USE OF STEREOLITHOGRAPHIC MODELS AS DIAGNOSTIC AND RESTORATIVE AIDS FOR PREDICTABLE IMMEDIATE LOADING OF IMPLANTS

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Implant dentistry has evolved into one of the most predictable treatment alternatives in all of medical science. Advances in the surgical and prosthetic components, implant designs and surface technologies, and imaging techniques have allowed for significant modifications to occur with respect to one- and two-stage surgical protocols, accelerating treatment times to the benefit of patient and clinician. This article presents a technique to improve surgical and restorative accuracy, allowing for predictable placement and immediate loading of implants through use of CT imaging, stereolithographic models, and CT-derived surgical templates.

Learning Objectives:
This article presents concepts for implant surgery simulation using advanced surgical templates fabricated from CT-derived data. Upon reading this article, the reader should:

• Understand the role of CT scanning in proper implant placement.
• Recognize the steps and considerations involved in implant surgery simulation.

Key Words: implant, stereolithographic model, computed tomography, template, guide, immediate loading

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Presurgical prosthetic planning is essential in delivering the restorative component to the patient following implant placement. This is particularly true when implants are to be loaded at the time of surgical placement. To determine proper fixture placement based on tooth position and occlusal demands, state-of-the-art diagnostic tools transfer the procedure to the virtual environment of a computer, where computed tomography (CT) imaging and three-dimensional assessment of the bone can be conducted. In this environment, optimal fixture positions should be chosen based on the restorative requirements of the patient and the quantity and quality of the bone. Precise virtual planning can be ideally achieved when a radiopaque representation of the desired occlusion in the form of a CT or scannographic template is incorporated intraorally during the CT scan. Stereolithographic models created from the CT software data set, combined with software-driven treatment planning, allow the fabrication of surgical templates that guide implants precisely to their desired positions. Utilizing advancements in imaging, diagnostic software application, and surgical templates facilitates the entire procedure, reducing surgical chairtime and accelerating treatment.

This article presents concepts that enable clinicians to simulate implant surgery on rapid prototype (RP) models utilizing advanced surgical templates fabricated from CT scan treatment planning data. These templates are then used to guide the surgical placement of the implants in the same position as on the RP model. The resulting technique can be used to enhance surgical and restorative accuracy for predictable placement and immediate loading of implants.

Background
Computed tomography has been used in fabricating exact replicas of the maxilla or mandible through stereolithography for almost two decades. Early utilization was to eliminate the surgical bone impression phase of the subperiosteal implant modality. Cranin et al, however, compared direct bone impression techniques to CAD/CAM-generated models for subperiosteal fabrication and found variations in accuracy. McAllister suggested that stereolithography offered a higher degree of build accuracy and repeatability for subperiosteal implant manufacture. Webb reviewed the use of the RP technique in the medical sector, concluding that the use of RP models was beneficial in terms of measurement and diagnostic accuracy.
Most clinicians accept the necessity of transferring the ideal tooth position to an accurate surgical guide. This is generally accomplished by using a duplicate of the patient’s existing denture, or through the creation of a diagnostic waxup that is replicated using radiopaque barium sulfate, which allows for the tooth form to be visible on the CT image. Variations on this modality have been reported as clinicians sought to determine the missing link that enabled a transfer of the treatment planning analysis to the surgery. Most solutions used surgical steel drill guide tubes or a series of telescoping metal tubes to facilitate accuracy of the osteotomy. Some included all-acrylic templates that supplied enough information for the clinician to understand the desired implant position in relation to the tooth replacement, but little about the condition of the recipient bone. Nevertheless, it was not until there was a connection between the treatment planning data and the stereolithographic model that the missing link was established. Thus, the use of CT has evolved from a diagnostic tool for implant placement to an integral part of the planning, surgical, and restorative phases of treatment.

Technical Protocol

A 55-year-old male presented with a failing maxillary 13-unit metal-ceramic fixed partial denture (FPD) (Figure 1). The left side of the arch contained a long-span FPD from tooth #11(23) to #13(25). Clinical and radiographic evaluation revealed decay at the margin of the mesially tilted #11 (Figure 2), which was easily penetrated with an explorer. The remaining metal-ceramic restoration was intact, with good marginal integrity for the abutments on teeth #3(16) through #10(22). The patient was informed that if the existing FPD was to be removed and the supporting abutments found to be nonrestorable, a new fixed replacement would not be possible due to lack of support. The patient’s principal desire was a fixed replacement as soon as possible, and he inquired as to the possibility of using implants to support the maxillary left side without having to remove the existing FPD on the right side. From the initial panoramic radiograph, it appeared that sufficient vertical bone was present for implant placement. Without three-dimensional imaging, however, little information could be obtained about the width, volume, or quality of the bone. The patient was thus referred to a local radiologist for a CT series, specifically reformatted for use with computer-imaging software (SIM/Plant, Materialise-CSI, Inc, Glen Burnie, MD). For this patient, a radiopaque template was not possible or necessary due to the existing metal-ceramic restoration.

The CT scan was evaluated in panoramic, axial, and cross-sectional views utilizing the imaging software. Implant receptor sites were determined for each cross-sectional slice that would best align with the emergence profile of the four teeth to be replaced. Each cross-section was evaluated based on the desired location of the implant in relation to the tooth position and embrasure areas. Sufficient information was present from the existing metal-ceramic restoration to afford accurate
positioning of the simulated implant (Figure 3). The software allowed a manufacturer-specific implant to be selected, and its corresponding shape was incorporated into the chosen slice along with an extension representing the simulated abutment. The four potential receptor sites were located and, once evaluated for volume of available bone, the implants were placed with their corresponding abutment extensions. These initial determinations were completed using only the two-dimensional axial, panoramic, and cross-sectional views to bring the implant into a position where it would also support the desired tooth position, described by the author as the "Triangle of Bone." Each potential receptor site was also evaluated for bone density using the Hounsfield scale to further assess its potential for immediate loading. This was important in deciding if there was adequate fixation to allow for traditional two-stage, one-stage, immediate, or early loading of the implants.

The three-dimensional modeling allowed the clinician to visualize all aspects of the anatomical site and the implant positions (Figure 4). The four implants were seen only through the abutment extensions (yellow), as they appeared buried in the bone model. This representation afforded the clinician with a better understanding of the actual bone topography than did any of the two-dimensional views. The implants were rotated into the most favorable positions and transferred from the two-dimensional cross-sectional view to the three-dimensional volumetric model. The 3D imaging allowed the author to avoid anatomical landmarks and neighboring tooth roots (Figure 5), to establish adequate interimplant distance, and to improve emergence profiles and embrasures of the restoration. The ability to manipulate the opacity of the model enabled the clinician to examine the implants in relation to the residual tooth roots (Figures 6 and 7).

The entire data set was e-mailed to the manufacturer for the fabrication of a stereolithographic model of the patient’s maxilla and corresponding surgical template. The CT scan data were used to generate a 3D computer model of the maxilla. Based on this 3D model and the plan derived from the imaging software, surgical templates were developed to securely fit on the alveolar bone and to exactly transfer position and angulation of
the planned implants. Both model and surgical templates were built on a stereolithographic machine where a liquid acrylate was hardened in layers using UV light. After polymerization, the RP stereolithographic model was then used to fabricate the bone-borne templates (SurgiGuide, Materialise-CSI, Glen Burnie, MD) used to position the implants during insertion. To accommodate the drilling sequence, several templates that corresponded to the manufacturer’s guidelines for osteotomy preparation were fabricated (Figure 8) utilizing 5-mm–high stainless steel tubes 0.2 mm wider than each drill.18

A diagnostic waxup was completed for the purpose of fabricating a processed acrylic transitional splint. The existing FPD would be sectioned at tooth #11, preserving its remaining right side. The bone-borne templates were then utilized in a novel technique that simulated the intraoral placement of the implants on the stereolithographic model of the maxilla. Osteotomies were created directly on the RP resin models (Figure 9). The first, third, and fourth sites received 3.7-mm–diameter tapered implants (Tapered Screw-Vent, Centerpulse Dental Division, Carlsbad, CA). The second implant received a 4.7-mm–diameter implant (Tapered Screw-Vent, Centerpulse Dental Division, Carlsbad, CA). A corresponding internally hexed implant replica analog was then placed into each simulated osteotomy and secured with light-cured acrylic resin (Figure 10). To facilitate the attachment of the transitional restoration to the implants and to synchronize the position of the abutment within the analog/implant, the flat of the internal hex was rotated to the facial surface.

Titanium fixture mounts were prepared in advance to conform to the tooth position and embrasure design of the transitional restoration. The Tapered Screw-Vent fixture mounts served three purposes: 1) as the implant carrier, 2) as an impression transfer post, and 3) as a prepable temporary abutment. Initially, each of the four fixture mounts were grossly reduced using heatless stones and then refined with titanium cutting laboratory burs (eg, Ganz Abutment Preparation Kit, Brasseler USA, Savannah, GA) until the desired shape was achieved (Figure 11). The transitional restoration was then adapted to the abutments with light-cured acrylic resin (Figure 12).
Surgical Phase

The long-span FPD was sectioned with a high-speed handpiece under copious irrigation. The left side was unattached to the residual roots due to marginal decay and was easily removed (Figure 13). A full-thickness, midcrestal incision and mucoperiosteal flap exposed the underlying alveolar crestal bone, and the mesially inclined canine was carefully extracted (Figure 14). All granulation tissue was curetted from the site. The remaining posterior molar was prepared and found to be satisfactory to retain as a terminal abutment. The templates were placed onto the bone to evaluate fit. If there was any soft tissue impingement, the flap was extended to allow for intimate fit of the template (Figure 15). Osteotomies were prepared sequentially with the use of the bone-borne template (Figure 16). The implants were subsequently placed without incident.

As in the stereolithographic model-simulated placement, each of the implants was rotated so that the flat of its internal hex was facing facially at the predetermined depth. This facilitated orientation of the previously prepared abutments in the correct rotational and interproximal position. Despite the bony defects at the residual extraction site, the bone-borne template allowed predictable, accurate preparation of each osteotomy, implant, and abutment (Figures 17 through 19). Additionally, the prepared abutment margins conformed to the shape of the bony topography. Prior to cementation of the temporary prosthesis but after primary closure, a fixture-level impression was taken to capture the position of the implants and the soft tissue in the sutured position. A bite registration was completed, and the restoration was cemented.

Restorative Phase

The patient healed without incident during the first month. The fixture-level impression was used to fabricate a soft-tissue working cast to help determine margin configuration for the anticipated custom abutments. The articulated models and the original diagnostic waxup of the desired restorative result were then scanned to create a “virtual occlusion” from which virtual abutments (Atlantis Components, Cambridge, MA) were designed (Figure 20). The individual CAD/CAM designs were completed according to the margin specifications as noted on the laboratory prescription. The first three abutments were to be splinted and required parallelism for passive fit of the framework (Figure 21). The three virtual abutment data sets were then sent to a CNC machine for processing (Figure 22). The fourth abutment was for the canine, which was fabricated using a standard custom-cast post technique.

After 8 weeks of healing, the provisional restoration was removed. The implants were nonmobile and integrated, and the soft tissue had matured to conform to the emergence profile of the transitional restoration. The prepared transfer post abutments were easily removed. To ensure the patented friction-fit for the computer-milled abutments, titanium blanks were provided by the manufacturer (Centerpulse Dental Division, Carlsbad, CA).
computer-milled abutments were then delivered to the patient, and the temporary splint was relined to seal the new margins. The duplicate abutments were then utilized on the master working cast as the die for the fabrication of the cast coping. A separate coping was cast for the natural molar tooth, and the custom cast post was created for the canine implant. Two weeks after the abutments were delivered, the cast copings were evaluated intraorally for fit. Three weeks later, the bisque bake of porcelain was evaluated for function and aesthetics. Upon patient approval, the final case was delivered two weeks later (Figures 23 through 25).

Discussion
Presurgical prosthetic planning is the foundation for successful immediate loading of implants. Positioning the implant in terms of the functional and aesthetic demands of the tooth is difficult due to limitations inherent with the most common two-dimensional imaging techniques. Computed tomography and sophisticated diagnostic software provide clinicians with an enhanced vision of bone anatomy. Such software applications permit an evaluation of the bone and simulated placement of implants. As advocated by the author, when a barium sulfate radiopaque CT template is utilized (representing fully contoured tooth morphology), additional planning for abutment type within the confines of the individual tooth position can be achieved with unparalleled accuracy.17-19

The primary criticism of this technology, however, has been in translating the simulated plan to the patient at the time of surgical intervention. The introduction of stereolithographic RP models and resultant surgical templates merges technology with reality, bringing the plan directly to the surgical site.14,16 The use of CT-derived templates fabricated to incorporate simulated virtual implant placement gives the surgeon an efficient, accurate mechanism for creating osteotomies within a high degree of correlation to the original plan, diminishing surgical time as well as reducing the length of osseous exposure.20

Immediate load protocols require adequate host bone as well as evaluation of the occlusion, an appropriate implant design that maximizes bone fixation and osseocompression, secure connection between implant and abutment to avoid micromovement, and accurate surgical guidance. The patient’s bone anatomy was evaluated and found to be acceptable in volume and density in terms of Hounsfield units, a determination that can be successfully assessed presurgically from CT scan data, differentiating this imaging modality from linear tomography.19 Specific implants were chosen based upon surface design features, mechanical stability, and the internal friction-fit connection of the abutments.21 In accordance with the planning software, four implants were then virtually placed in positions to maximize an immediate loading protocol.

Surgical templates of various designs have been utilized to accurately position implants according to the patient’s restorative demands. Computed tomography-derived templates have been found to be more accurate
than other methods, including the use of the SurgiGuide protocol.\textsuperscript{13,20,22} This presentation describes a novel approach where the stereolithographic replica of the patient’s maxilla served as the receptor site for the implant replica analogs. This differs from other methods described in the literature that utilize stone casts created from impressions of the patient’s dentition or diagnostic waxup. The analogs were placed into the stereolithographic model as guided by the prefabricated template processed from the software treatment plan data set. This allowed for the fabrication of milled provisional titanium abutments and laboratory-processed transitional restoration prior to the surgical procedure. The ability to thoroughly assess the existing bone anatomy and plan for both surgical and restorative phases enabled the procedure to be performed with confidence. The result was decreased surgical time, improved restorative efficiency, and a highly accurate predictable method for immediate loading protocols.

During the eight-week healing phase, a working cast that contained analogs replicating the intraoral implant positions was created. Using a diagnostic waxup, computer-milled abutments were created to meet the tooth-specific shapes of the missing dentition. The virtual abutment design process allowed for precise fabrication of each original abutment and its duplicate as well as for parallelism that ensured the passive fit of the prosthesis. The original abutments were then used introrally after integration was initially achieved to help with the continued soft tissue maturation around the transitional restoration. The duplicate abutments were utilized as dies on the same working cast that was created from the initial fixture-level impression at the time of surgery to fabricate the metal-ceramic copings. Therefore, the laboratory had precise control of the coping fit, as the die was the actual abutment. Utilizing CAD/CAM technology enabled the restorative phase to be completed with the highest degree of accuracy with a minimal number of impressions and office visits.\textsuperscript{23}

**Conclusion**

Implant dentistry has expanded to include advancements in computer-based imaging technology. This presentation demonstrated an expanded use of stereolithographic models in the presurgical phase, which is of utmost importance.
importance for immediate provisionalization protocols. The described technique enables a more complete understanding of the ultimate prosthetic goal in anticipation of implant support. The surgical placement of the implants guided by the precise treatment plan through the application of the template was followed by the immediate placement of transmucosal abutments and transitional restorations. The methodologies as described reduced surgical chairtime and the number of involved restorative steps, and accelerated treatment phases, ultimately achieving the expectations of both clinician and patient.

As immediate loading protocols gain momentum in accelerating treatment times closer to those of conventional prosthetics, CT scan treatment planning and CT-derived template design become a necessary diagnostic and surgical tool to understand anatomy, identify pathology, avoid complications, and to ensure predictability and long-term success. Additional research will be required to confirm the protocol as described herein.

Acknowledgment

The author declares that he is a consultant for Materialise-CSI and Atlantis Components and that he lectures on behalf of Centerpulse Dental Division. He receives no financial benefit from the sale of any product referenced herein.

References

1. Presurgical, prosthetic planning is essential in delivering the restorative component to the patient following implant placement. This is particularly true when implants are to be loaded at a separate time from surgical placement.
   a. Both statements are true.
   b. Both statements are false.
   c. The first statement is true, the second statement is false.
   d. The first statement is false, the second statement is true.

2. Varying designs of surgical templates have been fabricated to help:
   a. Determine proper fixture placement based upon restorative demands.
   b. Allow the restorative clinician to assess the quality of bone.
   c. Position the temporary prosthesis properly.
   d. All of the above.

3. For correct transfer of ideal tooth position, clinicians often use:
   a. The patient’s existing denture.
   b. A diagnostic waxup.
   c. Both a and b.
   d. Neither a nor b.

4. How long has CT been used to fabricate replicas of the maxilla and mandible through stereolithography?
   a. ~ 8 years.
   b. ~ 10 years.
   c. ~ 15 years.
   d. ~ 20 years.

5. The use of CT is an integral part of which treatment phase?
   a. Planning.
   b. Surgical.
   c. Restorative.
   d. All of the above.

6. Which of the following characteristics of bone is practically unobtainable without the use of 3D imaging?
   a. Quality.
   b. Volume.
   c. Width.
   d. All of the above.

7. In the author’s opinion, CT and sophisticated diagnostic software permit:
   a. Bone evaluation.
   b. Implant placement simulation.
   c. The enhancement of bone anatomy visualization.
   d. All of the above.

8. What is the primary criticism surrounding the use of CT technology?
   a. The translation of simulated plans to the patient at surgical intervention.
   b. Increased surgical time.
   c. Poor determination of bone quality.
   d. Difficult to master.

9. The use of stereolithographic models guided by CT-derived templates aid implant placement through:
   a. Improved restorative efficiency.
   b. Provision of an accurate method for immediate loading protocols.
   c. Both a and b.
   d. Neither a nor b.

10. In what way did 3D imaging aid the author during implant placement?
    a. It established adequate interimplant distance.
    b. It allowed for improved emergence profile.
    c. Anatomical landmarks and neighboring tooth roots could be avoided.
    d. All of the above.