Chapter 5

Can I rely on software-guided surgery?

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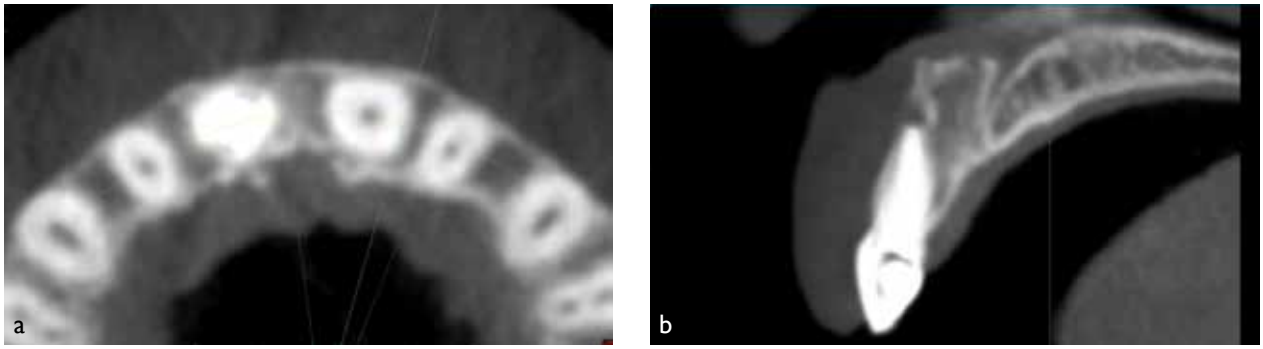
5.1 Introduction

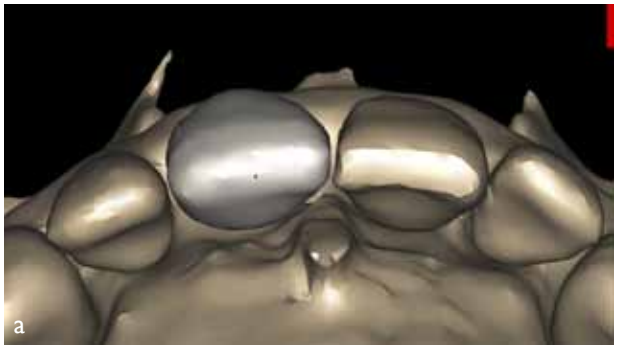
Traditionally, preoperative diagnosis in implantology was based on two-dimensional (2D) interpretation of radiographic information, obtained basically from panoramic and/or periapical radiographs. In the 1990s, evolution in this field led to more generalized use of computerized tomography (CT),[1] together with the elaboration of radiographic and surgical templates.[2,3] However, despite the availability of CT technology, during these early stages clinicians would only receive 2D information and had to go through a mental process of "limited three-dimensionalization" (Fig 5-1) in order to approach realistic surgical readiness and to adequately plan the placement of fixtures, which carried significant limitations.[4]

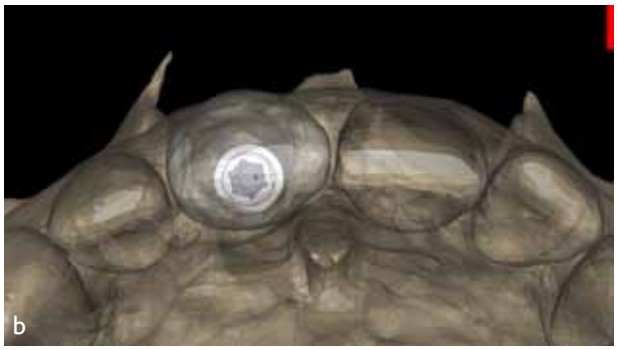
This need for more elaborate and trustworthy 3D information led to the design, at the turn of the century,[5] of specific implant design programs based on 3D handling (Fig 5-2) of information obtained by CT or cone beam computerized tomography (CBCT), creating the new concept of computer-aided implant surgery (CAIS).[4]

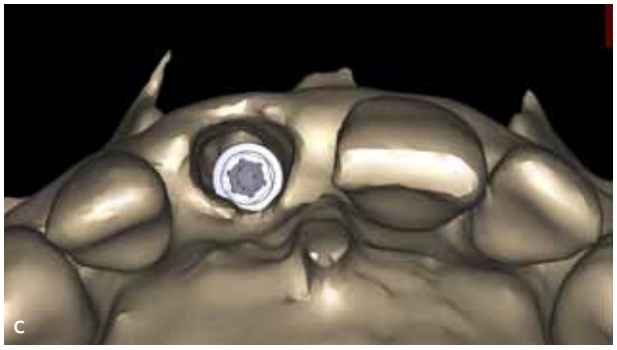
There is a certain terminological confusion in this field, so for the purpose of clarity, we will use in this chapter the term CAIS to refer globally to all procedures where information is obtained by scanning jaws (CT or CBCT), and then processed by a specific type of software that allows for the virtual 3D planning of dental implants, and which finally assists the surgeon during implant placement in the patient's mouth. The term "aided," while somewhat ambiguous, is also conveniently generic, as it encompasses all procedures based on the use of surgical templates and navigation systems, as well as other surgical uses of the 3D information obtained, which we will discuss at the end of this section.



Figs 5-1a and b Computerized tomography displayed with a traditional approach. The analysis was based on the clinician's evaluation of 2D images from different perspectives: occlusal view, perpendicular section of the ridge, and pantographic reconstruction. The clinician had to undergo a "limited 3D mental reconstruction" to carry out the planning.







Figs 5-2a to c The production of 3D models allows us to draw up a plan based on virtual surgery. This case, for example, involved the extraction of a central incisor (*a*), the virtual placement of an immediate implant (*b*), and the assessment of the resulting residual bone defect (*c*).

The following topics will be assessed:

5.2 What types of CAIS procedures are available for clinical use?

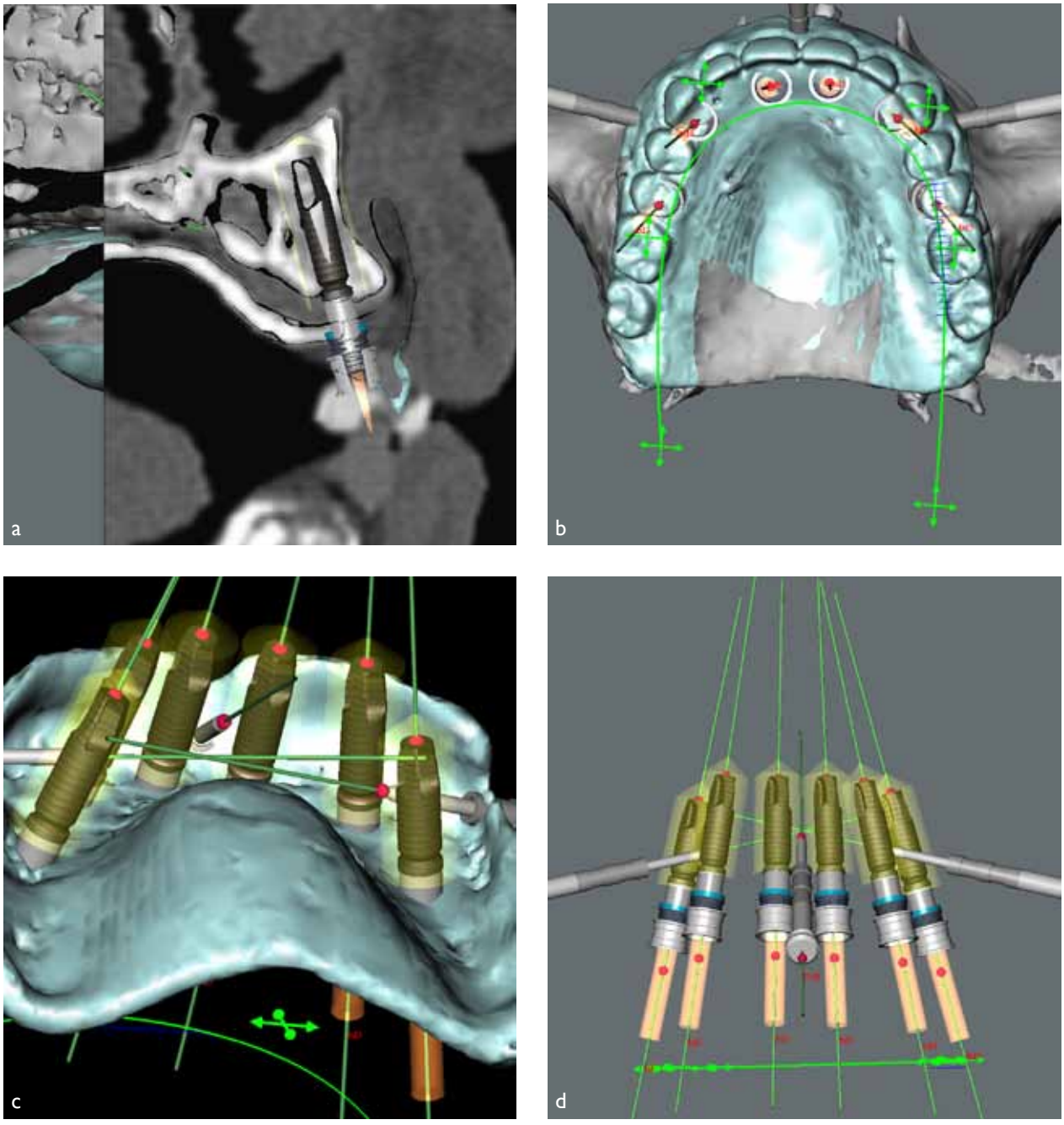
5.2.1 Template-based or static procedures

The most commonly used and widely documented approach is based on the creation of a surgical template using digital information. This is known as static computer-assisted surgery, or computer-guided surgery.[6] With this procedure, information obtained through 3D planning is used to produce a surgical template by means of CAD-CAM (computer-aided design/computer-aided manufacturing) procedures, which allows implants to be placed on the patient's jaws in a way that duplicates precisely the virtual design. This begins with the laboratory production of a radiographic template designed to hold a prosthetic base, teeth and/or markers, which could be radiopaque. This radiographic template is placed into the patient's mouth during the CT/CBCT scan, for which its precise positioning and stability are paramount. Information from the scanned jaws and from the radiographic template used is processed to build a 3D model from which the clinician creates the virtual plan (Fig 5-3). Finally, a surgical template is made, which will act as a link between the virtual world (3D planning) and the real world (the patient), as well as the immediate provisional prosthesis (Fig 5-4).[7]

There are two types of guided surgery, which differ essentially by the method used to build the surgical template: those that use stereolithographic templates and those that use mechanical templates.[6]

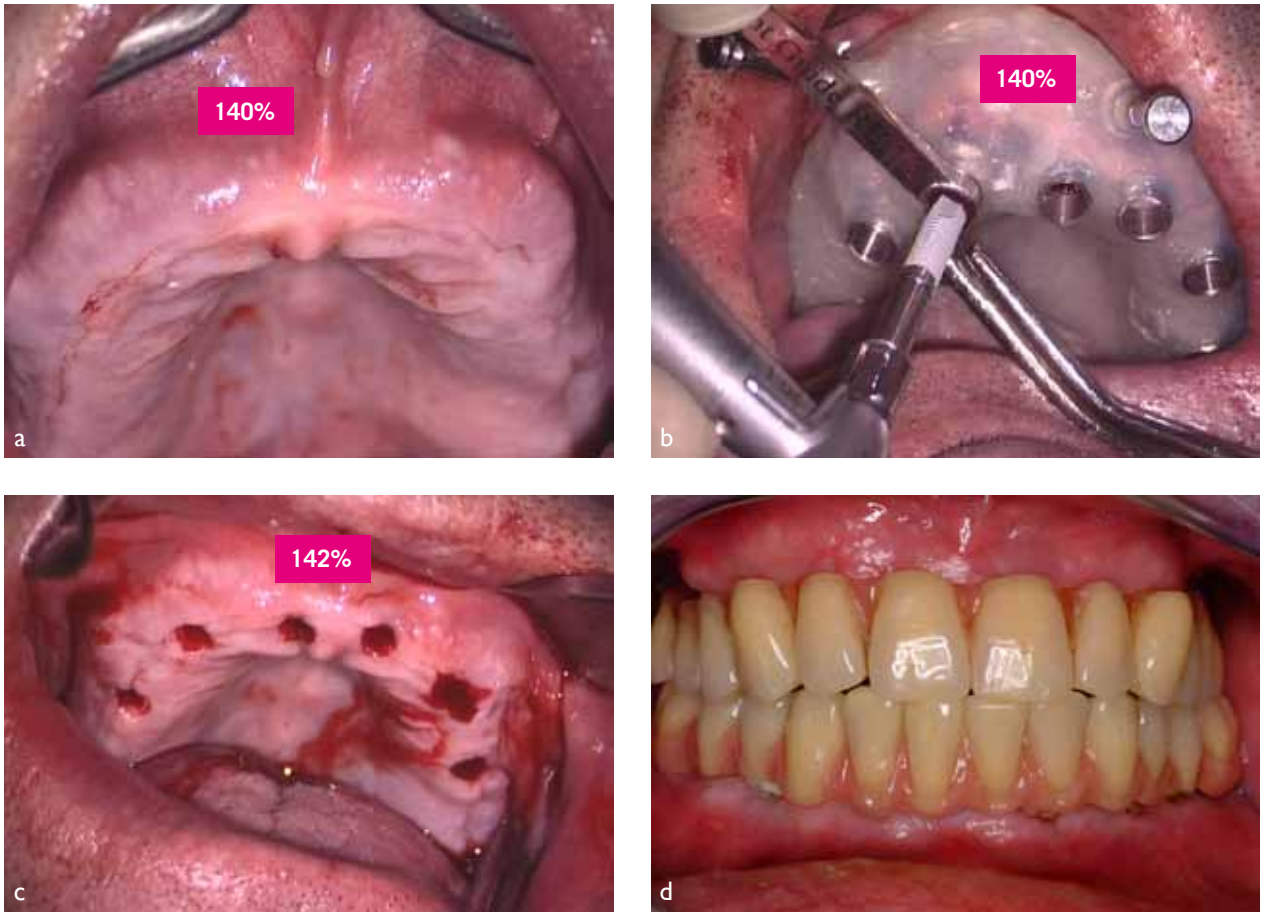
Stereolithographic templates

Stereolithography is a rapid prototyping procedure, patented by Chuck Hull in 1986. It is based on a digital



Figs 5-3a to d Following a full esthetic and functional examination, a radiographic template is produced, containing all the necessary information on the spatial positioning of the teeth and reference (fiducial) marks for patient indexing. This enables the virtual planning of the implants and provides digital information for creating the drilling template.

model of the element to be copied (in this case the surgical template), which is previously broken down by the design program into sections or layers, representing parallel planes perpendicular to a specific axis. The surgical template is built layer by layer. Stereolithographic production machinery, which is limited to industrial use, consists of a container filled with photopolymerizable resin set on a platform that can be moved vertically (Fig 5-5). When template construction begins, the platform is at its highest position, slightly below the surface of the resin. The information from the first layer is copied by means of laser-activated polymerization of the supernatant resin, and the laser draws onto it the information from that first layer. Once this process is



Figs 5-4a to d Aided by the stereolithographic template, implants can be placed by making small, circular incisions by means of a minimally invasive technique, which requires neither flap raising nor suturing. Surgery finishes with the immediate placement of an implant-supported provisional prosthesis.

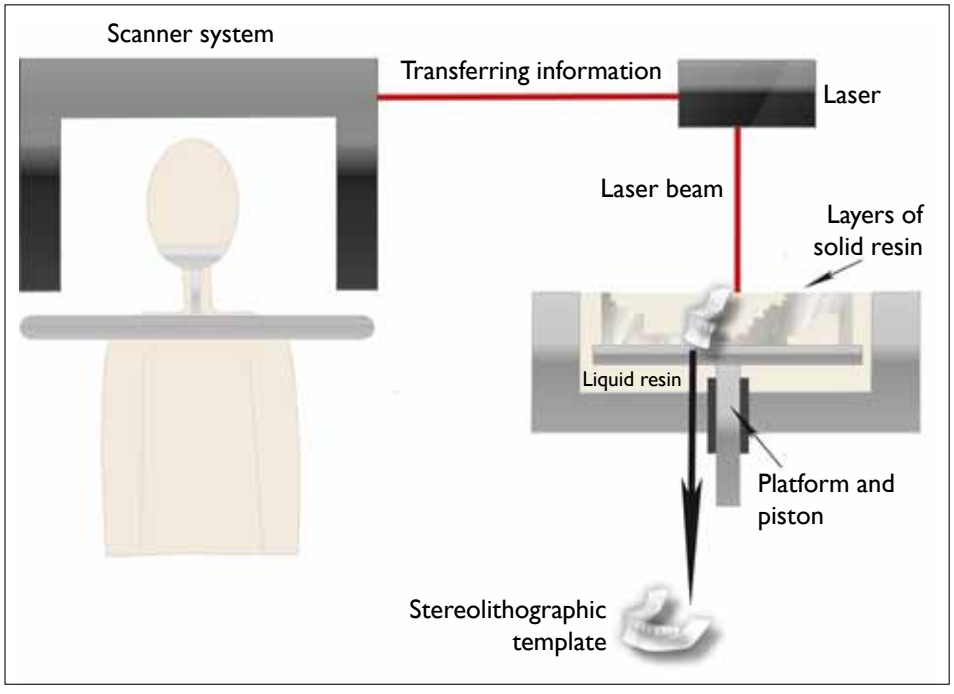
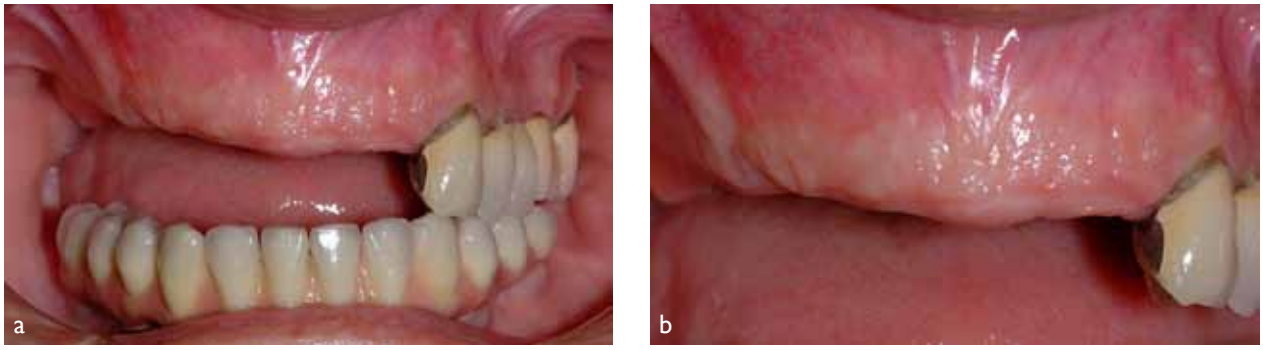


Fig 5-5 Diagram showing fabrication of a stereolithographic template.



Figs 5-6a and b A 45-year-old woman who, 6 months previously, underwent examination of the right maxillary sinus followed by extensive reconstructive surgery with horizontal ridge augmentation in the anterior section and maxillary right molar region. She shows good keratinized tissue and an adequately sized ridge. Transmucosal implant placement in 11, 21, 13, 15 and 16 (Med3D®) is scheduled.

complete, the platform moves downwards slightly and the laser beam draws the next layer onto the new supernatant resin, photopolymerizing an additional layer, which adheres to the previous one. Once this process is complete and the final prototype is cleaned, its photopolymerization is finalized in an ultraviolet oven and the titanium cylinders are manually fitted in the prototype, so that the clinician can use the instruments and components necessary to drill the alveoli and place the implants.

There are various systems that use this procedure, perhaps the most noteworthy being the SAFE® method based on the SimPlant® software program (Materialise Dental, Leuven, Belgium) (Fig 5-2) and the NobelGuide® method (Nobel Biocare, Göteborg, Sweden) (Figs 5-3 and 5-4).

Mechanical templates

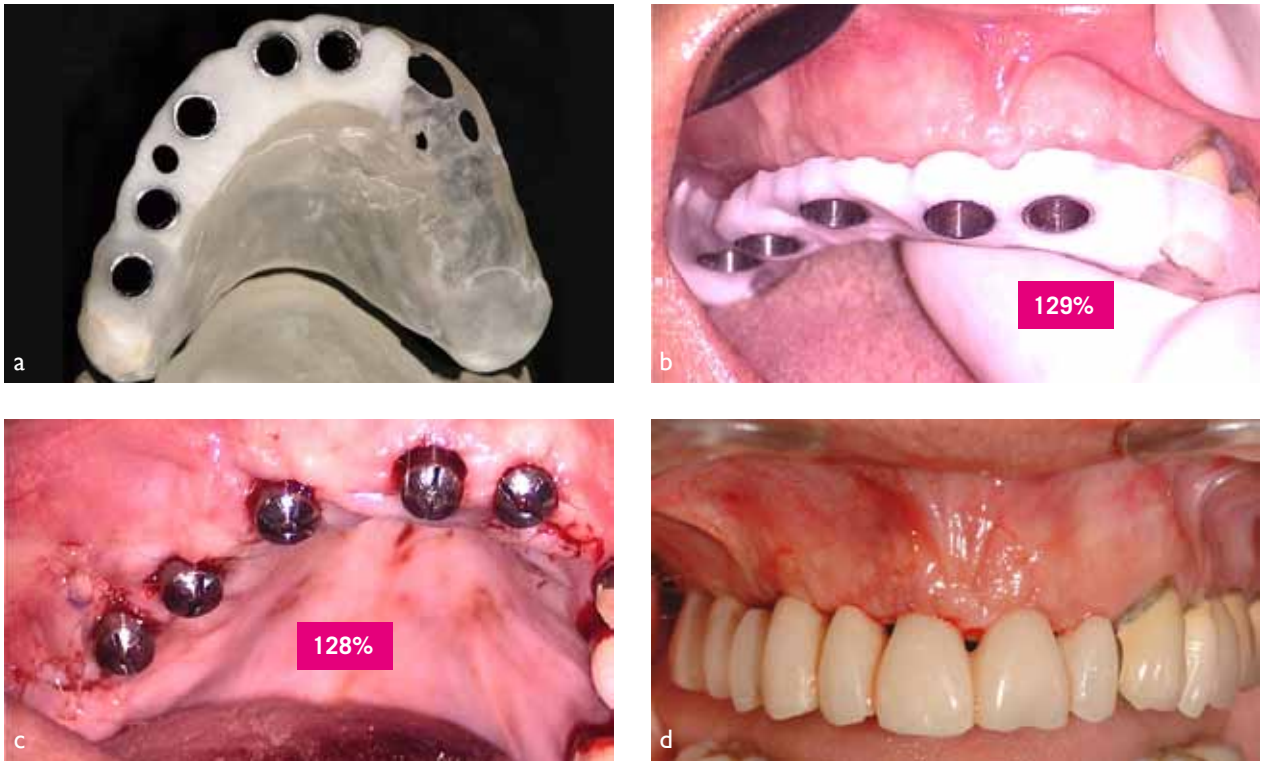
Mechanical template production is a simpler process, which may be carried out in a conventional dental laboratory or in the clinic itself. It is based on the initial manufacturing of an acrylic radiographic template, which features fiducial markers for indexing the patient. Once the planning stage is complete, using precision computer-guided mechanical devices, the template is perforated at the point in which the implants are to be placed and the titanium guide cylinders are set in place in the exact position and direction. Systems that utilize this procedure include Med3D® (med3D, Heidelberg, Germany) (Figs 5-6 to 5-8) and Straumann® CARES® Guided Surgery protocols (Straumann, Basel, Switzerland).

5.2.2 Navigation system or dynamic procedures

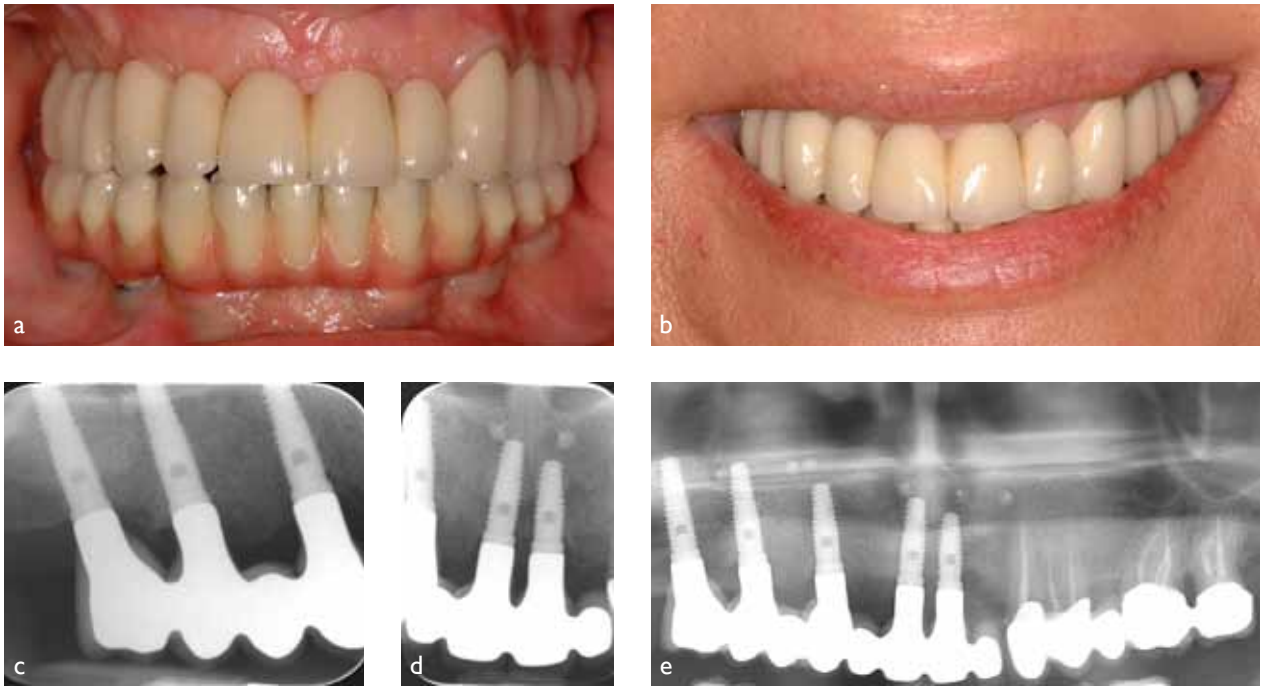
Conversely, in the so-called dynamic or navigation procedures, a communication system generally based on an infrared camera allows for the drilling and placement of the implant to be continuously monitored. The 3D planning and the patient are indexed by means of a template holding a bow with radiopaque markers. In this type of procedure, a "physical surgical template" has not been previously manufactured; instead, orientation is based on combined images transmitted by the navigation system (Figs 5-9 to 5-11). These can range from the display of the drills or of the implant superimposed over the 3D planning for the patient in real time, to the merging of information in symbol format, such as a target and a depth gauge for adjusting the drilling site, axis, and depth.[4,6] One of the most widespread navigation systems used in implant surgery is RoboDent® (RoboDent, Ismaning, Germany) (Figs 5-9 to 5-11).

5.2.3 Conclusion

Types of computer-assisted surgery include static systems, which use a surgical template, or dynamic systems that use navigation technology. Templates may be manufactured industrially (stereolithographic) or in a dental laboratory, or in the clinic itself using less complex computer-guided tools, known as mechanical systems.



Figs 5-7a to d (Same patient as in Fig 5-6) A mechanical surgical template is fabricated, followed by the performance of combined techniques of minimally invasive surgery, transmucosal surgery, and mini-flaps for implant placement with the least possible trauma. The connective tissue obtained after creating the access hole for implant placement is grafted to a cul-de-sac created on the vestibular side of each implant site, to improve the contour shape and increase the size of the keratinized buccal tissue. An immediate provisional metal-free acrylic prosthesis is placed.



Figs 5-8a to e (Same patient as in Fig 5-6) Final restoration with a non-segmented dental implant-supported prosthesis (teeth 17 to 12) and conventional prosthesis on the left side.

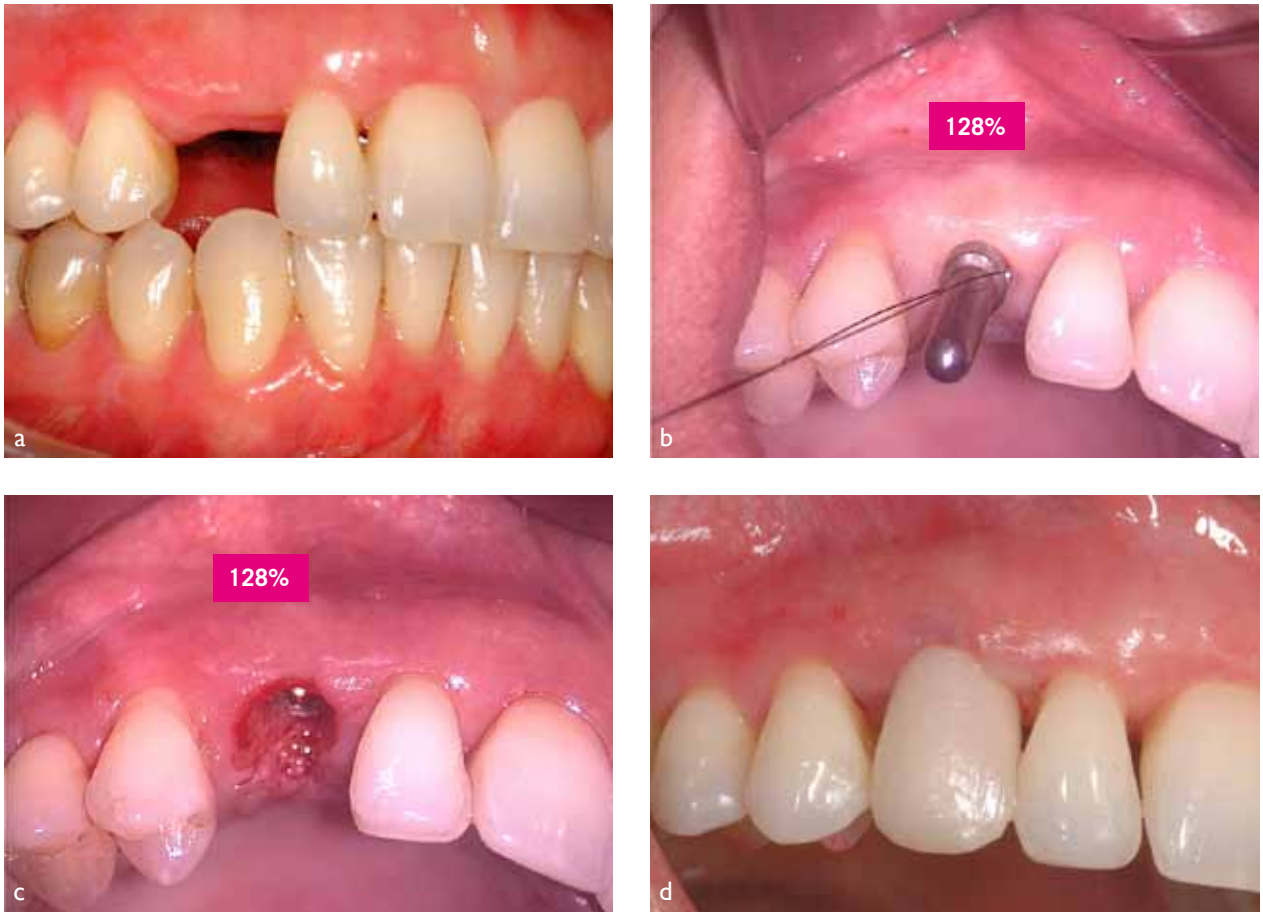
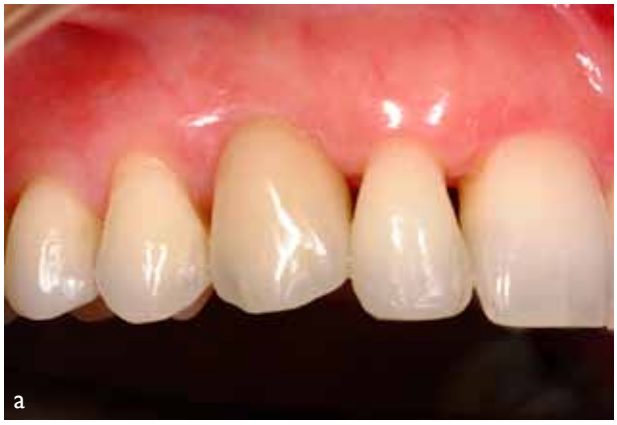


Fig 5-9a to d A 25-year-old woman with an intact alveolar ridge, but revealing a narrow crest with a marked concavity on examination with CBCT. The patient underwent transmucosal surgery, using the 2-mm twist drill with a navigation system to center the perforation on the remaining ridge. The soft tissues were then modified as necessary and a 3.3-mm diameter implant was placed, with the platform placed 4 mm from the future gingival margin of the restoration. Finally, the missing tooth was replaced with an immediate provisional prosthesis.

Fig 5-10 View of the CAIS from the case in Fig 5-9, using a navigation protocol (RoboDent®). The position of the drill (green-colored cylinder) can be seen in the three axes of the cavity and in the 3D model. In the upper right side of the screen, an illuminated green target shows that the position and axis of the drill are correct, and a depth gauge with audible alarm indicates the depth of the perforation.



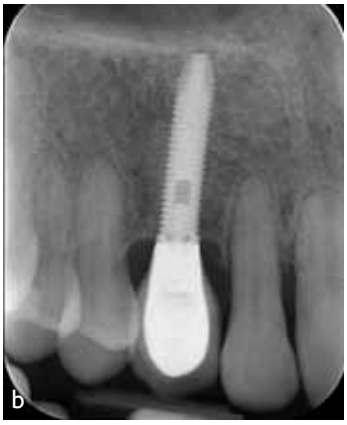


Fig 5-11a and b Final restoration with single screw-retained non-segmented implant-supported prosthesis.

Table 5-1 *Scientific interpretation of the terms precision and accuracy (from Hulley et al.[9])*

	Precision	**Accuracy**
Definition	The degree to which a treatment has nearly the same result when applied repeated times	The degree to which a treatment produces the result that it is supposed to produce
Best way to assess	Comparison among repeated applications	Comparison with a reference standard
Threatened by	Random error	Systematic error (bias)
	Reproducibility	Validity

5.3 How reliable are CAIS systems?

Computer-aided implant surgery has become a highly accessible technology today, documented by multiple studies.[4,6,8] Some of the systems studied are already implemented in clinical practice, while others are on the way to becoming a routine treatment option. The added safety provided in principle by this technology has made it the standard choice for non-invasive treatments, without the need for flap raising and suturing. It is also the first choice for complex cases such as situations with limited bone availability, or where the implants are to be placed very close to critical anatomical structures.[6] All of the above raise the need for an objective evaluation of the precision and accuracy of these procedures.

The terms precision and accuracy are often confused in the reviewed literature; from a colloquial English point of view, they are almost synonymous. However, when we delve into scientific resources, such as the now classic text by Hulley et al., Designing Clinical Research,[9] we find that they are both noticeably different and complementary concepts (Table 5-1). Precision represents the degree to which a treatment, or a procedure, has nearly the same result when applied several times. The best way to assess precision is to compare among repeated applications. It is affected by random error, and it is a synonymous with reproducibility. On the other hand, accuracy is the degree to which a treatment, or a procedure, produces the result that it is supposed to produce, and no other. The best way to assess accuracy is comparison with a reference standard. It is affected by systematic errors, and it is a synonymous with validity.

Focusing on the field of CAIS, we can try to understand the concept by imagining the behavior of a surgical template for placing six implants in a mandible.

Firstly, let us imagine a surgical template that is very stable in the mouth, which holds its position firmly while scanning and during surgery, but in which the adjustment between drills, implant holders, and drill sleeves and cylinders allows for a certain degree of movement. This lack of adaptation during drilling and positioning of the implant allows for a tilting of the drills and of the implant which, depending on multiple factors such as mouth aperture, bone quality, region of the mouth, skill of the surgeon etc., can lead to slight deviations, in opposing directions, with a different angle and of a different magnitude in each location (Fig 5-12). We would therefore encounter a lack of precision, and if the template was to be used repeatedly

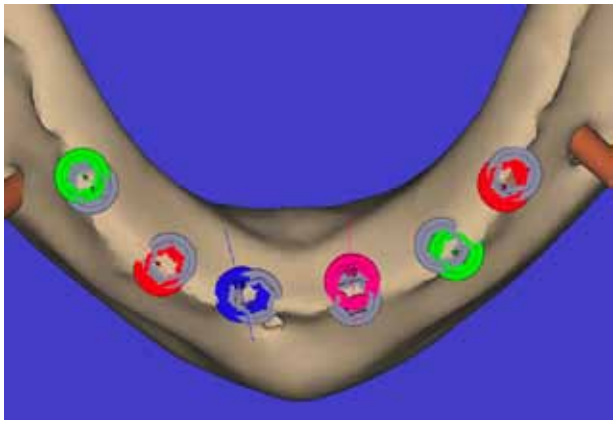


Fig 5-12 Example of lack of precision in the placement of six implants with a drilling template. The implants placed with the template (colored) show random and varied deviations with respect to the planned position (gray color).

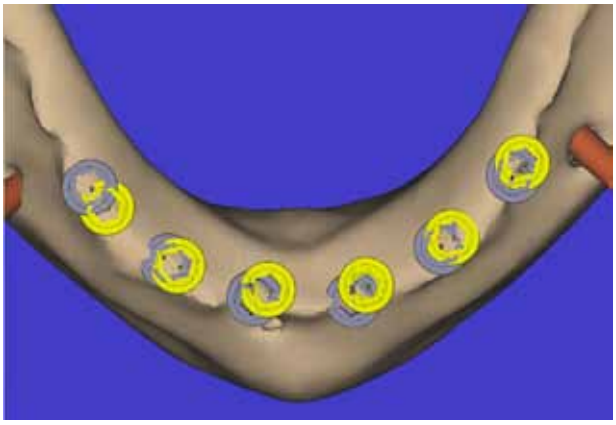


Fig 5-13 Example of lack of accuracy (systematic error) in the placement of six implants with a drilling template. The implants placed with the template (yellow color) show the same type of deviation in all sites with respect to the planned position (gray color).

on different models, the result would change in each case (ie the procedure would not be reproducible).

On the other hand, let's say we have a problem fitting the template into the mouth, which becomes unstable or changes position between scanning and surgery, shifting 1 mm to the left; and, at the same time, the quality of the sleeves of this template results in a perfect seating between the sleeves and drills and consequently the implant can be drilled and positioned without any deviation. In this case, we would be facing a general systematic error, equally affecting all implants which are all shifted 1 mm to the left, maintaining uniformity in all other parameters (Fig 5-13).

In the type of treatment discussed, where both concepts are tightly intertwined, it is difficult to determine when a deviation reported in a study is caused by a problem of precision or accuracy. On the other hand, almost all authors use the term accuracy to encapsulate both concepts, according to the definition of Widmann and Bale:[4] "The accuracy of an image-guided procedure is defined as the deviation in location or angle of the plan compared to the result, and includes all possible individual errors from image acquisition to surgical implant positioning." These types of errors are cumulative and interactive, and range from errors produced by image capturing techniques, possible template instability during x-ray and/or surgery and patient indexing system reliability, to deviations caused by the navigation system or during the surgical template manufacturing process.

Since it is extremely difficult to isolate the effect of each possible source of error, most authors choose to measure the deviations between the position of the planned implant and the position of the implant once placed in the mouth, taking two consecutive CT scans. These scans are then combined and used to evaluate four fundamental variables:

- deviation at the implant entry point
- deviation at the edge of the implant
- vertical deviation at the shoulder of the implant
- angular deviation of the implant.

A recent meta-analysis from our study group[10] evaluated the precision of these procedures using data from 20 published studies giving information on 12 systems, four of which were based on the use of surgical templates and eight on navigation systems. In total, information was evaluated from 1214 sites (570 implants and 644 drilled alveoli). It is important to bear in mind that the majority of the studies found, particularly those carried out with navigation systems, were performed on cadavers or "in vitro" (14/20), while only six were performed on patients.

Average deviation at the entry point was 0.73 mm (Figs 5-14 and 5-15a), very similar to previous meta-analyses,[6] for which when extrapolated to the general population of patients we could expect a deviation from 0.59 mm to 0.86 mm in 95% of cases. No significant differences were found between the use of template-based systems (average deviation 0.81 mm) and navigation protocols (0.68 mm), although in this second group,

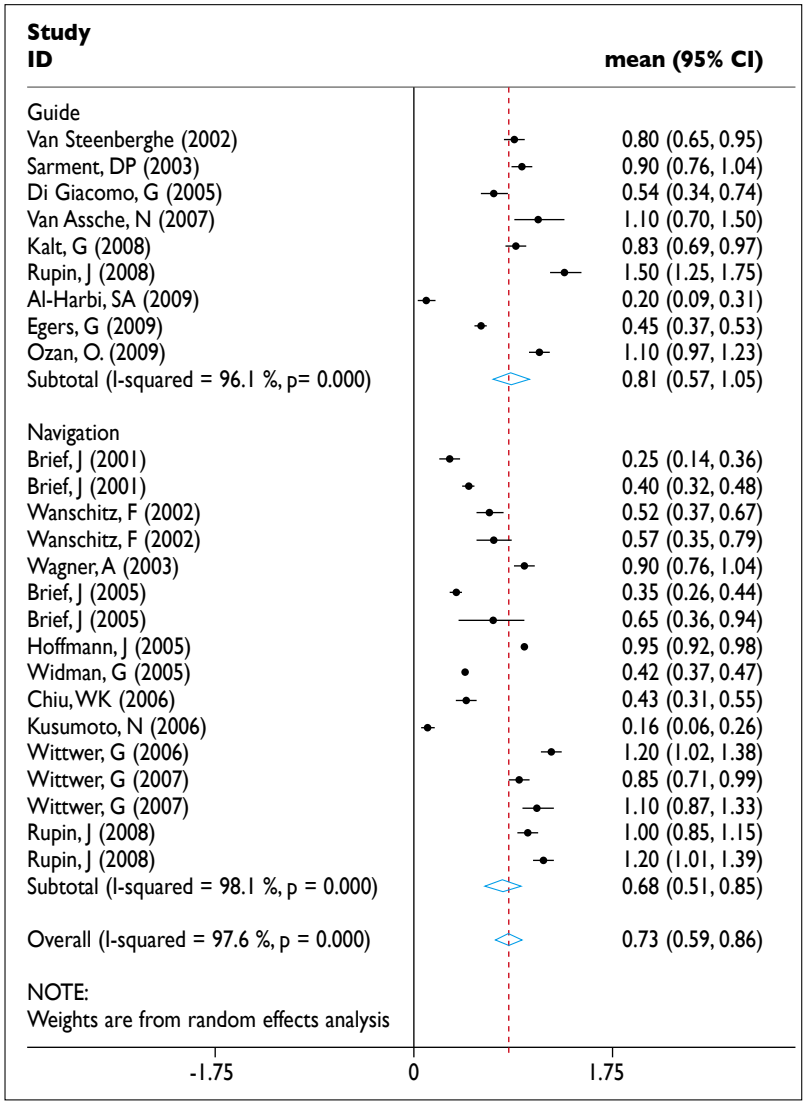


Fig 5-14 Forest plot of deviation analysis at the entry point. The discontinuous vertical red line and the lower diamond indicate the average deviation comprising the studies.[10] Each study is represented by a dot (showing the average) and a horizontal line (showing the standard deviation). The weighted average for each group of studies (template or navigation) is represented by a diamond.

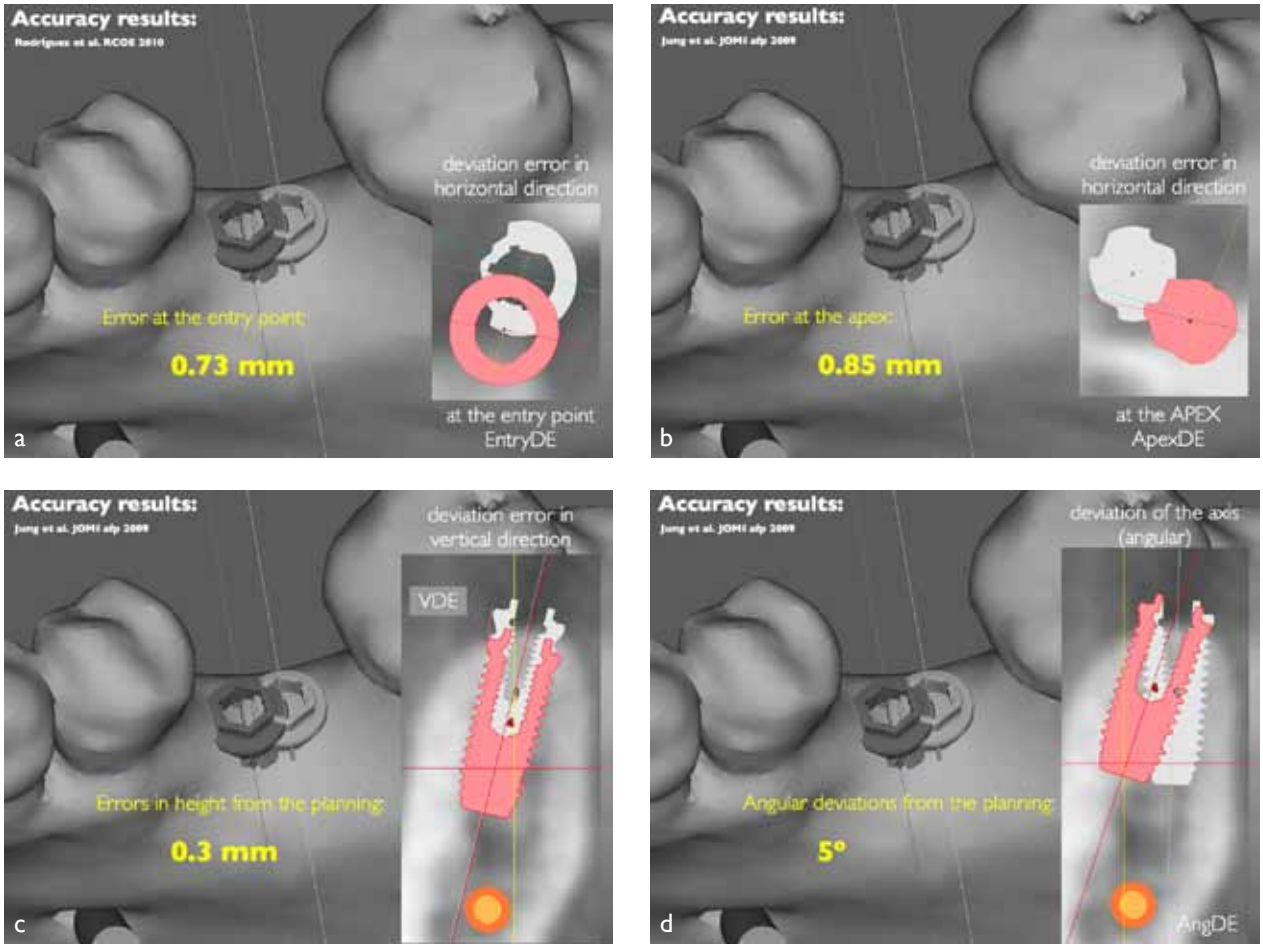
as already mentioned, there are fewer studies on patients. Reliability seems high, although we must consider that in certain cases, the deviations detected could have a significant clinical impact, with the maximum deviation at the point of entry found to be 3.4 mm.[10] Deviation at the apex was 0.85 mm (Fig 5-14), while vertical and angular deviation were 0.3 mm and 5 degrees respectively (Figs 5-15b to 5-15d).[6]

5.3.1 Conclusion

Computer-aided implant surgery is a reliable procedure, with average deviations of less than 1 mm. We must be particularly attentive to factors we can control that can affect the precision of the treatment, such as the correct adaptation of radiographic and surgical templates, adequate patient indexing, and an appropriate image capturing technique. During surgery, the clinician must strive to ensure that the drilling and placement of the implant do not deviate significantly from the plan. Surgery must be guided but must not be blind.

5.4 Is bone density useful as a planning tool?

Primary stability of implants is generally considered an essential factor for osseointegration[11] and capacity to withstand an immediate load, to the extent that if primary stability declines drastically in poor quality bone, osseointegration could be compromised.[12,13] However, primary stability is not only related to bone quantity and quality,



Figs 5-15a to d Measures of precision in CAIS: (*a*) deviation at entry point, (*b*) deviation at apex, (*c*) vertical deviation, and (*d*) angular deviation.[6]

but also to the morphology of the implant, and the alveoli drilling and the fixture placement techniques.[14,15]

Nowadays, clinicians are forced to make decisions every day during the planning stage, in which they must be able to assess the load capacity of a potential implant that is to be placed at a specific site; patients, meanwhile, expect this decision to be increasingly documented. Consequently, bone density testing of a site where an implant is potentially to be placed could be a parameter of great value.[16]

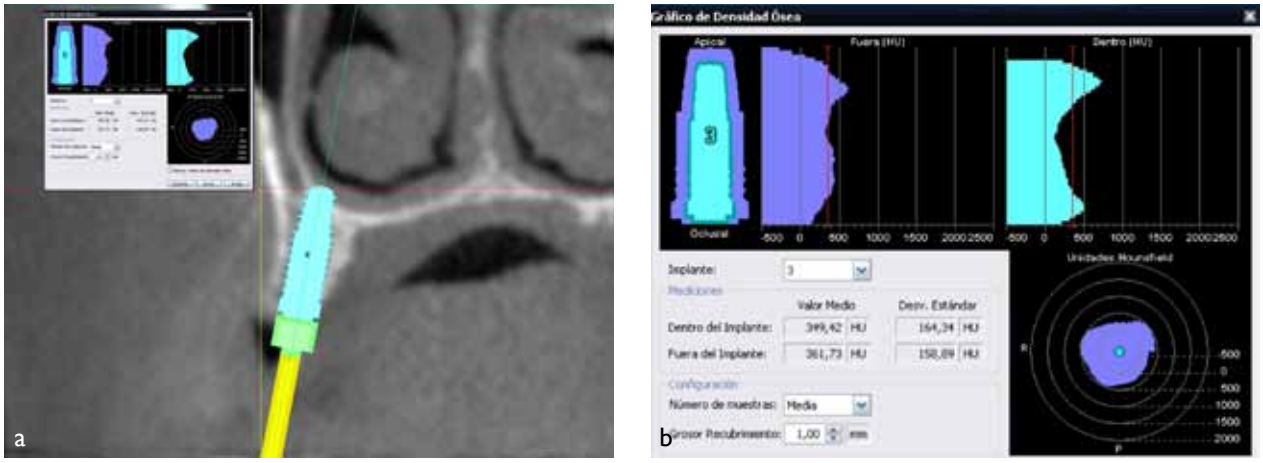
Bone density is measured in Hounsfield units (HU), which are based on the x-ray attenuation coefficient of the different materials and tissues submitted to x-ray beams. Distilled water at 25°C is defined as zero HU, soft tissues are defined as near-zero HU or negative HU values, while bone, in a CT scan, would fluctuate between 100 and 1900 HU.[16] Trabecular bone would be at the bottom of this scale, and negative values within the space occupied by the bone would represent fatty tissue that has replaced trabecular bone.[17]

Various authors have proposed scales to match HUs and the Lekholm and Zarb bone type classification. One of these is the Fanfani approach.[16]

- 100–350 HU for type IV bone
- 350–700 HU for type III bone
- 700–1200 HU for type II bone
- 1200–1900 HU for type I bone.

Today, the use of CBCT scanners has modified slightly this scale, although there is still a good correlation between bone types and HUs obtained with CBCTs. Like in CT scans, with CBCT studies it is more difficult to distinguish between types II and III bone, though these are clearly differentiated from types I and IV.[18] As a clinical guideline, the authors propose the following scale for CBCT data:

- -50–100 HU for type IV bone
- 100–250 HU for type III bone
- 250–400 HU for type II bone
- > 400 HU for type I bone.



Figs 5-16a and b Bone density analysis obtained using the SimPlant® software in an edentulous area of the alveolar ridge (*a*). This analysis provides the profile and values of the mean and standard deviation for the osseous portion that will surround the virtually placed implant (blue), and for the bone that is to be removed at the drilling stage (green) (*b*). The average value in peri-implant bone is 361.73 HU, showing a profile (blue graph) quite balanced with respect to the average (red line) (*b*).

From a clinical perspective, using CBCT in areas with bone density values over 250 HU gives a good prognosis for primary stability. Greater care must be taken in sites with values of 100 to 250 HU, where good primary stability can be achieved provided that it is performed with carefully customized progressive instrumentation and using an implant with the appropriate morphology (Fig 5-16).

This type of information lets us approach the problem with two different strategies: on the one hand, choosing an implant site that offers optimal immediate load capacity and the best long-term prognosis; on the other hand, establishing the drilling sequence and the type of implant preoperatively which, given the circumstances, would achieve the best possible primary stability.[15]

One of the drawbacks of measuring bone density in HU is that it is affected by the amount of energy passing through the tissues, which depends on the x-ray technique used with the CT or CBCT. Techniques that use less energy will provide images with higher HU values. As such, studies deriving from different CT or CBCT equipment, set up with different techniques, will give different bone density information in HU. From a research stand point and regarding the publication of results, the solution to this problem may lie in quantitative computerized tomography (QCT).[14] This technique is based on the use of a calibration phantom submitted to CT or CBCT testing at the same time as the patient, which allows calibration of the measuring tool and conversion of HUs into mg of hydroxyapatite per cm^3, or bone mineral density (BMD) units.[14,15] These data can be extrapolated amongst x-ray devices. The clinician can mitigate this problem internally by using the same CT or CBCT device configured using the same technique.

5.4.1 Conclusions

It is advisable to evaluate peri-implant bone density a priori in order to adequately choose the best site for the implant, to optimize the drilling technique, and to select the type of implant in order to obtain the best primary stability, particularly with immediate load methods. All CT or CBCT testing should be performed using the same equipment and configured applying the same technique in order to produce consistent bone density values.

5.5 What are the benefits and drawbacks of each type of system?

Each of the systems evaluated has its own advantages and disadvantages (Tables 5-2 and 5-3), therefore a specialized clinic would benefit from using different systems for different indications, which would broaden its range of use for computer-assisted surgery.

From a practical point of view, clinic and laboratory produced templates offer logistic and economic benefits. Moreover, the Med3D® system, as it is an open technique system, allows the use of cylinders in templates of

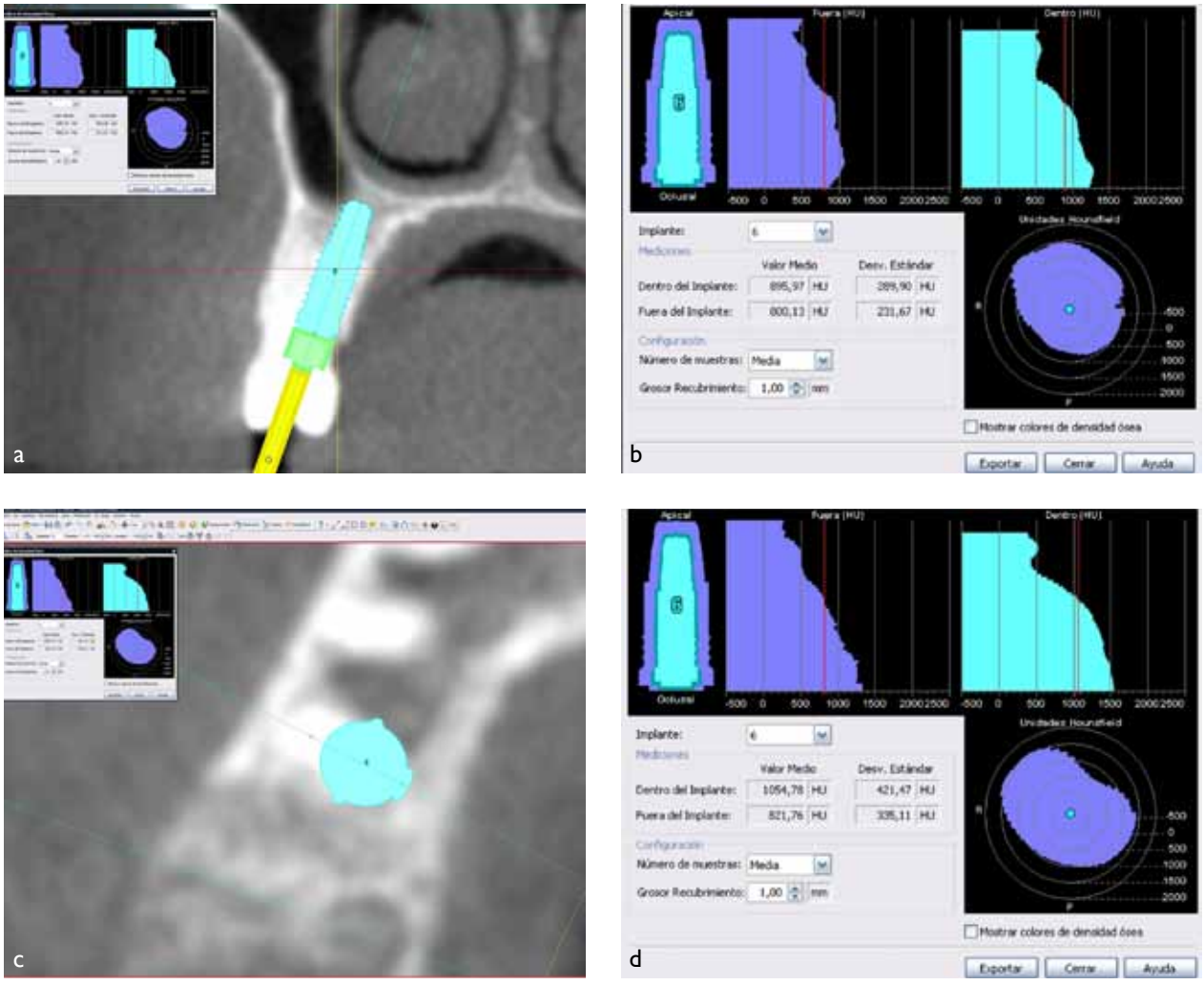
Table 5-2 Main differences among the different systems of computer-assisted implant surgery from a clinical point of view

System	Scanning procedure (simple or double)	Fully EP	Perpendicular guide pins to gain stability	Partially EP	Bone-supported templates	Hardware	Facilitates producing immediate provisional prostheses	Open or closed system	Industrial or lab-clinic fabrication of template
NobelGuide®	Double: Pat + Dent and Dent + Fiduc	+++	Yes	+ Scanning of plaster cast	No	+++	+++	Closed	Industrial
SimPlant®	Simple Pat + Dent + RO teeth	+++	Yes	+ Scanning of plaster cast	Yes	++	+++	Open	Industrial
Med3D®	Simple template + teeth + lego brick	+	Difficult	+++ No scanning of plaster cast	No	+++	+++	Open	Lab-clinic
RoboDent®	Simple plastic template + Fiduc	+	No	+++ No scanning of plaster cast	No	No need for special hardware	++	Open	No need

Pat, patient; Dent, denture; EP, edentulous patient; Fiduc, fiducials; RO, radiopaque.

Table 5-3 Main differences among the different systems of computer-assisted implant surgery from a software capabilities point of view

System	Ability to produce a high-quality 3D model	Helpful when exploring the arch anatomy	Helpful when planning implants	Bone density tool	Ability to separate/highlight anatomic structures	Virtual teeth	Allows precise information of soft tissues	Allows precise information of neighboring crowns/teeth	Planning of bone grafts
NobelGuide®	++ Automatic (editable)	++	++	+	+	No	No	No	No
SimPlant®	+++ (SimPlant Pro or higher version)	+++	+++	+++	+++	Yes	No?	No?	Yes (higher version)
Med3D®	++ Automatic (editable)	++	++	+	+	No	No	No	No
RoboDent®	+ Automatic	+	+	+	+	No	No	No	No



Figs 5-17a to d Bone density analysis in the planning of an immediate post-extraction implant (*a*). The high density of the tooth (close to 1000 HU; not yet extracted) increases the average density of the future peri-implant bone (800.13 HU) (*b*), which could lead to clinical confusion. At this point, it is important to observe the profile on the blue graph (b) and assess the bone density apical to the remaining tooth (close to 500 HU) and, from an occlusal perspective (*c and d*), the density profile of the mesial, distal, and palatine bone.

any implant manufacturer (provided that the company manufactures the corresponding cylinder positioning tool). This, together with its ability to adapt the template to the adjacent teeth (as it is basically created on plaster models, it is not affected by radiographic artifacts), makes this type of mechanical procedure the best choice for building a template for partially edentulous patients (ie to design and fabricate tooth-supported or tooth/mucosa-supported templates [Table 5-2]).

Planning stabilization pins on axes that are nearly perpendicular to those of the implants to be placed is more complex – and sometimes impossible – when using mechanical systems. For this reason, in fully edentulous patients, it seems more appropriate to use procedures based on the use of stereolithographic templates (NobelGuide® and SimPlant®), where stabilization pins can be placed (Table 5-2).

Finally, as it is easy to index patients with a plastic plate securing an arch with markers, and this shows a good stability in partially edentulous patients with teeth at both ends of the edentulous gap, navigation systems such as Robodent® are the most operative procedure. While these procedures reduced costs in each case, because templates are not needed, we do have to consider the cost of purchasing the equipment and tools, which is far greater (Table 5-2).

However, a computer-assisted surgery system needs to provide something more than the mere production

of templates or enabling the use of navigators: it needs to facilitate diagnosis and surgery planning. In this sense, it is essential that such a system allows for the creation of high-quality custom 3D models with tools for examining the jaw to be treated (beyond just the placement of implants), providing the clinician with an effective tool for evaluating bone density in each potential implant site (Figs 5-16 and 5-17) and allowing for the separation of the relevant anatomic structures and for virtual dental extractions (Fig 5-2; Table 5-3).

5.5.1 Conclusions

For a specialized center with a significant surgical volume, it may be convenient to use several CAIS systems alongside each other.

- In free-end partially edentulous patients and those requiring multiple implants with just a few remaining teeth, a mechanical system may be the best option.
- In partially edentulous patients with teeth on both sides of the edentulous area, a navigation system would be quicker and more versatile.
- In fully edentulous patients, greater template stability would be observed when using stereolithographic template systems.

5.6 What are the limitations of computer-assisted surgery?

5.6.1 Acceptable reliability, occasional deviations

We have previously reviewed the reliability of CAIS procedures, and reached the conclusion that average reliability is clinically acceptable, with deviations of less than 1 mm. However, we cannot rule out that occasional protocol alterations might cause significant deviations in assisted implant placement. Therefore, the drilling angle and implant placement must be continuously monitored throughout surgery.

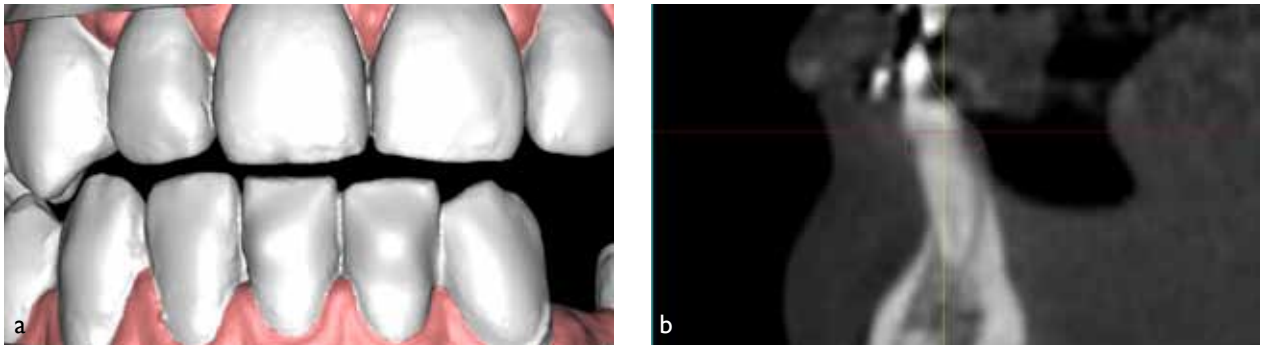
5.6.2 A need to combine different systems

Likewise, we have reviewed the CAIS systems and concluded that it would be interesting to use several procedures (mechanical and stereolithographic templates, navigation systems) for different types of clinical scenarios. Unfortunately, this versatility can only be achieved by combining diverse systems, which would multiply the workload and costs for the professional team. Consequently, the ideal situation would be to have a common diagnosis platform that allows for comprehensive diagnosis and planning, and for the creation of any type of template or the use of navigation procedures.

5.6.3 Lack of information on soft tissue

Finally, there is a crucial limitation regarding the information provided by our tomographic research on soft tissue and adjacent teeth morphology, as well as regarding the soft tissue margin position in relation with the position, height, and width of the alveolar crest. It is therefore quite complex to make a precise esthetic evaluation in current 3D models. To overcome this conflict, several experimental procedures have been established where patient's DICOM (digital imaging and communications in medicine) data are assembled with files created from scanning plaster models and pictures of the patient. However, this process shows complications arising from a lack of precision in its analogical factor, as well as from assembling 2D images (eg pictures) on 3D models.

Luckily enough, with the development of intraoral optical scanning technology, such as 3M LAVA (3M, St Paul, MN, USA) systems, information on soft tissue and morphology of adjacent teeth can now be retrieved digitally and in a more precise fashion, and this information can then be brought together in a .stl file that can be "assembled" with DICOM data. This new method of combining information will allow the surgeon to carry out more reliable planning, particularly regarding noninvasive surgical techniques, and a better preoperative assessment of esthetics issues. It could be used to measure esthetic parameters after implant surgery, such as the capacity to preserve the volume of the alveolar ridge after tooth extractions, or the progress of regenerative procedures. Nowadays, this is only possible by analyzing sawn and scanned sections of plaster models, and it will be of great help also in the fabrication of tooth- or mucosa- supported stereolithographic templates (Fig 5-18).



Figs 5-18a and b Resulting images after assembling a DICOM file obtained with a CBCT (iCAT) equipment and a .stl file created from an intraoral optical scanner (3M LAVA). Notice the precise morphology of tooth crowns and soft tissue (*a*), and its relation with the underlying DICOM data containing information about root morphology and the alveolar bone (*b*).

Figs 5-19a and b (*a*) Surgical environment with multiple screens for COIS. (*b*) At surgery, the surgeon and his team interactively manage information from the microscope camera, the preoperative intraoral picture, the 2D radiology, the planning information, and the 3D model.

5.7 Computer-oriented surgery: a new dynamic concept

The occasional lack of reliability, the need to use multiple systems in order to approach diverse indications, the scarce information on soft tissue and coronary structure of adjacent teeth, and the need for free, creative, and flexible surgical procedures that can adapt to different intraoral environments and scenarios have encouraged a simultaneous use of information in digital planning, as well as data directly retrieved from clinical reality at surgery, creating the so-called computer-oriented implant surgery (COIS).

In this type of procedure, the surgeon uses digital and analogical information in the planning stage (3D models, planning systems, virtual implant placement, real models, clinical pictures, and standard radiography). Moreover, the surgeon keeps a close rapport with this information during surgery through a computer multi-screen structure, where information from the microscope camera, the preoperative diagnostic picture, standard radiology, and the 3D planning software program are constantly adapted depending on the intraoral site in which the surgeon is working. This technology allows the surgeon to use a template or navigation system at the initial drilling phase using the 2-mm twist drill, in order to establish the position and axis of the future implant, and perform the remaining surgery stages applying a COIS procedure, or the surgery can be entirely carried out using a COIS method. The concept behind this proceeding is the interactive use of information in order to promote at each stage continued "documented real-time decision making" (Fig 5-19).

5.8 Disclosure agreement

The authors of this article declare that at the time of drafting, they had no economic ties whatsoever with any of the companies involved in the design and distribution of the products and equipment of CAIS described herein. Practical statements reflect the authors' experience in the direct use of the various systems analyzed and are merely intended to share their experience with clinicians getting started in this field.

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