CAD/CAM Guided Surgery in Implant Dentistry

A review of software packages and step-by-step protocols for planning surgical guides

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Author Profile

Dr. Michael Scherer, DMD, MS, is currently an assistant professor in residence at University of Nevada – Las Vegas, an assistant clinical professor at Loma Linda University, and a fellow of the American College of Prosthodontists. He has published articles related to clinical prosthodontics and implant dentistry and completed a master's degree related to implant overdentures with multiple publications pending. As an avid technology and computer hobbyist, Dr. Scherer's involvement in digital implant dentistry has led him to develop and utilize new technology with CAD/CAM surgical systems and implement student facilitated CBCT implant planning. Dr. Scherer serves as the director of the implant dentistry curriculum at UNLV and is actively engaged in guided surgical placement and prosthetic restoration of implants.

ABSTRACT

Three-dimensional radiographic imaging for dental implant treatment planning is gaining widespread interest and popularity. However, application of the data from 3D imaging can be a complex and daunting process initially. The purpose of this article is to describe features of three software packages and the respective computerized guided surgical templates (GST) fabricated from them. A step-by-step method of interpreting and ordering a GST to simplify the process of the surgical planning and implant placement is discussed.

The paradigm of 2-dimensional (2D) imaging, treatment planning with model-based surgical planning, and surgical guide fabrication for the purposes of dental implant placement has shifted to a completely digital workflow. Traditional imaging, such as panoramic and periapical radiographs is inherently difficult to utilize for dental implant planning because it does not represent all dimensions of the bone volume.[1-2] As a result, 3-dimensional (3D) imaging with cone-beam computed tomography (CBCT) in combination with computerized interpretation software packages enable the clinician to visualize a greater amount of diagnostic information.[3] This improved visualization improves assessment of bone volumes, enhances treatment planning, allows for more accurate and precise control of implant position, and offers the ability to link together guides and restorations with the 3D radiograph image.[4]

Three-dimensional radiographic imaging for dental implant treatment planning, however, can be a seemingly complex and daunting process. Multiple CBCT machines are commercially available and utilize different controls and scan settings. In addition, numerous software packages exist with varying capabilities and features with proprietary computerized guided surgical templates (GST), all of which may lead to confusion. Dental and medical radiologists have strived to standardize the complex world of medical imaging by setting a standard format for digital imaging in radiology: digital imaging and communications in medicine (DICOM). Engineering and modeling standards have also been established for enabling the sharing of optical imaging data and exporting stereolithography images (STL). This standardization allows for a common language to exist between software packages and greatly enhances the ability for a collaborative workflow with digital imaging.

The purpose of this article is to review three of the more popular software packages and computerized guided surgical templates (GST). This article provides a step-by-step method of interpreting and ordering GSTs to simplify the

process of the surgical planning and placement of implants.

Software Package Features

Multiple software packages are available for the clinician to choose from for analysis, treatment planning, and fabrication of guided surgical templates. In order to simplify the complex landscape of digital implant treatment planning, three major software packages are reviewed: Invivo (Anatomage; San Jose, Calif.), Simplant (Materialise NV; Leuven, Belgium), and NobelClinician (NobelBiocare; Yorba Linda, Calif.). While each software has unique features and specific protocols, they share common features (Table 1).

Invivo and Anatomage Guide

Anatomage Inc. is a medical imaging company that produces software for medical and dental specialties. Invivo Dental is a dental software that allows clinicians to visualize DICOM datasets in 3D volumetric renderings of hard and soft tissues, measure airway volumes, trace orthodontic landmarks, and plan dental implants. The dental implant module allows full control of 3D renderings allowing the clinician to section, slice, identify, and mark anatomical landmarks, and then determine placement of dental implants. In the implant module, the clinician can manipulate implant position, angulation, trajectory, and measure relative bone density. Unique features of the Invivo software are instantaneous 3D rendering / image processing (thresholding) (Figure 1), a dynamic clipping mode (virtual slicing), allowing the clinician to visualize 3D restorative space (Figure 2), and creation of virtual wax patterns based upon a digital restorative library (Figure 3).

Anatomage Guide is the surgical guide fabricated by Anatomage upon completion of the implant planning in the Invivo software. The following types of templates are currently available for Anatomage Guide:

- Tooth-supported
- Mucosa-supported
- Bone-supported reduction and implant surgical guides (mandible only)

Features

Software	*Automatically imports DICOMS*	*DICOM conversion fee*	*Imports STL files*	*Nerve mapping*	*Bone density prediction*	*Scan template required*	*Virtual wax-up*	*Virtual implant library*	*Implant abutment library*	*Surgical guide types*	*Bone reduction guides*	*Universal implant guide & drills*	*Plan & fabricate provisional*	*Guide fabrication time (days)*
Anatomage Invivo Dental	✓	-	✓	✓	✓	-	++	+	+	TSB	+ Mand only	++	+	3-5
Materialise Simplant Planner	-	$	-	✓	✓	✓ (Mucosa guided)	++	++	++	TSB	++	++	++	3-5
Materialise Simplant Pro	✓	-	✓	✓	✓	✓ (Mucosa guided)	++	++	++	TSB	++	++	++	3-5
Nobel Clinician	✓	-	-	✓	-	✓	-	+	++ (Nobel only)	TS	-	-	++	3-4

Key: (✓) Available, (-) Not available, (+) Partially featured, (++) Fully featured, (T) Tooth-supported, (S) Soft-tissue supported, (B) Bone-supported, ($) Fee required

Table 1.

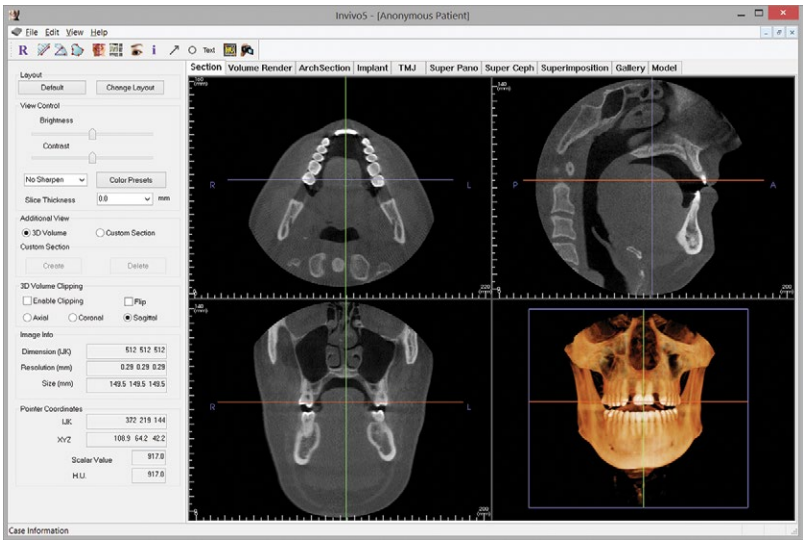

Figure 1. Invivo software features automatic thresholding and volumetric rendering.

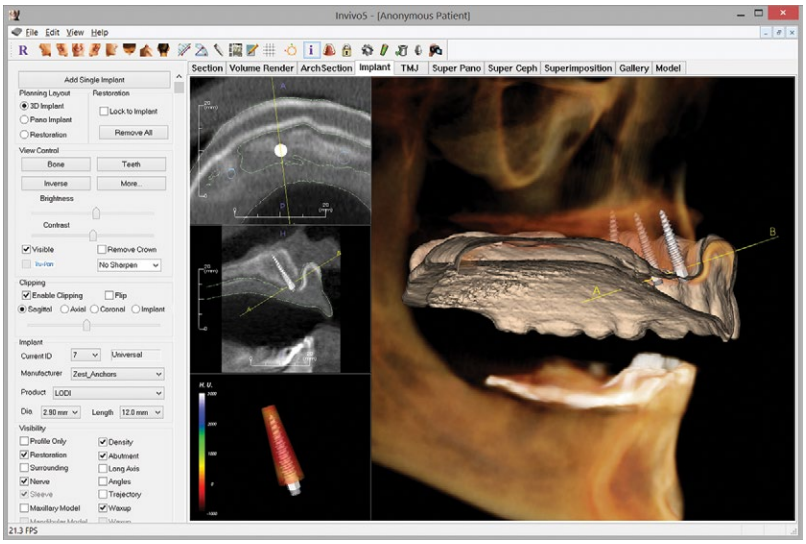

Figure 2. Clipping mode allows the clinician to visualize prosthetic space between implant platform and the occlusal surface of the planned restoration.

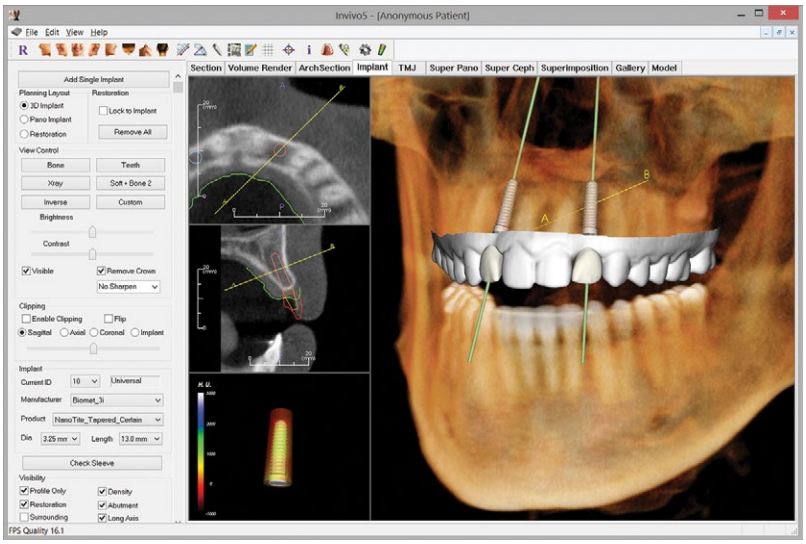

Figure 3. Virtual restorations added to dental implants to finely tune the implant angulation and position.

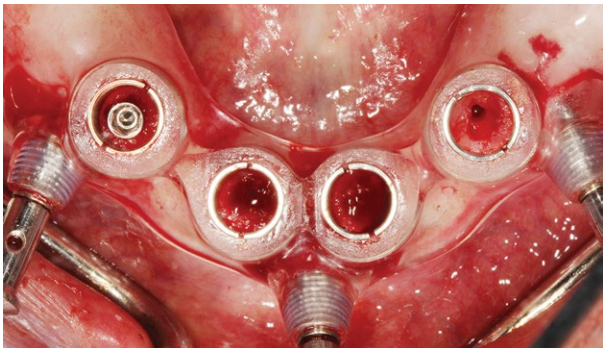

Figure 4. Zest Locator overdenture implant placed using an Anatomage guide with universal master sleeves and drills.

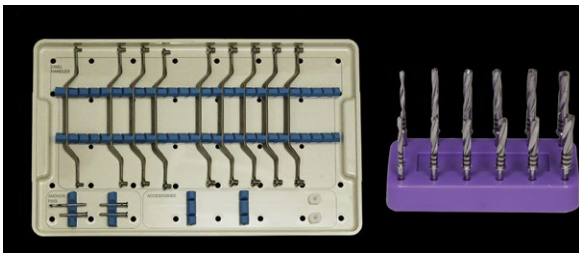

Figure 5. Universal Anatomage Guide drills and handles allow for osteotomy preparation for multiple systems.

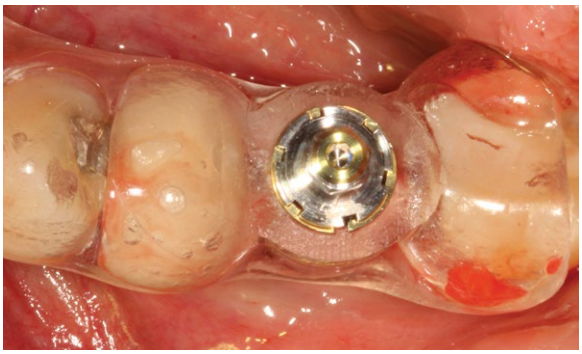

Figure 6. Manufacturer specific master sleeve with a universal guide allows for a fully-guided implant surgical procedure.

Author Profile

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Universal master sleeves

Anatomage Guide controls the trajectory and osteotomy depth through the master sleeve integrated into the acrylic drill guide template. A unique feature of the Anatomage Guide is the universal master sleeve that allows a clinician to insert any implant that uses a parallel drilling protocol such as Straumann Bone Level, Nobel Active/Speedy, Dentsply AstraTech, and Zest Locator Overdenture Implants (LODI). (Figure 4) The handle and drill kits accommodate narrow sleeves (3.1mm), regular sleeves (4.1mm), and wide sleeves (5.1mm), and the drill kit includes 21mm and 26mm universal drills. (Figure 5)

The universal kit allows full osteotomy preparation except for drill tapping and final implant insertion (partially-guided); these procedures should be performed without the guide in the mouth. If a tapered implant drilling protocol is required, universal drills should be used up until the last drill size and the final tapered drill in the manufacturer's kit used to prepare the final osteotomy. Implant trajectory is controlled by tilting the master sleeves relative to teeth, mucosa, or bone; implant depth is controlled by raising or lower the sleeve position in relation to the above. The clinician needs to be aware of the surgical drilling protocol for the respective implant when using a universal kit. For example, if a 3.5mm x 11.5mm Nobel Replace implant were to be placed, the universal drilling protocol would be a guided universal 2.0mm drill, followed by a guided universal 2.8mm drill, and finally by non-guided Nobel tapered 3.5mm x 13mm drill.

Manufacturer-specific master sleeves

If preferred, Anatomage can also fabricate a guide with manufacturer-specific master sleeves for the following systems:

Nobel Guide	Zimmer
3i Navigator	Straumann
Camlog	Implant Direct

Manufacturer-specific master sleeves allow for full trajectory and depth control, guided drill tap, and guided implant insertion (Figure 6). Fully guided implant insertion capability with Anatomage guide, however, is currently available only for NobelBiocare, 3i, and Camlog implant systems. Full implant guidance may be less of an issue with clinicians who routinely use guided surgery to place implants without immediate provisional restorations pre-fabricated in the laboratory. If a clinician wishes to have a provisional restoration pre-fabricated to deliver the day of implant insertion, fully guided implant placement may be important.

Figure 7. Soft tissue separation performed with cotton rolls held in place during the CBCT scan.

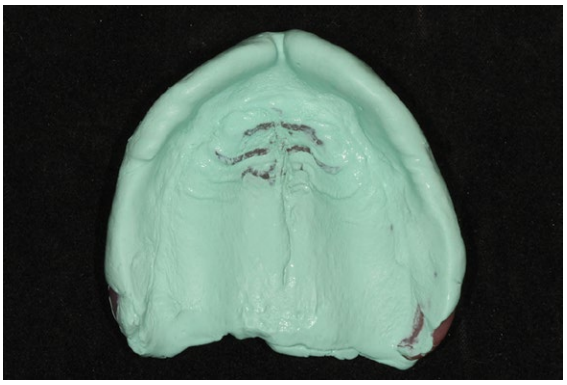

Figure 8. Radiopaque PVS placed prior to making a CBCT allowing the software to recognize the soft tissue profile.

- Checklist for Anatomage Guide
- Partially Dentate Teeth-Supported Guide
- Patient CBCT scan with occlusal and tissue separation (Figure 7)
- Patient cast optical or CBCT scan
- Diagnostic wax pattern optical scan (optional)

Fully Edentulous Bone-Supported Guide

- Patient CBCT scan

Fully Edentulous Soft Tissue-Supported Guide

- Patient CBCT scan with denture relined with radiopaque PVS material (Green-Mousse, Parkell, USA). (Figure 8)
- Prosthesis CBCT Scan
- Patient cast optical or CBCT scan

Submit for Surgical Guide Fabrication

For either partially or fully edentulous patients, it is recommended that the clinician initially plan implant positions according to proposed implant sites. Importing the DICOM files into the Invivo software will create an initial planning file (.inv) to facilitate upload to Anatomage's uploading service (Anatomodel). For fully edentulous templates, the clinician must import the prosthesis scan and convert the file to an initial planning file. Anchor pin placement is recommended for fully edentulous templates, and unless specified, 2 to 4 pins should be placed around the arch. Once approved, the surgical guide takes from 3 to 5 days to manufacture.

SimPlant and SurgiGuide

Materialise NV is a worldwide leader in medical additive manufacturing and biomedical research and produces SimPlant, one of the pioneering dental implant imaging software. SimPlant is an interactive dental implant software that allows clinicians to visualize DICOM datasets in 3D surface renderings with transparency controls. While most clinicians will typically use SimPlant Planner for dental implant planning, Materialise offers several different versions of the software package (Table 2).

In SimPlant, the dental implant module allows full control of 3D renderings, allowing the user to section, identify, and mark anatomical landmarks, and then determine placement of dental implants. In the implant module, the clinician can manipulate implant position, angulation, trajectory, and measure relative bone density. Unique features of SimPlant are the ability to section layers of scans based upon density value image processing and view in 3D layers, create virtual diagnostic wax-patterns, utilize a comprehensive implant and abutment library, and direct visualization of a virtual surgical guide on either bone, soft tissue, or on teeth (Figure 9).

SurgiGuide is the surgical guide fabricated by Materialise upon completion of the implant planning in the SimPlant software. The following types of templates are currently available for SurgiGuide:

- Tooth-supported
- Mucosa-supported
- Bone-supported reduction and surgical guides

In SimPlant, the dental implant module allows full control of 3D renderings.

VERSION	COST	DESCRIPTION
SimPlant View	Free	3D viewer for sharing previously planned surgical cases but does not allow the user to make modifications to a plan
SimPlant Planner	$	Full 3D planning software with virtual implant library. Requires a DICOM conversion fee (per scan)
SimPlant Pro	$$	Same as SimPlant Planner but DICOM conversion built in
SimPlant Master	$$$	Enterprise/Laboratory version that allows all of the above but enables you to convert DICOMs for other users

Table 2. SimPlant versions

Author Profile

Dr. Mathew T. Kattadiyil, DDS, MDS, MS, received his BDS from the College of Dental Surgery, Kasturba Medical College (KMC), Manipal, India in 1989. He completed his masters in dental science (MDS) in prosthodontics from the College of Dental Surgery, KMC, Manipal in 1992. He began full-time teaching in the department of prosthodontics at the College of Dental Surgery, KMC, Manipal, India in 1992.

In 1997, he received the professional certificate in prosthodontics from the School of Dentistry and, in 1999, earned his masters of science (MS) degree from Loma Linda University, Loma Linda, Calif.

Dr. Kattadiyil is a diplomate of the American Board of Prosthodontics and a Fellow of the American College of Prosthodontists. He is currently the director of the Advanced Specialty Education Program in Prosthodontics at Loma Linda University.

He has been a full-time faculty member at Loma Linda University since 1999 and limits his practice to prosthodontics.

Universal templates (Pilot SurgiGuide, Universal SurgiGuide)

Pilot SurgiTemplates control initial trajectory and osteotomy depth through the master sleeve integrated into the acrylic drill guide template. The pilot surgical guide provides drill guidance and depth control for the pilot drill only, which typically is 2.0mm in diameter. Once the pilot osteotomy is performed, the guide is removed and the remainder of the drilling and implant placement is performed without the assistance of the guide. This guide is recommended for experienced users who would like to have guidance during the initial drilling step.

Universal SurgiTemplates control full trajectory and osteotomy depth through the master sleeve. The universal guide allows for comprehensive drilling guidance from pilot to final drills, however, this depends upon the implant system being used. If an implant is being placed that requires a tapered drilling protocol (Nobel Replace or 3i Tapered Certain), the last drill must be performed without the assistance of the guide. Complete osteotomy can be performed entirely through the guide for cylindrical drilling protocol implants (Nobel Active, 3i Parallel, Implant Direct Legacy). After the completion of the drilling protocol, the guide is removed and the implant is placed without the assistance of the guide.

Either the pilot or universal SurgiGuide can utilize a drill and handle kit provided by the manufacturer. Available in three diameters (1.95, 2.75, 3.15 mm) & 6 lengths (15, 18, 20, 23, 25, 28 mm), drills are available from the manufacturer (SurgiGuideLongStop Drills, Materialise NV) for use in the pilot and universal templates (Figure 10).

Manufacturer-specific guide (SAFE SurgiGuide)

If preferred, Materialise can also fabricate a guide with manufacturer-specific master sleeves for the following systems:

AstraTech Facilitate	Camlog
3i Navigator	Straumann Safe
Nobel Guide	Friadent Expertease
	Zimmer

SAFE SurgiTemplates allow for full trajectory and depth control, guided drill tap, and guided implant insertion. This method allows for a fully guided implant insertion, however, fully guided implant insertion capability is currently available only for Nobel, 3i, Camlog, and AstraTech. Zimmer, Straummann, and Friadent implants can be placed through the guide but the guide will not be fully controlling the guidance depth and turn of the implant. Bone-supported templates are available with the option of a stereolithographic maxilla or mandible (Figure 11).

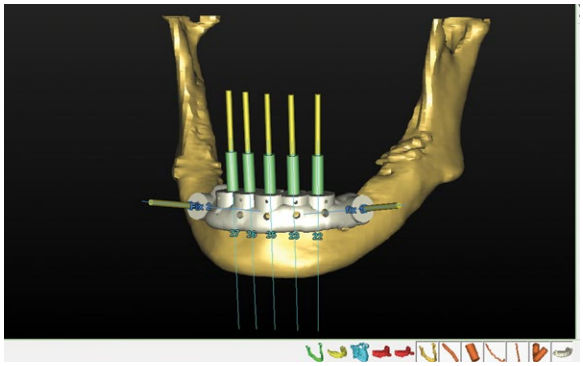

Figure 9. Simplant allows for visualization of a bone level surgical guide and implant surgical plan

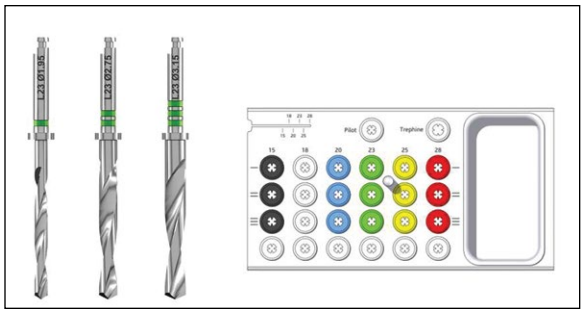

Figure 10. Universal drills for the Simplant SurgiGuide system allows for the initial osteotomy preparation.

Figure 11. Stereolithographic mandibles illustrating a bone reduction and an implant surgical guide.

Checklist for Materialise Guide

Partially Dentate Teeth-Supported Guide

- Patient CBCT scan with radiolucent PVS occlusal occlusal spacer and a radiographic template with 6-8 gutta percha markers
- Patient cast optical scan

Fully Edentulous Bone-Supported Guide

- Patient CBCT scan

Fully Edentulous Soft Tissue Supported Guide

- Patient CBCT scan with barium-sulfate radiographic template
- Prosthesis CBCT Scan

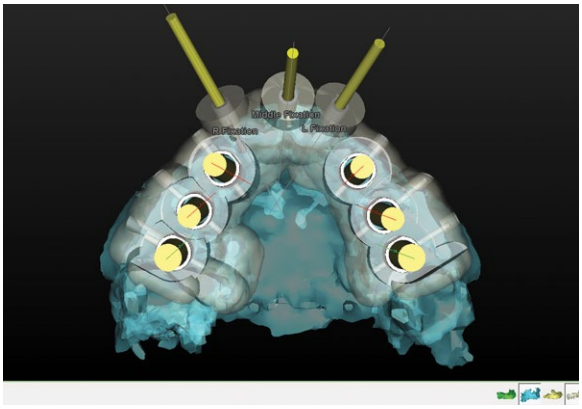

Figure 12. Virtual maxillary surgical guide with implant trajectories illustrating surgical plan

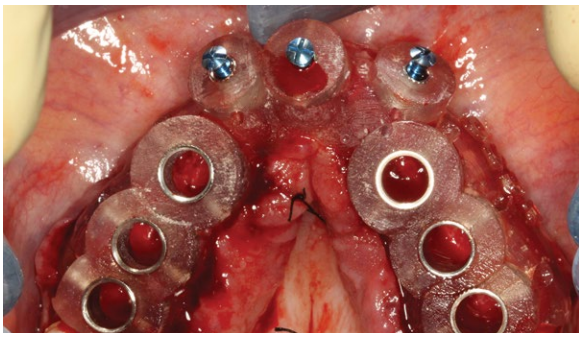

Figure 13. Materialise guide fixated to maxillary alveolar bone prior to implant placement

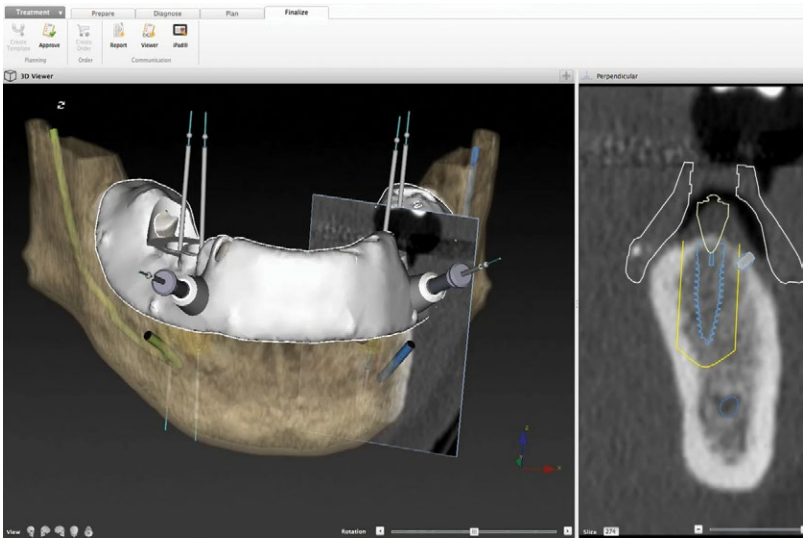

Figure 14. NobelClinician allows for full control and visualization of Nobel implants and abutments. *(Reproduced with permission from NobelBiocare)*

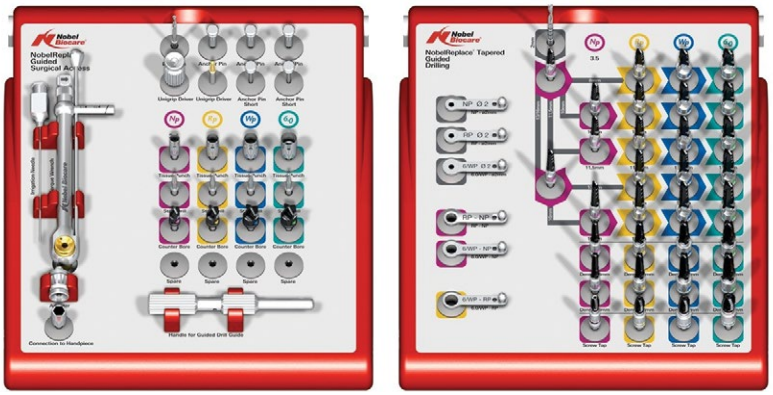

Figure 15. Guided surgical kit for Nobel Replace tapered implants

Submit for SAFE Surgiguide Fabrication

If using the SimPlant Pro or Master versions, importing the DICOM files will require no conversion; however, if using the SimPlant Planner software, it is necessary to convert the files prior to opening. Many conversion services are available for a fee, costing between $50 to $100 per scan. Once the files have been converted, they are opened into the software package and then thresholding limits for bone, soft tissue, and teeth are completed. Additionally, sectioning of prosthesis and/or teeth can be completed to create virtual layers by allowing the user to toggle (turning on and off the individual layers). A clinician can also input a second DICOM file dataset scan and/or an optical STL scan of the patient's cast to perform a dual scan digital registration using the dual-scan module. Alternatively, DICOM files can be sent to Materialise's planning service (DentalPlanit) to have the files converted and digital registration completed.

Implants are placed according to bone volumes and the restorative plan, while being cognizant of vital structures. System-specific abutments can be visualized for most major systems and generic abutment options are available to control the location of the implant platform's interface with the abutment to achieve a predictable result. Once satisfied with the dental implant plan, the software will allow visualization of the surgical guide prior to ordering (Figure 12). After confirming the guide design and shape compatibility with the surgical plan, the guide is ordered via a web-portal and is fabricated by a stereolithographic printing process (Figure 13). Surgical templates typically take 4 to 7 business days to fabricate and ship and rush services are available.

Nobel Clinician/Nobel Guide

Nobel Biocare is one of the largest manufacturers of dental implants and CAD/CAM-based individualized prosthetics with its own scanners and software. Nobel Biocare also developed a software program for clinicians (Nobel Clinician) for proper diagnostic studies and implant treatment planning, with production of customized, patient-specific, guided-surgery templates to assist in implant placement surgeries. Nobel Clinician allows full control of 3D renderings allowing the user to section, identify, and mark anatomical landmarks and to place virtual dental implants (Figure 14). In the implant module, the clinician can manipulate implant position, angulation/trajectory, and measure relative bone density. A unique feature of the software is the calibration procedure, allowing

> The combination of restorative-based digital planning and computerized guided surgical delivery allows for a tremendous integrative workflow.

Figure 16. Mucosa-supported guided surgical template for Nobel implants

the clinician to separate 3D renderings of the radiographic guide from the CBCT based on Isovalue. Nobel Guide is the surgical guide fabricated by Nobel upon completion of the implant planning in the Nobel Clinician software.

The following types of templates are currently available for Nobel Guide:

- Tooth-supported
- Mucosa-supported

Guided surgery kits

Nobel Biocare has surgical kits compatible with the following implant systems:

- Branemark System Guided Surgery Kit
- Nobel Active Guided Surgery Kit
- Nobel Replace Straight Guided Surgery kit
- Nobel Replace Tapered Guided Surgery Kit (Figure 15)

Checklist for Nobel Guide

(for either Partially Dentate Teeth-Supported or Fully Edentulous Tissue-Supported Guide)

- Patient CBCT scan with radiolucent PVS occlusal registration spacer and a clear radiographic template replacing the teeth to be restored with 6-8 gutta percha markers
- Prosthesis CBCT Scan

Submit for Surgical Guide Fabrication

DICOM files are automatically converted by the Nobel Clinician software. Once opened into the software package, image processing guidelines (limits) for bone, soft tissue, and teeth are completed. Nerve mapping and sectioning of prosthesis and/or teeth can be completed to create virtual layers to allow the user to switch (toggle) on and off. A clinician can also input a second DICOM file dataset scan to perform a dual scan digital registration using the dual-scan module.

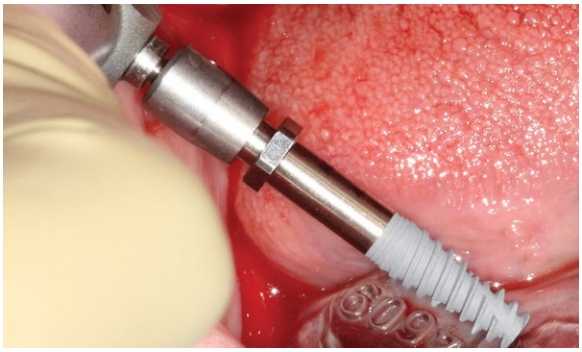

Figure 17. Implant with fixture mount assembly allows for an implant to be precisely placed according to plan. (Courtesy Nakul Rathi)

Implants are placed according to bone volumes, restorative plan, and with respect to vital structures. System-specific abutments can be visualized for most major systems and generic abutment options are available. Once satisfied with the dental implant plan, the software will allow visualization of the virtual surgical guide prior to ordering. After confirming the guide design and shape compatibility with the surgical plan, the guide is ordered via a web-portal and is fabricated by a STL printing process (Figure 16). Most clinicians will typically work with a NobelClinician certified laboratory to ensure that the pre-surgical and surgical requirements are properly coordinated to reduce surgical error (Figure 17).

Conclusion

Numerous implant software packages exist with varying capabilities and features that will allow for the design and manufacture of proprietary computerized guided surgical templates (GST). While these systems are diverse, many share similar features and methodology in how they interpret DICOM data and facilitate assessment of potential sites for placement of dental implants. The combination of restorative-based digital planning and computerized guided surgical delivery allows for a tremendous integrative workflow that facilitates the team approach to dental implantology. AO

Author Profile

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