TECHNIQUES AND TECHNOLOGIES

Use of Stereolithographic Templates for Surgical and Prosthodontic Implant Planning and Placement. Part I. The Concept

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Surgical and prosthodontic implant complications are often an inadvertent sequelae of improper diagnosis, planning, and placement. These complications pose a significant challenge in implant dentistry. Presented in this article is a technique using a highly advanced software program along with a rapid prototyping technology called stereolithography. It permits graphic and complex 3D implant simulation and the fabrication of computer-generated surgical templates. These templates seat directly on the bone and are preprogrammed with the individual depth, angulation, and mesio-distal and bucco-lingual positioning of individual implants as planned during the 3D computer simulation.

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INDEX WORDS: stereolithography, computer-aided design, implantology, treatment planning, dental implants, surgical templates

SINCE THE advent of osseointegration, the use of dental implants has evolved rapidly over the last decade. Research in the field of oral implantology has led to refinements resulting in highly successful and predictable restorative options for partially as well as completely edentulous patients; however, improper implant placement can have a profound and often detrimental effect on the long term predictability and success of the implant-supported prosthesis.[1,2]

Conventionally fabricated surgical templates have certain limitations in achieving optimal results:

1. When fabricated on diagnostic study casts, the soft tissue is a rigid, nonfunctional representation and does not provide information about the varying thickness of the mucosa, topography of underlying bone, or vital anatomical structures that lie within. In addition, the limitations of conventional dental radiography with regard to dimensional accuracy and inability to visualize anatomical structures in parasagittal sections further hinder accurate evaluation.
2. The limitations of current clinical techniques often do not allow fabrication of a surgical template that remains stable during surgery despite interference with reflected tissue, and that is capable of accurately transferring planned implant placement intraoperatively.

After a comprehensive diagnostic workup, arriving at an accurate diagnosis and a sound treatment plan, the measure of successful implant dentistry is to have implants successfully osseointegrate in the correct position. In certain

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This work has been previously presented at the following: 1. 1st Prize, Table Clinics session, American College of Prosthodontists (ACP), New York section meeting, October 22, 2001. 2. 1st Prize, Table Clinics session, ACP Annual Session, New Orleans, November 1 to 4, 2001. 3. Northeast Implant Symposium, University of Medicine & Dentistry of New Jersey. Presented clinical report, October 26, 2001. 4. Academy of Osseointegration, Dallas, TX, March 14 to 16, 2002. "Use of Stereolithographic Template for Ideal Surgical and Prosthodontic Implant Placement." Table clinic presentation. All fixtures and prosthetic components were provided by Nobel Biocare, Yorba Linda, CA. Stereolithographic models and templates were provided by Materialise, Leuven, Belgium.

Accepted June 23, 2005.

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1059-941X/06

doi: 10.1111/j.1532-849X.2006.0069.x

situations, to achieve this, the surgeon may need to modify the surgical template or discard it altogether to ensure placement of implants in sound bone. During the surgery, it is virtually impossible for the surgeon to visualize the location of the definitive prosthesis as envisioned by the prosthodontist, and implants could be placed in a less than desirable location. Compromised placement poses not only an esthetic and biomechanical problem but also requires alteration of the treatment plan as initially presented to the patient.

One of the commonly overlooked criteria for success is to have a restorable and esthetically positioned implant that is acceptable to both patient and dentist.[3] In order to address this, more advanced diagnostic imaging using computed tomography (CT) has been proposed for presurgical planning of dental implants.[4-10] These techniques allow the surgeon to visualize cross-sectional, axial, and panoramic views of the patient's maxilla and mandible for more accurate planning of implant placement within the bone. When a radiographic template is used during the scanning procedure, the prosthodontist can also visualize the location of planned implants from an esthetic and biomechanical standpoint. These images, however, are 2D, requiring a process of mental integration of multiple sections by the observer to derive 3D information.[11] Two-dimensional planning systems[12-15] are easier to view on the computer, but they are basically a digitized version of printed images. Reformatted 2D-CT is reliable for the preoperative assessment of the number and sites of implants in the jaws. It is less predictable for the implant size needed and poor for anatomical complications.[16] More recent publications describe a planning system[17-18] that allows simultaneous visualization of 2D reformatted images as well as 3D derived bone surface representations. Interactive placement of implant-like CAD models can be carried out on these images.

The authors concluded that this approach largely outperforms the manual planning practice based on 2D dental computerized tomographic images printed or on film.[16] They also stated that the 3D planning resulted in a better planned implant position with relation to bone quality and quantity, biomechanics, and esthetics. The improvements often avoid complications such as mandibular nerve damage, sinus perforations, fenestrations, or dehiscences.[17] The 3D planning system is a reliable tool for preoperative assessment of implant placement.[19]

The surgeon and prosthodontist can now simulate ideal implant placement on the reformatted CT images and treatment plan the exact dimensions of the implant, along with the ideal depth and angulation; however, despite such advanced diagnostic and treatment planning tools, one may still end up in compromised situations. This is because in the past, there was no way of transferring the ideal implant location from the computer planning to the surgical template. More recently, attempts to transfer this information using computer-generated surgical templates have shown favorable results.[20-23]

The purpose of this report is to present a technique that uses computer-generated stereolithographic templates to transfer implant position from a 3D computer model, intraoperatively, to stage one surgery. This technique uses advanced computer software (SurgiCase, Leuven, Belgium) along with a rapid prototyping technology called stereolithography to achieve this. It permits graphic and complex 3D implant simulation and fabrication of computer-generated surgical templates (SurgiGuides, Materialise, Leuven, Belgium) that seat directly on the bone and are preprogrammed with the individual depth, angulation, mesio-distal, and bucco-lingual positioning of individual implants as planned during the 3D computer workup.

Other commercially available software packages allow similar 3D planning:

1. SIM/Plant, Columbia Scientific Incorporated, Columbia, MD
2. coDiagnostiX, IVS Solutions AG, Chemnitz, Germany
3. ImPlacer, Pacific Coast Software Inc., CA

Technique

Diagnostic Wax-Up

Diagnostic study casts are properly articulated on a semi-adjustable articulator. After a comprehensive clinical and roentgenographic examination, a sound treatment plan is formulated and a diagnostic wax-up is completed. An impression of the wax-up is made using irreversible hydrocolloid impression material and a duplicate cast is made in Type IV dental stone. A radiographic template is

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Figure 1. Occlusal view of existing maxillary denture.

fabricated on a duplicate study cast. For complete dentures, a duplicate of a previously fabricated complete denture can also be used, if the denture contains correct relationships (Fig 1).

Radiographic Template

Radiographic templates fabricated using barium sulfate as the radio-opaque marker are most suitable for this technique.[24] In cases where a duplicate denture is being used for the radiographic template, radio-opaque markers can be placed in the center of the occlusal surfaces of the teeth corresponding to the screw access holes of the planned implant-supported prosthesis (Fig 2). The patient can be instructed to use denture adhesive to stabilize the template during the scanning procedure. Alternatively, barium sulphate denture teeth such as Vivo TAC/Ortho TAC (Ivoclar Vivadent, Amherst, NY) can be used for the radiographic template for more precise planning. The barium teeth are a more accurate representation of the intended restoration as they appear on the reformatted CT data. This would preclude the possibility of deviating from the confines of the intended restoration while moving the simulated implants or using angulation correcting abutments.

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Figure 2. Radiographic template. Duplicated denture with barium sulphate markers can be used.

CT Scan Procedure/Data Acquisition

The CT scanning procedure is performed with the radiographic template in place. The spiral CT (also referred to as helical or volume-acquisition CT) is preferred. It involves simultaneous translatory movement of the patient while the X-ray source rotates, so continuous data acquisition is achieved while scanning the entire volume of interest.[25] A conventional scanning protocol is followed;[8] however, some additional instructions to the radiologist should be included on a roentgenographic prescription.

1. Use a bone or high resolution image reconstruction algorithm to get sharp reformatted images where you can locate internal structures as the inferior dental alveolar canal.
2. Reconstruct the images with a 512 × 512 matrix and a field of view between 140 and 170 mm to include the entire arch.
3. Only the axial images are required, no dental reformatting has to be made.
4. The slice thickness, table feed per second and reconstructed slice increment should be 1.0 mm.
5. Gantry tilt should be 0°.
6. The images should be saved as a ".sim" file format on a suitable data storage medium like a ZIP disc or CD. If other software packages are used, the data should be stored in a file format compatible with that software.

3D Computer Simulation

Using the software, the surgeon and prosthodontist can simulate implant placement on the 3D model in conjunction with the parasagittal views (Fig 3). The dental team can select implants of

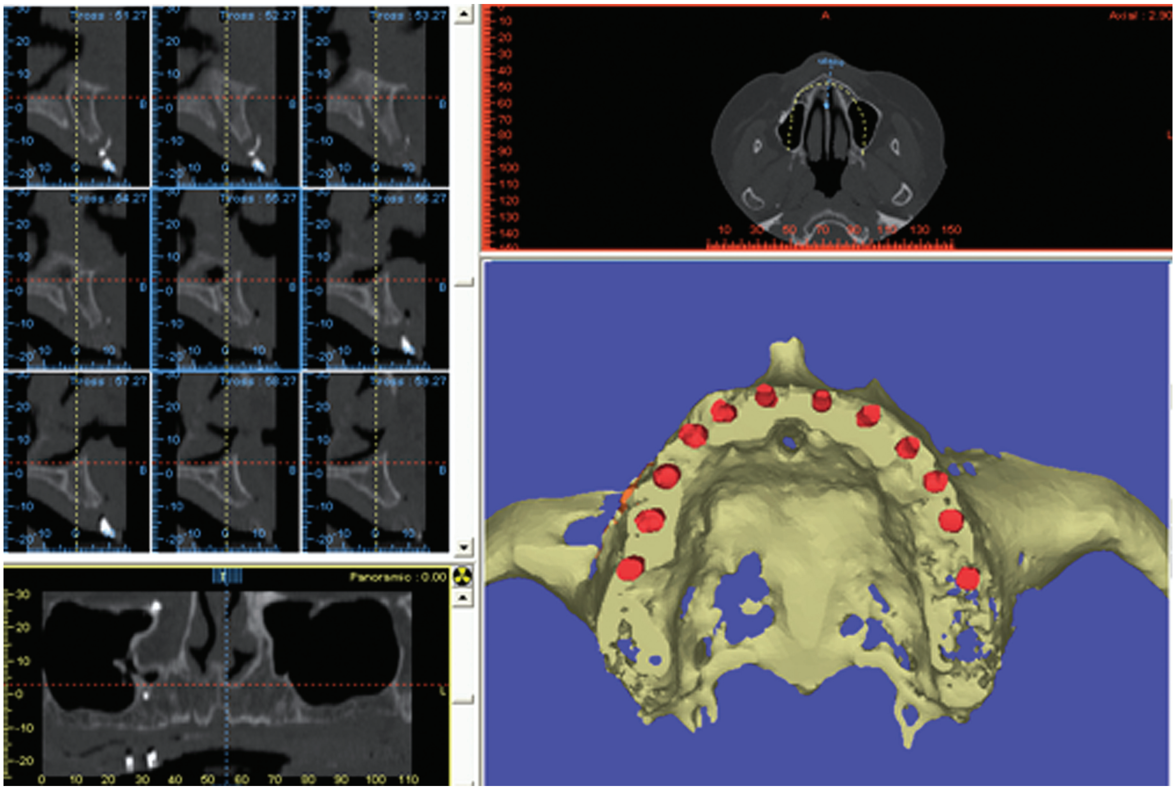

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Figure 3. Reformatted CT data using Surgicase software showing cross-sectional, panoramic, axial, and 3D views. Note the barium sulphate markers on the 3D model allowing easy and accurate planning of fixture position.

specific length and diameter from a database of most commercially available implants and reproduce a 3D replica of exact dimensions in the desired location on the computer model of the patient's jaw. The simulated implants can be bodily translated or tilted about their long axis until their ideal location within the bone is finalized (Fig 4). Another unique feature of the software is that it allows the user to make the surface rendering of the bone transparent (Fig 5). This allows complete visualization of all anatomical structures situated within the bone. Otherwise, these structures would be invisible. It is also possible to interactively rotate the 3D model along with the simulated implants in all directions.

The prosthodontist can see where the screw access holes are emerging as related to the 3D rendering of the radio-opaque markers incorporated in the radiographic template. At this stage, minor alterations can be made by changing angulation of the implants until the screw access holes are emerging through the center of the occlusal surface of the planned prosthesis. Optimal biomechanics involve ensuring axial loading of the implants and of the prosthetic superstructure in the available bone.[7] If the angulation deviation cannot be corrected in this manner without compromising the implant location in sound bone, the prosthodontist can select an angulated

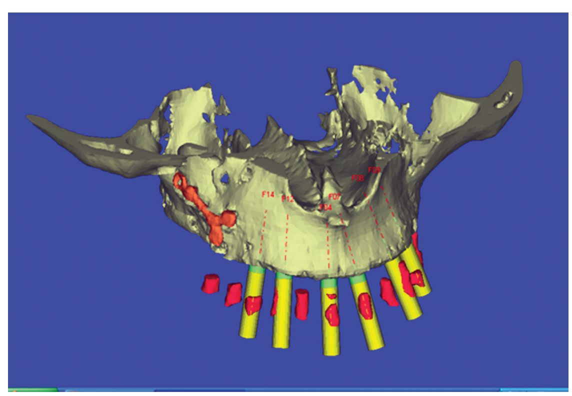

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Figure 4. Three-dimensional view during implant simulation. The prosthodontist can adjust length and angulation of fixtures and abutments using the radio-opaque markers as a guide for planning.

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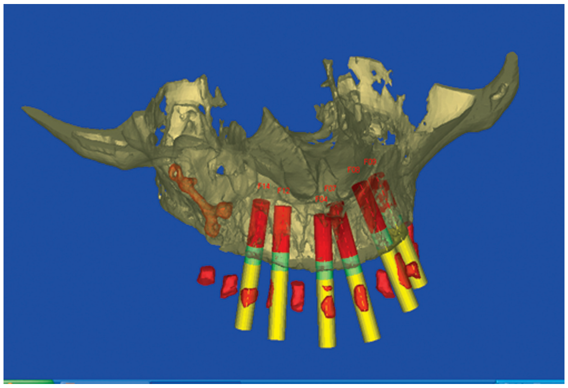

Figure 5. Three-dimensional view in bone transparency mode allowing the surgeon to position the fixtures in their ideal location in sound bone without impinging on vital anatomical structures. Inter-fixture distance and relative parallelism can also be incorporated in the planning.

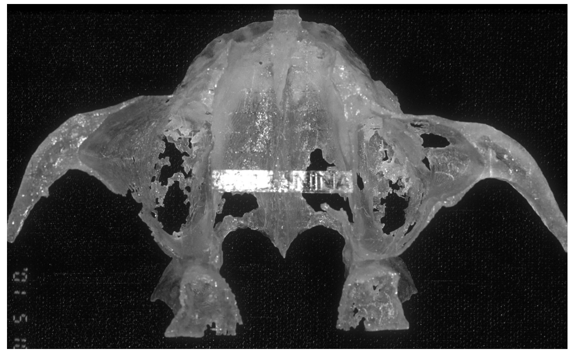

Figure 6. Stereolithographic model of the patient's maxillae.

abutment from a database of most commercially available abutments. The screw access hole automatically changes on the 3D model corresponding to the specific angulated abutment selected. Abutment collars can be selected based on the relation of the implant platform, the level of bone and the interproximal contact of the teeth projecting an optimal esthetic result. Mesio-distal implant placement can also be planned at this time to avoid placement of implants in interproximal embrasures. Other biomechanical considerations such as tripodization[26] to prevent a horizontal axis of rotation or extent of cantilevers[27] can also be incorporated into planning based on previously established criteria.

Once the computer simulation is completed, it is saved as a ".sim" file and sent to the processing center via e-mail. This file transfers geometrical information, consisting of numerous triangles, to another workstation which describes a volume by its boundary surface. Triangles have exactly three sides and vertices so they are always planar. This allows them to accurately define the surface topography of the bone without gaps or overlaps. This triangulated data is the interface to the stereolithographic apparatus (SLA).

Fabrication of Stereolithographic Templates

At this stage, a rapid prototyping machine using the principle of stereolithography is employed to fabricate the stereolithographic models (Fig 6).

The SLA (Fig 7) consists of a vat containing a liquid photo-polymerized resin. A laser mounted on top of the vat moves in sequential cross-sectional increments of 1 mm, corresponding to the slice intervals specified during the CT formatting procedure. The laser polymerizes the surface layer of the resin on contact. Once the first slice is completed, a mechanical table immediately below the surface moves down 1 mm, carrying with it the previously polymerized resin layer of the model. The laser now polymerizes the next layer above the previously polymerized layer. In this manner, a complete stereolithographic model of the patient's jaw can be created.

Approximately 80% of the total polymerization is completed in the vat; the remaining 20% can be completed in a conventional ultraviolet light curing unit. The surgical templates are fabricated in a similar manner. They are built onto the surface anatomy of the stereolithographic model and are connected to it by a series of minute triangles that are later removed during the finishing process. The extent of the buccal and lingual flange can be predefined based on the surgical flap design. The SL machine also reads the diameter and angulation of the simulated implants and selectively polymerizes resin around them, forming a cylindrical guide corresponding to each implant. A technician removes supporting resin triangles and connects surgical grade stainless steel tubes into the cylindrical guide. In this manner, surgical templates, which seat directly on the bone and have metal sleeves corresponding to each fixture site, are generated (Fig 8). Two sets of surgical templates containing different sleeve diameters corresponding to the incremental size of the osteotomy drill being used are required. The sleeves are 5 mm in height and 0.2 mm wider than

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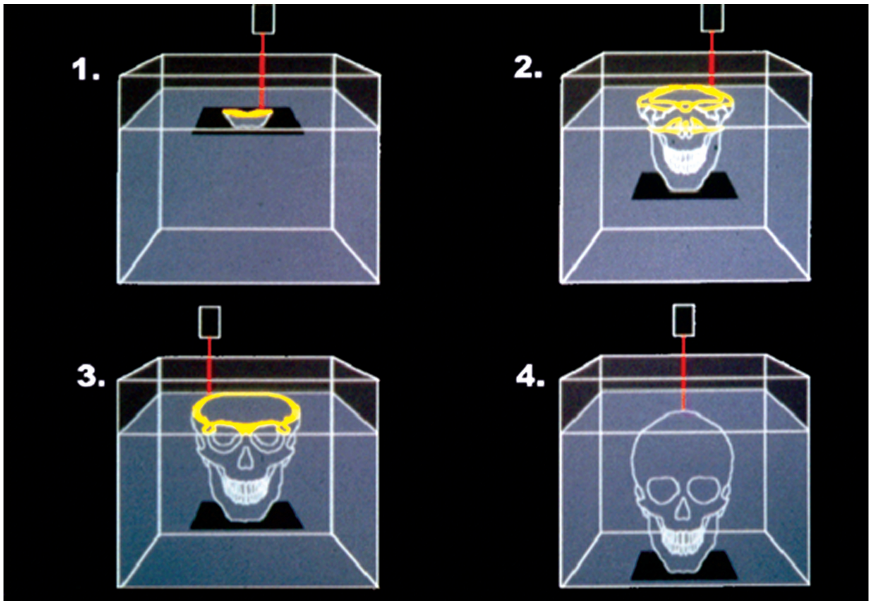

Figure 7. Principle of stereolithography.

the osteotomy drill being used. This configuration limits angulation deviation of the implants to less than 5°. The precise depth, angulation, and mesio-distal and bucco-lingual positioning of each implant as planned during the computer simulation is preprogrammed in the template. The template itself is fabricated of Stereocol resin (Zeneca Specialties, Blackley, Manchester, UK), which is a photo-polymerized resin and is FDA-approved for use in surgical procedures. The templates can be sterilized using most common techniques without the loss of properties. These include low temperature steam and formaldehyde at 80°C. There are windows on the buccal surface to allow for irrigation with saline. Because the template is precisely shaped to the unique surface topography of the bone, the template is extremely stable without the need for any external fixation. Also, the unique fit forms a peripheral seal allowing water from irrigation to escape only through the irrigation windows on the buccal aspect of the template or from the superior aspect of the guiding sleeves. In effect, there is a constant pool of water created at the osteotomy site, thereby providing more efficient cooling of the bone.

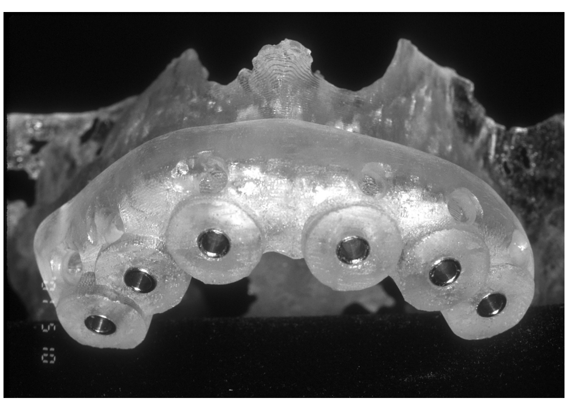

Figure 8. Stereolithographic model of the patient's maxillae with SL template. Metal sleeves of varying diameters accurately guide the osteotomy drills. Windows on the buccal aspect allow access for external irrigation.

Surgery

At the time of surgery, a full thickness mucoperiosteal flap is reflected and the first template corresponding to the 2 mm twist drill is secured in place. The flap is more extensive than for conventional surgical templates. Care should be taken to ensure that the flap does not interfere with proper seating of the template. Once the template is seated, the osteotomies are carried out. The configuration of the sleeves as they relate to the drill is such that there is only one direction for axial movement.

The second template corresponding to the wider osteotomy drill is used in the same manner. It is also possible to have a single template with interchangeable sleeves for both drill diameters and final implant placement. Once the implants are placed, conventional protocol is followed based on the implant system being used.

Discussion

The possible benefits of this approach using stereolithographic templates are apparent for the surgeon, prosthodontist, and the patient. Further research is necessary to validate the accuracy and usefulness of the system. Stereolithographic models of the patient's maxilla and mandible allow the dentist to physically hold, visualize, and manipulate an accurate representation of the patient's jaws prior to surgery. The models are transparent, and anatomical structures such as the inferior alveolar nerve, nasopalatine canal, maxillary sinus, and nasal cavity can be visualized providing a tremendous advantage in treatment planning.

Conclusion

The stereolithographic templates can be used in completely as well as partially edentulous situations. The templates can be entirely supported either by soft tissue, bone, or remaining teeth. The cost associated is higher than with conventional templates, but in more complex, fully edentulous cases, the benefit could justify the additional expense. The use of this approach could make the goal of ideal surgical and prosthodontic implant placement a distinct possibility. Considering the possible benefits and implications of achieving this goal, it would be prudent to direct further clinical research endeavors toward validating the accuracy and effectiveness of the system.

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