An Image-Guided System–Drilled Surgical Template and Trephine Guide Pin to Make Treatment of Completely Edentulous Patients Easier: A Clinical Report on Immediate Loading

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ABSTRACT

Purpose: An image-guided system has been developed to drill a conventional surgical guide following a preoperative three-dimensional plan for accurate placement of implant on bone. The aim of this study is to illustrate how this system facilitates treatment of completely edentulous patients by modifying both surgical and prosthetic protocols, thereby making flapless surgery possible as well as the preparation of the transitional prosthesis before surgery.

Materials and Methods: This system was tested on 10 consecutive patients, placing all planned implants without raising the mucoperiosteal flap and with the connection of all implants to pre-angulated abutments.

Results: A 1-year follow-up demonstrated stable and properly functioning prostheses in all cases.

Conclusions: This technique can be expected to flourish because implantology makes the highest demands on comfort, precision, and safety.

KEY WORDS: computer-aided surgery, implant dentistry, minimally invasive implant surgery, preoperative planning, surgical flap, tomography, trephine guide pin, x-ray computed

Successful implant treatment relies on the osseo-integration of the implant and on the final prosthetic outcome, both functional and aesthetic. Patients' aesthetic expectations challenge the dental surgeon to provide a precise duplication of the natural teeth. To achieve the best result, the implant position should be determined by the planned prosthesis.[1–3] Placement of the implant at a position that corresponds to the apical extension of the predetermined teeth may require the use of a surgical guide especially designed for complex clinical situations such as those involving the completely edentulous patient, tooth replacement in the appearance zone, extremely limited mesiodistal space, and converging roots of neighboring teeth.

In the past decade the use of medical imaging technology to ensure accurate implant placement has been proposed. Currently the objectives of image guidance are twofold: (1) defining an operative strategy that takes advantage of the localizing capabilities of imaging and (2) performing the previously defined operative procedure with a suitable guidance system. Guiding systems consist of an imaging workstation at which to plan the surgery and a technologic tool with which to transfer the planned surgery to the surgical field. For oral implant placement, the following different

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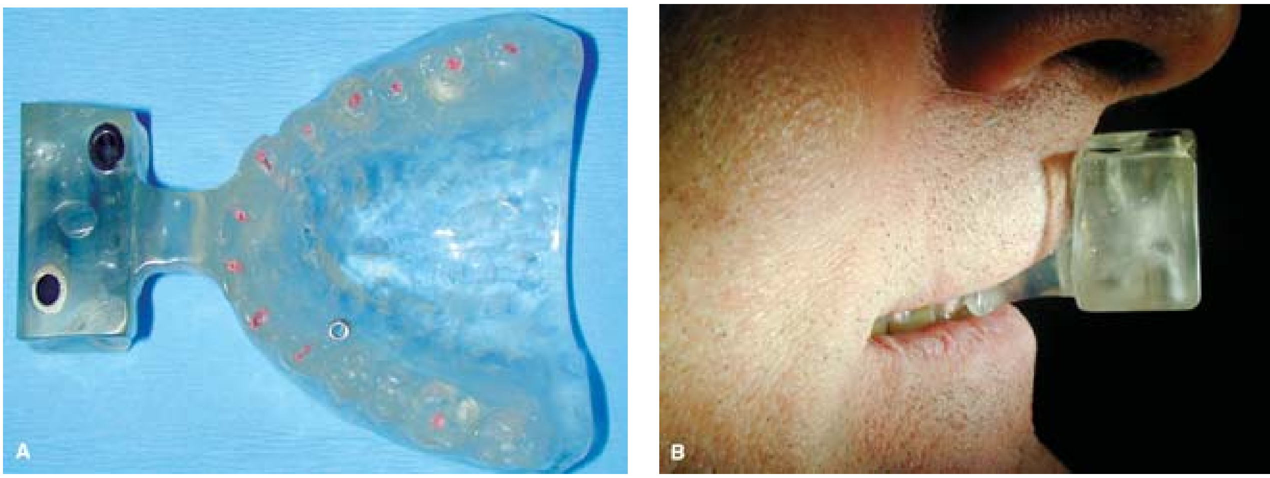

Figure 1 Scanning template. *A*, The scanning template is a duplicate of the study prosthesis and is made of acrylic resin with radiopaque markers. A prefabricated cube including two titanium tubes is attached. *B*, During the CT examination, the scanning template is immobilized under occlusal pressure, and the cube is outside the mouth, in front of the lip.

approaches to transferring the planned position to the surgical field have been proposed: navigating with an optical tracking system[4–6] or a magnetic tracking system[7]; using a template, fitted on soft tissue, as a drill guide on the surgical field[8–10]; and using a robot with a mechanical arm.[11] A more invasive procedure using a

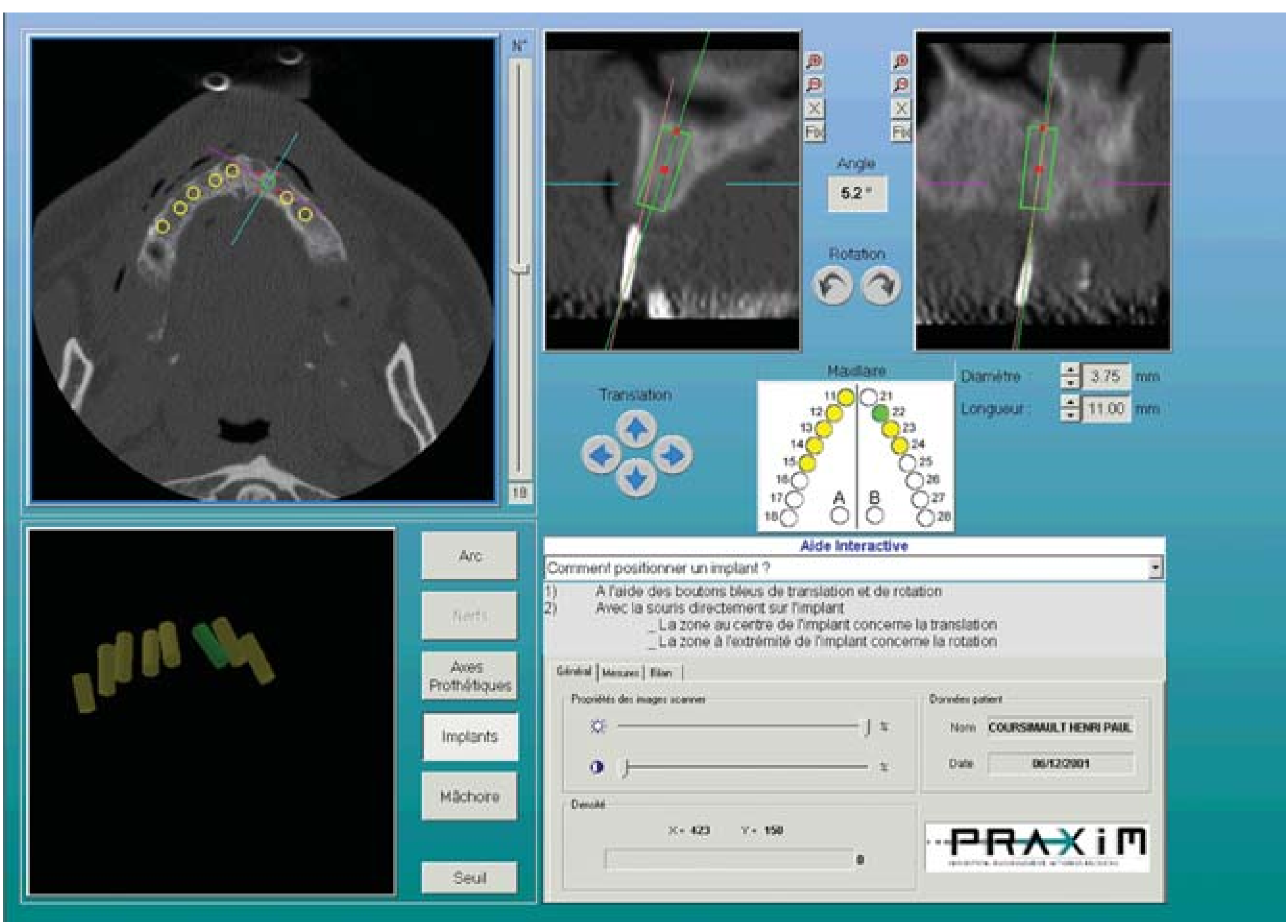

Figure 2 The planning software plans every implant on three planes: the axial plane (see the mark of the titanium tubes) and two reformatted planes (tangential and perpendicular) passing exactly through the implant axis. The practitioner can change the position of the implant on each plane and check the implants on a three-dimensional view.

Figure 3 *A*, Drilled template. The template, after being mounted on its plaster cast, is drilled by a drilling machine at the exact location of the planned implant axis. The practitioner can assess the implant position in relation to the planned prosthesis position on the template. *B*, Plaster cast, also drilled. The practitioner can assess the implant's emergence point on the plaster cast. The template and the plaster cast can be drilled with holes of different diameters.

template fitted on bone has also been proposed.[12–15] With a navigation system, implant positions and orientations are defined with the aid of a computer. Implementation of the preoperative plan, on the other hand, is performed manually by the surgeon, with graphic support from the navigation system when the holes for the implants are drilled. Clinical applications of these systems are helpful for positioning. They are known to be more flexible because modifications in the drilling procedure are always possible during surgery. The navigation-guided adjustment of the angulation, however, cannot be attained easily. Furthermore the influence of random factors such as trembling cannot be substantially eliminated solely with computer-assisted navigation; the surgeon's experience and skill remain crucial elements in the quality of the intervention. It should be mentioned that a breakthrough in robot-assisted systems for dental implantology did not appear until now because of problems involving cost and getting the robot synchronized with the jaw movement.

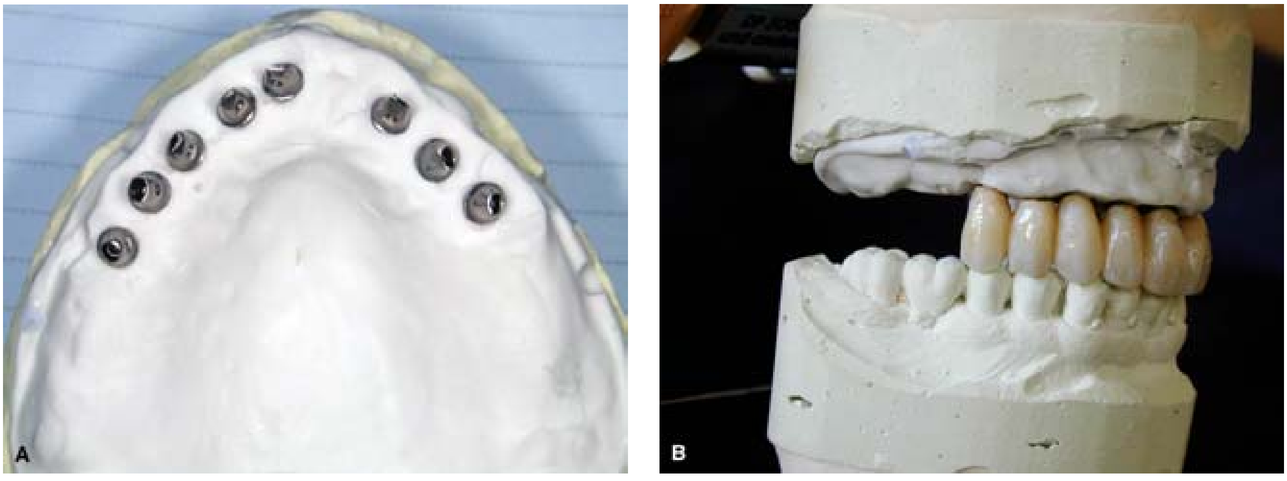

Figure 4 Premanufactured prosthesis. *A*, Definitive abutments made on the plaster cast. For the cemented prosthesis, if implant angulations are off the vertical to keep the implant body within the bone, the abutments are corrected by preparation on the plaster cast. *B*, Provisional prosthesis, also made on the plaster cast prior to surgery.

Figure 5 First osteotomy, done through the mucosa. To avoid slight motion during the drilling procedure, the template is tightly screwed onto the underlying bone (*arrow*) at the beginning of the procedure, with the template immobilized under occlusal pressure (as during the CT examination).

With a template, the axis of the drill under the surgeon's control is physically limited to the planned axis with a mechanical device.[8–10] Templates are therefore considered to be more accurate. In fact, using an optical tracking system, Birkfellner and colleagues reported a discrepancy of 1.23 ± 0.28 mm on average and a maximum of 1.87 ± 0.47 mm between the planned position of a fiducial point marker and its real position.[4] It has been demonstrated that templates provide submillimeter accuracy with little dependence on image resolution.[16]

In 2002 and 2003, Van Steenberghe and colleagues proposed the use of an image-guided system associated with a template fitted on the bone to place zygoma implants and to make a three-dimensional resin model of the desired area of the patient in order to build a master cast from which to make the prosthesis prior to surgery.[14,15]

The present paper describes the surgical and prosthetic protocol for an image-guided system based on a mechanical device coupled with a custom template fitted on the mucosa in preparation for flapless surgery and for making the transitional prosthesis prior to surgery.

MATERIAL AND METHODS

Clinical and Radiologic Examination

Following a complete examination of the patient, the restorative dentist makes a study prosthesis on diagnostic plaster casts representing the final restorative prosthesis. After satisfactory testing in the patient's mouth, the study prosthesis is duplicated in acrylic resin; this duplicate then serves as a conventional scanning template.[17] To be clearly visible on radiography, either the prosthetic teeth are made of radiopaque resin (SR Vivo TAC / SR Ortho TAC, Ivoclar Vivadent, Saint-Jorioz, France) or gutta-percha is glued to the teeth to indicate the ideal implant axis. A prefabricated acrylic resin cube called an X-cube (Cadimplant Inc., Medfield, MA, USA) is then attached to the scanning template before the computed tomography (CT) examination so that when it is in the mouth, the cube is outside, in front of the lip of the same maxilla (Figure 1). The X-cube will be used to transfer the planned position onto the template with a drilling machine. The X-cube includes two tubes made of titanium in a very precise position, perpendicular and uncrossed. CT is done with the template in the patient's mouth, and images are directly inputted to an imaging personal computer.

Planning Software

The preoperative plan is prepared with custom-designed CADImplant® software (Cadimplant Inc.). The position of the planned implant is visualized on three planes: the axial slice and two reformatted views. One of these latter two views is perpendicular to the arch of the jaw, and the other is tangential; they both not only intersect the fixture axis but pass through it. Thus the implant is precisely located in the three-dimensional volume; there is no approximation of the calculated position. Only the axial plane intersects the implant axis.

At the beginning of the planning procedure, the two reformatted planes are initialized with the gutta-percha axis. Taking into account the anatomic structures, the practitioner can interactively change the position of the fixture on each plane. Simulation is carried out in real time. The other planes are instantaneously recalculated so that cross-sectional slices always pass through the implant. When there are several implants, the practitioner works on one implant and then proceeds to the next one while the images of the previously planned implant remain on the axial slices. If necessary, their position can be changed until the result is satisfactory. To improve the relative position of implants in relation to one another, the clinician can also use the three-dimensional view showing the shape of the jaw, the ideal prosthetic axis, and the implant materialized by a cylinder (Figure 2).

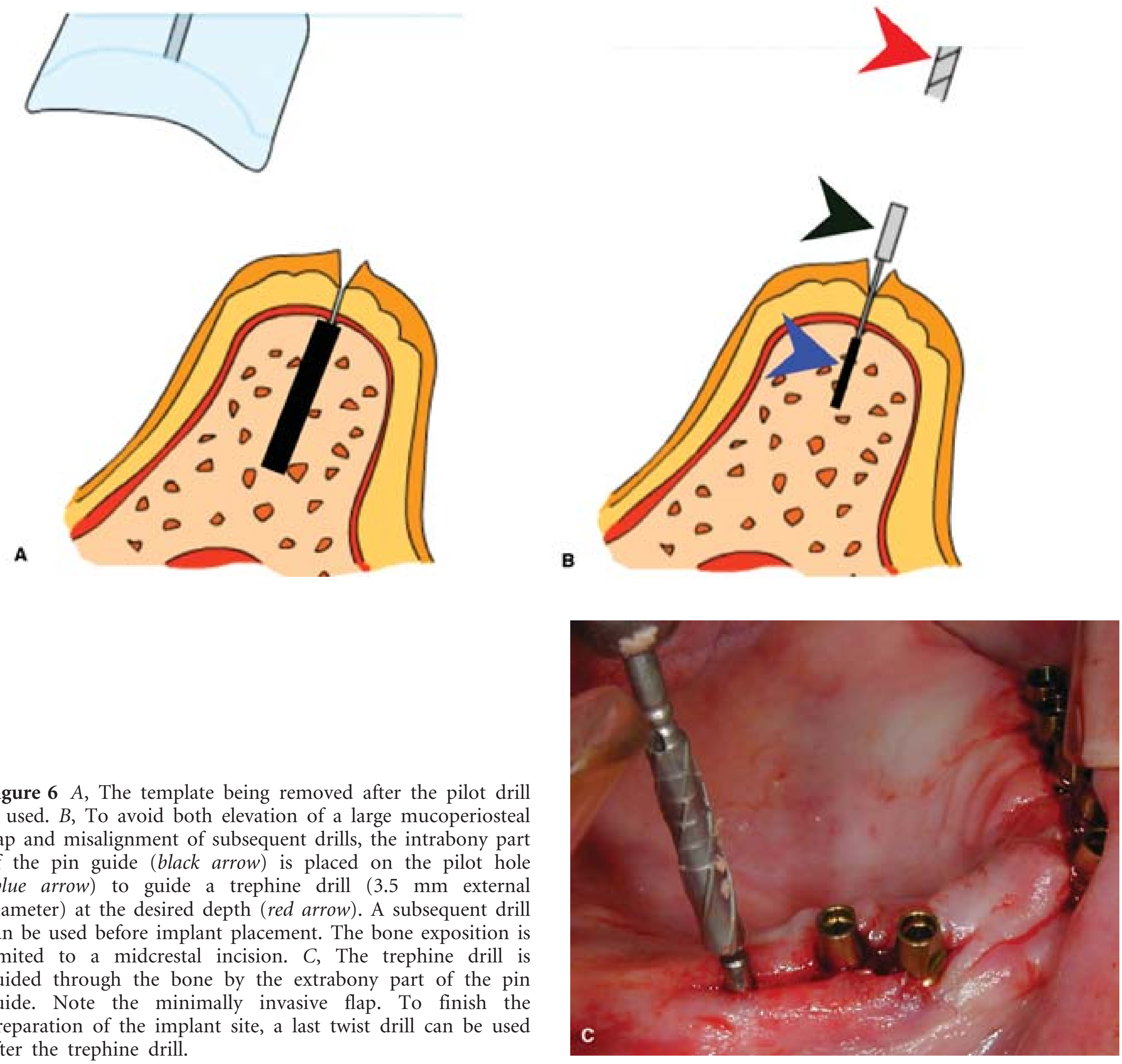

Figure 6 *A*, The template being removed after the pilot drill is used. *B*, To avoid both elevation of a large mucoperiosteal flap and misalignment of subsequent drills, the intrabony part of the pin guide (*black arrow*) is placed on the pilot hole (*blue arrow*) to guide a trephine drill (3.5 mm external diameter) at the desired depth (*red arrow*). A subsequent drill can be used before implant placement. The bone exposition is limited to a midcrestal incision. *C*, The trephine drill is guided through the bone by the extrabony part of the pin guide. Note the minimally invasive flap. To finish the preparation of the implant site, a last twist drill can be used after the trephine drill.

Template Drilling

Once the final positions of the implants are defined, the scanning template must be drilled at these exact positions. Thus, the template and the plaster cast are sent to a drilling center. The operator firmly attaches the scanning template and its plaster cast to a drilling machine by placing the resin cube on a dedicated device in the drilling machine and by passing two metal shafts through the two titanium tubes. While it is easy to extract the track of the titanium tubes in the resin cube from the CT images, they are used by the entire system to establish a mathematical link between the CT images and the drilling machine so that the position of the planned implant is drilled both on the template and on the plaster cast with high precision at the desired diameter. The diameters can be different for the template and for the plaster cast (Figure 3).

At this stage the practitioner can physically assess both the implant emergence position on the plaster cast in relation to the gingiva and the spatial orientation on the template in relation to the planned prosthesis. The

Figure 7 The definitive abutments are connected on the implants; the provisional prosthesis, reinforced by a metallic framework, is realigned with an autopolymerizing acrylic resin at the first surgical step or at the second-stage surgery.

coronal portion of the implant must be positioned to locate the abutment so that the final prosthesis can be cemented or screwed. If necessary, the planned position can be changed and the template redrilled.

Premanufactured Prosthesis

Since the surgical template has been drilled with the plaster cast, the position of the holes previously made on the plaster cast are the implant positions on the surgical site. Thus the definitive abutment and prosthesis are realized on this plaster cast (Figure 4). The provisional prosthesis can be reinforced with a metal framework for immediate loading.

Surgery

The resin cube is then separated from the template, which becomes a conventional surgical template. Metal tubes are used as drilling sleeves and are inserted through the hole of the template previously made by the drilling machine. During surgery, the surgical template is placed intraorally, fitted on the mucosa. In partially edentulous patients, the template is supported by residual teeth. With a completely edentulous patient, the curvature of the drilling template and the close contact with the hard-palate area reduce the degrees of freedom to zero. In addition, the template is tightly screwed onto the underlying bone. To reach the same position as during the CT examination, the template is screwed under occlusal pressure. A twist pilot drill 2.0 mm in diameter is inserted through the drilling sleeves for the first osteotomy, which is done through the mucosa (Figure 5). The template is then removed. To expose the bone, we use a midcrestal incision or a punch with a circumferential incision.

To avoid misalignment of subsequent drills, we use a trephine drill, guided over a pin guide.[18,19] The pin guide has an intrabony part 2.05 mm in diameter and 8 mm in length; to enhance the guidance, the extrabony part fits the trephine drill used. The differences between the diameters of the intra- and extrabony parts make it possible to insert the pin guide when it is placed on the bone. The length of the extrabony part depends on the depth the trephine requires for drilling; consequently the surgeon does not have to pay attention to the drilling depth. To start preparation of the implant site, the surgeon places the pin guide on the bone; the trephine drill is then guided by the extrabony part of the pin guide. Depending on the surgeon and on the implant used, a last twist drill can be used to finish the preparation of the implant site after the trephine and the pin guide are retracted. Implants are placed until the rough surfaces are submerged (Figure 6).

For greater accuracy during bone preparation, the template should be maintained on the gingiva with a series of titanium sleeves of different diameters that exactly match the series of twist drills used.[15]

Placement of Provisional Prosthesis

The abutments are screw-tightened onto the implants. The provisional restoration is relined with an autopolymerizing acrylic resin (Figure 7) to obtain either a cemented or screwed restoration, depending on the abutment used. The provisional restoration is finished and polished. The occlusion and articulation are checked and adjusted if necessary (Figure 8).

The provisional prosthesis made in advance can be

Figure 8 Temporary bridge in place. Occlusion and articulation are carefully checked and adjusted if necessary.

used either for immediate loading or for the second-stage surgery in order to shorten the prosthetic protocol and to take advantage of gingival healing around an abutment with a toothlike form.

RESULTS

This technique was tested on 10 consecutive completely edentulous patients, both for immediate and for delayed loading. All implants were used for connecting the pre-angulated abutments. A 1-year follow-up demonstrated stable and properly functioning prostheses in these cases. After 1 year, all transitional prostheses were removed, and all implants were successfully assessed clinically before elaboration of the definitive prosthesis. According to Miyamoto and colleagues, when using the pin guide technique, the discrepancy between the formed implant channel and the planned position could lead to a substantial alteration of the inner part of the transitional prosthesis.[18] However, it must be noted that in these 10 patients, no overhanging prosthesis restoration to enlarge the prosthesis was necessary, and no external tooth parts were injured. This demonstrated the high accuracy of this technique.

DISCUSSION

It appears from these results that it is possible to achieve precise placement of the implant on bone (according to the planned prosthesis and the individual anatomic situation) with an image-guided system (IGS), eliminating the need for flap surgery. This can be achieved by means of a workflow that provides a predictable procedure for accurate transfer of positioning information from the planning software to the dental arch. The three-dimensional planning must provide images of the anatomic situation around the axis of the planned implant to illustrate possible anatomic complications (ie, fenestration, dehiscence, poor bone density) that could lead to bone alteration during the surgical procedure. Predictability cannot be achieved with software that provides only multiplanar reformation perpendicular to the arch of the jaw and to the axial slices without taking into account the spatial orientation of the planned axis.[20] The planned position must then be transferred to the surgical site with submillimeter accuracy by means of a technologic tool. For accurate placement when using a template, the template must be drilled at the precise location of the planned axis, and it must be placed in the mouth during surgery at the same position as the radiologic template during the CT examination, particularly for flapless surgery, which is a blind technique. These two requirements are fulfilled with the technique presented here.[21] The template is drilled with a precision of 0.2 mm in translation and 1.1° in rotation, with little dependence on the spatial resolution of the CT images.[16] Furthermore, the surgical template is the drilled radiologic template. Thus it can be placed on the mouth at the same position during the CT examination and during the surgical procedure, supported by residual teeth. For the completely edentulous patient, the template is stabilized under occlusal pressure by the individual form of the arch and is secured by screws for surgery.

Using the same template for both the radiologic guide and the surgical guide to ensure precise placement of the surgical guide according to the planned position is an easy and cost-effective method for accurately transferring positioning information from the planning software to the dental arch.

Van Steenberghe and colleagues illustrated the use of an IGS to make prostheses prior to surgery and to reline them at the completion of surgery.[15] They proposed using a stereolithographic three-dimensional model that reproduces the jawbone to prepare the drilling template. Compared with conventional advance prosthesis preparation,[22] this approach takes advantage of the localizing capability of the IGS, but this technique is highly dependent on the quality of the CT image and on image segmentation. A three-dimensional stereolithographic model cannot be as accurate as a plaster cast, especially when preparing a prosthesis that takes into account the gingiva and mucosa. Furthermore, in the flapless technique, using two templates may make the placement of the surgical template on the gingiva approximate.

Although the application of IGSs in the medical field is gaining importance because this field makes the highest demands on precision and safety, many questions remain regarding the improvement of patient outcomes, effectiveness, and cost. This system can be expected to continue its expansion even if its place in surgical and prosthetic practice is not yet perfectly clear. Problems such as extended duration of intervention, pain, modification of surgical and prosthetic procedure, and a questionable cost-benefit ratio have yet to be assessed. In our opinion, the need for an IGS should be discussed with regard to how surgery is evolving; an evolution from imprecision toward precision, difficult surgery toward simple surgery, and stress toward relative patient and surgeon comfort points to flapless surgery. An IGS should provide reproducibility by providing the surgeon with reliable preoperative information and very precise drilling guidance during the surgical phase. This has a significant impact on systematizing treatment success in terms of aesthetics, biomechanics, and the protection of vital structures by eliminating possible manual-placement errors and by matching the planned position to prosthetic requirements.

The drawback of the IGS for oral implant placement lies in the use of CT as the radiologic modality providing three-dimensional information. Nevertheless, CT requirements are described for several clinical situations.[23,24] Furthermore, the number of implant placements by a variety of practitioners of different levels of experience is increasing. Thus the use of the IGS may be of greater importance to some clinicians than to others in obtaining a high success rate. We can also presume that the recent and future development of IGS applications both for surgical and for prosthetic protocols will justify the use of CT even when CT requirements are not already described. Higher doses and higher costs, the main drawbacks of CT when compared to conventional tomography, can be significantly reduced by using cone beam CT.[25] Mozzo and colleagues showed that the radiation dose from cone beam CT is approximately one-sixth that of conventional spiral CT.[26] The low radiologic power and low mechanical requirements as compared with those of conventional CT also decrease the cost.

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