A novel approach to predict implant placement utilizing CT-derived model-based surgery was performed for a maxillary-anterior aesthetic immediate extraction/immediate restoration; root proximity and inter-implant positioning was an additional complication. The use of state-of-the-art diagnostic and treatment-planning tools described in this article has been shown to be effective for both partial and completely edentulous patient presentations. These tools can serve as a foundation for accurate, highly practical, and repeatable CT-scan-derived model-based presurgical prosthetic planning for the immediate loading of dental implants.

Learning Objectives: This article discusses the use of CT scanning as an effective tool in planning and placing implants as part of restorative treatment. Upon reading this article, the reader should:

• Understand the benefits of CT scans in obtaining diagnostic information.
• Appreciate the importance of presurgical prosthetic planning in successful implant reconstruction.

Key Words: immediate load, implants, aesthetic, CT scans, restorative, surgical template, interactive treatment planning

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The traditional two-stage approach to dental implant placement required a closed surgical site, burying the implant under the soft tissue during a healing phase of three to six months prior to activation, or uncovering with a second surgical intervention. Early-loading techniques evolved when two-stage implants were placed into the bone, a healing collar was attached immediately, and the soft tissue was sutured around the transmucosal element, obviating a second surgical procedure. While not functionally loaded, the implants did have some stimulation from the oral environment. Immediate-loading protocols allowed for the restorative components to be attached at stage-one surgery to support a transitional restoration, whether single, multiple, or full-arch reconstruction. Success rates for the change in protocols have demonstrated results as favorable as those achieved with two-stage protocols.

In order to achieve success with immediate or delayed loading, several requirements must be satisfied. These include: 1) the presence of sufficient host bone; 2) primary fixation of the implant; 3) nonmobility of the interim prosthesis for a minimum of eight weeks; 4) excellent presurgical prosthetic planning; 5) template guidance for the surgical placement according to the restorative plan; and 6) management of the soft tissue. The author believes it imperative that all six parameters be met in order to achieve success, as any missing components can lead to disappointment. While all are important, too little emphasis has been placed on the presurgical prosthetic planning phase. Ideally, diagnostic study models must be acquired in advance to assess the tooth position and surrounding anatomy. A diagnostic waxup or denture tooth setup may be necessary in certain cases to address the desired functional and aesthetic outcomes. It has been stated that the goal of implant dentistry is not the implant, but the tooth that is being replaced. Implant dentistry must, therefore, be restoratively driven, and the importance of presurgical prosthetic planning and accelerated treatment protocols are to be implemented.

A 26-year-old female presented four months after a trauma that nearly avulsed her four maxillary incisors.
The teeth were splinted together until a proper treatment plan could be developed (Figure 1). The patient’s medical history was unremarkable, and the dental examination revealed that she did not have any other dental restorations present. The patient desired an immediate fixed-type replacement that preserved the healthy teeth and avoided a removable transitional denture.

After clinical examination and review of the periapical radiographs, the possibility of four extractions, implant placement, and immediate loading seemed impractical. The patient was advised that CT-scan imaging would yield the information necessary to recommend the best treatment alternative, based upon a complete assessment of the bone for the potential implant placement. An appointment was made, and the digital CT information was processed for use with implant planning software (ie, SimPlant, Materialise Dental Inc, Glen Burnie, MD).

The crosssectional CT-scan data revealed the extent of the traumatic injury and confirmed the need to remove all four maxillary incisors. The cross-sectional images conveyed the anatomical relationships necessary for diagnosis and treatment planning as well as the existing tooth position in relation to the surrounding bone (Figure 2). The normal tooth trajectory could be appreciated, along with the narrow band of bone surrounding the facial and palatal/lingual aspects of the teeth. Using interactive software, the clinician could visualize the placement of a proposed implant receptor site within the alveolar housing as defined by the Triangle of Bone™ concept (Figure 2). The green overlay was an accurate 3D CAD representation for bone length and diameter, with the yellow extension simulating an abutment at the desired tooth position. The latest generation of software applications allowed further examination of the bone and root structures through the virtual 3D model of the maxilla (Figures 3 and 4).

The individual implant positions were virtually repositioned using the interactive 3D model and the other available views. This was extremely important when evaluating the planned implant positions relative to their final restorations. Using the features of the planning software, the virtual maxillary bone was hidden from view to allow for an unobstructed perspective of the implants. The individual implants were then evaluated for parallelism, emergence profile, inter-implant distances, and projection of the abutments. The selected Tapered Screw-Vent implants (Zimmer Implant, Carlsbad, CA), 13 mm in length by 3.7 mm in diameter, were positioned to allow for proper prosthetic reconstruction while maximizing available bone for adequate fixation. The ability to rotate the realistic 3D images granted the clinician the opportunity to understand all aspects of the proposed implant positions.
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Figure 7. After using the template as a drill guide, the analogs were positioned to the planned depth as measured from the CT-scan data.

Figure 8. Each tooth was removed from the original stone cast so that the soft tissue architecture could be preserved and the FMTs could be prepared.

Figure 9. The four laboratory-prepared titanium FMTs allowed an acceptable emergence profile to be established for the immediately-placed provisional restorations.

The next step of the process linked the simulated plan directly to the patient at the time of surgery through the transfer of the CT-software planning data to a surgical template. Once the implant locations were determined, the plan data were sent via e-mail for the fabrication of accurate templates to unite the plan to the surgical site. The implants chosen for this case required three sequential drills for conservative site preparation: a pilot, intermediate, and final sizing drill. Therefore, more than one template was created (Figure 6), each corresponding to the specific drill to be used during the surgical procedure. The acrylic templates contained embedded stainless steel tubes, 5 mm in height and varied in diameter, to correspond to the specified drills.

In order to fabricate a tooth-borne template, a stone cast was sent to Materialise Dental Inc (Glen Burnie, MD). Once the series of three templates were received, a novel laboratory step was undertaken to aid in the immediate loading process. Each tooth was carefully removed from the original stone cast in an attempt to preserve the soft tissue architecture. Using the manufacturer-supplied drills and the surgical templates, osteotomies were cut into the stone model, which corresponded to the exact location as planned by the CT-scan software. Implant replicas were then attached to long screws that were placed through the templates. The analogs were then positioned within the stone models to the planned depth as measured from the CT-scan data (Figure 7). The flat side of the antirotational internal hexagon was oriented to the facial for prosthetic consistency, and the alveolar surgical housing was maintained (Figure 8). Fixture mount transfers (FMTs) included with each implant allowed the clinician: 1) to deliver the implant to the site; 2) to use it as an impression transfer post; and 3) to modify it as a temporary titanium abutment. Four FMTs were milled in advance of the surgical procedure, leaving enough bulk to allow for adequate preparation, which would serve as temporary abutments within the envelope of the teeth. This allowed an acceptable emergence profile to be established for the immediate temporary restorations (Figure 9).

Once the preoperative laboratory phase was completed, the patient was scheduled for surgery. Prior to the administration of anesthesia, blood was drawn from the patient and collected for later use. The hopeless incisors were atraumatically removed with the use of periodontal grafts (Figure 10). The first surgical template was firmly seated onto the adjacent teeth (Figure 11). The secure tooth-borne position allowed for accurate guidance of the drills in the irregular contours of the fresh extraction sockets. Once the drilling sequence was complete, the implants were then placed into each osteotomy and rotated to depth with the flat side of the hex positioned facially (Figures 12 and 13).
Figure 10. The hopeless incisors were atraumatically removed with the use of peritomes.

Figure 11. The first surgical template was secure in its tooth-borne position, which allowed for the drills to be guided accurately within the fresh extraction sockets.

Once it was determined that all of the implants and abutments were properly positioned, the abutments were removed and the FMTs were replaced. The soft tissue was gently approximated, and a full-arch impression was made to transfer the location of the implants to a working cast for later prosthetic component fabrication. Defects in the bone were then filled in with mineralized cancellous particulate allograft material and mixed with platelet-rich plasma (PRP) that had been prepared at the onset of the procedure. The site was covered with a collagen matrix soaked in PRP, and the soft tissue was approximated around the transmucosal temporary abutments. A four-unit, laboratory-processed, acrylic temporary restoration was seated and adjusted to remove any lateral, protrusive, and occlusal interferences (Figure 14).

In an attempt to reduce the load on the prosthesis during the healing phase, no occlusal contacts were desired during any jaw movements. The prosthesis was cemented and remained in place for approximately eight weeks.

Use of the CT-scan-derived surgical templates allowed the implants to be placed as planned, accurately engaging bicortical bone without perforation into the nasal cavity as previously defined by the Triangle of Bone™ (Figures 15 and 16). Additionally, the previously prepared abutment margins were clearly visualized in the postoperative radiographs in relation to the surrounding cortical bone.

After an uneventful eight-week healing phase, the acrylic transitional restoration was removed and the site was examined. The soft tissue response was found to be excellent (Figure 17). The prepared FMTs had served their purpose but, due to their initial size limitation, did not have the proper morphology or fit to serve as final abutments. Four CAD/CAM abutments (ie, Atlantis Components, Inc, Cambridge, MA) designed with correct morphology and emergence profiles were fabricated from the articulated soft tissue model. The properly contoured, computer-milled abutments (CMAs) were seated onto the implants, which favorably impacted the soft tissue contours. The abutments were computer-created via a virtual abutment design process and then milled from a block of titanium. A clear matrix of the diagnostic waxup, placed over the working cast, revealed the ideal shapes of the abutments in both facial and occlusal dimensions (Figure 18). New transitional temporary restorations were adapted to the morphologically correct CMAs, and the tissue was allowed to mature for another two months.

At approximately four months, the gingival tissue was evaluated for maturation. The CMAs were removed in order to permit visualization of the sculpted soft tissue contours. The facial view revealed well-formed interdental papillae in response to the morphology and emergence profile of the CMAs and the transitional restorations. From a lateral angle, the alveolar sulcus and interdental papilla formation could be more readily assessed (Figure 19). The CMAs that were delivered...
to the patient supported the provisional restoration and allowed for soft tissue maturation. The advantage of state-of-the-art CAD/CAM design and fabrication is that it affords the clinician the option of obtaining exact duplicate abutments. One set of abutments, therefore, remained seated in the mouth to maintain the alveolar sulcus form, while the second set was forwarded to the laboratory for coping fabrication.

Due to the precision of implant placement, excellent bone fixation, and fit of the internal connection abutments, four individual (non-splinted) metal-ceramic crowns were fabricated. The definitive restorations conformed to the original diagnostic waxup with proper morphology, embrasures, contacts, emergence profiles, and aesthetics. The original position of the muscle attachment (ie, frenum) at the midline was removed at the time of implant surgery and resulted in a more pleasing appearance while helping prevent additional stress during the healing phase. The final retracted view at three years demonstrated long-term success in the functional and aesthetic replacement of the four anterior maxillary incisor teeth (Figures 20 and 21).

Discussion
This case represented the combined use of CT planning, CT-derived tooth-borne templates, presurgical stone casts for abutment preparation, and temporary fabrication, as well as the use of CMAs to bring the simulated treatment plan to a successful result. With the duplicate abutment, no further impressioning was required to capture margins, allowing the laboratory to directly wax and cast copings to the second set of abutments with confidence that they would fit properly when placed intraorally.17 The ability to utilize the duplicate abutments dramatically reduced chair-time, did not require abutment removal to check fit, minimized the number of impressions, and increased accuracy. It was also less morbid for the patient and decreased overall expense to the clinician.18 Without any other impressions except at the time of surgery, the laboratory was able to fabricate four metal-alloy copings that fit precisely to the abutments intraorally.

As implant dentistry has evolved into one of medical science's most predictable treatment alternatives, there has been a concurrent progression in available diagnostic imaging tools, from the standard periapical...
Figure 17. At eight weeks, the CAD/CAM CMAs were connected to the implants, which favorably impacted the soft tissue contours.

Figure 18. A clear matrix of the diagnostic waxup, placed over the working cast, revealed the ideal morphology of the abutments within the envelope of the teeth.

Figure 19. Lateral view depicts the alveolar housing of the soft tissue and maintenance of the interdental papillae.

Figure 20. The three-year retracted view illustrates a functional and aesthetic replacement of the four anterior maxillary incisor teeth.

Radiograph, panoramic radiography, two-dimensional tomography, and the latest advances in CT scan technology. With recent emphasis on immediate or early loading of implants, the importance of understanding the existing anatomy in all dimensions is paramount to successfully integrating the desired plan with the interoperative surgical effectuation.

The mechanism of transferring the restorative information to the moment of surgery is defined as the surgical template or surgical guide. The template itself, however, is only as good as the available diagnostic and treatment-planning tools that provide the data set to construct the template. The information obtained from a laboratory-fabricated diagnostic waxup and stone cast can provide accurate guidance to create an osteotomy, but affords no information relating to the underlying condition of the bone. Fortunately, CT imaging technology provides the clinician with all of the presurgical information necessary to make informed decisions and accurate treatment plans. CT scan technology takes the guesswork out of the planning process by providing a 3D view of the patient’s anatomy.

Advanced diagnostic imaging technology is further enhanced by software applications that allow for interactive treatment planning, and the fabrication of surgical guides that link the simulation to the patient. The introduction of new, smaller footprint, lower radiation Cone-Beam CT scanning machines has served as a significant catalyst to promote the use of CT scanning technology, not just for placing implants, but also for diagnosing pathology, horizontal and vertical impactions, bone grafting, and orthognathic surgery.

Conclusion

CT scans, when properly utilized, will help remove the limitations associated with two-dimensional imaging modalities for planning implants, and will empower clinicians with more diagnostic information to make informed decisions for their patients, especially when considering immediate load protocols. The techniques described herein have been shown to be effective for both partial and completely edentulous patient presentations, and can serve as a foundation for accurate planning.
highly practical, and repairable CT-driven, model-based, presurgical prosthodontic planning for the immediate loading of dental implants. 14, 15 The ability to visualize root, tooth-implant and implant-implant proximity through 3D technologies is an important step in the advance-
mant of the science of dental implantology. Incorporating the restorative goal with interactive 3D planning tools for the creation of CT-driven surgical templates allows for the highest degree of accuracy and consistency in trans-dent the treatment plan to the patient at the time of surgical intervention.

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The author declares that he is a consultant for Zimmer Dental, Materialise (SimPlant), and Atlantis Components.

References

1. Which of the following are needed for successful immediate/delayed loading?
   a. Template guidance for surgical placement.
   b. Ample host bone availability.
   c. Non-mobility of the interim prosthesis for at least eight weeks.
   d. All of the above.

2. Often, not enough emphasis is placed on which of the following during implant planning?
   a. Soft tissue management.
   b. Primary fixation of the implant.
   c. Pre-surgical prosthetic planning.
   d. Mobility of the interim prosthesis.

3. Which of the following was NOT part of the evolution of early loading techniques?
   a. Two-stage implants were placed into the bone.
   b. The follow-up surgical procedure gained greater importance.
   c. A healing collar was attached immediately.
   d. Soft tissue was sutured around the transmucosal element.

4. What would be a possible reason for requiring multiple templates?
   a. To account for each implant in a multi-implant case.
   b. To correspond to each specific drill used for implant surgery.
   c. To have one preoperative and one (tentative) postoperative template available for the patient to see.
   d. To have multiple comparisons against the CT scan.

5. Which previously-used technique was NOT used in this model-based surgery?
   a. The stone was poured using a special boxing technique.
   b. The teeth were first removed, and holes prepared freehand.
   c. Using manufacturer-specific drills, “osteotomies” were prepared using the CT-derived tooth borne template.
   d. Special analogs were used to replicate the exact position of the implants.

6. Which of the steps were followed (in order) after the implants and abutments were properly positioned?
   a. The FMTs were replaced; the soft tissue was gently approximated; a full-arch impression was made.
   b. The soft tissue was gently approximated; a full-arch impression was made; the FMTs were replaced.
   c. A full-arch impression was made; the soft tissue was gently approximated; the FMTs were replaced.
   d. The FMTs were replaced; a full-arch impression was made; the soft tissue was gently approximated.

7. FMTs for implants allow the clinician to do which of the following?
   a. Modify for use as a temporary titanium abutment.
   b. Deliver the implant to the site.
   c. Easily take either a closed or open-tray impression.
   d. A and B only.

8. What was the purpose of orienting the flat of the internal hex connection toward the facial?
   a. The flat of the hex correlated to the prefabricated prosthetic components.
   b. To aid in prosthetic consistency and presurgical prosthetic planning.
   c. The rotational position of the antirotational feature is important for a cement-retained restoration.
   d. All of the above.

9. What benefit is there to using duplicate abutments?
   a. They minimize the number of impressions needed.
   b. They reduce chairtime.
   c. They increase accuracy.
   d. All of the above.

10. What material was used to fill in defects in the bone?
    a. Mineralized cancellous particulate allograft mixed with PRP.
    b. Mineralized cancellous particulate allograft mixed with serum.
    c. A collagen matrix soaked in PRP.
    d. A methacrylate-based resin sealer.