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CAD/CAM

international magazine of digital dentistry

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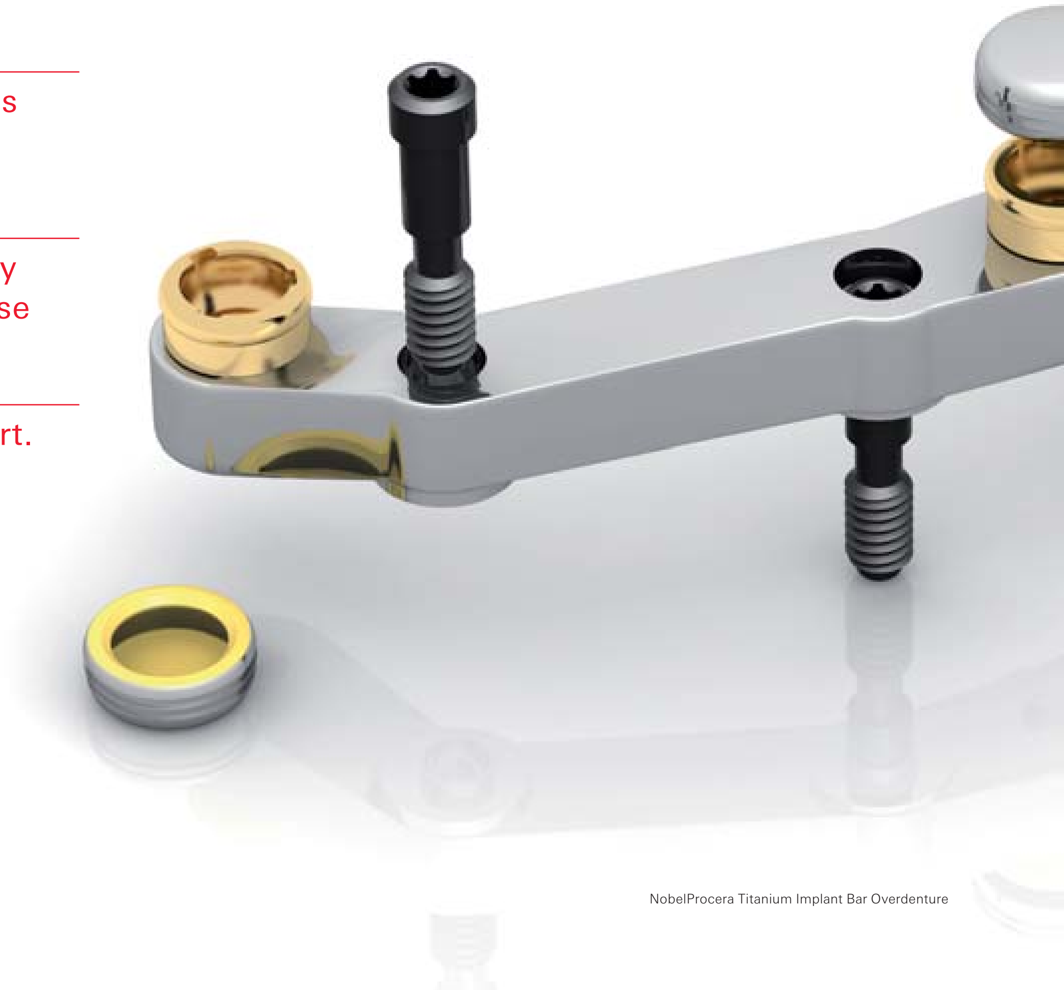

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Dear Reader,

Magda Wojtkiewicz
Managing Editor

_Passion makes the world go round. Some of us are passionate about music, others about painting, yet others about movies or photography. Passion can drive the fulfilment of our dreams, but requires that we look ahead. It is difficult to imagine that we could pursue our passions today with magnetic tape, film photography, analogue techniques or an ancient computer.

In recent years, the pace of life has changed significantly: we use fast Internet, speed couriers and require instant responses. The same is true of dentistry. Patients demand quick and inexpensive therapeutic solutions, yet expect the highest standard of work. In order to meet these demands, dentists have to rely on the latest technologies.

Initially, the use of CAD/CAM in dentistry was a novelty, requiring an inordinate amount of time to produce a viable product. Over the last 30 years, the development of new equipment, materials and software has advanced digital dentistry to the next level, facilitating the use of CAD/CAM technologies in both dental offices and laboratories. Nowadays, digital dentistry is a part of daily practice for a growing number of dentists and dental technicians. By incorporating CAD/CAM automation and digital imaging into their strategic business models, dental offices and laboratories are able to save on time and labour, while improving the quality and precision of their work.

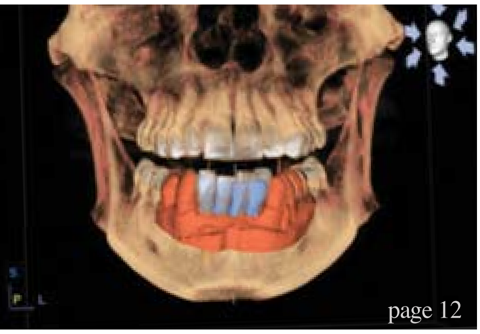
The way ahead is digital dentistry; it saves time, enhances treatment and ensures precision like never experienced before. Successful use of the technology, however, depends on you, whether you wish to be a pioneer in the field or prefer to use the proven technologies.

This edition of CAD/CAM is concerned particularly with implantology and orthodontics. You will find information on new concepts in computer-guided implantology, using CBCT and CAD/CAM techniques, as well as the latest industry news and information on upcoming and past meetings.

I hope that you will find the magazine informative and find inspiration to follow your path!

Yours faithfully,

Magda Wojtkiewicz
Managing Editor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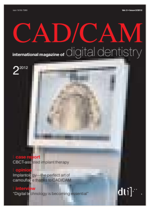

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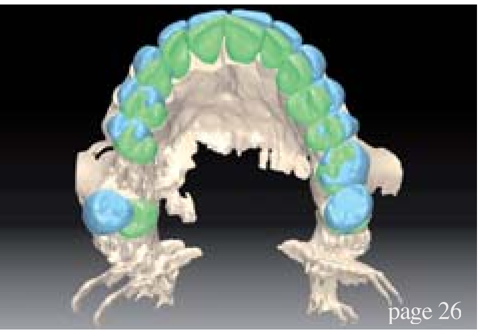
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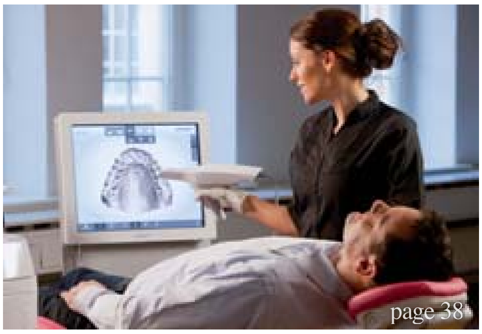
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New concepts in computer-guided implantology

Part II: Error analysis and accuracy verification

Author_Dr Gian Luigi Telara, Italy

_Abstract

In recent years, there has been a growing interest in guided implantology. A digital work-up is certainly of great benefit for clinicians to better understand their patients' bone morphology and density and consequently to plan implant positions correctly, and to have their hands guided during implant placement by means of a surgical guide. There are many systems on the market today and many researchers have studied post-operative CT scans and planning scans by means of superimposition, in seeking to understand the secret to achieving perfect correspondence and the best system, but this perfect accuracy has not yet been found and there appears to be a mismatch between planning and the actual implant position.

I have developed a device (Dental Implant Positioning System, International PCT IT 2009 000192, WO 2010/125593 A1; patent pending) that respects the implant's spiral movement in accordance with mathematical criteria. The same criteria are also important in theorising limits and achieving accuracy using computer-guided implantology.

_Introduction: Passive systems and the limits of the human visual, auditory and spatial resolution

Is it possible, using one technique, among the many on the market, to create repeatable results in terms of a final prosthesis? How many of the presently marketed systems in guided implantology really are passive? Do passive infra-red systems really facilitate repeatability?

Human visual resolution limits do not allow for accuracy: eye, ear and fine hand movements have not yet crossed this threshold. Human spatial resolution can be evaluated with reference to the modulation transfer function (MTF). This is also a good means of evaluating the optical properties of CT scans. Spatial frequency has been widely studied and it is now generally accepted that line pairs (black and white) can be perceived up to a tenth of a millimetre (human visual acuity). The same is true for hearing (in hertz) and hand movements (we cannot control a movement beyond 0.1 mm).

A passive device therefore appears necessary to ensure that the same implant position can be reproduced repeatedly and independently of the operator within the threshold defined above. This fulfils my definition of "passivity".

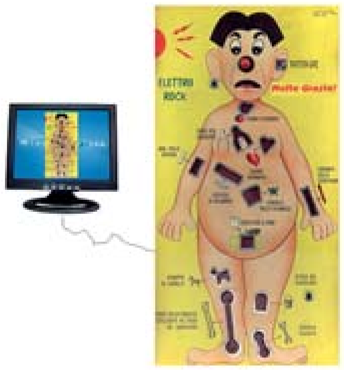
_The limitations of infra-red control systems

This last point also means that infra-red control systems are excluded by definition, since their accuracy is operator dependent. Apart from spatial resolution limits, this kind of technology is affected by time-delay problems, partially due to the machine itself and partly due to the temporal resolution limits of the operator (eye, ear, hand). Therefore, infra-red control should not be considered passive. These systems are equipped with a virtual smooth sleeve and are operator dependent. Furthermore, they can be monitor or mouse guided, when the handpiece is transformed into a computer mouse. Ironically, we tend to consider the surgical tutoring toy a passive tutoring system only because it is provided with sensors along its holes (Figs. 16a & b), but not because of its functionality.

It is my opinion therefore that an entirely passive device, in which all necessary information is included, is superior to semi-active devices. Furthermore, passive devices should be easy to handle and intuitive to use, and their design should not allow any freedom for the operator (the operator has already decided upon the location of the implant through planning and the surgical guide).

_Accuracy verification

Many studies on accuracy verification have been conducted. In these, scientists have sought to determine and measure accuracy by means of comparing the planning data and data acquired post-operatively. Their aim is to evaluate which of the marketed systems delivers the most accurate results.



In this „little Surgeon" toy is my hand guided by a passive tutoring system down the hollow to get the target?

No!
Only a red nose will notice me I'm touching the guardrail.

Does it make sense? Is it transformed into a passive methos if I can do the same thing with a mouse-handpiece and looking into a screen?

No!
These are semi-active monitor-guided systems.

Fig. 16b

Fig. 16a

Fig. 16a_The surgical tutoring toy.
Fig. 16b_Operator-dependent super technological system.

In Part I, I discussed smooth-sleeve-related inaccuracy from a theoretical perspective. We must also realise that a reliable evaluation of accuracy requires measuring device. Is CT a reliable technique? Is superimposition a good means of evaluating accuracy in implant placement? Does it consider all the parameters that define the implant position (including the hex)? To prove validity and measurement accuracy, repeatability should be considered as important as its underlying mathematics.

Even if a perfect superimposition has been carried out, CT artefacts and the voxel size (which is 0.125 mm at the best) not being an issue, and considering the CT scan as a continuum, its results appear to be invalid information. Scanners, like any

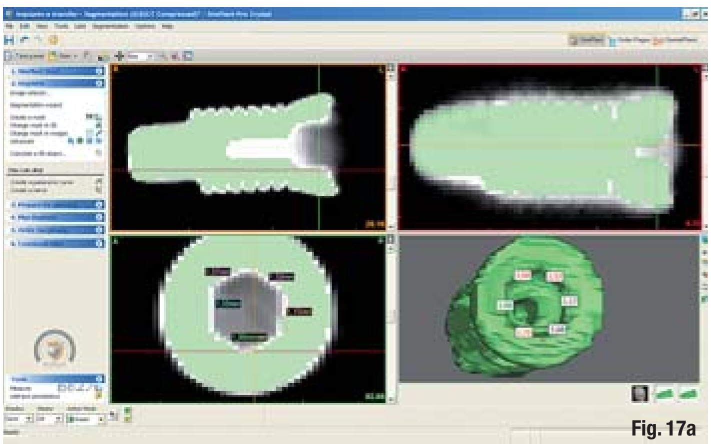


Fig. 17a

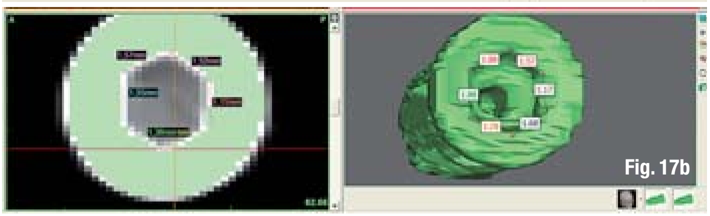


Fig. 17b

Fig. 17a–b_CT scan MTF limits.

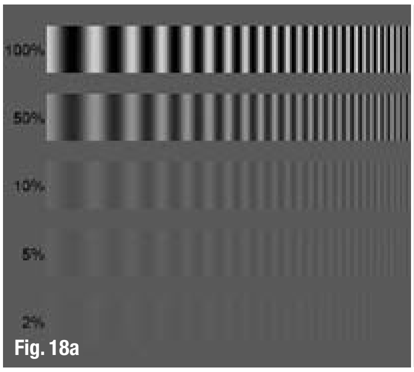


Fig. 18a

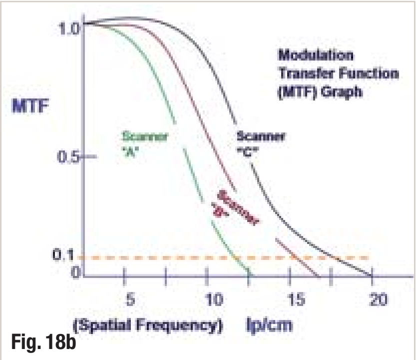


Fig. 18b

Fig. 18a–e_MTF concept.

other optical system, have optical limits and owing to CT's MTF and intrinsic limits, CT scans can be considered low-resolution 3-D images. They also achieve spatial resolution levels far from those needed in our field to ascertain placement precision. Consequently, statistical inferences based on superimposition cannot be said to deliver valid proof.

_High-contrast spatial resolution

I scanned an implant using the latest NewTom CBCT (CB3D VG-I MARK 3), and viewed the scan using SimPlant Crystal (Materialise Dental) to verify the resolution and the precision of the measurement. The best I was able to achieve was 0.1 mm. This means that a real measurement of 1.43 mm could be achieved on CT within 1.33 and 1.53 mm, and 0.3 mm is the possible measurement error (Fig. 17a). The same difficulties also arise with MSCT scans (Fig. 17b).

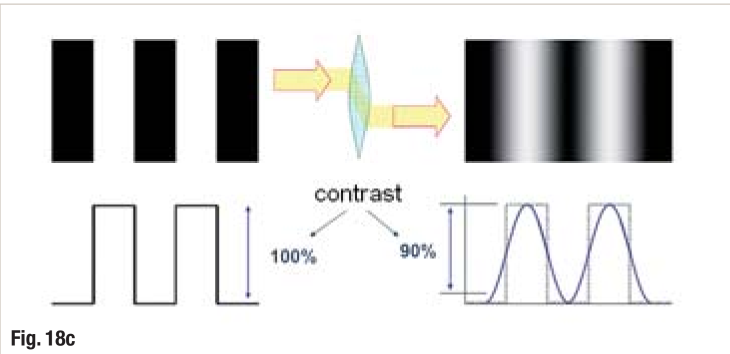


Fig. 18c

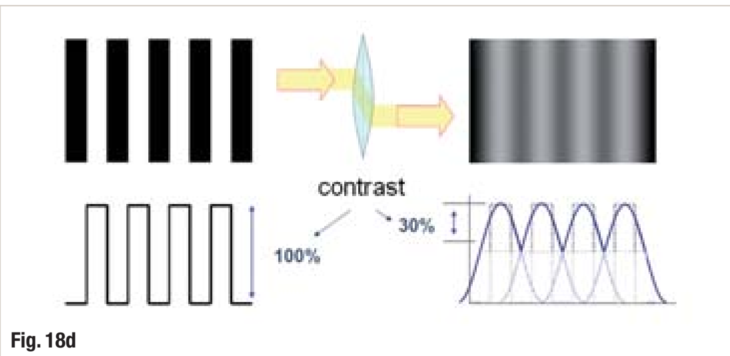


Fig. 18d

Spatial frequency is evaluated by means of MTF, the ratio between the output and the input signal, with one describing an ideal system with no loss of information at the output. MTF defines limiting resolution, which describes the ability of a system to perceive two objects as distinct. At high frequencies, that is a high number of line pairs per mm (lppm), MTF will approach zero (Figs. 18a & b). When taking MTF into account, we must evaluate a CT scan according to its optical performance. When the frequency is increased, a series of square waves, corresponding to a 1:1 ratio with combined white and black lines, changes into a series of bell-shaped waves. This process is termed the point spread function. As a result, the contrast decreases, which makes it increasingly difficult to visualise the edge of the lines. MTF is the Fourier transformation of the point spread function. When the frequency is low and the quality ratio is one, the wave corresponds perfectly to the square waves. When the frequency increases, the ratio decreases and the wave becomes increasingly bell shaped. At an MTF of 2 %, the image will be of a uniformly grey colour (Figs. 18c & d). The CT scan limiting resolution is therefore 2 lppm at best (Fig. 18e).

_Low-contrast spatial resolution

Moreover, we can extend our discussion to the contrast level at which an image is observed and analyse low-contrast spatial resolution.[6] When the contrast decreases at high frequencies, we have to cope with a low-contrast level image that is noise dependent. Furthermore, the optical spatial resolution properties depend on the part of the screen at which we are looking. The resolution is at its best at the isocentre, worsening both in the radial direction and along the circumference, the azimuthal direction (Fig. 19). While this phenomenon holds true for the cone beam in particular, a cone-beam effect is also achieved with MSCT: the more slices we have, that is, the greater the fan beam width of each subsequent MSCT scan, the greater the cone-beam effect (Figs. 20a & b). When the isocentre is considered the central part of the radiation fan, this effect can be seen in the outermost slices of the radiation fan beam especially (Fig. 20c). Axial reconstruction algorithms report this cone-beam effect in relation to a spiral path in the axial images (Fig. 20d).[7]

Compensating cone-beam reconstruction algorithms or spiral interpolation algorithms help to solve this problem, for instance the multi-row Fourier reconstruction. Similarly, an extension of the advanced single-slice rebinning method (ASSR), which combines the idea of ASSR with a z-filtering approach, has been proposed as a solution to this problem, but its validity has not been adequately

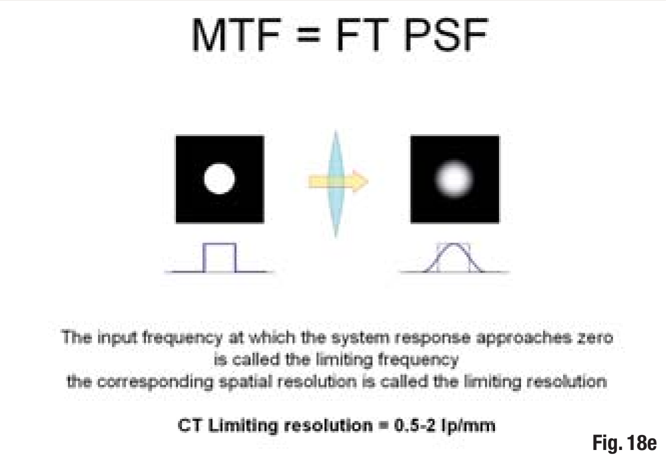


Fig. 18e

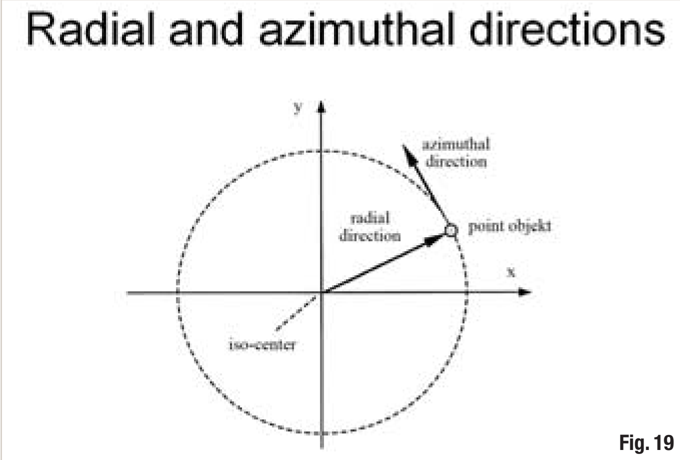


Fig. 19

Fig. 19_Radial and azimuthal resolution.

demonstrated. This is because, thus far, interpolation has only shown a reorientation of the optical limits for both cone beam and MSCT.[8,9]

_Errors in sleeve placement

CT is also responsible for errors in sleeve placement inside the surgical guide. These errors are caused by an inescapable approximation in the CT resolution limits. CT cannot exceed its MTF limit, and this should be considered during planning and data transfer.

There can be repercussions on the sleeve placement inside the surgical guide, both for smooth or threaded sleeves. Sleeve position and axis are parameters associated with this procedure, and the distance to the ridge and adjacent teeth, as well as the sleeve axis, should be considered. However, from a practical perspective, they have no relevant influence on this procedure, but the limits given by these parameters are sufficient for the production of a surgical guide. Furthermore, they respect the structures adjacent to the implant site, for example plates and vascular adjacent structures, IANs, sinuses, nasal cavities, pterygopalatine fossae, mental foramina and adjacent roots.

Owing to the technical production limits of CT, the sleeve position in the surgical guide tends to be inaccurate, regardless of the technique applied (STL or stone surgery).

_Evaluation of data-transfer techniques

As for data transfer in the course of producing a surgical guide, the chosen technique should result in the sleeve being placed in the centre of the palate bone. In order to decide between CAD/CAM and stone surgery for this process, a cadaver study may help in comparing and evaluating the various techniques on the market.

In order to prove repeatability, each cadaver must be scanned several times. Each scan should consider the protocol of a different company or manufacturer. The corresponding surgical guides should be tested on the same cadaver in order to evaluate the precision of each technique in placing the sleeves in the centre of the bone, according to position and axis.

Surgical kits should fit into the mouth and I assume that the axis should respect the palate's anatomy. Furthermore, drilling and implant placement should be avoided in order to prevent inaccuracy errors other than those derived from using smooth sleeves. Likewise, a repeated scan for superimposition is not of any use. Mathematically speaking, a system can be considered reliable if its repeatability can be confirmed. In the cadaver study, the cadaver should therefore be tested to fit several repeated surgical guides. A similar technique proposed by Al-Harbi, in which the accuracy of the sleeve axis is assessed via CMM (coordinate measuring machine) and laser techniques, also appears promising.[10]

The study by Bou Serhal et al. is based on a cadaver study, but once again, the cadaver was scanned according to a superimposition protocol.[11] But why expect to obtain more information from a second CT scan if we know that CT can be imprecise? There are many articles on the reliability of CT and its correspondence to the anatomical truth, such as the studies by Lou et al.,[12] Brown et al.[13] and Damstra et al.[14]

However, these publications appear to restrict their interest to the scanned fiducial landmark measurements and record an error between 0.1 and 0.5 mm for 2-D CT. It is therefore my opinion that these studies fail to distinguish sources of error such as the MTF limit and smooth sleeves by concentrating on the superimposition of two low-quality 3-D images.