With the recent introduction of new three-dimensional (3D) diagnostic and treatment planning technologies in implant dentistry, a team approach to the planning and placement of dental implants, according to a restoratively driven treatment plan, has become the norm in quality patient care. The team can now start with the end result, the planned tooth, and then place an implant into the correct position according to the restorative plan. The accurate and predictable placement of implants according to a computer-generated virtual treatment plan is now a reality, taking the virtual plan from the computer to the patient clinically. Recent advances in 3D imaging in dentistry, in combination with the introduction of third-party proprietary implant planning software and associated surgical instrumentation, have revolutionized dental implant diagnosis and treatment and created an interdisciplinary environment in which communication leads to better patient care and outcomes.

HISTORICAL OVERVIEW

Since the introduction of the first dental radiographs, dentists have become comfortable with evaluating and diagnosing patients using two-dimensional (2D) images (ie, periapical, bitewing, panoramic, and cephalometric radiographs, and so forth). The obvious limitations of these technologies in evaluating 3D problems required clinician acceptance because few options were available. Because of their hospital-based training, oral and maxillofacial surgeons have long used computed tomography (CT) scans for the 3D evaluation of facial trauma and pathologic lesions. These CT evaluations typically were viewed in 2D as axial or reformatted frontal or coronal slices.
through the area of interest of a patient’s anatomy, printed on plain films, or viewed as such on a computer screen. The remainder of the dental community had little, if any, exposure to 3D image evaluation.

The first medical-grade helical CT scanners were all single-slice, slower machines that were based in hospitals or private radiology facilities. Typical medical multislice CT scanners of today are capable of performing a scan of the upper and/or lower jaw in a few seconds, but the size and cost of the machines, the radiation exposure, the lack of familiarity and training amongst dentists, and the perceived cost/benefit ratio in patient care made them inappropriate for a dental office setting. With the development and introduction of the New Tom 9000 (Quantitative Radiology, Verona, Italy) in 1998, cone beam volumetric tomography (CBVT/cone beam computed tomography [CBCT]) was introduced to the dental community. Although the first machines were larger than those available today, the advantages were that they produced good 3D images at lower radiation doses, and the footprint of the machines were small enough to fit into a dental office. The disadvantages were that, although the radiation was less than medical-grade CT, it was more than conventional dental radiographs and, because of the reduced radiation, the images produced had less definition than medical CT. Since the first CBCT was introduced, machines with multiple different features have been developed and introduced by various manufacturers. The gold standard for accurate 3D diagnosis continues to be medical-grade CT. The recent introduction of adaptive statistical iterative reconstruction (ASIR) software has been reported to allow up to a 50% radiation dose reduction in medical CT scans, without diminishing image quality. There are different average deviations and percentage error measurements for all CBCT scanners.

In the late 1980s, articles began to appear in the literature discussing the use of Den taScans to evaluate the bone of the maxilla and mandible in preparation for placement of dental implants. Columbia Scientific (CSI) introduced the 3D Dental software in 1988. This software converted CT axial slices into reformatted cross-sectional images of the alveolar ridges for diagnosis and evaluation. In 1991, a combination software was introduced, ImageMaster-101, which allowed the additional feature of placing graphic dental implants on the cross-sectional images. The first version of Sim/Plant was introduced by CSI in 1993, allowing the placement of virtual implants of exact dimensions, on CT images, in cross-sectional, axial, and panoramic views. In 1999, Simplant 6.0 was introduced, adding the creation of 3D reformatted image surface rendering to the software. Materialise (Leuven, Belgium) purchased CSI in 2001, introducing the technology for drilling osteotomies to exact depth and direction through a surgical guide in 2002. NobelBiocare (Zurich, Switzerland) introduced the NobelProcera/NobelGuide technology in 2005. The NobelGuide technology was introduced as a complete implant planning and placement system, for both straight-walled and tapered NobelBiocare implants. Appropriate instrumentation was developed to create osteotomies of accurate depth and direction, as well as the ability to place implants flapless, to accurate depth, through a guide. The system was designed for conventional postimplant insertion treatment (cover screws or healing abutments), immediate loading of implants, and the fabrication of partial or full arch restorations before implant placement. A completely redesigned upgrade of the NobelGuide software, NobelClinician, has been introduced in 2011. Software from other manufacturers, such as EasyGuide (Keystone Dental, Burlington, MA, USA), Straumann coDiagnostiX (Straumann, Basel, Switzerland), VIP Software (BioHorizons, Birmingham, AL, USA), Implant Master (IDent, Foster City, CA, USA), and others, are now available as well. Other implant manufacturers have developed instrument trays for the guided placement of their implants using the Simplant software for implant
planning (ie, Facilitate, AstraTech Dental, Molndal, Sweden; Navigator, Biomet 3i, Palm Beach Gardens, FL, USA; ExpertEase, Dentsply Friadent, Mannheim, Germany.)

GENERAL TECHNOLOGY CONCEPTS

CT/CBCT scanners allow the dentist and surgeon to visualize a patient’s anatomy in 3 dimensions. Visualization of the height and width of available bone for implant placement, soft tissue thicknesses, proximity and root anatomy of adjacent teeth, the exact location of the maxillary sinuses, and other pertinent vital structures such as the mandibular canal, mental foramen, and incisive canal are possible.18–20 Once images are imported into proprietary software programs (eg, Simplant, NobelClinician) the clinician can then virtually treatment plan the placement of implants for an individual patient’s anatomy and case plan. 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 vital structures can be determined before performing surgery.18–22 Computer-generated surgical drilling guides can then be fabricated from the virtual treatment plan. These surgical guides are used by the doctor to place the planned implants in the patient’s mouth in the same positions as in the virtual treatment plan, allowing more accurate and predictable implant placement23–27 and reduced patient morbidity.28–31

All of the current systems have similar restorative and surgical protocols. Upper and lower arch impressions are made and a bite registration is obtained. Models are poured and mounted on an articulator. Guided surgery requires reverse planning. The prosthodontist or restorative dentist first creates an ideal restorative treatment plan, determining the planned tooth position by creating a diagnostic wax-up that indicates the exact anatomy and position of the teeth to be replaced. An acrylic prosthesis is then fabricated that reproduces the planned restorations in the acrylic appliance. Depending on the system to be used, this scan prosthesis can be a partial or full denture (Figs. 1–3). Most systems, other than NobelGuide, require that the planned restorations contain a 20% to 30% barium sulfate mixture in the acrylic to allow for radiopacity of the planned restorations in the CT/CBCT images. NobelGuide uses a double-scan technique with a hard acrylic scan prosthesis and gutta percha marker reference points, with no barium sulfate. The CT/CBCT scan is then taken with the patient wearing the scan prosthesis according to the individual system protocols.

Fig. 1. NobelGuide radiographic guide, fully edentulous.
The CT scan (Digital Imaging and Communication in Medicine [DICOM]) images are then imported into the various proprietary software programs (eg, Simplant, NobelGuide, EasyGuide). The software programs are then used to virtually place implants into their ideal positions related to the planned restoration and the underlying bony

Fig. 2. Simplant radiographic barium stent, partially edentulous.

Fig. 3. EZ Guide radiographic appliance, partially edentulous.
anatomy (Figs. 4–6). The digital treatment plan is then uploaded to the manufacturer for fabrication of a surgical guide (Figs. 7–9). The surgical guide is used, with implant-specific drilling instrumentation, to precisely place the implants in the same positions, depths, and angulations as was planned virtually.

Many CT-guided implant planning technologies require radiopaque fiducial reference markers to be placed in the scan prosthesis that the patient wears during the CT/CBCT scan. These reference markers are then used by the software to virtually position the scanning appliance and, with it, the parameters of the planned restoration(s) as related to the patient’s jaw. Some CBCT scanners have difficulty in accurately assessing these geometric markers. This problem has the potential to add error into a precise planning system. This error can lead to inaccurately fitting surgical guides and error in implant placement. It is advisable to make every effort to investigate and use CBCT scanners that have high levels of accuracy or medical CT scanners when using these technologies.32

INDICATIONS FOR USE

Because of its precision and accuracy in implant placement, an argument could be made for the use of CT-guided implant surgery in almost all cases. As with anything in medicine, a cost/time/benefit determination must be made by the clinician based on the circumstances of an individual case. The increased patient and treatment planning time, the additional expense, and the additional patient radiation exposure may outweigh the clinical benefits in certain cases. We have found that these technologies are most beneficial to the patient and the doctor in the following clinical situations:

- Three or more implants in a row
- Proximity to vital anatomic structures
- Problems related to the proximity of adjacent teeth
- Questionable bone volume
- Implant position that is critical to the planned restoration
- Flapless implant placement
- Multiple unit or full arch immediate restorations, with or without extractions and immediate placement

Fig. 4. NobelGuide virtual treatment plan, fully edentulous.
Fig. 5. Simplant virtual treatment plan, partially edentulous.

Fig. 6. EZ Guide virtual treatment plan, partially edentulous. "A" and "B" on image are associated with software measurement tool.

Fig. 7. NobelBiocare NobelGuide fabricated from treatment plan, Figs. 1 and 4.
Significant alteration of the soft tissue or bony anatomy by prior surgery or trauma. Patients with physical, medical, and psychiatric comorbidities.

Conventional surgical stents to aid in implant positioning have been used in implant dentistry for many years. Guides of these types can be simple (ie, vacuform shells with the buccal or palatal/lingual facings of the planned restorations) or more complex (ie, stents with 2-mm drill holes or metal tubes). The problem is that there is no correlation in these appliances between the planned restoration and the underlying bony anatomy. With the use of computer-guided implant surgical guides, this anatomic relationship can be predictably established and considered before surgery.

The fabrication of a surgical guide, used in implant treatment, is determined by 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. With increasing length of the edentulous area, fewer anatomic references are present for the predictable accurate placement of implants. In a fully edentulous case, other than the soft tissue ridge and palate, all local references are lost. Bone and soft tissue loss from periodontal disease and atrophy, long-term denture wear, and sinus pneumatization can make it difficult to predictably use a traditional surgical guide.
In cases in which 3 or more implants in a row are planned, concepts of implant spacing and angulations, implant parallelism in all dimensions, proximity of implants to anatomic structures, and relationships between implant positions and the planned restorations are significant considerations for the clinician. CT/CBCT-guided surgery allows for the ideal placement of multiple dental implants according to the planned restoration, the relationships of implants to surrounding anatomy, and principles of ideal implant positioning and spacing (Figs. 10–13).

Differences in radiograph machines and radiographic techniques commonly lead to distortion of anatomic structures on conventional 2D images, such as elongation, shortening, stretching, and contraction. Accurate 3D evaluations and measurements of the relationship between a planned implant and the position of the mental nerve, inferior alveolar nerve (Figs. 14 and 15), nasopalatine/incisive nerve (Fig. 16), maxillary sinuses, and nasal floor (Fig. 17) are best visualized, evaluated, and measured by using CT-generated images. In cases in which there are questions of nerve or sinus proximity related to the patient’s available bone, implants are most accurately placed using computer-generated surgical guides. These technologies minimize potential patient morbidities.

All proprietary implant planning softwares have the functionality to isolate the roots of teeth in the edentulous areas to aid in the accurate placement of implants between and adjacent to tooth roots in the planned sites. Some softwares use virtual dots or lines to outline tooth roots (Fig. 18), whereas others have the ability to alter the software’s sensitivity to Hounsfield units or isovalues to virtually remove bone from around tooth roots (called segmentation) (Fig. 19). These technologies are most beneficial when tooth roots are in extremely divergent or convergent relationships or when implants must be placed in tight spaces because of close root proximities.

Surgical dilemmas that require implant placement in only 1 location, and/or at only 1 implant depth, are common. Difficult clinical scenarios frequently require the placement of implants into tight spaces with minimal bony leeway either mesial-distally, buccal-lingually, or both (see Fig. 16; Fig. 20). Adjacent tooth root proximity can make implant placement feel to the clinician like threading a needle. This is a common problem with congenitally missing teeth. Scenarios of limited bone volume often leave situations in which the patient’s anatomy dictates where the implant can be placed. Essentially, there is only 1 location in which an implant can be placed.

Some of the most complex restorative and surgical cases treated in implant dentistry involve single and multiple implants in the esthetic zone. Thicknesses of crestal and buccal soft tissues and buccal and palatal cortical plates, buccal-lingual

![Fig. 10. Lower right mandible, 3 implants in a row, virtual treatment plan.](image-url)
Fig. 11. Three implants in a row, NobelGuide in place. Note implant mounts with attached implants placed to depth.

Fig. 12. Final periapical radiograph. Note implant parallelism, different diameters and lengths, and spacing corresponding to the implant site and the planned restorations.

Fig. 13. Final individual restorations, 3 implants in a row.
ridge dimensions, proximity to adjacent teeth, implant-to-root relationships, gingival
and papilla support and contours, gingival exposure, smile lines, and implant angula-
tions and emergence are just a few of the many complex considerations. In addition,
knowledge of the appropriate implant position based on the type of restoration

Fig. 14. Severe atrophy posterior mandible, implant placement planned lingual to the infe-
rior alveolar nerve.

Fig. 15. 3D reformation of Fig. 14. Note appearance of proximity between implant and infe-
rior alveolar nerve in lateral view.
planned (i.e., cement or screw retained) is an important prosthetic-based consideration. Very small variations in implant positions can lead to difficult restorative dilemmas in these cases. Proper implant position can be critical to the esthetic and functional success of the planned restoration. CT/CBCT-guided implant planning and placement allows for the evaluation and visualization of the ideal restoration for

![Fig. 16. Implant placement planned in close proximity to enlarged nasopalatine canal.](image)

planned (i.e., cement or screw retained) is an important prosthetic-based consideration. Very small variations in implant positions can lead to difficult restorative dilemmas in these cases. Proper implant position can be critical to the esthetic and functional success of the planned restoration. CT/CBCT-guided implant planning and placement allows for the evaluation and visualization of the ideal restoration for

![Fig. 17. Severe maxillary atrophy. Implant planned in the anterior nasal spine, in close proximity to the nasal floor.](image)
a site based on the surrounding bony and soft tissue anatomy, then the virtual placement of implants based on the planned restoration related to the underlying bone. Surgical guides then position the implants accurately and predictably into the optimal position for the planned restoration (Figs. 21–24).

Implant technologies and surface characteristics in use today have dramatically reduced the time required from implant placement to loading. Immediate placement and immediate loading of implants is now commonly performed. In some cases, teeth can be extracted, implants can be placed immediately, and temporary crowns can be placed at the time of implant insertion. Concepts of cross-arch stabilization and loading of multiple implants have changed the way treatment is planned. Depending on the clinical circumstances and the experience and comfort level of the dental

Fig. 18. Outlining of tooth roots with virtual treatment planning.

Fig. 19. Segmentation of images with virtual treatment planning.
Fig. 20. Implant virtually placed in location with limited buccal-palatal width.

Fig. 21. Figs. 21–24: 17 year old female, over-retained maxillary right primary canine and lateral incisors and congenitally missing right canine and bilateral lateral incisors and second premolars. Preoperative grafting procedures were necessary to prepare each site for dental implants. A 17-year-old girl before surgery.
team, these technologies can be used to place single units, multiple units, or full arches of implants. Implants can be placed as a 2-stage, a single-stage with healing abutments, or as an immediate-placement/immediate-load case. Implants can be placed accurately with a tissue incision or flapless. Patients experience less surgical trauma, pain, and swelling. Recovery time is reduced and the return to their normal lives is expedited.\textsuperscript{22–29}

Taking CT-guided technology to the next step involves accurate fabrication of a provisional restoration before implant insertion, with immediate insertion at the time of surgery. After the virtual treatment plan is created by the clinician (Figs. 26 and 33), computer-generated stereolithographic surgical guides are fabricated by

![Virtual treatment plan.](image1)

![Virtual treatment plan, occlusal view. Note implant planned in the right canine site for 2 unit cantilever bridge anteriorly.](image2)
**Fig. 24.** The 17-year-old female from Fig. 21, final restorations.

**Fig. 25.** Figs. 25–31: A 20-year-old man bilateral maxillary central incisors avulsed traumatically. Treatment using AstraTech Dental Facilitate technology. A 20-year-old man before surgery.

**Fig. 26.** Facilitate virtual treatment plan.
Fig. 27. Presurgical laboratory placement of implant analogs into the Facilitate surgical guide, before pouring stone into the guide for fabrication of a master model.

Fig. 28. Presurgical fabrication of provisional restorations on the poured master model.

Fig. 29. Guided osteotomy preparation using the Facilitate instrumentation.
Fig. 30. Implants inserted, temporary restoration placed at the time of surgery.

Fig. 31. Final restorations in place, 5 months later.

Fig. 32. Figs. 32–40: A 60-year-old man, fully edentulous mandible. The patient desired immediate fixed restorations and, ultimately, as many fixed individual crowns as possible. Preoperative mandibular ridge. Note areas where temporary implants have been removed.
the manufacturer from the virtual treatment plan (Figs. 27 and 34). A dental laboratory then uses the fabricated surgical guide, along with mounted patient models, to fabricate temporary, and in some cases final, restorations, before implant placement surgery (see Figs. 27, 28, 35, 36). The surgical guide can then be used to place implants flapless, only removing a core of tissue in the planned implant sites. Typically, once the surgical guide is accurately secured, implants can be placed through the surgical guide without removing it until all implants are inserted to proper depth and direction (Figs. 29 and 38). Abutments can then be immediately placed on the implants, and temporary or, in some cases, final restorations inserted (see Figs. 25–31 and 32–40).

In most circumstances, placing the implants where the bone is has become an outdated concept. Current techniques allow the surgeon to perform soft tissue and bone augmentation procedures to prepare the planned implant site before placing implants. Large and small soft tissue and connective tissue grafts, as well as sinus floor grafts, block grafts, alveolar ridge splits, and alveolar distraction procedures, are a few of the procedures routinely performed to prepare the recipient jaw before placing implants.
Previous surgical procedures, including prior placement of different types of dental implants (ie, blade and subperiosteal implants), can leave patients with challenging reconstructive bony defects (Figs. 41 and 42). Loss of bone, teeth, and soft tissue, with resultant defects of varying sizes, can result from traumatic injuries or benign and malignant abnormalities of the jaws. Reconstructive procedures to treat these defects can leave areas of abnormal bony anatomy and scarred soft tissue. 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 during healing and maturation.\textsuperscript{33–35} CT/CBCT-guided technologies allow the surgeon to predict the volume of sinus graft material necessary to augment an area of the maxilla to a desired height of bone.\textsuperscript{36} Newer technologies are being investigated and developed in which customized block bone grafts can be created after evaluating bony defects from CT/CBCT data.

Using these technologies allows for the visualization and evaluation of distorted anatomy without making an incision.\textsuperscript{37} Implants can be placed accurately and
Fig. 37. Accurate surgical positioning of the NobelGuide using a surgical index (a bite registration, made on mounted models, which relates the position of the surgical guide to the opposing arch) before guide pin/screw stabilization.

Fig. 38. Surgical guide in place with 10 implants placed to correct depth using appropriate guided instrumentation.

Fig. 39. Surgical guide removed, temporary abutments placed on inserted implants.
predictably with a clear knowledge of available bony anatomy, without flapping and removing periosteal blood supply (Figs. 43–46).

COMPROMISED PATIENTS

Pre- and postoperative radiation therapy potentially alters healing capacities in patients who have head and neck cancers. The literature advocates pre- and postoperative courses of hyperbaric oxygen therapy (HBO) to increase bone vascularity before implant placement in these patients.\textsuperscript{38–41} Placing implants with minimal flap elevation and hard and soft tissue trauma is indicated in these patients to minimize the likelihood of the development of osteoradionecrosis.\textsuperscript{38,42} Bleeding, swelling, and alteration of the blood supply are limited by using these technologies.\textsuperscript{43}

Fig. 40. Temporary full arch mandibular restoration immediately inserted at the time of surgery.

Fig. 41. A 68-year-old woman who had a prior full arch maxillary subperiosteal implant. Note severe atrophy and distorted anatomy.
Patients with associated medical problems, such as bleeding dyscrasias, anticoagulation issues, or significant cardiovascular disease, may require specific medication protocols that cannot be altered before surgery. Minimizing bleeding by limiting surgical trauma to the soft and hard tissues is indicated in patients with difficult

Fig. 42. Virtual treatment plan, for the case shown in Fig. 41, 4 implants planned for overdenture restoration.

Fig. 43. A 32-year-old man, severe atrophy anterior maxilla from a sports injury. Preoperative cross-sectional image in area of right lateral incisor, Simplant. Note measurements revealing deficiencies of bone in all dimensions.
medical management issues. 3D implant evaluation and planning, with CT-guided implant placement, allows for flapless, minimally traumatic, accurate implant placement, an indication for use in patients with these challenging medical management problems.

Patient’s historical experiences in dental offices vary greatly. Procedures that require long periods in a dental chair can prevent some patients from seeking treatment because of extreme levels of anxiety, stress, and phobias. Orthopedic and spinal disorders may limit the amount of time a patient can sit in a dental chair. Wheelchair-bound patients pose another set of logistical treatment problems. These types of patients can require extensive planning and preparation before treatment. Treatment must be performed quickly and efficiently, without compromising quality. Computer-generated implant planning allows for the preoperative visualization of most of the potential planning and anatomic issues that may be encountered during surgery, all before the patient sits in the dental chair. By using surgical guides, implants can be placed quickly and predictably, thus minimizing patient stress, pain, and time in the dental chair.

DISCUSSION

Three types of computer-generated surgical guides are currently available: tooth supported, mucosa supported, and bone supported. Tooth-supported guides are used in partially edentulous cases. The surgical guide is designed to rest on other teeth in the arch for accuracy of guide fit. Mucosal-supported guides are used primarily in fully edentulous cases and are designed to rest on the mucosa. Accurate interarch bite registrations are of utmost importance when using these guides to assure accurate
surgical guide positioning and placement of securing screws or pins before the placement of implants (see Fig. 37). Bone-supported guides can be used in partially or fully edentulous cases, but are used primarily in fully edentulous cases in which significant ridge atrophy is present and good seating of a mucosa-supported guide is questionable. These guides require elevation of an extensive full-thickness flap to expose the bone in the planned implant sites and in the adjacent areas for full, stable seating of the guide over the bony ridge. At this time, only Simplant (Materialise) manufactures bone-supported surgical guides.

Fig. 45. Cross-sectional view, after sinus lift graft. Note bone graft placement primarily laterally, virtual implant placed.

Fig. 46. 3D reconstruction of left mandible after ameloblastoma resection and iliac crest reconstruction. Virtual treatment plan, 4 implants.
Dental implant placement using CT-guided surgery with drill guides is known to enhance safety compared with using a freehand technique. According to the NobelGuide protocol, when using the Guided Abutment to secure the immediate restoration, the accuracy should be sufficient for inserting a prefabricated final restoration at the time of implant surgery. However, no available CT-guided drill guide technology exists today with absolute precision. All articles on stereolithographic guides show error in all dimensions between virtual planning and obtained implant positions. According to the literature, implants placed by bone-supported guides have the highest mean deviations, whereas implants placed by mucosa-supported guides have lower deviations. Tooth-supported guides have the lowest measured deviation. A single guide, using metal guide sleeves and rigid screw or pin fixation with specific drilling instrumentation, further minimizes error. Most systems use these fixation techniques to stabilize mucosal-supported guides.

The main advantage of inserting a final restoration immediately after implant placement is reduced treatment time. More commonly, clinicians who are using these technologies are placing temporary restorations after implant placement for many reasons. Regardless of whether a case is done flapless or not, there is no way to accurately predict the contours and anatomy of the healed gingiva, a significant issue for a laboratory technician fabricating a final restoration. Patients’ esthetic demands can sometimes be great. Observation of the tissue response to the temporary restoration gives the restorative dentist invaluable information as to the gingival contours and esthetics required in preparation for the final restoration. In addition, regardless of whether an implant is placed guided or nonguided, a small number of implant failures occur. Typically, most surgery-related implant failures occur within the first 3 to 4 months after placement. Management of an implant failure, both surgically and restoratively, is best done before insertion of the final restoration. According to Abrahamsson and colleagues, changing from a healing abutment to a permanent abutment did not result in a change in the dimension and quality of the transmucosal attachment that developed, and did not differ from the mucosal barrier that formed to a permanent abutment placed after surgery. In addition, an acrylic occlusal surface or a composite restoration has been found to have better shock absorbing behavior and reduces the force of occlusal effect compared with ceramic materials. These are all valid reasons to place immediate acrylic temporary restorations, not immediate final porcelain restorations.

NobelGuide/NobelClinician (NobelBiocare) and Simplant (Materialise) are the 2 major systems currently in use. Clinically, the NobelGuide system is a more comprehensive system, with a full set of specific instrumentation for fully guided placement of NobelBiocare implants. NobelGuide is the only system currently available with the instrumentation for placement of tapered implants. The NobelGuide technology and instrumentation can be used for performing osteotomies for a straight-walled implant from any implant manufacturer. However, in these cases, the system can only be used for depth and direction of osteotomies. Because NobelGuide Implant Mounts are designed only for NobelBiocare implants, implants from other implant manufacturers cannot be accurately placed fully guided, through the guide. In these cases, the depth of implant placement should be evaluated with the guide off, usually after tissue flap elevation.

Simplant is designed as an open system for all implant systems. Although this feature increases its functionality, it is also a limitation because it is not perfectly adapted to 1 implant system in a comprehensive manner. Some clinicians believe that the Simplant software currently is more intuitive and easier to learn. Several implant manufacturers have recently developed and marketed instrumentation specific for the
placement of straight-walled implants, flapless and fully guided, using the Simplant software (eg, Facilitate, AstraTech Dental; ExpertEase, Dentsply Friadent; Navigator, 3i/Biomet). Other manufacturers have developed nonstereolithographic model technologies for the fabrication of surgical guides (eg, IDent, Foster City, CA, USA; EZ Guide, Keystone Dental, Burlington, MA, USA; Straumann coDiagnostiX, Straumann, Basel, Switzerland) In these technologies, the surgical guide is created by scanning the patient while they are wearing a barium radiographic appliance, planning the implant placement virtually, then creating the surgical guide by milling the radiographic appliance according to the digital CT-based treatment plan. Guide sleeves are then added to the guide to aid in the depth and direction of osteotomies before implant placement.

The rationale for using minimally invasive procedures is to maximize patient comfort by minimizing traumatic injury to the tissues. Flapless insertion of dental implants has been found to have implant success rates comparable with conventional implant placement, also minimizing potential complications from soft tissue elevation such as infection, dehiscence, and soft and hard tissue necrosis. Surgical guidance for drill depth and angulation, in combination with a flapless technique, minimizes the potential injury to underlying anatomic structures during the implant osteotomy preparation. Because fully guided instrumentation for implant insertion is not available in most Simplant cases, fully flapless surgery is not advised. Depth and angulation guidance of all osteotomies is possible, but accurate implant platform placement requires direct visualization of the bone, necessitating elevation of a flap. If using Navigator, ExpertEase, Facilitate, or Simplant fabricated NobelGuide compatible surgical guides, fully guided and flapless placement of implants is possible using available instrumentation.

CT-based technologies available today have limitations and questions that require further investigation as to their effect on guided surgery outcomes. The resolution and accuracy of specific CBCT machines compared with the gold standard of medical-grade CT scanners has been questioned. NobelBiocare markets a calibration object that calibrates an individual CBCT/CT machine to an acrylic object of a known contour and density specifically for the NobelGuide protocol. Although theoretically the concept of a calibration object of this type makes sense, its efficacy is yet to be proved in the scientific literature.

The manufacture of a stereolithographic surgical guide or model involves reproducing the digitally planned dimensions of the surgical guide or model by using a laser beam to selectively solidify an ultraviolet-sensitive liquid resin. Stereolithographic materials have inherent potential problems that can lead to light sensitivity and expansion and/or shrinkage of the material. Leaving them exposed to light for extended periods of time, as well as sterilization in high-temperature autoclaves, distorts stereolithographic materials. The literature concludes that implant site preparation using surgical drill guides generates more heat than classic implant site preparation, regardless of the irrigation system used.

SUMMARY

New technologies, based on 3D evaluation of patients for dental implants, has opened new avenues to clinicians for accurate and predictable diagnosis, planning, and treatment in a multidisciplinary patient-based approach. Communication between clinicians and understanding of these technologies are key components to improved case results and clinical outcomes. Analyzing, understanding, and adopting these technologies will open new doors for the dental team and benefit patients with more predictable outcomes.
The use of CT-guided implant planning and placement does not remove the need for the surgical and restorative team to diligently adhere to the basic principles of implant surgery and prosthetic dentistry. Well-established concepts of implant spacing, depth and angulation, case planning and engineering, minimally traumatic manipulation of soft and hard tissues, soft tissue and bone grafting, osseointegration healing time, soft and hard tissue healing, heat generation, dental materials, ideal occlusion, and many others must be maintained and adhered to. CT-guided implant surgery facilitates the placement of dental implants into an ideal position according to a restoratively driven treatment plan. The final tooth position is determined first. The ideal implant position is then planned, and the implant is then placed into that position with precision. Treatment plans should be created according to the requirements of an individual case and the comfort level of the surgical and restorative team. Cases can be treated with implants staged, with healing abutments, or immediately loaded with temporary, or in some circumstances, final restorations. Proper case selection and patient awareness, education, and compliance are all critical factors for success. There is often a steep learning curve before there is successful incorporation of CT-guided surgery into a dental implant practice. Clinicians interested in these technologies are strongly encouraged to pursue continuing education. CT-guided implant surgery is not conventional implant surgery. Knowledge of CT scans, proprietary treatment planning software, the complete treatment protocols, and guided surgery instrumentation and surgical techniques, are all instrumental to a successful outcome. In addition, clinicians should take into consideration the inherent additional costs involved in the use of proprietary software and CAD/CAM processing technologies. Of primary importance is good patient selection, in addition to appropriate diagnosis, planning and treatment. These requirements are best facilitated by a knowledge of CT-based technologies that enables the clinician to adhere to surgical, prosthetic, and biologic principles that will optimize patient care.

REFERENCES


25. Rosenfeld AL, Mandelaris GA, Tardieu PB. Prosthetically directed implant placement using computer software to ensure precise placement and predictable...


rosseous oral implants in patients after ablative tumour surgery: assessment of ac-
less implant surgery and immediate loading in the edentulous mandible. Int J Oral 
47. D’Haese J, Van De Velde T, Komiyama A, et al. Accuracy and complications using com-
puter-designed stereolithographic surgical guides for oral rehabilita-
48. Arisan V, Karabuda ZC, Ozdemir T. Accuracy of two stereolithographic guide 
systems for computer-aided implant placement: a computed tomography-
49. Ozan O, Turkyilmaz I, Erosy AE, et al. Clinical accuracy of 3 different types of com-
puted tomography-derived stereolithographic surgical guides in implant 
51. Gracis SE, Nicholls JI, Chalupnik JD, et al. Shock-absorbing behavior of five 
52. Arisan V, Karabuda CZ, Ozdemir T. Implant surgery using bone- and mucosa-
supported stereolithographic guides in totally edentulous jaws: surgical and 
post-operative outcomes of computer-aided vs. standard techniques. Clin Oral 
less-placed implants supporting maxillary full-arch prostheses: a randomised 
placement based on pre-surgical planning of three-dimensional cone-beam 
55. Misir AF, Sumer M, Yenisey M, et al. Effect of surgical drill guide on heat gener-