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PRE-IMPLANT RADIOLOGY

Introduction

Today the diagnostic options for a correct approach to implants are virtually infinite. Radiology classically divides pre-implant investigations into first- and second-level examinations. For pre-implant planning, the former include orthopantomography (OPG) and intraoral radiographies, the latter specific tomographic imaging (CT). This chapter will deal mainly with tomography, although first-level analyses permit a general evaluation of the clinical case.

Unlike first-level examinations, where equipment and software have led to standardized results, for second-level examinations and precision tests - when conditions and indications are met - the choice of one device over another depends on the level of accuracy that is needed.

Guidelines have been proposed for the optimal use of technology and as a way to obtain unambiguous answers to the problems faced by dentists and maxillofacial surgeons. Nonetheless, it seems useful to examine the motives behind a reasonable request for additional second-level radiological information, because there is a specific device that is preferable for each examination.

It is appropriate to examine the reasons that seem to contraindicate CT examinations and explain how they must be used responsibly:

- longer time frames;
- radiation doses.

Longer time frames

The wide view afforded by panoramic X-rays is an indispensable complement to CT examination. As paradoxical as it may seem, teeth and voids are better observed through the comprehensive view offered by the orthopanoramic X-ray than in CT imaging. We seek different answers from tomography, which by definition identifies smaller sectors with a view of details as diagnostic elements within the three explorable dimensions. At the same time, a template with opaque markers in the areas of interest should always be used so that, following a panoramic X-ray as a preliminary examination, a CT targeting the area of interest can be performed. The radiologist must always take the panoramic X-ray with a template to better target the subsequent CT.

Just as the radiologist is willing to accept a longer time frame for performing the first-level investigation prior to the CT, so too must the dentist be aware that the preoperative template is a necessary aid for accurate surgery, regardless of its preparation time. Exceptions can be represented by emergencies, e.g. immediate post-extractive implantations.

Radiation doses

It is interesting to note that the absorbed radiation varies depending on the equipment that is used.

The dentist should be aware that - diagnostic results being equal - some devices have a lower radiation emission. He/she must thus recommend that it is essential to undergo only the prescribed radiographic investigations, explaining this to the patient.

Modern CT equipment (such as the volumetric scanners described ahead) emits very low radiation, even if the doses are higher than those emitted during orthopantomography.

The reasons for conducting a second-level investigation are the following:

- surgical safety;
- more accurate measurements;
- legal issues.

Surgical safety

By surgical safety we mean a set of objective and subjective reasons for performing the examinations. They can be identified as follows:

- aesthetic planning, especially for edentulous patients;
- questionable OPG images;
- unforeseen bone mineralization problems;
- patient perception of the dentist's professionalism.

Aesthetic planning

We must premise this by saying that CT is the only test that can clarify the three fundamental aspects for which it is used. The peri-implant assessment should, in fact, provide information on the following anatomical parameters:

- height;
- thickness;
- degree of mineralization.

Even if the OPG is able to provide approximate information on the height of the structures (and, in part, their mineralization), only the CT scan can also assess bone thickness. With this three-dimensional view, the dedicated CT examination is the only analysis that can provide an exact image for model construction, not only on the articulator but also for masticatory function, laying the groundwork for correct morphofunctional rehabilitation.
The CT examination will thus answer the three questions we always ask, but it will also provide valuable information on measurements and reference points that would be unattainable otherwise. In short, this is what we refer to as radioguided implantology.

Questionable OPG images and unforeseen mineralization problems

The more we learn about the merits of orthopanoramic radiography, the more we can understand its limitations.
From a spatial standpoint, it seems futile to repeat that the two-dimensionality of the reference images is an insurmountable limit for the implantologist who would like to know the alveolar thickness. This aspect and possible mineralization artifacts are why orthopanoramic X-rays cannot be considered a comprehensive diagnostic examination for pre-implant assessment.

Patient perception of the dentist's professionalism

What is the basis for the perception of the dentist's professionalism by the patient and among the community in general? What is the patient's opinion when his/her care provider does or does not prescribe preliminary examinations before implant surgery?
The answer is based in my own experience, as I am often asked: "Doctor, can you place an implant?"
The radiologist's opinion cannot be definitive based on orthopanoramic X-rays alone. In fact, how can one answer based only on a view of the height (which, moreover, is not always accurate)? How can one decide without a clear image of the mandibular nerve, when there is a sinus close to the alveolus, when there is an artifact, and so on? Therefore, the radiologist cannot fail to mention that a specific tomographic investigation exists, and that it will permit better insight and assessment of the clinical case.
In this specific case, modern equipment is so highly specific (volumetric CT) that, considering the risk-benefit balance between "therapeutic value and radiation dose", it is clearly more beneficial to undergo to a radiological examination with a low radiation risk than to avoid in-depth diagnostic studies.
It is crucial for the patient to understand the utility of in-depth radiological examinations. Furthermore, it is advisable to provide him/her with a written note to give the radiologist so that the report will be aimed at implant planning.

More accurate measurements

Investigations that provide accurate 1:1 dimensional measurements allow the dentist to plan carefully and select the implant with the most suitable size and best material.
There is no doubt that, without a tomography and the certainty of accurate measurements obtained by a well-executed examination, the cautious dentist will opt for smaller implants, thus creating the "ideological" basis for choosing a material with less potential for good primary stability inside the bone: an objectionable choice when the actual dimensions involved effectively require longer and/or larger implants.

Legal issues

> Radiographs should not be taken only for medicolegal purposes. The medicolegal significance of radiographs cannot be ignored (Paolo Mezzanotte).

Having acknowledged the validity of further investigations that engender no real risk of biologi-

cal damage, the only remaining doubt involves selecting those that emit lower radiations - while assuring equivalent diagnostic results - among the specific equipment now available. The consensus conferences aimed at drawing up guidelines to minimize the margin of discretion, benefiting the safety of the patient, who is often psychologically submissive or misinformed, introduce the concept of informed consent. In this regard, tomography has acquired probative value in medical malpractice cases, and lawsuits can be lost if CT imaging is not included in the clinical protocol.

Radiological protocol

CT imaging is acquired by radiologists whose reports will provide the dentist with information about measurements and bone status. To arrive at these results, the specialist relies on a protocol that strictly follows standardized execution procedures accompanied by accurate preparation of the patient through precise indications and, if possible, known landmarks in the oral cavity. The radiologist follows a meticulous process to obtain the definitive answer, carefully selecting among various options concerning:

- equipment;
- projections;
- reference images;
- reports.

Equipment

CT imaging employs different technologies, which can basically be split up into two categories: fan-beam scanners (Fig. 1), and cone-beam scanners (Fig. 2). The illustrations show the reciprocal movements between objects and X-ray tube in the two main equipment categories.
A fan-beam (spiral) CT scanner uses a dedicated program called Denta Scan, which is a software application for implantology and is loaded into the equipment, as opposed to the programs designed for cone-beam (volumetric) CT scanners, which have the same cognitive purposes but operating modes that vary from machine to machine.
Figures 3 and 4 show the typical configuration of a cone-beam CT scanner.

Projections

Implant planning relies on a clinical protocol in order to obtain images with fixed 1:1 magnifica-

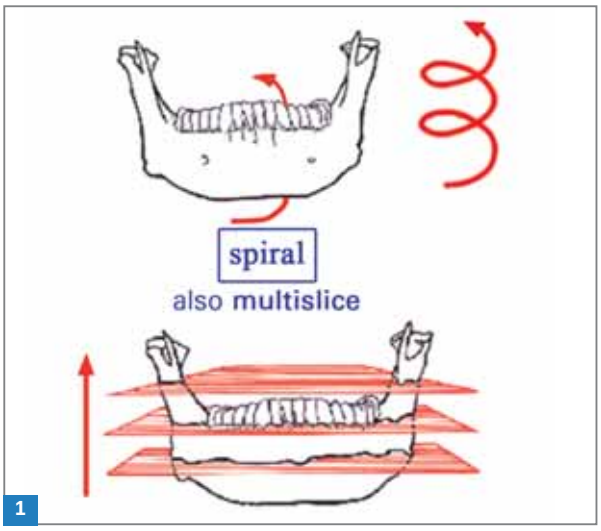

Fig. 1 Fan-beam technique.

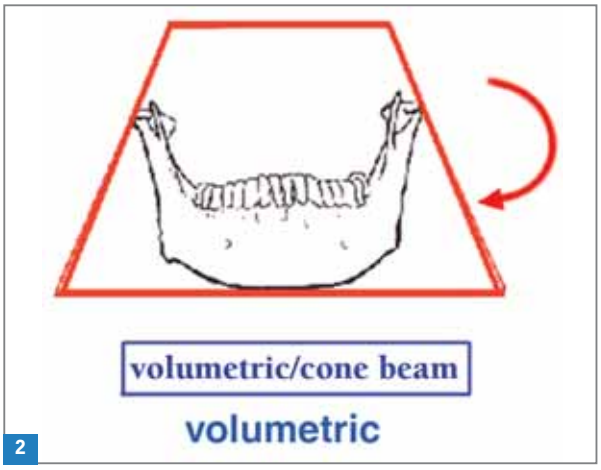

Fig. 2 Cone-beam technique.

Fig. 3 Cone-beam equipment.

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Fig. 4 Cone-beam configuration.

tion parameters. Consequently, images orthogonal to each other and that fulfill these characteristics are preferable.
Figure 5 show the basic projections, which are sagittal (the same principle employed for panoramic-like X-rays, which follow the curvilinear profile of the bone), transverse (or cross or paraxial), axial slices, and coronal or frontal slices used for comparison and for a general overview.
The elaboration of these combined projections yields the final report.

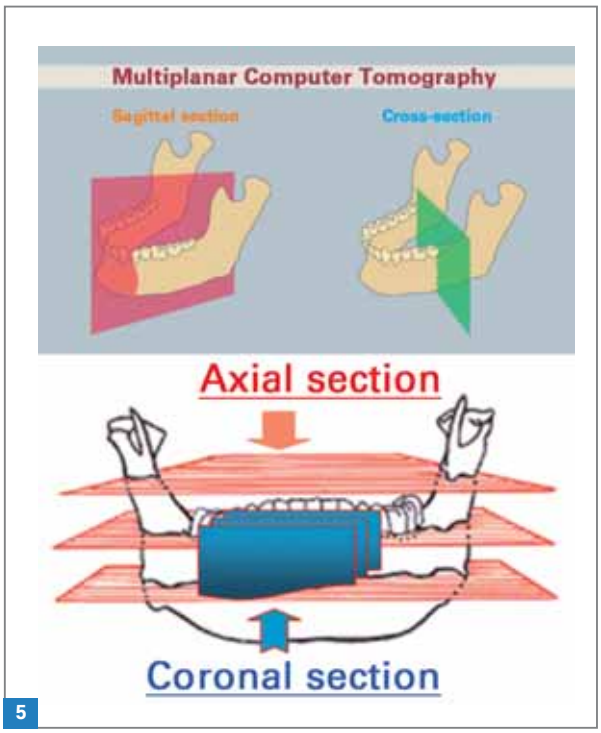

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Fig. 5 CT projections.

Before image printing, it has to be underscored that the examination should always include good landmark assessment.

Reference images

Images obtained by positioning a template, which can vary in shape and material, and indicating the areas of interest on the CT scan are referred to as reference images.
Templates are usually manufactured from opaque materials by the dental technician or dentist. They are preferably small in size and cylindrical, in order to indicate on the radiographs not only the site but possibly also the bucco-lingual-palatal inclination.
Once composed of metal beads (but with limitations in radiographic quality and information about inclination), today these markers tend to be made from less dense materials that are more visible on the CT scan. They are represented by:

- gutta-percha and titanium markers;
- markers consisting of opaque crowns (barium-loaded resins).

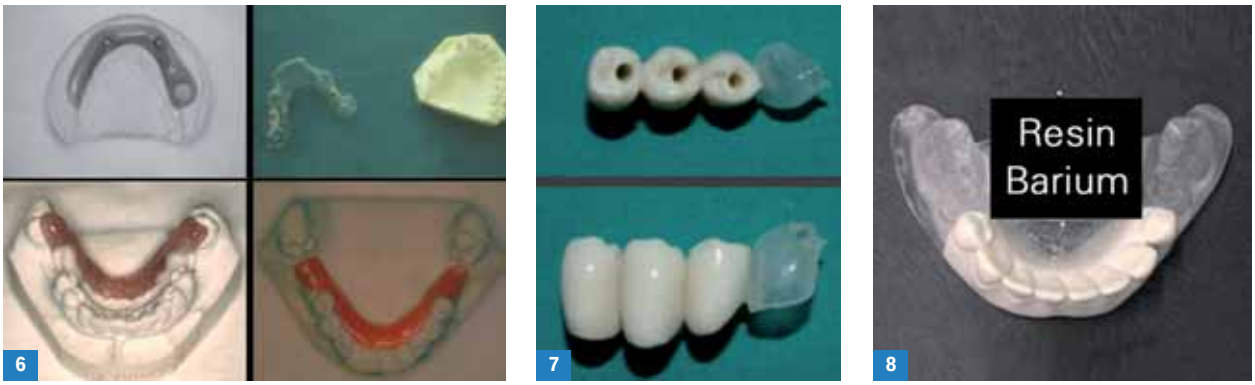
Figures 6-13 show examples of classic markers made of these materials. In particular, Figures 14 and 15 also show the results in 3D sections.

Report

The report is the result of a careful choice of the appropriate projections needed by the dentist for information about thickness, available height and bone mineralization status (when possible), along with measurements, angles and significant remarks.
The report thus represents the conclusions of the radiological examination that will be used by the dental specialist. With modern technology, they can also be copied to a CD or DVD for handy consultation and record keeping.
The upper maxilla and the mandible usually show slight differences in the formation of the images, and this is useful for diagnostic purposes.

Upper maxilla

The following illustrations show the sequential image elaboration process from the raw data of the irradiated area of interest.
Note that the CT examination follows the execution of an orthopanoramic X-ray (Fig. 16), possibly taken with reference markers.
Elaboration of the report generally begins with a scout view (Fig. 17), which is a lateral projection of the skull used to choose the most suitable axial reference to locate the sites of interest.
The panoramic-like projections (Fig. 19) are cho-



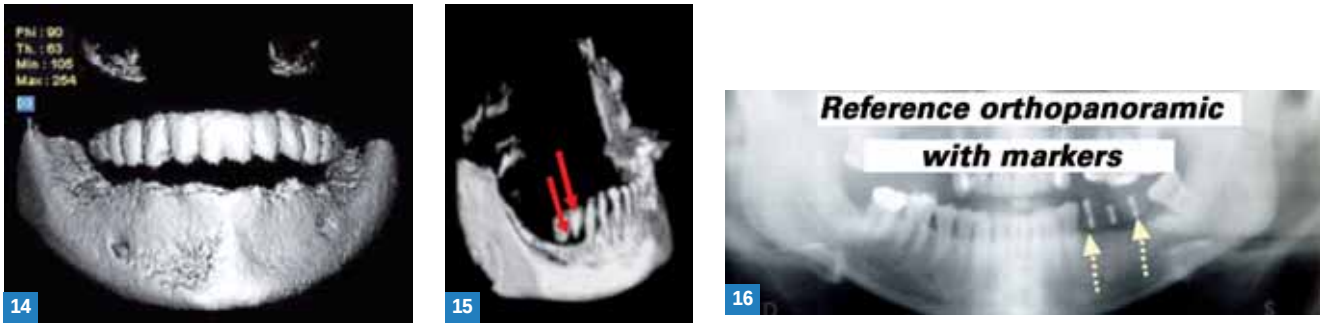
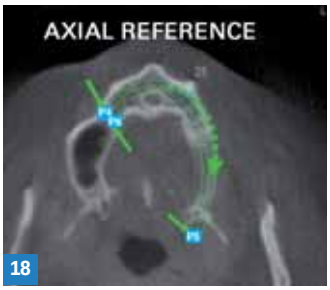


Fig. 6 Opaque markers (beads) on templates. **Fig. 7** Barium-loaded resin opaque markers.
Fig. 8 Barium-loaded resin opaque markers. **Fig. 9** Titanium markers.
Fig. 10 OPG with a gutta-percha marker. **Fig. 11** OPG with gutta-percha markers.
Fig. 12 Panoramic-like CT image with perforated titanium markers. **Fig. 13** OPG with perforated titanium markers.
Fig. 14 3D CT with barium-loaded resin markers. **Fig. 15** 3D CT with barium-loaded resin markers.
Fig. 16 A good starting point: OPG with markers.

sen on the axial reference of the upper arch (Fig. 18), which are useful to identify the segment needed by the dentist. The segment may include one or more sites or the whole arch.
The transverse or cross-sectional projections are then extracted from the axial reference by means of dedicated programs such as Denta Scan, which will determine the size of the alveoli (Figs. 20, 21).
With some programs, the markers can often clearly outline the limits of the segment of interest (Fig. 22).
The report will thus show the axial reference projection, the panoramic-like images indicating the segment of interest, the cross-sectional slices with the measurements of the available height and thickness, as well as any other significant information such as the distance between the alveoli and the maxillary sinus.
An additional sheet with axial projections will identify any pathological conditions of the maxillary sinus, which is very useful to know in case of sinus lift procedures.
In the event of sinus conditions, assessment of the sequential involvement of the dental elements affected by the inflammatory process can also be useful. The diagnosis will be formulated on the basis of the subsequent bucco-palatal slices through the execution of sagittal projections.
The following images show a report of the upper arch both with the cone-beam technique, which is usually more detailed (Figs. 2-26), and the fan-beam technique (Figs. 27, 28).
There are axial, cross-sectional and panoramic-like slice images, variously combined, and sometimes also sagittal slices in order to better evaluate the concomitant sinus disease.



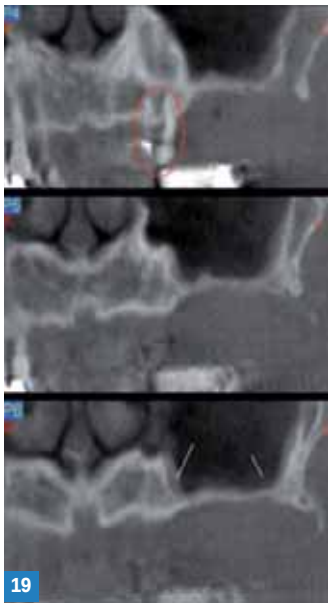
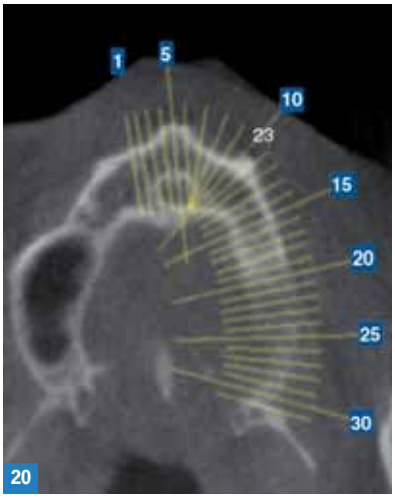
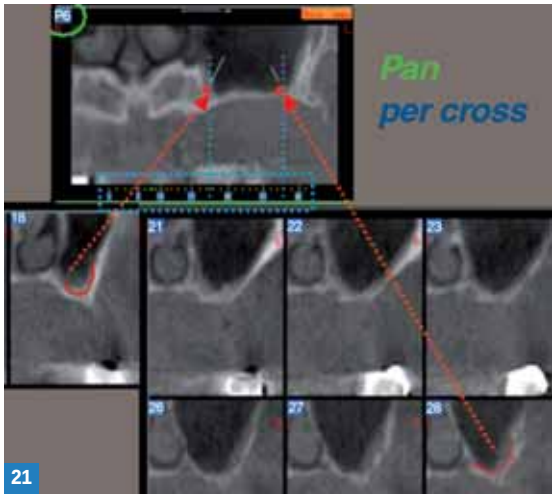


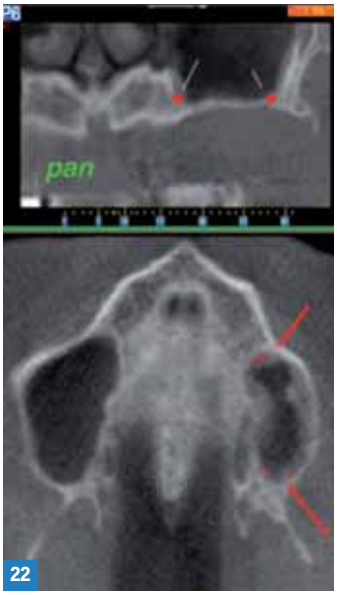
Fig. 17 Cone-beam CT: lateral scout view.
Fig. 18 Cone-beam CT: axial reference.
Fig. 19 Cone-beam CT: panoramic-like images.

Lower maxilla (mandible)

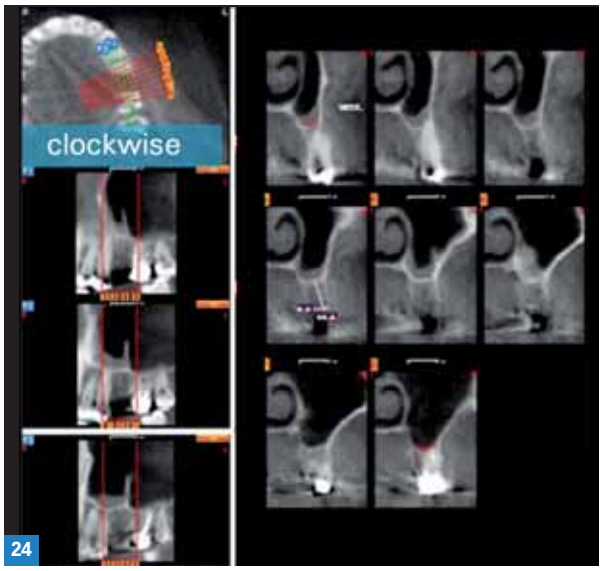
In this case the axial reference of greatest interest, akin to a scout view, is chosen. The mandibular slice with the metal reference markers does not always correspond to the same slice that shows the mandibular nerve course, as required by the dentist.
Therefore, using the OPG as a reference (Fig. 29), the two axial references of interest (Fig. 30) extrapolated from the CT are identified, one with the markers and the other with the mandibular nerve

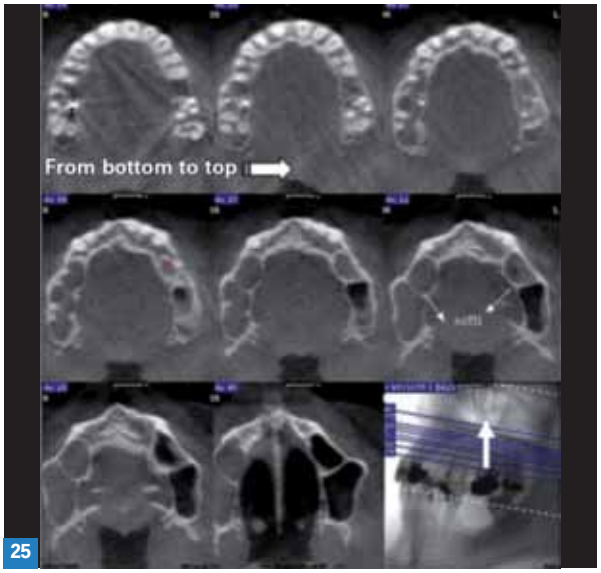


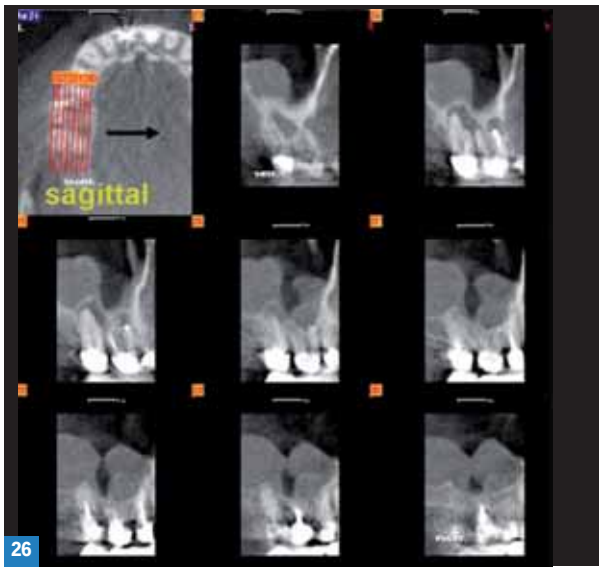




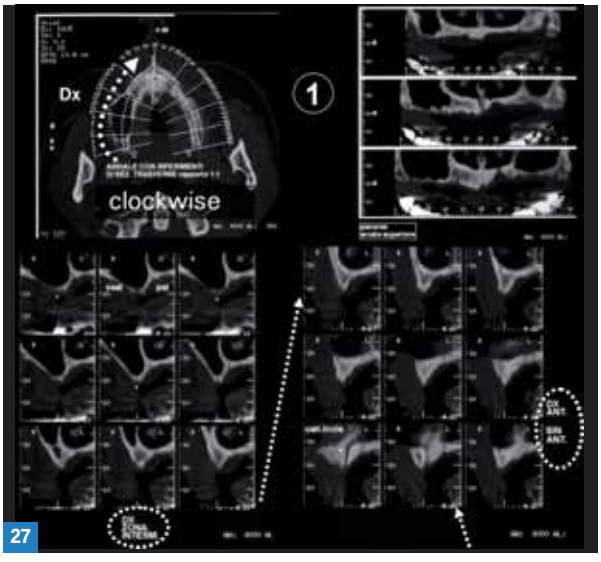
Figs. 20, 21 Cone-beam CT: cross-sectional image extrapolation from axial projection.
Fig. 22 Panoramic-like (NewTom program) (above) and axial images of the segment of interest with the cone-beam CT and reference points (red) (below).

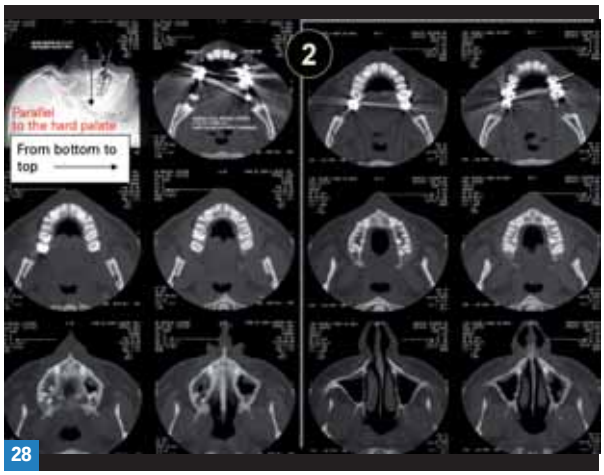






Figs. 23-25 Cone-beam CT scan report of the upper arch. **Fig. 26** Cone-beam CT: set of bucco-palatal sagittal projections to visualize the sinus pathology.





Figs. 27, 28 Fan-beam CT scan report of the upper arch, showing analogous results.

(Figs. 31, 32).
Figure 33 show all the axial references used for elaboration of the cross-sectional images of interest.
Figure 34 shows the cross-sectional slices of interest of Figure 35 in the axial projection, where the measurements and references for the identification and direction of the opaque marker, the mandibular nerve, and so on are indicated.
Figures 36–38 show the report of the mandible, both with the cone-beam and the fan-beam techniques. Unless a clear pathological condition of the jaw is present, the set of axial projections can usually be omitted from the report.
It is useful to stress that when a bifid mandibular nerve - of various configurations - is suspected, evaluation of the superficial bone with a 3D projection may be helpful (Figs. 39, 40).

The (already present) future

Within the sphere of CT imaging, we must emphasize that an accurate response is the result of a well-planned examination, which in turn is the fruit of constant and specific cooperation between dentist and radiologist.
More and more often, the complexity of the clinical cases requires that the radiological examination go beyond the bounds of the radiologist's report to form part of a comprehensive analysis that will culminate in a three-dimensional image to be used by the dentist. The final stereolithographic model (Fig. 41), obtained thanks to the standardization of methods, can be stored and retrieved in DICOM format (Digital Imaging and Communications in Medicine).
Similarly, the method of applying a reconstruction model to raw data is also evolving, making it possible to insert preoperative templates prepared based on the CT examination. This makes it possible to identify the bucco-lingual-palatal or mesiodistal implant placement directions using dedicated software, such as the recent SimPlant and Brånemark programs.
In this respect the dentist usually takes the place of the radiologist, according to his/her own clinical needs.
Of course, much more remains to be done. In particular, information on bone mineralization status is currently done in the form of punctiform recordings, whereas it would be more useful by homogeneous areas. The same holds true for the parameters pertaining to bone density, expressed as Hounsfield units (HU), ranging from negative values (air = -1000 HU) to very high values (compact bone = +1600 HU), and encompassing a very wide range of values within the Misch classification (4


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Fig. 29 Reference OPG of the lower arch, with two opaque markers.

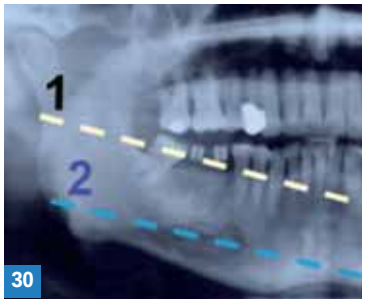

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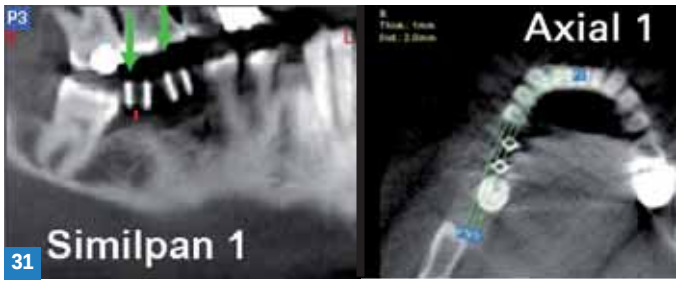
Fig. 30 OPG: diagram showing the choice of the two panoramic-like images of interest.



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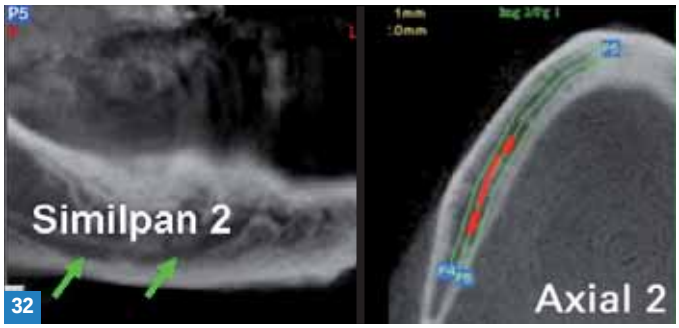

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Figs. 31, 32 Cone-beam CT: panoramic-like images and corresponding axial images.

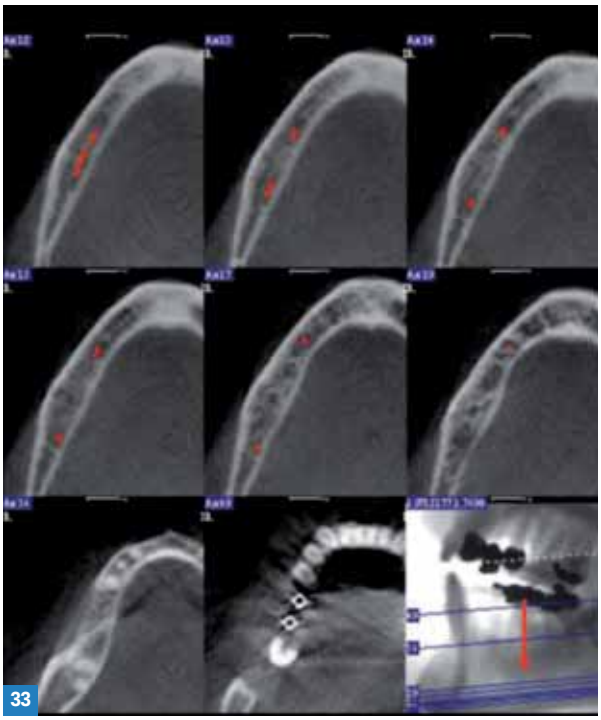
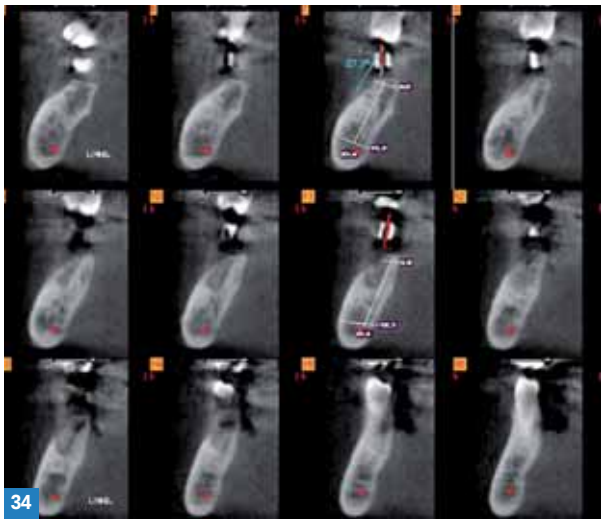
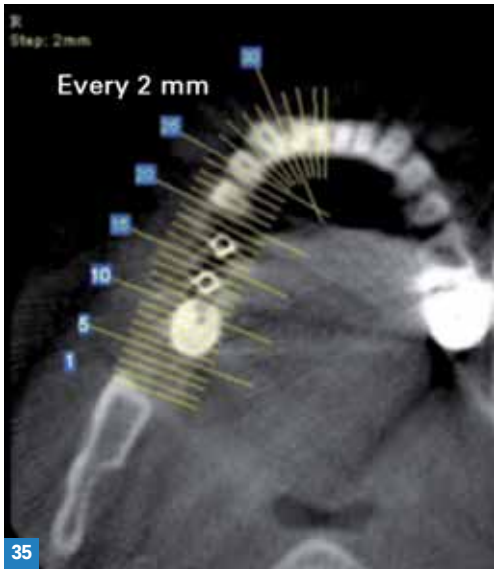


Fig. 33 All the axial images included in the segment of interest.

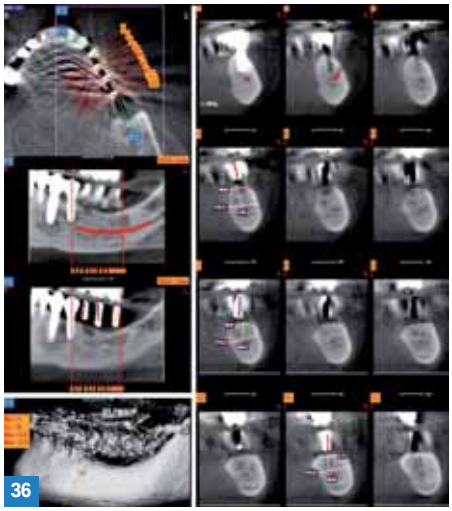
classes) or with smaller ranges of the gray scale, also derived from highly variable punctiform density values.

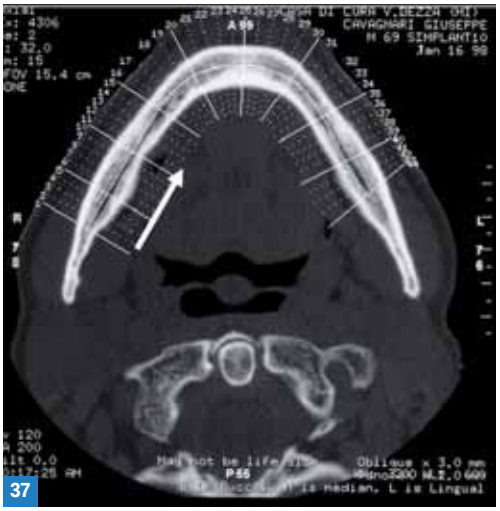
In conclusion, modern radiology gives dentists tools with a level of safety and precision that was once unimaginable. We can rightly state that the current achievements in the field of surgical implantology have made by taking giant steps hand in hand with radiology, which follows clinical indications to provide appropriate answers.

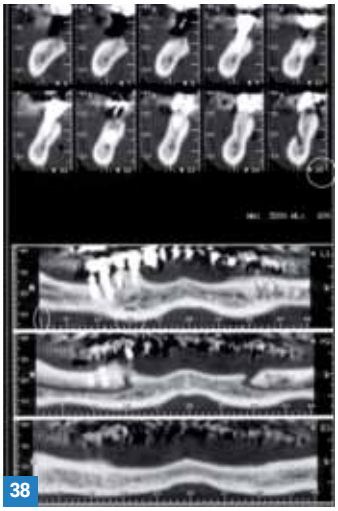




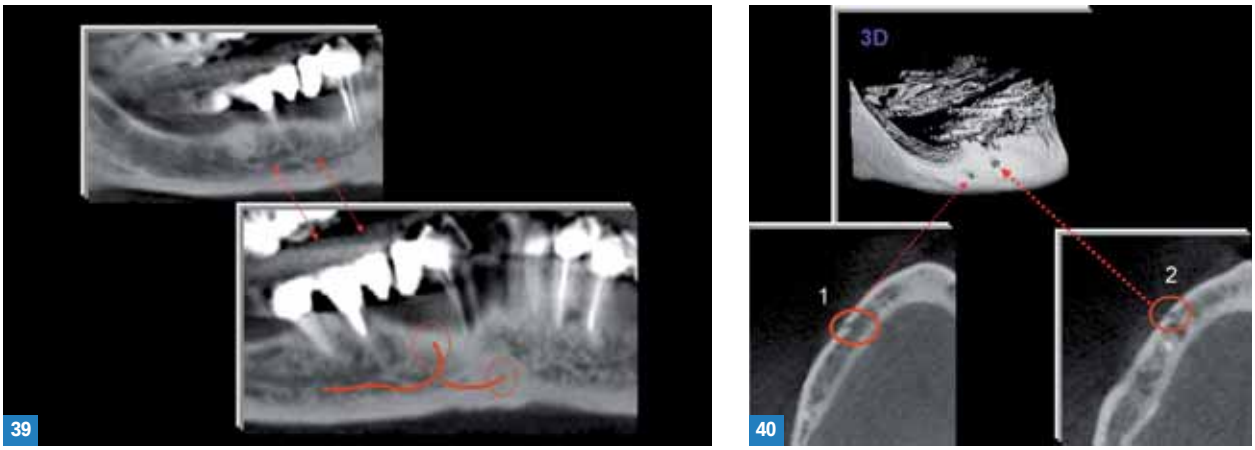
Figs. 34, 35 Cross-sections of interest in axial projection, showing the measurements and references for the identification and direction of the opaque marker, and the mandibular nerve.







Figs. 36-38 Cone-beam CT scan of the lower arch. Analogous fan-beam CT scan report.



Figs. 39, 40 Cone-beam CT, panoramic-like images and 3D image: the two buccal points of emergence of the mandibular nerve.

Fig. 41 Stereolithographic models.

Suggested readings

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