A Logical and Progressive Approach to Computed Tomography–Guided Implantology

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A Logical and Progressive Approach to Computed Tomography–Guided Implantology

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Focused Clinical Question: What are the important factors contributing to the success of computed tomography (CT)–guided implantology, and how might this technology best be incorporated into practice?

Summary: CT-guided implantology has provided an opportunity to more completely assess and plan the surgical placement of dental implants. This technology allows viewing of both anatomic and prosthetic information preoperatively in an interactive format. A precise plan can be developed and transferred to the surgery with a computer-generated surgical template. In addition, it facilitates preoperative collaboration among the restoring dentist, laboratory technologist, surgeon, and patient that establishes treatment goals and expectations. There are several types of guides that may be used in CT-guided implantology, with each having different levels of guidance. A logical and progressive approach to implementing CT-guided technology in practice involves a gradual increase in complexity while minimizing risk during the learning curve. Each case can be evaluated, planned, and suited to the patient's needs, as well as the clinician's preference, experience, and risk tolerance.

Conclusions: Incorporating technological advances, such as CT-guided implantology, into clinical practice requires cooperative and collaborative input of all those responsible for patient care. Each clinician must determine the most appropriate diagnostic approach for a given situation. Success in CT interpretation and guided surgery execution is proportional to experience and detail in planning. This paper provides some guidelines and options to incorporate such technology into practice and suggests a logical and progressive approach to ensure success. *Clin Adv Periodontics* 2012;2:263-273.

Key Words: Cone-beam computed tomography; dental implantation; dental implants; implant-supported dental prosthesis; surgery, computer-assisted.

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Background

Historically, implants were placed in the available bone with little consideration of the prosthetic rehabilitation. More recently, a "top-down, prosthetically driven" approach using conventional surgical templates has been used to ensure optimal final tooth position. Understanding the planned prosthetic outcome during surgical placement improves the predictability of implant restorations based on providing a visual positioning reference. Interactive computed tomography (CT) technology has allowed for greater preoperative knowledge of a patient's anatomy, aiding in diagnosis and strategic execution of therapy. In addition, CT-based analysis provides for prosthetic and surgical performance objectives to be established before the rendering of irreversible treatment. Furthermore, this process allows for preoperative collaboration among the restoring dentist, laboratory technologist, surgeon, and patient. This multistep process has been called "collaborative accountability."[1]

The use of CT in implant dentistry was originated by Schwarz et al. in 1989.[2] At that time, CT was an analog film that did not contain prosthetic information. Barium scanning appliances were added to CT-scan-based presurgical analysis to incorporate prosthetic information in the 1990s. In 1994, this was coupled with the introduction of software that allowed for interactive three-dimensional (3D) analysis and planning in a digital format. In this way, the restoring dentist, laboratory technologist, surgeon, and patient could collaborate and preoperatively plan the surgery so that it supported the desired final prostheses. Although this software allowed for virtual implant placement, the virtual plan could not be accurately transferred to the surgery. In 2002, the first computer-generated guides were made available in North America through additive manufacturing using the process of stereolithography. This breakthrough allowed the virtual plan to be transferred to the surgical procedure through a computer-generated surgical guide. Anatomic and planning information obtained by a CT dataset could now be transferred to the patient at the time of surgical execution. The first stereolithographic drilling templates were bone supported. These were later followed by mucosal-supported options in 2004 to allow for "flapless" or minimally invasive surgery. The first generation of stereolithographic drilling templates controlled the bucco-lingual and mesio-distal orientation but lacked vertical control. In 2006, the next generation allowed for similar surgery to be completed that included control in all three planes and simplified delivery of an immediate load provisional prosthesis. In 2008, the release of specialized surgical kits as a companion to stereolithographic surgical guides allowed for computer-aided design/manufacturing-guided surgery and prosthesis fabrication and delivery. These kits are available as part of several implant manufacturers' armamentarium. The dates mentioned in this paragraph that are not cited refer to milestones in the development of computer guided implant dentistry achieved by one of the authors (AR) of this study in collaboration with the company that developed the computer software and computer generated surgical guides. The account of his historical accomplishments in this area are unpublished and therefore not cited.

Today, this technology provides many options, each with inherent levels of risk. A logical and progressive approach to implementing CT-guided technology in practice involves a gradual increase in complexity while minimizing risk during the learning curve. Each case can be evaluated, planned, and suited to the patient's needs, as well as the clinician's preference, experience, and risk tolerance. Interactive CT studies containing anatomic and prosthetic information can be used to plan surgery that is executed with a conventional surgical guide (Fig. 1). Alternatively, the surgical plan can also be executed with bone- or tooth-supported computer-generated stereolithographic drilling guides in a surgery that is partially guided (i.e., no depth or vertical control) (Fig. 2). Also, surgery can incorporate total guidance with a bone-supported, tooth-supported, tooth–mucosa-supported, or completely mucosa-supported stereolithographic drilling guide in which mesio-distal, bucco-lingual position, vertical depth, and hex timing are controlled through one guide (Fig. 3). Options may also include a flapless approach in which a preoperatively fabricated immediate load provisional prosthesis is delivered. Drilling guide stability may also be enhanced with fixation screws (Fig. 4). There are many important considerations when using CT information to assist in developing a surgical plan. Factors affecting the quality and outcome of implant-based care using interactive CT technology have been reported previously.[3,4]

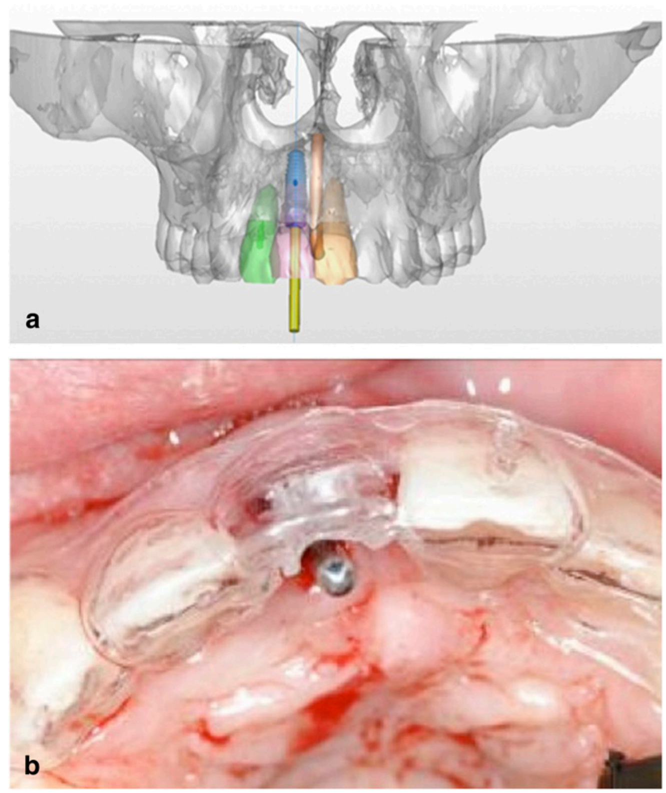

FIGURE 1 Virtual plan with a conventional surgical guide. **1a** Virtual plan in three dimensions. **1b** Conventional surgical guide.

Factors Affecting the Quality of Data Contained in a CT Study

Several factors can affect the quality of the data contained in a CT study. A detailed description of the technical aspects of CT imaging for computer-guided implantology has been published previously.[1] The first step in incorporating accurate prosthetic data into the CT study is careful fabrication of a scanning prosthesis.[5] Case-type patterns have been described to help determine the most suitable diagnostic wax up to address the tooth and/or dento-alveolar dimensions that have been compromised by tooth loss.[6] These case type patterns lead to a patient-specific diagnostic wax up, which in turn is transferred to the scanning appliance so that imaging is performed with as much meaningful and accurate prosthetic information as possible to prepare the team for 3D treatment planning. In general, the scanning appliance should be derived from high-quality mounted study models and a diagnostic wax up that accurately represents the desired final prosthesis. The wax up should be completed with proper consideration of the final occlusal scheme, esthetic concerns, and appropriate spacing of dental implants. The scanning prosthesis, derived from the wax up, must be fully seated and stabilized by a radiolucent bite registration during scanning. Inspection windows in the prosthesis can be helpful to verify seating (Fig. 5). Consideration should be given to removing metallic restorations that are planned for replacement before CT scanning to minimize radiographic artifact/noise. The data quality in CT can primarily depend on the extent of radiation artifact if a patient has a heavily restored dentition. The quality of the 3D reconstruction and segmentation process completed by the technician converting the raw DICOM (digital imaging and communications in medicine) data into the interactive planning software may be severely limited by artifact. If metallic artifact is extensive, it may not allow for a tooth- or mucosa-supported stereolithographic drilling template to be created because a reproducible triangulated plane needs to be confirmed between the CT scan plan and an optically imaged stone model. In fact, 3D reconstructions produced with the interactive software during the segmentation process often do not represent anatomic reality. A bone-supported surgical guide may be the only option possible.

Factors Affecting the Quality of the Surgical Plan in the Interactive Software

As indicated above, accurate prosthetic information in the CT dataset is critical for surgical planning. The

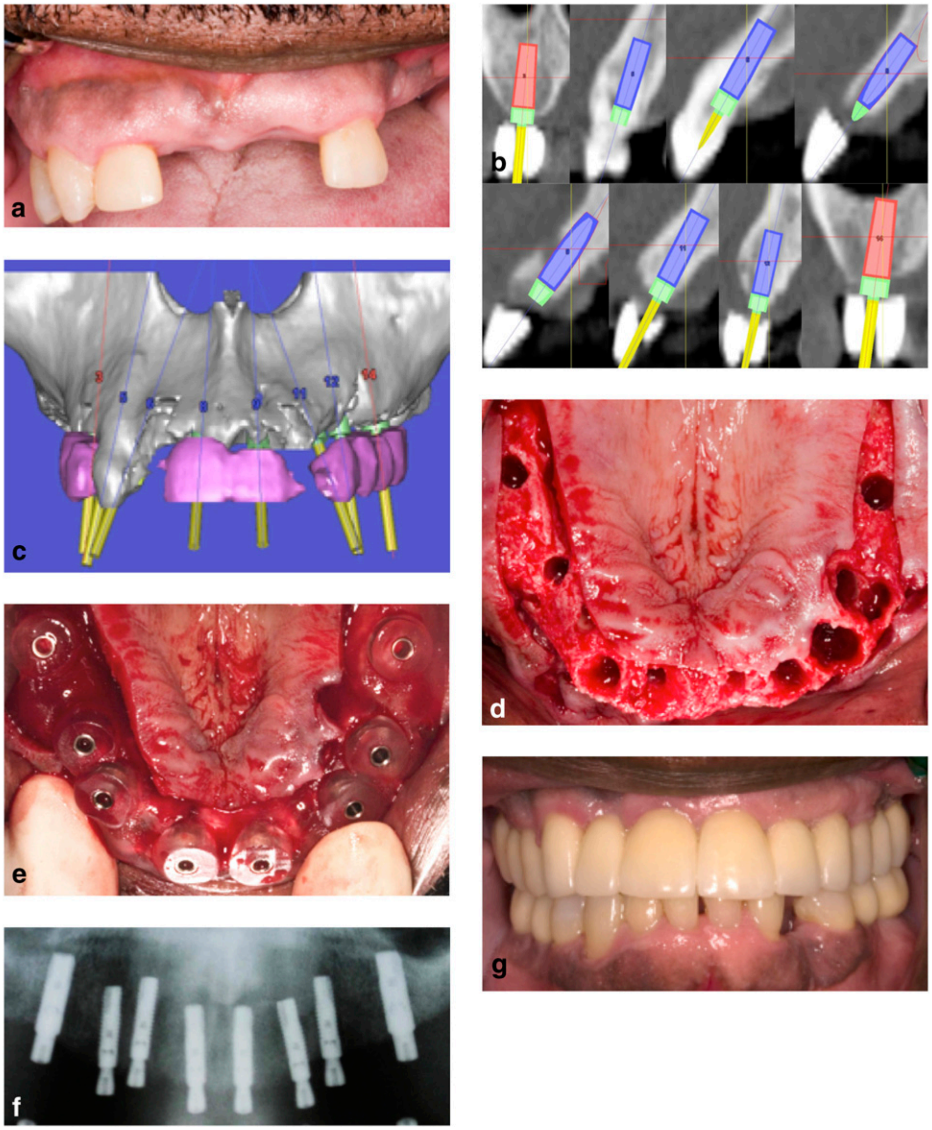

FIGURE 2 Partially guided case with bone-supported stereolithographic surgical guide. **2a** Preoperative facial view. **2b** Virtual plan in two dimensions. **2c** Virtual plan in three dimensions. **2d** Edentulous ridge after flap reflection and extractions. **2e** Surgical guide in place. **2f** Postoperative radiograph. **2g** Final restorations.

knowledge and experience of the attending clinicians are also important factors in developing a treatment plan. The process for developing a treatment plan using CT imaging and computer software has been described previously.[6,7] If the prosthetic workup and/or the quality of the imaging and/or conversion process is compromised or is inaccurately represented in the diagnostic setup and scanning appliance, the surgical planning and execution will be inaccurate. This is especially important when a totally guided approach to surgery is used. Outsourcing diagnosis and case-planning responsibilities to a third party should be considered carefully. It is the opinion of the authors that the dentist who has examined the patient and who will be executing the surgery in consultation with the restorative dentist should complete the surgical planning.

Factors Affecting the Quality of the Surgical and Prosthetic Outcome

The surgical outcome in any guided case is dependent on all the steps that preceded the surgery. Any compromise in the quality of the data incorporated into the CT scan and/or surgical plan will be transferred to the stereolithographic guide. The dimensional stability of the stone model (if needed for a tooth- or mucosa-supported guide) and quality of the rapid prototype medical modeling and stereolithographic surgical guide construction will further affect the accuracy of the surgical procedure. An accurate stereolithographic guide that precisely incorporates a well-thought-out surgical plan must be properly used during the surgery for the implants to be placed as planned. The techniques involved in their use have been described previously.[1,3,8-10] The guide must be fully seated and stable during the surgery. As recommended for the scanning appliances when indicated, inspection windows can ensure proper seating of the drilling guides. Cross-referencing can be made between the stone models and the patient to confirm seating accuracy. In addition, a surgical dress rehearsal can be performed on a stone model or stereolithographic medical model before the actual surgery to further validate the accuracy of transfer of the virtual plan to the patient before live surgery. Fixation of the

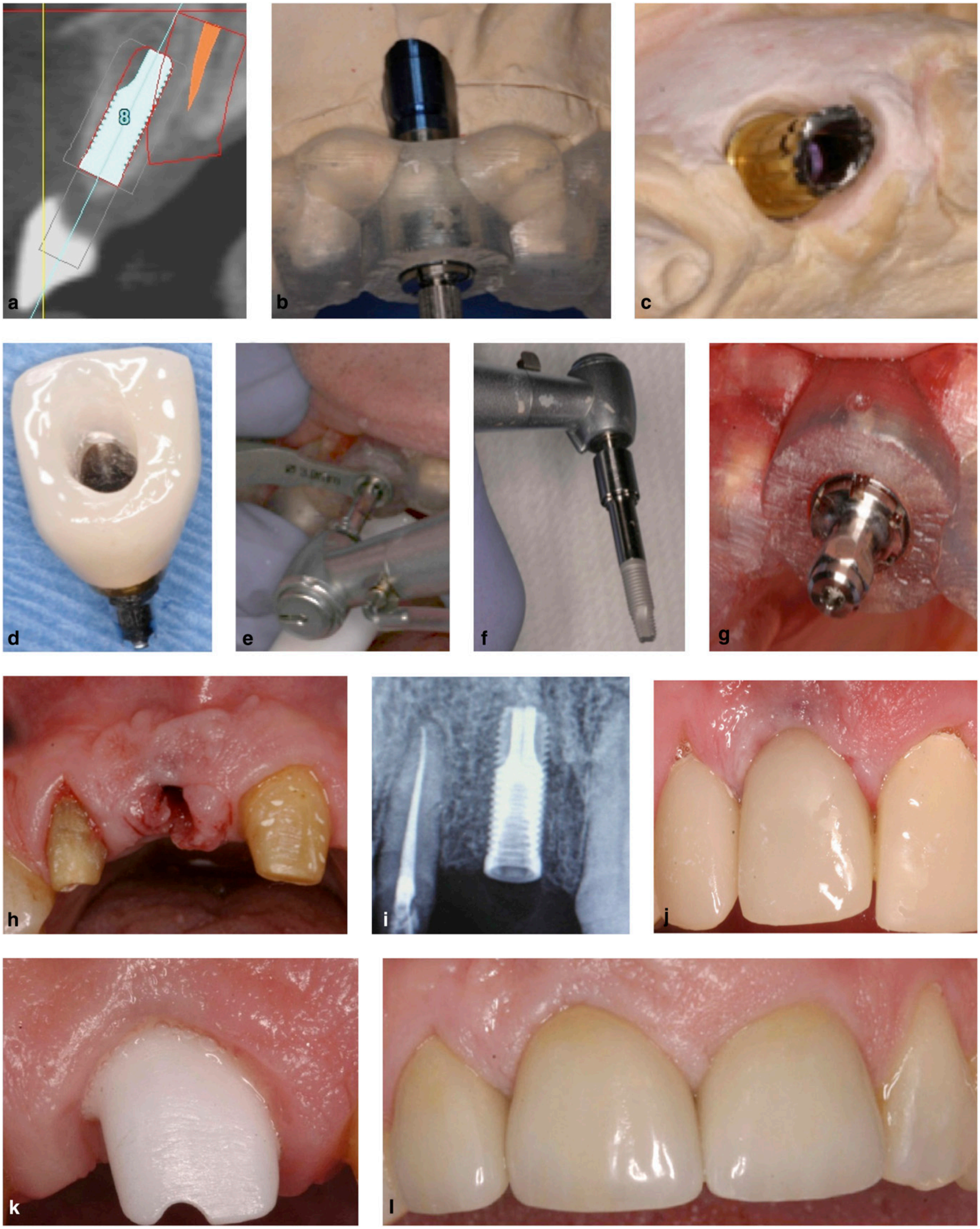

FIGURE 3 Fully guided case including hex timing with tooth-supported stereolithographic guide. **3a** Virtual plan in two dimensions. **3b** Stereolithographic guide with laboratory analog. **3c** Model with analog and temporary abutment in place. **3d** Provisional restoration. **3e** Osteotomy preparation. **3f** Implant with carrier for placement with guidance. **3g** Implant placed (note that hex timing is not perfectly lined up; this was torqued further to line up hex, allowing placement of provisional). **3h** Surgery complete. **3i** Postoperative radiograph. **3j** Provisional placed and shortened to remove contact in protrusive. **3k** Final abutment. **3l** Final restoration.

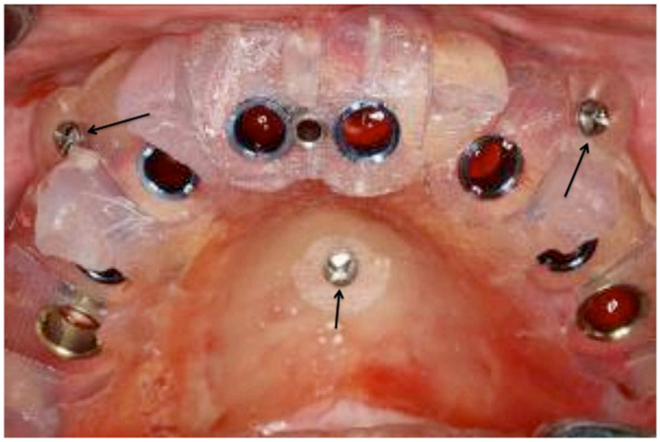

FIGURE 4 Mucosal-supported stereolithographic guide with fixation screws (arrows indicate fixation screws).

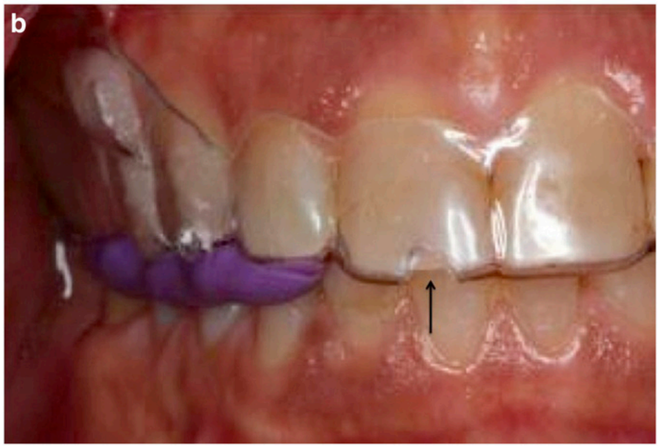

FIGURE 5a Scanning appliance. **5b** Appliance in place stabilized with a radiolucent bite registration; note the inspection window to confirm seating (arrow).

guides during the surgery can be considered, especially in totally guided cases (Fig. 4). The final outcome is dependent on the execution of the surgical procedure. Any errors in previous steps will be incorporated into the surgical guide and unfortunately transferred to the surgery, affecting the outcome.

Considerations in Determining the Type and Degree of Guidance in Implant Surgery

There are several guides that can be considered for use in implant surgery (Fig. 6, Table 1). One may choose to use CT technology for data acquisition only and use the scanning prosthesis as a conventional surgical guide during surgery (Fig. 1). This approach is superior to planning using conventional radiography because there is much more clinical information pertaining to regional anatomy available in advance of the surgery. In addition, it provides a representation of desired prosthetic tooth position and its relationship to the available bone and other important anatomic structures. Operator error in terms of axial deviation and angle discrepancy from the virtual plan are generally greater with a conventional surgical guide.[11,12]

The next level of guidance is a partially guided case in which a bone-supported computer-generated guide is used to carry the virtual plan to the surgery (Fig. 2). In this case, the guide determines the axial (mesio-distal and bucco-lingual) position of the implant. The apico-coronal position of the implant is determined directly by the surgeon. In this open procedure, the surgeon can verify the accuracy of the guide and preoperative plan during the surgery. One advantage of this approach is that, if the anatomy observed during the surgery is at odds with the plan or there are other circumstances that decrease confidence in the accuracy of the stereolithographic drilling guide, the surgeon can abort use of the computer-generated guide and complete the procedure with a conventional surgical approach.

A tooth- or tooth–mucosa-supported drilling template can be used with or without a flap (when appropriate) (Figs. 7 and 8). Use of these guides requires experience and attention to detail in seating accuracy. The apico-coronal position of the implant is again determined by measurements made intraoperatively. If the case is completed with a flapless approach, there is less opportunity for the clinician to verify and validate the regional anatomy as well as the accuracy of implant position during the surgery. There is a greater reliance on the guide in determining implant position. Although decreased postoperative pain and swelling have been reported with flapless minimally invasive options, there is a greater risk for an adverse event because visual confirmation is not possible and tactile sensation is reduced.[10,13] The diminished feedback decreases the information available regarding primary stability in terms of insertion torque during the surgery. When it is not possible to visually confirm implant position during the surgery, there is an increased risk of an unfavorable outcome. A surgical dress rehearsal through "model surgery" performed preoperatively can help avoid these potential problems. The feasibility for a flapless approach is highly dependent on the regional anatomy characteristics and other patient-related factors.

Finally, in a totally guided case, the surgical guide determines the apico-coronal, bucco-lingual, and mesio-distal orientation of the implant (Figs. 3 and 9). Some implant

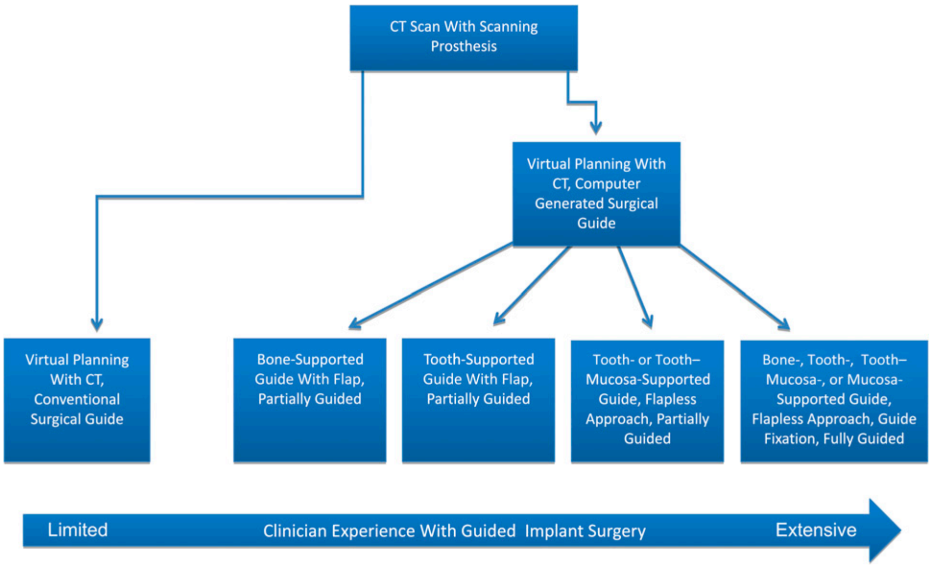

FIGURE 6 Logical and progressive implementation strategy.

systems also allow for rotational position control of the implant platform (i.e., hex timing) (Fig. 3). This facilitates presurgical construction of a provisional that can be placed as an immediate restoration at the time of surgery. With a totally guided approach, the drilling guide is often fixed and the case is sometimes completed with a flapless or minimally invasive approach.

Table 1 lists the guide options available with increasing levels of control. The greater the dependence on the computer-generated stereolithographic drilling guide to control implant position, the greater the importance of clinical and prosthetic accuracy that is embedded into the CT study. Any concern regarding the quality of the preoperative data collection would dictate a lower level of control by the guide, with more intraoperative verification by the surgeon using direct vision (i.e., a bone- or tooth-supported guide with an open approach might be selected in these cases). Greater control by the guide calls for greater knowledge, skill, and experience by the clinician. The case complexity and degree of risk to local anatomic structures are also important considerations in guide selection (Fig. 6; Table 1). For example, placement of a single implant in a mandibular first molar position in which the edentulous ridge is wide, without lingual undercuts, and when there is sufficient bone height above the inferior alveolar nerve may not justify a computer-generated guide. This assumes that the typical potential axial deviations and angle discrepancies associated with a conventional guide would not affect the prosthetic outcome. In this case, virtual planning would allow for accurate anatomic measurements and patient safety measures to be evaluated in advance, leading to surgical therapy using a conventional surgical template (Fig. 1). When the bone volume is limiting, the risk to anatomic structures is increased, multiple implants are planned, and/or esthetic concerns are more demanding, there is a greater need for precision and accuracy of implant placement (Figs. 3 and 9). In these clinical situations, use of a computer-generated stereolithographic drilling template for partially or totally guided implant therapy may be critical.

Conclusions

Incorporating technological advances, such as CT-guided implantology, into clinical practice requires cooperative and collaborative input from all those responsible for patient care. Each clinician must determine the most appropriate diagnostic approach for a given situation. Success in CT interpretation and guided surgery execution is proportional to experience and detail in planning. Computer software and computer-generated stereolithographic surgical guides are not a substitute for appropriate surgical training and experience. Rather, they relate anatomic and prosthetic information preoperatively that fosters collaborative treatment planning and carry the plan to the surgery in a precise manner. This paper provides some guidelines and options to incorporate such technology into practice and suggests a logical and progressive approach to ensure success. It is clear that this technology can play a valuable role in improving the quality and predictability of patient care. ■

Acknowledgments

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TABLE 1 CT Guidance Options

Type of Guidance	Advantages	Disadvantages
Virtual planning, conventional surgical guide (Fig. 1)	Maximum preoperative information Preoperative planning for anatomic challenges Lower cost	Less precision for implant placement Virtual plan cannot be taken precisely to surgery Involves intraoperative decision making Reduced level of collaboration between surgeon and restorative dentist
Bone-supported computer-generated guide, partially guided (Fig. 2)	Open surgical approach allows for intraoperative verification of guide/plan and ridge augmentation surgery if needed Easier to verify seating of guide and maintain stability during surgery Decreases risk to anatomic structures Greater precision of implant placement Greater collaboration among clinicians Minimal intraoperative decisions	Requires flap Additional cost Vertical and rotational position determined without surgical guide Requires greater clinical knowledge, skill, and judgment Implant is delivered without surgical guide
Tooth-supported computer-generated guide, open surgical approach, partially guided (Fig. 7)	Open surgical approach allows for intraoperative verification of guide/plan and ridge augmentation surgery if needed Greater precision of implant placement Greater collaboration among clinicians Minimal intraoperative decisions	Requires flap Additional cost More difficult to seat guide and verify and maintain guide stability Vertical and rotational position determined without surgical guide Requires greater clinical knowledge and skill Implant is placed in osteotomy without surgical guide
Tooth- or tooth–mucosa-supported computer-generated guide, flapless approach, partially guided (Fig. 8)	Flapless approach associated with less postoperative pain and swelling Possible greater precision of implant placement Greater collaboration among clinicians Minimal intraoperative decisions	Additional cost More difficult to seat guide and verify and maintain guide stability Vertical and rotational position determined without surgical guide Requires greater clinical knowledge and skill Implant is placed in osteotomy without surgical guide

TABLE 1 (Continued) CT Guidance Options

Type of Guidance	Advantages	Disadvantages
Bone-, tooth-, tooth–mucosa-, or mucosa-supported computer-generated guide, flap or flapless approach, fully guided, may include immediate load provisional, may include fixation of guide (Figs. 3 and 9)	Control of horizontal, angulation, vertical, and rotational position of implant Flapless approach associated with less postoperative pain and swelling Greatest precision of implant placement Greater collaboration among clinicians Minimum intraoperative decisions Implant is delivered with guidance Preoperative fabrication of provisional restoration possible	Additional cost Requires greatest amount of clinical knowledge and skill Highest risk as a result of greater dependence on guide with decreased verification Modification of alveolar bone by augmentation or alveoloplasty not possible

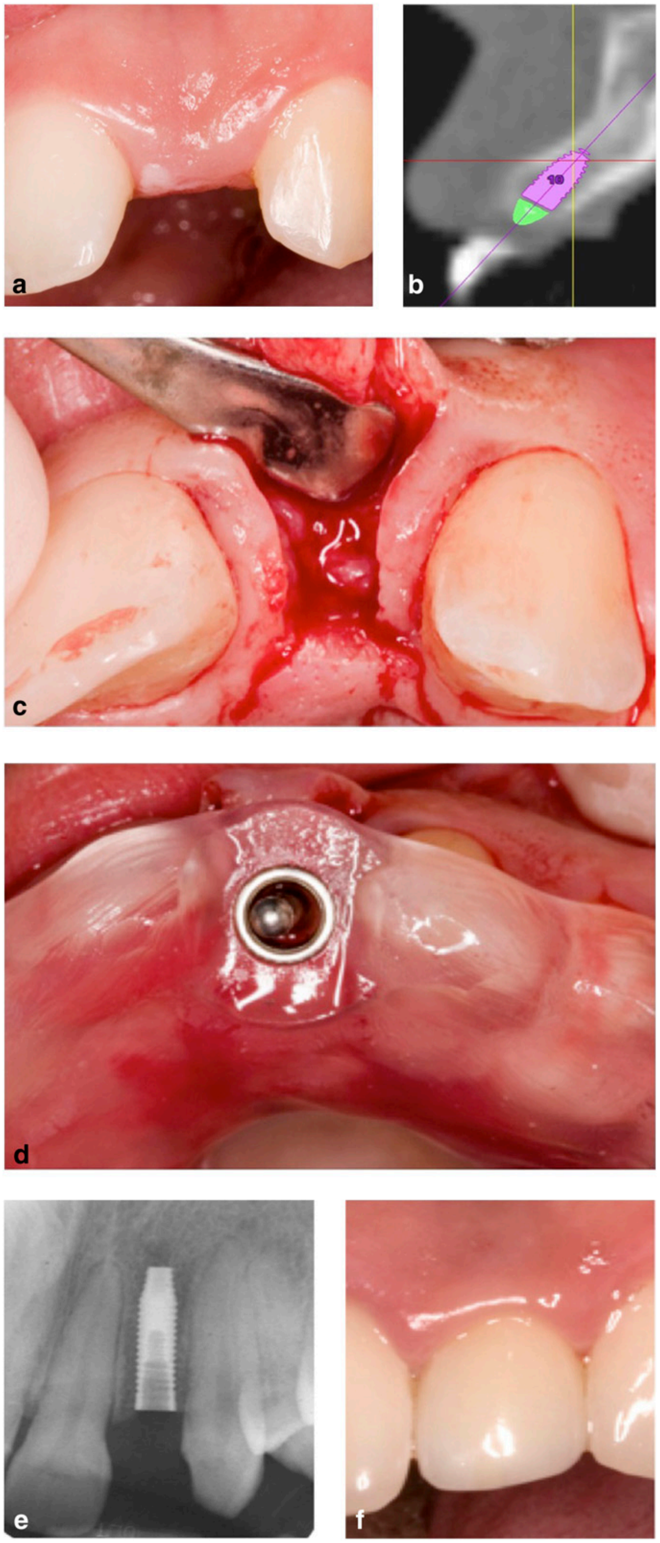

FIGURE 7 Partially guided case with tooth-supported stereolithographic guide used with a flap. **7a** Preoperative facial view. **7b** Virtual plan in two dimensions. **7c** Flap reflected. **7d** Guide and guide pin in place after osteotomy complete. **7e** Postoperative radiograph. **7f** Final restoration.

FIGURE 8 Partially guided case with tooth-supported stereolithographic guide used without a flap.

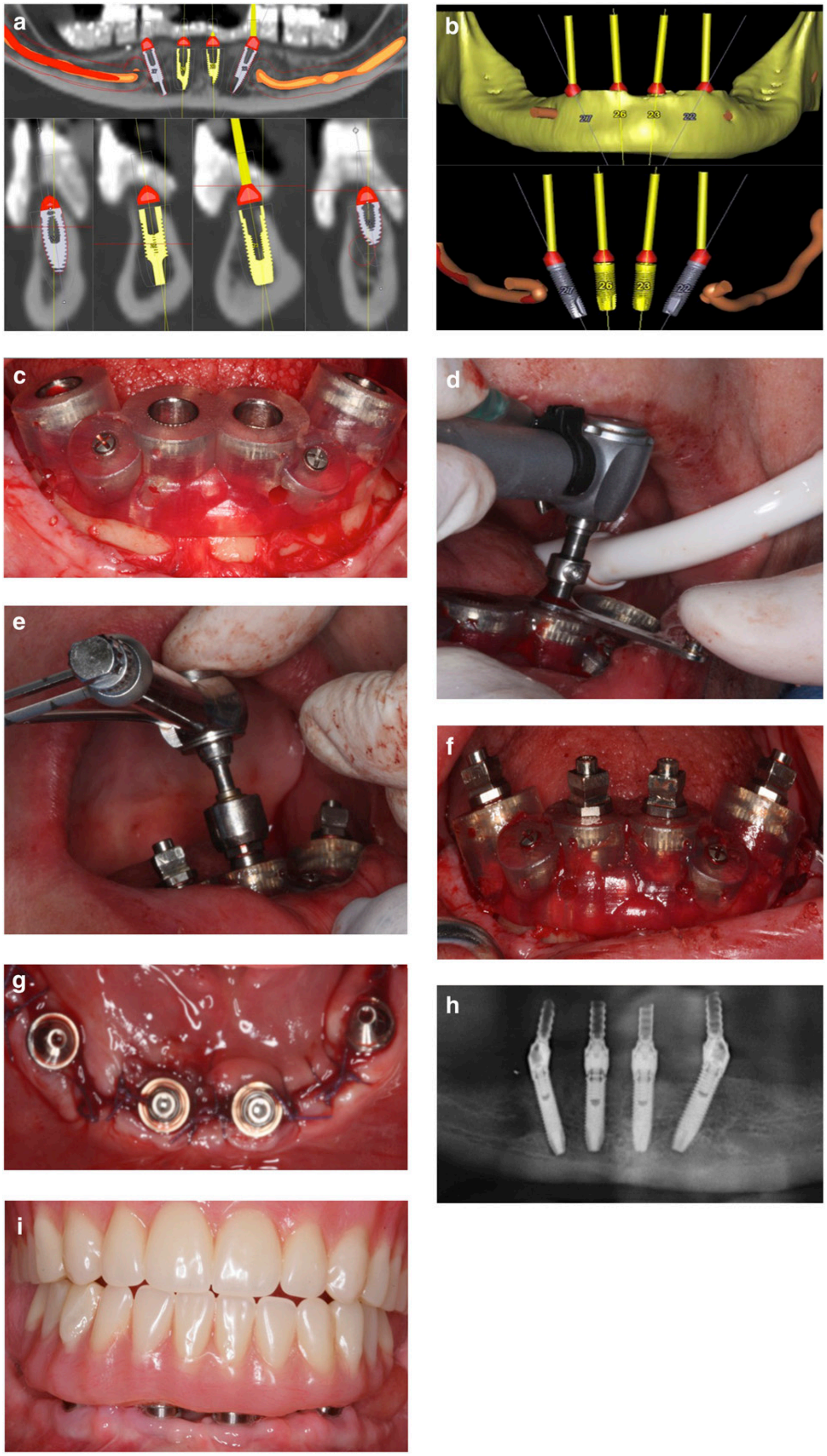

FIGURE 9 Fully guided case with bone-supported stereolithographic guide. **9a** Virtual plan in two dimensions. **9b** Virtual plan in three dimensions. **9c** Flap reflected, guide in place with fixation screws. **9d** Osteotomy preparation. **9e** Implant placed with guidance. **9f** Implant placement complete. **9g** Abutments placed. **9h** Postoperative radiograph. **9i** Existing denture converted to an immediate fixed provisional (image taken at 1 week after surgery).

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