Techniques for the Use of CT Imaging for the Fabrication of Surgical Guides

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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 two-stage surgical approach that allowed for the biological aspects of osseointegration to be achieved at the cellular level, insuring long-term success. 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 and has compelled clinicians to search for new and improved methods to deliver such care within a shorter time period without sacrificing accuracy. As treatment protocols have progressed, implant manufacturers have met the challenge of providing 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. Most dental students who were 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 two-dimensional cephalometric or tomographic films (analog or digital), 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 time of surgery) to placing implants with consideration of the final prosthetic outcome, soft tissue management, emergence profile, and tooth morphology. 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.

Conventional template design

When a single missing tooth needs to be replaced, the surgeon can free-hand 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 is positioned based upon 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 whereby 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 word “stent” is a misnomer) is fabricated based upon information of the final tooth form, not the bone. A template design based upon conventional prosthodontic protocols, including tooth morphology, emergence profile, occlusion, contacts, and embrasures, guides the implant placement in the position that best allows for proper restoration.

The first step required to fabricate a basic template are impressions of the patient’s existing dentition, which yield 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 demonstrates 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 and 2). This vital information helps the surgeon to visualize the restorative requirements during the surgical procedure and can often lead to satisfactory results. An all-acrylic template that indicated the desired tooth position facilitated the placement of four implants, which led to successful restoration in the anterior mandible as illustrated by the postoperative panoramic radiograph in Fig. 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. Using drills of similar diameter to the actual implant, a hole is created in the stone model that corresponds to the diameter of the implant to be placed. The appropriate implant analog is placed into the cast at the desired angulation and at a vertical depth approximately 3 to 4 mm below the cemento-enamel junction (CEJ) 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 captures this position and insures that the plan is easily transferred to the patient (Fig. 4). The steel tube should be slightly wider that the drill to prevent accidental deviation. The tube should be of a known height, and the acrylic should be relieved so that the head of the drilling unit is not impeded (Fig. 5).

Many solutions have been presented to help solve the dilemma of translating the restorative requirements 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, Mountain View, California). 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 inserted into the hole, and any angle correction can be done 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 is adapted to the surrounding teeth. As it cools, the EZ-Stent returns to a hardened state.

Fig. 1. A processed acrylic template indicating desired implant position on the master cast. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2]:60; with permission.)
Fig. 2. The holes in the occlusal/lingual surface are used to start the osteotomy preparation. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2]:60; with permission.)

Fig. 3. The postoperative, panoramic radiograph revealing successful implant placement that supported a six-unit ceramics-metal restoration. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2]:60; with permission.)

Fig. 4. A hole was drilled into the stone model, the appropriate analog was placed, and a surgical stainless steel tube was dropped over a long fixation screw to facilitate acrylic template fabrication over the remaining teeth. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2]:61; with permission.)

Fig. 5. The stainless steel tube allows for greater accuracy when drilling into the underlying bone. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2]:61; with permission.)
that is strong and retentive (Fig. 7). The template is 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 is correct, the result is a well-placed implant, as evidenced by the positioning of the Tapered Screw-Vent (Zimmer Dental, Carlsbad, California) illustrated in Fig. 10. These techniques (drilling into the stone model without three-dimensional [3-D] 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 anatomy 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, 3-D visualization of the maxillary or mandibular bone to determine potential receptor sites for the placement of dental implants in three or four views: (1) axial, (2) cross-sectional, (3) panoramic, and (4) 3-D 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 a final restorative goal. Radiopaque CT scan templates that 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 give new
information that could be viewed in relationship to the underlying bone. However, it is 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 3-D presurgical planning based upon 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 were 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 surgery; using the drill guide tubes created from the interpreted CT scan data. A dual axes table was developed to help with the positioning osteotomies in the cast. This was a tedious and time-consuming task, but it offered a link between the CT film and the patient.

The inherent limitations of CT scan film were overcome in July 1993 when an innovative software program was introduced. SIM/Plant for Windows (Materialise-CSI, Inc., Glen Burnie, Maryland) was 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. 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. To achieve predictable results and to enhance communication, these advanced imaging techniques are advocated for the surgeon and the restorative members of the implant team to help anticipate and deliver definitive implant-supported restorations.

Fig. 8. The tooth-borne template comes packaged with the integrated tube. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2];62; with permission.)

Fig. 9. The E-Z Stent thermoplastic material is positioned in the maxillary arch to facilitate proper implant placement. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2];62; with permission.)
CT scan simulation

Using computer software to visualize potential implant receptor sites has revolutionized the manner in which imaging data are assimilated. The cross-sectional image relates the height and width of available bone, 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 permit simulated placement of the implant and restorative abutment to help plan the most ideal position based upon the restorative needs of the site. Fig. 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 bicortical 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. Initially, the simulated implants were represented as cylinders that had the same dimensions as the implants to be used, based upon implant manufacturers’ specifications. Recent software updates permit the clinician to place realistic computer-aided design (CAD) images from an implant library, slice, or section through the virtual model (in cross-sectional or axial planes) for enhanced visualization of the 3-D information with advanced diagnostic tools (Fig. 12).
CT-derived tooth-borne templates

Additional revealing and sometimes dramatic information can be achieved by removing or hiding the bone from view, leaving 3-D representations of the underlying roots of the natural teeth. Evaluation of adjacent tooth roots can be 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 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. Fig. 13 represents a 3-D image where the bone has been removed to better appreciate root morphology and spacial location. Sufficient room was found for the placement of two implants. Using the manufacturer’s supplied implant library, two Tapered-Screw Vent implants (seen in green) were virtually positioned with the abutments (in yellow) extending out to help verify proper trajectory and inclination (Fig. 13). The implants are to scale, are CAD versions of the real implants, and can be rotated and tilted interactively within the virtual 3-D model. The ability to visualize the physical shape, contour, taper, thread pattern, and antirotational features is helpful when choosing an ideal receptor site.

Once planned using SIM/Plant the data were sent electronically via e-mail to 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 and must provide the...
drill sequence for the specific procedure. Because this was to be a tooth-borne template, a plaster cast was created from an alginate impression and sent separately to Materialise (Fig. 14). Using the CT data and treatment plan, a series of templates was fabricated, one 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 guides the drill sequence accurately, allowing for precision placement of the implants intraorally while avoiding contact with adjacent structures (Fig. 17).

**Stereolithography and CT-derived, bone-borne template designs**

To facilitate parallel implant placement in the anterior mandible, CT scans can provide the information to construct accurate surgical guides. A further advance in the evolutionary development of this imaging modality involves the use of stereolithography. 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. Fig. 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 upon the restorative requirements, bone contours, bone density, and path of the inferior alveolar nerve. A close-up view reveals the six embedded stainless steel tubes designed to guide one diameter of the sequential drills used to create the osteotomies (Fig. 19).

The partially edentulous mandible presents challenges because the overall contours and bone volume may differ from the contralateral 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. The height of bone can be estimated, but there is no information related to the width of bone, thickness of the cortical plates, density between the cortices, or the 3-D 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 3-D imaging. Variations in bone contours and location of important anatomy that can be assessed in multiple dimensions enable the clinician to accurately determine the best treatment plan. Careful analysis of the undistorted reformatted axial CT image revealed potential receptor sites for five implants of various lengths and diameters (Fig. 21). The anatomic permutations revealed in three cross-sectional images illustrate how the bone is dramatically different

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**Fig. 14.** The data from the software application SIM/Plant is sent to Belgium via e-mail. A plaster cast model of the patient’s dentition is also sent. From this information, a tooth-borne template can be fabricated. (From Ganz SD. Pre-surgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2]:64; with permission.)
Fig. 15. A tooth-borne template with the incorporated surgical stainless steel tubes for accurate drill guidance. Each tube is 0.2 mm wider than the sequential drills to be used. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2];64; with permission.)

Fig. 16. The facial view of the tooth-borne template seated over the working cast. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2];64; with permission.)

Fig. 17. The template snaps over the adjacent teeth, and with great stability the osteotomies can be created based upon the virtual plan. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2];65; with permission.)
Fig. 18. A stereolithographic model of the patient’s mandible with a template for the placement of six implants. The template is fabricated from the CT scan data and treatment plan. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2];65; with permission.)

Fig. 19. Close-up view of the six embedded stainless steel tubes of the anterior mandibular template. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2];65; with permission.)

Fig. 20. A preoperative panoramic radiograph reveals the left mandibular partially edentulous areas where the patient desires a fixed restoration. It is difficult to assess the 3-D topography of the mandible or path of the inferior alveolar nerve. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2];65; with permission.)
within a short distance between three adjacent consecutive implants. 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 again (slice 91) for the third implant site (Fig. 22C). Once identified, the implant positions can be “tweaked” for parallelism and ease of restoration (Fig. 23). The best opportunity to accurately assess the implant placement is when the 3-D reconstruction is evaluated. The virtual model and the implants can be individually rotated or tilted in various positions to determine the trajectory of each implant in relation to the other and nearby vital structures within the envelope of the desired tooth position (Figs. 24 and 25).

Once the plan has been verified, the information can be transferred for the creation of a stereolithographic model. An appreciation of the variations in bone morphology is evident in occlusal and side views (Figs. 26 and 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 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. An intraoral preoperative occlusal view indicates variations in the soft and hard tissue but does not provide as much information as CT imaging (Fig. 30). Due to the speed, efficiency, and accuracy of the sequence of templates provided by the virtual plan, osteotomy preparation is highly accurate and leads to less patient morbidity. Five Tapered Screw-Vent implants were placed as planned, using a one-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

Fig. 21. The reformatted axial CT view allows for the individual implant receptor sites to be chosen based upon the restorative needs of the patient if the underlying bone anatomy and nerve position are favorable. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2];66; with permission.)

Fig. 22. Cross-sectional views show that over a short span, the bone geometry can change dramatically. Note the facial bone defect in the area where the first implant was planned and how the mandibular bone differs in shape for the second and third sites. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2];66; with permission.)
Fig. 23. The reformatted panoramic radiograph reveals the presurgical planning of five implants. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2];66; with permission.)

Fig. 24. A virtual 3-D model allows the clinician to interactively plan for the placement of the five implants and to evaluate interimplant distances, implant-to-tooth relationships, and overall parallelism, which affect the final restorative result. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2];67; with permission.)

Fig. 25. A lateral view of the 3-D 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 transmitted via e-mail for the fabrication of the templates. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2];67; with permission.)
Fig. 26. An occlusal view of the stereolithographic model of the mandible that allows for a close inspection of the 3-D anatomy. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2]:67; with permission.)

Fig. 27. The lateral view demonstrates the changes in bone topography position of the natural teeth and reveals the location of the mental foramen. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2]:67; with permission.)

Fig. 28. The surgical templates fit over the bone and transfer the virtual plan to the patient. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2]:68; with permission.)
Fig. 29. The lateral view shows how the template fits over the natural remaining premolar tooth while giving guidance for the five implants to be placed. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2]:68; with permission.)

Fig. 30. Occlusal view of the intraoral clinical site. Note the volumetric change of the ridge in the edentulous areas. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2]:68; with permission.)

Fig. 31. Five implants successfully placed with sequential drilling techniques and sequential templates. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2]:68; with permission.)
and often accelerated laboratory and restorative phase (Fig. 33). The postoperative panoramic radiograph illustrates the final restorative result, which returned the patient to form and function (Fig. 34). The implants avoided the superior aspect of the inferior alveolar canal and adjacent tooth roots.

**Stereolithography for ridge reduction and immediate loading protocols**

Clinicians are often faced with irregular patterns of bone resorption in the maxillary or mandibular arch. Planning for an immediate load case with irregular bone height or width is difficult at best, even with CT scan imaging. Additionally, it is difficult to achieve accurate implant placement without guidance if the relationship between the desired tooth position and the underlying bone is not known or appreciated in advance. Many planning obstacles can be overcome with the use of sophisticated software tools and stereolithographic models. A female patient presented with a problematic complete mandibular denture. The anterior section was painful during mastication due to the thin remaining crestal bone (Fig. 35). After clinical evaluation, the patient was referred for a CT scan of the mandible. After processing and reformatting by SIM/Plant, the 3-D image revealed the extent of the narrow bony spin on the superior aspect of the mandible (Fig. 36A). The higher anterior segment was found to be too narrow for implant placement. To facilitate the placement of dental implants, it was determined that the anterior ridge would be reduced to an adequate width (Fig. 36B). Using interactive features of the software, five simulated implants and abutments (yellow extensions) were to be placed.
Fig. 34. Postoperative panoramic radiograph showing completed restorations for the five implants and single natural tooth in harmony with the remaining dentition. Note the avoidance of the vital structures in the area. (From Ganz SD. Presurgical planning with CT derived fabrication of surgical guides. J Oral Maxillofac Surg 2005;63[Suppl 2]; 69; with permission.)

Fig. 35. Retracted view of patient with a fully edentulous mandible. Note the thin, severely resorbed anterior ridge.

Fig. 36. (A) The CT scan revealed the extent of the thin bony spin on the superior aspect of the mandible. (B) The higher anterior segment was found to be too narrow for implant placement.
after the anterior ridge was reduced, as illustrated by the transparent segment in Fig. 37. The five implant receptor sites were found to be acceptable for length and fixation required for immediate loading.

A stereolithographic model was fabricated in advance to allow for better presurgical planning of restorative and surgical phases (Fig. 38A). The lateral view reveals the knife-edged aspect of the residual ridge, concavities, and other anatomic aspects of the mandible (Fig. 38B). To accurately transfer the simulated plan to the patient, four templates were fabricated. The first was to be used as a bone reduction template to aid the surgical modification of the bony ridge to the desired configuration for ideal implant placement. Three additional surgical templates were to be used to place the implants into the newly flattened ridge (Fig. 39). The three bone-borne templates allow the clinician to follow the manufacturer’s sequential drilling sequence for the (1) pilot, (2) intermediate, and (3) final sizing drills. Each stainless steel tube has a diameter of 0.2 mm greater than the drill, leaving little room for error. Based upon the presurgical virtual planning as transferred to the surgical intervention, the case proceeded to completion with complete confidence. The reduction template seated on the stereolithographic model indicated the amount of bone to be sectioned from the anterior mandible (Fig. 40A). The distance from the desired level of bone to the height of the alveolar crest was 10 mm (Fig. 40B). Once the bone was properly removed from the stereolithographic model, the surgical implant guide fit securely (Fig. 40C).

At the time of surgery, a full-thickness mucoperiosteal flap was raised to expose the underlying ridge. The reduction template was seated on the anterior residual ridge indicating the amount of vertical bone to be removed (Fig. 41A). Vertical cuts were made at the level of the reduction template (Fig. 41B), and the bone was removed until the ridge was flattened to the desired dimensions (Fig. 41C). The implant placement guide (SurgiGuide) was firmly seated onto the bone with embedded tubes to guide the implant drilling sequence (Fig. 42B).

Before the surgical procedure, a simulation was performed on the stereolithographic model fabricated from the CT scan data. Osteotomies were accurately cut into the stereolithographic models using the templates as seen in Fig. 40C. Five Tapered Screw-Vent replica implants were successfully placed into the model as per the CT scan plan (Fig. 43A). Because the implants were planned to be parallel in the SIM/Plant plan, the simulated implants guided by the templates also achieved parallelism, as noted by the fixture mounts in Fig. 43B. An important aid to the prosthetic reconstruction, the five implant replicas were placed at the same vertical height (Fig. 43C). Using five titanium tubes and screw abutments, the fixed-detachable prosthetic solution was planned in advance to be delivered at time of surgery (Fig. 43D). After the implants were placed, the five titanium screw–retained abutments were attached, and soft tissue closure was achieved (Fig. 44A). Using a rubber dam pickup technique to protect the underlying tissue and sutures, the prosthesis was seated over the abutment and secured with acrylic (Fig. 44B). The fixed detachable hybrid restoration allowed for immediate loading of the implants and increased function for the patient using techniques that significantly reduced surgical time. Within minutes, the prosthesis was finished, polished, and delivered to the patient, with the screw-access holes covered with a light cured material (Fermit; Ivoclar-Vivadent, Amherst, NY) (Fig. 45).
Fig. 38. (A) The stereolithographic model was fabricated to allow for presurgical planning. (B) The lateral view reveals the knife-edged aspect of the residual ridge.

Fig. 39. To accurately transfer the simulated plan to the patient, four templates were fabricated: one as a reduction template and three to place the implants on the flattened ridge.

Fig. 40. (A) The reduction coping seated on the prereduced stereolithographic model. (B) Ten millimeters of bone height was to be removed to facilitate implant placement. (C) The surgical template adapted after bone of the stereolithographic model was reduced.
The use of presurgical planning and stereolithography enabled the prosthetic solution to be designed in advance on an irregular ridge (in height and width) that required reduction before implant placement. The use of a CT-derived bone reduction template and surgical implant templates facilitated the surgical aspect, increased accuracy, reduced operatory time, and helped accomplish a successful immediate load protocol with parallel implants.

**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 one 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” (Ganz, 1995.)

Fig. 41. (A) The retracted view of the reduction template seated on the anterior residual ridge. (B) Vertical cuts were made at the level of the reduction template. (C) The completed ridge flattened to the desired dimensions.

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Fig. 41. (A) The retracted view of the reduction template seated on the anterior residual ridge. (B) Vertical cuts were made at the level of the reduction template. (C) The completed ridge flattened to the desired dimensions.

Fig. 42. (A) The surgical template seated on the reduced ridge. (B) Five Tapered Screw-Vent implants successfully placed as per the CT scan plan.
Assimilating the CT data for purposes of correct diagnosis and treatment planning may be the most critical step in transferring accurate information to the patient at the 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 is the intention 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 be translated into a precision surgical template that insures successful treatment outcome.

As implant dentistry turns its focus to be driven more and more by the restorative requirements and as traditional protocols shift to accelerated immediate or delayed loading techniques, advances in template design will continue to improve out of necessity. Klein and
Abrams [28] developed a link between the CT data and template fabrication by sending the 3-D coordinates of the SIM/Plant plan to a five-axis computer numerical-controlled milling machine. The drill guide system is incorporated into the milled surgical template in 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).

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. The ability to visualize potential implant receptor sites as correlated to the final tooth position via CT imaging and advanced software applications has been illustrated as the first step toward the goal of restoring the patient to proper function and esthetics. Linking the virtual plan to the patient at time of surgery was also illustrated by the clinical presentations contained in this article. Although the use of a bone reduction surgical guide has been demonstrated in the literature, it was for a specific system (Novum; Nobel Biocare, Göteborg, Sweden) and was based upon understanding the vertical dimension of occlusion required for the procedure, using standard prosthetic protocols and diagnostic work-up to create the surgical guide. The bone is reduced, with the guide placed intraorally several times until the correct vertical dimension of occlusion is achieved, as judged by posterior vertical stops becoming completely engaged. Because the original cast surgery without CT now seems primitive, the novel reduction template as described in this article represents an evolutionary step whereby the exact amount of bone removal was determined in advance by the use of CT imaging combined with stereolithographic models. The reduction template, as seated over the mandible, guided the surgeon in accurately removing the proper amount of bone so that a secondary template fit on the prepared site. The secondary template was used to guide the osteotomies for implant placement. This type of accuracy has not previously been within the reach of all clinicians.

Summary

This article illustrates the advantages of using CT scan–based templates but does not attempt to cover all available methods for fabrication or 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 overcome with interactive software applications that provide this information seamlessly. Based upon information contained within, templates derived from CT-scan planning data, which embed stainless steel tubes, are highly accurate and easy to use in bone-, tooth-, or soft tissue-borne (not shown) configurations. It is 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 done.
in advance of the procedure. Procedures were illustrated for single and multiple tooth applications in 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 who are 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, benefitting the patient, the surgeon, the restorative dentist, and the laboratory. Using CT imaging to assess bone anatomy and to determine implant receptor sites allows for improved techniques for flapless surgical procedures (when appropriate), which can be performed with greater levels of confidence and are less invasive. Novel CT-derived bone reduction templates allow surgeons to reduce irregular bony crests for purposes of accurate implant placement, thereby achieving results with more predictability and with greater efficiency than with conventional methods. However, the template is only as good as the planning. Achieving five or six well-fixed and parallel implants cannot be achieved with a free-hand surgical approach. Predictability can be enhanced only by thorough presurgical diagnosis and treatment planning using the information obtained from the CT imaging devices, which is then translated into accurate surgical guides. 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.

Further readings


Petrungaro PS. Using the Temp Stent technique to simplify surgical stent and esthetic temporary fabrication in immediately restored implants in the esthetic zone. Contemp Esthetics Restorative Pract 2002;6:84–90.


