A Novel Stereolithographic Surgical Guide Template for Planning Treatment Involving a Mandibular Dental Implant

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Purpose: In recent years, the concept of prosthodontic-driven implantology has received more attention. The precise placement of implants in accordance with greater safety and confidence allow the practitioner to offer a safer, more secure and predictable treatment than could previously be provided. In this report, this novel approach is illustrated through description of 1 difficult case.

Materials and Methods: Using principles of computer-assisted design and rapid manufacturing, the data acquisitioned from computerized tomography was used to plan implant rehabilitation and to transfer this information to the surgery as well.

Results: The procedure of implant planning in this sophisticated technique has potential to yield substantial public health benefits.

Conclusions: It was demonstrated that the versatility of the technique allows not only precise translation of the treatment plan to the patient's mouth, but also offers many additional significant benefits including use of special guides during surgery which would be difficult to achieve with traditional procedures.

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In recent years, the concept of prosthodontic-driven implantology has received more attention. The precise placement of implants in accordance with greater safety and confidence allows the practitioner to offer a safer, more secure, and predictable treatment than could previously be provided. While anatomic limitations and bone quantity and quality can now be evaluated precisely using 3-dimensional (3D) radiographic techniques such as computed tomography (CT) technology, accurate transfer of this information to the surgical phase has only recently been developed. Today, computer-assisted design (CAD) and manufacturing have made it possible to use data from computerized tomography not only to plan implant rehabilitation, but also to transfer this information to the surgery. One such technique uses stereolithography, a laser-dependent, rapid prototyping polymerization process that can duplicate the exact shape of the patient's skeletal anatomical landmarks in a sequential layer of a special polymer. In this report, this novel approach is illustrated through description of 1 difficult case, demonstrating that the versatility of the technique not only allows precise translation of the treatment plan to the patient's mouth, but also offers many additional significant benefits including use of special guides during surgery which would be difficult to achieve with traditional procedures.

Today, the implant-supported restoration is an increasingly used treatment option for edentulous and partially edentulous patients. After more than 25 years of experience, the methodology involved has become refined as to the material involved as well as the planning and surgical procedures. It is clearly understood that successful implant treatment is characterized not only by achieving osseointegration but also by correct placement for prosthetic restoration.[1] Many factors must be considered when planning implant treatment in the partially edentulous jaw. Historically, dental surgeons have tended to place implants where the greatest amount of bone was present, with less regard to placement of the definitive restoration. However, the clinical outcome and long term prognosis of implant-supported restorations largely depend on the stable and strong fixation of dental implants in the bone. Failure to recognize the pros-

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thetic demands often leads to a compromised definitive prosthesis with a jeopardized occlusal scheme, poor esthetics, and unfavorable biomechanics.[2-5]

Recently, a new concept of prosthodontic-driven implant placement has emerged as a treatment modality that combines functional and esthetic philosophies.[6,7] In prosthodontic-driven implant placement, diagnostic casts and the diagnostic wax-up of the prosthodontic restoration guide the planning of positions for the proposed implants.[8] To precisely transfer the prosthetic plan to the operative site, customized radiographic and surgical templates have become a routine part of treatment.[6,9-11]A thorough radiographic examination and exact diagnosis of the bony architecture are fundamental prerequisites.[12,13] Conventional dental panoramic tomography and plain film tomography are usually performed with the patient wearing a radiographic template with integrated metal spheres at the position of the wax-up. Based on the magnification factor and the known dimensions of the metal sphere, the depth and dimensions of the implants are planned. Plain radiography, which is widely used, has important diagnostic limitations; however, such as magnification and distortion, setting error, and position artifacts. Conventional radiography does not provide 3D information about the dental arch.[13-15] Although conventional surgical templates allow guidance of entry of the drill into bone, such templates will not provide exact 3D guidance. The templates are fabricated on the diagnostic cast without knowledge of the exact anatomy below the gypsum surface. Thus, when conventional implantation techniques are used, the clinical outcome is often unpredictable and, even if the implants are well placed, the location and deviation of the implants may not meet optimal prosthodontic treatment requirements. To overcome these problems, CT, 3D implant planning software, and computer-aided surgery have been introduced.[12,13,16,17]

In CT, multiplanar reformatting (MPR) allows the prosthodontist to reformat a volumetric dataset in axial, coronal, and sagittal cuts and to build multiple cross-sectional and panoramic views.[18,19] Special planning software has been adapted to allow practitioners to virtually plan location, angle, depth, and diameter of virtual implants, which are superimposed on the 3D data set. Following very delicate backward planning, the diagnostic wax-up is visualized on the CT scan through a special radiographic template.[11,20] This radiographic template is fabricated as an exact replica of the desired prosthetic end result and is supported with different radiopaque markers. Based on the information in this "visible template," dental implants are planned on the CT data with respect to vital structures such as the inferior alveolar nerve, the roots of adjacent teeth, and the maxillary sinus.[10,21,22] In addition to visualization and other diagnostic tools, such as the evaluation of bone density,[23] these software programs allow for placement of virtual implants and further assist the surgeon in foreseeing positioning and size of implants before surgery.[21,24]

Transfer of a sophisticated plan to the surgical field is not easy, however, and to overcome this difficulty, several novel approaches have been recently developed. One approach uses a computer-aided manufacturing (CAM) technique to generate osseous, mucosal, or tooth-supported surgical guides and anatomic models (SurgiGuide; Materialise Dental, Leuven, Belgium). With this technique, transfer of the DICOM files and the clinician's implant planning are used to design the surgical guides with the aid of a widely used computer software package, SimPlant (Materialise, Leuven, Belgium). A special 3D transparent resin model, SurgiGuide, which fits intimately with the hard and/or soft tissue surface is then processed: a computer-guided laser beam passing through a photosensitive bath of special liquid polymer causing layer by layer polymerization (stereolithography). Once hardened, the polymeric prototype and, in our case, surgical guides contain spaces for stainless steel or titanium drill-guiding tubes. The metal cylinders are then glued into the spaces, and the guides are ready for clinical use.[25] It has been shown that these bur guiding cylinders allow for intraoperative real-time tracking of the drill according to the planned trajectory.[26-28] In this report, using the concepts developed by Materialise, the technical steps involved in the generation of a special stereolithography template will be outlined, while highlighting the significant benefits over traditional therapeutic methods in a case involving implant rehabilitation.

Materials and Methods

The patient whose treatment is described in this report was treated in Imam-Ali Dental Clinic, Division of Prosthodontics (Tehran, Iran). She had worn 2 removable partial dentures for more than 15 years and neither was satisfactory to her. Early clinical findings revealed many carious lesions and progressive periodontal involvement of all remaining teeth. An uneven resorption of remaining bone in the anterior region and moderate to severe resorption in the posterior areas were observed (Fig 1). A mandibular full implant-supported fixed partial denture was proposed. However, a preliminary analysis including clinical observation, diagnostic models, and panoramic radiography revealed difficulties that precluded simple implant placement. Because the bone was not in good condition, treatment involving the use of CAD/CAM software and protocols of computer-assisted implantology was decided on. To fully utilize the possibilities of

FIGURE 1. The patient at first visit. Observe the uneven bone resorption of the anterior segment and the remarkable resorption of the posterior mandible.

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this treatment modality, multiple steps were proposed for implant treatment as described in this report.

First, the original cast with diagnostic wax-up was duplicated, and a removable partial denture-like appliance was fabricated to serve as a radiographic template to be worn during the CT scan (Fig 2). The scanning template prepared by this method is an exact replica of the desired prosthetic end result. Incorporation of the scanning template into the CT scanning data allows the clinician to base implant planning on the desired prosthetic outcome. The treatment plan is thus driven by the prosthetic end result, rather than conversely.[17] The patient was sent to the radiologist with the scanographic (radiographic) template. After completion of the scan, the

FIGURE 2. The scanographic template ready to position in the mouth.

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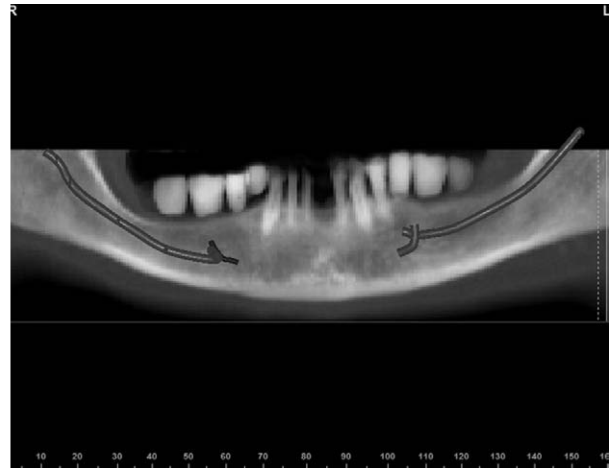

FIGURE 3. 2D panoramic view demonstrating the uneven resorbed bone. Observe the sketched nerve fibers that facilitate evaluation of the exact position and trajectory of the nerve in all dimensions.

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resulting DICOM files were sent to a "data processing center" using the sending files over Internet protocol (FTP). At the data processing center, a computer engineer edited the raw scan, removing scattered and irrelevant images (eg, spinal column, antagonist teeth, scattered image, etc). The scanning template prepared by this method can be easily identified in axial sections and the uneven resorption of bone in reformatted sagittal and panoramic sections observed (Fig 3). Various anatomic structures, such as the mandible, the scanographic template, and the anterior remaining teeth, are separated into different masks. Each of these masks can be toggled on or off to allow separate visualization and interpretation.

After calculation of the corresponding 3D models, the resulting data were forwarded via FTP to the treating clinician, who was then able to evaluate and place virtual implants in the resulting accurate 3D model of the intended surgical implant site. During this phase, using a well-known software program (SimPlant, version 10), many parameters were checked, including bone density surrounding the proposed implant sites and maximum available and acceptable implant length and width (Fig 4). The initial findings in the 3D reconstruction of the patient's jaw confirmed the periodontal problems associated with the remaining teeth, uneven resorption of residual bone, and a much dispersed bone density pattern (Fig 5).

By using an innovating smart module called "Dr James," the software program automatically selects the length and diameter of the selected implants according to an existing library of implant dimensions. The position of the implant can then be paralleled by shifting, tilting, or adaptation of its dimensions in a panoramic as well as 3D reconstruction plane. Owing

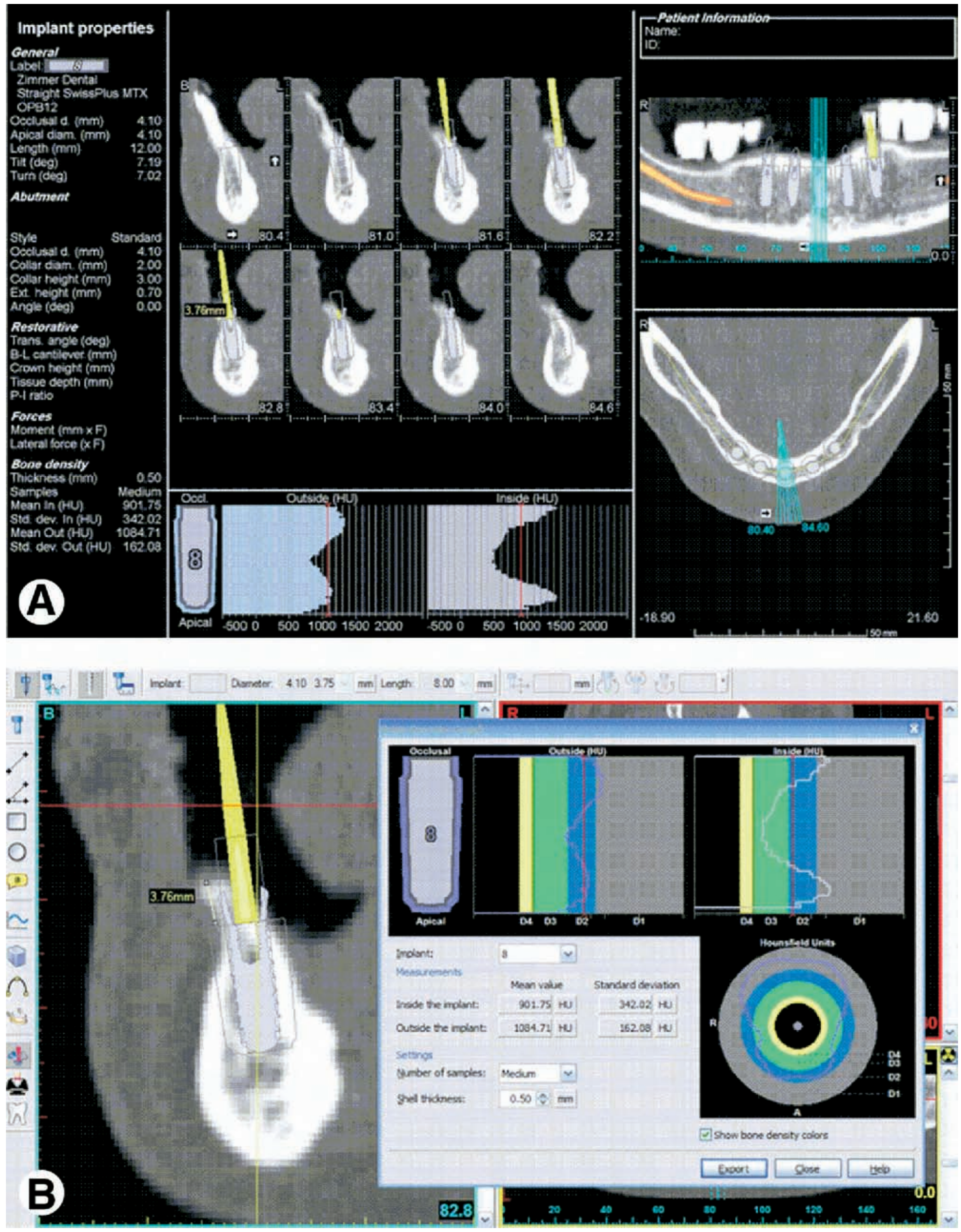

FIGURE 4. *A*, Complete report, showing the exact position of proposed implants in all dimensions, including density information along both the inside and outside of proposed implant location. *B*, 2D axial view with the image of one of the proposed submerged implants. Bone density around the implant location is sketched in color.

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to the problem of existing unevenly resorbed and narrow bone, it was proposed to utilize the concept of “submerge planning” for implant positioning and direction. With an even distribution of implants in mind, the height of implants was planned precisely in 1 plan and below the narrowing depression of remaining bone (Fig 4B). The remarkable versatility of the software in manipulation of the implants permits the selection of optimal placement locations according to a complex set of prerequisites, including correspondence with the initial prosthetic plan, visual check that the implant is encased in bone in all directions, and optimal positioning so that the implant is located in a zone with the highest possible density.

Because it was proposed to remove unnecessary bone, the next step was to order a special SurgiGuide for preparing the bone appropriately. The role of this special guide is to specify exactly the bone level desired for implant insertion. Because of its function, the company has denoted it “Reduction Guide.” In addition to this special guide, the finalized treatment plan is also sent to Materialise, the SimPlant manufacturer, for fabrication of a specialized surgical drill guide to maximize bone support. The position and direction of the cylinders correspond exactly to the position and direction of the planned implants. During manufacture of the guides, surface coverage is maximized to increase the stability and retention of the templates on the osseous surface. Multiple SurgiGuides were fabricated using tube diameters of increasing size that corresponded to the increasing twist drill diameters used during surgical implant

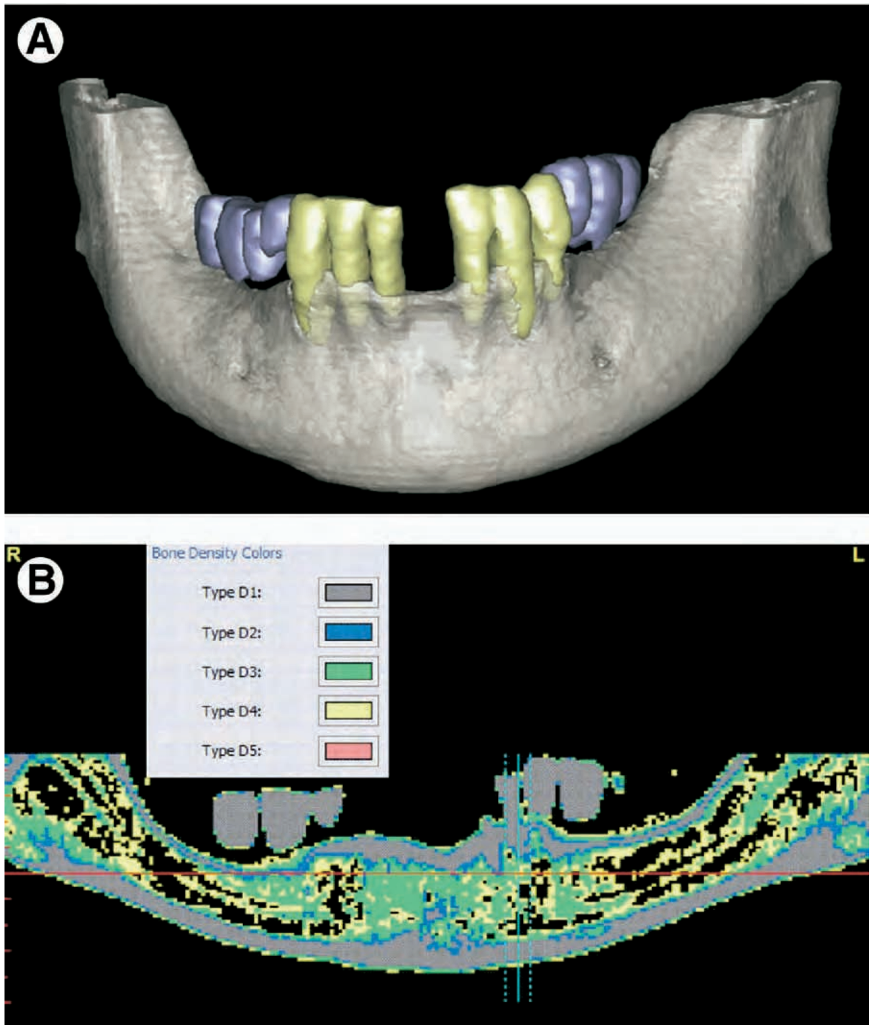

FIGURE 5. *A*, 3D view of the patient's jaw and colored masks of bone, teeth, and scanographic template. Notice too the situation of reconstructed bone around remaining teeth. Masks can easily toggle off and on as required. *B*, 2D panoramic view of the patient's jaw showing the overall bone density. Note the very disperse and porous bone.

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placement (Fig 6). Accuracy was verified by placing the surgical templates on the fabricated anatomic models.

Standard surgical protocol was used to gain access to the surgical sites. After flap elevation, tooth extractions were made and the remaining bone carefully evaluated. During this phase, the predetermined diagnosis of uneven bone resorption in relation to anterior teeth was confirmed and the precision of the software treatment plan was fully verified (Fig 7). To check the precision of the so-called "reduction guide," it was positioned in the remaining bone after extraction (Fig 8A). The bone that was extruded from the aperture of the guide was delicately shortened to the predetermined level (Fig 8B). After completion, the bone was ready to receive the first drill guide and sequential implant osteotomy. The first guide, with 2-mm diameter drill guides, was positioned (Fig 9). Osteotomies were prepared traditionally using twist drills in angulations exactly defined by the SurgiGuide. Continuous irrigation was facilitated through holes placed on the facial surfaces of the special surgical templates (Fig 6). After completion of the initial osteotomies, the first surgical templates were removed and the second and third guides were placed in sequence. Because of the accuracy of these templates, pilot drills were no longer necessary. After completion of the osteotomies, the templates were removed and the implants placed. Flaps were adapted and sutured to ensure primary closure. The result of surgery after 1 week was apparent and is shown in Figure 10.

Results

The use of computer-assisted treatment planning, anatomic model building, and surgical template fabri-

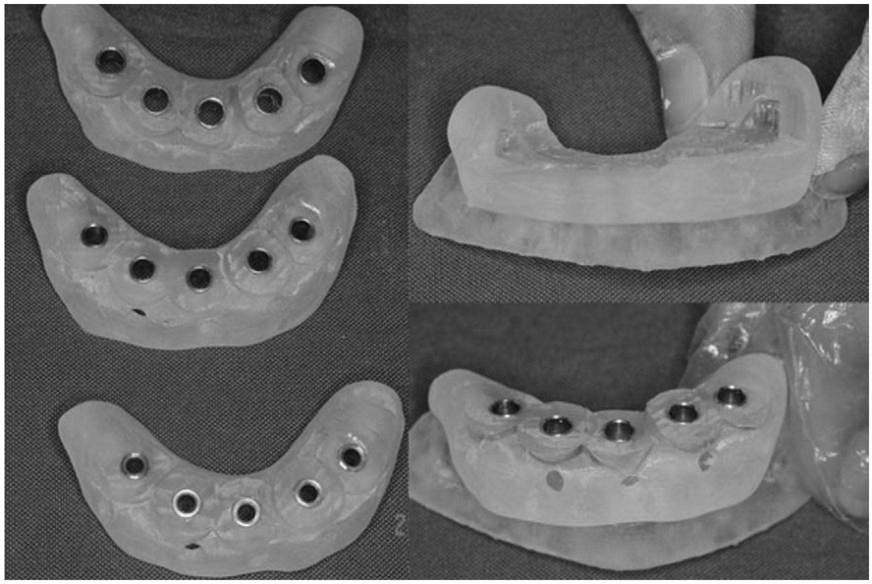

FIGURE 6. Stereolithographic surgical templates used. Observe the sequential drilling holes on the left and fitness of guides on the anatomic model of the patient's mandible. The so-called "Reduction Guide" is shown on the top right on the model of mandible. Notice the aperture of the reduction guide and holes that are incorporated in the SurgiGuide for better irrigation during the drilling phase.

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cation prior to surgical implant placement provides extensive, invaluable information otherwise unavailable in existing radiographic surveys. This allowed exceptional presurgical evaluation and planning, which in turn resulted in straightforward and predictable surgical as well as prosthodontic treatment. Osseous topography and local anatomic limitations, such as concavities, irregularities, and bone density could be readily evaluated. Proposed implant positions were evaluated for cortical bone existence, osseous density along the implant body, and ideal restorative design from the standpoint of biomechanics. At the time of surgery, all implants were positioned exactly as previously planned, without the need for modification of implant lengths, widths, or angulations. The versatility of the procedure is so high that special guides can be ordered for special situations that can be relied on and that are predetermined during the virtual planning phase and before beginning surgery.

FIGURE 7. Flap elevation has been accomplished and the remaining anterior teeth have been removed. Compare this view with one presented virtually in Figure 5*A*. The precision of virtual modeling with SimPlant is evident.

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Discussion

Proper implant placement is crucial to ideal prosthetic reconstruction and long term success.[29] In cases such as the one presented in this report, traditional 2D radiographic surveys are inadequate in preparing for predictable, accurate surgical implant placement. According to recommendations provided by The American Academy of Oral and Maxillofacial Radiology (AAMOR), "The goal of presurgical dental implant treatment planning is to position the optimum number and size of implants for the best restorative results. This can only be done if the location and axial angulations of each implant are determined by a thorough knowledge of the patient's bony anatomy is provided in a complete radiographic examination that includes the third dimension. . . . Successful treatment planning requires that the clinician evaluate the suitability of the remaining bone for placement of implants. The clinician must determine if there is enough height, density, width of bone, and an appropriate axis of orientation for a successful prosthodontic result."[30]

These recommendations consider the balance between simple radiologic cases, while several studies have shown the advantage of CT scanning over other techniques. Studies have shown that balancing risk and clinical benefit requires reliance on enhanced radiographic diagnosis to improve clinical treatment outcome.[31,32]

When assessing implant recipient sites, Todd et al[33] reported that CT imaging is more valuable than conventional radiographic techniques. Naitoh et al[34] have clearly shown the improved predictability of preimplant planning involving the use of CT over other modalities. Clinicians using only 2D cross sections will make numerous modifications during the surgical phase of treatment. The addition of a 3D representation, however, improves the correlation between planning and actual placement. Although only implant position is reproducible, implant lengths and widths are still frequently modified. Additionally, little correlation has been found between foreseen anatomic complications and the presence of these complications at the time of surgery.[35,36] A limitation of these studies is that they used only printed images, while, as suggested in this report, the incorporation of computer-assisted treatment planning offers significant advantages, including evaluation of the 3D anatomy from an infinite number of views and fabrication of both anatomic site models and surgical guides. The

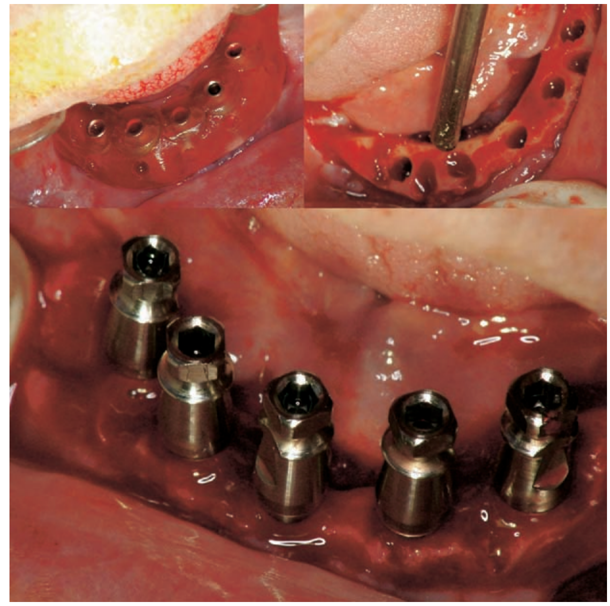

FIGURE 9. Position of the "SurgiGuide" over the diminished ridge. After consecutive steps the osteotomies have been completed with maximum accuracy.

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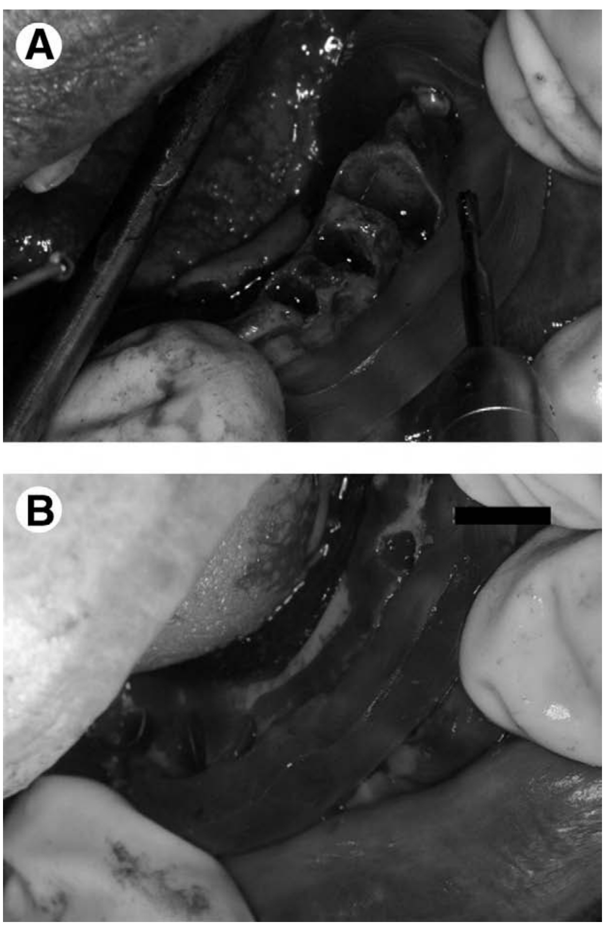

FIGURE 8. *A*, Position of the "Reduction Guide" over the ridge. The precision of guide in relation to the bone is noticeable. The exact amount of bone for reduction is accurately marked by the guide. *B*, Position of the "Reduction Guide" over the ridge after reduction has taken place. The newly formed bone is ready for implant osteotomy.

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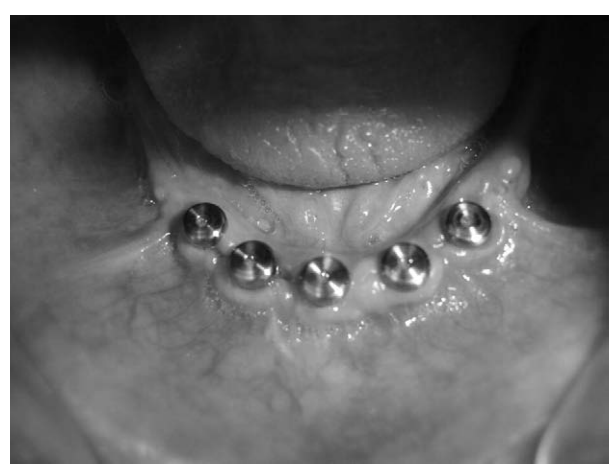

FIGURE 10. Observation of treatment 1 week after surgery. The precise paralleling and exact spacing of implants are relevant. It is obvious that this level of accuracy is difficult to achieve with conventional surgery.

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scanographic template is a key to the system because it allows the transfer of a predetermined prosthetic setup to actual implant planning. When using a cross-sectional image as in traditional surveys, the bucco-lingual positioning of the implant can be correlated with the tooth outline, while the panoramic view verifies mesiodistal inclination. However, only 3D views reproduced by computer software programs allow for analysis of virtual implants in all dimensions. Directional modifications are immediately translated to all 3 axes, as well as to the 3D model reconstruction. Complete virtual parameter analysis ultimately provides the implant team with a broader knowledge of the patient's anatomic features, deficiencies, and variations. With the advent of coordinated CAM of anatomic models and surgical templates based on CAD images, the clinician can directly transfer information gathered during preplanning to the surgical phase of implant placement. The stainless steel tubes embedded in the templates precisely guide the osteotomy drills, precluding the need for the pilot drills described in standard protocols. In a number of studies, the accuracy of this type of drill guide has been demonstrated,[37,38] and it has been clearly shown that implant placement is improved by use of stereolithographic surgical guides. It has also been shown that specialized open and easy-to-use software (like the package described in this report) can optimize dental implant surgery and, therefore, significantly reduce time and expenditure.[39,40]

Despite many advantages, it must be emphasized that there are also some disadvantages for computer guiding methods. Among these the familiarity with the whole system and the total cost of required tools, including software program, surgical templates, and so on, are most important and must be carefully reviewed with the patient. Moreover, it must also be noted that the degree of accuracy of the technique depends in many aspects to the degree of precision of image acquisition technique, which must be carefully controlled by the radiologist. Any discrepancy, motion, or inappropriate positioning of the patient during the CT scanning procedure may lead to errors on preparing guides. Several different recommendations have been advocated by manufacturers to properly position the patient during acquisition time. It must be pointed out that the stereolithographic templates are made of some type of resin. It is noteworthy that these types of materials are nevertheless water absorbable and heat sensitive and therefore may undergo some deformation during delivery time.

It may be concluded that new technologies such as the one described in this report allow the clinician to achieve a high level of accuracy and safety that is difficult with conventional treatment options. The precision of implant positioning with this technique may help to reduce the cost of subsequent prosthetic treatment, avoiding the use of additional abutments to realign implants. The advantages of the described treatment protocol are relevant to today's clinical practice and can be summarized as follows:

- With a CT scan-based planning system, the clinician is able to select the optimal locations for implant placement, taking into account specific anatomic requirements of the patient and using optimal bone location as well as densities.
- Incorporation of prosthetic planning using a scanographic template allows the treatment to be optimized from a prosthodontics and biomechanics point of view.
- The high versatility of the technique and software program was remarkable. The degree of design probabilities with this sophisticated technology can be considered high, which may cover many requirements in everyday practice.

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