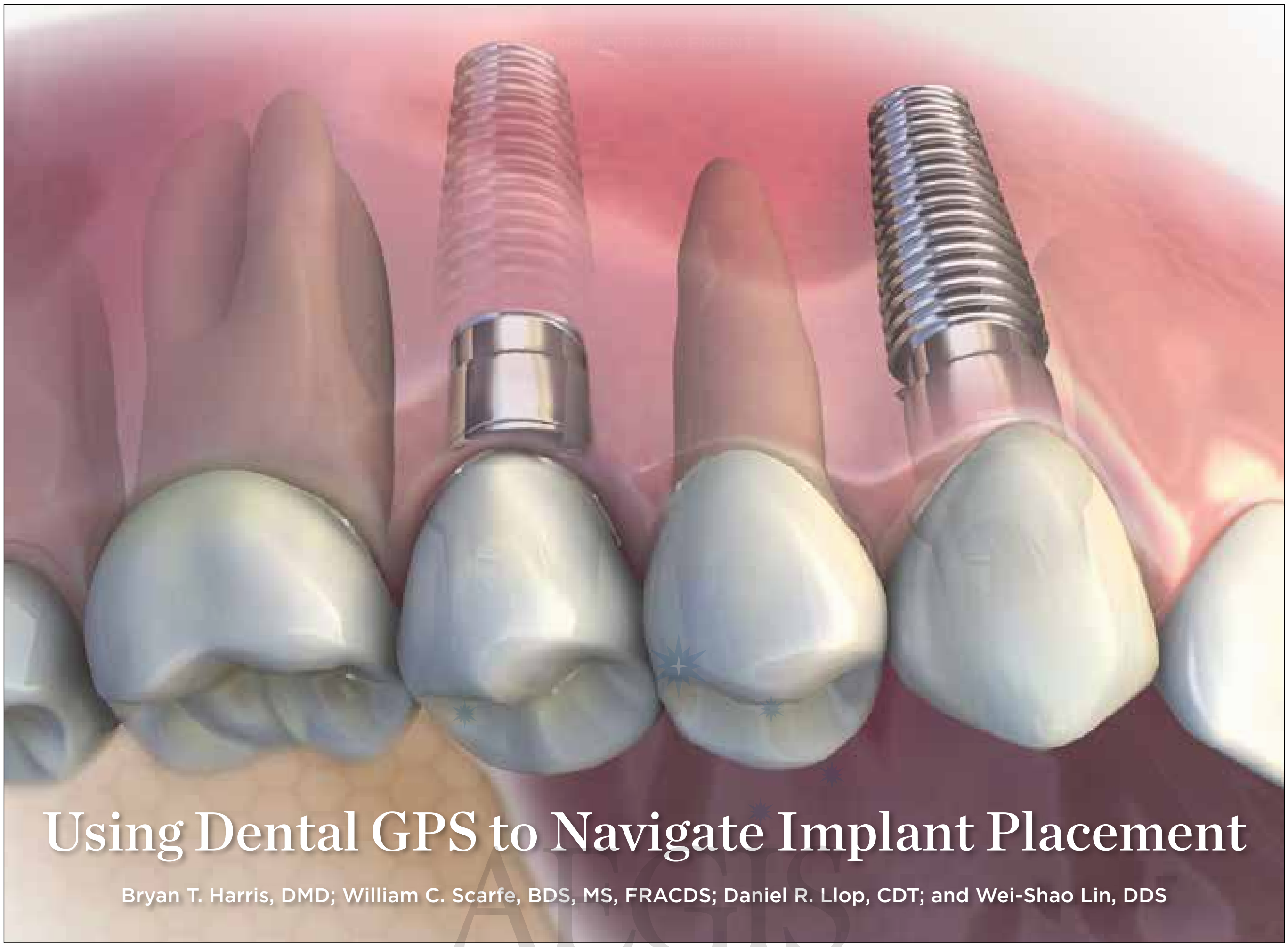

Using Dental GPS to Navigate Implant Placement

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Abstract: Digital advances have changed implant planning to improve outcomes in placement and restoration. Layering multiple image inputs, such as volumetric radiology, photography, and 3-dimensional (3D) surface scans, has allowed better assessment of patients with partial or complete edentulism, and this can aid in producing 3D visual predictions, implant guides, and prosthetics to execute the proposed plan.

For years, automobile drivers have used 2-dimensional (2D) maps to find new destinations. The advent of digital maps using satellite-based navigation systems—global positioning system (GPS)—has enabled multiple inputs such as real-time traffic patterns, up-to-date construction detours, and weather patterns to improve traveling efficiency. A radiographic image of the jaws is like a map, in that it provides 2D information on the status of the teeth and some appreciation of residual alveolar bone in edentulous areas. However, software integration of several digital sources using cone-beam computed tomography (CBCT) as the scaffold has become the "Dental GPS" in that it enables development of a prosthetic plan in three dimensions to guide placement of dental implants.[1] Dental GPS results in improved esthetic restorations that are functional and maintainable, and it has emerged as the most efficient tool to help improve implant outcomes.

Historically, radiographic evaluation of a patient for implant therapy has been performed using 2D radiographic modalities such as periapical and panoramic images. These images have multiple limitations, including distortions and dimensional inaccuracies, and inherently lack information in 3D. In 1993, prosthetic evaluations in implant dentistry shifted toward 3D evaluations with the early "dental" software packages (eg, SIM/Plant, Columbia Scientific Inc, www.materialise.com) available for medical computed tomography.[2] With the introduction of volumetric imaging in the early 2000s, along with increased availability and access, CBCT has become the current standard for osseous 3D dental imaging. However, in prosthetics, the existing teeth and alveolar bone volume provides only a portion of the information necessary for accurate implant planning. Prosthetics has moved away from the idea of "bone setting the tone" (ie, placing an implant in proper bone volumes); instead, the primary objective of implant placement is now directed by restorative considerations such that implant position functionally and esthetically supports the restoration.[3] While the foundation of the bone volume is critical, other factors need to be considered in planning and placement of dental implants. These include the nature and amount of available soft tissue and the esthetics of the final restoration.

"Tooth guided," or "restorative driven," implant planning is not a new concept in implant dentistry; however, putting the elements together is technically time consuming and labor intensive. The original analog pathway involves the use of diagnostic casts, a laboratory wax-up, and fabrication of a radiographic template incorporating a prosthetic plan. This template is placed intraorally and a CBCT is acquired. Then, after the images have been interpreted, implant virtual simulations can be performed by importing DICOM (Digital Imaging and Communications in Medicine) data into proprietary implant-planning software. If bone volume is insufficient at the potential implant site, this procedure needs to be repeated after bone augmentation occurs. Once the planning is approved, a conversion of the radiographic template or design and fabrication of a new specific surgical guide is necessary. This usually involves the export of a "digital plan" from the implant planning software and subsequent design and manufacturing of a surgical guide by a laboratory.[4] Such a pathway requires multiple clinical visits and coordination between restorative, imaging, and surgical aspects of the case. This is labor intensive and may need to be done multiple times. The adoption of this pathway by practitioners is low, due to cost and time.

With advances in technology and increased availability in the last 5 years, implant planning and placement has changed dramatically. It is rapidly evolving into alternate pathways incorporating digital inputs other than DICOM data from various devices that address costs, clinical efficiencies, and treatment outcomes.

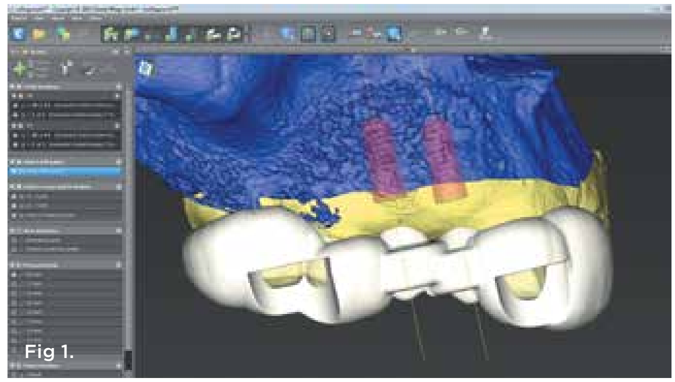
Fig 1.


Fig 2.


Fig 3.

Fig 1. Surface scans (STL) and volumetric data (DICOM) are combined to provide a "Dental GPS" prosthetic plan. **Fig 2.** CAD of the provisional restoration following the computer-guided surgery planning. **Fig 3.** Immediate provisionalization completed with computer-guided implant placement and CAD/CAM provisional restoration.

New Pathways to Success

While CBCT DICOM data have submillimeter resolution that is satisfactory for the clinical tolerances involved in surgical implant placement, detail may be too coarse and artifacts due to metallic scatter too pronounced to design and incorporate specific prosthetic elements into the implant plan.[5] Recently, in-office and intraoral scanning technology has been introduced that generates surface optical impressions with sufficient detail for prosthetic purposes. The data from these scanners are stereolithography (STL), not DICOM. Software is now available to the clinician that enables the roadmap provided by CBCT to be integrated with STL data to provide a true dental GPS for restorative-driven implant planning and placement. The ability to merge high-resolution surface scans (ie, STL) and volumetric data (ie, DICOM) increases dentists' clinical inputs, enabling clinicians to better plan and execute.

STL data can be captured through 2 pathways. The first still involves the use of a dental laboratory–based scanner to create an STL file from a silicone impression of the jaw or the dental cast. If inaccuracies or distortions exist in the silicone impression, the created STL file will replicate this error. The second pathway involves clinical use of an in-office intraoral scanner. While this technology has been available since the early 1980s, it is only recently that export of STL optical surface data has been possible.[6] Both pathways require a scanner and use STL data that are exported to CAD software for manipulation, implant planning, and prosthetic design. Two systems are possible: proprietary "closed" platform systems, which necessitate the purchase and use of specific hardware to provide STL and DICOM data, and, now more frequently, "open" platform systems that support integration of

Fig 4. 3D virtual patient composed with volumetric data of craniofacial hard tissue and 3D extraoral facial scan. This 3D virtual patient can be used to gain patient's preoperative approval and design a surgical and prosthetic plan. **Fig 5.** A 3D virtual patient with virtual diagnostic tooth arrangement harmonized with facial features. **Fig 6.** Surgical and prosthetic plan for a mandibular edentulous implant treatment. **Fig 7.** Smile presentation of patient with computer-guided implant placement and CAD/CAM provisional restoration.

STL and DICOM data from various devices.[7]

In application for a partially edentulous patient, the integration of DICOM and STL data has enabled planning to be performed without the use of a scan appliance and provides an ability to fabricate surgical guides with improved fit and stability. After optical scanning of the region with an edentulous area, the STL file is imported to a CAD software program, such as Dental Wings (Dental Wings, www.dentalwings.com) and a digital "wax up" layered over the surface scan. CBCT DICOM data can then be combined into a montage to provide a prosthetic plan, linking these vital pieces of information together (Figure 1).

Multiple fabrication pathways are possible to proceed to surgical placement. The CAD of the final prosthetic plan can be exported and a fabricated diagnostic wax up produced by additive manufacturing. This cast can now be used to create a surgical guide using thermoplastic material, which can then be used surgically as an unrestrictive template to guide implant placement. This is a cost-effective pathway that can be applied to many surgical implant applications.[8,9] Alternately, with the recent introduction of 3D desktop printing devices capable of using biocompatible resins (Dental SG, Formlabs, www.formlabs.com), the surgical guide can be designed by the clinician, exported as an STL file, and printed in-office.

A second pathway produces a surgical guide and an immediate provisional. This links the surgical plan and fabrication of a provisional restoration between the CAD and implant-planning software. This allows the surgical, restorative, and laboratory goals to be planned in real time, accounting for the bone, tissue, and restoration (Figure 2). The advancement provides a dental GPS for implant placement and restoration (Figure 3).

In patients who present as edentulous, the replacement of those missing structures influence the facial features. The smile design is influenced by many patient-specific factors. When a patient's CBCT is reviewed, this 3D volume does not allow the ability to evaluate how an implant reconstruction will influence the patient's lip support and smile. Lip translation, the lip support, and the position of the teeth for smile design are within the frame of the canvas of the individual patient (Figure 4). Therefore, more inputs are necessary to help plan and predict these changes in the form of a 3D virtual patient ~~(Figure 5)~~. The advent of facial scanning (3dMD, www.3dmd.com) has allowed more input.[10,11] With the use of software (Dolphin, www.dophinimaging.com), clinicians can predict soft-tissue changes as teeth positions are modified. This has many benefits to this: patient education, diagnosis, and presurgical evaluations ~~(Figure 6 and Figure 7)~~.

More Information, Control, and Predictability

With technological advances, these digital pathways are ever evolving to provide more data to clinicians in fewer steps, increasing efficiency in implant dentistry. The ability to add more information in the digital pathways allows clinicians to better predict final outcomes in the planning stages. This increase in visualizing the GPS map from the beginning produces improved placement that could enhance outcomes functionally and esthetically.

Increasing user friendliness of optical image-capture technologies, integration of various digital inputs into open-platform implant-planning software, and 3D desktop printing now offer the clinician more control in planning, implant placement, and restorative manufacturer for greater predictability. The adaptation and application of the proposed digital protocols is the future—a dental GPS to help us arrive at our destination to provide an esthetic functional restoration safely and promptly with success.

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