Presurgical Planning With CT-Derived Fabrication of Surgical Guides

Scott D. Ganz, DMD*

As implant dentistry is evolving toward accelerated treatment protocols, with immediate or delayed functional and nonfunctional loading, the importance of presurgical planning becomes paramount. The paradigm for restorative-driven implant placement works best when templates are used to transfer information from the desired plan to the surgical reality. The advent of computed tomography (CT) imaging, and CT-derived surgical templates allow for clinically significant improvements in accuracy, time efficiency, and reduction in surgical error, benefiting the patient, surgeon, restorative dentist, and the laboratory. Continued advances in the state-of-the-art software applications that enable enhanced planning give clinicians the vision necessary to deliver the desired results, while serving as an excellent communication tool between all members of the implant team. This article illustrates the advantages of using CT scan-based templates through various clinical presentations. Procedures were illustrated for single and multiple tooth applications in both mandibular and maxillary arches.

Implant dentistry has evolved into one of the most predictable treatment alternatives for partially and completely edentulous patients. The initial excitement about successful osseointegration has allowed clinicians to offer an extended set of treatment alternatives that include single tooth replacement to full mouth reconstruction. Pioneering protocols of the early 1980s relied on a 2-stage surgical approach allowing for the biological aspects of osseointegration to be achieved at the cellular level, ensuring long-term success. However, these procedures often required extended periods of time to complete. Through strategic marketing and word of mouth, demand for implant-related treatment continues to grow, which in turn has compelled clinicians to search for new and improved methods to deliver such care within a shorter time period, without sacrificing the accuracy required to meet patient expectations. As treatment protocols have progressed, implant manufacturers have met the challenge of providing both surgical and prosthetic components to maximize outcomes in function and esthetics. However, as with any surgical intervention, problems can arise. Often, difficulties related to poor surgical or prosthetic outcomes can be directly linked to the diagnostic and treatment planning phase.

Proper treatment planning should consist of a thorough assessment of the intraoral hard and soft tissue via direct examination, periapical and panoramic radiography, mounted study models, and when required a diagnostic wax-up of the desired result. Although basic in concept, most dental students trained during the last 25 years (in the United States) were not taught how to adequately diagnose or plan a dental implant case. Other available diagnostic tools for preoperative assessment can include 2-dimensional cephalometric or tomographic films (analog or digital), and tissue or bone mapping techniques to assess underlying bone geometry, and drilling into stone models to simulate intraoral implant positioning. Recently emphasis has shifted from relatively arbitrary implant placement in good available host bone (assessed by the surgeon at the time of surgery) to placing implants with consideration of the final prosthetic outcome, soft tissue management, emergence profile, and tooth morphology. Remember, the goal of implant dentistry is not the implant, it is the tooth that we replace. To facilitate accurate translation from the desired plan to the surgical reality, templates or surgical guides should be used.

When a single missing tooth needs to be replaced, the surgeon can freehand the drill without a prefabricated template, and hope to align the osteotomy perfectly between adjacent teeth in all directions.
mesial, distal, facial, and lingual. The implant will then be positioned based on the surgeon's idealized vision of the fixture within the bone, which may differ from the restorative needs of that particular site. In the fully edentulous arch, orientation and bone topography can vary greatly, creating an atmosphere where implants can be misaligned, or worse. Templates can be created by various methods to help guide the surgical specialist or implantologist during the surgical placement of the implant, leaving most of the decision making process at the presurgical level, whether in partially edentulous or completely edentulous presentations. In its elementary form, a template (the use of the word “stent” is a misnomer) is fabricated based on information of the final tooth form, not the bone. A template design based on conventional prosthodontic protocols, including tooth morphology, emergence profile, occlusion, contacts, and embrasures would guide the implant placement in the desired position which will best allow for proper restoration.\(^2\)\(^3\)

The first steps required to fabricate a basic template are impressions of the patient’s existing dentition, which yields plaster or stone models that can be articulated and analyzed in terms of the desired occlusion and tooth morphology. A diagnostic wax-up or placement of denture teeth onto the stone model will demonstrate the desired restorative replacement, which can be translated to the surgeon through a simple vacuum-formed matrix, or a laboratory-processed acrylic prosthesis (Figs 1, 2). This vital information helps the surgeon visualize the restorative requirements during the surgical procedure, and can often lead to satisfactory results.\(^1\)\(^5\) An all acrylic template indicates the desired tooth position, facilitates the placement of 4 implants, which leads to the successful restoration in the anterior mandible as illustrated by the postoperative panoramic radiograph in Figure 3. Basic templates made entirely of acrylic, or with cut-out windows, are less accurate than those that incorporate a metal sleeve or tube to help stabilize the drill during the osteotomy.\(^6\)\(^7\) Using drills of similar diameter to the actual implant, a hole is created in the stone model that corresponds with the diameter of the implant to be placed. Once created, the appropriate implant analog is placed into the cast at the desired angulation and vertical depth approximately 3 to 4 mm below the cemento-enamel junction of the adjacent teeth. Using a long screw attached to the analog, a stainless steel tube can be dropped into position. A light or heat cured acrylic material then captures this position, and ensures that the plan will be easily transferred to the patient (Fig 4). The steel tube should be slightly wider that the drill, preventing accidental deviation. The tube should be a known height, and the acrylic should be relieved so that the head of the drilling unit is not impeded in any way (Fig 5).

Many solutions have been presented to help solve the dilemma of translating the restorative require-
ments from the laboratory to the patient at the time of surgery. Recently, an innovative thermoplastic template kit was introduced that allowed clinicians or laboratory technicians to quickly create a surgical guide without the use of a vacuum former (EZ-Stent; Applied Dental, Inc, Mountain View, CA). First, using the included drill, a hole is drilled into the stone model at the ideal position and trajectory. A guide pin of similar diameter is then inserted into the hole, and any angle correction can be performed at this time (Fig 6). The thermoplastic template is placed in hot water until it turns translucent. It is then slid into position over the guide pin, and the softened material adapted to the surrounding teeth. As it cools, the EZ-Stent returns to a hardened state that is strong and retentive (Fig 7). The template is then removed from the stone cast, and placed into cold sterilization before the surgical procedure (Fig 8). After anesthesia, the template can be placed intraorally over the adjacent teeth, allowing the stainless steel tube to help guide the drill into the bone (Fig 9). If the original planning was correct, the result will be a well-placed implant as evidenced by the positioning of the Tapered Screw-Vent (Zimmer Dental, Carlsbad, CA), illustrated in Fig 10. However, these initial techniques (drilling into the stone model without 3-dimensional computed tomography [CT] guidance) do not afford clinicians with reliable information relating to the underlying bone.

Advances in diagnostic imaging such as tomography, digital radiography, and CT scan film allow for a more accurate presurgical evaluation. Conceivably, the most important technological advancement to enhance the clinician’s ability to visualize bone anat-
omy has been the CT scan. CT scans have been used for medical imaging since 1973. It was not until 1987 that CT scans became available for dental applications. Even today, the most common method for obtaining CT scan data is through a referral to a radiologist, in a radiology imaging center or hospital setting. From the CT machine, specially formatted diagnostic images can be created from scan data for diagnostic purposes. The resultant radiographic films offer true, undistorted 3D (3D) visualization of the maxillary or mandibular bone to determine potential receptor sites for placement of dental implants in 3 or 4 views; (1) axial, (2) cross-sectional, (3) panoramic, and (4) 3D reformatted images. Despite the advanced imaging techniques, the potential for linking the visualization on film is limited if there are no indicators for the ultimate position of the tooth or final restorative goal. The advent of radiopaque CT scan templates, which incorporate some information as to tooth position (usually in the form of gutta percha radiopaque markers incorporated into a patient’s existing denture or via some type of barium coating) gave new information that could be viewed in relationship to the underlying bone. However, it was still not an easy task to transfer the identified sites to the patient. Weinberg and Kruger tried to overcome these limitations in developing a concept for 3D presurgical planning based on CT scan film data and using surgical drill guide tubes. A radiographic guide constructed of vertically placed titanium pins marked the central fossa of each tooth where an implant was desired. The patient wore the guide during the scanning process. Data was then collected and transferred to a working cast using the guide to drill osteotomies in the stone. A set of special drills was developed to facilitate the actual surgery, using the drill guide tubes created from the interpreted CT scan data. Eventually, a dual axes table was developed to help with the positioning of the osteotomies in the cast. This was a tedious, time consuming task at best, yet it did offer a link between the CT film and the patient.

The inherent limitations of CT scan film were overcome in July of 1993 when an innovative software program was introduced. SIM/Plant for Windows (Materialise-CSI, Inc, Glen Burnie, MD) was first introduced as an intuitive, user-friendly interactive computer-based interface that revolutionized the world of diagnostic imaging for dentists by helping to translate the power of CT technology for the creation of accurate presurgical plans for their implant patients. SIM/ Plant for Windows enabled the clinician to examine the CT scan data in an environment that surpassed the limited information afforded by CT scan film alone. Significantly, film cannot relate information on bone density, which is an important factor in determining an adequate location for osseointegration to occur.
Since the development of SIM/Plant, other similar applications have been introduced in the marketplace for the purposes of making CT scan technology available to clinicians around the world. To achieve predictable results and enhance communication, these advanced imaging techniques are advocated for both the surgeon and the restorative members of the implant team to help anticipate and deliver definitive implant-supported restorations.17-20

Using computer software to visualize potential implant receptor sites has revolutionized the manner in which imaging data is assimilated. The cross-sectional image relates not only the height and width of available bone, but the thickness of the cortical plates and the overall shape of the residual ridge. Bone density values can be obtained for various potential sites using intuitive tools, taking guesswork out of the equation. Interactive software applications then permit simulated placement of the implant, and restorative abutment to help plan the most ideal position based on the restorative needs of the site. Figure 11 illustrates a cross-sectional image, representing a maxillary site where an implant has been virtually situated. An imaginary triangle can be drawn over the cross-sectional image where the base is at the widest aspect of the apical bone, and the apex of the triangle is positioned at the midline of the ridge. If there is ample bone within the triangle, then an implant can be placed that would bisect the triangle of available bone gaining increased bi-cortical stabilization in many cases. The “Triangle of Bone” concept was originally developed by the author to help diagnose potential receptor sites, and for instances where the bone was inadequate, to identify sites that required hard or soft tissue regeneration.22 Initially, the simulated implants were represented as cylinders that had the same dimensions as the implants that were to be utilized, based on implant manufacturers’ specifications. Recent software updates now permit the clinician to place realistic computer-aided design (CAD) images from an implant library, and slice or section through the virtual model (in cross sectional or axial planes) for enhanced visualization of the 3D information with advanced diagnostic tools, as seen in Figure 12.

Additional revealing, and sometimes dramatic, information can be achieved by removing or hiding the bone from view, leaving 3D representations of the underlying roots of the natural teeth. Evaluation of adjacent tooth roots can be very helpful when positioning implants to avoid proximity issues near vital structures. Congenitally missing lateral incisor teeth present many potential hazards that can be avoided with careful diagnosis and planning. CT scan imaging or volumetric tomography can be very helpful in this regard. The minimally required space between teeth is often compounded by convergence of the adjacent tooth roots, limiting access for an implant. Figure 13 represents a 3D image where the bone has been removed to better appreciate root morphology and spatial location. Sufficient room was found for the placement of 2 implants. Using the manufacturer’s supplied implant library, 2 Tapered-Screw Vent implants (seen in green) were virtually positioned with the abutments (in yellow) extending out to help ver-
ify proper trajectory and inclination (Fig 13). The implants are to scale, CAD versions of the real implants, and can be rotated and tilted interactively within the virtual 3D model. The ability to visualize the actual physical shape, contour, taper, thread pattern, and anti-rotational features are very helpful when choosing an ideal receptor site.

Once planned using the SIM/Plant, the data was sent electronically via email to Belgium (Materialise, Inc, Lueven, Belgium) for the fabrication of templates to be used at the time of surgery. The surgeon must indicate the type, length, and diameter of each implant to be used, with the actual drill sequence for the specific procedure. As this was to be a tooth-borne template, a plaster cast was created from an alginate impression, and sent separately to Materialise, Inc (Fig 14). Using the CT data and treatment plan, a series of templates were fabricated, 1 for each drill diameter in the sequence of osteotomy preparation (Fig 15). The templates fit accurately on the working cast, preventing movement during surgery (Fig 16). The tooth-borne template is an essential tool that accurately guides the drill sequence, allowing for precision placement of the implants intraorally while avoiding contact with adjacent structures (Fig 17).

To facilitate parallel implant placement in the anterior mandible, CT scans are invaluable when they provide the information to construct accurate surgical guides. A further advance in the evolutionary development of this imaging modality involves the use of stereolithography.22,23 Stereolithographic models are created from the CT scan data set through rapid prototyping technology and serve multiple purposes in medicine and dentistry. The ability to hold an acrylate model of the patient’s mandible or maxilla in
hand is an invaluable tool for learning anatomy, diagnosis, treatment planning, and template fabrication, which may evolve further into the fabrication of the transitional and final restorations. Figure 18 reveals a stereolithographic model of the mandible with a surgical template (SurgiGuide; Materialise, Inc) that was fabricated from the planning data. Implant receptor sites were chosen based on the restorative requirements, bone contours, bone density, and path of the inferior alveolar nerve. A close-up view shows the 6 embedded stainless steel tubes designed to guide 1 diameter of the sequential drills used to create the osteotomies (Fig 19).

The partially edentulous mandible exhibits challenges as the overall contours and bone volume may differ from the contra-lateral side. A panoramic radiograph can be taken as an initial scout film to help determine potential implant sites and the location of vital structures. However, the inherent distortion factor of a panoramic radiograph can be as much as 7.5 mm, which can result in paresthesia, perforation, or other surgical complications if not recognized.24 The height of bone can be estimated, but there is no information related to the actual width of bone, thickness of the cortical plates, density between the cortices, nor the 3D position of the inferior alveolar nerve as it travels through the mandible and exits at the mental foramen (Fig 20). Changes in the mandibular morphology cannot be detected without the use of cross-sectional and 3D imaging. Variations in bone contours and location of important anatomy that can be assessed in multiple dimensions enables the clinician to accurately determine the best advised treatment plan. Careful analysis of the undistorted reformatted axial CT image re-
revealed potential receptor sites for 5 implants of various lengths and diameters (Fig 21). The anatomic permutations revealed in 3 cross-sectional images illustrate how, within a short distance between 3 adjacent consecutive implants, the bone is dramatically different. There is a fenestration noted in the cortical bone in Fig 22A, with the apical portion at a distinct facial angle from the crest of the bone (slice 79). A few slices posterior (slice 84), the bone contours change again (Fig 22B), and then changes again (slice 91) for the third implant site (Fig 22C). Once identified, the implant positions can “tweaked” for parallelism, and ease of restoration (Fig 23). However, the best opportunity to accurately assess the implant placement is when the 3D reconstruction is evaluated. The virtual model and implants, individually, can be rotated or tilted in various positions to determine the trajectory of each implant in relation to each other and nearby vital structures within the envelope of the desired tooth position (Figs 24, 25).

Once the plan has been verified, the information can then be transferred for the creation of a stereolithographic model as previously described. An appreciation of the variations in bone morphology is evident in both occlusal and side views (Figs 26, 27). From the data set determined through software planning, the surgical templates can be fabricated to easily guide the placement of each implant with manufacturer-specific sequential drills. The bone-borne templates fit securely on the alveolar crestal bone during the time of surgery (Fig 28). In this clinical presentation an access hole was created to adapt the template over the existing natural premolar (Fig 29). With the plan, the stereolithographic model, and the series of templates, the patient is prepared for the surgical procedure to take place. An intraoral preoperative occlusal view indicates variations in the soft and hard tissue, but not nearly enough information as the assessment afforded by the CT imaging (Fig 30). Because of the speed, efficiency, and accuracy of the sequence of templates provided by the virtual plan, osteotomy preparation is highly accurate, with less morbidity to the patient. Five Tapered Screw-Vent implants were placed as planned using a 1-staged approach, at the correct depth and trajectory avoiding adjacent and proximal structures (Fig 31). After 8 weeks of healing, impressions were taken to transfer the intraoral position of each implant to a soft tissue model (Fig 32). Upon close inspection, the working
cast exhibits excellent parallel positioning of the implant analogs, enabling a smooth and often accelerated laboratory and restorative phase (Fig 33). The postoperative panoramic radiograph illustrates the final restorative result, which returned the patient to both form and function (Fig 34). Note that the implants clearly avoided the superior aspect of the inferior alveolar canal and adjacent tooth roots.

The maxillary arch has a different and unique bone topography as compared with the mandible. The anterior maxilla contains the incisal canal, the floor of the nose, and nasal cavity, and the posterior maxilla contains the sinus and tuberosities. The panoramic radiograph is often obscured at the midline, making it difficult to assess the anatomic structures, and certainly impossible to determine the medial-lateral dimension of the maxillary sinus. The clinical presentation illustrated in Fig 35 exhibits bilateral distal extension edentulous areas, with remaining natural anterior teeth. Note the undulations in the lateral-facial aspect of the residual maxillary ridge. It is difficult to achieve accurate implant placement without guidance if the relationship between the desired tooth position and underlying bone is not known or appreciated in advance. However, with the information obtained from the CT scan, simulated implants can be placed into the best available receptor sites based on the required restorative parameters. This information can again be transferred through a stereolithographic model, and surgical templates can then be fabricated (Fig 36). For this example, 3 bone-borne

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**FIGURE 24.** A virtual 3D model allows the clinician to interactively plan for the placement of the 5 implants, and evaluate inter-implant distances, implant-to-tooth relationships, and overall parallelism that affects the final restorative result.


**FIGURE 25.** A lateral view of the 3D model reveals the path of the inferior alveolar nerve and the extensions (in yellow and green) of the simulated path of the abutment trajectories on top of the implants. The data set from this plan is then transmitted via email for the fabrication of the templates.


**FIGURE 26.** An occlusal view of the stereolithographic model of the mandible, which allows for a close inspection of the 3D anatomy.


**FIGURE 27.** The lateral view demonstrates the changes in bone topography, position of the natural teeth, and reveals the location of the mental foramen.

templates allow the clinician to follow the manufacturer’s sequential drill sequence, with each stainless steel tube having a diameter of 2 tenths of a millimeter greater than the drill, leaving little room for error. For this case, 3 separate templates were used for the (1) pilot, (2) intermediate, and (3) final sizing drills (Fig 37). A close-up view exhibits the close adaptation of the intermediate drill guide (Fig 38). Based on the presurgical planning transferred to the surgical reality, the case can then be completed with complete confidence.

Discussion

Implant dentistry is a proven, highly predictable method for replacing missing natural teeth. The advent of advanced imaging tools has enabled clinicians to expand their view into the third dimension. The ability to obtain a CT scan for a patient is only 1 part of the equation. Simply stated, “It is not the scan, it is the plan,” describes the most crucial aspect of the process. Interactive software applications help to visualize the CT scan data, and plan for functional, esthetic, and predictable outcomes before the “scalpel ever touches the patient.” Assimilating the CT data for purposes of correct diagnosis and treatment planning may be the single most critical step in transferring accurate information to the patient at time of surgery. Once the plan has been established and accepted by the patient, the template can be fabricated. The template is the link between the plan and the execution of the plan. Templates have been proven to be far more accurate than the traditional free-hand method of implant placement. Although templates can be fabricated without CT, it was the inten-
tion of the author to illustrate how important it is to understand the underlying anatomic structures so that the implant receptor sites can be located without infringing upon nerves, sinus cavities, or adjacent tooth roots. The plan should therefore be based on a sound understanding of the bone anatomy as it relates to the restorative needs of the patient, taking the guesswork out of the equation. The definitive simulation can then be translated into a precision surgical template that ensures successful treatment outcome.

As implant dentistry turns its focus to be driven more and more by the restorative requirements, and traditional protocols are shifting to accelerated immediate or delayed loading techniques, advances in template design will continue to improve out of necessity. In 2001, Klein and Abrams developed a link between the CT data and template fabrication by sending the 3D coordinates of the SIM/Plant plan to a 5-axis computer numerical-controlled milling machine. The drill guide system is then incorporated into the milled surgical template in either basic or advanced designs (Compu-Guide Surgical Template System; Implant Logic Systems, Cedarhurst, NY). This was followed by the incorporation of a CT-based surgical template that could be converted into a tooth colored temporary acrylic fixed provisional restoration (Compu-Temp, Implant Logic Systems). The use of stereolithographic models expands the clinician’s ability to understand the patient’s anatomy, create accurate surgical templates, manage simple and complicated cases, and link this to the restorative phase as described by Ganz in 2003.
This article illustrates the advantages of using CT scan-based templates, but does not attempt to cover all available methods for fabrication, nor review navigational or robotic technology which, although innovative, may not be at the point where they are practical or efficient solutions. Even with CT imaging, clinicians have labored to link the information from the scan data to the surgical site, transferring angles and positions manually. This is totally overcome with interactive software applications that provide this information seamlessly. Based on information contained within, templates derived from CT scan planning data, which embedded stainless steel tubes are highly accurate, and easy to use in either bone-borne, tooth-borne, or soft tissue-borne (not shown) configurations. It is quite simple to place the drill through the tube and precisely drill into the bone, creating the desired osteotomy, when all of the planning and decision making is completed in advance of the procedure. Procedures were illustrated for single and multiple tooth applications, in both mandibular and maxillary arches.

Computer-guided surgery is here to stay. With the acceptance and proliferation of new in-office cone-beam CT machines, the technology will become more accessible as the benefits become more apparent to the growing number of clinicians performing implant surgical procedures. Additionally, many new solutions continue to be developed to help clinicians plan cases more accurately. CT-derived surgical templates allow for clinically significant improvements in accuracy, time efficiency, and reduction in surgical error, benefiting the patient, surgeon, restorative dentist, and laboratory. Using CT imaging to assess bone anatomy and determine implant receptor sites additionally allows for improved techniques for flapless surgical procedures (when appropriate), which can be performed with greater levels of confidence and are less invasive to the patient. However, the template is only as good as the planning. Predictability can only be enhanced by thorough presurgical diagnosis and treatment planning using the information obtained from the CT imaging devices. Continued improvements in the state-of-the-art software applications that enable enhanced planning give clinicians the vision necessary to deliver the desired results while serving as an excellent communication tool between all members of the implant team.

References
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