CAD/CAM Guided Surgery in Implant Dentistry: A Brief Review

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ABSTRACT

Advanced imaging and CAD/CAM technologies and their applications in enhancing treatment outcomes in implant dentistry have gained widespread interest. Guided implant surgery utilizing these advanced technologies has significant applications in implant dentistry. This article provides information on some of the perceived advantages and disadvantages for planning guided versus conventional implant surgery as well as basic steps involved in the fabrication of guided surgical templates (GST).

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The planning and execution of a treatment plan in implant dentistry typically involves a team approach, with the placement of implants determined by a definitive restorative goal. Radiographic imaging plays a critical role in this process. Traditionally, 2-dimensional imaging and a guide made on the dental cast, also known as a conventional surgical template (CST), (Fig. 1) were used to assist in proper surgical placement and angulation. More recently, cone beam computerized tomography (CBCT) has gained popularity and is routinely used in the planning process.[1]

With the introduction and advances of 3-dimensional (3D) imaging and computer aided design and computer aided manufacturing (CAD/CAM) technology, implant placement can be virtually planned. This planned information is then transferred with stereolithographic (STL) rapid prototyped (RP)[2] or computer numeric control (CNC) milled templates[3] or through a computer controlled surgical navigation system.[4] Three-dimensional imaging allows the clinician to study the area of interest and place virtual implants into the computer model of the jaw. This information can be used to manufacture a physical surgical template for (guided) surgery. (Fig. 2). This surgical template for guided surgery, or guided surgical template (GST), will ultimately

Figure 1. View of a tooth-supported CST. The access hole is made to allow accurate placement of the implant in an ideal location.

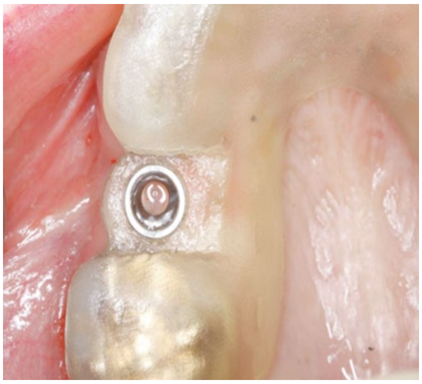


Figure 2. Occlusal view of a GST. The metal sleeve guides the drills during the osteotomy.

control the precise outcome of the implant placement.

Guided vs. Conventional Surgery

CSTs are made in the dental laboratory on casts generated from impressions and have been used routinely for the placement of dental implants. However, during implant placement, CST's allow for potential clinician-mediated positioning errors due to inadvertent angular and linear deviations during osteotomy or drilling sequences, reducing the degree of accuracy. Furthermore, CSTs have limited capability to control precise depth location of the implant in the apico-incisal position. The use of CSTs can be a significant disadvantage during placement as proper angulation and depth of dental implants are critical factors related to the final esthetic and functional outcome of a restoration.[6,7]

The potential limitations of 2-dimensional radiographic imaging and CST are amplified when planning implant placement near critical anatomical structures such as nerves, blood vessels, and sinus cavities.[8]

Alternatively, GSTs are virtually planned and designed using data accrued from 3D imaging utilizing computer software and digital workflow for planning and manufacturing.[9] The GSTs have metallic sleeves that direct and allow precise implant placement in the x, y, and z axes. CBCT scanning and digital imaging techniques, which allow visualization of the placement of dental implants in three dimensions, have gained popularity in their applications given their ability to achieve predictable and accurate results.[10] In addition, this improved precision and accuracy reduces the need for flap reflection. (Fig. 3)

Flapless surgery for implant placement using a CST can be unpredictable especially when multiple implants are being placed. Since the CST is not manufactured using 3D imaging, less information and guidance for the osteotomy is available compared to the GST. Additionally, when using a CST, it is prudent to elevate a flap to allow direct visualization and ensure placement of the implants within the bone. This is more traumatic to the patient, increases postoperative complications, and results in delayed wound healing time as compared to flapless surgery. (Fig. 4)

Figure 3. Occlusal view of a maxillary arch on the same day after surgery using a GST for placement. The utilization of the GST enabled precise positioning even with a flapless surgical procedure.

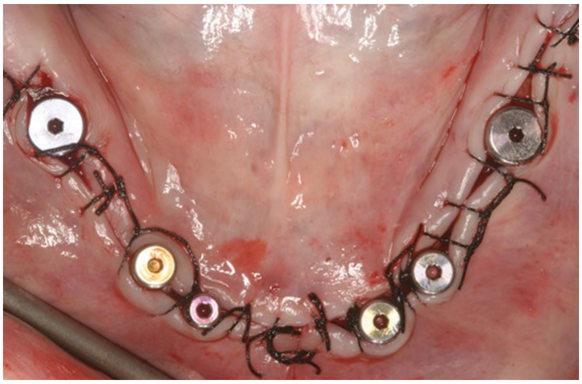
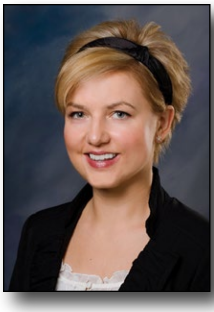


Figure 4. Occlusal view of the mandibular arch where the implants were placed using a CST. A flap was elevated for this surgery and significant initial soft tissue healing has to occur compared to the situation in Figure 3.

The accuracy of surgical templates utilized for guided surgery has been extensively researched and documented. Sament et al[2] compared the accuracy of implant placement with GSTs made using stereolithographic rapid prototyping to CST utilizing an in-vitro model and reported that implant placement was improved when a GST was used. Widman and Bale[11] compared the accuracy of computer-aided guided implant surgery with that of surgeries performed with CSTs. They reviewed multiple studies and concluded that while the guided surgery did improve accuracy and consistency, the costs and additional steps associated with guided surgery offset some of these advantages. Di Giacomo et al[12] reported that the fit and stability of GSTs significantly influenced accuracy in implant placement and observed a discrepancy between the planned and placed position of the implant, which was greatest at the implant apex versus the implant head. This is likely due to cumulative error of placement and angulation. Van Steenberghe et al[13] reported a high degree of accuracy in implant placement when utilizing GST in cadavers. They were able to place definitive fixed prosthesis on completely edentulous arches with only minor adjustments immediately after implant placement. Utilizing CBCT imaging, Van Assche et al[14] compared the deviation between planned and placed implants

Author Profile



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and reported that an average 2 degree angular and 2 mm linear deviation at the apex should be factored as negative errors when performing guided surgery.

Hence, utilization of GSTs allows for efficient and precise implant placement, reduced morbidity, and the potential for improved patient satisfaction. Compared to the CST, which has a drilled access hole that directs the clinician in the initial osteotomy (Fig 5), the GST has unique metallic sleeves that factor the dimensions of the implant planned for placement (Fig. 6) and provides instrumentation in the form of sequential drill guides that control position, angulation, and depth of the osteotomy (Fig. 7).

Figure 5. Example of a CST where access holes have been placed for ideal implant placement

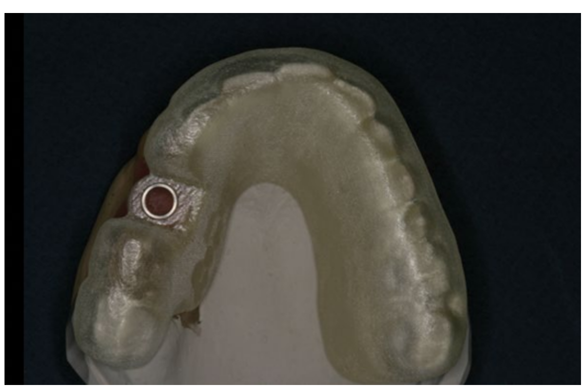

Figure 6. Occlusal view of a GST

Figure 7. Horizontal sleeves are available for insertion into the metallic sleeves for the different drill diameters during osteotomy.

While computerized guided surgery has many advantages, one must carefully consider the factors related to each specific patient's situation to ensure success (Table 1). This is especially significant when available bone is not sufficient for the implant dimension selected for a specific site and flap reflection for bone grafting is necessary.

Multiple software and guided surgical systems are available to the clinician. Examples of these guided systems are NobelClinician/NobelGuide™ (Nobel Biocare, USA), iDentiGuide (iDent, USA), Invivo 5 Anatomy Imaging/Anatomage Guide (Anatomage, USA) and SimPlant®/Surgiguide® (Materialise, Belgium).

Classification of GST Based on Support

Surgical templates are often categorized based on their mode of support: teeth-supported, teeth-mucosa supported, mucosa supported, and bone supported.

1. Teeth supported templates are typically used in partially dentulous sites such as a single missing tooth with flapless implant placement (Fig. 8).
2. Teeth-mucosa supported templates are used when multiple teeth are missing and when the surgical template is supported partially by the mucosa and the soft tissue as in a Kennedy classification I situation.[15]

Figure 8. Teeth supported guide

3. Mucosa supported templates are used in completely edentulous patients and with flapless implant placement (Fig.9).
4. Bone supported templates are used in either partially or fully edentulous sites but typically require extensive flap elevation so that the surgical template is placed directly on the bone (Fig 10).

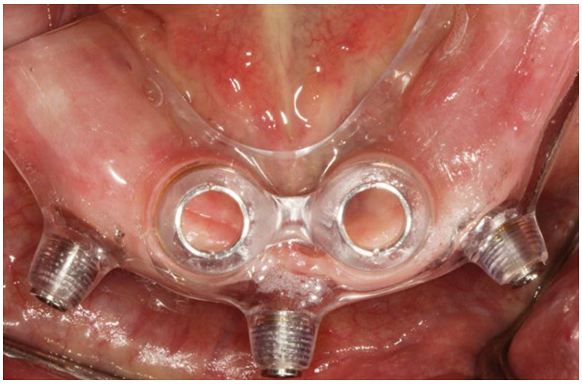

Figure 9. Mucosa supported guide

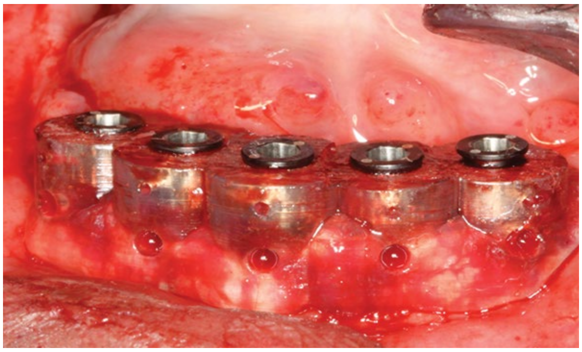

Figure 10. Bone supported guide

Protocol Involved in Fabrication of GST

The standard protocol for guided implant placement is comprised of a diagnostic phase (clinical and radiographic examination), planning phase, (designing and fabricating the guided surgical template), and the surgical phase. Steps involved for fabrication might differ depending on the various software options available and their individual applications as prescribed by respective manufacturers. The following steps describe the basic protocol utilized in fabrication.

Step 1: Fabrication of a radiographic template. The radiographic template is a prototype of the CST typically made from acrylic resin with radiopaque markers incorporated to allow assessment of the relationship of the bone to the planned prosthesis. For some systems, radiographic templates are not mandatory. These systems would alternatively offer the option of a virtual diagnostic wax pattern (Figure 11).

Step 2: When scanning the patient for guided surgery, artifacts (e.g., metallic scatter) can be introduced. Therefore with most systems, a dual scan procedure is followed, to improve the overall accuracy. The first scan is of the

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ADVANTAGES OF GUIDED SURGERY	DISADVANTAGES OF GUIDED SURGERY
Could offer improved precision (consistency in achieving the same implant position each time) and better accuracy (achieving desired implant location) when protocol is followed precisely, with detailed attention to every step and with appropriate patient selection,	Longer initial treatment time (multiple steps and appointments for radiographic template fabrication)
Flapless surgery is possible (potential for lower morbidity)	Technique sensitive (precise data collection is important and each step in the fabrication process is critical for a successful outcome)
Efficiency (reduced surgical time)	More radiation exposure to the patient from 3-D imaging (which is required for fabrication) compared to routine 2-dimensional imaging
Faster initial healing time (reduced trauma to soft tissues)	Instrumentation can be awkward in limited interarch space situations (difficult in posterior region, especially in patients with limited mouth opening)
Safety (avoidance of important anatomical structures)	Reduced cooling efficiency during osteotomy (Due to the close approximation between the drill and the surgical guide; less irrigant reaches the surgical site)
Provisional restorations can be fabricated prior to the surgery	Increased cost
Could help control and maintain drill trajectory when implants are placed immediately in a fresh extraction socket	Limited application when insufficient bone is present and bone grafting is needed.
	Increased complexity especially when considering the number of systems and software programs available on the market, each with their own unique characteristics and guide fabrication methodology.

Table 1. Advantages and disadvantages of guided surgery

patient's maxilla and/or mandible. There are four options for the second scan to capture the teeth.

- ***Option 1:*** A CBCT scan is obtained of a radiographic template
- ***Option 2:*** A CBCT scan is obtained of the patient's cast
- ***Option 3:*** An optical scanner is used to scan the patient's cast
- ***Option 4:*** An optical scanner is used to scan the patient's teeth directly

Optical scans produce STL files, and CBCT scans produce Digital Imaging and Communications in Medicine (DICOM) files. The STL or the DICOM files are then imported and superimposed with the DICOM files from the CBCT scan of the patient. The digital planning is carried out at this stage using the software features, which are specific to each system. However, most systems will allow planning for multiple implant manufacturers' products.

Step 3: The clinician must initially plan the implant positions according to the proposed implant sites. For fully edentulous templates, anchor pin placement should be considered, since soft tissue supported templates will be less stable during surgery. Two to four pins can be placed around the arch by the technician, and the template will be eventually secured to the patient utilizing these anchor pins.

Once an initial plan is completed, the clinician then submits the planning files to the company that will fabricate the templates. In a few business days, a final planning file will be available for review. The clinician should review the final planning file and, if acceptable, sign the consent for GST fabrication. If unacceptable, changes must be made and the modified file resubmitted to finalize the surgical plan. Surgical templates typically take seven business days to fabricate and ship, and rush services are available.

The information is accepted and signed by the planning dentist to comply with the legal and liability requirements for each manufacturer. When this information is received, along with the payment, the order for the GST is complete. Depending on the manufacturer, the GST is fabricated by rapid prototyping, CNC milling or utilizing a surgical navigation system. It is then returned and tried in prior to surgery, except in the case of a bone supported guide.

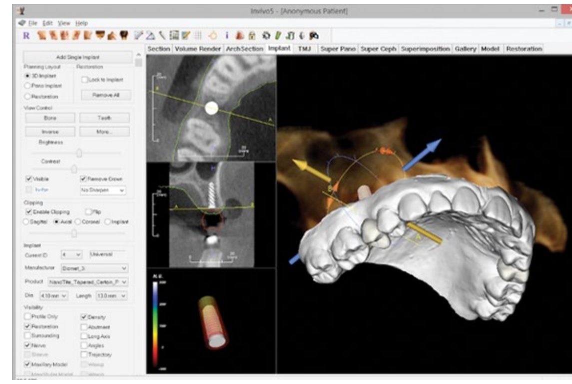

Figure 11. Virtual wax pattern with overlay optical scan of dental cast on CBCT scan

Discussion

With increased demand for implants, technology for guided surgical applications will continue to improve allowing clinicians to place implants more accurately, predictably, and efficiently. However, the drawbacks with guided surgery need to be understood in order to avoid complications. Many studies have evaluated guided surgery for dental implants. Though the results vary based upon each study design, it has been documented that there are discrepancies between the planned implant location and the actual location of the implant.[10,11,14,16] This should caution the clinician from attempting to place implants through guided surgery when adequate bone is not present to accommodate minor errors. The clinician should avoid trying to 'thread the needle' utilizing guided surgery, as slight deviations might result in perforations. Furthermore, since flapless techniques are commonly utilized for guided surgeries, the clinician is unable to visualize perforations if they do occur. Postoperative CBCTs are one way to confirm accurate implant placement, but even then it is impossible to detect minor perforations that can lead to complications later. The authors suggest that in situations when the proposed implant diameter is almost similar to existing bone dimensions, it is prudent to elevate a flap prior to implant placement so that any perforations can be managed by guided tissue regeneration. Guided surgery is challenging when the patient has limited mouth opening.[17] Due to the extra height of the metal sleeves and the additional length of the drills used for the osteotomy, it might be difficult for some patients to open wide enough, especially when implants are being placed in the posterior region. Clinicians need to evaluate mouth opening prior to incurring the additional expenses involved in the fabrication of GST.

Conclusion

Implant surgery with guided surgical templates can provide several advantages over those

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performed with conventional surgical templates. However, to date there has been no conclusive evidence that suggests that one type of surgery (conventional versus guided) is superior. The clinician must understand the limitations and advantages associated with guided surgery so as to apply the benefits of this rapidly evolving technology when appropriately indicated. Bone dimension at the edentulous site, proximity of the planned implant site to vital anatomic structures, cost, need for sophisticated equipment and additional steps, increased accuracy and efficiency are all factors to be considered when selecting the type of surgical template for implant placement. **AO**

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