has further potential benefits to implant treatment planning (Fortin et al. 2011), for computer guided surgery (Vercruyssen et al. 2008), and rapid manufacturing of drill guides and prosthetic components.

What is the radiation dose from X-ray imaging in implant dentistry?

The method of calculating effective dose was changed by the International Commission on Radiological Protection in 2007 (ICRP 2007). There have been numerous publications on radiation doses from dental X-ray imaging modalities over the preceding years, but, limiting the review to those which have been published using these recent ICRP methods, the effective doses of imaging methods relevant to implant dentistry are shown in Table 1.

There is a range of radiation doses for each imaging modality and sometimes these ranges are broad. This may seem confusing to those unfamiliar with radiation dosimetry, but reflects the equipment and materials used along with specific details of the research methodologies. What is clear from this is that the practice of defining the dose of one particular imaging technique as a multiple of another, e.g. that the dose from one panoramic radiograph is equal to *X* intraoral radiographs, can be misleading and often incorrect. It is far better to recognize the ranges of dose which exist and to examine the bigger picture, as illustrated in Fig. 1. The following is a very simple overview:

- Intraoral, panoramic, and lateral "profile" techniques all deliver a relatively low level of effective dose, equivalent to additional days of background radiation.
- CBCT typically gives doses which are an order of magnitude greater than this, equivalent to a week or more of additional background radiation.
- CT can be associated with doses which are an order of magnitude greater than CBCT, equivalent to several weeks of background radiation but which, as discussed below, can be optimized by low-dose protocols to levels similar to some CBCT systems.

Table 1. **Effective doses and dose-area-product (DAP) values associated with dental X-ray imaging modalities. Effective dose data (ICRP 103) derived from Faccioli et al. (2009), Garcia Silva et al. (2008), Hirsch et al. (2008), Lofthag-Hansen et al. (2008), Loubele et al. (2009), Ludlow et al. (2006, 2008), Ludlow & Ivanovic (2008), Okano et al. (2009), Palomo et al. (2008), Pauwels et al. (2012), Qu et al. (2010), Roberts et al. (2009), Silva et al. (2008), Suomalainen et al. (2009). DAP values are derived from Helmrot & Thilander-Klang (2009, 2010)**

Modality	Effective dose (mSv)	DAP (mGy/cm^2)
Intraoral radiograph*		
Single radiograph	<0.002	8–29
Full mouth survey (20 radiographs)	0.020–0.040	
Panoramic radiograph	0.003–0.024	80–130
Lateral "profile" radiograph	<0.006	50–80
Conventional tomography	0.047–0.088	70 (2 × 2 mm cuts) 250–390 (4 × 4 mm cuts)
CBCT		
Dento-alveolar†	0.019–0.674	140–967
Craniofacial†	0.030–1.073	284–695‡
Computed Tomography	0.280–1.410	About 1250/2050

*Assumes use of F-speed film or photostimulable phosphor plate with rectangular collimation. The use of slower film (D and E-speed) and round collimation substantially increases the dose.

†The height of the dento-alveolar FOVs is smaller than 10 cm allowing imaging of the lower and upper jaws. For the craniofacial FOVs, the height is greater than 10 cm allowing maxillofacial imaging.

‡DAP value only includes i-CAT, Imaging Sciences International.

A more exact comparison between different imaging modalities used in a particular clinic can be achieved by the use of a dose indicator (e.g. DAP value) per modality.

In the "real world," effective dose cannot be determined by clinicians. A practically useful measurement of "dose" is the DAP, also known as Kerma Area Product (KAP), measured in mGy/cm^2 (European Commission 2004; International Atomic Energy Agency 2007; Helmrot & Thilander-Klang 2010). This can be measured by a medical physicist using special equipment, but is often available to the clinician as an automatic digital readout on CBCT equipment. There are as yet no generally accepted conversion factors between DAP and effective dose for dental examinations (Thilander-Klang & Helmrot 2010), but DAP has far greater value in everyday clinical practice as an aid to optimization strategies. Some DAP values are given in Table 1.

How can I limit the dose and risk from X-ray imaging in implant dentistry?

There are two ways in which you can limit the dose and risk to your patients: *justification* and *optimization*. As described earlier, *justification* is the process of determining whether an X-ray examination is likely to be beneficial to the individual patient; in other words, whether the benefits outweigh the risks. The principle of justification is included in international, European and national directives, laws, and guidelines. The key aspect is that each patient should be considered an individual. "Routine" protocols for imaging patients are not compatible with this. Instead, all individual X-ray exposures should be justified in advance taking into account the specific objectives of the exposure and the characteristics of the individual patient involved.

The use of Referral Criteria (also known as Selection Criteria) can help the practice of

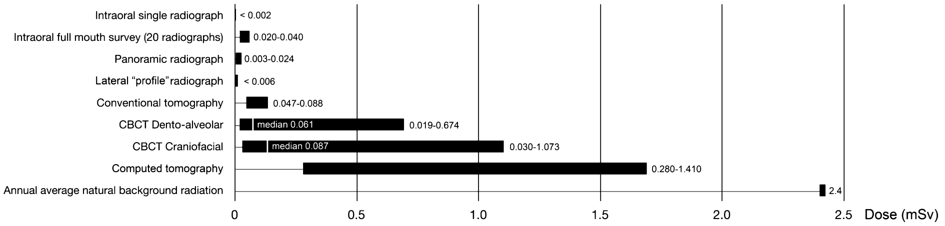

Fig. 1. Ranges of effective dose for the imaging modalities used in implant dentistry.

justification in the clinic. Referral Criteria are "systematically developed statements to assist practitioner and patient decisions about appropriate health care for specific clinical circumstances." They are not a rigid constraint on clinical practice, but a concept of good practice against which the needs of the individual patient can be considered.

The European Guidelines on Radiation Protection in Dental Radiology (European Commission 2004) give the following general guidelines:

- No radiographs should be selected unless a history and clinical examination have been performed. "Routine" radiography is unacceptable practice.
- When referring a patient for a radiographic examination, the dentist should supply sufficient clinical information (based on a history and clinical examination) to allow the practitioner taking clinical responsibility for the X-ray exposure to perform the justification process.

The current document provides more detailed referral criteria for imaging for implant dentistry.

In addition, special attention should be given to the justification of those X-ray exposures where there is no direct benefit for the patient undergoing the exposure and especially for those exposures on medico-legal grounds. X-ray exposures for research should be examined and approved by an ethics committee, set up in accordance with national procedures and/or by the competent authorities.

Optimization is concerned with ensuring the principle that all doses due to X-ray exposure for radiological purposes should be kept *as low as reasonably achievable* consistent with obtaining the required diagnostic information, taking into account economic and social factors. Optimization includes the following:

- Selection of equipment,
- Consistent production of adequate diagnostic information as well as the practical aspects,
- Quality assurance including quality control,
- Assessment and evaluation of patient doses.

In everyday practice, optimization involves selection of equipment and exposure factors which suit the individual patient and the specific clinical purposes of the examination. Table 2 lists the main aspects which will influence dose and image quality and which should be considered part of optimization, for example, using fast image receptors and using collimation (field size limitation) to exclude clinically irrelevant areas from the exposure. Because CBCT usually has higher radiation doses than conventional radiography and equipment is often under the direct control of the practitioner, dose optimization deserves special attention. The "Basic Principles" of dental CBCT (Appendix 1, Horner et al. 2009) include some specific guidelines on *optimization*.

Particularly with CBCT equipment, clinicians may be presented with a bewildering array of exposure controls and the tendency may be to set a "standard" exposure for all patients and all examinations. In X-ray imaging, it is good practice to adjust the exposure (tube current [mA] and/or exposure time) according to patient size. Thus, a large male will require higher exposures than a small female or child to achieve adequate image quality. There is evidence that reduction in exposure factors from manufacturer-recommended levels on CBCT equipment can be performed without unacceptable loss of image quality. "Low-dose protocols" for CBCT examinations can be used in selected cases by exploiting available exposure variables. Ideally, such protocols should be developed with

***Table 2.* Imaging modalities used in implant dentistry and the main aspects that influence dose and image quality and that should be considered part of optimization**

Modality	Main aspects for optimization
Intraoral radiography	Digital detector, image plate, or F-speed film Rectangular collimation Paralleling technique using film holder with aiming device Upper jaw: palate horizontal Lower jaw: mandibular base horizontal
Panoramic radiography	Proper collimation Digital detector, image plate, or rare earth screen Proper patient positioning: - Orbito-meatal plane horizontal - Head symmetrical - Lower jaw protruding ("edge to edge" position) - Lower and upper incisors inside the image layer - Neck extended - Dorsum of tongue in contact with hard palate during exposure
Lateral "profile" radiography	Proper collimation Digital detector, image plate, or rare earth screen Median plane of head vertical
Conventional tomography	Digital detector or image plate or rare earth screen As few "cuts" as possible Proper positioning The tomographic plane perpendicular to the hard palate (maxilla) or the mandibular canal (mandible) and at the same time perpendicular to the tangent of the alveolar process in the region of interest
CBCT	Tube voltage kV: 75–120 mA optimized for each patient Field of view matched to clinical needs Proper degree of rotation Largest voxel size consistent with clinical needs Proper image processing
Computed tomography	Tube voltage kV: 80–120 mAs: <100; request low-dose protocol Slice thickness: 1 mm Pitch: 1–1.5 Suggested window: 1250; level: 250 Maxilla: slices parallel with hard palate from alveolar crest up to/including hard palate Mandible: slices parallel with mandibular base in region of interest Dose reduction possible by reducing number of slices, increasing pitch and/or lowering mAs

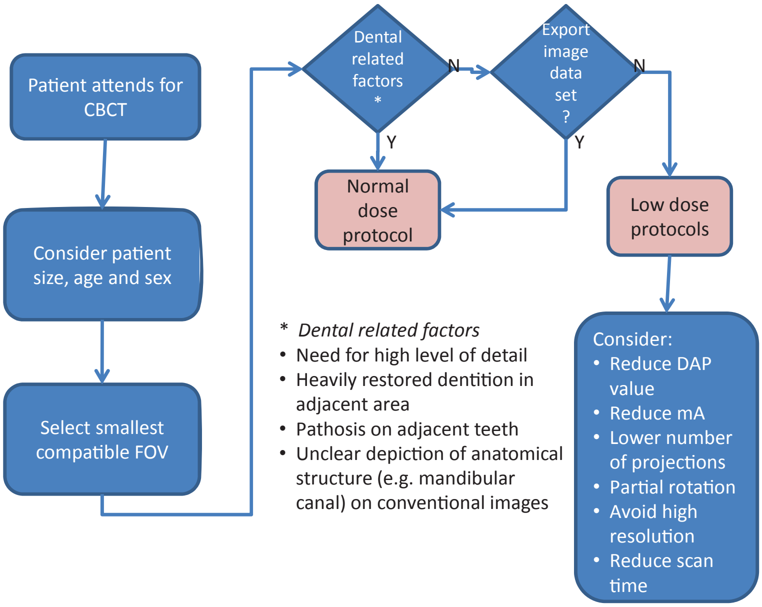

Fig. 2. Dose optimization strategy flow chart for cone beam computed tomography (CBCT) when used in implant dentistry.

the input of a medical physics expert, but if this is unavailable there is still scope for attempting optimization. Fig. 2 is designed to be a further guide for implant dentists to selection of exposure in CBCT, taking into account the patient's physical characteristics, FOV selection, dentally related factors, and whether the image dataset is to be exported to implant planning software.

Quality Assurance (QA) includes Quality Control tests and the administrative procedures to ensure that these are performed properly and according to a planned timetable that the results of these techniques are evaluated promptly and accurately and that necessary corrective measures are taken in response to these results. X-ray equipment should undergo critical examination, followed by commissioning and acceptance testing when first installed. Regular tests should be performed on a routine basis. Details of QA for dental radiology are outside the scope of this article, but further information can be obtained from European sources (European Commission 2004; SEDENTEXCT 2011; European Commission 2012) and must be supplemented by adherence to national requirements.

The final stage in imaging is the viewing. The viewing conditions should be optimized so that the maximum amount of information is obtained from the images. With conventional (film) radiography, the value of an illuminated viewing box, masking of images, and magnification are well established. Where digital images are used, monitors should have the following characteristics:

- Proper calibration,
- Screen resolution $\geq$ 1500 $\times$ 2000 pixels,
- Screen size (viewable diagonal) $\geq$50 cm ($\approx$20″),
- Maximum luminance $\geq$ 500 cd/m^2,
- Luminance contrast ratio $\geq$ 500 : 1,
- Grayscale bit depth $\geq$ 10-bit grayscale.

Monitors should be cleaned regularly and a suitable test pattern, such as an AAPM TG18 or SMPTE image, should be installed on the computer and viewed on the monitor. It should be ensured that all distinct grayscale levels on the test pattern can be individually resolved. The small black and white squares within the larger black and white squares should also be clearly resolved. It should also be ensured that all the bars on each of the resolution patterns on the AAPM TG18 or SMPTE test image can be clearly resolved (SEDENTEXCT 2011; European Commission 2012).

What is the recommended imaging modality for different clinical situations?

Table 3 provides an overview of the diagnostic capabilities of the different imaging modalities used in implant dentistry. The scope and limitations of these techniques have been discussed above, but this table attempts to grade their efficacy and appropriateness. The choice of imaging modality should be dictated by the specific needs of the patient and the proposed treatment. The availability of imaging modalities will also influence the choice. Where the key information required is detailed measurement of proposed implant sites, it is clear that CBCT and CT offer distinct advantages although, with meticulous technique, two-dimensional imaging can still be useful.

What training do I need when being involved in X-ray imaging in implant dentistry?

You should have received adequate theoretical and practical training, including radiation protection, for the purpose of radiology as part of dental undergraduate training. After qualification, you must also receive continuing education and training, particularly when new imaging modalities are adopted. One of these new imaging modalities is CBCT. Training requirements for CBCT are often, but not always, set nationally.

As a dentist involved in CBCT imaging for implant dentistry, you should undergo a per-

***Table 3.* Diagnostic capabilities of the imaging techniques used in implant dentistry. A four point rating scale is used in which "-" indicates that the modality is not useful for diagnosis, "+, ++, and +++" indicate diagnostic value, with "+++" being the highest score**

						Measurements			
Modality	Dental pathology	Jawbone pathology	Structure and density	Bone shape and contour	Anatomical boundaries	*Sup-inf*	*Mes-dist*	*Bucc-ling*	Export for implant planning
Intraoral radiography	++	+	++	-	+	++[†]	++	-	N
Panoramic radiography	+	++	++	-	+	++[†]	-	-	N
Lateral (profile) radiography	-	-	-	-/+	-	-	-	-	N
Conventional tomography	-	+	-	+	++	++	-	++	N
Cone beam computed tomography	+/+++[*]	+++	+/+++	+++	+++	+++	+++	+++	Y
Computed tomography	+[*]	+++	+	+++	+++	+++	+++	+++	Y

[*] Depending on parameters.
[†] Assuming calibration and meticulous technique.

Table 4. **Appendix to the EADMFR basic principles on the use of cone beam CT, outlining "adequate theoretical and practical training" for dentists using CBCT. Adapted from Horner et al. (2009) and the SEDENTEXCT Guidelines (2011) and from the European Commission (2012) data**

- The referring dentist
  - Theoretical instruction
    - Radiation physics in relation to CBCT equipment
    - Radiation doses and risks with CBCT
    - Radiation protection in relation to CBCT equipment, including justification (referral/selection criteria) and relevant aspects of optimization of exposures
    - CBCT equipment and apparatus
  - Radiological interpretation
    - Principles and practice of interpretation of dento-alveolar CBCT images of the teeth, their supporting structures, the mandible and the maxilla up to the floor of the nose (e.g. 8 cm × 8 cm or smaller fields of view)
    - Normal radiological anatomy on CBCT images
    - Radiological interpretation of disease affecting the teeth and jaws on CBCT images
    - Artifacts on CBCT images
- The CBCT practitioner
  - Theoretical instruction
    - Radiation physics in relation to CBCT equipment
    - Radiation doses and risks with CBCT
    - Radiation protection in relation to CBCT equipment, including justification (referral/selection criteria), optimization of exposures and staff protection
    - CBCT equipment and apparatus
    - CBCT image acquisition and processing
  - Practical instruction
    - Principles of CBCT imaging
    - CBCT equipment
    - CBCT imaging techniques
    - Quality assurance for CBCT
    - Care of patients undergoing CBCT
  - Radiological interpretation
    - Principles and practice of interpretation of dento-alveolar CBCT images of the teeth, their supporting structures, the mandible and the maxilla up to the floor of the nose (e.g. 8 cm × 8 cm or smaller fields of view)
    - Normal radiological anatomy on CBCT images
    - Radiological interpretation of disease affecting the teeth and jaws on CBCT images
    - Artifacts on CBCT images

iod of additional theoretical and practical training that has been validated by an academic institution (university or equivalent). Depending on your role in CBCT imaging, you will require a different level of additional training. For example, a dentist who refers patients to another establishment (dental practice or hospital) for CBCT acts as a "referrer" and requires a different training to the dentist in the referral center who is responsible for justification, optimization and the practical aspects of the examination (the "CBCT practitioner"). The content of the training must satisfy any national requirements, but Table 4 outlines a suggested core curriculum. The recommended duration of theoretical and practical training varies considerably in those countries where requirements exist, but extend to as much as 2 days of theoretical and three of practical training.

The role that has not been addressed above is the training of equipment manufacturers and suppliers, particularly of applications specialists who may contribute themselves to training of dentists and dental staff. Their recommendations to the CBCT user on exposure and optimization are of critical importance in determining future day-to day practices of CBCT practitioners. The content of training should be based on the theoretical content of the curriculum outline in Table 4, with the addition of elements of dental terminology and radiological interpretation which will allow an understanding of clinical needs and more effective communication.

Clinical considerations

What radiological information does a surgeon require when planning for implant surgery and at what stage should it be obtained?

In investigating a patient for implant treatment, a clinician requires information on bone volume, structure and density, topography, and the relationship to important anatomical structures, such as nerves, vessels, roots, nasal floor, and sinus cavities and any clinically relevant pathology. This information is initially obtained with a clinical examination and appropriate conventional radiographs. The decision to proceed to cross-sectional imaging should be based on clearly identified needs and the clinical and surgical requirements of the clinicians involved. Surgical technique and implant choice may be influenced by bone structure and density. Information about bone structure and density can be obtained preoperatively based on radiographs and partly during the surgical procedure (Lekholm & Zarb 1985; van Steenberghe et al. 2002; Bergkvist et al. 2010).

What type of clinical situations might potentially benefit from cross-sectional imaging for diagnosis and treatment planning?

1. When the clinical examination and conventional radiography have failed to adequately demonstrate relevant anatomical boundaries (see Appendix 1) and the absence of pathology.
2. When reference to such images can provide additional information that can help to minimize the risk of damage to important anatomical structures and which is not obtainable when using conventional radiographic techniques.
3. In clinical borderline situations where there appears to be limited bone height and/or bone width available for successful implant treatment.
4. Where implant positioning can be improved so that biomechanical, functional, and esthetic treatment results are optimized. The diagnostic information can be enhanced by use of radiographic templates, computer-assisted planning, and surgical guides.

Although cross-sectional imaging may enhance some aspects of diagnosis and treatment planning, the necessity and desirability of this must also take account of the socioeconomic implications and availability of these modalities.

What type of clinical situations might potentially benefit from cross-sectional imaging during and following implant treatment?

During the surgical procedure conventional radiographic techniques are adequate to confirm the position of an implant in relation to anatomical boundaries.

In the absence of symptoms, there is no indication for follow-up cross-sectional imaging; however, it may be helpful for the diagnosis and management of certain post-operative complications.

Cross-sectional imaging cannot be justified where there is no direct benefit to the patient, except as part of ethically approved clinical research. Informed consent based on the Helsinki Declaration is always mandatory.

What are the roles and responsibilities of health professionals involved in cross-sectional imaging?

It is the responsibility of the clinician to understand the fundamental principles of cross-sectional imaging and to be capable of interpreting images of the jawbones. When imaging extends beyond this area, assessment by an adequately trained person is required.

1. Clinicians providing surgery should decide on the basis of the clinical examination and treatment requirements and on information obtained from conventional radiographs, whether cross-sectional imaging will be of benefit.
2. If the patient is to be referred to a radiologist with specialized knowledge in the field, the clinician must clearly indicate what information is required from the investigation. The radiologist should decide on the appropriate "field of view" and other optimization procedures based on the information provided by the clinician. The technique chosen should provide the required diagnostic information with the least radiation exposure to the patient (ALARA).
3. Where a clinician is providing the cross-sectional imaging the same requirement for justification and the appropriate "field of view" and other optimization procedures should apply, including a reliable and adequate interpretation of the volume involved. The technique chosen should provide the required diagnostic information with the least radiation exposure to the patient (ALARA).

Recommendations for the use of cross-sectional imaging in implant dentistry

General considerations

If the clinical assessment of implant sites indicates that there is sufficient bone width and the conventional radiographic examination reveals the relevant anatomical boundaries and adequate bone height and space, no additional imaging is required for implant placement.

Many anatomical boundaries can be identified during the surgical procedure; however, cross-sectional imaging may enhance the identification and location of certain anatomical structures and boundaries and their relationship to the potential surgical site.

Cross-sectional images can also help in the planning and in enhancing the predictability of the prosthetic outcome.

It is important to realize that errors can occur when transferring information from a cross-sectional computer image to the surgical situation. The surgeon should be aware of these and be careful to allow an adequate "safety margin" in all cases.

Bone defect considerations

Where the clinical and radiographic examinations indicate a bone defect at the proposed implant site, which the surgeon considers can be managed by a local augmentation procedure, additional cross-sectional imaging may not be required. Where the surgeon considers that the nature of the defect requires a more extensive augmentation procedure, cross-sectional imaging can provide additional information regarding the extent and size of the defect.

Sinus augmentation considerations

Clinical examination and conventional radiographic techniques, including sinus radiographs, can provide preoperative information for sinus augmentation procedures. However, it has been established that panoramic views of the posterior maxilla will underestimate the amount of bone available for implant placement and, if relied on, will therefore overestimate the number of clinical situations requiring a sinus augmentation. CBCT can overcome this problem as it provides more accurate measurements of the available bone volume and, in a proportion of borderline cases, will show that implants can be placed without recourse to sinus surgery (Fortin et al. 2011; Temmerman et al. 2011).

Cone beam CT can also provide information on arterial channels in the lateral wall of the sinus, the presence, and extent of any septa, as well as on the health of the sinus such as absence of sinus membrane thickening, polyps, or fluid levels.

Because cross-sectional imaging offers improved diagnostic efficacy, it is the preferred method for preoperative assessment for sinus augmentation surgery. In some clinical situations, when there is evidence of sinus pathology, or it is the clinicians opinion that sinus drainage is impaired and may jeopardize the outcome of the procedure to be undertaken, there may be a justification to extend the FOV to include the whole of the sinus including the ostio-meatal complex (Pignataro et al. 2008; Carmeli et al. 2011; Janner et al. 2011; Ribeiro-Rotta et al. 2011).

Following staged sinus augmentation conventional radiography may be used to assess the prospective implant site. Cross-sectional imaging can provide additional information regarding the volume, extent, and density of the augmented region.

Intra-oral bone donor sites

In most cases clinical examination in conjunction with conventional radiographs will provide sufficient information about the anatomical boundaries of the donor site. Where the surgeon considers that further information is required, cross-sectional imaging can enhance the ability to assess the topography and dimensions of the bone available for grafting.

Special techniques

Special techniques (e.g. zygomatic implants and osteogenic distraction) may also dictate the need for additional cross-sectional imaging.

Computer-assisted planning and placement

Computer-assisted planning and placement of implants should only be undertaken when there is a justifiable benefit to the patient, because cross-sectional imaging is required. In all cases of guided surgery, it should be appreciated that the computer-assisted planning may not accurately transfer via the surgical guide to the implant site.

Post-operative complications

In cases of post-operative complications diagnostic imaging may be indicated to supplement the clinical examination. In most cases, conventional radiographs will provide the necessary information. In some situations where complications have occurred, e.g. nerve damage or postoperative infections in relation to sinus cavities close to implants, cross-sectional imaging may be justified.

Future developments and trends

Developments within the field of radiology are progressing rapidly as new techniques and applications are introduced. Consequently, there is a need for a continuous updating of knowledge by clinicians. Radiation protection and optimization aspects should be emphasized and Pan-European guidelines should be developed to encourage uniformity of practice.

There is an urgent need to enhance and improve the knowledge and skills of dentomaxillofacial radiology in undergraduate and postgraduate education, as well as in continuing professional development programs. This need is particularly acute in the case of new and emerging technologies like CBCT.

Table 5. **Desirable future developments in imaging relevant to implant dentistry identified by panel**

Intraoral radiography
Provision of ergonomically better sensor holders
A reduction in the bulk of solid-state sensors
An increase in the active area of solid-state sensors compared with the outside dimensions
Greater robustness of phosphor plates to extend their life and limit artifacts
Panoramic radiography
Multimodal panoramic machines, incorporating high-quality small volume CBCT would be of considerable value in implant dentistry
CBCT
Automatic exposure control
A freely adjustable FOV, or at least variable selection of FOVs, suitable for implant related imaging
Improved artifact reduction software for dental restorations and implants
Integration of implant planning software
Improvements in soft tissue contrast
Full DICOM capability
Dose indicator/DAP readout on CBCT equipment should be available and standardized across manufacturers
Dose maps should be available, depicting the amount of scattered radiation, to assist in planning the design of CBCT facilities in dental practices
Improved positioning aids should be developed, as well as better head support, to prevent movement and allow examination of patients with positioning challenges (e.g. spinal deformity)
There is a need to develop objective image quality criteria for the use of CBCT in implant dentistry so that dose optimization strategies can be adopted

When clinicians also provide diagnostic imaging services they should always consider the optimum imaging technique for the patient, even if this means referral to another center.

The information available on preoperative radiographic images should be fully exploited to facilitate planning of implant surgery. In that respect, there is still a need to develop objective and precise methods of measuring bone density and texture.

Patients can benefit from communication among clinicians and experts for second opinions and interaction during the planning of oral implants. The EC Medical Exposures Directive (European Commission 1997) highlights that clinicians should seek, wherever practicable, to obtain previous diagnostic information or medical records relevant to the planned exposure and consider these data to avoid unnecessary exposure. Data transfer that does not infringe national data protection regulations can aid this process. The latter will be facilitated when all digital radiographic data are stored and communicated in a standardized form and format. Such actions may allow the patient seeking expert or second opinion advice, to avoid unnecessary repeat X-ray examinations. In the interest of the patient, and subject to individual country regulations and practice, copies of all digital radiographic data might be provided to the patient in a universally accepted form and format for future use.

The principle of justification of medical exposures to radiation requires that the use of alternative techniques requiring less, or no, exposure to radiation should be taken into account (European Commission 1997). In the context of imaging for planning oral implants, the potential of MR imaging, which does not use ionizing radiation, is worth further investigation.

As part of the guideline development process, panel members identified a number of desirable future developments in imaging relevant to implant dentistry. These are presented in Table 5 as a stimulus to researchers, clinicians, and equipment manufacturers.

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Appendix 1

Anatomical structures and boundaries that may need to be considered. Only those structures that are directly relevant to the area in which the implants are to be placed need to be identified.

Anterior maxilla:

- Nasal floor
- Naso-palatine canal
- Anterior superior alveolar canal

Posterior maxilla:

- Maxillary sinus and related structures
- Posterior superior alveolar canal
- Maxillary tuberosity
- Pterygoid plates

Anterior mandible:

- Lingual foramen
- Incisive canal
- Genial tubercles

Posterior mandible:

- Inferior alveolar nerve canal
- Mental foramina
- Retromolar foramen
- Sublingual fossa (lingual undercut)
- Mylohyoid undercut
- Lingula of ascending ramus

Zygomatic region:

- Orbital floor
- Infraorbital foramen
- Zygomatic bone

References

Bergkvist, G., Koh, K.J., Sahlholm, S., Klintström, E. & Lindh, C. (2010) Bone density at implant sites and its relationship to assessment of bone quality and treatment outcome. *The International Journal of Oral & Maxillofacial Implants* **25**: 321–328.

Carmeli, G., Artzi, Z., Kozlovsky, A., Segev, Y. & Landsberg, R. (2011) Antral computerized tomography pre-operative evaluation: relationship between mucosal thickening and maxillary sinus function. *Clinical Oral Implants Research* **22**: 78–82.

European Commission (1997) Council Directive 97/43/Euratom of 30 June 1997 on Health Protection of Individuals Against the Dangers of Ionizing Radiation in Relation to Medical Exposure, 22–27. Luxembourg: European Commission.

European Commission (2004) Radiation Protection 136. European Guidelines on Radiation Protection in Dental Radiology. Luxembourg: Office for Official Publications of the European Communities. Available at http://ec.europa.eu/energy/nuclear/radioprotection/publication/doc/136_en.pdf (accessed March 13, 2012).

European Commission (2012) Radiation Protection 172. Evidence Based Guidelines on Cone Beam CT for Dental and Maxillofacial Radiology. Luxembourg: Office for Official Publications of the European Communities. Available at: http://ec.europa.eu/energy/nuclear/radiation_protection/publications_en.htm [accessed on March 13, 2012]

Faccioli, N., Barillari, M., Guariglia, S., Zivelonghi, E., Rizzotti, A., Cerini, R. & Mucelli, R.P. (2009) Radiation dose saving through the use of cone-beam CT in hearing-impaired patients. *Radiologia Medica* **114**: 1308–1318.

Fortin, T., Camby, E., Alik, M., Isidori, M. & Bouchet, H. (2011) Panoramic images versus three-dimensional planning software for oral implant planning in atrophied posterior maxillary: a clinical radiological study. *Clinical Implant Dentistry & Related Research*, doi: 10.1111/j.1708-8208.2011.00342.x.

Garcia Silva, M.A., Wolf, U., Heinicke, F., Gründler, K., Visser, H. & Hirsch, E. (2008) Effective dosages for recording Veraviewepocs dental panoramic images: analog film, digital, and panoramic scout for CBCT. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology & Endodontics* **106**: 571–577.

Harris, D., Buser, D., Dula, K., Gröndahl, K., Harris, D., Jacobs, R., Lekholm, U., Nakielny, R., van Steenberghe, D. & van der Stelt, P. (2002) E.A.O. guidelines for the use of diagnostic imaging in implant dentistry. *Clinical Oral Implants Research* **13**: 566–570.

Helmrot, E. & Thilander-Klang, A. (2009) Stråldoser inom odontologisk radiologi - metodutveckling och kartläggning. Projekt SSI P 1604.

Helmrot, E. & Thilander-Klang, A. (2010) Methods for monitoring patient dose in dental radiology. *Radiation Protection Dosimetry* **139**: 303–305.

Hirsch, E., Wolf, U., Heinicke, F. & Silva, M.A. (2008) Dosimetry of the cone beam computed tomography Veraviewepocs 3D compared with the 3D Accuitomo in different fields of view. *Dentomaxillofacial Radiology* **37**: 268–273.

Horner, K., Islam, M., Flygare, L., Tsiklakis, K. & Whaites, E. (2009) Basic principles for use of dental cone beam computed tomography: consensus guidelines of the European Academy of Dental and Maxillofacial Radiology. *Dentomaxillofacial Radiology* **38**: 187–195.

ICRP (1977) Recommendations of the International Commission on Radiological Protection. Publication 26. *Annals of the ICRP* **1**: 3.

ICRP (2007) The 2007 Recommendations of the International Commission on Radiological Protection. Publication 103. International Commission on Radiological Protection (ICRP). *Annals of the ICRP* **37**: 2–4.

International Atomic Energy Agency, IAEA (2007) Dosimetry in diagnostic radiology: an international code of practice. Technical Reports Series. STI/PUB/1294. ISSN 0074–1914; no. 457. Austria: IAEA.

Janner, S.F.M., Caversaccio, M., Dubach, P., Sendi, P., Buser, D. & Bornstein, M.M. (2011) Characteristics and dimensions of the Schneiderian membrane: a radiographic analysis using cone beam computed tomography in patients referred for dental implant surgery in the posterior maxilla. *Clinical Oral Implants Research* **22**: 1446–1453.

Lekholm, U. & Zarb, G.A. (1985) Patient selection and preparation. In: Brånemark, P.-I., Zarb, G.A. & Albrektsson, T., eds. Tissue Integrated Prostheses: Osseointegration in Clinical Dentistry, 199–209. Chicago, IL: Quintessence.

Lofthag-Hansen, S., Thilander-Klang, A., Ekestubbe, A., Helmrot, E. & Gröndahl, K. (2008) Calculating effective dose on a cone beam computed tomography device: 3D Accuitomo and 3D Accuitomo FPD. *Dentomaxillofacial Radiology* **37**: 72–79.

Lofthag-Hansen, S., Thilander-Klang, A. & Gröndahl, K. (2011) Evaluation of subjective image quality in relation to diagnostic task for cone beam computed tomography with different fields of view. *European Journal of Radiology* **80**: 483–488.

Loubele, M., Bogaerts, R., Van Dijck, E., Pauwels, R., Vanheusden, S., Suetens, P., Marchal, G., Sanderink, G. & Jacobs, R. (2009) Comparison between effective radiation dose of CBCT and MSCT scanners for dentomaxillofacial applications. *European Journal of Radiology* **71**: 461–468.

Ludlow, J.B., Davies-Ludlow, L.E., Brooks, S.L. & Howerton, W.B. (2006) Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. *Dentomaxillofacial Radiology* **35**: 219–226.

Ludlow, J.B., Davies-Ludlow, L.E. & White, S.C. (2008) Patient risk related to common dental radiographic examinations: the impact of 2007 International Commission on Radiological Protection recommendations regarding dose calculation. *Journal of the American Dental Association* **139**: 1237–1243.

Ludlow, J.B. & Ivanovic, M. (2008) Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology & Endodontics* **106**: 106–114.

Okano, T., Harata, Y., Sugihara, Y., Sakaino, R., Tsuchida, R., Iwai, K., Seki, K. & Araki, K. (2009) Absorbed and effective doses from cone beam volumetric imaging for implant planning. *Dentomaxillofacial Radiology* **38**: 79–85.

Palomo, J.M., Rao, P.S. & Hans, M.G. (2008) Influence of CBCT exposure conditions on radiation dose. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology & Endodontics* **105**: 773–782.

Pauwels, R., Beinsberger, J., Collaert, B., Theodorakou, C., Rogers, J., Walker, A., Cockmartin, L., Bosmans, H., Jacobs, R., Bogaerts, R., Horner, K. & The SEDENTEXCT Project Consortium. (2012) Effective dose range for dental cone beam computed tomography scanners. *European Journal of Radiology* **81**: 267–271.

Pignataro, L., Mantovani, M., Torretta, S., Felisati, G. & Sambataro, G. (2008) ENT assessment in the integrated management of candidate for (maxillary) sinus lift. *Acta Otorhinolaryngologica Italica* **28**: 110–119.

Qu, X.M., Li, G., Ludlow, J.B., Zhang, Z.Y. & Ma, X.C. (2010) Effective radiation dose of ProMax 3D cone-beam computerized tomography scanner with different dental protocols. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology & Endodontics* **110**: 770–776.

Ribeiro-Rotta, R.F., Lindh, C., Pereira, A.C. & Rohlin, M. (2011) Ambiguity in bone tissue characteristics as presented in studies on dental implant planning and placement: a systematic review. *Clinical Oral Implants Research* **22**: 789–801.

Roberts, J.A., Drage, N.A., Davies, J. & Thomas, D. W. (2009) Effective dose from cone beam CT examinations in dentistry. *British Journal of Radiology* **82**: 35–40.

SEDENTEXCT (2011) Radiation protection: cone beam ct for dental and maxillofacial radiology. evidence based guidelines. A report prepared by the SEDENTEXCT project. Available at http://www.SEDENTEXCT.eu (accessed March 13, 2012).

Silva, M.A., Wolf, U., Heinicke, F., Bumann, A., Visser, H. & Hirsch, E. (2008) Cone-beam computed tomography for routine orthodontic treatment planning: a radiation dose evaluation. *American Journal of Orthodontics and Dentofacial Orthopedics* **133**: 640.e1–5.

van Steenberghe, D., Jacobs, R., Desnyder, M., Maffei, G. & Quirynen, M. (2002) The relative impact of local and endogenous patient-related factors on implant failure up to the abutment stage. *Clinical Oral Implants Research* **13**: 617–622.

Suomalainen, A., Kiljunen, T., Käser, Y., Peltola, J. & Kortesniemi, M. (2009) Dosimetry and image quality of four dental cone beam computed tomography scanners compared with multislice computed tomography scanners. *Dentomaxillofacial Radiology* **38**: 367–378.

Temmerman, A., Hertelé, S., Teughels, W., Dekeyser, C., Jacobs, R. & Quirynen, M. (2011) Are panoramic images reliable in planning sinus augmentation procedures? *Clinical Oral Implants Research* **22**: 189–194.

Thilander-Klang, A. & Helmrot, E. (2010) Methods of determining the effective dose in dental radiology. *Radiation Protection Dosimetry* **139**: 306–309.

UNSCEAR (2010) Sources and effects of ionizing radiation. United Nations Scientific Committee on the Effects of Atomic Radiation. UNSCEAR 2008 Report to the General Assembly with Scientific Annexes. Volume 1. ISBN 978-92-1-142274-0.

Vercruyssen, M., Jacobs, R., Van Assche, N. & van Steenberghe, D. (2008) The use of CT scan based planning for oral rehabilitation by means of implants and its transfer to the surgical field: a critical review on accuracy. *Journal of Oral Rehabilitation* **35**: 454–474.