Computed tomography for implant planning

WHEN YOU NEED MORE INFORMATION FOR TREATMENT PLANNING - WHAT CAN YOU EXPECT FROM A DENTAL CT SCAN AND HOW CAN YOU MAKE BEST USE OF ITS POTENTIAL? MARK ATKINSON DISCUSSES

The most significant diagnostic aid to preoperative dental implant treatment planning remains Computed Tomography also known as the CT scan.

Dental implantology is probably the most sophisticated discipline in modern dentistry. Consequently, highly sophisticated diagnostic procedures are necessary, relegating traditional techniques such as ridge mapping and reliance on two-dimensional plain film radiography to a secondary role in the task of treatment planning.

Whilst the principles of CT scanning are relatively mature, the latest generation of equipment can acquire the images with greater speed and clarity, and more importantly, at reduced radiation doses. Over the last ten years the same image quality can be obtained at 60-80% lower radiation dose and whilst further reductions are likely to be less substantial, we can expect future progress to remove an extra 20-40% from the current levels (Figures 1a and 1b).

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Figure 1: 3-D view of edentulous mandible showing images of porcelain teeth

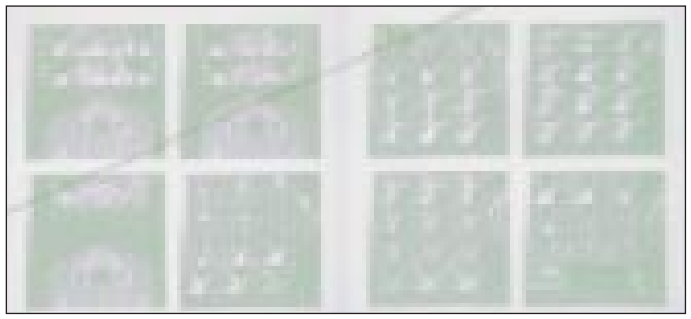
THE FOUR BASIC IMAGES PRESENTATIONS OF CT

Modern dental CT scanning, far from being a mysterious world in which axials, pixels and grey-scales rule, simply provides access to four basic image groups.

The first is the 3-D view (Figure 2), which provides useful information regarding form and size and can provide information showing the position of radio-opaque markers, superficial bony anatomy and remaining teeth.

Secondly, the data can be further cut and trimmed electronically to produce panoramic views (Figure 3) similar in some respects to a

Figure 1a: A modern CT scanner



Figures 1b: Traditional A3 sized film transparencies mounted on light boxes showing part of the CT data set

routine DPT. The main differences are that there is no distortion or magnification and the image is an actual cross-section, not a composite of the anatomy within a wide focal trough. Furthermore, the panoramic views are confined to the maxilla or the mandible and are normally presented in multiples covering the full width of the jaw.

Thirdly, and most importantly, are the cross-sectional views. It is from these that the ultimate observations regarding bone quality, implant size and angulation can be made typically by direct measurement, if they are presented in a life-sized format (Figure 5).

And finally, the original transaxial or axial slices from which the 3D, panoramic and cross-sections are created (Figure 4). Probably through unfamiliarity these are commonly neglected by dentists, but axial slices have been the backbone of CT since its inception in the early 1970s. Through their training, consultant radiologists have the ability to create 3-D, panoramic and cross-sectional views from the axial slices in their heads. You have no need to since the software does it all, and far more accurately.

Figure 2: An anterior 3-D view of the maxilla showing radio-opaque markers

Electronic images or prints

With the availability of software such as SIM/Plant and 3-D/Dental there is a choice between print or PC viewing. Traditional large transparencies can also be made but at Image Diagnostic Technology Ltd (IDT), we opted not to pursue this line since the large majority of dentists do not have suitable viewing boxes and images printed in this way are subject to considerable variation in quality and magnification (Figures 6 and 7) and 3-D/Dental prints being in hard copy format are consistent, compact and easy to use.

Figure 3: Panoramic view of the mandible clearly showing nerve canal

They are also simple to transport when planning with surgical or restorative colleagues.

If however, you want the full benefit of interactivity and want to place implants in a `virtual experience' then SIM/Plant has many attractions.

The diagnostic wax-up

A basic foundation of treatment planning is to prepare mounted study models and create a diagnostic wax-up (Figure 8) that reinstates the missing dental hard and soft tissues. Verify this in the patient's mouth and discuss with them relevant options such as whether the prosthesis be fixed or removable and the consequences of reduced hard and soft tissues as they relate to them (Figure 9).

Removing the pink wax from the buccal surface during this try-in stage can reveal many future pitfalls or may gain the acceptance of a patient simply because any aesthetic compromises are overshadowed by the benefits of fixed teeth.

In addition to giving the patient a greater understanding of their treatment, the mounted study models also allow measurement of the interarch clearance for the assembly of intraoral components and the relationship of the residual ridge to the opposing jaw.

By duplicating the diagnostic set-up in stone you can build a CT guide which is, in most respects, very similar to an acrylic mouthguard or bite plane. In the example shown (Figure

Figure 4: Transaxial view which form the original images

Figure 5: Cross-sectional view showing a radio-opaque outline of the missing tooth

> ***Scanning the patient parallel to the occlusal plane has many advantages***

Figure 6: A4 sized black and white image sheets with life-sized images of the region of interest

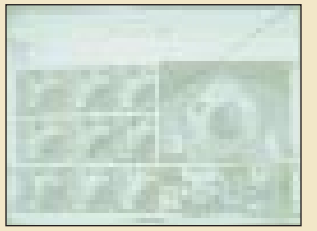


Figure 7: Interactive SIM/Plant images on the PC

10) the actual wax try-in was duplicated and converted to acrylic. If you are going to use a stone duplicate of the set-up, it may be necessary to remove some of the wax covering soft tissues areas so that the finished device can be stabilised by the soft tissues where required.

Radio-opaque markers

The important design features for a CT guide are generally that the facial and lingual surfaces of the missing units are fully covered and that the buccal flanges are over extended into the sulcus and about 3-4mm thick.

You can then place radio-opaque markers into the thickened buccal flanges and if the guide covers edentulous regions air spaces can be incorporated. The air spaces will produce a clear black outline visible on the cross-sections.

For greater clarity including radio-opaque materials within the tooth form or overpainting internally or externally with barium sulphate will enhance the outline of the crown in relation to the underlying bony ridge. Add to this markers in the buccal flange which positively identify the mesio-distal position of each proposed implant and you have virtually all the information you need to plan this aspect of treatment (Figure 11).

Buccal flange markers can be made from the following readily available materials: model stone, glass ionomer, composites, gutta percha (Figure 12).

I advice cutting a spherical hole into the buccal flange precisely aligned with the proposed implant site. The minimum dimensions should be a 2.75mm sphere and the largest should be no greater than the width of an average 3.75mm implant.

The minimum size ultimately depends upon how far apart the cross-sectional views are. Each cross-section represents an image layer of about 0.25mm and these are commonly 1 or 2mm apart. Therefore, if the marker is smaller than the distance between cross-sections, it is possible that it will not be visible on the final images (Figure 13). Conversely, the larger the marker is, the more of the cross-sections it will appear on - you will then need to choose the most central one.

When placing multiple markers it may be beneficial to place them in a coded arrangement. These will appear on the respective cross-sections and make it easier to identify each respective implant site (Figure 14).

Keep this type of marker beneath the alveolar crest wherever possible to avoid metallic artefact from adjacent restorations (Figure 15).

Where you also wish to include detail about the position of the crown in relation to the underlying ridge the external surface of the CT guide can be overpainted with a thin layer of barium sulphate powder (Figure 16). The needs to be sealed onto the guide with a resin varnish so that it is not washed off during the scan. For optimum results keep the barium sulphate layer as thin a possible. This is best achieved with a slurry of powder which is allowed to dry in situ before sealing (Figure 17).

Information flow - diagnosis through to prosthetics

Scanning the patient parallel to the occlusal plane has many obvious advantages once the geometry of the treatment and the diagnostic images is understood. Knowing how the plane of scan affects what you see and how it relates to a surgically exposed ridge is pivotal in the flow of information from

Figures 8: A typical diagnostic set-up for planned replacement of the missing upper left quadrant

Figures 9: Intraoral verification of the set-up including replacement of the missing soft tissues

> ***Stress repeatedly the importance of keeping completely still***

Figure 10: Diagnostic wax-up duplicated in acrylic to provide support for glass ionomer occlusal surface radio-opaque markers in the CT guide

diagnosis to prosthetics.

The diagnostic wax-up will have an occlusal plane and it is highly likely in the majority of cases that implants will have a clearly defined relationship to it. A CT guide made from the diagnostic wax-up includes the occlusal plane, therefore scanning parallel will lead to the generation of cross-sectional images that are at right angles to the occlusal plane. The cross-sectional views will be in exactly the same vertical orientation as our intended implant placements which is particularly beneficial if we are trying to minimise non-axial forces on our implant supported restorations.

Furthermore, if the CT guide is designed appropriately it can be converted to a surgical guide maintaining the continuity of information and enabling completion of the treatment sequence (Figure 13).

Hollow acrylic CT guides will create black outlines on the images where air spaces are present and convert easily to surgical guides. The buccal flange marker accurately identifies the mesio-distal location of the implant site on the cross-sectional images.

Sending your patient for a CT scan

When sending patients for a CT scan we would all like to receive results that clearly show where each implant should go, how long and wide it should be, at what angle, which system would be best, and where is the sensitive anatomy. Sadly, nothing is ever that simple or complete, - and CT is no exception. It is only with experience or by careful discussion with more experienced colleagues that we can hope to answer some of these questions before the surgical phase.

We have a tradition in dentistry for 'treatment planning as we go' and for much of our simpler work this is perfectly adequate. Dental implants are not simple and are accordingly, far less tolerant to this ambivalent approach (Figure 18). Indeed, when incorrectly positioned they serve as very immovable reminders of poor planning or technique.

Although the number of patient variations is limitless, this article aims to provide the reader with a few simple clinical guidelines showing what additional preparation is recommended and how it will ultimately benefit treatment.

Patient preparation

Assuming our patient has general and dental health compatible with implant treatment - how can we improve our treatment

TABLE 1:

THE DIFFERENCES BETWEEN SIM/PLANT FOR PC AND 3D/DENTAL PRINTS

3D/Dental	SIM/Plant
3D, panoramic, cross-sections and axial views	Panoramic, cross-sections and axial views (No 3D views)
Results presented on A4 black and white prints	Added functionality of image enhancement to help visualise complex anatomy, marking the ID canal or other vital anatomy with a colour pen, placement of implants from a variety of manufacturers including components
Photographic quality allowing direct measurements from life-sized images	Bone dimensions, density and restorative angle can be measured on-screen
No start-up costs.	High start-up costs - but definitely the future of modern dental CT imaging
	Screen Views of treatment plan can be printed with your Laser Printer (these printouts are for reference only, not diagnosis since the image quality is reduced by most laser printers when compared to the screen image).

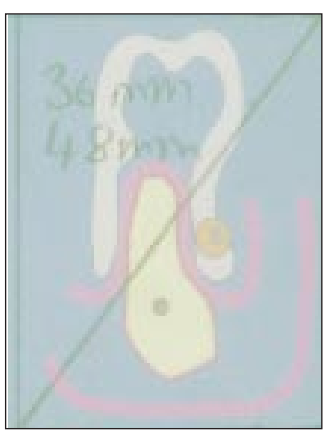
Figure 11: Image created by the CT guide in the 3D views

planning and diagnosis?

The simple answer is `Preparation.' Whether you want images on transparencies, paper or on your PC, it is preparation that will unlock the true potential of CT. Successful CT requires the referring practitioner to understand what he or she would like to know and how this information can be enhanced - for example by the construction of custom made diagnostic guides to provide tooth position indices.

It has been said many times by many people that, 'implant dentistry should be prosthetics driven'. This has certainly never been more true and the desired effect can easily be realised by creating a replica of the required result and then working methodically backwards to determine how implants should be applied.

Figure 12: Hollow acrylic CT guides will create black outlines on the images where air spaces are present and convert easily to surgical guides. The buccal flange marker accurately identifies the mesio-distal location of the implant site on the cross-sectional images



PATIENT INSTRUCTIONS

Ensure your patient is familiar with the procedures involved and stress repeatedly the importance of keeping *completely still* for the duration of the scan, which can take anything between 30 seconds and 10 minutes to complete depending on the type of scanner.

Ensure your patient is provided with a suitable means to maintain their jaws in a fixed relationship during the scan. This can be achieved in one of the following ways:

- Using existing teeth to provide interarch stability
- Wax bite blocks adjusted as for a routine jaw registration
- Use patients' own dentures provided that there are no metal clasps, metal reinforcements or chrome-cobalt bases
- Custom made diagnostic guides as described.

PATIENT POSITIONING

Good scans are the result of clear instructions to the radiographer and careful technique by trained staff. The dental CT is one of the most exacting procedures that radiographers undertake and attention to detail is essential. Modern computing techniques can create excellent image quality but are ultimately only as good as the original data and communication between staff and dentist.

It is very important to instruct the radiographer how to position the patient in the correct Scanning Plane which may be:

- Parallel to the occlusal plane. Suitable for the maxilla or the mandible.
- Parallel to the hard palate. Frequently this is identical to the occlusal plane. It is highly visible on the radiographic scout views that are used for final positioning before the actual scanning sequence.
- Parallel to the lower border of the mandible. Much less commonly used but is recommended if the patient

Figure 13: A cross-sectional image from the same patient through the region of the first premolar confirmed by the two marker spheres located in the buccal flange of the CT guide

Figure 14: Multiple marker code which can be adapted or modified to suit each particular situation. These would routinely be placed in the buccal flange of an acrylic duplicate of the original diagnostic set-up

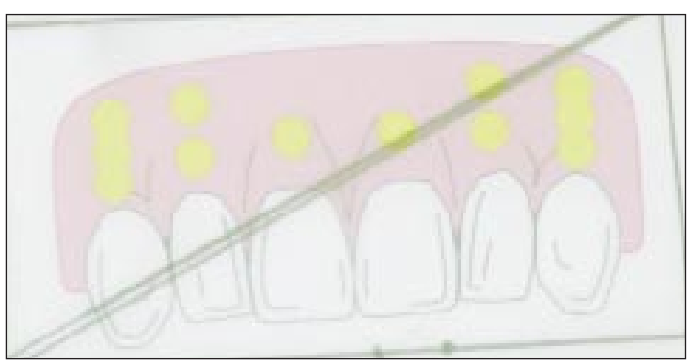


Figure 15: A simple radio-opaque marker incorporated in the thickened buccal flange of an acrylic CT guide

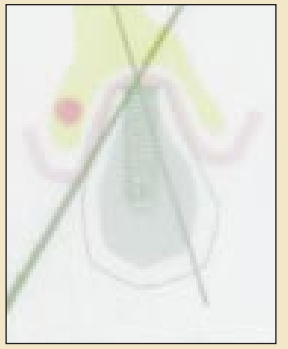


Figure 16: A radio-opaque marker (red) incorporated in the thickened buccal flange of an acrylic CT guide in conjunction with the external surface overpainted with barium sulphate

has a very steep angle of mandible. Commonly the lower border of mandible and the occlusal plane are not coincident.

The occlusal plane is always the preferred patient alignment for a dental CT scan for the reasons outlined in the next section (Figure 19).

The main advantage of scanning parallel to the lower border of the mandible is that it generally results in slightly fewer axial slices to cover the region of interest.

Minimal or optimal preparation

The choice of patient preparation ultimately depends upon the requirements of each individual case (Figure 20). However, we should be clear that when adopting a `minimal approach' there is a significant loss of important visual and positional data which cannot be added retrospectively. In many situations some of the information that could have been included within a CT guide can be calculated by carefully studying the images, however this is considerably more time-consuming and can result in operator error.

The construction of a simple CT guide with radio-opaque markers is highly recommended because radio-opaque markers:

•Always enhance the diagnostic yield from a CT scan

•Help identify the position of an implant within the arch

•Save time and are definitely worth the effort!

•Remaining teeth and roots are highly effective radio-opaque markers

•With simple attention to design, the CT guide can be adjusted after the scan to create a surgical guide.

Converting a CT guide to a surgical guide

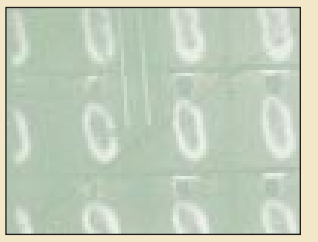


Figure 17: Barium sulphate profiles of missing mandibular molars. The absence of buccal flange markers means that the centre of the proposed restoration is less clear

Figure 19: Patient positioned correctly with the plane of scan parallel to the occlusal plane. The cross-sectional and panoramic images are reconstructed at right angles to this axis

Figure 18: Preoperative diagnostic wax-up to focus the treatment planning on the desired result and to address issues such as lip support and aesthetics

Figure 20: Mounted study models reveal information about the interarch clearance and the relationship of the edentulous ridge to the opposing teeth

The basic requirements of a Surgical guide are:

• It will locate positively in the mouth during surgery

• It will not interfere with flap design and retraction

• If possible, the guide can be inserted when a mouth prop is in place

• The surgical guide should provide sufficient information about the buccal and or lingual surfaces of the intended crown form

• It should also allow access through the occlusal surface for drilling the implant site.

The CT guide previously described fulfils very few of the above criteria but with simple modification can become a valuable tool for accurate surgical technique (Figures 21 & 22).

TABLE 2:

THE CT GUIDE HAS SEVERAL IMPORTANT FUNCTIONS:

- To provide interarch stability and occasionally separation of the opposing jaws where a deep overbite is present
- To provide a solid device into which radio-opaque markers can be incorporated
- When carefully designed the CT guide can be converted to a Surgical guide, thereby reducing treatment costs and ensuring an accurate continuity in the flow of diagnostic information

Figure 21: Mandibular CT guide with buccal flange markers aligned with the second premolar and first molar

Figure 22: Mandibular CT guide seperated from the occlusal coverage on the left along with removal of the buccal and lingual flanges. The centre section is then prepared with holes through the occlusal surface for drill access

Simply remove the buccal flange containing any radio-opaque markers leaving only the acrylic representing the buccal and lingual coronal surfaces of the edentulous areas. If you are dealing with a partially dentate situation, section the acrylic so the guide can be placed without having to remove the mouth prop during surgery, and ensure that you leave enough tooth support and engagement of undercut for the guide to snap securely into place. If possible, test the guide before surgery to verify it is performing correctly. Lastly, remove sufficient acrylic through the occlusal surfaces to leave adequate space for any of the drill steps you may wish to perform. Also, ensure adequate clearance so that particles of acrylic are not carried into the surgical site during drilling. Finally, sterilise the guide prior to use.

Radiation aspects

Most medical or dental procedures have risks as well as benefits associated with them and dental CT scanning is no exception. Roughly speaking a dental CT scan produces a radiation dose equivalent to between five and 10 full mouth (14 film) periapical sets taken with E-speed film.

Current medical statistics suggest that the estimated risk of developing fatal cancer from a CT scan using an average low dose protocol is highest for a 20 -year-old male at 1:20,000 and is lowest for a 65-year-old female at 1:200,000. The cancer risk is slightly higher for the maxilla. By way of comparison, smoking 10 cigarettes or driving 250 miles in a car carries a fatality risk of 1:20,000. Current medical statistics suggest that one in three of the population will develop some form of cancer during their life-time due to the combined effects of genetics, background radiation, environmental factors, medical and dental exposure.

In a dental CT scan the whole body dose equivalent received by the patient is primarily affected by the number of axial slices taken to cover the region of interest which is dependent upon the patient's jaw size and whether or not teeth or CT guides are being imaged.

It is possible to perform a dental CT scan using much lower exposure factors than would be used for a routine diagnostic procedures such as a brain scan. A routinely used scanning technique is 1mm axial slices taken at 1mm increments, with an average jaw requiring 30-35 slices.

Requesting that the radiographer images the coronal portion of the teeth to include radio-opaque markers will increase the radiation by up to 30% through adding another 8-10 slices to the diagnostic set. Other factors which affect the number of slices will be directly related to the size of the patient's maxilla or mandible.

Full height of teeth + alveolar ridge + basal bone requires the maximum number of axial slices (Figure 23).

Alveolar ridge and basal

Figures 25 and 26: Metallic artefact obscuring the image on the left can be significantly reduced using proprietary software during image processing

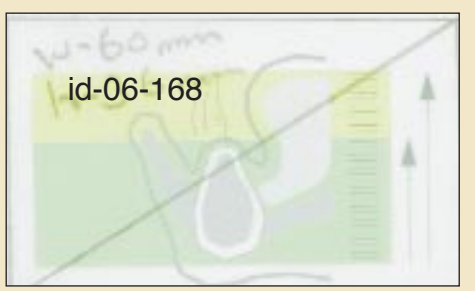
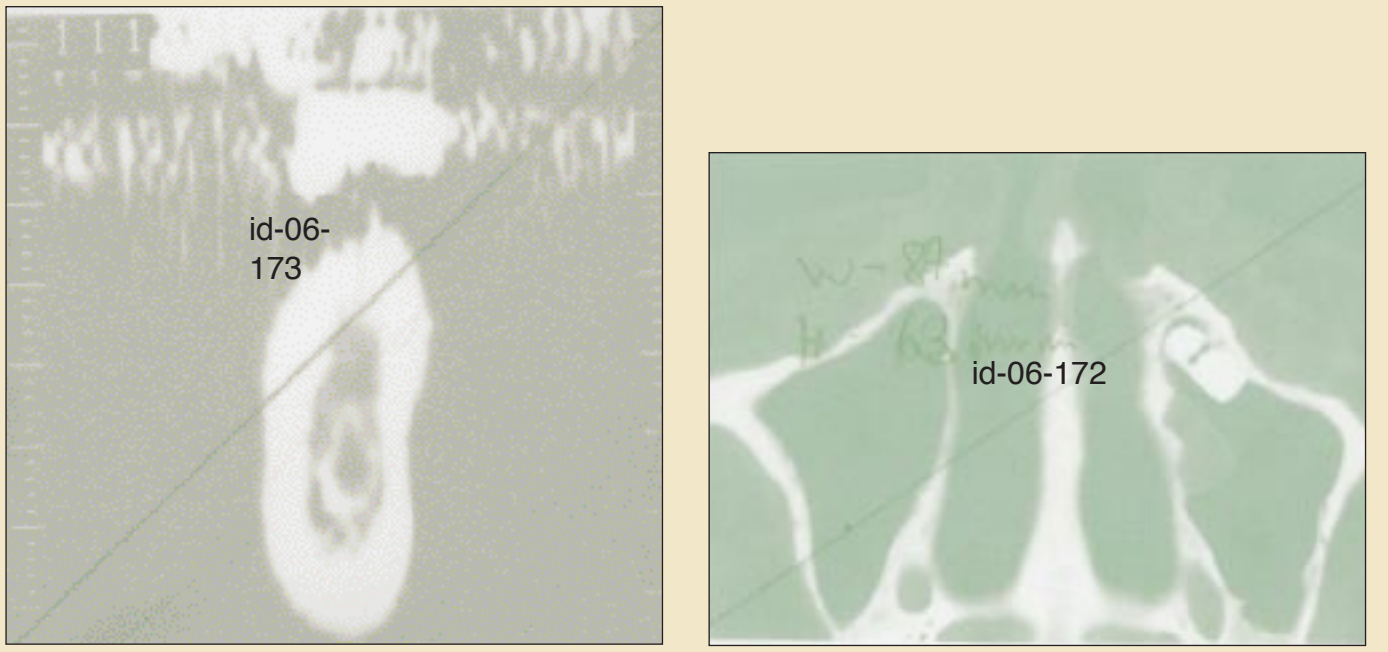


Figure 23: A typical cross-section through an edentulous mandible showing how the radiation exposure is increased when the scan includes teeth or radio-opaque markers within the coronal region

Figure 24: Radio-opaque marker (red) located at or below the crest of the ridge will not increase the number of axial slices and provide valuable information with reduced radiation exposure



Figures 27 and 28: The image on the left shows artefact from adjacent metal restorations directed above the alveolar ridge when the patient is positioned correctly. The image on the right shows that minimal artefact is produced when loking at titanium, in this case an implant displaced into the maxillary sinus

bone requires the minimum number of axial slices (Figure 24).

If radio-opaque markers are included beneath the crest of the ridge using the buccal flange concept they have no effect on the overall number of axial slices required to image the jaw and appropriately are the most radiation sensitive way of scanning a patient.

Metallic artefact

Metallo-ceramic restorations and large amalgam fillings may obscure detail at the level of the occlusal plane but rarely affect detail beneath the alveolar crest - the main exceptions are large gold or precious metal alloy posts which can cause localised loss of image detail.

The effects of artefact can be removed to some extent through IDT's proprietary image processing techniques. Artefacts are always more pronounced on the axial slices (Figure 26). Construction of the reformatted images involves algorithmic procedures which minimize the artefacts in the final images. For these reasons, even datasets with severe artefacts in the Axial slices rarely result in unusable 3-D, panoramic and cross-sectional views (Figure 27 left).

Titanium and titanium alloy do not produce artefact on images. They are clearly visible in healthy or compromised situations (Figure 28 right).

Summary

This article is intended to give the reader an overview of the potential benefits and pitfalls of CT scanning when used for diagnosis and treatment planning. In no way should this be considered a definitive guide to the principles and practices involved. ■

References

Dula K et al (1996). Hypothetical mortality risk associated with spiral computed tomography of the maxilla and mandible. European Journal of Oral Sciences **104**: 503-510

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