

Computer-Generated Implant Planning and Surgery: Case Selection

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Implant dentistry is in the midst of a revolutionary change. Medical-grade computed tomography (CT) scanners and in-office cone-beam scanners allow the surgeon to see a patient's anatomy in three dimensions. Visualization of the available bone for implant placement, soft-tissue thicknesses, and location of the maxillary sinuses and pertinent vital structures, such as the mandibular canal, are possible.¹⁻³ The images can be imported into proprietary software programs (eg, Simplant®[Materialise Dental NV,

Leuven, Belgium], Procera®[Nobel Biocare, Göteborg, Sweden], EasyGuide™ [Keystone Dental, Burlington, MA], Facilitate™ [Astra Tech, Mölndal, Sweden]) that allow the surgeon to “virtually” place implants. The type and size of the planned implant; its position within the bone; its relationship to the planned restoration and adjacent teeth and/or implants; and its proximity to the mandibular canal, incisive canal, and maxillary sinuses

can be determined before surgery.¹⁻⁵ Computer-generated drilling guides then can be fabricated from the virtual treatment plan. These surgical guides enable the clinician to surgically place the planned implants, in the patient's mouth, in the same positions as planned on the virtual treatment plan. This process permits more accurate and predictable implant placement⁶⁻¹⁰ and reduces patient morbidity.¹¹⁻¹⁴

All of the current systems have similar protocols. First, the surgeon creates a prosthesis for the patient to wear

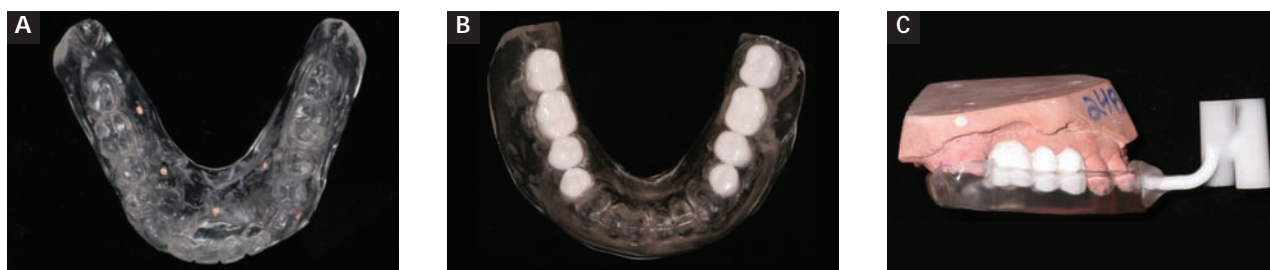


Figure 1 Examples of scan prostheses: NobelGuide™ (Nobel Biocare) radiographic guide (A), Simplant (B), and EasyGuide (C).

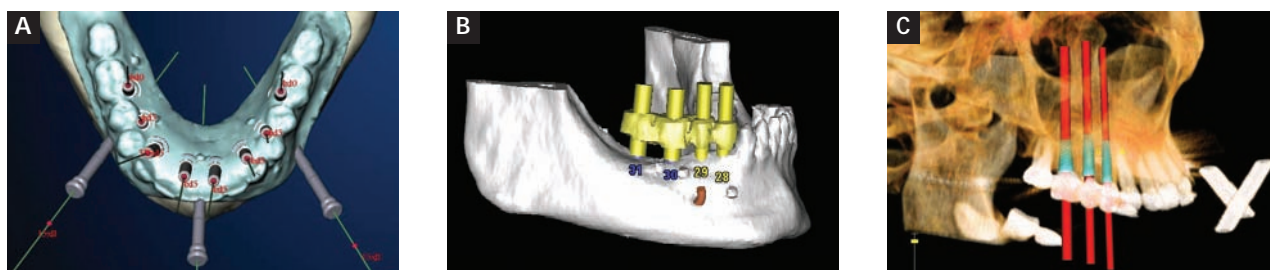


Figure 2 NobelGuide treatment plan (A), Simplant (B), and EasyGuide (C).

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Figure 3 Surgical guides: NobelGuide (A), Simplant (B), and EasyGuide (C).

during the CT scan. This is a partial or full denture (termed the scan prosthesis) that duplicates the planned final restorations (Figure 1A through Figure 1C). The CT scan then is taken with the patient wearing the prosthesis. Next, the images are imported into one of the software programs (eg, Simplant, Procera, EasyGuide), which is used to virtually place implants into their ideal positions related to the planned restoration and underlying bone (Figure 2A through Figure 2C). Then, the surgeon electronically sends the virtual treatment plan to the software company, which fabricates a surgical guide (Figure 3A through Figure 3C). With this guide, the surgeon uses implant-specific drilling instrumentation to place the implants precisely according to his or her virtual treatment plan.

Virtual treatment planning and computer-generated drilling guides benefit the patient by enabling flapless

surgery, reduced surgical time, less discomfort and swelling, and a quicker return to life and work.^{6,11-19} These technologies help the surgeon by reducing chair time, lessening the patient's stress at the time of surgery, facilitating an accurate means of placing dental implants, and reducing the risk for surgical complications.^{7-10,20} The potential for mistakes is greatly alleviated.

Computerized implantology can be used for any implant case. The increased time for treatment planning and the increased expense may outweigh its benefits in certain cases. In the authors' practice, these techniques are the appropriate means of treatment for many cases, including those with:

- questionable bone volume,
- problems related to proximity of adjacent teeth,
- proximity to vital anatomic structures,
- three or more adjacent implants,



Figure 4 NobelGuide plan for three implants, posterior left maxilla (A). Note the parallelism of the planned implants. Postoperative panoramic radiograph (B). Final restoration (C).



Figure 5 Fully edentulous mandible, occlusal view, implant placement plan (A). Fully edentulous mandible, implants in place using NobelGuide (B). Provisional full-arch restoration placed immediately (C).

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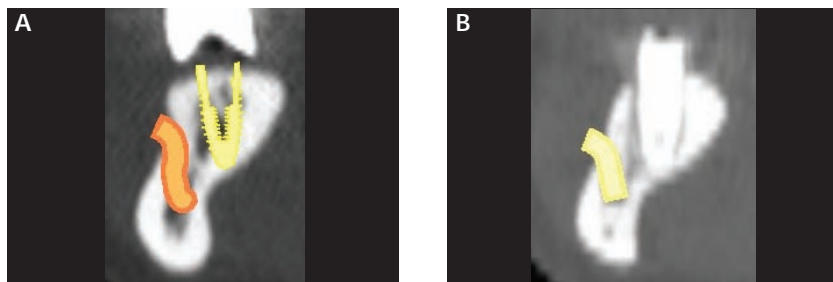


Figure 6 Virtual treatment plan image (A) for placement of implant No. 21. Compare with CT scan of actual implant placement (B). Note the close proximity of the planned implant and the actual implant placement to associated nerves and foramina.

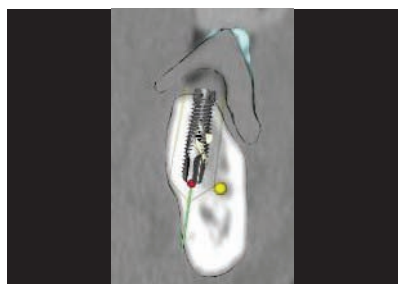


Figure 7 Implant planned close to inferior alveolar nerve.

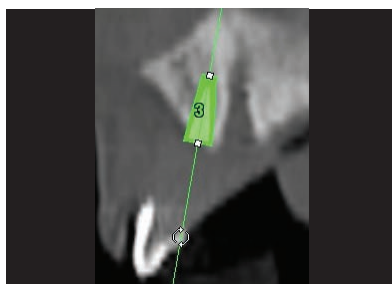


Figure 8 Implant planned close to incisive nerve/canal.

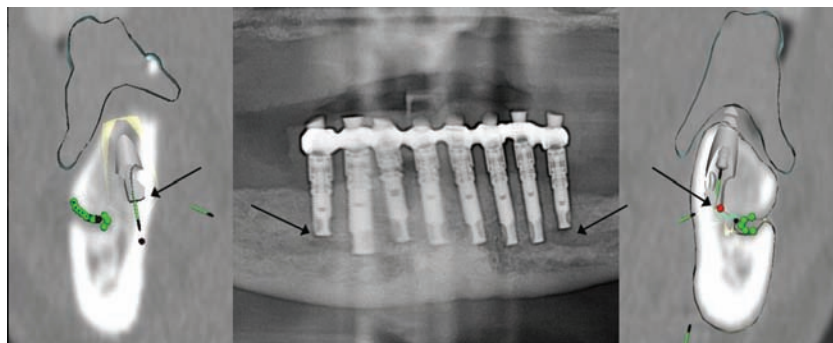


Figure 9 Postoperative panoramic radiograph of an eight-implant mandibular case (center). Note the most posterior implants appear to be encroaching on the mental foramina bilaterally. Compare this with the right and left images showing the planned positioning of the implants in the virtual treatment plan. Clinically, the implants were placed lingual to the mental foramina.

- placement of a multiple-unit or full-arch immediate restoration,
- significant alteration of the soft tissue or bony anatomy by prior surgery or trauma, and
- medical comorbidities.

This article will not only illustrate cases in which these techniques benefit the surgeon and patient, but it will also help dentists determine those cases in which these techniques are the appropriate means of treatment.

PLANNING FOR THREE OR MORE ADJACENT IMPLANTS AND FULLY EDENTULOUS ARCHES

When placing a dental implant, the surgeon commonly uses a surgical guide that is fabricated on articulated patient models. These types of guides can be simple (eg, vacuforms with the buccal or palatal/lingual facings of the planned restorations) or more complex (eg, 2-mm drill holes or metal tubes in the middle of hard acrylic appliances that reproduce a planned restoration). The one commonality of these appliances is their lack of correlation between the planned restoration and underlying bony anatomy. Only with virtual implant surgical guides can this anatomic relationship be established predictably and considered prior to surgery.

A surgical guide for implant placement is fabricated based on the patient's anatomy and local references, such as the numbers and locations of teeth in the arch to be treated or in the opposing arch. As the length of the edentulous area increases, the surgeon has fewer anatomic references to accurately predict implant placement. When the case is fully edentulous, all local references, other than the soft-tissue ridge, are absent. Additionally, as the bone and soft tissue are lost from periodontal disease, bony atrophy, sinus pneumatization, and

long-term denture wear, it becomes more difficult to predictably use a traditional surgical guide.

Because of these issues, virtual implant evaluation and treatment planning and implant placement using computer-generated guides is an ideal technology for most cases in which three or more adjacent implants are planned (Figure 4A through Figure 4C). The spacing and angulation relationships of multiple planned implants, as well as implant to bone relationships, all can be established before surgery. Implants can be

placed flaplessly and immediately loaded^{6,11-19} (Figure 5A through Figure 5C).

NERVE PROXIMITY CLOSE TO THE PLANNED IMPLANT POSITION

Panoramic and periapical radiographs are 2-dimensional representations of a patient's 3-dimensional (3D) anatomy. Differences in x-ray machines and radiographic techniques commonly lead to distorted images, such as elongation and shortening of anatomic structures. Accurate evaluation and measurement of the relationship between the position of the mental nerve, the inferior alveolar nerve, or the nasopalatine/incisive nerve and the location of the planned implant can only truly be determined and planned by a 3D evaluation of the patient's anatomy as it relates to the planned restoration³ (Figure 6A and Figure 6B). These anatomic relationships are best visualized, evaluated, and measured by using CT images. Placement of implants when there is a question of nerve or sinus proximity to the patient's available bone is most accurately performed using virtual implant treatment planning and implant placement with computer-generated surgical guides. With these techniques, the potential for patient morbidity because of possible implant placement in close proximity to vital structures is minimized (Figure 7 through Figure 9).

QUESTIONABLE BONE VOLUME

Frequently, dental implant surgeons confront surgical dilemmas that require the placement of dental implants in only one possible location and/or at only one possible implant depth. At times, surgeons are required to place dental implants into tight spaces with minimal bony leeway—mesial-distally, buccal-lingually, or both (Figure 10A through Figure 11I). Proximity of adjacent tooth roots can require the surgeon to “thread the needle” with the implant placement. This is often a problem with congenitally missing teeth. Clinical situations of limited bone volume often leave the clinician with scenarios in which the patient's anatomy dictates the location of implant placement, sometimes leaving only one available location.



Figure 10A A 17-year-old female with congenitally missing tooth No. 7. Orthodontics were used to open the space between teeth No. 6 and No. 8 to accommodate an implant. The ideal implant position was limited both buccal-palatally and mesial-distally. Preoperative photograph.

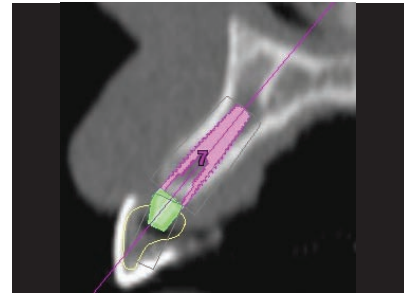


Figure 10B Cross-sectional view (Simplant). Note placement of virtual angled abutment.

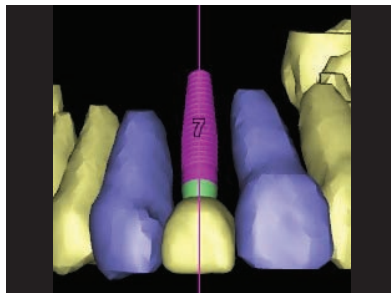


Figure 10C and Figure 10D Segmentation has been performed, removing the bone surrounding the adjacent teeth (C). Then, an implant can be accurately placed virtually between the roots of the adjacent teeth. Postoperative radiograph, implant in place (D).

3-D planning software allows for segmentation, enabling the virtual removal of surrounding bone tissues, leaving only the crowns and roots of the teeth visible. This visualization of the roots of the adjacent teeth enables the precise positioning of an implant in limited mesial-distal spaces. Selection of the best implant for that specific clinical application then can be determined. Some software allows for the selection and determination of virtual stock and custom abutments, as well. Implant placement then can be performed predictably and accurately according to the patient's anatomy. Because of their precision and accuracy, 3D computer-generated technologies are ideally suited for these difficult cases.²¹

FLAPLESS SURGERY AND MULTIPLE-UNIT IMMEDIATE PLACEMENT/IMMEDIATE-LOAD CASES

Today's implant technologies and surface characteristics have dramatically shortened the time required from implant

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Figure 11A A 79-year-old female with severe degeneration of the maxilla secondary to a long-standing maxillary subperiosteal implant. This resulted in chronic and acute infections, sinusitis, and sinus perforations. The subperiosteal implant was removed prior to the CT scan. The 3D planning software indicated that, without performing bone grafting procedures prior to implant placement, implants could be placed into only four select sites. A maxillary overdenture restoration was planned. Subperiosteal implant in place in the maxilla.



Figure 11B Preoperative radiograph.

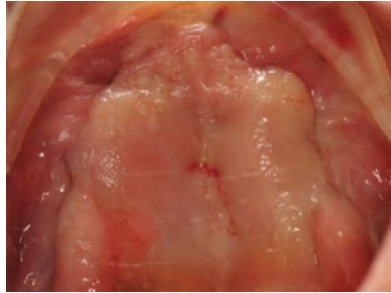


Figure 11C Maxillary ridge prior to implant placement.

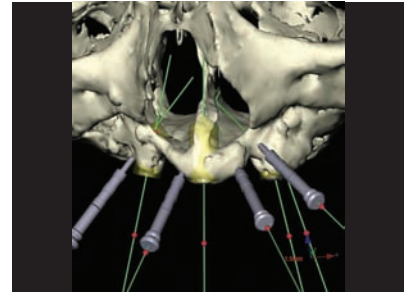


Figure 11D CT scan (Procera) with implants virtually placed.

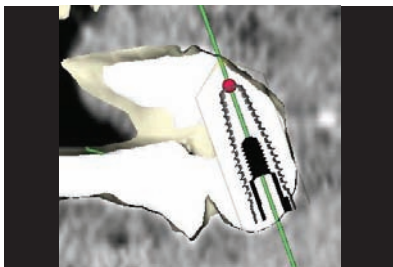


Figure 11E and Figure 11F Cross-sectional images, virtual treatment plan for implant placement in the anterior nasal spine region (E), and left premolar region (F).

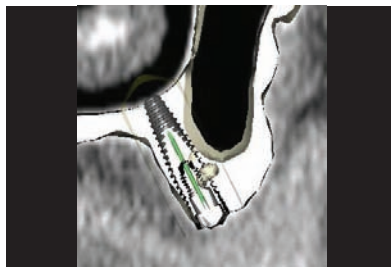


Figure 11G NobelGuide fabricated from virtual treatment plan for this patient.



Figure 11H and Figure 11I Postoperative radiograph, implants in place (H). Implant placement in the maxilla (I).



placement to implant loading. Immediate placement and immediate loading of implants is now common in many dental surgical offices. In some cases, teeth can be extracted, an implant immediately placed, and a temporary crown placed at the time of implant insertion. Concepts of cross-arch stabilization of implants and loading of multiple implant cases have changed the way many dentists approach treatment

plans. These new technologies are available to place single, multiple, or a full arch of implants flaplessly, without making an incision or elevating a tissue flap. Patients experience less surgical trauma, pain, and swelling. Recovery time is reduced, and the ability to return to normal life is expedited.^{6,11-19}

The utilization of virtual implant treatment planning allows the dentist to evaluate the patient's bony anatomy as

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Figure 12A A 65-year-old female with a bilateral partially edentulous mandible. Treatment planned for implant placement with immediate loading. Preoperative panoramic radiograph.

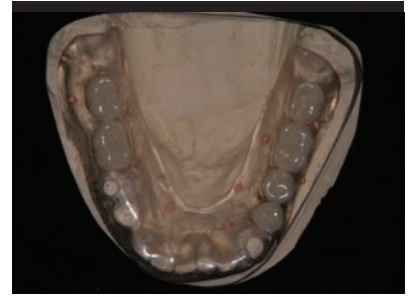


Figure 12B Radiographic guide, mandible.

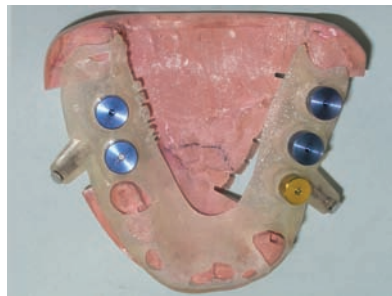
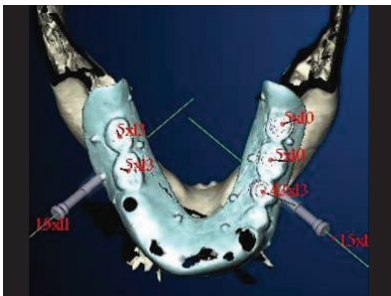


Figure 12C through Figure 12E Next, the virtual treatment plan, occlusal view, NobelGuide (C). Model with stone removed posteriorly, implant analogs secured bilaterally in NobelGuide (D). Provisional restoration with internal titanium framework, fabricated prior to implant placement surgery (E).



Figure 12F and Figure 12G Then, surgical guide in place, implants placed (NobelGuide) (F). Implant abutments immediately placed (G).



Figure 12H and Figure 12I Next, immediate temporary restorations, right side (H). Immediate temporary restorations, left side (I).

it relates to the planned restoration and then plan the ideal placement and position of a dental implant in that clinical situation. Computer-generated stereolithographic surgical guides are then fabricated from these virtual treatment plans. A dental laboratory then uses the surgical guide, along with mounted patient models, to fabricate temporary, and in some cases, final restorations, before implant placement surgery. At the time of surgery, the surgeon can use this guide to place the planned implants flaplessly, removing only a core of tissue in the planned implant sites. Abutments are then immediately placed on the implants, and temporary, or in some cases final, restorations are inserted (Figure 12A through Figure 12L).

Depending on the clinical circumstances and the dentist's experience and



Figure 12J Immediate postoperative panoramic radiograph.



Figure 12K and Figure 12L Final restorations, 4 months after implants placed, mandibular right (K) and left (L) quadrants.

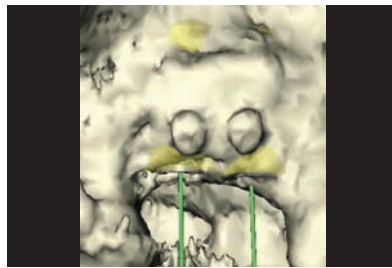


Figure 13A and Figure 13B Maxillary buccal block bone graft, clinically (A) and CT scan (B) with placement of implants virtually (Procera).

comfort level, the technologies can be used to place implants as a two-stage, a single-stage with healing abutments, or an immediate-placement/immediate-load case. Implants can be positioned accurately with a tissue incision or flaplessly.^{7-10,20}

COMPLEX PROBLEMS WITH A SIGNIFICANT ALTERATION OF THE BONY ANATOMY

Implant dentistry is shifting from the days of “placing the implants where the bone is.” Current technologies allow the surgeon to do various soft-tissue and bone procedures to prepare the planned implant site. Sinus lift grafts, block bone grafts, ridge splitting, and alveolar distraction procedures, as well as large and small soft-tissue and connective-tissue grafts, are a few of the procedures that are performed routinely to prepare the recipient jaw site for implant placement. Previous surgical procedures, including the placement of many different types of dental implants (eg, blade and subperiosteal), can

leave patients with challenging reconstructive bony defects (Figure 11A through Figure 11I). Patients may have lost bone, teeth, and soft tissue from traumatic injuries (Figure 14A through Figure 14G). Bony defects of various sizes can occur because of benign or malignant pathology of the jaws. Reconstructive surgical procedures to treat benign or malignant diseases can leave areas of abnormal bony anatomy and scarred soft tissue (Figure 15A through Figure 15I).

After healing, graft maturation, and settling of graft materials, resultant bone and soft-tissue volumes can be unpredictable. Lateral block onlay grafts can resorb a portion of their bone volume before implant placement²¹⁻²³ (Figure 13A and Figure 13B). In sinus-lift grafting, CT technology permits the surgeon to predict the volume of graft material necessary to augment the area to a desired height of bone.²⁴ In alveolar distraction procedures, the shape and width of the new distracted bone can vary. Evaluating these areas with conventional panoramic or periapical radiographs is inadequate; a 3D analysis can facilitate a better assessment.

These are all examples of ideal situations in which computer-guided implant surgery should be used to evaluate and plan the placement of dental implants. These technologies allow visualization and evaluation of a patient’s distorted anatomy without making an incision or removing any soft tissue or bone.²⁵ The surgeon can then accurately and predictably place the dental implants with clear knowledge of the patient’s underlying distorted bony anatomy as it relates to the planned dental restoration. Additionally, dental implants can be placed flaplessly, without making an incision and removing the periosteal vascularization from grafted areas.

PATIENTS WITH MEDICAL COMORBIDITIES

Patients with head and neck cancers are often treated with pre- and postoperative radiation therapy, which potentially may alter healing capacity. Research and treatment protocols call for patients who received radiation therapy to undergo

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pre- and postoperative courses of hyperbaric oxygen therapy (HBO) to increase the vascularity of the bone prior to implant placement.²⁶⁻²⁹ To limit the likelihood of such patients developing osteoradionecrosis of the jaws, placing implants with minimal flap elevation and soft- and hard-tissue trauma is indicated.^{26,30} Bleeding, swelling, and alteration of bone and soft-tissue vascularization are minimized by using these technologies³¹ (Figure 16A through Figure 16G).

Some patients may have associated medical problems, such as blood dyscrasias, anticoagulation problems, or significant cardiovascular disease. These issues may necessitate specific medication protocols that cannot be adjusted prior to surgery. Limiting surgical trauma to the soft and hard tissues, thus minimizing bleeding, is indicated in the management of these patients.

3D implant evaluation and planning with CT-guided implant placement allows the surgeon to place implants flaplessly, with precision.^{6,11-19} Implants can be placed accurately while minimizing soft- and hard-tissue trauma as much as possible.⁷⁻¹⁰ These technologies are ideally indicated for use in patients with these challenging medical management problems.³¹

PATIENTS WITH EMOTIONAL AND PHYSICAL PROBLEMS

Dental patients come to offices with different historical experiences, most

good, but sometimes bad. Their stress, anxiety, and phobias can prevent them from undergoing procedures that require long periods in a dental chair. Orthopedic and spinal problems may limit how long a patient can sit. Additionally, wheelchair-bound patients pose another set of logistical problems.

Patients such as these can require extensive planning and preparation prior to surgery, which must be performed quickly and efficiently, without compromising quality.

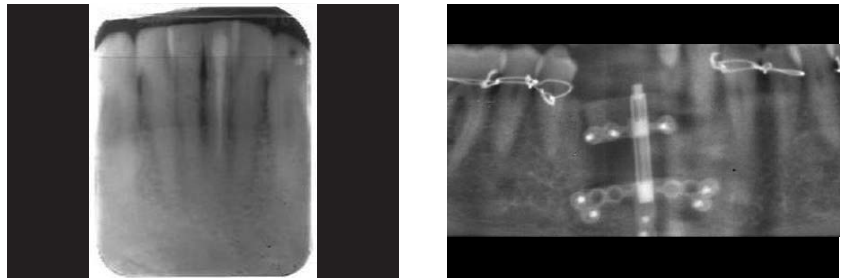


Figure 14A and Figure 14B A 50-year-old male patient with mandibular anterior trauma. The patient underwent removal of the superior 6 mm to 8 mm of the traumatized irregular mandibular alveolar bone, followed by a mandibular anterior alveolar distraction. Note the inferior bone gap below the distracted island of bone. Although not fully calcified radiographically, clinically this area was hard osteoid bone. Periapical radiograph prior to injury (A). Postoperative panorex (B). Note mandibular anterior distractor fully activated.

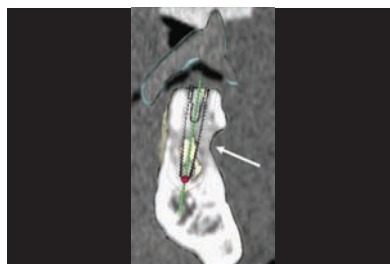


Figure 14C Cross-sectional image (Nobel-Procera) of planning of implant placement. Note the differences in buccal-lingual contour and density of the distracted bone.

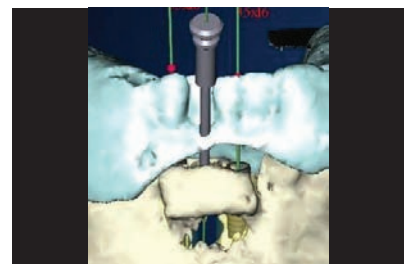


Figure 14D The 3D reformation of alveolar distraction area, implants virtually placed.



Figure 14E NobelGuide in place, implants inserted.

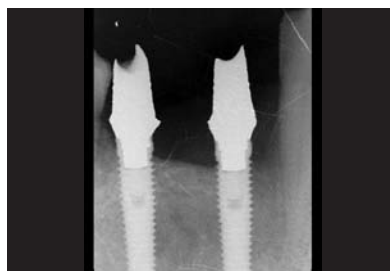


Figure 14F Periapical radiograph, after alveolar distraction, implant placement, and restoration. Note the normal pattern of bone surrounding implants.



Figure 14G Final restoration in place.

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Figure 16A A 60-year-old female who received treatment for a squamous cell carcinoma of the right lateral border of her tongue. Treatment included tumor excision with a neck dissection, followed by 5500 rads to 6300 rads of radiation therapy postoperatively. Surgical treatment protocol included pre- and postoperative HBO treatments. (Images printed with permission from the *Journal of Oral and Maxillofacial Surgery*.)

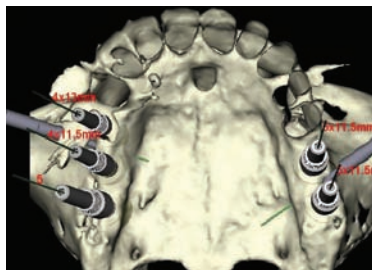


Figure 16B and Figure 16C Virtual treatment plan, maxilla (B). Virtual treatment plan, mandible (Procera) (C).

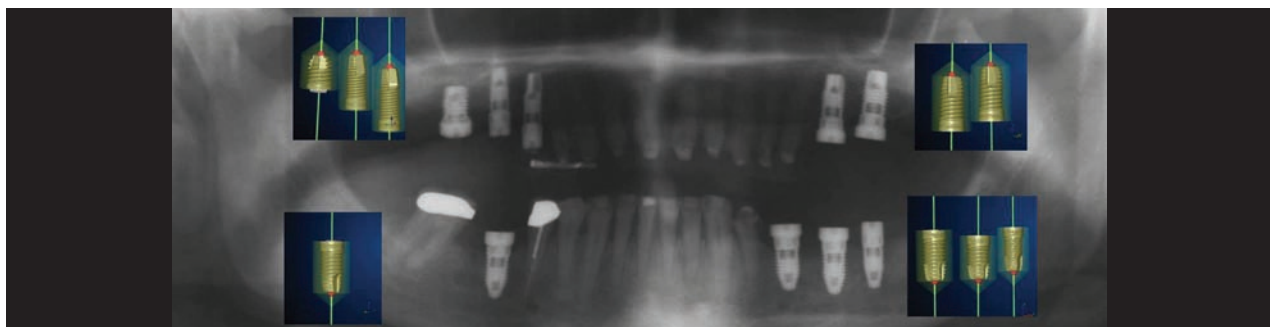


Figure 16D The postoperative panorex with superimposition of treatment-planned implants, maxilla and mandible.



Figure 16E and Figure 16F The patient's final restorations, right (E) and left (F) sides.



Figure 16G Final panorex. Note the failure of her implant in the site of tooth No. 18.

accuracy, according to a predetermined plan. If desired, implants can be placed flaplessly, with predictability. The use of these technologies in planning and placing dental implants greatly benefits the patient and clinician. These technologies are ideal for use in the following cases: the placement of three or more adjacent implants; fully edentulous arches; when implants are planned in close proximity to nerves, teeth, and other vital anatomic structures; immediate-placement and immediate-load cases; complex cases with

questionable bone volume and unusual bony contours and anatomy; difficult medical comorbidities; and patients with physical and emotional issues.

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