Diagnostic casts may help guide preimplant and treatment prosthodontics. Once the preimplant phase is satisfactory, prosthetically driven implant placement also must accommodate anatomical limitations, and possible adaptations of the original planning may be necessary. This set of requirements can be achieved using precise surgical guides. In recent years, advanced guidance has been developed to achieve predictable, precise placement. This chapter emphasizes important components of the diagnostic phase and then describes how guided placement can overcome anatomical limitations.

DIAGNOSTIC CASTS

The value of diagnostic casts or study models is critical in all of dentistry and especially in oral implantology. Many patients have been partially edentulous for an extended time. The combination of continued bone loss and dentition changes related to missing teeth greatly increases the number of factors that must be considered for oral rehabilitation compared with traditional prosthodontic treatment. The dentist selects the final prosthesis, the number and location of ideal and optional abutment sites, and the occlusal schemes before surgery. Diagnostic casts enable the dentist to evaluate several prosthodontic criteria in the absence of the patient. Ninety percent of dentists in the United States use a team approach to insert implants and restore implant patients. These casts permit an open discussion of treatment with other practitioners and laboratory technicians for consultation. In addition to all the data provided that are similar to nonimplant treatment evaluation, the casts also assist with implant site selection and angulation requirements during the surgical phase. Surgical templates often are designed from the diagnostic casts or after diagnostic wax-up of the designed prosthesis. One set of casts may be used as a permanent record of pretreatment conditions for dental-legal issues because nonreversible procedures may be performed. The diagnostic casts and pretreatment setups also may be used for presentations to motivate the patient’s acceptance of the proposed treatment. Diagnostic casts mounted with an accurate record of centric jaw relationship and maxillomandibular occlusion on a semiadjustable articulator provide much information related to treatment that influences the final prosthodontic treatment plan. Important factors include the following:

1. Occlusal centric relation position, including premature occlusal contacts
2. Edentulous ridge relationships to adjacent teeth and opposing arches
3. Position of potential natural abutments, including inclination, rotation, extrusion, spacing, parallelism, and esthetic considerations
4. Tooth morphology, structure of potential abutments, and overall conditions (e.g., wear facets and fractures)
5. Direction of forces in future implant sites
6. Present occlusal scheme, including the presence of balancing or working contacts
7. Edentulous soft tissue angulation, length, width, locations, permucosal esthetic position, muscle attachments, and tuberosities

Figure 10-1 Diagnostic casts allow the dental team to evaluate a patient’s intraoral condition and plan treatment. However, unmounted casts cannot be used to evaluate the relationship of one arch to another.
Diagnostic casts should be mounted with an open bite registration in centric relation. When the registration material between the teeth is removed, the arch of closure of the mandible should simulate the patient. This requires a face-bow mounting from the patient to the articulator.

**Figure 10-2**

A mounted maxillary cast without a face-bow and an open bite mandibular relationship do not allow proper evaluation or reconstruction of the patient’s intraoral condition. For example, a maxillary cast mounted to the rear causes premature anterior contacts when the bite registration is removed. B, When a reconstruction fabricated on models mounted as in part A is placed intraorally, a posterior premature contact is observed and the anterior teeth have no contact. A maxillary cast mounted too high on an articulator also exhibits premature anterior contacts when the open bite registration is removed. When the reconstruction is placed intraorally, a posterior premature contact is observed, similar to the previous scenario. The reverse scenario is observed when the maxillary cast is mounted too far forward or inferior to the hinge axis of the patient.

**Figure 10-3**

A, A mounted maxillary cast without a face-bow and an open bite mandibular relationship do not allow proper evaluation or reconstruction of the patient’s intraoral condition. For example, a maxillary cast mounted to the rear causes premature anterior contacts when the bite registration is removed. B, When a reconstruction fabricated on models mounted as in part A is placed intraorally, a posterior premature contact is observed and the anterior teeth have no contact. A maxillary cast mounted too high on an articulator also exhibits premature anterior contacts when the open bite registration is removed. When the reconstruction is placed intraorally, a posterior premature contact is observed, similar to the previous scenario. The reverse scenario is observed when the maxillary cast is mounted too far forward or inferior to the hinge axis of the patient.
8. Interarch space  
9. Overall occlusal curve of Wilson and curve of Spee  
10. Arch relationships  
11. Opposing dentition  
12. Potential future occlusal schemes  
13. Number of missing teeth  
14. Arch location of future abutments  
15. Arch form and asymmetry

The dentist should evaluate the existing occlusion before implant placement. Partially edentulous patients often present occlusal interferences as a result of tooth migration. The dentist identifies and eliminates deflective contacts before the implant prosthodontic phase. A face-bow transfer and centric and eccentric occlusal records should help mount the casts on a semiadjustable articulator (Figs. 10-2 to 10-5). Occasionally, a panographic recording of mandibular movements and a fully adjustable articulator may be indicated. The diagnostic casts are mounted in centric relation occlusion with a wax spacer between the arches. Premature contacts can be detected on removal of the wax spacer. The dentist then may perform an occlusal adjustment on duplicates of the diagnostic casts and replicate them in the mouth.⁵

A considerable prosthetic advantage is present when centric relation occlusion is harmonious with centric relation. Lack of change in the occlusal vertical dimension permits a closed-mouth centric recording during prosthetic reconstruction for the fabrication of the prosthesis, without the need for an accurate hinge axis recording of the condyles or fully adjustable articulators. When incisal edge position of the maxilla is determined, its position usually causes a steeper protrusive or excursive position than the condylar disk assembly. As a result, posterior disocclusion can be established easily. These conditions permit the reconstruction to be fabricated in the laboratory and transferred accurately to the patient.

The occlusion may require complete rehabilitation to eliminate potential unfavorable forces against the implant(s). Both arches may require prosthodontic treatment to establish the desired occlusal schemes. Parafunctional bruxism with loss of incisal guidance from attrition or an opposing single denture are the most common conditions that mandate more involved opposing dentition modification. The first condition often indicates a need to increase the anterior guidance for posterior disclusion in excursions, whereas the second warrants bilateral balance occlusion.

Duplicate diagnostic casts also may be mounted on an articulator for selective alterations and prewaxing to determine the desired contour, occlusal scheme, and esthetic aspects of the final restoration. The diagnostic wax-up usually is described in detail and performed by the laboratory technician. The specific laboratory communicative processes are thereby begun before actual treatment and may be modified during treatment as required. These considerations include occlusal plane correction, edentulous ridge position and its effect on implant placement, occlusion, esthetic considerations, and interarch distance. The dentist may use the altered diagnostic wax-up casts to provide a guide for provisional restorations and may evaluate them during the provisional stages of reconstruction.

The dentist also may use the diagnostic casts to estimate the underlying bone volume. The dentist inserts a needle equipped with an endodontic stop through the patient’s mucosa overlying the implant site and measures the mucosal thickness on the crest, facial, and lingual areas. The dentist also can use a bone caliper that contains sharp beaks penetrating soft tissues at a known height. Once the calipers are inserted, bone width can be measured by the calibrated instrument.⁶ The edentulous region of the diagnostic cast is cut perpendicular to the ridge. The diagnostic cast cross section then is shaded with a pencil to represent the tissue thickness observed while probing. The remaining...
cross section of the cast roughly estimates the bony contours under the soft tissue.6,8

RESTORATIVE DIAGNOSIS VERSUS SURGICAL DIAGNOSIS

Although a prosthetically driven implant placement is best for simplification of abutment selection, ideal force distribution,9 and long-term success, anatomical limitations may force the surgeon to redirect the implant angulation. When buccal bone loss has occurred, modification of the treatment plan and placement of a bone graft for better implant angulation are possible. But other areas cannot be grafted, and a change in angulations or implant selection is the only option. A typical instance of such limitation is in the mandibular first molar area. A panoramic or periapical radiograph does not show a possible severe lingual concavity, which can be depicted only with careful clinical examination or cross-sectional imaging. Prosthetically driven implant placement would lead only to a risk of lingual perforation. If a concavity is suspected, further radiographs such as a traditional tomogram or a computed tomography scan, together with a diagnostic radiographic template, will reveal the angulation dilemma and allow for clear communication between the restorative dentist and the surgeon.

The example in Fig. 10-6 represents an actual case in which the diagnostic wax-up was transferred to a scannographic template,10 but the prosthetic requirement cannot be met surgically: an implant placed in the long axis of the diagnostic tooth would force the surgeon to perforate the lingual cortical bone. In addition, the mandibular nerve is relatively high. Therefore the dentist must make a decision to modify the angulation and later redirect the implant path with an angulated abutment, position a shorter implant, or avoid this site altogether. A careful clinical examination with the diagnostic template in place would have revealed the issue as well, but radiographic visualization is more ideal to ensure surgical success, limit liability, and communicate and discuss planning. Unfortunately, such anatomical limitations often are revealed during surgery, when decision making is more difficult and debate is impossible. Other common locations for similar limitations include the prominent premaxilla or the severely resorbed anterior part of the mandible. As discussed subsequently, precise diagnosis to rule out anatomical limitations can be followed by a thorough plan that can be transferred to the surgical field using surgical guidance.

SURGICAL GUIDES

To establish a logical continuity between diagnosis, prosthetic planning, and surgical phases, use of a transfer device is essential. The restoring dentist fabricates the surgical guide template after the presurgical restorative appointment(s), once the final prosthetic design, occlusal scheme, and implant location, size, and angulation have been determined. The surgical template dictates to the surgeon the implant body placement that offers the best combination of (1) support for the repetitive forces of occlusion, (2) esthetics, and (3) hygiene requirements. A well-developed plan should be transferred precisely, leaving little decision at the time of surgery.

Several methods of fabrication for the surgical template are available. The requirements are more relevant than the options of fabrication. The template should be stable and rigid when in correct position. If the arch treated has remaining teeth, the template should fit over or around enough teeth to stabilize it in position (Fig. 10-7). When no remaining teeth are present, the template should extend onto unreflected soft tissue regions (i.e., the palate and tuberosities in the maxilla or the retromolar pads in the mandible). In this way, the template may be used after the soft tissues have been reflected from the implant site.

The dentist should determine the ideal angulation for implant insertion on the diagnostic wax-up, and the template should relate this position during surgery. This requires at least two reference points for each implant.

![Figure 10-6](image1.png) An implant following an ideal prosthetic position must have ideal bone volume and angulation. In many situations the bone width or angulation requires slight modification of the implant to avoid perforations of the lateral cortical plates. In this case, the vertical implant insertion caused a perforation through the lingual cortical plate of the posterior mandible.

![Figure 10-7](image2.png) A template for a partially edentulous patient should engage the teeth for stabilization and fixation during surgery. Templates for the anterior regions of the mouth should indicate the facial contour of the restoration.
For that purpose, the surgical guide must be elevated above the edentulous bone. The distance between two points located respectively on the occlusal surface (central fossa or incisal edge) of the planned abutment crown and the crest of the ridge represents about 8 mm. As a result, these two points of reference can be joined by a line that represents the path of ideal implant insertion. The ideal angulation is perpendicular to the occlusal plane and parallel to the most anterior abutment (natural or implant) joined to the implant.

Other ideal requirements of the surgical template include size, surgical asepsis, transparency, and the ability to revise the template as indicated. The template should not be bulky and difficult to insert or obscure surrounding surgical landmarks. The surgical template must not contaminate a surgical field during bone grafts or implant placement and should be transparent and allow easy access for the surgeon and the assistant. Visualization of what side of the arch is operated on, where the surgeon and assistant will be seated, and whether the surgeon is right- or left-handed is recommended. In this way, the bony ridge and drills can be more easily visualized when the template is in place, and the assistant can position the irrigation without blocking the surgical view.

The surgical template should relate the ideal facial contour. Many edentulous ridges have lost facial bone, and the template can determine the amount of augmentation required for implant placement or support of the lips and face (see Fig. 10-7). The surgical template may be used for a bone graft, and later the same template may be used for insertion of implants and again for implant uncovery. A study template permits resterilization and use for several procedures.

To construct a surgical guide, modification of the radiographic guide is often possible if an ideal wax-up of the teeth was used as a template for the radiographic guide. Ideal tooth position is already present, and enlargement of the access hole and buccal or lingual opening is achieved easily. When the long axis of the teeth is visible and can be maintained, after verifying bone availability, then enlargement of the long-axis channel guarantees accurate implant guidance.11

An easy method to fabricate a surgical guide is to use a modification of Preston’s clear splint for the diagnosis of tooth contours, tooth position, and occlusal form.12 The diagnostic wax-up is completed to preview the tooth size, position, contour, and occlusion in the edentulous regions where implants will be inserted. No selective grinding or modification is performed on any teeth that have not been altered before surgery; otherwise, the template will not fit correctly in the mouth. A full-arch irreversible, hydrocolloid impression is made of the diagnostic wax-up and poured in dental stone. On the duplicate cast of the wax-up teeth, a vacuum acrylic shell (0.060 to 0.080 inch) is pressed and trimmed to fit over the teeth and gingiva contours of the buccal aspect of the ridge. If no natural teeth remain, the posterior portion of the template should be maintained and cover the retromolar pads or tuberosities and palate to aid in positioning.

The occlusal surface is trimmed over the ideal and optional implant sites, maintaining the facial and facioocclusal line angle of the surgical template (Fig. 10-8). A black line then is drawn on the template with a marker to indicate the center of each implant and the desired angulation.

This provides maximum freedom for implant placement yet communicates the ideal tooth position and angulation during surgery.

A surgical guide template with 2-mm holes through the occlusal surface of a denture tooth is too limiting for the surgeon, although it identifies precisely the ideal implant placement. While the template is in position, the crest of the edentulous ridge should be visible to avoid stripping of the facial plate of bone during the osteotomy.

In the edentulous arch the vacuum form may be of the existing removable prosthesis, if within accepted guidelines. A soft tissue liner then may be added in the tuberosity or retromolar pad regions and other soft tissue areas not involved in surgery. Acrylic resin then is added over the occlusal portion of the template where no implants are planned. The patient then occludes into this index after using petroleum jelly over the opposing teeth. In this manner, the template can be correctly positioned over the edentulous ridge during surgery once the tissue is reflected. Otherwise, template position too far facially or off to one side is likely (Figs. 10-9 to 10-12).

A surgical template for the complete edentulous arch also may engage the occlusal aspect of the opposing teeth.13,14 The following are the fabrication steps on the edentulous cast mounted against the opposing dentition at the proper final occlusal vertical dimension and occlusal relationships:

1. A full wax-up of the missing teeth in the edentulous regions is performed. A hole is prepared through the middle of the central fossa of each future posterior abutment tooth and through the incisal edge position of anterior teeth.

2. On the stone model, each site chosen should be drilled to a depth corresponding to the approximate soft tissue thickness measured on a panoramic radiograph (usually about 2 to 3 mm). An orthodontic wire is passed through the teeth and into the holes. This allows each pin of the template to contact bone once the tissue is reflected during the
Figure 10-9  The complete edentulous template can be fabricated from a press or vacuum form over the patient’s denture.

Figure 10-10  A soft tissue liner is added in the area that will not be reflected during surgery. An index also is made of the opposing dentition.

Figure 10-11  The complete edentulous template is trimmed to indicate the facial contour of the restoration in the anterior regions of the mouth. The crestal and lingual contour is completely visible for surgical access.

Figure 10-12  The template is indexed to the opposing arch once the tissue is reflected. The template then is held in position while the patient opens the mouth. The maxillary denture is removed (when present) and the mandibular bone width and angulation are noted before the initial osteotomy. The 2-mm direction indicator then may be inserted and evaluated with the template in position.

Figure 10-13  A Laney-Poitras template for the edentulous arch provides complete surgical access. The denture teeth are positioned on the arch. A hole is drilled through each prospective implant site and into the cast 2 to 3 mm. (Courtesy Yvan Poitras, Montmagny, Quebec, Canada.)
surgery, without modifying the occlusal vertical dimension and consequently the emergence position of the implant. A small loop is made at the other end of the wire to create a retention form. The wire should approach within 1 to 3 mm of the opposing arch (Fig. 10-13).

3. On the antagonist model painted with separator, an acrylic resin template is built on the occlusals that embed the retention loops of the indicator pins. Each pin must be embedded fully in the acrylic at the proper centric and vertical relationships (Fig. 10-14).

Once the soft tissue is reflected, the template is positioned over the teeth of the opposing arch.

The patient may occlude on the pins, and each one determines the ideal center position of the teeth (Figs. 10-15 and 10-16). A pilot drill can mark each implant body position. The angulation of the osteotomy also can be determined with the template. The surgical guide easily determines the implant position, yet the surgeon can have the patient open and drill into the bone with complete access and vision. This template also may be used with a panoramic radiograph before surgery to determine vertical magnification or horizontal distortion (Fig. 10-17). The template also may be used at Stage II uncoverly to find the position of each implant when soft tissue carving for fixed prosthesis type 1 (FP-1) restorations are indicated, rather than complete reflection of the tissue.

The FP-1 and FP-2 restorations require more ideal implant placement. The ideal implant position allows the placement of a straight abutment directly under the incisal edge of the final crown for a cemented prosthesis. For screw-retained prostheses, the implant should emerge toward the cingulum of the anterior tooth so that the access hole does not affect the esthetics. In an FP-3 restoration, the mesiodistal position of implant abutments may be placed without regard to the actual position of the crowns because the soft tissue replacement region separates the crowns from the implant abutment.

An implant placed adjacent to a natural tooth should remain 1.5 to 2 mm away from the crown in esthetic regions, where the contour of the interdental papilla is a determining factor. Therefore the pilot hole should be almost 4 mm away from the natural tooth to place a 4.1-mm diameter implant at the crest module. This requires at least a 7-mm mesiodistal space. In unesthetic regions, where the interdental papilla is not as critical, an implant placed at least 1.5 mm away from an adjacent tooth minimizes the risk of surgical error and provides easier access for hygiene and long-term maintenance.

A maxillary anterior implant placed for an FP-1 restoration requires the most careful pretreatment planning and precise implant placement. The incisal edge of the final
crown, emergence profile, and labial cervical position are related to implant position.

The treatment plan for an implant in the maxillary first premolar position must reflect careful consideration for the angulation of a natural canine when present. The 11-degree average distal inclination and distal curvature of the canine root bring the apex of the root into the first premolar implant area. Therefore the implant should be angled to follow the root of the canine and prevent contact with or perforation of the natural root. A shorter implant often is indicated, especially when a second premolar is also present.

**ADVANCED SURGICAL GUIDANCE**

Diagnosis and implant planning for complex cases with anatomical limitations and poor bone quality now can be evaluated using sophisticated radiographic techniques. Although precision positioning has long been recognized as an important goal, transfer of detailed information to the surgical phase has been at best a difficult task. In fact, a single-tooth implant also requires placement accuracy, even when diagnosis is simple. A surgical guide should be used to guarantee precise placement. Indeed, studies show that modification of the radiographic guide to a surgical guide allows for a precision of less than 1 mm at the implant apex and a good control of the angulation. But these preclinical and clinical studies assume no modification of angulation compared with the ideal prosthetic alignment. As discussed previously, the angulation often must be modified to account for anatomical limitations. Until recently, no method existed to transfer an ideal implant position precisely to a surgical guide, especially if the long axis of the diagnostic teeth could not be used.

To refine surgical guidance, innovative developments in software technology and recently developed manufacturing techniques have been applied to fabricate highly accurate templates. In addition, peroperative robotic assistance also is foreseen for future clinical applications. These technologies allow for more accurate implant positioning by guaranteeing transfer of the implant planning to the surgical field and by forcing the surgical drills in a steady position. They also open venues to new surgical techniques, such as flapless osteotomies, while improving operative timing.

Advanced surgical guides require computed tomography (CT) scanning as a prerequisite for analysis because of its superior precision compared with all other radiographic techniques. These guides also necessitate a software-supported rendering to improve planning by using three-dimensional visualization, as demonstrated by Jacobs et al., who reported that dentists using two-dimensional cross sections make numerous modifications during the surgical phase of treatment, whereas the addition of a three-dimensional representation improves the correlation between planning and actual placement. They also found little correlation between foreseen anatomical complications and the presence of these complications at the time of surgery when only flat projections were used. Verstreken et al. also found that planning was improved with regard to position, considerations of biomechanical spread, and esthetics.
More importantly, software rendering that includes CT data and implant planning can be exported later to a computer-aided design (CAD) software. For these applications, scannographic templates with precise visualization of diagnostic teeth are strongly recommended to visualize the prosthetic plan together with the osseous topography. In addition, when advanced surgical guidance is considered, several techniques require specifically designed scannographic templates, as described subsequently. Therefore dentists who intend to use one of these methods first must be aware of the entire sequence before the diagnostic stage.

**COMPUTER-ASSISTED DESIGN AND MANUFACTURING OF SURGICAL GUIDES**

Multiple engineering techniques such as laser sintering are available to fabricate three-dimensional models. One of the systems (marketed under the name SurgiGuide, CSI Materialise, Glen Burnie, Maryland) uses a computer-aided manufacturing (CAM) process called stereolithography (Fig. 10-18). This rapid prototyping process has been used largely in the industry to obtain three-dimensional models: a layer of liquid polymer is deposited and cured by a computer-driven laser. Additional layers or sections are stacked and polymerized until a final model is generated. For medical or dental application, the data source is a CT scan file. The accuracy of anatomical models generated by this method depends on the quality of the CT scanner and the thresholding method (the computer process that determines what is bone and what is soft tissue), but studies have shown a dimensional stability in the range of 0.6 mm. In addition, when advanced surgical guidance is considered, several techniques require specifically designed scannographic templates, as described subsequently. Therefore dentists who intend to use one of these methods first must be aware of the entire sequence before the diagnostic stage.

**Figure 10-18** Stereolithographic fabrication of surgical guides. After scanning and planning, files are submitted to the manufacturing facility. A, A computer-driven laser cures a thin layer of liquid polymer. B, A moving table is lowered, another layer is applied, and C, the process is repeated until completion of the surgical guide.
Figure 10-19  A, Planning has been forwarded for design and manufacturing of surgical guides. B, The surgical guides first are designed virtually to maximize stability and retention and then are sent for processing using the method previously described.

Figure 10-20  A, The dentist receives the anatomical model and surgical guides by mail and can observe the anatomy before proceeding with surgery. B, Because the topography is obtained from the computed tomography scan data, this process is best suited for osseous-supported templates with wide edentulous areas.

Figure 10-21  Stage II surgical guide. Implants were placed using a CAD/CAM osseous-supported guide. Because a scannographic template was present at the time of scanning (A), a soft tissue Stage II guide also could be fabricated with the same method (B). Metal tubes are not necessary, and cylinder diameters accommodate a tissue punch.
avoided, keeping in mind that mucosal stability is inferior to bone. In addition, a similar method may be used to fabricate Stage II templates: a soft tissue-locating template is prepared without metal tubes to accommodate insertion of a tissue punch, thus also avoiding a large incision over two-stage implants (Fig. 10-21). Surgical guides also can be fabricated for various maxillofacial implants such as pterygoid or zygomatic implants where access and visualization is difficult. Finally, similar surgical guidance is applicable to the medical field such as fusion of vertebrae in which precise osteotomies are necessary to avoid vital structures.

In contrast to the system described previously, an alternative method (Compu-Guide, Implant Logic Systems, Cedarhurst, New York) uses tooth-borne surgical guides. The method necessitates the incorporation of metal markers at specific locations in the scannographic guide that therefore must be provided by the manufacturer. Once returned and used during CT scanning, the dentist creates a surgical plan using a software (SimPlant, CSI Materialise) in a traditional manner. The dentist then returns the plan, model, and scannographic template for conversion of the template into the surgical guide. To achieve transfer of the plan, the model is set onto a computer-controlled milling machine, which matches the fiducial landmarks to their CT-scanned images. The plan then is transferred to the guide using the computer-driven drill press (Fig. 10-22). Metal guide sleeves then are added for an ideal guidance of surgical drills. In this system, only one template is fabricated, but drill guides with incremental diameters are inserted sequentially into receiving master cylinders. Because of the ability of the guide to rest on natural teeth, this method can be applied to small edentulous spans. If increased stability is needed when few or no teeth are present, a tacking system can be added, away from implant sites. Finally, the surgical guide can be converted into a provisional restoration for immediate loading cases. A similar technique has been described by Fortin et al., who placed reference tubes in the scannographic guide. After scanning and planning, the template also is positioned on a computer-driven drilling table to modify the appliance into a precise surgical guide.

Although these advanced methods aim at improving surgical guidance, accuracy rarely has been measured objectively. Unpublished data from the manufacturers and clinical experience support the hypothesis that planning and actual placement are related more closely in terms of horizontal positioning (mesiodistal and buccolingual) and implant angulation. We found similar results using a preclinical study design to compare traditional surgical guides modified from scannographic templates with SurgiGuides. Coronal osteotomy was improved from an average of 1.5 mm to 0.9 mm, and the apical position at 10 mm was improved from 2.1 mm to 1 mm, and this improvement was due to a better angulation (from 8 to 4.5 degrees). An important note is that average enhancements also were accompanied by overall decrease in standard deviations, revealing minimization of surgical errors. In a recent publication, van Steenberghe et al. evaluated placement of 45-mm long zygoma implants on human cadavers. They reported less than 3 degrees of deviation, and no more than 2.7-mm discrepancy at the apex. Fortin et al. found that the transfer error was less than 0.2 mm and 1.1 degrees.

Improvements of these surgical guides are ongoing, in particular for control of the coronoapical positioning. In a recent development, Tardieu and Vrielinck proposed a modification to the first method described. These new templates (SAFE, Materialise, Leuven, Belgium) are secured onto the bone surface using tacking screws. Only one template is used and cylinders are replaced. This protocol also includes a limited sequence of specially designed surgical burs with stops, as well as implant carriers allowing for control of the insertion depth. Therefore another potential benefit to CAD/CAM surgical templates could be the elimination of sequential osteotomy drills because their accuracy precludes the need for angulation correction offered by multiple enlarging osteotomies. Further research is warranted because single, larger drill osteotomies potentially can overheat the osseous surface.
**Image-Guided Surgery**

Image-guided surgery, first developed for medical applications, recently has been introduced to implant dentistry. Close surgical field and difficult accesses drove the need for computer guidance in medical applications such as neurosurgery, and dental implant placement may benefit from these technologies by offering a peroperative three-dimensional assessment of osteotomies. Similarly to the techniques described before, a CT scan is necessary. The scannographic guide includes fiducial markers for cross-referencing jaw positions with the CT scan, and virtual implant planning is performed using software. For surgery the handpiece is equipped with a three-dimensional positioning device such as electromagnetic digitizers or light-emitting diodes. Extraoral markers attached to the surgical guide are also necessary so that the computer can analyze the positions of the jaw and the handpiece relative to each other. Continuous reevaluation of locations and matching to the CT scan data during surgery allow for visualization of osteotomies and comparison of planning and drilling. Some computer systems are equipped with audible or visual warnings when osteotomies deviate from planning or when a vital structure is about to be entered.

One example of such application is commercialized under the name IGI (Image Guided Implantology, DenX, Jerusalem, Israel). To perform a surgery using this system, a CT scan must be processed in the presence of a special scannographic template. This appliance includes an acrylic custom bite attaching a manufactured arch form registration device that includes ceramic balls. The CT scan data then are transferred to custom software, and implant planning takes place using virtual implants. Before surgery, the registration device is repositioned on a stone model, and the matching process is performed by locating the ceramic markers with a handpiece while maintaining a reference

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**Figure 10-23**  
A. Virtual implant placement was forwarded for fabrication of surgical guides.  
B. The first surgical guide containing 2-mm metal guides is followed by identical guides with wider diameters.  
C. For comparison of planning and execution, the implant level impression was overlaid by virtual implant plan A to create the image (D), demonstrating a clinical accuracy.
probe (called reference body) in place. Both the probe and the handpiece possess light-emitting diodes that can be located in space via infrared cameras mounted above the dental chair. Once this registration has taken place, the surgery may begin using the reference body to locate the patient’s jaw and the diode-equipped handpiece to locate the surgeon’s movements. A computer screen displays real-time positioning of the drill in the mesiodistal, buccolingual, and coronoapical planes (Fig. 10-24). For edentulous patients, temporary implants must be inserted because of the necessity to obtain a stable reference guide containing the markers.

Another similar system is the VirtualScope (Areall, France), which features an advanced registration method allowing for elimination of positioning markers during CT scanning (Fig. 10-25). The rationale for not using fiducial radiopaque landmarks in the scanographic template is that although matching of the markers and their CT image is possible, a small distortion at their level may become a severe mismatch at a distance from them. For instance, an implant coronal position may remain accurate while its apex is 2 to 3 mm from its intended location. Instead, this system offers a real-time three-dimensional capture of the arch via an ultrasound probe. Mapping of the clinical image
can be matched to the CT-scanned data and updated continuously, thus creating an accurate registration independent from a guide. Flags are attached to the handpiece and the ultrasound probe, and their position in space is located by two sets of cameras above the surgeon. The reformatted CT scan, the implant plan, and the actual drill position are viewed at all times through glasses worn by the surgeon. In future versions, a semirigid arm also will connect to the handpiece so that position and angle will be guided by the computer while the surgeon applies the pressure. In addition, a similar registration approach will be used for periapical radiographs. The film holder position will be recorded in relation to an edentulous space. Multiple films will be taken at various angles, and the computer will be able to create a three-dimensional view of the site, thus eliminating the need for a tomogram or a CT scan for small span implant restorations. Interestingly, this system is being developed for dental applications but is also of interest for medical applications, such as for the ear, nose, and throat or neurosurgery.

Other similar methodologies are available, such as the system reported by Wanschitz et al., in which the handpiece and mandible are positioned using light-emitting diodes. In the latest version, the surgeon wears an optical tracking system that allows simultaneous visualization of diodes. In the latest version, the surgeon wears an optical tracking system that allows simultaneous visualization of the surgical field and the plan is the glasses.

These promising computer-guided technologies are currently under development, although most are marketed already. Manufacturers claim a precision within less than 1 mm at the osteotomy entrance and high control of angulations. Using the light-emitting diode localization approach and a tracking system, Wanschitz et al. performed an in-vitro test of accuracy and found it to be within less than 1 mm. Further studies are necessary, but clinical application is beginning and will likely grow rapidly once costs are reduced.

SUMMARY

Surgical models and guidance have acquired a new dimension with the integration of CAD/CAM technology and computer-guided surgery. Precision has been improved and uncertainty and surgical time have been reduced, thus addressing complex rehabilitation with greater confidence. In addition, predictable positioning allows for better prosthetic outcome by simplifying abutment selection and avoiding complex laboratory fabrication when misalignment must be corrected. In addition, novel techniques are emerging that may enable the preparation of the final prosthesis before implant placement. Precise guidance is crucial to such complex reconstruction so that minimal adaptation is performed after surgery. Future technical improvements likely will allow dentists to access these technologies while controlling costs, reducing surgical time, and minimizing restorative steps.

References