CT scanning for dental implantology

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Abstract

Modern dentistry involves a number of complex procedures, such as implanting artificial teeth directly into the bone, which require detailed pre-surgical planning. The purpose of this planning is to determine whether the quantity and quality of bone is sufficient to provide anchorage for a serviceable restoration, and to avoid damaging sensitive structures such as nerves. Pre-surgical planning must be based on highly accurate imaging to be effective.

Computed Tomography (CT) is increasingly employed to plan dental implant surgery because of its accuracy, sensitivity, and freedom from geometrical distortion. The latest generation of CT scanners can image the complete mandible or maxilla in under one minute, delivering high spatial resolution in both the transaxial and the paraxial directions at modest radiation doses.

1. INTRODUCTION

1.1 Dental Implantology

Dental implants are, in effect, titanium roots placed directly into the bone of the jaw to support replacement teeth. An average sized implant is around 3.5mm in diameter and 12mm in length. The dentist or surgeon placing the implant needs to determine whether or not there is enough bone of adequate consistency for long-term function and stability. The images that can be generated from reformatted CT scans provide exactly that information.

Dental implantology holds out the promise of permanent restoration of the edentulous or partially edentulous mouth to near-original condition. It is the next best thing to "getting your own teeth back". However, this precise and sophisticated technology requires careful planning, based on highly accurate imaging, to be effective[6].

To be successful, implantology requires both permanent integration of the titanium fixture into the bone, and a good aesthetic restoration of the teeth and gums. Involving the implant surgeon, the restorative dentist and the dental laboratory technician in the detailed pre-operative planning is therefore extremely important.

The implantology team uses pre-surgical imaging to indicate the following:

- *where each implant should go*
- *how long and wide it should be*
- *at what angle it should be inserted*
- *whether the bone quality (eg its density) is sufficient*
- *which system of prosthetic restoration hardware would be the most appropriate*
- *where the sensitive anatomy is located.*

Dental implants have raised new hopes in patients who find normal dentures unacceptable or inconvenient. Biting and chewing with successful implants is the same as with normal teeth. Depending on the patient's physical and psychological state, implants may be suitable for fully edentulous patients or for partial edentulousness such as one or two teeth missing after trauma. Unlike conventional bridges, no natural teeth have to be destroyed during the procedure or included in the solution.

In cases where the patient exhibits extreme resorption or the quantity or quality of natural bone is insufficient, bone grafts can be used to build up the implant site. Once the implant has been placed and allowed to heal, it becomes firmly embedded in the bone (a process known as osseointegration).

Successful implants require a commitment to life-long maintenance both from the osseointegration team and from the patients themselves. Patients typically receive regular check-ups involving several intra-oral radiographs a year. If complications occur, they are usually manifest during the first 12 months; after that complications are quite rare.

1.2 Dental implant systems

The earliest dental implant system was developed by Professor Per-Ingvar Brånemark in Gothenburg, Sweden, in the early 1950's, and implant fixtures and the matching prosthetic hardware have been available commercially since 1978[1]. Brånemark pioneered a two-step procedure in which the titanium fixture is embedded into the bone first, under local or general anaesthetic, and an abutment connection is made as much as six months later to support the final restoration.

To install the titanium fixture, an osteotomy is established using successively wider spiral drills. The drilling must be carried out slowly to avoid bone necrosis due to heat. The drilled site is tapped to create threads congruent with the implant fixture. The implant is then installed, a temporary cover screw is fitted, and the mucous flap is sutured back over the fixture to promote healing and osseointegration.

At abutment connection time, the surgeon exposes the mucosa above each fixture, removes the cover screw and attaches the abutment cylinders which project through the gum. The final prosthodontic restoration may require the fabrication of a metal framework or bridge prosthesis to which teeth and soft tissue analogues can be added.

In contrast to Professor Brånemark's pioneering work, some of the most recent implant systems make use of "trans-mucosal implants" which are designed for single-step installation. When these titanium fixtures are embedded into bone, part of them sticks up through the soft tissue of the gum. The embedded portion has a roughened surface to promote positive osseointegration, whereas the trans-mucosal portion has a smooth surface which discourages bony attachment.

Modern implant systems use "sculptured" healing abutments which mimic the gingival margins of natural teeth, thus encouraging the mucosa to grow back with an appropriate shape. This ensures that the gums align correctly with the emergence profile of the final restoration, producing an excellent cosmetic result.

2. THE CT-BASED IMPLANT PLANNING PROCESS

In the early days of dental implantology, the surgeon would often drill and insert implants wherever he could find adequate bone, without regard to the engineering aspects of the artificial teeth that must be supported and the occlusal (biting) forces that would ultimately be applied. Nowadays it is recognised that the implant locations should be chosen to provide the optimal support for the desired final restoration; bone thickness can be built up with bone grafts where necessary. "Create a model of the desired result, then work backwards to determine how it can be achieved" is today the rule of thumb.

2.1 The stone model

Taking this maxim quite literally, a mock-up of the final restoration is made from a "stone model" replica of the patient's mouth and the remaining teeth. The stone model is produced by taking a dental impression which in turn is used to produce a plaster cast. An acrylic plate with coloured wax representing the missing hard and soft tissues is then accurately fitted to the model.

2.2 The CT scanning guide

Once the desired restoration has been decided upon, a CT scanning guide can be prepared. The CT scanning guide is based on the stone model and is similar to the acrylic mock-up plate, but serves the following additional purposes:

- *provides positive stabilisation of the lower jaw, so that the patient will be able to keep entirely still*
- *indicates to the radiographer how the scanning plane should most appropriately be aligned*
- *indicates radiographically the position of the desired implant sites.*

The CT scanning guide differs from the acrylic mock-up plate in that some of the analogues of the patient's existing teeth and soft tissues may have to be excluded to ensure a proper fit. Also, the CT scanning guide may have elongated buccal flanges, extending into the sulcus and about 3-4 mm thick, as these are a convenient place to insert radiopaque markers[2].

2.3 Radiopaque markers

The position of the desired implant sites can be indicated radiographically in one or more of the following ways[3].

- *small radiopaque markers approximately 3mm in diameter and made from model stone, glass ionomer or gutta percha can be inserted into the thickened buccal flanges to indicate the mesiodistal position of each proposed implant. These markers will show up clearly on the CT images.*
- *the external surface of the CT scanning guide can be painted with a thin barium sulphate paste and sealed with a resin varnish. This will provide detail about the desired position, size and orientation of the crowns in relation to the underlying bony ridge.*
- *air spaces can be used to indicate the position of missing teeth, as they will produce black outlines clearly visible on the axial slices and reformatted cross-sectional images.*

The radiopaque markers must be large enough not to fall between the reconstructed cross sections (which are typically 1-2mm apart) and should be no larger than a typical implant (otherwise they will show up on too many cross-sectional images). Multiple markers can be placed in a coded sequence to assist in subsequent identification. Markers placed in the buccal flange below the alveolar crest are less likely to be obscured by artefact from metallic restorations.

2.4 Converting the CT guide to a surgical guide

Once the CT scan has been taken and the desired implant locations have been verified, the CT guide can be converted to a surgical guide relatively easily.

The purpose of the surgical guide is to communicate to the surgeon precisely and accurately where the implants will be required. This is best done by incorporating pre-drilled pilot holes into the surgical guide - effectively constraining the drilling options at the time of surgery.

The basic requirements of the surgical guide are as follows:

- *should locate positively in the mouth during surgery*
- *should not interfere with flap design and retraction*
- *should be capable of being inserted when a mouth prop is in place*
- *should allow access through the occlusal surfaces for drilling the implant site*
- *should provide information about the buccal and lingual surfaces of the intended crown form.*

The CT guide can be modified to achieve these objectives by simply removing the buccal flange with its radiopaque markers[2]. If necessary, the guide can be divided into sections, so that it can be inserted and removed during surgery when a mouth prop is in place. Pilot holes should be made for any drilling to be performed. Finally, the guide must be sterilised prior to use.

3. THE CT SCAN AND ITS DERIVED IMAGES

3.1 The lateral scout view

The lateral scout view, sometimes called a "scan projection radiograph" (SPR) or "alignment image", is typically acquired by moving the CT table and patient smoothly through the gantry while the x-ray tube and detectors remain fixed at the "three o'clock" or "nine o'clock" position. The resulting projected image (similar in appearance to a conventional radiograph) provides an overview of the patient's anatomical landmarks and establishes the region to be scanned precisely. The radiographer uses the lateral scout view to ensure the following [**figure 1**]:

- *that the patient is not rotated or misaligned laterally in the gantry*
- *that the scan plane is in keeping with the referring dentist's or surgeon's instructions*
- *that the volume to be scanned encompasses the required bony anatomy and radiographic markers with the minimum number of axial slices.*

If the patient's position needs to be adjusted, then the lateral scout view will need to be repeated to ensure that it is consistent with the axial slices.

3.2 Axials

These are the basic CT images from which the panoramics and cross sections are generated using special "dental software"[4,5]. The axial slices are the "gold standard" on which to look for abnormalities such as tumours, osteomyelitis, empty tooth sockets or retained root tips.

3.3 Panoramics

Computer-generated panoramics are similar in appearance to conventional orthopantomographs (OPGs) but represent thin sections through the bone, customised to follow the contours of an individual maxilla or mandible [**figure 2**]. The panoramics are generated at right angles to the plane of the original axial slices and are useful for locating anatomical landmarks such as the inferior dental canal, the incisive canal, and the maxillary sinus. About 5-10 panoramics spaced 1-2mm apart and generated from a stack of closely-spaced axial slices should be sufficient to cover the entire jaw.

Computer-generated panoramics differ from conventional OPGs in that the image is a true cross-section, not a projection, and there is no magnification or distortion. Consequently, they can be printed out life-size for direct measurement.

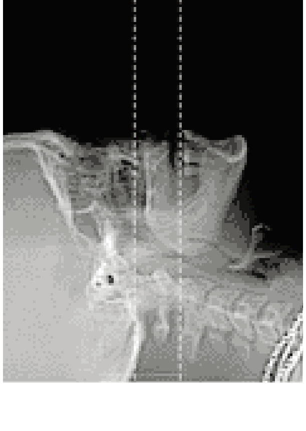


FIGURE 1
Lateral scout view showing patient positioned correctly for a maxilla scan.

3.4 Cross sections

These computer-generated images are reformatted in planes cutting across the maxillary or mandibular bone, at right angles to both the panoramics and the original axial slices [**figure 3**]. Cross-sectional images are in general the most useful views for planning implant placement, as they provide the surgeon with the cross-sectional width of the implant site, together with an indication of bone quality.

Cross-sectional images, like panoramics, can be printed out life-size or explored electronically with special computer software such as SIM/Plant (Columbia Scientific Incorporated, Columbia, MD 21045, USA). Decisions regarding bone quality, implant size and angulation can then be made directly.

3.5 Three-dimensional (3D) views

These computer-generated images provide a useful overview of the bony architecture of the patient's mouth, complete with the positions of radio-opaque markers and/or the remaining teeth [**figure 4**]. They can be helpful in understanding structures that vary significantly in three dimensions (eg the floor of the maxillary sinus).

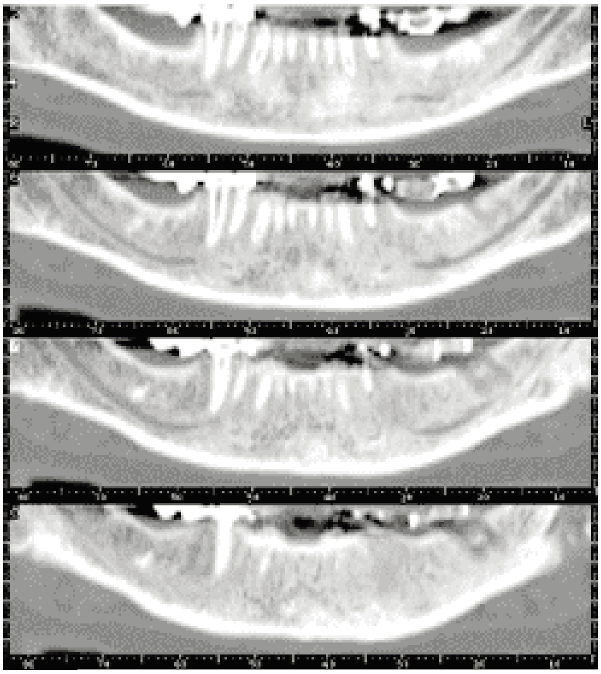
3.6 Electronic images versus prints

SIM/Plant, first introduced in 1993, is a pre-implant planning software package designed to run on a Personal Computer (PC) under Windows(r)95/98, that combines the accuracy of CT with the power of computer-aided design (CAD). The operator can insert (simulated) implants directly into the (imaged) bone and view them in their final desired positions [**figure 5**]. Advantages of this approach include:

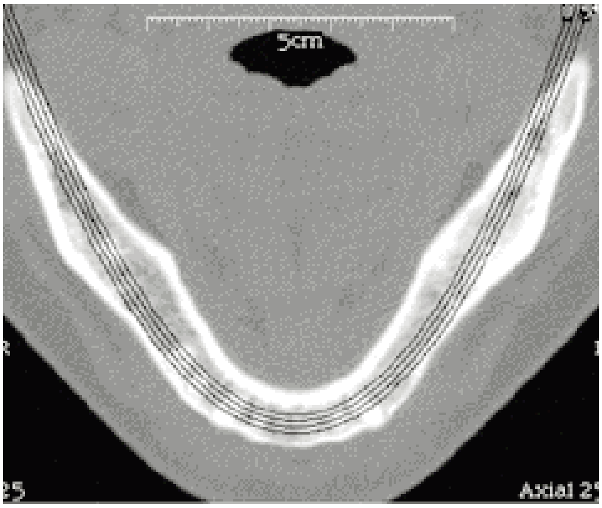
- *accurate distance, angle and volume measurements*
- *bone density calculations based on CT numbers*
- *access to the full range of contrast (ie the CT numbers)*
- *ability to trace difficult-to-see anatomy (eg the inferior dental nerve) by highlighting it in colour in one set of images and having it automatically highlighted in the others*
- *selection of various implant hardware and abutment types*
- *calculation of the biting forces and how they will affect the implant*
- *determination of bone graft volume needed for ideal implant positioning*
- *direct determination of implant-related parameters such as subgingival depths, crown heights, horizontal cantilever, prosthesis/implant ratio, and transitional emergence angle.*

4. HOW TO GET PERFECT SCANS EVERY TIME

Dental CT scans are designed for the pre-operative assessment of patients who are or may be candidates for the placement of dental implants. The images are required for "treatment planning" rather than diagnostic purposes. Accurate patient positioning and strict adherence to a pre-



(a)



(b)

FIGURE 2a and b
(a) Panoramic images reformatted from a stack of axial slices. The inferior dental canal is clearly visible. (b) One of the corresponding axial slices.

scribed protocol is, therefore, of primary importance; obtaining diagnostic-quality images which are free from noise or artefact is secondary.

The radiographer's responsibility is to provide the transaxial images of the region of interest, which will be either the maxilla or the mandible. The transaxial slices are then post-processed using suitable software to convert them into panoramic, cross-sectional and 3D views. A number of dental software packages are available for this task. Some of these run on the CT scanner itself; others are designed for independent workstations or stand-alone Personal Computers.

4.1 Patient preparation

Before commencing a dental CT scan, ask the patient to remove any metal dentures, false teeth or braces, and also any jewellery which might interfere with the region to be scanned. If they have been provided with a CT scanning guide, they should be asked to wear it, as directed by the referring dentist or surgeon. If the patient has plastic (non-metal) dentures they may be worn during the scan.

Align the patient and ensure there is no rotation. This is important so that the reformatted images will be as symmetrical as possible. Remember, it is the region to be scanned (maxilla or mandible) that must be straight - the alignment of the rest of the head is unimportant.

Centre the region of interest on the patient's maxilla or mandible (not on the centre of the head). This may require setting the table at its lowest position.

4.1.1 Keep the jaws in a fixed relationship

It is very important that the patient is able to keep their jaws firmly and positively related to one another during the scan. This is achieved with a CT scanning guide, the patient's own (non-metal) dentures or by the relationship of the remaining teeth.

If none of the above is available at the time of the scan and you consider that the patient needs some additional stabilisation between the jaws, you can have the patient bite down on a tongue depressor wrapped with gauze.

When scanning the mandible it is especially important that the lower jaw should not move with respect to the rest of the head. The jaws can normally be scanned closed, unless a deep overbite is present, in which case the jaws may need to be separated - especially if artefact from metal restorations in one jaw might interfere with the images of the other.

4.1.2 Instruct the patient to keep entirely still

It is very important that the patient remains entirely still for the duration of the scan (which may take from 25 seconds on a spiral scanner to over 10 minutes on older machines). Dental packages make use of the positional relationship between one slice and the next, as well as the relationship between the lateral scout view and the axial slices. Therefore, the patient must not move or be moved (other than by moving the scanner table) from the start of the scout view until the final axial slice has been acquired.

Advise the patient to remain completely motionless during the entire scanning procedure. Normal breathing will not adversely affect the study; however, any motion of the head including swallowing can diminish the image quality, possibly to the point where the images cannot be used. Tell the patient not to fall asleep since this may cause motion such as jerking or involuntary opening of the mouth.

4.2 Choosing the scanning plane

The CT scanning guide may have a "proposed scanning plane" marked on it with radiopaque gutta percha - in which case it is highly likely that the surgeon intends to insert the implants with a clearly defined relationship to this plane (eg at right angles to it). Since the reformatted panoramic and cross-sectional views will be at right angles to the scanning plane, this means that the cross-sectional views will have exactly the same vertical orientation as the intended implant placements. This helps ensure that non-axial biting forces on the implant-supported restorations will be minimised.

It is the referring surgeon's responsibility to indicate the desired scanning plane (either by oral or written instruction or by marking it on the CT scanning guide), as this depends on the architecture of each individual patient's moutah. The specification will generally be to scan parallel to the occlusal plane, the hard palate or the lower border of the mandible.

The patient should be positioned so that the scanner gantry is parallel to the plane that the referring surgeon has indicated. The best reformatted image quality is gen erally obtained if this is accomplished by adjusting the patient and not by tilting the gantry. In fact, some dental packages will not accept axial slices acquired with a non-zero gantry tilt.

4.2.1 The occlusal plane

The occlusal plane is defined by the biting surface of the teeth (either the existing teeth or those to be restored). On a lateral scout view image, the occlusal plane can be estimated from a line joining the back of the molars to the tip of the incisors. If the patient is completely edentulous, then only the dentist knows where the occlusal plane will be!

If the jaws are closed, then a line passing between the biting surfaces of the upper and lower teeth will be the correct occlusal plane for both jaws and the patient need not be repositioned between maxilla and mandible scans. However, if the jaws are not closed, there may be different "occlusal planes" for the mandible and the maxilla and the patient will need to be positioned for each jaw separately.

4.2.2 The hard palate

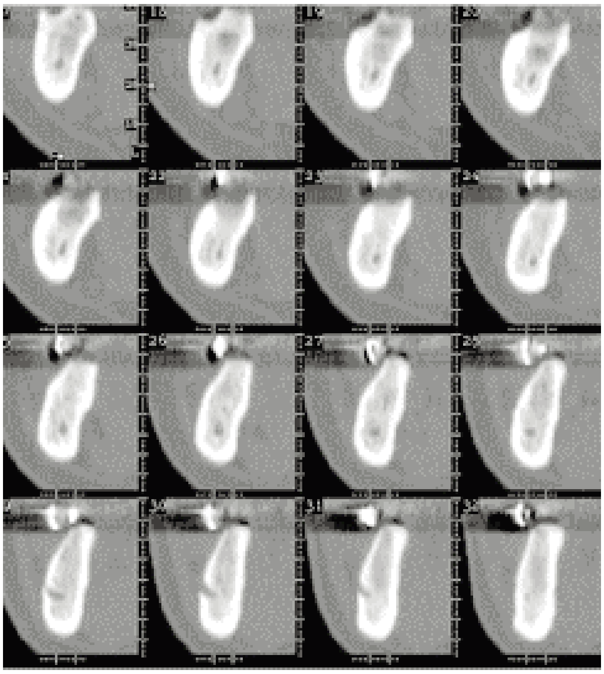
Occasionally the surgeon will request the scan to be taken parallel to the hard palate as this gives the most accurate assessment of its bony content. The hard palate can usually be visualised without difficulty from the lateral scout view [**figure 1**].

4.2.3 The lower border of the mandible

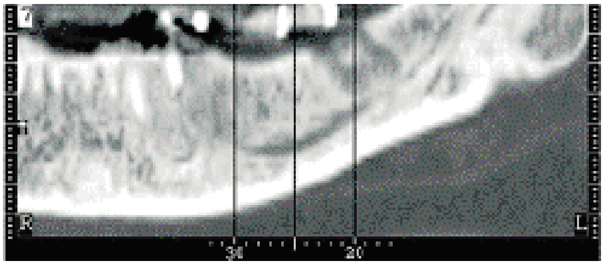
The lower border can usually be assessed either visually or from the lateral scout view. The main advantage of scanning the mandible parallel to its lower border is that this generally results in fewer axial slices. Sometimes, the inferior dental canal and its associated nerve bundle are visualised better on mandible scans taken parallel to the lower border.

4.3 How many axial slices?

If the patient has been provided with a CT scanning guide, this may contain radio-opaque markers. Make sure



(a)



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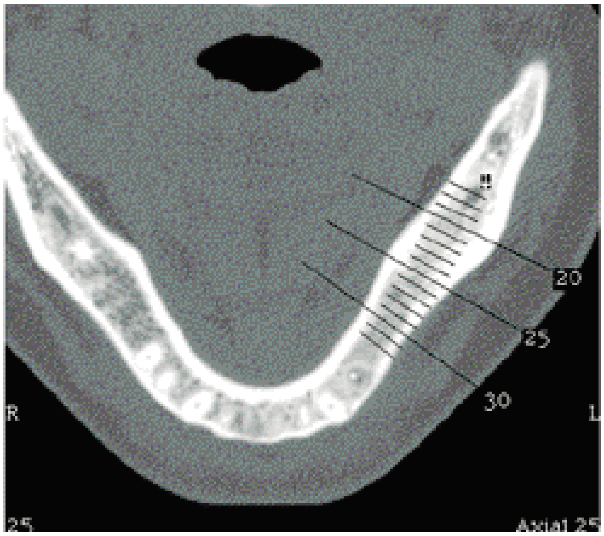

(c)

FIGURE 3

(a) Cross-sectional images reformatted at right angles to both the panoramics (b) and the axials (c).

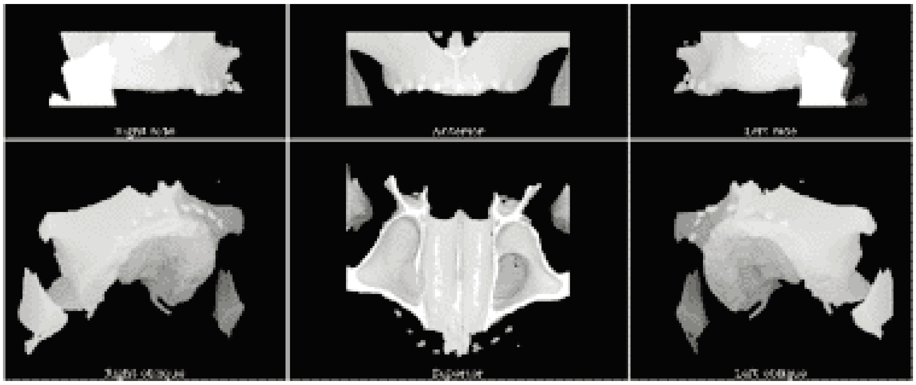

FIGURE 4
Three-dimensional views of the maxilla demonstrating radiopaque markers.

that you include all of the markers, since these may be designed to provide important information to the referring surgeon or the dental technician.

Believe it or not, the referring dentist is generally more interested in the bone than in the teeth. In the absence of teeth or a CT scanning guide, set the first slice of a maxilla scan below the inferior border of the maxillary ridge and set the last slice about 5mm above the floor of the nasal cavity. An average maxilla study will require 25-35 slices spaced at 1mm intervals.

Check the first slice before you continue scanning to make sure it is correctly positioned. If there are no teeth, there should be soft tissue only (no bone) present in this slice. The axial slices should form a "bony sandwich" with at least one non-bony slice above the bone and at least one non-bony slice below the bone, so that the exact extent of the bone can be accurately measured.

The first slice of a mandible scan should be below the inferior border of the mandible. The last slice should be high enough so that about half the height of all the mandibular teeth are included (or just above the alveolar ridge if there are no teeth). An average sized mandible will require 35-45 transaxial slices spaced 1mm apart.

Many dental packages require that all the slices must be acquired with the table moving in the same direction, without changing the slice thickness, table increment, table height, field of view or target centre. This is to avoid inconsistencies in the reformatted images.

4.4 Artefacts caused by metallic restorations

Metallo-ceramic restorations and large amalgam fillings may obscure detail at the level of the occlusal plane but rarely affect bony detail below the alveolar crest. The main exceptions are root canal fillings and gold or precious metal alloy posts that extend down into the bone.

Titanium and titanium alloy produce much less severe artefacts. Consequently, existing titanium implants are well visualised by CT [**figure 6**].

Artefacts are always more pronounced on the axial slices than on the panoramics or cross sections. This is because computer generation of the panoramics and cross sections involves algorithmic processes that minimise the artefact in these reformatted images. Additionally, standard image processing techniques can sometimes be introduced to minimise the effects of artefact.

Judicious patient positioning often allows artefact to be directed away from the region of interest. The mandible shown in **figure 7** is poorly positioned because artefact from the fillings will affect many of the axial slices. Had the jaw been scanned parallel to the occlusal plane, only the first few slices would have been affected.

Always scan the entire anatomical region requested, even if metal will be included. Although the axial slices may not be aesthetically pleasing, the computer-generated panoramics and cross-sections will still be clinically useful.

5. MAXIMIMUM IMAGE QUALITY AT MINIMUM DOSE

The technical specifications of CT scanners have radically improved over the last few years. This is primarily due to the introduction of high-speed "helical" or "spiral" scanners. Important advances in x-ray tube design, radiation detectors and computer technology have also played a part.

The new generation of high-speed spiral scanners virtually eliminate the problem of patient movement and offer complete imaging examinations at acceptable patient doses (well below 1mSv).

Spiral scanners offer a multitude of scanning protocols. Parameters that may be varied include pitch, slice reconstruction interval, and interpolation algorithms to name a few. The visibility of sensitive structures depends on factors such as high contrast resolution, low contrast resolution, the sharpness of edges and the presence of noise - and these in turn depend on the scanning protocol chosen.

Using the smallest available slice thickness (typically 1mm) provides the highest possible spatial resolution. This improves the clarity of high contrast objects such as bone. However, a small slice thickness also results in noisy images. This can lead to difficulty in distinguishing low-contrast structures such as the inferior dental nerve.

On a spiral scanner, slices are retrospectively reconstructed from interpolated projection datasets after the data collection is complete. The spacing of these "virtual slices" can be chosen by the radiographer to be 1mm apart, 0.5mm apart or even closer, without any increase in radiation dose. There is good evidence that reducing the reconstructed slice spacing leads to improved resolution in the paraxial or z-axis direction (ie in the panoramic and cross-sectional images which are of most value to dental implantologists, **figure 8**). The main disadvantage of reconstructing additional slices is the technical difficulty of processing and storing a large amount of data.

Last but not least, it is important to make sure that the table moves smoothly and predictably throughout a spiral scan. Any errors in the recorded table position will result in unacceptable inaccuracies in the reformatted dental images.

Taking the above considerations into account, the protocol shown in Table 1 has been found to produce very satisfactory image quality on an IGE CT/i (and was used to produce **figures 2, 3 and 4**).

Using the same protocol, entrance (skin) dose to a phantom was measured to be 12.5mGy for a 35-revolution maxilla study. Effective Dose was estimated to be less than 0.2mSv.

kVp	**120**
mA	**100**
Pitch	**1.0**
Scan time	**1s per revolution**
Matrix	**512 x 512**
Field of view	**130mm**
Slice thickness	**1.0mm**
Reconstructed slice increment	**1.0mm**
Reconstruction algorithm	**Bone**

TABLE 1.
Protocol for IGE CT/i.

6. CONCLUSIONS

Because of its accuracy, sensitivity, and freedom from magnification and geometrical distortion, Computed Tomography is increasingly employed in the planning of dental implant surgery. The latest generation of spiral CT scanners can image the complete mandible or maxilla in under one minute, delivering high resolution images at acceptable radiation doses. Carefully constructed scanning guides with radiopaque markers can greatly enhance the information provided by the scan. The role of the radiographer in positioning the patient correctly and implementing the optimal scanning protocols is vital in achieving high quality results.

ACKNOWLEDGEMENTS

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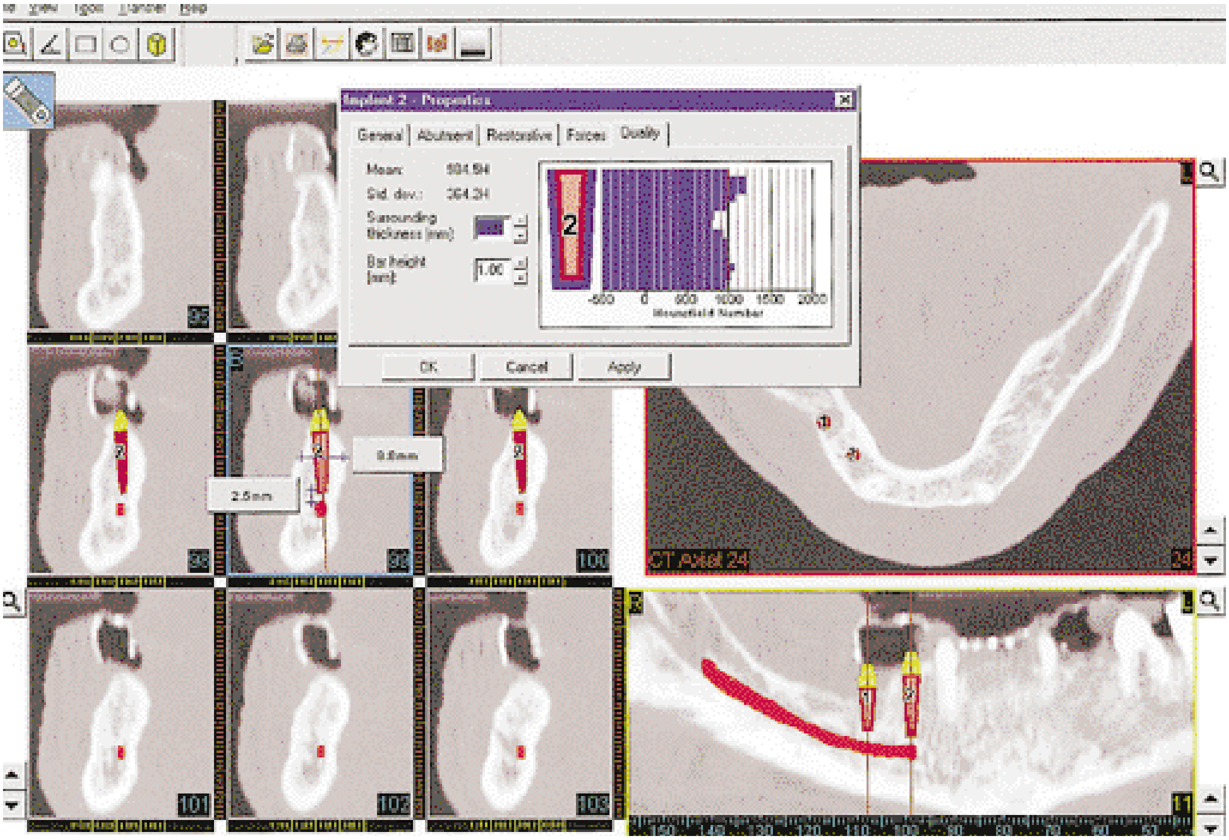


FIGURE 5

Simulating implant placement using SIM/Plant software. *(This image was kindly provided by Columbia Scientific Incorporated. SIM/Plant is trademark of Columbia Scientific Incorporated).*

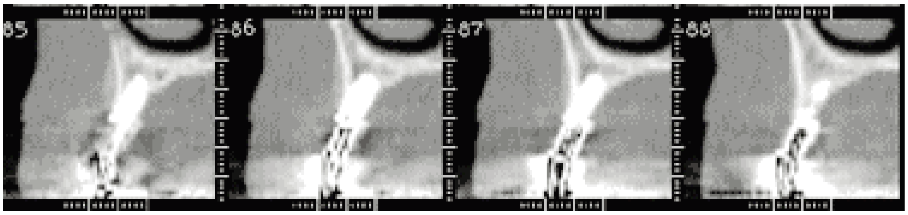
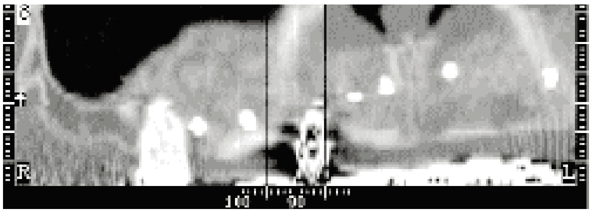


FIGURE 6 a and b

(a) (b) Titanium implants do not cause severe artefact.



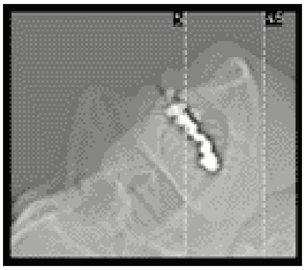


FIGURE 7

A poorly positioned mandible. Scanning parallel to the metal fillings would have restricted the artefact to just the first few slices.

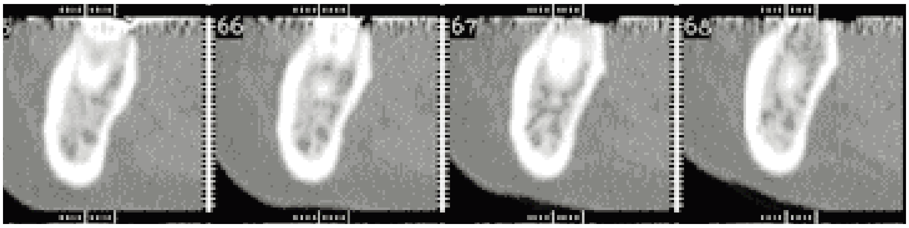


FIGURE 8

Images reformatted from axials reconstructed with 0.2 mm spacing can achieve near radiograph-like resolution.