The Radiographic Assessment of Implant Patients: Decision-making Criteria

Karl Dula, DDS, Dr med dent[1]/Roberto Mini, Dr phil nat[2]/
Paul Frans van der Stelt, DDS, PhD[3]/Daniel Buser, DDS, Dr med dent[4]

Indications for the most frequently used imaging modalities in implant dentistry are proposed based on clinical need and biologic risk for the patient. To calculate the biologic risk, the authors carried out dose measurements. They demonstrated that the risk from a periapical radiograph is 20% of that from a panoramic radiograph. A panoramic radiograph and a series of 4 conventional tomographs of a single-tooth gap in the molar region carry 5% and 13% of the risk from computed tomography of the maxilla, respectively. Panoramic radiography is considered the standard radiographic examination for treatment planning of implant patients, because it imparts a low dose while giving the best radiographic survey. Periapical radiographs are used to elucidate details or to complete the findings obtained from the panoramic radiograph. Other radiographic methods, such as conventional film tomography or computed tomography, are applied only in special circumstances, film tomography being preferred for smaller regions of interest and computed tomography being justified for the complete maxilla or mandible when methods for dose reduction are followed. During follow-up, intraoral radiography is considered the standard radiographic examination, particularly for implants in the anterior region of the maxilla or for scientific studies. In patients requiring more than 5 periapical images, panoramic radiography is preferred. (INT J ORAL MAXILLOFAC IMPLANTS 2001;16:80–89)

Key words: *dental implants, dental radiography, practice guidelines, radiation protection*

Treatment modalities in dentistry changed markedly when osseointegration became the basis for a predictable outcome of oral implant treatment.[1,2] Currently, the rehabilitation of partial or complete edentulism using osseointegrated implants can generally be regarded as the method of choice if there are no local or systemic contraindications. However, one of the most common problems in implant dentistry is bone atrophy after tooth loss that, in some cases, prevents immediate implant placement or requires additional surgical intervention to reestablish bone volume.[3–5] This report describes the evaluation of implant patients as performed in one institution.

An acceptable clinical examination and an appropriate radiographic examination are mandatory prior to every implant surgery. Basically, the clinical examination should consist of visual examination; palpation of the superficial structures; metric measurements such as gap width, crest width, and maxillomandibular relationships; and the analysis of mounted casts or split diagnostic casts combined with a bone-mapping procedure.[6–8] If the clinical examination and radiographic findings with plain films do not provide sufficient information about alveolar process morphology, there are 2 possibilities for cross-sectional imaging of both the maxilla or mandible, namely, conventional or computed tomography (CT). Initially, conventional tomography was difficult to apply because problems occurred when adjusting the location of the tomographic slices.[9] To facilitate its use, a radiographic unit was developed that used the principles of spiral tomography and

[1]Head, Section of Dental Radiology and Diagnostic Stomatology, Department of Oral Surgery, School of Dental Medicine, University of Berne, Berne, Switzerland.
[2]Chairman, Department of Radiooncology, Division of Medical Radiation Physics, School of Medicine, University of Berne, Berne, Switzerland.
[3]Professor, Head, and Chairman, Department of Oral Radiology, Academic Center for Dentistry Amsterdam (ACTA), Amsterdam, The Netherlands.
[4]Professor and Chairman, Department of Oral Surgery, School of Dental Medicine, University of Berne, Berne, Switzerland.

Reprint requests: Dr Karl Dula, Section of Dental Radiology and Diagnostic Stomatology, School of Dental Medicine, University of Berne, Freiburgstrasse 7, CH-3010 Berne, Switzerland. Fax: +41-31-382-46-09. E-mail: karl.dula@zmk.unibe.ch

narrow-beam radiography, placing the cross-sectional slices at defined locations.[10] With CT, axial slices from the maxilla or mandible can be recorded.

In 1987, a special program for CT was described[11,12] that provided cross-sectional, reformatted images from axial slices of the maxilla and mandible, demonstrating a "coronal view" that follows the parabolic curve of the jaws. Indications for 1 of the 2 modalities should be based on selection criteria derived from clinical and plain-film findings, knowledge of both imaging techniques, images to be expected, and the biologic risk related to each technique. Only then can the appropriate radiologic examination for a specific patient be carefully considered and determined.

Current radiation protection regulations, both nationally and internationally, are based on justification and the ALARA principle (*a*s *l*ow *a*s *r*easonably *a*chievable).[13] This implies that every radiographic examination must be carried out to the benefit of the patient by application of the lowest possible dose. Therefore, the selection of imaging technique is already part of radiation protection measures.

The dose applied by a specific exposure in dentomaxillofacial radiology is well known from several reports.[14–20] However, these studies have been carried out with different protocols and phantoms, so the dose values can only be compared in orders of magnitude. For the first time, comparative dose measurements of nearly all imaging techniques used in dentomaxillofacial radiology and many of those used in general radiology have been performed by the authors in a series of studies with the same protocol and the same phantoms by the present authors.[21–24] These studies facilitate estimation of the radiation burden of different imaging techniques in dentomaxillofacial radiology and allow comparison with imaging techniques in general radiology, so that the values can be seen in a broader context. In this report, the values for hypothetic mortality risk were chosen to grade the various imaging techniques because they are intelligible for those unfamiliar with mere physical data. This may offer an objective basis for correlating the requirements of an implant surgeon and the anatomic conditions of implant patients with the appropriate image selection and will provide comparable figures that can be used to communicate with the patient.

MATERIALS AND METHODS

In a series of studies, dose measurements were conducted with imaging techniques common in oral radiology. The imaging techniques comprised simulations of:

- Single periapical radiographs from the maxillary and mandibular incisors, the maxillary and mandibular premolars, and the maxillary and mandibular molars
- An intraoral survey consisting of 14 periapical radiographs and 2 bitewings with x-ray films and with digital sensors
- Two bitewings alone
- An occlusal view of the maxilla
- Panoramic radiography with conventional technique (film)
- Panoramic radiography with digital technique (charge-coupled device [CCD])
- Curved-linear tomography for cross-sectional imaging of 3 definite locations of the mandible with digital technique (CCD)
- Spiral film tomography for cross-sectional imaging of a single-tooth gap in the maxilla and mandible with 2 different x-ray units
- Spiral film tomography for cross-sectional imaging of the whole maxilla and mandible
- Computed tomography of the maxilla with and without methods for dose reduction (number of axial slices and mA settings reduced)
- Computed tomography of the mandible without methods for dose reduction

For all intraoral radiographs, exposure conditions for Kodak E-Speed films (Rochester, NY), film holders, and round and rectangular collimation were simulated using Transdent S (Ritter, Karlsruhe, Germany) working at 70 kV tube current, 7 mA anode voltage, and an exposure time from 0.25 to 0.65 s depending on the area exposed. Conventional panoramic radiography was performed with an Orthoralix DC (Gendex, Hamburg, Germany) working at 68 kV and 19 mA/16 s. Digital panoramic radiography and digital curved-linear tomography were produced with an Orthophos DS (Sirona AG, Bensheim, Germany), with digital panoramic radiography at 69 kV/15 mA/14 s and curved-linear film tomography at 80 kV/14 mA/21.4 s. Spiral tomography was executed with a Scanora and a Cranex Tome (Soredex, Helsinki, Finland), operating at 70 kV from 2.5 mA/82 s to 5 mA/82 s and at 57 to 70 kV, 1 mA, and 46 s, respectively. Prior to spiral tomography, a panoramic radiograph was taken to determine the sites of the transverse tomographic cuts, as is the standard procedure. Computed tomography was carried out with a Somatom Plus S spiral CT (Siemens, Erlangen, Germany) working at 120 kVp and 125/165 mAs. Details concerning film tomography and computed tomography have been described previously.[21,22]

Dose measurements were carried out with 2 different types of phantoms. The first was an Alderson Remab phantom (Alderson Research Laboratories, Stamford, CT), an actual full-body skeleton embedded in body-shaped soft tissue–equivalent material (acrylic glass and water). This phantom was used to measure the dose from the central beam, as well as scatter radiation to the whole body, to determine the effective dose. The second was a Pedo-RT humanoid phantom (Humanoid Systems, Torrance, CA), a head and neck phantom with ten 2.5-cm sections intended for detailed recording of the dose profile in the head and neck region. For dosimetry, 2 different types of thermoluminescent dosimeters (TLDs) were used: TLD-100 lithium fluoride (LiF) and TLD-200 calcium fluoride (CaF_2, Harshaw Chemical Company, Cleveland, OH). The TLD-100 LiF has a signal proportional to the dose within a great range of x-ray energies, whereas the response of the TLD-200 CaF_2 is more energy-specific but has a sensitivity that is 20 times higher. Thus, in the Alderson Remab phantom, a total of 280 TLDs were inserted at 70 different sites. From the head to the level of thorax 10, two TLD-100 LiF as well as two TLD-200 CaF_2 were inserted at each measuring point. Down from that level, two TLD-200 CaF_2 were used in each of the remaining measuring points. In the Pedo-RT humanoid phantom, 142 TLD-100 LiF were introduced at 71 different places. All sites corresponded to radiosensitive organs or tissues that were likely to be irradiated during the examinations studied in the investigations. The phantoms were positioned with the dosimeters as if they were actual patients, and the examinations were carried out separately and with both phantoms in the same way. To obtain measurements clearly above background level, the phantoms were exposed 5 times. This was corrected by dividing the TLD counts by 5 before they were converted into mGy.

From the measured organ doses, the mortality risk was calculated utilizing the model proposed by the International Commission on Radiologic Protection (ICRP Publication 60).[13] Here, an effective dose results from the sum of all mean organ doses to radiosensitive organs or tissues. According to the ICRP instructions for the use of this calculation method, a weighting factor of 0.025 was applied to the parotid gland, because it received a mean organ dose in excess of the highest dose in any of the 12 organs for which a weighting factor is specified. The same factor was assigned to the mean organ dose to all other remainders together. Phantoms, dosimetry, and calculations have been previously described in detail.[21]

RESULTS

In Table 1, the kV and mA settings, the effective dose, and the biologic risk calculated according to the risk model of ICRP 60 are listed for all examinations. A grouping was made for simulations of intraoral radiography using E-Speed film with round and rectangular collimation, respectively, followed by survey examinations and cross-sectional imaging with conventional and computed tomography.

The kV settings were highest for CT (120 kV); all other radiographic exposures studied were exposed at kV settings ranging from 60 to 80 kV. The mA settings, however, varied within a wider range. The lowest value was 1.8 mA for a periapical radiograph in the mandibular anterior region, and the highest value was 7,280 mA for CT. For periapical radiographs with both round and rectangular collimation, the mA values ranged from 1.80 in the mandibular anterior region to 4.50 in the maxillary molar region. During all extraoral imaging, patients were exposed to distinctly higher mA settings. When panoramic radiography was carried out with conventional or digital systems, the mA settings ranged from 210 to 304 mA. Cross-sectional imaging of a single-tooth gap with conventional tomography required settings between 196 and 523 mA. For conventional tomography with perpendicular slices of the whole maxilla or mandible, the settings ranged from 1,580 to 1,880 mA, whereas 7,280 mA were applied when CT with standard procedures was performed. The mA settings could be reduced to 3,805 mA when different methods for dose reduction were used.

The effective dose ranged from 0.001 mSv for a periapical radiograph to 0.564 mSv for a standard examination with CT of the maxilla. Intraoral radiography was connected with the lowest effective dose as long as single images were taken. A full-mouth survey with round collimation, however, resulted in an effective dose that was 52 to 73% higher than panoramic radiography. Rectangular collimation reduced the effective dose for the full-mouth survey by about 31%. Generally, examinations of the maxilla resulted in a higher effective dose. This is clearly shown by a comparison of the values obtained for cross-sectional imaging procedures.

The estimated mortality risk varied according to the differences in the effective dose. Generally, the probability for fatal cancer ranged from 0.1 to 28.2 $\times 10^{-6}$. It was found that the risk was reduced on average by one-third when rectangular collimation, rather than round collimation, was used for periapical radiographs. Panoramic radiography imparts a 30% lower risk to the patient than a full-mouth survey taken with rectangular collimation and a 53%

Table 1 Type of Examination, Exposure Settings, Effective Dose, and Hypothetic Mortality Risk

Examination	Exposure settings kV	Exposure settings mA	Effective dose (mSv)	Mortality risk ($\times 10^{-6}$)*
Round collimation, E-speed film				
Maxillary anterior region	70	2.80	0.002	0.10
Mandibular anterior region	70	1.80	0.001	0.05
Maxillary premolar region	70	3.50	0.004	0.20
Mandibular premolar region	70	2.30	0.003	0.15
Maxillary molar region	70	4.50	0.006	0.30
Mandibular molar region	70	3.50	0.006	0.30
Bitewings	70	3.60	0.050	2.50
Full-mouth and bitewings (14 exposures)	70	121.7	0.063	3.15
Rectangular collimation, E-speed film				
Maxillary anterior region	70	2.80	0.001	0.05
Mandibular anterior region	70	1.80	0.001	0.05
Maxillary premolar region	70	3.50	0.003	0.15
Mandibular premolar region	70	2.30	0.002	0.10
Maxillary molar region	70	4.50	0.005	0.25
Mandibular molar region	70	3.50	0.004	0.20
Bitewings	70	3.60	0.004	0.20
Full-mouth and bitewings (14 exposures)	70	121.7	0.043	2.15
Survey radiographs				
Occlusal view, maxilla (E-speed film)	70	11.88	0.008	0.40
Standard panoramic radiograph	68	304	0.030	1.50
Digital panoramic radiograph (standard)	69	210	0.021	1.05
Digital panoramic radiograph (dose-reduced)	60	224	0.017	0.85
Conventional tomography				
Digital cross-sectional tomography, mandible	80	300	0.092	4.60
Cranix Tome, region 16	70	196	0.074	3.70
Cranix Tome, region 46	70	196	0.037	1.85
Scanora, region 16	70	523	0.134	6.70
Scanora, region 46	70	431	0.059	2.95
Scanora, complete maxilla (6 $\times$ 4 images)	70	1880	0.477	23.80
Scanora, complete mandible (6 $\times$ 4 images)	70	1580	0.264	13.20
Computed tomography				
Maxilla, standard	120	7280	0.564	28.20
Mandible, standard	120	7280	0.364	18.20
Maxilla with dose reduction 40 scans	120	5465	0.448	22.40
Maxilla with dose reduction 25 scans	120	3805	0.242	12.10

*According to a risk model of the International Commission on Radiological Protection.[13]
Region 16 = maxillary right first molar; region 46 = mandibular right first molar.

lower risk than a full-mouth survey taken with round collimation. The risk related to cross-sectional imaging is different for CT and conventional tomography. When the whole maxilla or mandible is imaged with conventional tomography or CT with standard procedures, the risk is lower for conventional tomography, especially in the mandible. If methods for dose reduction in CT are applied, the risk for CT examinations can be decreased by 57%. However, if conventional tomography is used to study a single-tooth gap, the risk is only 30% of the risk imposed by CT with dose reduction.

DISCUSSION

Calculations of the Hypothetic Mortality Risk

To the authors' knowledge, this is the first report on the selection of imaging techniques in implant dentistry based on a risk-benefit comparison, taking the clinical requirements and the biologic risk for the patient into account. To estimate the biologic risk from radiographs, the model suggested by the ICRP in 1977 and 1990[13,25] has become a common method of calculation. However, this calculation model is based on effects from the high dose range

	Maxilla	Mandible
Anterior region	Canine fossa Nasopalatine nerve	Mental fossa Minor vessels, muscles
Premolar region	Sinus	• Sublingual artery • Submental artery • Mental rami from submental artery
Molar region	Sinus	Submandibular fossa • Facial artery • Tonsil rami from ascending pharyngeal artery • Lingual nerve • Mylohyoid nerve

Fig 1 Anatomic and tomographic structures in the maxilla and mandible that are pertinent to implant placement. Anatomic structures are shown in dark grey, and topographic structures are shown in light grey.

sustained by survivors of the atomic bombs dropped on Hiroshima and Nagasaki, Japan. Originally, it was used to estimate the effects after a diffuse exposure to low levels of radiation for occupational radiation protection. There is doubt as to whether extrapolation from the high dose range to the low level of radiation may be done and whether it can be applied to medical exposure. However, it is the only reasonable way of comparing different radiographic examinations and it is commonly done in diagnostic radiology.

According to ICRP 60, biologic risk was calculated for the mean population of 35-year-old individuals of both genders. Generally, the risk is lower for older people and even higher for younger people than indicated by the data published in the present study. However, these data were chosen, as they are easier to compare with data from other studies, which were performed mostly with this method of calculation.

Significance of Surgical Complications Related to Implant Dentistry

A reliable estimate of bone width is essential for uncompromised implant placement. Complications may arise from individual patterns of atrophy and remodeling of the maxilla and mandible after tooth loss, altering the topographic location of vital structures in distance and course relative to the bone. The anatomic and topographic structures pertinent to implant therapy are identified in Fig 1. It can be seen that in the maxilla, no vital structures other than the nasopalatine nerve and small vessels can be injured during surgery. Here, most of the problems arise from widely varying patterns of atrophy. Hence, a lateral perforation or a sinus perforation may be encountered, and if poor bone quality is combined with a severe perforation, insufficient primary stability of the implant may occur.[26]

In the mandible, however, the situation becomes more complex, because injury may occur not only to structures within the bone, such as the inferior alveolar nerve, but also to soft tissues after a lingual perforation. In the premolar region and sometimes even in the canine region, the sublingual artery, the submental artery, and the mental rami of the submental artery take a course close to the mandible. In the molar region, the facial artery, the tonsil rami from the ascending pharyngeal artery, and the lingual nerve and the mylohyoid nerve are vital structures within reach of a perforating bur. Hemorrhage in the floor of the mouth can be a severe and life-threatening situation because it extends into the oropharynx, and the surrounding soft tissues provide no self-tamponing effect. This may require acute tracheotomy and/or nasotracheal intubation.[27–31] Additional intraoperative complications based on inappropriate bone volume have been reported by Truab.[32]

Imaging Techniques in Implant Dentistry

Periapical Radiography. Periapical radiographs provide the contrast, resolution, and delineation of objects necessary to be used as the "gold standard" in comparative studies.[33–36] Although absence of the screen requires a dose higher than otherwise necessary, the effective dose and biologic risk for the patient from an E-Speed periapical radiograph of the molar region is still 5 times lower than that of a panoramic radiograph (Table 1). However, considering its limited overview, a periapical radiograph appears to have a restricting disadvantage because it could lead to incomplete radiographic findings important for the treatment of implant patients.

Panoramic Radiography. The great advantage of panoramic radiography is the broad overview provided. Pathologic changes, other than caries, in regions not assigned for implant placement can be detected and treated, which corresponds with the philosophy that implant treatment should be carried out only in patients undergoing comprehensive dentistry.[37] Because it is a survey radiogram, panoramic radiography allows for assessment of structures such as the maxillary sinus or the course of the mandibular canal, and it provides the possibility for vertical measurements with sufficient accuracy if the magnification factor of the panoramic x-ray unit is known.[38] In addition, the better overview helps to indicate the need for intraoral x-rays for questionable sites to elucidate details. For instance, to judge the periodontal situation of neighboring teeth in an implant recipient site, the sharper delineation of a periapical radiograph may be necessary. However, the need for additional intraoral radiographs can be significantly reduced when a panoramic device is used, which provides better image quality because of optimized layer thickness.[39] Thus, to achieve a comprehensive examination, panoramic radiography should be performed as a standard radiographic examination in partially edentulous and completely edentulous patients; subsequently, periapical radiographs will help to elucidate details from objects not clearly visible in the panoramic radiograph. In patients in whom determination of the bone width is possible by clinical findings, these imaging techniques may remain the only radiographs necessary for treatment planning.

Conventional and Computed Tomography. The available bone volume cannot be judged only from panoramic radiography. In many situations, bone width can be determined by clinical examination, as previously described. However, in patients in whom soft tissue structures prevent proper assessment of the jaw, the surgical site may reveal another bone volume than that expected by the preoperative examination.[40,41] With conventional tomography, it is possible to obtain cross-sectional images that can be used to determine bone width. Contemporary machines for panoramic radiography generally include the possibility of curved linear tomography, parallel linear tomography, or spiral tomography. There are also x-ray units that include a coordinate system for object localization and a wide selection of dental and maxillofacial imaging programs.[10] Computed tomography uses software that performs multiplanar reformatting (CT/MPR) from axial slices, yielding cross-sectional images that are perpendicular to the curvature of the dental arch. In addition to these images, 3 to 5 reformatted image layers are shown parallel to the dental arch, which are called panoramic views.

With both conventional and computed tomography, it is possible to obtain information about the width, height, and inclination of the alveolar process; anatomic and topographic structures; and, to some extent, the trabecular architecture. Differences may be seen in the depiction of images, the power of object delineation, and the dose to the patient. Conventional tomography provides cross-sectional images with a magnification factor of 1:1.5 or 1:1.75, which requires the surgeon to scale up distance measurements with the help of templates. The perpendicular images provided by the axial slices from CT are printed life-size in alignment with a 1-mm measuring scale on the left, providing the observer with immediate distance measurements. By the nature of image formation in conventional tomography, a sharper central layer is superimposed by blurred objects at a larger distance from this layer; this sometimes requires good experience in object recognition. This explains why untrained observers are sometimes confused when looking at a conventional tomograph instead of a reformatted CT image. Here, objects seem to be better delineated; the microstructure, however, seems to be worse, and faint objects are not detectable. Comparative studies reporting on the image quality of both systems should be carried out to elucidate the significance of this difference.

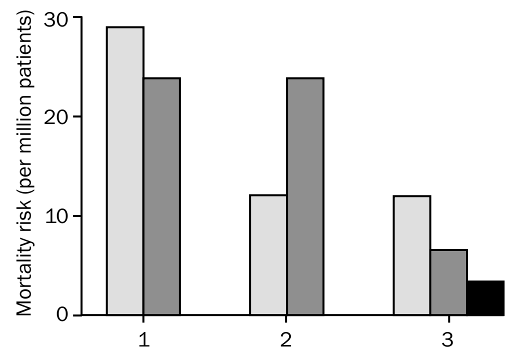

Fig 2 Comparison of the hypothetic mortality risk for various examination techniques. 1 = standard CT *(left)* versus conventional tomography *(right)* of the whole maxilla; 2 = CT with methods for dose reduction *(left)* versus conventional tomography *(right)* of the whole maxilla (using Scanora); 3 = dose-reduced CT *(left)* versus conventional tomography of a single-tooth gap in the maxillary molar region (using Scanora *[center]* and Cranex Tome *[right]*).

A decisive difference between conventional and computed tomography is that conventional tomography generally applies a lower dose of radiation to the patient (Table 1). If the complete maxilla or mandible is examined with cross-sectional images, the dose involved in conventional tomography is about 80% of that of CT. If methods for dose reduction in CT are applied, the dose to the patient can be reduced to 50% of that of conventional tomography when the complete maxilla or mandible is examined. However, if an edentulous region of 1 to 3 teeth is examined, the dose from conventional tomography is smaller than that from CT with dose reduction (Fig 2).

Table 2 Comparison of Estimated Mortality Risk Values from Radiographic Examinations in Dentomaxillofacial Radiology and General Radiology

Type of examination	Hypothetical mortality risk
Conventional examinations	
Teeth	0.05 to 0.3×10^{-6}
Extremities	$< 0.1 \times 10^{-6}$
Lung (posterior-anterior)	3×10^{-6}
Pelvis (anterior-posterior)	20×10^{-6}
CT examinations in general radiology	
Thorax	260×10^{-6}
Pelvis	300×10^{-6}
Cross-sectional imaging in maxillofacial radiology	
CT (standard maxilla)	28.2×10^{-6}
CT (standard mandible)	18.2×10^{-6}
CT (maxilla with dose reduction, 40 scans)	22.4×10^{-6}
CT (maxilla with dose reduction, 25 scans)	12.1×10^{-6}
Tomography (complete maxilla)	23.8×10^{-6}
Tomography (complete mandible)	13.2×10^{-6}
Tomography (single-tooth gap 16)	3.7 to 6.7×10^{-6}
Tomography (single-tooth gap 46)	1.85 to 2.95×10^{-6}
Special examinations	
Renal angiography	1110×10^{-6}

*According to a calculation model from the International Commission on Radiological Protection (ICRP). Data from Mini[24] and the present study.

Decision-Making Criteria

Recommendations for the application of imaging techniques should be based on clinical necessity, ie, the need for portrayal of anatomic or topographic conditions (dependent to a great extent on the experience of the surgeon); ease of image production; information expected from the image; biologic risk for the patient (especially for young patients); and financial considerations. The hypothetic mortality risk from dentomaxillofacial radiology may be put in its proper place by comparing it with the hypothetic mortality risk of general radiologic imaging techniques (Table 2). The risk from dental radiology may be the lowest in medical radiology; however, the risk from maxillofacial radiology is comparable to the risk from conventional exposures in general radiology. For this reason, a classification is proposed regarding when to perform cross-sectional imaging. This classification is founded on weighing the need for an accurate assessment of the anatomic and topographic structures against the risk of harm to the patient from radiographic examination. For this purpose, the maxilla and mandible could be simply, but effectively, classified as follows:

- Class 1: Anterior segments in the maxilla (from canine to canine)
- Class 2: Posterior segments distal to the canines in the maxilla
- Class 3: Anterior segments in the mandible (from canine to canine)
- Class 4: Posterior segments distal to the canines in the mandible

These 4 different regions gain clinical importance when taking into account the anatomic and topographic structures related to them (Fig 1). It can be clearly seen that more vital structures are located in the mandible, which establishes a relationship between frequency of injury and the floor of the mouth. This is confirmed by an analysis of the literature about severe surgical complications during implant placement. Thus, one could argue that in the mandible, cross-sectional imaging should be mandatory, just as the use of CT in implant dentistry has already been generally recommended by many authors.[42–47] However, if this recommendation is followed, the radiation burden would increase considerably but unnecessarily, because as long as no intraoperative navigation is used, implant placement is always dependent on the skill and experience of the implant surgeon and his or her ability to manage the soft tissues. Therefore, the principle should be accepted that cross-sectional imaging should be performed only in special cases for reasons of treatment planning. Generally, the radiographic evaluation of implant patients should be carried out according to the following 3 axioms.

Axiom No. 1: General Considerations (Fig 3). A distinction should be made between treatment planning and follow-up. Prior to implant placement, it seems appropriate to consider panoramic radiography as a standard radiographic examination for referred patients, because it provides a low biologic risk while giving an excellent survey and an accurate means of determining implant length in both the maxilla and mandible. Periapical radiographs may be used to complete the findings in regions not sharply depicted in the panoramic radiograph. Considering the dose involved, intraoral radiography may be considered as the standard radiographic examination during follow-up, particularly for implants in the anterior region of the maxilla, or for scientific studies. In situations where more than 5 periapical images are required, panoramic radiography may be used instead.

Axiom No. 2: Applications for Cross-Sectional Imaging (Table 3). In the maxilla, cross-sectional imaging should be used: *(1)* in patients with severe

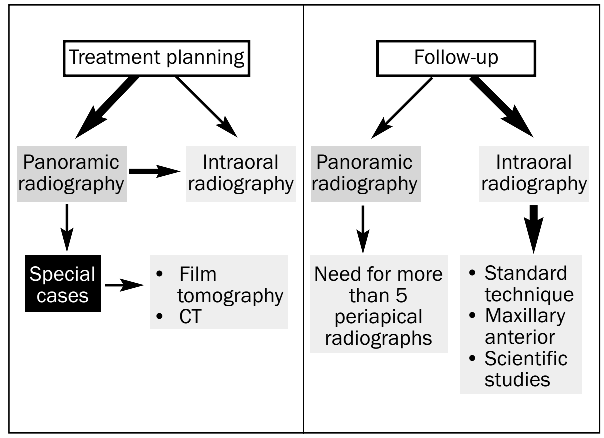

Fig 3 Recommendations for radiographic examination in implant dentistry. Generally, a differentiation between treatment planning and follow-up is proposed. Treatment planning should be based on a panoramic radiograph completed by periapical radiographs for details where necessary. Cross-sectional imaging should be confined to special cases. For follow-up, periapical radiographs are generally proposed except in patients where more than 5 periapical radiographs are required; in such cases a panoramic radiograph can be performed.

Table 3 Classification of When to Perform Cross-Sectional Imaging in Implant Dentistry

Region	Indications	Optional indications
I: Anterior segments in the maxilla (areas from canine to canine)	Severe bone loss with enlarged incisor canal for single implants in the incisor region or multiple implants in the incisor and canine regions	Bone volume impossible to assess by means of clinical examination because of unfavorable soft tissue conditions
II: Posterior segments distal to the canines in the maxilla	Severe bone loss and close proximity of the maxillary sinus For a fixed prosthesis in the completely edentulous maxilla	Bone volume impossible to assess by means of clinical examination because of unfavorable soft tissue conditions
III: Anterior segments in the mandible (areas from canine to canine)	For a fixed prosthesis in the completely edentulous mandible	Bone volume impossible to assess by means of clinical examination because of unfavorable soft tissue conditions For interforaminal implantation in case of atrophy corresponding to Cawood and Howell[48] level V and VI
IV: Posterior segments distal to the canines in the mandible	For a fixed prosthesis in the completely edentulous mandible	Bone volume impossible to assess by means of clinical examination because of unfavorable soft tissue conditions In cases of a pronounced mylohyoid line and submandibular fossa or other distinct anatomic undercut

bone loss in the alveolar process, together with signs of enlargement of the incisor canal in the periapical radiograph, for single implants in the incisor region or multiple implants in the incisor and canine region; *(2)* in sites with severe bone loss and close proximity of the maxillary sinus; and *(3)* in patients in whom a fixed prosthesis in the completely edentulous maxilla is planned. In the mandible, cross-sectional imaging should be used when a fixed prosthesis in the completely edentulous mandible is planned.

Axiom No. 3: Optional Applications for Cross-Sectional Imaging (Table 3). In both the maxilla and mandible, conventional or computed tomography can be used where it is impossible to assess bone volume by means of clinical examination because of unfavorable soft tissue conditions. In the mandible, it can be employed either in patients with a pronounced mylohyoid line and submandibular fossa or other distinct anatomic undercut, or when interforaminal implantation is planned for atrophy corresponding to Cawood and Howell level V/VI.[48]

From a radiobiologic point of view, conventional tomography should be preferred whenever possible for single-tooth gaps and extended edentulous spaces up to a quadrant. Applications may thus be classified according to Table 3. For the first time, both the clinical and the radiobiologic considerations may provide an objective basis for the selection of imaging procedures in implant dentistry.

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