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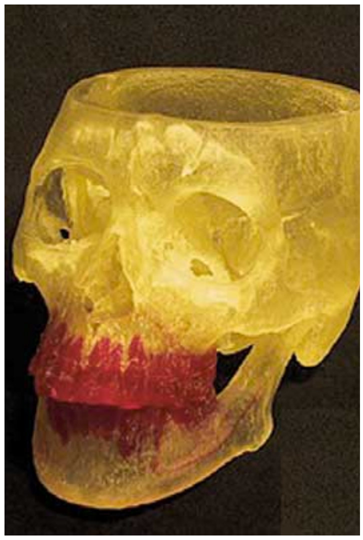

Planning dental implants - What are the options?

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Planning Dental Implants - what are the options?

Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) have arrived in the form of commercial products for planning and placing dental implants. Anthony Reynolds and Sean Goldner explore the available options

The primary objectives of implant planning are to determine the available bone quantity and quality, identify nearby anatomical structures, and diagnose pathology such as buried roots.

No single radiographic procedure provides ideal images for all of the steps in the implant planning process. Most patients will undergo a series of imaging studies including intra-oral x-rays, lateral skull films, and dental panoramic tomography (DPT).

Increasingly however computed tomography (CT) is being regarded as the modality of choice for detailed planning prior to the surgery itself.

The production of reformatted cross-sectional and panoramic images presented life size on an x-ray film or as a booklet of photographic quality prints has been long established.

However now for the first time surgery planned on the computer can be translated to the operation itself through laser fabricated surgical drill guides.

Today more than ever a plethora of imaging modalities is available for the dentist who is contemplating implants for his patients. To carve a path through this jungle one can categorise the imaging options that are available for pre-surgical planning by their availability, cost, radiation dose, accuracy and other advantages and disadvantages (Table 1).

Plain films

Intra-oral radiographs, especially digital ones, can be produced very rapidly and inexpensively and require a low radiation dose; however, they are not always sufficient for pre-implant assessment.

The primary disadvantage is that bone width cannot be assessed in the bucco-lingual dimension, and any estimate of bone height may be inaccurate unless the film/detector is exactly at right angles to the radiation beam.

Studies have shown that the inferior dental (ID) nerve can be seen in only 25 per cent of patients using intra-oral radiographs.

A cephalometric radiograph (skull film) may be taken on a cephalostat, craniostat or similar device. These images are primarily designed to study maxillofacial growth, or the results of orthodontic treatment; however, they show the proclination of the existing teeth and a good view of the maxillary sinuses.

Lateral views are the most useful for implant planning, but they are restricted to the molar and premolar regions.

Conventional tomography

Conventional film tomography is a technique whereby the x-ray tube and film are moved reciprocally in such a way that only a single plane of the object remains in focus and all other planes are blurred. Consequently a thin sectional image is created.

Conventional tomography is ideal for evaluation of a single implant site. It is relatively easy to identify an edentulous area and position the patient so that the tomographic plane is perpendicular to the bone at the implant site.

It is much more difficult to produce images of several implant sites, as this requires repeatedly repositioning the patient. Conventional tomography images are, by their very nature, somewhat blurry.

Dental panoramic tomography (DPT) uses conventional tomographic techniques to create an overview of the patient's maxillary and mandibular dentition.

However, DPTs are subject to distortion. This is because the magnification in the vertical plane depends on the focus-film distance (which is constant for each exposure) whereas the magnification in the horizontal plane varies with the changing position of the film and the x-ray beam.

To compensate for these errors and add orientation information, stents are often used. These may be copies of old dentures incorporating radiopaque markers of known dimension, or vacuum-moulded stents painted with radiopaque material.

DPTs are very useful in identifying areas of periodontal erosion and other pathological conditions of the alveolar bone. They are widely available, require a low radiation dose and are relatively inexpensive to perform.

The main problem with DPTs, as with other plain films, is that they are two-dimensional in nature. Bone height may appear to be adequate on the DPT, but there may be insufficient bone width to support an implant.

The Scanora is a sophisticated piece of equipment which produces a series of (conventional) tomographic images with a constant magnification.

The machine is specifically designed to produce cross-sectional images perpendicular to the jaw bone. Consequently Scanora images help to determine the available bone width bucco-lingually, and also to locate more precisely the inferior dental nerve.

The Scanora produces a series of four cross-sectional images per site, each 4 mm apart, on a single film. Up to six sites may be required to image an entire jaw. It is commonly believed that the patient dose from the Scanora is much lower than the dose from a dental CT scan.

This is only true if a small region of the jaw is to be imaged (e.g., a single implant site). If the entire jaw is to be imaged then the dose from the Scanora is very similar to the dose from a dental CT scan.

Table 1: Pre-implant imaging modalities compared by availability, cost, radiation dose and advantages and disadvantages (all figures are approximate).

	Availability	Cost to patient	Radiation dose (mSv)	Advantages	Disadvantages
Intra-oral radiographs	dental practice	£10 to £30	0.001 per image	good spatial resolution	non-uniform magnification; no bone width
DPT	general hospital	£30 to £50	0.01 per image	very useful overview	non-uniform magnification; no bone width
Skull films	general hospital	£50 to £100	0.1 per study	accurate if carefully used	limited application
Scanora	specialised hospital	£100 to £300	0.05 per site; 0.3 per jaw	accurate bone width and height	blurry images
Reformatted CT scans	hospital / IDT	£150 to £500	0.3 per jaw	all measurements very accurate	cost; availability

[Sidebar 1]

Image quality parameters

Spatial resolution is the ability to distinguish between closely spaced objects, and to faithfully reproduce sharp edges.

Contrast resolution is the ability to distinguish between objects that are of a similar radiographic density, such as neural tissue and fat.

Any contributions to the image which have no counterpart in the object are considered to be *noise*.

In CT scanners, *artefacts* arise from sampling limitations when dense objects are encountered - they are not caused by scattered radiation.

These images are usually presented as life-size and of photographic quality.

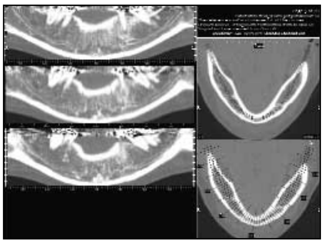

**Figure 1a:
Panoramic images of a mandible.**

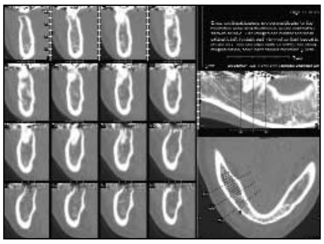

**Figure 1b:
Cross-sectional images of a mandible.**

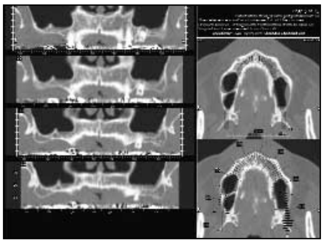

**Figure 1c:
Panoramic images of a maxilla.**

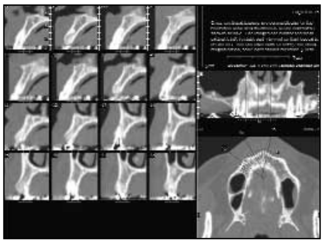

**Figure 1d:
Cross-sectional images of a maxilla.**

[Sidebar 2]

A CT scanning service

Image Diagnostic Technology Ltd (IDT) specialises in arranging CT scans for dental implantologists, and post-processing the axial slices to make them suitable for pre-surgical planning.

Our primary business is to provide the multi-planar reformats and 3-D views that are most useful for planning pre-operatively the placement of dental implants in the maxilla or mandible. We also convert CT datasets into formats suitable for the major implant planning packages (SIM/Plant, SurgiCase and coDiagnostiX) and arrange the manufacture of patient-specific life-sized anatomical models and drill guides.

IDT has made arrangements with a number of hospitals to accept referrals from registered dental implantologists, scan the patient following a suitable low-dose protocol, and send the computer data to us for further processing. For further information visit the website: www.ctscan.co.uk or tel: 020 7723 5552.

Computed tomography

Computed tomograms are superior to conventional tomograms for several reasons. CT scanners produce very high image quality, in terms of both spatial and contrast resolution [Sidebar 1].

There is no blurring, as there is in conventional tomography, and the images are free from magnification and geometrical distortion.

Most importantly, CT scanners produce a numerical readout of the pixel values which leads directly to quantitative assessment of the bone density at proposed implant sites.

CT scanners build up a three-dimensional representation of the body as a series of thin cross-sectional "slices". As these images are most frequently taken at right angles to the long axis of the patient they are often referred to as "axial slices". The cross-sections are produced by mathematical computation, not by blurring (hence the name "computed tomography").

Reformatted CT images

The first CT scans made for the evaluation of dental patients were done by angling the patient's head so that the slices were taken in the coronal plane.

However, several drawbacks were found to this "direct coronal" method. Firstly, it is very difficult to obtain scans truly perpendicular to the alveolar ridge, and secondly, in the coronal plane, the x-ray beam traverses the crowns of the teeth and any restorations will produce prominent streak artefacts. These artefacts can make it difficult or impossible to see the alveolar bone.

To avoid these problems, specialist software was developed to produce virtual panoramic and cross-sectional images by re-processing or "reformatting" axial CT slices. Much of this software is based on the original DentaScan program produced by the MultiPlanar Diagnostic Imaging company (MPDI). Later software packages vary slightly in their display formats, but all follow the same basic principles.

At the completion of the CT examination, the operator has a stack of axial slices stored digitally. Using software tools the operator draws a curve, following the midzone of the bone on a representative axial slice. The computer then creates a panoramic curve by connecting these points. Once the central panoramic curve has been established, the computer can create a family of panoramic curves parallel to it. The next step is for the computer to search through the stack of slices and find all the pixels along each panoramic curve, on each of the axial slices. These pixels are then organised into panoramic and cross-sectional images and printed out life size for diagnosis and measurement (Figure 1).

The main advantage of dental CT scans is that life-sized images can be displayed without distortion, and these are suitable for direct measurement of bone width and height. The main disadvantages are expense and availability. To redress these issues, Image Diagnostic Technology Ltd (IDT) has established a dental CT scanning service using local hospitals throughout the UK and Ireland (Figure 2).

These hospitals will accept referrals from registered dentists, scan the patient following a low-dose protocol that IDT has established, and send the computer data to IDT for further processing [Sidebar 2].

Figure 2:

Hospitals in the UK and Ireland which will accept referrals for a dental CT scan from dentists registered with IDT.

Planning Dental Implants - what are the options?

The CAD Principle - computerised surgical planning

As an alternative to hard copy prints, the data obtained from the CT scan can be fed into a personal computer for interactive treatment planning. There are a number of companies behind this exciting and revolutionary technology, and several software packages are available - SIM/Plant, SurgiCase, coDiagnostiX, and ImPlacer to name a few (Table 2).

One of the leading innovators is Materialise NV of Leuven, Belgium, who pioneered the automatic fabrication (in acrylic) of exact replicas of the patient's maxilla or mandible complete with templates or "drill guides" to assist with the actual drilling at the time of surgery.

Recently, Materialise have acquired all of the assets of Columbia Scientific Incorporated (makers of SIM/Plant), and have also developed their own dental implant planning software, SurgiCase.

The following description takes SurgiCase as an example, but the other software packages function similarly. After the CT scan and post-processing by a service bureau such as IDT, the patient dataset is sent to the dental implantologist via email or on a CD. It is then read into the SurgiCase software on the dentist's own PC. SurgiCase displays the original axial slices, reformatted cross sections and panoramic images (Figure 3a).

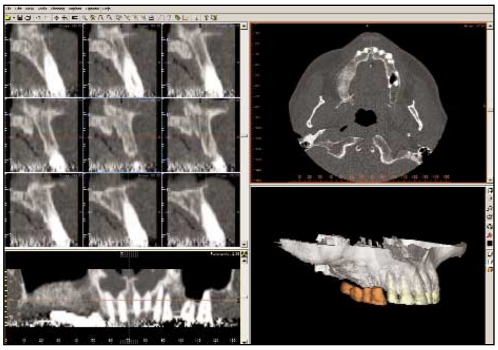

Figure 3a:
SurgiCase images of a maxilla.

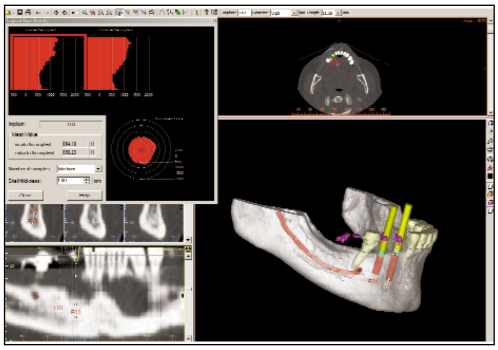

Figure 3b: SurgiCase images of a mandible, showing bone densities at an implant site.

It also produces an interactive 3-D representation of the patient's bone structure. This 3-D can be rotated to any angle, and when virtual implants are placed they appear in the 3-D and can be manipulated to any angle. In this way a number of implants can be carefully lined up having been placed in the optimum position. The ID nerve can be highlighted, and bone densities can be displayed numerically as a profile or histogram at the proposed implant site (Figure 3a).

SurgiCase and the other software packages provide all the information that is available on the hardcopy prints, but with easier navigation. A simple click on a region of interest (on the axial slice, for example) updates all the cross sectional and panoramic images to the corresponding position. Conversely, a click on an area of interest in one of the cross-sections updates the axial and panoramics to this position.

Once a careful plan has been made a surgical drill guide can automatically be produced which is unique to the patient and fits on to the bone crest at the time of surgery, guiding the drill bit to the exact anatomical position and orientation shown on the computerised treatment plan (Figure 4).

The surgeon need only concentrate on drilling to the required depth.

The CAM Principle - from computer plans to reality

Coming from an engineering background, Materialise has had vast experience in producing software for the design of mechanical parts such as those used in the automotive industry, and translating these designs into physical models through the technology of stereolithography.

Recently, because of its high accuracy and rapid production cycle, this technology has been used by some of the Formula One teams to produce new wing designs for wind tunnel testing prior to deployment on their racing cars.

Stereolithography is one of several Rapid Prototyping (RP) techniques whereby a physical model can automatically be fabricated from computer data. A high precision laser directs ultra-violet (UV) radiation onto a bath of liquid acrylic resin, in which a flat plate, known as an elevator, has been placed just below the surface. This plate functions as a barrier, as the laser cannot penetrate beyond it. Thus, only a thin layer of the model is created at a time. Wherever the laser interacts with the liquid, the resin is cured and hardens. By lowering the elevator a small amount (e.g. 0.25 mm), the next layer of the model can be created.

It is not only dental drill guides that can be fabricated by this technology - models of the mandible, maxillofacial region, or the entire skull can be produced (Figure 5).

The applications in medicine are far reaching, ranging from obturator prostheses for oncology patients to complex maxillofacial reconstructions and cranioplasty.

In dental implantology, the use of CT scans and interactive surgical planning software combined with RP models and surgical drill guides can help to reduce the operating time and costs and improve the predictability of satisfactory aesthetics and a successful outcome.

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Table 2: Dental Implant Planning Software

A number of software packages are available. For further information please visit the websites indicated.

Product	Manufacturer	Website
SIM/Plant®	Columbia Scientific Incorporated*	www.simplant.com
SurgiCase™	Materialise NV	www.surgicase.com
coDiagnostiX®	IVS Solutions AG	www.ivs-solutions.de
ImPlacer®	Pacific Coast Software Inc.	www.pacificcoastsoftware.com

■ *Columbia Scientific Incorporated is now a wholly-owned subsidiary of Materialise NV.*

Figure 4: SurgiCase drill guide located on an anatomical model of a mandible, showing the exact fit (courtesy of Dr. A. Sethi).

Figure 5:
Anatomical model of a skull made by coloured stereolithography.