Computer-Guided Planning and Placement of Dental Implants

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The goal of dental implant therapy is the accurate and predictable restoration of a patient’s dentition. These goals are best achieved when all members of the surgical and restorative team are working together on diagnosis, planning, and reconstruction. The recent introduction of new 3-dimensional (3D) diagnostic and treatment planning technologies in implant dentistry have created an environment for the team approach to the planning and placement of dental implants, according to a restoratively driven treatment plan. 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, transferring the virtual plan from the computer to operative treatment. Third-party proprietary implant software and associated surgical instrumentation, in combination with 3D imaging technologies, has revolutionized dental implant diagnosis and treatment. This development has created an interdisciplinary environment in which communication between the team members leads to better patient care and outcomes.

Historical overview

Standard dental diagnosis involves evaluating and diagnosing patients using 2-dimensional radiographic images (ie, periapical, bitewing, panoramic, and cephalometric radiographs). Clinician acceptance of the limitations of these technologies was required in the evaluation of actual 3D problems, because few options were available. Oral and maxillofacial surgeons, because of their hospital training, have long used computed tomography (CT) scans for the 3D evaluation of facial trauma and pathologic lesions. These CT evaluations were commonly viewed in 2 dimensions as axial or reformatted frontal or coronal slices through the area of interest of a patient’s anatomy, viewed as sheets of printed films or 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 slower, single-slice machines, typically based in hospitals or private radiology facilities. Today’s medical multislice CT scanners are capable of performing an upper and/or lower jaw scan in a few seconds. However, radiation exposure, the lack of familiarity and training among dentists, the size and cost of the machines, and the perceived cost-benefit ratio in patient care made them inappropriate for a dental office setting. In 1998, with the development and introduction of the New Tom 9000 (Quantitative Radiology, Verona, Italy), cone-beam volumetric tomography (CBVT/CBCT) was introduced to the dental community [1]. Although the early machines were large, the advantages were that they produced good 3D images at lower
radiation doses [2–4]. The newer machines of today have a much smaller footprint and are small enough to fit into a dental office. The disadvantages were that although the radiation was less than medical-grade CT, it was larger than conventional dental radiographs and because of the reduced radiation, the images produced had somewhat less definition than medical CT. Medical-grade CT remains the gold standard for accurate 3D diagnosis [5,6]. Adaptive statistical iterative reconstruction (ASIR) software has recently been reported to allow up to a 50% reduction in radiation dose in medical CT scans, without diminishing image quality [7–10]. There are different average deviations and percentage error measurements for all CBCT scanners [11,12].

In the late 1980s articles discussing the use of Dentascans to evaluate the bone of the maxilla and mandible in preparation for placement of dental implants began to appear in the professional literature [13–16]. 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 named ImageMaster-101 was introduced by CSI, which added the ability to place graphic dental implants on the cross-sectional images. The first version of SimPlant was introduced by CSI in 1993. This software allowed 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 images to the software [17]. Soon after Materialise (Leuven, Belgium) purchased CSI in 2001, the technology for drilling osteotomies to exact depth and direction through a surgical guide was introduced. SimPlant was designed as an open system to perform osteotomies for the placement of straight-walled implants from all implant manufacturers. It was not designed for the final placement of implants to depth, through a surgical guide, or for tapered implant systems. NobelBiocare (Zurich, Switzerland) introduced the NobelProcera/NobelGuide technology in 2005. This technology was introduced as a complete implant planning and placement system, for both straight-walled and tapered NobelBiocare implants. Instrumentation was developed to create osteotomies of accurate depth and direction, as well as the ability to place implants flaplessly, to accurate depth, through a guide. The system was designed for typical postimplant insertion treatment (cover screws or healing abutments), immediate loading of implants, and the fabrication of partial-arch or full-arch restorations before implant placement. In 2011, NobelClinician, a completely redesigned upgrade of the NobelGuide software, was introduced. 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**

Using CT/CBCT scanners, the 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, sinus septae, and other pertinent vital structures such as the mandibular canal, mental foramen, and incisive canal are possible [18–20]. Variations and aberrations of normal anatomy are also easily visualized. Once images are imported into proprietary software programs (SimPlant, NobelClinician, and so forth), the clinician can then virtually plan treatment for the placement of implants according to 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 on a patient [18–22]. Surgical drilling guides can then be fabricated from the virtual treatment plan. These surgical guides are used by the clinician to place the planned implants in the same positions as those of the virtual treatment plan, allowing for more accurate and predictable implant placement [23–27] 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. Poured models are 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. This ideal diagnostic wax-up is then incorporated, by a dental laboratory, into an acrylic prosthesis, referred to as a radiographic guide, scan prosthesis or scan 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 NobelClinician, 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. NobelClinician uses a double-scan technique with a hard acrylic scan prosthesis and gutta percha markers as reference points, with no barium sulfate. According to the individual system protocols, the CT/CBCT scan is then taken with the patient wearing the scan prosthesis. The CT scan DICOM (Digital Imaging and Communication in Medicine) images are then imported into the various proprietary software programs (SimPlant, NobelClinician, EasyGuide, and so forth). The software programs are then used to virtually place implants into their ideal position related to the planned restoration and the underlying bony anatomy (Figs. 4–6.) The digital treatment plan is then downloaded 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 positions, depths, and angulations as 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. The software uses these reference markers to virtually position the scan appliance, and with it the parameters of the planned restoration(s), to the patient’s jaw. The accurate assessment of these geometric markers can be difficult for some CBCT scanners and has the potential to add error into a precise planning system, ultimately leading to inaccurate fitting of surgical guides and error in implant placement. It is advisable to make every effort to investigate which CBCT scanners have high levels of accuracy or to use medical CT scanners when using these technologies [32].

Fig. 1. NobelGuide Radiographic Guide, fully edentulous. Modification of a patient’s well-fitting existing denture.

Fig. 2. SimPlant radiographic barium stent, partially edentulous.
Fig. 3. EZ Guide radiographic appliance, partially edentulous.

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.

Fig. 7. NobelBiocare NobelGuide fabricated from treatment plan in Fig. 4.

Fig. 8. SimPlant SurgiGuide fabricated from treatment plan in Fig. 5.
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. In certain cases the increased patient and treatment planning time, the additional expense, and the additional radiation exposure to the patient may outweigh the clinical benefits. The authors have found that these technologies are most beneficial to the patient and the dental team in the following clinical circumstances.

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
Significant alteration of the soft tissue or bony anatomy by prior surgery or trauma
Patients with physical, medical, and psychiatric comorbidities.

Conventional surgical guides 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, dental laboratory–fabricated guides with 2-mm drill holes or metal tubes). The problem in their use is that there is no correlation in these appliances between the planned restoration and the underlying bony anatomy. This anatomic relationship can be predictably established and considered before surgery only with the use of 3D visualization and the use of computer-guided implant surgical guides.

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. Fewer anatomic references are present for the predictable accurate placement of implants as the length of the edentulous area increases. In a fully edentulous case, all local references are lost other than the soft tissue ridge and palate. 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 for 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 all significant considerations for the clinician. CT/CBCT-guided surgery allows for the ideal placement of multiple dental implants according to the planned restoration(s), the relationships of implants to surrounding anatomy, and principles of ideal prosthodontic implant positioning and spacing (Figs. 10–13).
Fig. 10. Lower right mandible, 3 implants in a row, virtual treatment plan.

Fig. 11. Three implants in a row, NobelGuide in place. Note Implant Mounts with attached implants placed to depth.

Fig. 12. Final posteroanterior 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.
Differences in x-ray machines and radiographic techniques commonly lead to distortion of anatomic structures on conventional 2-dimensional 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 using CT-generated images. In cases for 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 software has the functionality to isolate the roots of teeth adjacent to the edentulous areas to aid in the accurate placement of implants between and adjacent to tooth roots in the planned sites. Some software will 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 (known as segmentation) (Fig. 19). These technologies are most beneficial when implants must be placed in tight spaces because of close root proximities, or when tooth roots are in extremely divergent or convergent relationships.

Surgical dilemmas that require implant placement in only one possible location or implant depth are common. 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). Tooth root proximities can require “threading the needle” with implant placement, 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.

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 ridge dimensions, proximity to adjacent teeth, implant-to-root relationships, gingival and papilla support and contours, gingival exposure, smile lines, and implant angulations and emergence are just a few of the many complex considerations. Knowledge of the appropriate implant position based on the type of restoration planned (ie, cement or screw retained) is an important prosthetic-based consideration. 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 a site based on the surrounding bony and soft tissue anatomy. The virtual placement of implants based on the planned

Fig. 14. Severe atrophy of posterior mandible, implant placement planned lingual to the inferior alveolar nerve.
Fig. 15. Three-dimensional reformation of Fig. 14. Note appearance of proximity between implant and inferior alveolar nerve in lateral view.

Fig. 16. Implant placement planned in close proximity to enlarged nasopalatine canal.

Fig. 17. Severe maxillary atrophy. Implant planned in the anterior nasal spine, in close proximity to the nasal floor.
restoration related to the underlying bone is then performed. Surgical guides are then used to position the implants accurately and predictably into the optimal position for the planned restoration (Figs. 21–24).

The time required from implant placement to loading has been dramatically reduced by implant technologies and surface characteristics in use today. Immediate placement and immediate loading of implants are 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 cases are planned for treatment. Depending on the clinical circumstances and the experience and comfort level of the clinician, these technologies can be used to place single units, multiple units, or full arches of implants, with a tissue incision or flaplessly. Implants can be placed as a 2-stage, a single-stage with healing abutments, or as an immediate-placement/immediate-load case. Patients experience less surgical trauma, pain, and swelling while their recovery time is reduced and the ability to return to their normal lives is expedited [22–29].

Taking CT-guided technology to the next step involves the accurate fabrication of a restoration before implant insertion, with its immediate insertion at the time of surgery. After the virtual treatment plan is created by the clinician (Figs. 26 and 36), computer-generated stereolithographic surgical guides are fabricated by the manufacturer from the virtual treatment plan (Figs. 27 and 37). Using
the fabricated surgical guide along with patient models, a dental laboratory then fabricates temporary, and in some cases final, restorations, before implant placement surgery (see Figs. 27, 28, 41, 42). The surgical guide can then be used to place implants flaplessly, only removing a core of tissue in the planned implant sites. Once the surgical guide is accurately secured in the patient’s mouth it rarely is removed until all implants are inserted to the 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 can be inserted (see Figs. 25–31 and 32–49).

In most circumstances, “placing the implants where the bone is” has become a concept from the past. Large and small soft tissue and connective tissue grafts, as well as sinus-lift grafts, block-bone grafts, ridge splitting, and alveolar distraction procedures are a few of the procedures routinely performed to prepare the recipient jaw sites before placing implants. Previous surgical procedures, including the prior placement of different types of dental implants (ie, blade and subperiosteal implants) can leave patients with challenging reconstructive bony defects (Figs. 50–54). Traumatic injuries or benign or malignant pathology can result in the loss of bone, teeth, and soft tissue, with resultant defects of varying sizes. Reconstructive procedures to treat these defects can leave areas of abnormal bony anatomy and scarred soft tissue. Bone and soft tissue volumes can be

![Fig. 20](image-url) Implant virtually placed in location with limited buccal-palatal width.

![Fig. 21](image-url) A 17-year-old female patient with overretained, 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. Preoperative photo.
Fig. 22. Virtual treatment plan for the patient described in Fig. 21.

Fig. 23. Virtual treatment plan, occlusal view, for the patient described in Fig. 21. Note implant planned in the right canine site for 2-unit cantilever bridge anteriorly.

Fig. 24. Final restorations for the patient described in Fig. 21.
Fig. 25. A 20-year-old man with bilateral maxillary central incisors avulsed traumatically. Treatment was done using Astra-Tech Dental Facilitate technology. 20 year old male, preoperative photo.

Fig. 26. Treatment of the patient described in Fig. 25. Facilitate “virtual” treatment plan.

Fig. 27. Treatment of the patient described in Fig. 25. 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. Treatment of the patient described in Fig. 25. Presurgical fabrication of provisional restorations on the poured master model.
Fig. 29. Treatment of the patient described in Fig. 25. Guided osteotomy preparation using the Facilitate instrumentation.

Fig. 30. Treatment of the patient described in Fig. 25. Implants inserted, temporary restoration placed at the time of surgery.

Fig. 31. Treatment of the patient described in Fig. 25. Final restorations in place, 5 months later.

Fig. 32. 68 year old male, partially edentulous mandible. Case treatment planned for immediate extraction, immediate implant placement, and immediate loading with a provisional restoration. Preoperative panoramic radiograph.
Fig. 33. Treatment of the patient described in Fig. 32. Preoperative clinical photo, mandibular ridge.

Fig. 34. Treatment of the patient described in Fig. 32. Multiple piece Radiographic Guide.

Fig. 35. Treatment of the patient described in Fig. 32. Mandibular Radiographic Guide and Radiographic Index in place at time of CT scan.
Fig. 36. Treatment of the patient described in Fig. 32. Virtual treatment plan, immediate extraction, 8 implant placement planned.

Fig. 37. Treatment of the patient described in Fig. 32. NobelGuide planned from virtual treatment plan in Fig. 36.

Fig. 38. Treatment of the patient described in Fig. 32. Osteotomy drilling through the NobelGuide, using NobelGuide for NobelActive surgical instrumentation.
Fig. 39. Treatment of the patient described in Fig. 32. Clinical photo, minimally traumatic extractions with implants in place.

Fig. 40. Treatment of the patient described in Fig. 32. Postoperative panoramic radiograph.

Fig. 41. Treatment of the patient described in Fig. 32. Master cast fabricated from NobelGuide, Quick Temp abutments with nylon pick up sleeves in place.

Fig. 42. Treatment of the patient described in Fig. 32. Fabrication of provisional restoration on master cast.
Fig. 43. Treatment of the patient described in Fig. 32. Provisional restoration, pick up of nylon Quick Temp sleeves. Six implants incorporated in provisional restoration.

Fig. 44. Treatment of the patient described in Fig. 32. Provisional restoration in place, occlusal view.

Fig. 45. Treatment of the patient described in Fig. 32. Master cast, planned occlusion with provisional restoration, frontal view.

Fig. 46. Treatment of the patient described in Fig. 32. Provisional restoration in place at time of surgery, frontal view.
Fig. 47. Treatment of the patient described in Fig. 32. Final restoration, frontal view.

Fig. 48. Treatment of the patient described in Fig. 32. Final restoration, right side.

Fig. 49. Treatment of the patient described in Fig. 32. Final restoration, left side.

Fig. 50. Preoperative panoramic radiograph of a 45-year-old woman who had a blade implant placed in the left mandible in 2003, resulting in multiple infections and implant and bridge loosening. After implant removal, osseointegrated implants were planned for mandibular right and left sides.
Fig. 51. Treatment of the patient described in Fig. 50. Defect of the left mandible after removal of blade implant and restoration.

Fig. 52. Treatment of the patient described in Fig. 50. Virtual treatment plan, 3 implants in the left mandible.

Fig. 53. A 68-year-old woman with prior full-arch maxillary subperiosteal implant. Note severe atrophy and distorted anatomy.
unpredictable after healing, graft maturation, and settling of graft materials. Lateral block-onlay
grafts can resorb a portion of their bone volume during healing and maturation [33–35]. CT/
CBCT-guided technologies allow the surgeon to predict the volume of sinus-lift graft material neces-
sary to augment an area of the maxilla to a desired height of bone [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 a patient’s distorted
anatomy without making an incision or removing any soft tissue or bone [37]. Implants can be placed
accurately and predictably with knowledge of the patient’s underlying distorted bony anatomy,
without making an incision and removing the periosteal blood supply from the areas (Figs. 55–58).

Compromised patients

Preoperative and postoperative radiation therapy potentially alters healing capacity in head and
neck cancer patients. To increase bone vascularity before implant placement, the literature advocates
preoperative and postoperative courses of hyperbaric oxygen therapy in these patients [38–41]. Minimizing flap elevation and hard and soft tissue trauma is indicated in these patients to minimize the likelihood of the development of osteoradionecrosis of the jaws [38,42]. Bleeding, swelling, and alteration of the blood supply to the bone and soft tissue are limited by using CT Guided implant placement technologies [43].

Fig. 56. Postgrafting cross-sectional image of the patient described in Fig. 55. Area of right lateral incisor after maxillary anterior distraction osteogenesis and lateral block grafts (NobelGuide). Note measurements of 13.0 mm (height) and 9.6 mm (width).

Fig. 57. Cross-sectional view after sinus-lift graft. Note bone graft placement primarily laterally, virtual implant placed in image.
Patients with medical problems such as bleeding dyscrasias, anticoagulation issues, or significant cardiovascular disease may necessitate specific medication protocols that cannot be altered presurgically. Minimizing bleeding by limiting surgical trauma to the soft and hard tissues is indicated in patients with difficult 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.

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. The amount of time a patient can sit in a dental chair can be limited by orthopedic and spinal disorders. Wheelchair-bound patients pose another set of logistical treatment problems. These types of patients can require extensive planning and preparation before treatment. Without compromising quality, treatment must be performed quickly and efficiently. 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 to place the implants, implants can be placed quickly and predictably, thus minimizing the patient’s 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 designed to rest on the mucosa and are primarily used in fully edentulous cases. 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 Figs. 37 and 38). Bone-supported guides can be used in partially or fully edentulous cases, but are used primarily in fully edentulous cases when significant ridge atrophy is present and good seating of a mucosa-supported guide will be questionable. An extensive full-thickness flap is necessary when using bone-supported guides 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.

Dental implant placement using CT-guided surgery with drill guides is known to enhance safety compared with the freehand technique [44,45] while being compatible with conventional flap elevation surgery or flapless procedures [46] 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. No available CT-guided drill guide technology exists today that has absolute precision. All articles on stereolithographic guides show error in all dimensions between virtual planning and actually obtained implant positions [47]. According to the literature, implants placed by mucosa-supported guides have the lowest mean deviations whereas implants placed by bone-supported guides have higher deviations [48]. Tooth-supported guides have been found to have the lowest measured deviation, likely because there are
teeth present in the arch acting as accurate stops for guide placement [49]. 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; some use
them to stabilize all guides.

A reduction in treatment time is the main advantage of inserting a final restoration immediately
after implant placement. Clinicians who are using these technologies more commonly place
temporary restorations after implant placement for many reasons. An accurate prediction of the
contours and anatomy of the healed gingiva is impossible, whether a procedure is flapless or not. This
issue is a significant one for a laboratory technician fabricating a final restoration. The patient’s
aesthetic demands can sometimes be great. Observation of the tissue response to the temporary
restoration can give the restorative dentist invaluable information regarding the gingival contours and
aesthetics in preparation for the final restoration. In addition, a small number of implant failures
occur, regardless of whether an implant is placed guided or nonguided. Most surgery-related implant
failures typically 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 [50], 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 to reduce the forces of impact when compared with
porcelain materials [51]. These factors are all additional reasons to place immediate acrylic temporary
restorations rather than immediate final porcelain restorations.

SimPlant (Materialise) and NobelGuide/NobelClinician (NobelBiocare) are the 2 major systems
currently in use. Clinically the NobelGuide system is a more comprehensive one, with full sets of
specific instrumentation for the fully guided placement of all NobelBiocare implants to accurate
position, depth, and angulation, and the components to immediately load implants if desired.
NobelGuide and 3i Navigator are the only systems currently available with instrumentation for the
placement of tapered implants. The NobelGuide technology and instrumentation can be used for
performing osteotomies for a straight-walled implant from any implant manufacturer. In these cases, the
system can only be used for depth and direction of osteotomies. Because the NobelGuide Implant
Mounts are designed only for NobelBiocare implants, implants from other manufacturers cannot be
accurately placed and fully guided. In these cases, the depth of implant placement should be evaluated
with the guide off, usually after an incision and 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 one 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
their straight-walled implants, flapless and fully guided, using the SimPlant software for planning (eg,
Facilitate [AstraTech Dental], ExpertEase [Dentsply Friadent], Navigator [3i/Biomet]). Other
manufacturers have developed nonstereolithographic model technologies for the fabrication of surgical
guides as well (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 he or she is wearing a barium radiographic appliance, the implant
position(s) are then planned virtually, and then the surgical guide is created by milling the radiographic
appliance according to the digital CT-based treatment plan. Guide sleeves are then added to the guide to
accommodate the instrumentation for osteotomies and guided implant placement.

Maximizing patient comfort by minimizing traumatic injury to the tissues is the rationale for using
minimally invasive procedures. Flapless insertion of dental implants has been found to have success
rates comparable with conventional implant placement, while minimizing potential complications from
soft tissue elevation such as infection, dehiscence, and soft and hard tissue necrosis [30,52,53]. Surgical
guidance for drill depth and angulation, in combination with a flapless technique, minimizes the poten-
tial injury to underlying anatomic structures during the implant osteotomy preparation. Fully flapless
surgery is not advised in most SimPlant cases because fully guided instrumentation for implant inser-
tion is not available. Depth and angulation guidance of all osteotomies is possible, but accurate implant
platform placement will require direct visualization of the bone, necessitating an incision and 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 because of available instrumentation.

CT-based technologies available today have limitations and questions that require further investigation regarding 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 [54]. A calibration object is marketed by NobelBiocare, which calibrates an individual CBCT/CT machine to an acrylic object of a known contour and density specifically for the NobelGuide protocol. This object adds to the precision of the stereolithographic fabrication of the NobelGuide [55].

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, will distort stereolithographic materials. The literature concludes that preparation of the implant site using surgical drill guides generates more heat than classic implant-site preparation, regardless of the irrigation system used [56].

Summary

New technologies based on the 3D evaluation of patients for dental implants have opened new avenues to clinicians for accurate and predictable diagnosis, planning, and treatment in a multidisciplinary patient-based approach. Communication between clinicians and understanding these technologies are key components of improved case results and clinical outcomes. Analyzing, understanding, and possibly adopting future technologies will not only benefit and open new doors for the dental team but will benefit patients, with more improved predictable outcomes.

The use of CT-guided implant planning and placement does not separate the surgical and restorative team from diligent adherence to the basic principles of oral and implant surgery and prosthetic implant 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 times, 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. Essentially, the final tooth position is determined first. The implant position is then planned and placed into that ideal position related to the restoration, with accuracy and 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 buried with cover screws and 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.

It must be understood that a steep learning curve is necessary for the successful integration of CT technology and CT-guided surgery into dental implant practice. Clinicians interested in these technologies are strongly encouraged to pursue continuing education on the technologies before their clinical use. CT-guided implant surgery is not conventional implant surgery. Knowledge of CT scans, proprietary treatment planning software, the complete treatment process protocols, and guided-surgery instrumentation and techniques are all instrumental to successful treatment outcomes. In addition, clinicians should take into consideration the inherent additional costs involved in the use of the proprietary software and computer-aided design and manufacturing processing technologies. Of primary importance, good patient selection and diagnosis, pretreatment planning, knowledge of the technology, and adherence to surgical and prosthetic principles will strongly affect clinical outcomes.

References


