Surgical Planning and Prosthesis Construction Using Computed Tomography, CAD/CAM Technology, and the Internet for Immediate Loading of Dental Implants

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ABSTRACT

This report describes a protocol that uses computer technology and medical imaging to virtually place anterior and posterior dental implants and to construct a precise surgical template and prosthesis, which is connected at the time of implant placement. This procedure drastically reduces patient office time, surgical treatment time, and the degree of post-treatment recovery. Patients with an edentulous arch or a partially edentulous area had a denture with radiopaque markers constructed for computed tomography (CT) scans of the appropriate jaw. The CT images, having acquisition slices of 0.4 mm, are transposed in a three-dimensional image-based program for planning and strategic placement of dental implants. After virtual implant placement on the computer, the surgical treatment plan is sent to a manufacturing facility for construction of the surgical template. The manufactured surgical components and surgical template arrive on the clinical site. From the surgical template, the dental laboratory retro-engineers the master cast, articulates it with the opposing dentition based on a duplicate of the scanning denture, and creates the prosthesis. Using the surgical template, minimally invasive surgery is performed without a flap, and the prosthesis is delivered, achieving immediate functional loading to the implants. Minor occlusal adjustments are made. The total surgical treatment time required is typically between 30 and 60 minutes. Postoperative symptoms such as pain, swelling, and inflammation are dramatically reduced.

CLINICAL SIGNIFICANCE

Identification of the bone in relationship to the tooth position via three-dimensional CT prior to surgery allows the clinician to precisely place implants. Computer-aided design/computer-assisted manufacture technology using the three-dimensional images allows for fabrication of the surgical template. This is a significant advancement in implant dentistry and promotes interdisciplinary approaches to patient treatment. The implant surgeon and restorative dentist can agree upon implant locations and screw access locations prior to the surgical episode.

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INTRODUCTION

Patient treatment with dental implants for oral reconstruction originally required a two-stage process: implant placement itself, followed by abutment connection months later.[1] More recently, many studies have shown comparable osseointegration success rates with immediate loading of implants,[2–28] in some cases minimizing treatment time to a single visit.[9–12,14,18,19,28] With the use of computed tomography (CT), computer-aided design/computer-assisted manufacture (CAD/CAM) technology, and the Internet, implant dentistry is now evolving so that surgical treatment time is minimized to 1 hour or less.

Treatment planning with dental implants, typically done with the use of periapical and panoramic radiographs, has provided sufficient information for successful planning in the past; however, there is no clear precision for the placement of the implants.[29] CT is a medical imaging technique where images are digitally acquired in slices. These slices are then reformatted into virtually any two-dimensional (2D) or three-dimensional (3D) perspective.[30] The ability of the computer software to reformat computerized axial tomograms into 2D and 3D image orientations with a 1:1 replication allows more accurate planning for implant placement.[31]

One of the first computer software programs (SimPlant, Materialise, Columbia, MD, USA) that used CT images had the capability of planning and practicing surgery, but had no direct way to correlate computer images to the mouth. Other CT/CAD/CAM systems offer the ability to place implants in the bone with a developed drill guide; however, they do not provide for an immediate prosthesis.

The 3D computer-assisted technology is continually expanding. A 3D image-based program (NobelGuide powered by Procera, Nobel Biocare AB, Göteborg, Sweden) for converting CT slices into the 3D space, along with planning and placement of dental implants, was recently introduced. This program allows the user to view a selected 3D image volume of the patient's bone and prosthetic appliance as a 3D scene in which these image-derived features can be rotated on all axes to provide any desired perspective. Exact virtual representations of the implants, abutments, and other surgical accessories can be inserted into the 3D scene and positioned in the precise 3D coordinates that the planner/clinician deems appropriate. These virtual representations can then be rotated with the image-derived features.

The intention of this article is to report a thorough explanation of the current protocol for interactive imaging and virtual implant planning. This current protocol has evolved from the original design techniques previously reported.[32] This article will also discuss the limitations of the protocol and proper patient selection.

MATERIALS AND METHODS

Pre-treatment Procedures

The technique illustrated here for a surgical template and prosthesis construction is dependent on the patient's existing denture because the definitive fixed prosthesis created from the imaging and prototyping models is a virtual clone of the original denture in a fixed bridge configuration.[33] Therefore, all the characteristics of the original denture, such as centric and vertical positions and tooth arrangement, are transferred to the end esthetic result. Other characteristics of the original denture, such as thickness and extensions of the buccal flanges, are also transferred to the surgical template. Furthermore, it is imperative to achieve excellent soft tissue adaptation so that the surgical template will seat in the mouth as precisely as the original denture does.

Once the patient and clinician are satisfied with the characteristics of the original denture, either the original denture itself or an exact duplicate of it is then prepared as the scanning prosthesis. This denture is dotted with radiopaque markers

(gutta-percha, Coltene-Whaledent, Cuyahoga Falls, OH, USA) at approximately 10 to 12 sites at different levels in relation to the occlusal plane, with each site about 1.5 mm in circumference (Figure 1). Vinyl polysiloxane bite registration paste (Regisil, Dentsply, Milford, DE, USA) is used to create a centric occlusion index at this stage to stabilize the denture and opposing dentition during the CT scanning procedure.

A double-scan technique is used to acquire the CT data. Either spiral CT scanners or cone-beam CT scanners can be used. The data acquisition from the CT scan must be compatible and adequately detailed—slices of about 0.4 mm—to acquire images of the jaws being treated. The first scan is performed with the patient wearing the scanning denture and the bite index in place, ensuring the correct placement of the denture and arrangement of teeth during the scan. The second scan is then performed with the scanning denture alone positioned in the CT scanner in the same orientation as it was during the first scan. After the CT scanning procedures, the bite index is preserved for the upcoming laboratory procedures.

The computer software uses the radiopaque markers laced in the scanning denture to perform an accurate fusion of the two separate scans. Resulting from this fusion is an exact representation of the patient's bone structure and scanning denture in 3D space. At this point, the virtual surgical procedure can be performed.

The computer software uses two viewing panels to see the image-derived features. The panel on the left is used for visualizing an overview of the 3D scene, which can be rotated around all axes. The right panel is the slice viewer, which can be altered by moving along the slice curve in the left panel (Figure 2). Moving along the slice curve allows the user to assess bony contours and defects and to ultimately identify the optimal positions for implant placement. The implants are then placed into the 3D scene. Automatically brought into the 3D scene with each implant are the virtual representations of the abutment (guided abutment, Nobel Biocare USA, Yorba Linda, CA, USA) and the stainless steel sleeves of the surgical template (Figure 3). These components are fixed based on the positioning of the implant, so proper implant placement must take into consideration these surgical components as well. When all implants and abutments are virtually placed in the 3D scene, the virtual prosthesis can be overlaid onto the image to evaluate the position of the implants in relationship to the prosthesis. Lastly, three or four horizontal stabilizing pins—for fully edentulous patients—must be positioned to secure the correct location of the surgical template during the clinical implant placement (Figure 4). The inclination, depth, and distance from other virtual components of the anchor pins need to be considered when adding them to the virtual planning. Once the virtual planning is completed, the planning files are sent through

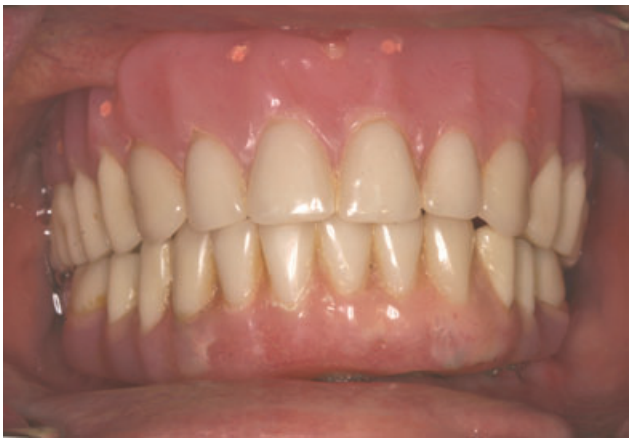

Figure 1. Frontal view of a maxillary scanning prosthesis, laced with gutta-percha markers, opposing a screw-retained all-acrylic mandibular implant prosthesis.

the Internet to the Procera manufacturing facility (Nobel Biocare AB) for surgical template, duplicate denture, and surgical accessory construction. The duplicate denture is necessary for a laboratory to articulate the master cast with the opposing model.

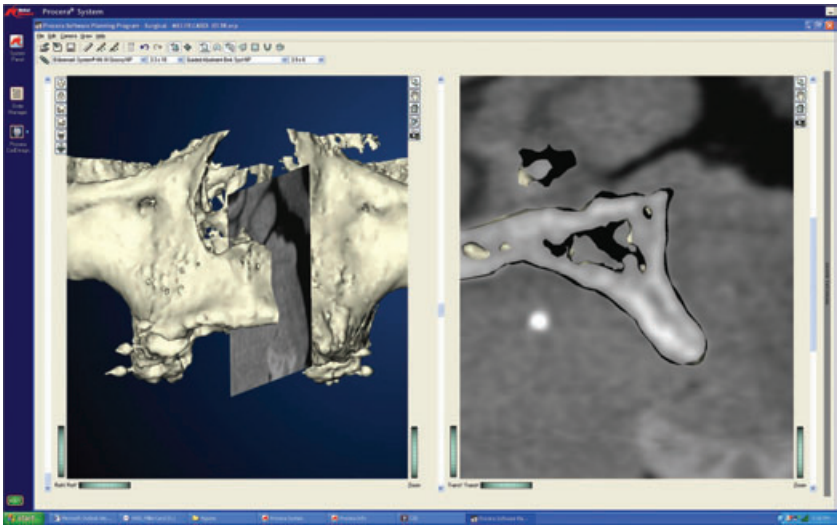

Figure 2. Computer-generated images of a fully edentulous maxillary arch that were converted from the double computed tomography scan technique using the Procera System software package. The left panel illustrates the three-dimensional image of the patient's bone structure, while the right panel shows a two-dimensional image of the cross-section of bone at the selected location.

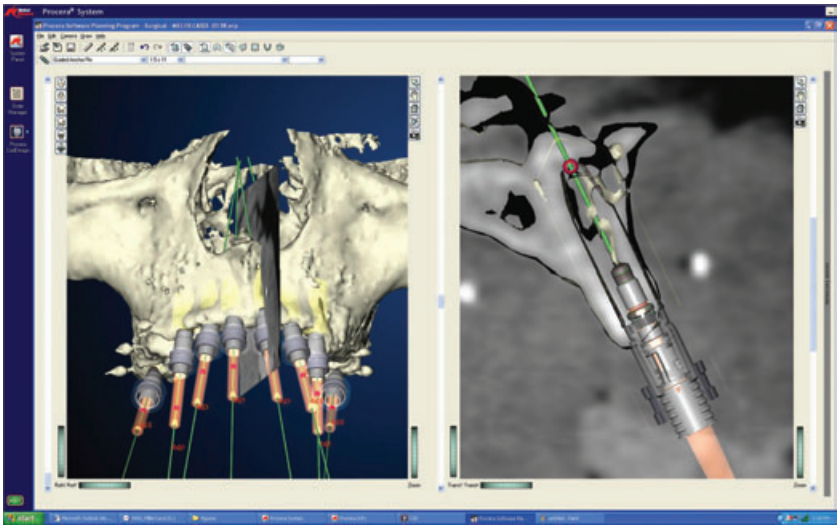

Figure 3. Computer-generated three-dimensional images of the transmucosal abutments positioned on the implants.

The current surgical template is constructed stereolithically of a light-sensitive resin using the computer data files from the virtual implant planning. The duplicate denture is constructed in the same manner using the 3D computer file of the scanning denture. Therefore, both of these items are sensitive to moisture and ultraviolet (UV) light. It is important for both the clinician and the laboratory to keep these materials in the UV protective plastic bag in conjunction with the moisture absorber when they are not being used to fabricate the temporary or final prosthesis.

The surgical template contains all the necessary information for making the master cast, on which a permanent or provisional prosthesis can be fabricated. Because the tissue-bearing surface of the surgical template and duplicate denture are identical, the surgical template can be articulated with the opposing model. The bite registration applied during the CT scanning procedure is used to verify the relationship of the duplicate denture with the opposing model. Once articulated, the duplicate denture is removed and the surgical template is set into place (Figure 5). This allows for the fabrication of the surgical index (Figure 6), which is used to accurately seat the surgical template in the patient.

Surgical Procedure

The patient is prepared and anesthetized in the typical approach for dental implant surgery. The surgical template is positioned using the surgical index that was fabricated in the laboratory (Figure 7). Vertical pressure applied in the centric position properly seats the surgical template for horizontal anchor pin insertion. Using a 1.5-mm twist drill, the sites for the horizontal stabilizing pins are created and the pins are inserted. The surgical template is now set in place with good initial stability and the surgical index can be removed (Figure 8). To provide further stability, the surgical template is attached to strategically placed implants in the anterior sleeves. First, the counterbore is used in one of the selected sleeves. This spade-like drill is designed to remove the soft tissue over the eventual implant site and clears the path for the osteotomy drills. Twist drills are then used in conjunction with a precise handheld drill guide until the desired depth and width of the osteotomy are attained. These drill guides have evolved from the original design to resemble the drill guides that were specifically designed for placement in the pterygomaxillary region.[33] Optional drill stops can be placed on the twist drills so the clinician does not overprepare the osteotomy. The exact dimensions of each site are determined in the virtual planning on the computer. The predetermined implant size accord-

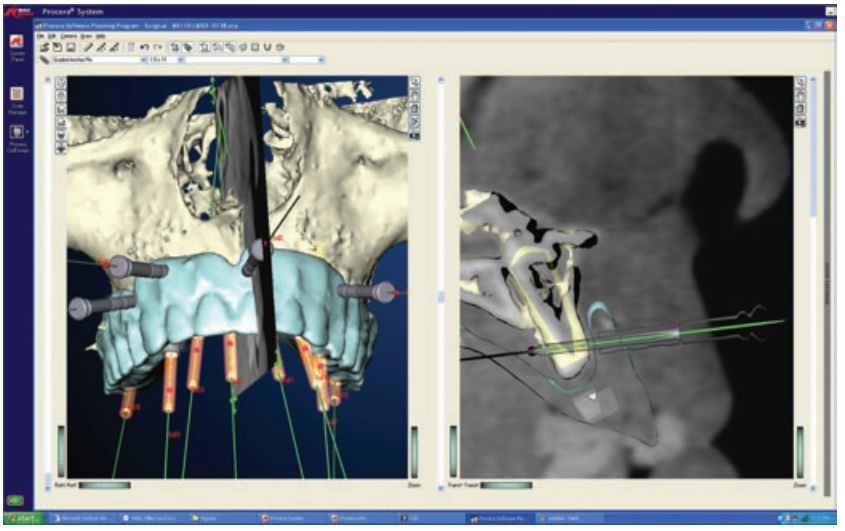

Figure 4. Computer-generated three-dimensional images of the virtual prosthesis with its relation to the implant positions. Horizontal anchor pins will stabilize the surgical guide as the implants are placed.

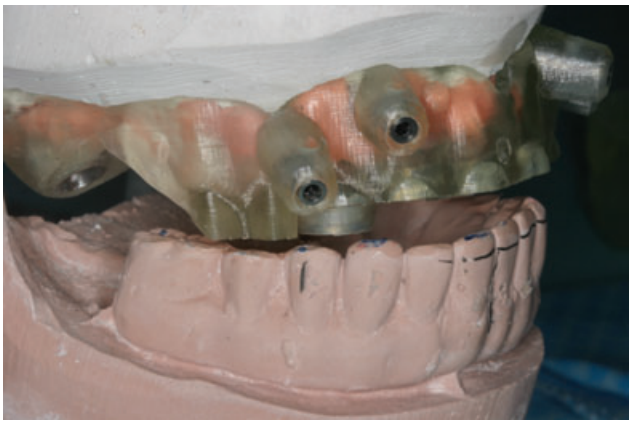

Figure 5. Lateral view of the articulated surgical template with the opposing model.

Figure 6. Lateral view of the surgical index, used to ensure an accurate relationship between the surgical guide and opposing dentition once removed from articulator.

ing to the operating map can then be placed into the prepared osteotomy site using a depth-controlling fixture mount specific for the diameter of the implant and the stainless steel sleeve that is incorporated into the surgical template. The implants are rough surfaced and have either an internal hex (NobelReplace, Nobel Biocare USA) or external hex head connections (Mk III, NobelSpeedy, Nobel Biocare USA). It is critical not to overtighten the implant at the time of insertion as it may alter the orientation of the surgical template (Figure 9). The template abutment, a specifically designed abutment with expanding sidewalls, is inserted into the same surgical sleeve as the implant and stabilizes the surgical template at this implant position while additional sites are being prepared (Figure 10). This template abutment also prevents the soft tissue from collapsing above the implant hexes. The other

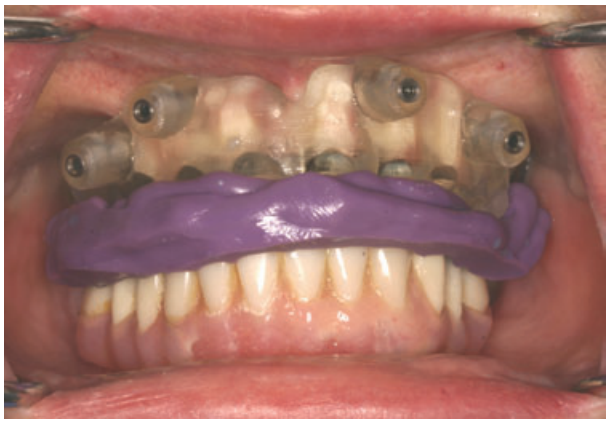

Figure 7. Frontal view of the installation of the surgical template using the surgical index as a reference.

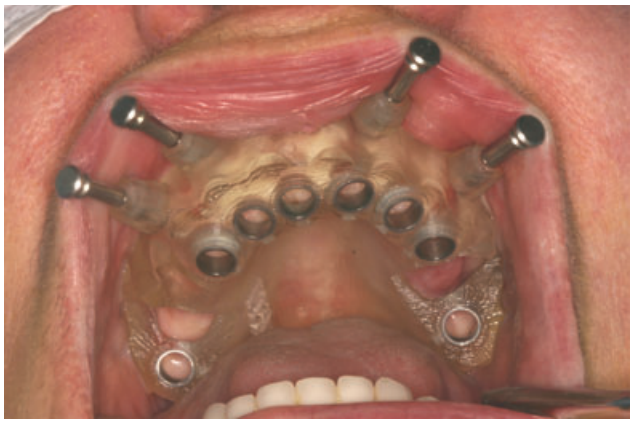

Figure 8. Occlusal view of surgical template installed and stabilized with four horizontal anchor pins. Treatment planning was for six implants anterior to the maxillary sinuses and two implants posterior to the sinuses in the pterygomaxillary region.

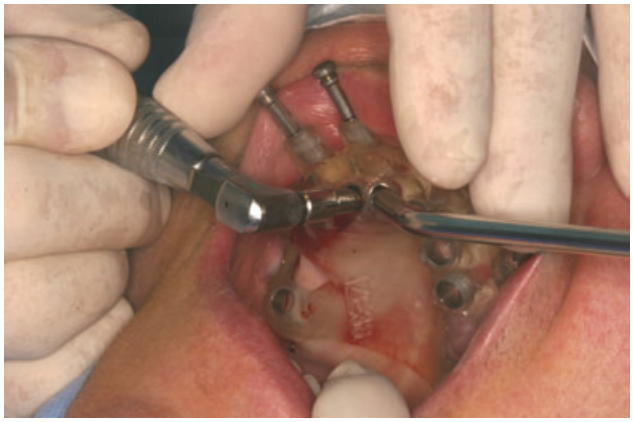

Figure 9. The first implant is used as a stabilizing implant by placing a template abutment, locking the surgical template in place in the relation to that implant.

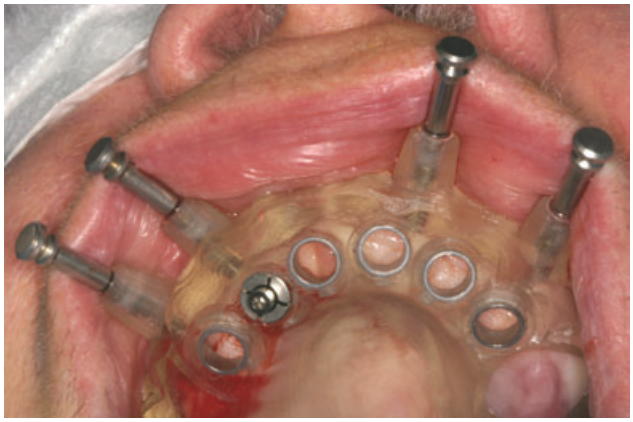

Figure 10. After placement of the template abutment, the surgical template is now stabilized in a vertical position as well as a horizontal position from the previously placed anchor.

strategically selected sites are prepared in the same manner; implants are placed and the template abutments are connected. The number of implant sites used for surgical template stabilization will depend on the virtual treatment plan. For a fully edentulous arch with both anterior and posterior implants, two or three template abutments may be necessary. For a partially edentulous scenario, only one template abutment may be required.

Once a sufficient number of template abutments are connected and the surgical template is firmly anchored, the remaining implants can be placed (Figure 11). The clinician does not need to totally prepare the remaining osteotomies for each site one at a time. Each step, as previously described, can be performed to all the remaining implant locations. After all implants have been seated and the template abutments have been removed, the horizontal anchoring pins and surgical template can also be removed.

The implants can be visualized in their subgingival positions (Figure 12). The prosthesis delivery is performed rapidly after removal of the surgical template in order to take advantage of the patency of the soft tissue openings that exist from placement of the template abutments. The soft tissue openings are checked for clear access to the implants. The screw-retained nonengaging self-adjusting guided abutments are positioned into the appropriate cylinders of the prosthesis (Figure 13). The prosthesis is then delivered, assuring that the abutments are seated flush on each implant. The screws are tightened to 35 N/cm, which results in two outcomes: (1) secure tightening between the guided abutment and implant and (2) secure metal-to-metal contact between the expanding wings of the guided abutment and the prosthesis. Any necessary occlusal adjustments are made and screw access holes are sealed.

The completed restoration should have a precise fit at the implant abutment interface, as observed in the panoramic radiograph (Figure 14), and the prosthesis should appear to have an esthetic arrangement similar to that which preoperatively existed with the patient's scanning denture (Figure 15A–C).

DISCUSSION

Computer technology and medical imaging have elevated expectations in implant dentistry. In the fast-paced world where style and appearance are premium, this protocol requires the patient to have as

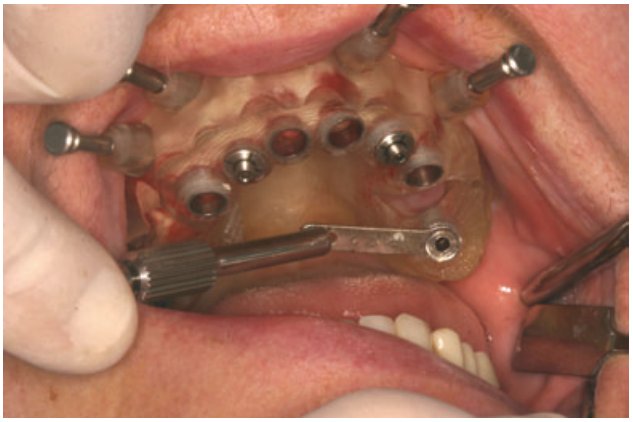

Figure 11. Twist drill guides are used to ensure proper preparation of the osteotomy sites. This Regular Platform 2-mm drill guide is positioned to prepare the left pterygomaxillary implant site.

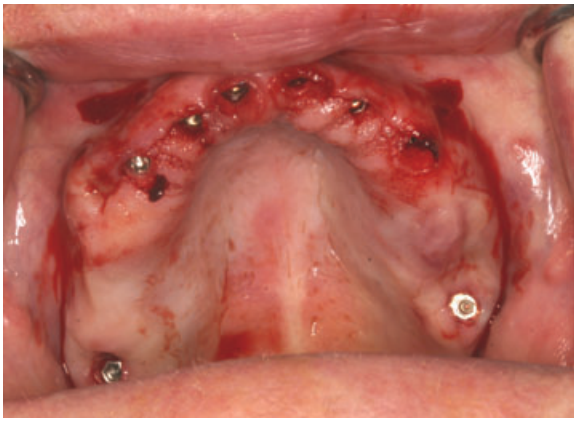

Figure 12. Implants are visible when surgical template is removed, illustrating a flapless procedure.

few as two visits: (1) the initial exam, preparation of an acceptable scanning denture, and CT scan and (2) the less-than-60-minutes operation. In addition to the duration of treatment, there is also a decrease in the postoperative recovery period from the minimally invasive procedure. The use of a flapless surgery decreases the amount of swelling and inflammation, thereby resulting in less discomfort and pain.

This technique is successful for placement of implants in all areas of the mouth. Implants placed posterior to the sinus in the maxilla or posterior to the mental foramen in the mandible are done so with more confidence. With this computer-guided protocol, there is a significant decreased risk of parethesia, because the placement of the implants is predetermined in the virtual planning. Longer implants can be placed to increase primary stability.

Pretreatment Considerations

Not all patients are immediate candidates for NobelGuide. Currently, patients who present with natural teeth in the area of the intended implant reconstruction must have extractions performed prior to proceeding with this protocol. Many patients are not willing to commit

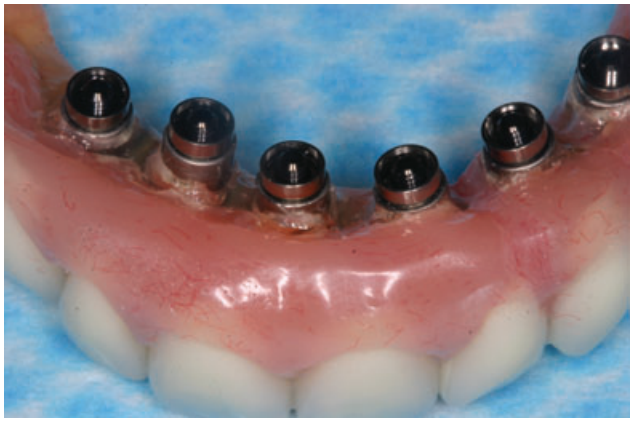

Figure 13. Expandable titanium abutments are positioned into the final prostheses.

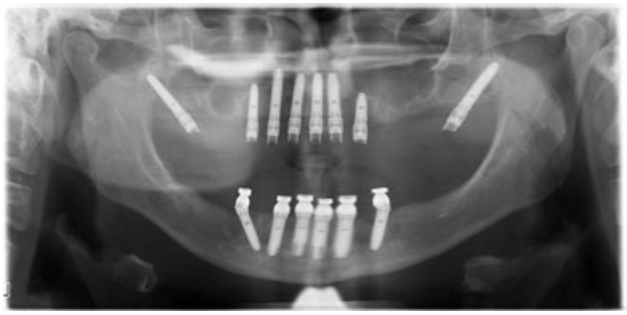

Figure 14. Panoramic radiograph taken immediately after implant placement and all-acrylic provisional prosthesis delivery.

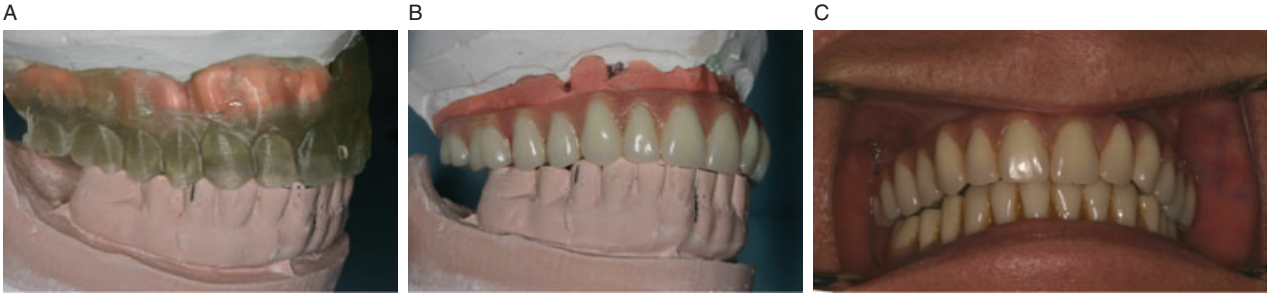

Figure 15. A, Articulated duplicate denture that was created with computer-aided design/computer-assisted manufacture to identically resemble the scanning prosthesis. B, Articulated provisional prosthesis that illustrates a similar esthetic arrangement as the duplicate denture in Figure 15A. C, Postoperative frontal view of immediate maxillary provisional prosthesis in place.

to a removable prosthesis from the time between extractions and the guided surgery/fixed prosthesis delivery. These patients, even though they are well educated about the different protocols, will elect for the Teeth in a Day (TIAD) protocol[11,14,19,34] because they will leave the dental practice with a new smile that same day. Other patients who are not immediate candidates for NobelGuide are those with high smile lines. When the alveolar ridge is visible in their smile line, an alveolectomy must be performed in order to move the transition zone of natural and false tissue out of view. These patients will also proceed with the TIAD protocol so that they only encounter one surgical episode.

Excessive soft tissue thickness, usually noted in the posterior maxilla, can present a problem during placement of the surgical template in the mouth. The stainless steel sleeves incorporated into the surgical template are always at a fixed distance from the collar of the implant. If the patient's soft tissue thickness is greater than 8 mm, the surgical template will be forced to compress the soft tissue in those areas, resulting in an inaccurate placement of the surgical template. It is important to remember that the surgical template will have the exact same soft tissue adaptation as the scanning denture. However, if implants are placed too deep in the bone, or the soft tissue thickness is too great, the stainless steel sleeves will be below the tissue-bearing surface of the surgical template and the accuracy of the guide will be lost. The excess soft tissue needs to be removed prior to the fabrication of the scanning denture and the CT scanning procedure.

Scanning Procedures

The importance of the scanning denture cannot be overemphasized in this protocol. Both the surgical template and the immediate prosthesis are a direct result of the scanning denture. The tissue-bearing surfaces of the scanning denture are the most important aspects that relate to the surgical template. Well-extended buccal flanges will help stabilize the template in the mouth and will also allow for greater flexibility in the horizontal anchor pin placement. The arrangement and esthetics of the teeth and the centric and vertical dimensions of the scanning denture will be transferred to the immediate prosthesis. With these characteristics determined prior to surgery, the ideal placement of implants in relation to the prosthesis can be determined in advance. This will result in optimal screw access positions.

The double-scan technique for the CT protocol is used to obtain the most accurate 3D scene possible for both the patient's bony anatomy and scanning prosthesis. The program that converts the 2D slices into the 3D scene utilizes the Hounsfield system of relative density.[35] Because the Hounsfield units generated for the scanning denture closely resembles that of soft tissue, the second scan of the scanning denture alone allows for the accurate extracting of the prosthesis without incorporating any soft tissue anatomy. This would not be possible with a single CT scan. The gutta-percha points laced in the scanning denture will be in the exact same locations in relationship to each other in both CT scans. These radiopaque markers allow for the fusion bone and prosthesis into the 3D scene.

Patient Treatment

The accuracy of the implant placement with this guided protocol is directly related to the accuracy of fit of the surgical template. This template is expected to have the same soft tissue adaptation as the scanning denture. When administering local anesthesia to the patient, the volume of CCs injected into the soft tissue area will affect the area of the soft tissue anatomy, thereby affecting the accuracy of fit of the surgical template. In order to overcome this clinical scenario, the patient is asked to insert his or her denture back into the mouth and compress. After approximately 10 minutes of light compression, the volume of liquid is driven away from the edentulous area; however,

the area still remains numb. The surgical template can then be inserted into the mouth with the surgical index and the drilling procedure can begin.

The NobelGuide protocol allows for immediate delivery of either a provisional or definitive restoration. The precision of the system, a function of the CT scanning procedure, can be accurate to one hundredth of a millimeter (0.01 mm). This precision will allow the clinician to deliver a definitive restoration with a Procera milled titanium framework if so desired. The tremendous benefit of delivering the definitive prosthesis is that the patient will receive their "final" set of teeth the same day as the implant placement and will not be required to return for final impression tryins, among other visits.

The authors of this report suggest the delivery of an all-acrylic screw-retained provisional prosthesis. Even though the patient is instructed to accept the functional and esthetic arrangement of teeth based on the scanning denture prior to surgery, the patient may still elicit dissatisfaction with the result. With a provisional restoration, it is possible to adapt to the patient's satisfaction; not so with the titanium framework. Osseointegration is also not yet 100% predictable. From research, it is known that the majority of implant failures will occur in the first months following implant placement. If an implant would fail to integrate, that implant must be removed and the provisional prosthesis can be modified to splint the remaining integrated implants. Once osseointegration is noted both clinically and radiographically, a final prosthetic reconstruction can be delivered.

If the patient is delivered a provisional bridge at the time of surgery and then a definitive restoration several months later, the restorative clinician should retain the provisional prosthesis in storage. If this same patient several years later presented with a fractured crown, the clinician could simply remove the definitive prosthesis and replace it with the provisional prosthesis while laboratory work is being completed to repair the definitive restoration. Directly going to the definitive prosthesis with this protocol eliminates this option for the patient and clinician.

Limitations

The majority of the limitations are in the number of patients who are immediate candidates for the NobelGuide protocol. However, once a patient is deemed acceptable for the protocol, there are only a few limitations that are not considered in conventional implant surgery. Because this protocol uses a surgical template for implant placement, the virtual planning must consider the proximity of the stainless steel sleeves to one another. In other words, implants are not able to be placed as close together as they can be in conventional placement techniques. There is a minimum requirement of 1.5 mm between each stainless steel surgical sleeve so that the integrity of the surgical template remains and the template does not fracture during the drilling procedure.

Because the orientation of the implant hex is not known until it is physically in place in the bone, the abutment used for this protocol is a nonengaging abutment. At this time, there is only one abutment choice available for each implant platform in the Procera Software. This abutment is a straight abutment. This limits the degree of divergency between any two implants. Although recent developments have been made for nonengaging angulated abutments, these have not been virtually represented into the computer software at this time.

Future Considerations

The NobelGuide protocol allows the clinician to treat patients with dental implants while reducing the amount of bone grafting and sinus lifts procedures. Treatment of the severely atrophic maxilla by utilizing the zygoma and pterygomaxillary regions is a treatment option for all patients. While this guided

protocol can incorporate the use of pterygomaxillary implants,[33] surgical templates are not manufactured for cases with zygoma implants at this time.

CONCLUSION

Identification of the bony anatomy in relation to the teeth prior to surgery allows the clinician to place implants in areas where the implant–bone interface can be maximized and the prosthetic result is optimized. This is a tremendous advantage for both the clinician and the patient. The clinician can provide a treatment plan that reduces the operating time, surgical trauma, and postoperative recovery period from conventional freehand implant surgery, yet maintain a precise, stable, and biomechanically sound outcome. The time saved with this revolutionary procedure is remarkable. There is no second-stage abutment connection surgery, no need for impressions, and no additional clinical or laboratory procedures. The time for the patient is minimum—a single 1-hour procedure versus numerous longer visits following the traditional implant protocols. This is a significant advancement in implant dentistry and prosthodontics and forces an interdisciplinary approach to the treatment of patients.

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