

Digitally Assisted Implant Therapy

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ABSTRACT

Introduction: Techniques and workflows have been developed to use guided surgery in most clinical patient case applications, such as immediate implant placement; tilted implant/hybrid restoration and implant placement.

Aims: Integrating the guide sleeves is a manual process, as is the removal of holding or support structures.

Methods/Materials: Different techniques have been developed to transfer the ideal implant position to the surgical field, using templates. Implant planning software matches CT data to wax up information, allowing the clinician to view a 3D image of the jaw when planning implant position.

Results: Guided implant surgery makes it easy for the clinician in rendering optimal clinical outcome. Computer-assisted implantology has found to overcome the errors encountered during implant site preparation more precisely.

Conclusion: The protocols that need to be followed by this technique are based upon the concept of prosthetic-driven implantology and CT-scan analysis.

Key Words: Surgical Guide, Data Acquisition, STL File, Intraoral Scanner, Computer assisted, Guided surgery

INTRODUCTION

Dental implants have been used as a way to replace missing teeth hence is considered to be an important contribution to dentistry. The success depends on the ability of implant material to integrate with surrounding tissue depends on several factors like bone quality and quantity, and the implant loading condition.¹

The tissue that surrounds implants is known as peri-implant tissue and an intimate contact between the peri implant bone and implant surface, known as osseointegration should be achieved for success of an implant. The peri-implant soft tissue mimics to that of the natural teeth.²

To plan implant cases properly much time and effort is needed with the use of stone models and diagnostic wax-ups. However, use of digital technology and workflow, has now made it possible to digitally plan both surgical and prosthetic modalities.³

Digital implant planning requires three dimensional radiograph data (DICOM: digital imaging and communications

in medicine) as well as STL data (STL: standard tessellation language) from an intraoral scan or the scan of a plaster cast. The digital implant planning is virtually performed on 3D images of the jawbone acquired from computed tomography (CT) or cone-beam computed tomography (CBCT).⁴

Different techniques have been developed to transfer the ideal implant position to the surgical field, using templates. Implant planning software matches CT data to wax up information, allowing the clinician to view a 3D image of the jaw when planning implant position.⁵

Clinician can position specific implants into pre-surgically determined sites by computer guided implant dentistry, taking into account both the jawbone anatomy and the planned prosthesis within the CT images. Also, to obtain the optimal final tooth position, the appliance need to be scanned for designing and fabricating a surgical template.⁶

Guided implant surgery clearly reduces the inaccuracy as compared to free-hand surgery, recommended for complex anatomy, need for minimal invasive surgery, optimization of

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ISSN: 2231-2196 (Print)

ISSN: 0975-5241 (Online)

Received: 22.12.2020

Revised: 20.01.2021

Accepted: 21.02.2021

Published: 10.03.2021

implant placement (e.g., critical esthetic cases), and immediate loading. The accuracy of computer-assisted template-based implant placement depends on several factors, from dataset acquisition to the placement of the surgical guide for drilling and implant placement. In recent years, new technologies have been developed, matching DICOM (Digital Imaging and Communications in Medicine) data from computed tomography (CT) or cone beam CT (CBCT) images, directly with stereolithographic (STL) files derived from intraoral scans of the patient anatomy (teeth and soft tissues) or optical scans of a conventionally poured cast. Surgical guides may be produced by computer aided design/computer-assisted manufacture (CAD/CAM) technology (such as stereolithography), manually in a dental laboratory, or by using a high-resolution 3D printer.⁷

The introduction of optical scanners made it possible to design and produce surgical templates directly from a dataset (Jones, 2013; Reich, Kern, & Ritter, 2014). Employing this application in the digital workflow eliminates the analogue pre-operative waxing since a virtual wax-up can be created along with reduction in cost (Reich et al., 2014).⁸

HISTORY

To borrow the highly popular advertising slogan from the 1970s and 1980s, implant dentistry has come a long way over the past four decades. In the year 1982 Toronto Conference on Osseointegration in Clinical Dentistry in which the evidence-based concept of osseointegration was first introduced in North America to the present, the growth of implant dentistry has changed the dental industry and changed the lives of millions of patients aesthetically. Since 1982, there's been no looking back. Nothing has revolutionized the diagnosis and treatment planning of dental implants more than the introduction of CBCT by Mozzo et al in 19981 and its approval by the US Food and Drug Administration (FDA) in 2001.⁹

CLASSIFICATION

According to the type of navigation system, implant surgery can be classified into following: first- dynamic, second- static navigation, and static navigation can further be divided into full (FG)- and half-guided (HG) implant surgery, and also the static navigation can also be classified based on the type of the surgical guide stents into: open and closed guided; or mucosa, bone, tooth-crown supported guided.

Dynamic navigation

Dynamic navigation known as navigation-guided surgery, it involves the 3D planning with cone beam computed tomography (CBCT) exploration, and prosthetic analysis before

the surgical procedure. A guided template is not used while special instruments and a specific software, the bone drilling and the implant placement is completely tracked with the navigation system.

Dynamic navigation can improve the precision of implant placement compared to the FH method (Block et al., 2017; Brief et al., 2005; Hoffmann et al., 2005; Kramer et al., 2005), and to the pilot-drill HG surgery (Block et al., 2017; Somogyi-Ganss et al., 2015). The dynamic navigation software allows correct implant placement with proper parallelism, and the feedback provided by the clinician gives the possibility to modify the planned surgical approach during the surgery (Block et al., 2017).

An error in the system that would affect the spatial relationship between the reference points and the patient can lead to a mistake during the drilling and implant placement (Brief et al., 2005).

Static navigation

Static navigation uses static surgical templates during the bone implant drilling sequence and the implant placement. The surgical templates transmit the information from pre-surgical prosthetic and surgical planning to the patient.

The static navigation surgery can be classified into: 1. the type of the guide support; 2. the type of surgical visibility; 3. Implant placement facility.

Guide support

Mucosa-supported guide: Guides supported by the oral mucosa are associated to flapless surgery. Transmucosal fixation pins are often used in fully edentulous patients to better stabilize the template. {Fig 1}

This offer greater accuracy than osseous-supported guides (Vercruyssen et al., 2015b), while lacking major differences (Arisan et al., 2013a; 2010). This procedure also involves the highest patient satisfaction (Amorfini et al., 2017; Pozzi et al., 2014) and a significant reduction in chair-time compared to flap surgery (Arisan et al., 2013a; Vercruyssen et al., 2014b). Flapless surgery avoids bone augmentation procedures that reduce the amount of cases where it can be utilized

Bone-supported guide

This type of guide requires reflection of a full-thickness flap and are indicated in cases with bone deficiencies, where bone augmentation procedures are indicated, or with areas with anatomical limitations.

Tooth/crown supporter guide

The remaining teeth or crowns are used for enhancement of stabilization, to guide templates in partially edentulous patients (Figs. 2-4).

According to the systematic review of Raico Gallardo, the tooth-supported guides offered more accuracy than bone or mucosa-supported guides (Raico Gallardo et al., 2017).

Guide visibility

Closed guides

Closed guide stents cover the entire surgical field and do not allow visibility of the bone/ the mucosa during the bone drilling sequence and the implant placement. Closed guides do not allow cooling fluid to come in direct contact with the drills during bone preparation, which can raise the bone temperature and the possibly compromise the healing (Boa et al., 2016; Liu et al., 2018).

Open guides

Open guides have an open access located in the buccal side of the template that allows a buccal view of the surgical field, the direct visual control of the bone and the mucosa during the bone drilling sequence and implant placement.

Drilling and implant placement

Full-guided (FG)

They are also known as guided-surgery or computer-guided surgery. FG static navigation involves CBCT exploration, 3D planning, the prosthetic analysis before a computer-guided template is obtained to perform a guided implant placement. The computer-stent guides the entire surgical procedure, the drilling bone preparation, and the implant placement. Accuracy is one of the major advantages of a full guided implant surgery. Full-guided templates determine the bone drilling and implant placement but removes the possibility to change anything during surgery. 3D-planning skills are needed and any error in pre-surgical planning or within the guided-system will result in a wrong implant positioning. Thus, surgical experience is highly recommended to prevent this inconvenience and overcome any inaccuracy. Ultimately, the cost of FG surgery is higher, especially in comparison with the FH technique where no templates are used (Ravida et al., 2018).

Half-guided (HG)

This approach which has also referred to as partial guided surgery, which may involve the prosthetic, pre-surgical planning with CBCT exploration (3D) and cast-model planning (3D). A computer-fabricated or non-computer-fabricated surgical stent can be used in different following approaches:

1. drilling-guided, 2. pilot-drill guided, 3. non-computer guided.

Drilling guided

A surgical guide is used during all drilling bone sequence. Once the implant is in the placed, the surgical guide is then removed.

Pilot-drill guided.

It has also termed first-drill guided surgery. This technique only requires for the surgical guide during the pilot drilling bone sequence. Thus, after the pilot drill is used, the surgical guide is removed.

Non-computer guided.

A surgical non-computer fabricated template is used during the bone drilling phase and sometimes even at the implant placement. This surgical stent is produced from the 3D planning, which requires a CBCT or XR exploration, and a cast model analysis. It is easy to perform both in the clinic and in the lab and requires less cost than computer-guided systems, including dynamic navigation, full and half-guided static navigation systems. Guides are usually open or transparent, offering open-guide advantages. They often times allow modification during the bone drilling sequence and during the implant placement. They also provide better implant positioning accuracy than the free-hand approach (Noharet et al., 2014). Surgical experience in implant placement is recommended to achieve adequate results.

Free-hand guided

It is also known as conventional surgery and mental or brain guided surgery. Although 3D planning is highly recommended the a pre-surgical planning may or may not to be involve CBCT exploration. Surgical templates are not used during the bone drilling and during the implant placement. This requires less presurgical laboratory and clinical preparation. It offers the greatest surgical view during treatment without using any devices that can interfere with direct vision to the implant bed and surrounding tissues. It allows best contact of cooling fluids to the drills, resulting in better bone temperature control (Boa et al., 2016; Liu et al., 2018).

RADIOGRAPHIC

The first CBCT device was introduced in the late nineties (NewTom 9000, QR, Verona) with the help of initial scientific reports dating back from 1998. The overall advantages of the using CBCT in implant dentistry is related to its ability to acquire detailed volumetric image data of the maxillofacial region for diagnostic and pre-surgical planning purposes. CBCT is related to the use of CBCT in implant dentistry, with two out of three on the presurgical use of CBCT, primarily for presurgical planning and transfer to implant placement. One of the most frequent applications of the presurgical use of CBCT is the computer-aided planning and transfer for oral implant placement.¹⁰

DATA ACQUISITION

Superimposing surface data in STL format with three-dimensional DICOM data from radiological imaging is basic prerequisite for the digital implant planning. All the necessary data can be acquired at a single appointment. In addition to the DICOM data obtained by cone-beam computed tomography (CBCT) or standard computer tomography (CT), STL data of the intraoral clinical situation in the form of an intraoral or model scan are required.⁴

DATA PROCESSING - DATA FUSION

The surgical template is generated based on the STL surface data of the clinical situation. To allow this following- two data sets (STL and DICOM data) are imported into the implant planning software and superimposed.¹⁰

PROSTHETIC PRE-PLANNING AND IMPLANT PLANNING

A scanned or directly digitally produced wax-up is imported into the planning software or generated. This first virtual prosthetic planning covers both functional and aesthetic aspects it helps to optimally align the implant position with the prevailing anatomical conditions or, in some cases, forces the prosthetic planning to be reconsidered. The CBCT-related radiation exposure can vary between 10 μ Sv and 1000 μ Sv, depending on the device, the settings, and the size of the FOV.¹¹

IMPRESSION

Dental impressions are a critical step in implant dentistry. The imprecise transfer of an implant location can lead to an ill-fitting prosthesis, which may ultimately result in both biological and mechanical difficulties. Currently, the advancement of computer-aided design and computer-aided manufacturing (CAD/CAM) has enabled the generation of digital impression from the patient's mouth through digitizing a conventional impression (CI) with a laboratory scanner.¹²

Intraoral Optical Scanners (IOS)

Over the years, the ergonomics and size of the scanners have improved and gotten smaller, the software and the hardware requirements simpler, the number of available machines has grown, costs have dropped, and the applicability of utilizing the digital information has expanded. As a result, IOSs are now being integrated into many specialty practices as well. The ability to import the standard triangulation language (STL) files, created from IOSs and model/impression scanners, into treatment planning software applications has

allowed for the expanded use of these scanners in orthodontics, periodontal surgery, oral and maxillofacial surgery, and dental implantology. Most major dental implant treatment planning software applications currently can overlay STL files with the digital imaging and communication in medicine (DICOM) files created from CT/CBCT imaging. Once combined, software applications will commonly allow for the additions of the "virtual" teeth and the accurate, predictable virtual placement of dental implants. In Implant treatment, this technique is to be provides a panoramic view of implants in an arch and, therefore, is accurate. The presence of blood and saliva does not affect the measurement of precision of the PIC camera. However, photogrammetry does not register the soft tissues, and a second STL file is required to provide this information.¹³

Extraoral Scanners (EOS)

Extraoral scanners are dental scanning equipments that use an optical technology similar to intraoral scanners to digitize a gypsum model obtained by a conventional impression. Such methodology can also be considered an effective alternative to conventional dental impressions. When compared, intraoral and extraoral scans do not show significant differences in quality and accuracy of the digital models obtained. Therefore, intraoral scans are the preferred option to obtain digital models, since the reduced number of steps minimizes the risk of acquisition errors.¹⁴

SURGICAL TEMPLATE

The template is the information carrier for diagnostic wax-up, imaging, and surgical guidance. It is central to successful fixture placement and to the outcome of implant therapy.¹⁵

RADIOGRAPHIC TEMPLATE

Maxillary and mandibular stone casts are made from irreversible hydrocolloid impressions and mounted by split-cast technique in an articulator. A diagnostic wax up of teeth to be replaced is made, and an acrylic resin template is fabricated extending over the occlusal surfaces of several adjacent teeth for accurate localization.¹⁵

PRECISION SURGICAL TEMPLATE

The radiographic template can be converted into a surgical template. If the patient's gape (i.e. access) is adequate, a surgical template can be made by modifying the radiographic template. The cast is secured on the parallelometer in the new orientation. The lead foil and gutta-percha are removed from the template, and the channels are repaired

with an autopolymerizing resin. The thickness of the template at the implant sites is reduced to allow better access for the surgical drill and irrigation. If gape (i.e., access) is limited and if a lateral approach for the surgical drill is necessary, the acrylic resin buccal to the channel can be removed, leaving the lingual half of the channel remaining. If a metal guide channel is preferred, a small piece of wire can be soldered to a 3-mm diameter sectioned stainless-steel tube for secure attachment to the acrylic resin template.¹⁵

Designing the surgical template

It is possible to perform an either partially guided approach, where only the pilot drill is template-guided, or a fully guided procedure, where special guide sleeves adapted to the selected implant system are incorporated into the surgical template. When the implant planning has been approved, the software provides a planning report specifying the type, size and position of the planned implants. The 'drilling protocol' it provides the surgeon with the relevant technical information on the correct use of the system-specific surgical instruments.⁴

Fabricating the surgical template

Once the design process has been completed, the data set can be exported as an STL file and converted directly into the physical surgical template by means of additive or subtractive CAM procedures. Methods frequently used for this purpose include 3D printing or rapid prototyping technologies, especially stereolithography (SLA), digital light processing (DLP), or selective laser sintering (SLS). Integrating the guide sleeves is a manual process, as is the removal of holding or support structures and the finish of the template.⁴

Different methods for surgical guide manufacturing have been proposed to be transfer the planning on CT images to the surgical field. It can be manually fabricated or computer-controlled (CAD/CAM) fabricated. The surgical guide should closely fit with tissue surface in order to accurately transfer the pre-operative treatment plan.⁶ The main disadvantage is the inability to directly visualize anatomic landmarks, however this is overcome using an accurate and detailed pre-surgical computer-guided planning protocol.¹⁶

ADVANTAGES AND DISADVANTAGES OF DAIT¹⁷

Simplified clinical procedures	Simplified impression for complex cases such as multiple implants No need to repeat the entire procedure for recapturing impression
Higher time efficiency	Capturing a full-arch scan takes less than 3 min No need to pour stone casts and obtain physical plaster models All 3D data can be emailed

Less patient discomfort	No more inconvenience and hardship stemming from impression materials
Improved communication with dental technicians	Clinician and the dental technician can assess impression quality in real time Files can be easily transferred
Improved communication with patients	With 3D images it is easier to explain procedures to the patients. Higher patient acceptance

DIGITALLY ASSISTED GUIDED IMPLANT SURGERY

Guided implant surgery simplifies the execution of implant placement procedures and renders optimal clinical outcomes. Digital implant planning allows the accurate diagnosis of an implant site and virtual visualization of the final prosthetic restoration. The additional clinical benefits include reduced surgical time and a lower complication rate leading to increased patient acceptance and satisfaction. The implant insertion can be executed without the surgical guide or through the guide via a fully guided approach. Proper selection of case and planning throughout the digital workflow allow for accurate execution.¹⁸

THE DIGITAL WORKFLOW

The digital workflow can generally be divided into 6 steps:¹⁸

- (1) patient assessment
- (2) data collection
- (3) data manipulation
- (4) virtual implant planning
- (5) guide and prosthesis manufacture
- (6) execution of surgery and delivery of an immediate provisional prosthesis

SOURCES OF INACCURACY

Each of the aforementioned steps within the digital workflow carry a margin of inaccuracy. Patient-related and surgery-related factors affect the accuracy of the computer-aided surgery. Patient-related factors include the type of support and location, whereas surgery-related factors include the skill of the clinician, flap design, and drilling technique.

Patient-Related Factors

- (1) Type of support - In general, guided surgeries are more accurate in partially edentulous patients than in fully edentulous patients.¹⁸ Tooth-supported guides are considered the most accurate, followed by mucosa-supported guides. Bone-supported guides are considered the least accurate.¹²

- (2) Location – Studies have shown that there is no difference.^{12,19} whereas some studies indicate that guided surgeries in the mandible are more accurate whereas others indicate greater accuracy of guided surgeries in the maxilla.^{20,21,22}

Surgery-Related Factors

- (1) Clinician experience - Higher levels of accuracy can be obtained by expert surgeons when initially using computer-guided surgery, especially the accuracy of implant depth. Nonetheless, guided surgery has a positive correlation with the reduction of surgical complications.^{23,24}
- (2) Flap versus flapless approach - Fixation pins and mucosal resilience affect the stability and accuracy of the mucosa-supported guides. Fully guided implant placement using the flapless approach with fixation screws is the most accurate approach.^{20,21,22}
- (3) Drilling technique - Eccentric drilling through the sleeve has a substantial effect on accuracy, especially with limited access to the posterior jaw or limited mouth opening. This factor may be of clinical importance, affecting the overall accuracy. It may be concluded that fully guided surgery is more accurate than partially guided surgery.¹²

CONCLUSION

The guided implant placement increases predictability, with decreased surgery time and complication rate. Static guides remain the most commonly used for guide computer-assisted implant surgery. The digital workflow can be divided into 6 steps. Each step may produce the deviations from the virtual plan. The accuracy, efficacy, and complication rate of computer-guided implant treatment remain within the acceptable clinical limits. Proper execution of each digital workflow step must be carefully verified to reduce inaccuracies. Guided implant surgery is thought as accurate, precise, and reliable compared with free-hand implant surgery. However, there may be deviation between implant virtual planning and implant real position because of the surgical learning curve and the errors that may occur throughout the multiple steps of the digital workflow.

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Figure 1 : Closed mucosa-supported full-guided template (Limaguide system. Innovacion Dental SL. Barcelona, Spa.

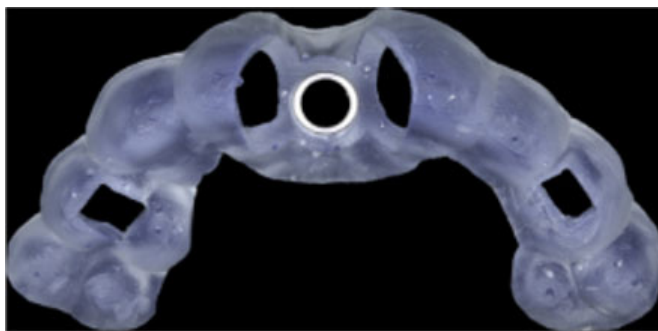


Figure 2: Closed tooth-supported full-guided template (Formlabs, Form 2 3D printer. Formlabs Inc. Somerville, USA; Blue Sky Bio, Grayslake, USA).

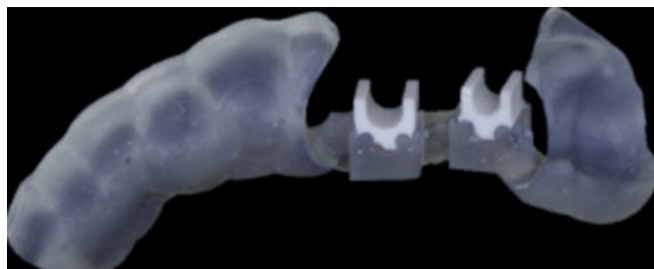


Figure 3: Open tooth-supported half-guided template (Formlabs, Form 2 3D printer. Formlabs Inc. Somerville, USA; Blue Sky Bio, Grayslake, USA).



Figure 4: Closed tooth-supported non-computer half-guided template (Vacuum, Machine III, Keystone Industries, New Jersey, USA).