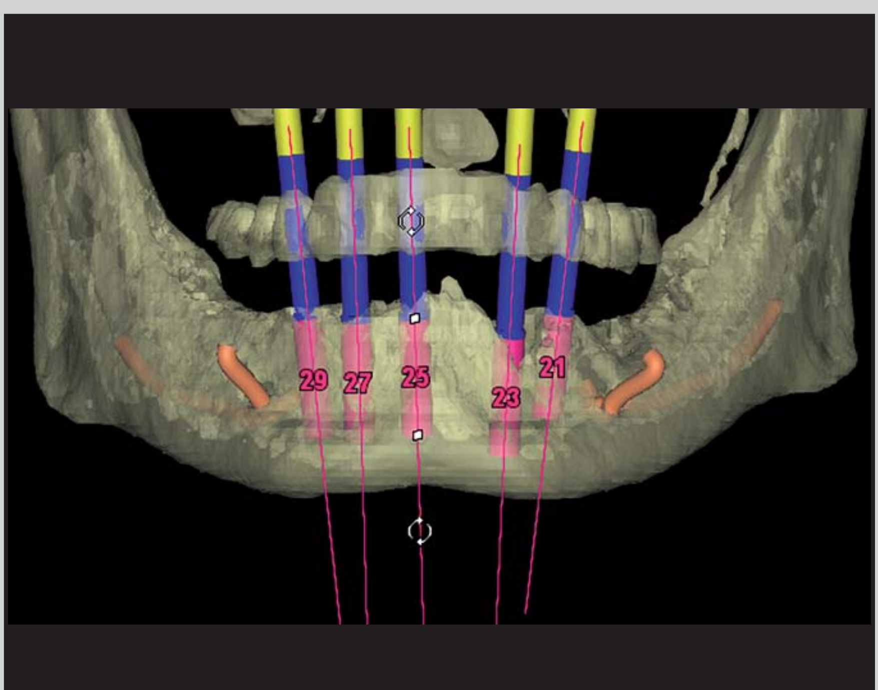
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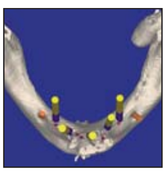
Prosthetically Directed Implant Placement Using Computer Software to Ensure Precise Placement and Predictable Prosthetic Outcomes. Part 2: Rapid-Prototype Medical Modeling and Stereolithographic Drilling Guides Requiring Bone Exposure



*Alan L. Rosenfeld, DDS, FACD**
*George A. Mandelaris, DDS, MS**
*Philippe B. Tardieu, DDS***

The purpose of this paper is to expand on part 1 of this series (published in the previous issue) regarding the emerging future of computer-guided implant dentistry. This article will introduce the concept of rapid-prototype medical modeling as well as describe the utilization and fabrication of computer-generated surgical drilling guides used during implant surgery. The placement of dental implants has traditionally been an intuitive process, whereby the surgeon relies on mental navigation to achieve optimal implant positioning. Through rapid-prototype medical modeling and the ste-reolithographic process, surgical drilling guides (eg, SurgiGuide) can be created. These guides are generated from a surgical implant plan created with a computer software system that incorporates all relevant prosthetic information from which the surgical plan is developed. The utilization of computer-generated planning and stereolithographically generated surgical drilling guides embraces the concept of collaborative accountability and supersedes traditional mental navigation on all levels of implant therapy.
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*Private Practice, Periodontics and Dental Implantology, Park Ridge and Oakbrook Terrace, Illinois.
**Private Practice, Dental Implantology, Grenoble, France.

Correspondence to: Dr Alan L. Rosenfeld, 1875 Dempster Street, Suite 250, Parkside Center, Lutheran General Hospital, Park Ridge, IL, 60068; e-mail: IMPLANDDS@aol.com.

Implant placement has been and continues to be intuitively guided for most clinicians. In many instances, this may lead to suboptimal implant positioning. While less-than-optimal implant placement may appear to be insignificant at the time of surgery, the impact of its discrepancy and the magnitude of prosthetic reconciliation required to compensate can lead to an unsatisfactory prosthetic outcome, complicating patient care.[1]

Recent technologic advances in computer-guided implantology software allow for osteotomy site preparation and implant positioning to be guided by a computer rather than intuitively driven.[2] This process is a prosthetically driven approach to implant treatment planning and requires the use of scanning appliances designed to transfer the prosthetic outcome information to a computerized tomographic (CT) study.[2,3] Through the use of computer software (SimPlant, Materialise) it is now possible to precisely transfer a prosthetically directed

Fig 1 (left) *A stereolithographic resin model has been constructed with nine osteotomy site preparations at planned implant positions. Laboratory implant analogs have been placed in the five anterior sites. Abutment selection is performed presurgically for a "dress rehearsal" of the proposed implant treatment. Note the color rapid prototyping of the right mental foramen and inferior alveolar nerve.*

Fig 2 (right) *The patient's existing denture is converted to an immediately loaded prosthesis presurgically on the stereolithographic resin model.*

treatment plan to a stereolithographic medical model for construction of surgical drilling guides. The purpose of this paper is to introduce the concept of rapid-prototype medical modeling and describe the fabrication and utilization of computer-generated surgical drilling guides used during bone exposure surgery.

Rapid prototyping and medical modeling: Bone models

Rapid prototyping is a method of producing solid, physical, "hard copies" of human anatomy from three-dimensional (3D) computer data.[4] Because CT is used to obtain 3D data from hard tissue structures, it is the radiographic modality that has the most applicability to computer-guided implant diagnostics. Three main techniques are used to create rapid-prototype medical models.[4] These include: stereolithography, fused deposition modeling, and selective laser sintering. Each of these methods involves similar processing, which includes data acquisition, image processing, and model production and finishing. All rapid prototyping techniques are based on the same principle of constructing a 3D structure in layers. The most direct benefits to the dental implant patient include: *(1)* a better understanding of the treatment requirements and commitment needed for successful therapy; *(2)* a significant reduction in surgical time and proportional decreases in postsurgical pain, discomfort, and swelling; *(3)* the ability to review risks and benefits of treatment with the patient for a better understanding of anticipated outcomes and alternative types of treatment.

Medical modeling has several principal uses.[5–7] First, it enables visualization of anatomic features such as tumor size and location, bone morphology, and orientation of vital structures. Second, it facilitates communication between surgical team members, restorative practitioners, and patients. Third, it enables the rehearsal of surgical procedures such as osteotomy preparation, implant positioning, abutment selection, and implant provisionalization. Complex surgical interventions, for example, can be performed on a stereolithographic medical model as a "dress rehearsal" prior to actual patient intervention (Figs 1 and 2). Fourth, the design of future component prototypes can easily be made and used on medical models.

Stereolithography is the most well known and used rapid-prototype technique.[4,7] It is also the technique most commonly used for the generation of medical models and computer-generated drilling guides used for osteotomy site preparation in dental implant surgery.[6,8] The stereolithographic process is unique in that it builds 3D medical models in layers through laser scanning of a light-sensitive resin in the area defined by the object's cross section, which, in the case of bone data, is defined by a CT scan. A controller positions a vertical elevator, housed inside a vat filled with a liquid photosensitive acrylic resin, so that it rests just below the liquid surface. An optical scanning system directs ultraviolet laser light, which "draws" a shape—one layer at a time—onto the surface of the resin. As the laser strikes the surface, the resin is solidified and the first layer of the model is built. The scanning process is repeated, and the second layer is built on top of the first one. Subsequent layers are generated similarly. This process continues until the entire anatomic model defined by the CT is constructed. The resin is further cured in an ultraviolet oven to ensure complete solidity.

Accuracy and reliability are distinguishing characteristics of the stereolithographic process.[9] In addition, stereolithography allows for medical models to be generated that are transparent, constructed in a timely manner, and cost effective; such models also allow for selective colorization of regions of visual interest.[10] These areas include (but are not limited to) proposed osteotomy/implant site locations, locations of vital structures, and tumor boundaries. Finally, the resin's low toxicity and Food and Drug Administration approval (USP Class VI) allows for it to be in contact with the patient during surgery. The dimensional accuracy of anatomic skull replicas derived from 3D CT imaging using stereolithography has been shown to be within 1 mm.[11–13]

Fabrication of drill guides

SurgiGuides (Materialise) are successive-diameter surgical osteotomy drill guides that are computer generated and constructed through the process of stereolithography. Common to all drilling guides is selection of the most appropriate scanning appliance to ensure that the surgical treatment plan is based on the prosthetic outcome, which is transferred onto the CT. The SurgiGuide design is based on the presurgical 3D positioning of implant icons using SimPlant interactive software. Drill guide support can come from bone, teeth, mucosa, or preexisting dental implants. Stereolithographic drilling guides that require bone exposure for precise osteotomy site preparation are discussed here. Part 3 of this series will discuss the use of tooth- and mucosa-supported drilling guides.

Each SurgiGuide possesses a defined number of steel tubes that corresponds to the number of desired osteotomy preparations and the specific drill diameters. Each 3D axial position of the drilling tube is based on the ideal implant position. Each drilling tube has a specific diameter and height. The diameter of the steel tube depends upon the diameter of the twist drill used for osteotomy site preparation (based on the manufacturer's specifications); typically, the diameter of the tube is 0.2 mm greater than the diameter of the twist drill. Each drill diameter requires fabrication of a different successive SurgiGuide. The accuracy of the guide can be checked on the stereolithographic model. Surgical dress rehearsals can be performed if necessary.

Use of bone-supported drilling guides during implant surgery

Bone-supported SurgiGuides are designed to fit intimately and precisely on the patient's full or partially edentulous jawbone to facilitate planned osteotomy site preparation and implant positioning. The use of bone-supported SurgiGuides requires an open flap technique to gain access to the underlying bone. At least 30 mm of supporting mesiodistal bone surface is required. The stability of the guides is directly related to the seating surface. SurgiGuide stability is enhanced with increased surface area of bone contact, so the potential for guide dislocation during osteotomy preparation is minimized. These guides are best used in completely edentulous patients, although they can be used for partially edentulous patients as well. In the partially edentulous patient, alternative guide designs may be required because of insufficient surface area for guide support. Combined bone- and tooth-supported guides are one option.

Once the surgical field is defined and exposed, the guide is placed on the patient's jawbone to check for stability. It is imperative to ensure adequate flap reflection for guide insertion and to completely remove residual tissue tags that may be adherent to the underlying bony cortex and extraction deformities. Because bone-supported SurgiGuides are based on successive drill diameter osteotomy site preparation, it is important to demonstrate proper fit of all guides. A tactile sense for proper positioning of each guide will help ensure correct guide alignment for successive osteotomy preparations when increasing the diameter at each osteotomy position. Within each SurgiGuide is a drilling cylinder whose diameter is slightly larger than the twist drill that is to be used for the preparation of that particular osteotomy site. For example, a typical osteotomy site preparation for a standard-size implant (4.0-mm diameter)

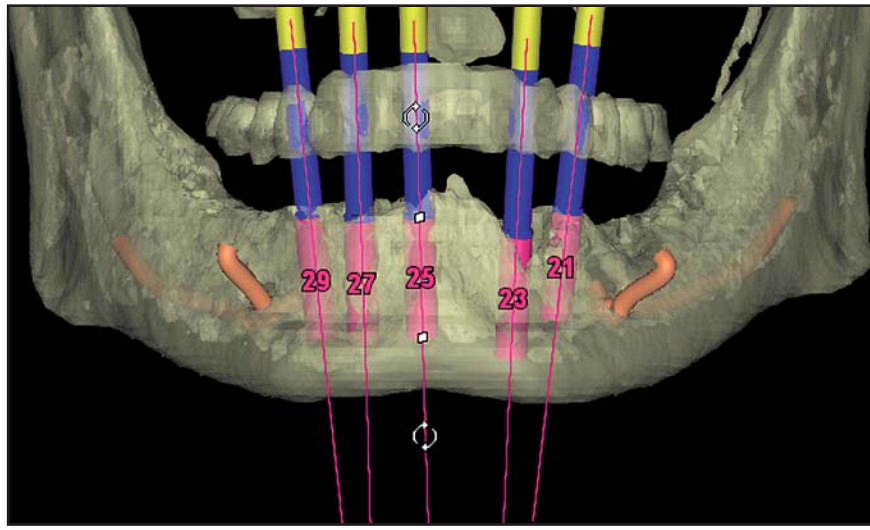


Fig 3a (above) *Preoperative view of a completely edentulous mandible.*

Fig 3b (right) *Three-dimensional CT reconstruction and collaborative implant treatment planning are performed using SimPlant software directed by a second-generation scanning appliance.*

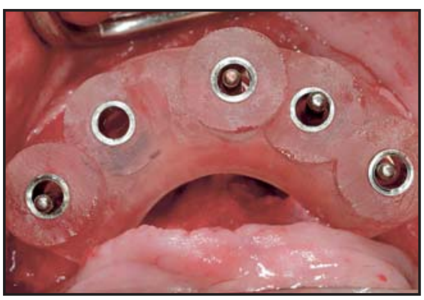
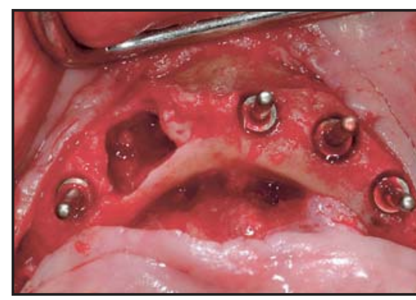


Fig 3c (left) *The bone-supported SurgiGuide sits on the patient's mandibular bone with four guide pins in prepared osteotomy sites.*

Fig 3d (right) *The SurgiGuide is removed to inspect osteotomy preparation sites. A residual extraction defect will be grafted and an implant introduced after sufficient healing has occurred.*



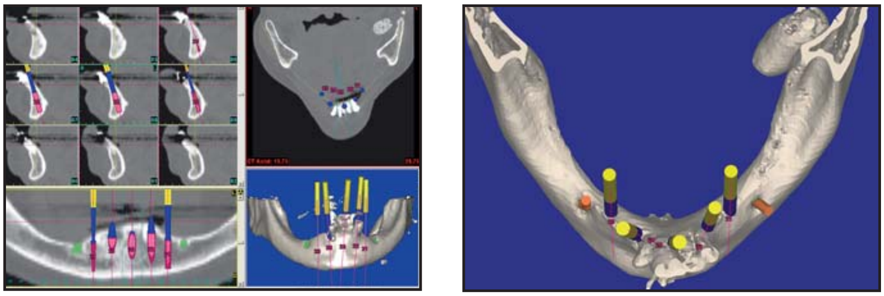
would consist of site preparation beginning with a 2.0-mm twist drill using a SurgiGuide with a 2.2-mm drilling tube diameter and increasing to 3.0 mm using a SurgiGuide whose drilling tube corresponds to 3.2 mm.

Two cases of bone-supported SurgiGuide utilization are presented in Figs 3 and 4.

Discussion

For any therapeutic intervention, the risk of an adverse outcome is generally directly proportional to the time of discovery. In implant therapy, this discovery can come preoperatively, intraoperatively, or postoperatively. The availability of detailed pretreatment diagnostic data reduces the risk of an adverse surgical outcome because it facilitates information management and disclosure among those participants responsible for patient care.

Fig 4a *Preoperative view of patient's compromised mandibular dentition.*



Figs 4b and 4c *Three-dimensional CT reconstruction and plan for collaborative implant treatment planning are created using SimPlant software.*

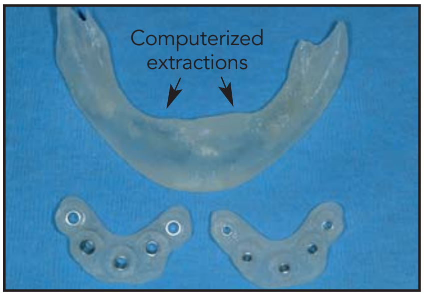


Fig 4d (top) *A stereolithographic resin bone model of the mandible is created with computerized extractions.* (bottom) *Bone-supported drilling guides are based on the 3D implant plan.* (left) *3-mm guide;* (right) *2-mm guide.*

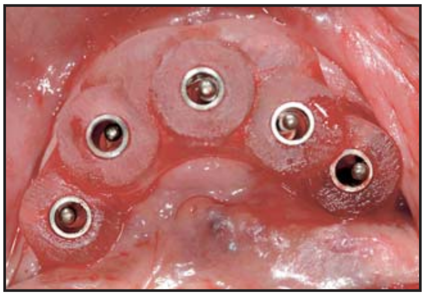


Fig 4e *The bone-supported SurgiGuide sits on the patient's mandible following extractions of remaining natural dentition. Guide pins are seated in prepared osteotomy sites.*

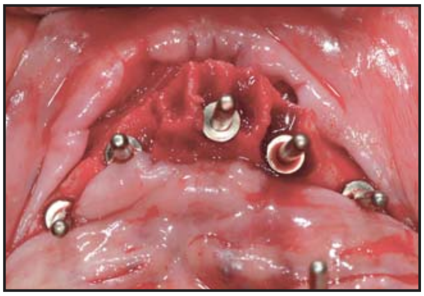
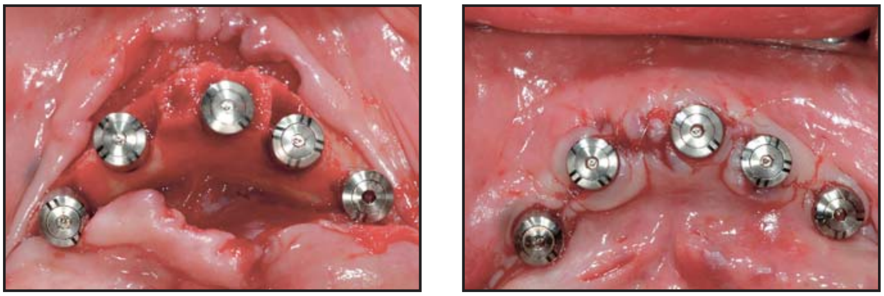


Fig 4f *The SurgiGuide is removed to inspect osteotomy preparation sites. Note the irregular bone morphology, which would make traditional preparation of the immediate extraction osteotomy sites extremely challenging. Guide pins are positioned exactly as planned using the prosthetically directed 3D plan despite the loss of spatial orientation that an unstable conventional surgical guide might provide.*



Figs 4g and 4h *The implants are positioned, with healing abutments placed and flaps closed.*

Fig 4i *Definitive prosthetic outcome (courtesy of Dr Ken Milin, Winnetka, IL).*

The major advantages of bone-supported SurgiGuides include visualization of the surgical field, stability of guide fit, ease of drill placement in the drill tubes, elimination of drills used solely to perforate the bone cortex, reduction in interoperator variability, improved treatment consistency, and a reduction in overall surgical time. The one disadvantage includes the need for bone exposure, although the duration of bone exposure is reduced by the computerized treatment planning process. It is important to remember that time spent in preoperative treatment planning is related to reduction in surgical treatment time. Prosthetically directed surgical planning is completed on the computer. Last, because there is no representation of final tooth position in space with the SurgiGuides, the ability to verify precise positioning by the surgeon at the time of surgery demands a transfer of trust and confidence in the technology. This underscores the importance of accurate diagnostics and prosthetically directed implant planning by the interdisciplinary team and, in part, reinforces the definition of collaborative accountability.[2]

Conclusions

1. Stereolithographic medical modeling is accurate and applicable to prosthetically directed implant surgery.
2. Bone-supported surgical drilling guides enable more precise osteotomy preparation with a reduction in surgical equipment and surgical time.
3. Bone-supported drilling guides enable standardization of treatment outcomes.
4. Bone-supported drilling guides allow for the execution of a collaboratively based treatment plan.

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