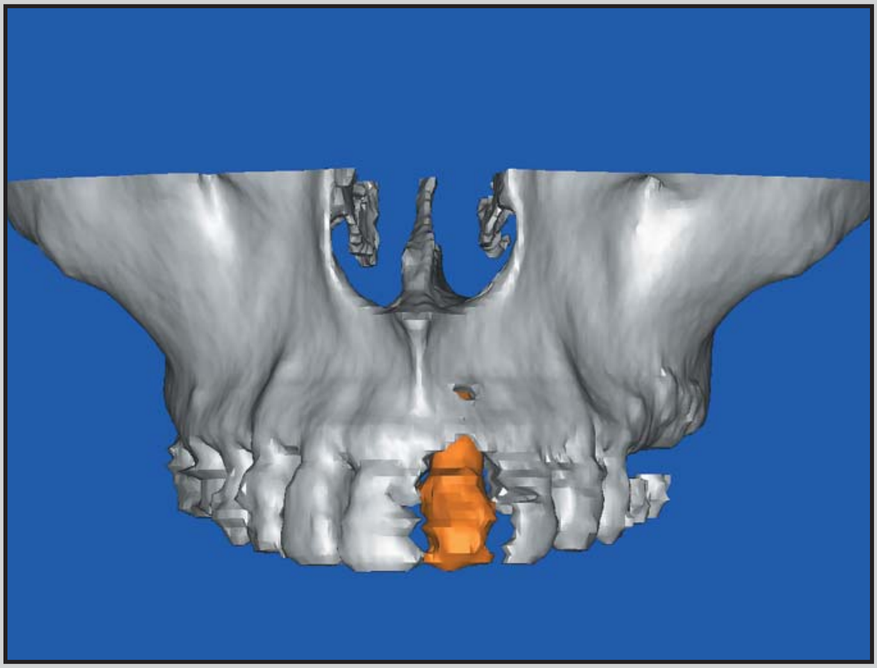

Prosthetically Directed Implant Placement Using Computer Software to Ensure Precise Placement and Predictable Prosthetic Outcomes. Part 1: Diagnostics, Imaging, and Collaborative Accountability

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The need for an accurate diagnosis and treatment plan remains essential for predictable treatment outcomes with dental implants. Advances in computerized tomography (CT) technology now enable the execution of a surgical outcome based on presurgical planning. Precise implant placement no longer relies on so-called mental navigation but rather can be computer guided, based on a three-dimensional, prosthetically directed plan. Current CT technology enables all implant team members to embrace the concept of collaborative accountability, which can ensure consistent outcomes. Clinicians can fabricate an implant-supported prosthesis presurgically using patients' CT scan data. The purpose of this paper is to discuss the use of scanning appliances to transfer clinically relevant prosthetic outcome information to a CT data set. With SimPlant software, this information can be used to provide a pretreatment outcome analysis, which can be used for fabrication of stereolithographic models and surgical drilling guides used during osteotomy preparation. (Int J Periodontics Restorative Dent 2006;26:215–221.)

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The opportunity for restorative practitioners to set surgical performance standards for implant placement outcomes marks a paradigm shift in implant dentistry. Collaborative accountability has emerged as the standard for prosthetically directed implant therapy. With the introduction of dental reformatted computerized tomography (CT) in 1987, practitioners were able to view precise, accurate anatomic representations of both arches.[1,2] However, this breakthrough fell short of presurgical prediction of prosthetic outcomes. The ability to use this information in diagnosis and treatment planning was further enhanced by the introduction of radiopaque scanning appliances (ie, appliances created specifically for CT scanning), which allowed for the transfer of prosthetic information directly to the CT scan.[3–5] The earliest scanning appliances were simple and lacked the necessary detail required to predict the prosthetic outcome. This prosthetic information led to the development of classification strategies, which identified the soft and hard tissue require-

Fig 1a *First-generation scanning appliance. A barium-coated template shows the optimal final positions for the maxillary right first and second molars.*

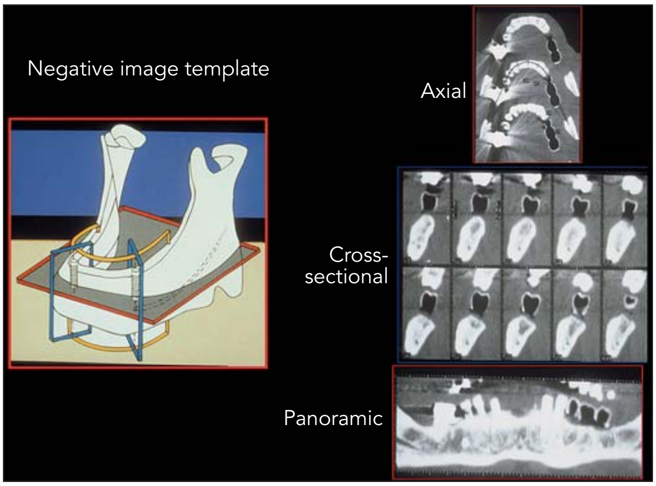

Fig 1b *Representation of optimal final tooth positions using a first-generation scanning appliance and noninteractive CT data. Axial, cross-sectional, and panoramic views are shown.*

ments to achieve prosthetic outcomes that addressed patients' needs and concerns.[3,6,7]

Traditional radiographs are analog, exhibit wide variations in accuracy, fail to determine prosthetic outcomes, and do not permit the transfer of prosthetically relevant information to guide the surgeon at the time of implant placement.[8] Recognizing the limitations of traditional dental radiographs, the American Association of Oral and Maxillofacial Radiologists (AAOMR) released a position statement in 2000: "The AAOMR recommends that some form of cross-sectional imaging be used for implant cases and that the conventional cross-sectional tomography be the method of choice."[9p631] Radiation safety notwithstanding, the evidence-based merit of this statement warrants challenge. With the advent of sophisticated scanning appliances, rapid prototyping via stereolithographic resin modeling, and the construction of computer-generated surgical guides that accurately reflect the prosthetic outcome to submillimeter accuracy, the restoring clinician has the opportunity to assume a collaborative leadership role in implant dentistry.[10–12]

The purpose of this paper is to discuss the use of scanning appliances to transfer clinically relevant prosthetic outcome information to a CT dataset. With SimPlant (Materialise), a CT scan–based implant treatment planning software system, this information can be used to provide a pretreatment outcome analysis that can be used for the fabrication of stereolithographic medical models and surgical drilling guides.

Background

Since the early 1990s, the medical community has embraced the application of medical modeling of three-dimensional (3D) data to assist in the diagnosis, surgical planning, and treatment of complex medical conditions,[13–16] notably in the separation of conjoined twins.[17] Application of this technology is now finding its way into implant dentistry.[12,18] Its greatest strength in this field is the development of prosthetically directed surgical outcomes.

As recently as 2000, rapid prototype, medical modeling and the use of stereolithographic surgical drilling guides generated from CT scans and 3D jaw imaging became available for use with dental patients.[19–22] Medical modeling gives the treatment team a preoperative appreciation of the surgical requirements needed to deliver the desired prosthetic outcome. This technology has the potential to reduce interoperator error and can establish a standard of collaborative accountability between the surgeon and the restorative clinician.

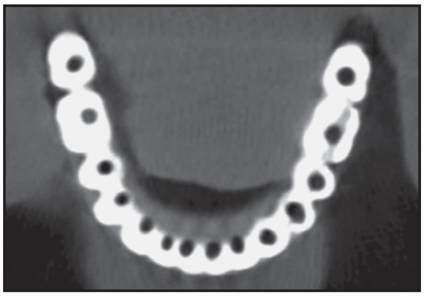

Fig 2a (left) *Three-dimensional representation of second-generation scanning appliance. Radiopaque barium teeth with negative image centers define the precise central fossae or cingulum of each tooth.*

Fig 2b (right) *Second-generation scanning appliance for CT implant diagnostics. The scanning appliance is a duplicate of the patient's maxillary provisional fixed prosthesis, with the teeth at a density of 30% barium sulfate. Proposed implant sites include the premolars and first molars. Holes in the central fossa identify the axial center for each proposed implant tooth. (Image courtesy of Dr Joseph Caruso.)*

Fig 3a (left) *The Tardieu Scannoguide, a differential barium-density gradient solid acrylic resin scanning appliance. The denture base and teeth, respectively, have 10% and 30% barium sulfate concentration by proportion.*

Fig 3b (right) *Three-dimensional CT reconstruction of a patient with mandibular complete edentulism imaged with a Tardieu Scannoguide. Masks of the mandible, denture base, and denture teeth are all present.*

Transfer of prosthetic information to the CT study

The transfer of prosthetic information to an interactive CT scanning software program to develop collaborative treatment has been discussed.[3,6,7,22] There are three generations of scanning appliance designs. The first two designs can identify optimal final tooth position, while the third expands this information to include the identification of soft tissue boundaries.

The first-generation scanning appliance includes a barium-coated silhouette of the proposed final tooth positions.[3] This enables the compatibility of the proposed tooth position in space to be analyzed relative to implant positioning in the patient's native bone with CT software (ie, SimPlant) (Figs 1a and 1b). The second-generation scanning appliance is similar, except that the hollow portion of the vacuum-formed template is completely filled with an acrylic resin/barium (30% barium sulfate by weight), which will represent a solid radiopaque tooth (Figs 2a and 2b). A first- or second-generation scanning appliance is best used when study of isolated teeth is desired.

The Tardieu Scannoguide is a third-generation scanning appliance. It is a differential barium-gradient scanning appliance (Figs 3a and 3b). It not only allows for the transfer of prosthetic outcome requirements but also defines the soft tissue boundaries on the CT study. This offers the potential for fabrication of a specialized surgical drilling guide for flapless implant placement. In addition, it offers the opportunity to construct a prosthesis from a CT study alone.[23] An immediately loaded prosthesis can be placed at the time of implant placement, eliminating the need for a traditional dental impression (ie, the Immediate Smile procedure, Materialise).

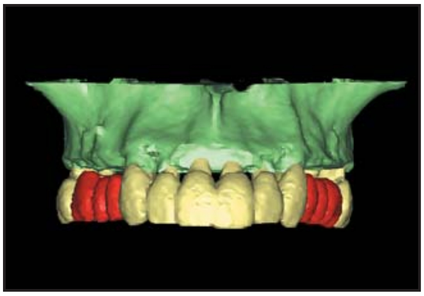

Fig 4 *Masks can be incorporated on 3D CT reconstructions to enable the isolation of structures for specialized viewing. Here, masks of the maxilla, natural teeth, and proposed implant prostheses are observed. Proposed final tooth positions are highlighted in red.*

Fig 5 *Three-dimensional reconstruction of the maxilla.*

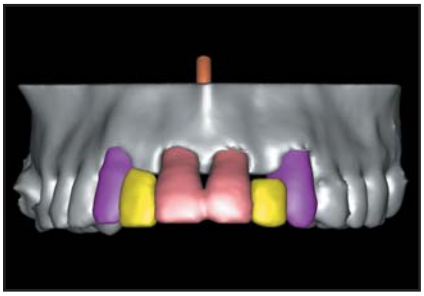

Fig 5a *Masks incorporated include the maxilla, anterior natural teeth, nasopalatine nerve, and proposed optimal positions of the lateral incisors. This was done with a first-generation scanning appliance.*

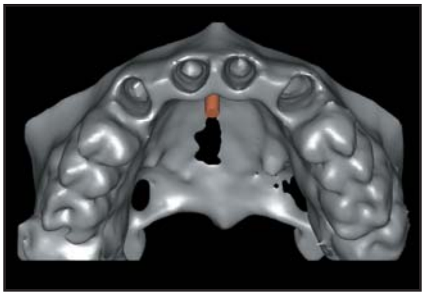

Fig 5b *Masks of the natural teeth and the scanning template, representing optimal final positions of the lateral incisors, have been toggled off to analyze the alveoli.*

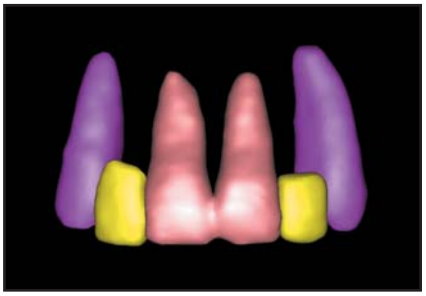

Fig 5c *Masks of the maxillary bone and nasopalatine nerve have been toggled off.*

Referral for CT study

The patient is referred to a facility that can obtain high-quality axial CT images, which can be reformatted with the most recent version of SimPlant. Image quality depends on the production of thin-sliced, high-resolution axial images. "Masks" can be requested to allow objects with different densities to be manipulated to create specialized viewing opportunities, which will assist in the treatment-planning process (Figs 4 to 6; see also Fig 3b). The incorporation of different objects based on differences in density and their application to the 3D analysis is also performed with SimPlant.[24] Surgical drilling guides (SurgiGuide, Materialise) are designed and generated from the CT images and the prosthetically directed preoperative surgical plan.

When the data file is converted at a SimPlant Master or Pro site, the radiology technician will introduce the requested masks and reduce artifacts wherever possible. The study now includes the prosthetically directed radiopaque scanning data and becomes the basis of collaborative accountability. Collaborative accountability sets the restoratively directed performance standards that are required to ensure the desired prosthetic outcome.

Retrieval of patient-specific information

Local and regional anatomy influences the position of dental implants. It is well understood that even under the most ideal circumstances, implants are not placed entirely in bone previously occupied by the tooth root (see Figs 6a to 6c). The fundamental incompatibility between implant position and optimal tooth position is the greatest challenge facing the implant team.[3,6,7,25] The selection of the appropriate scanning appliance is important to maximize the retrieval of relevant prosthetically directed information. Because the radiodensity of the scanning appliance differs from that of the anatomic

Fig 6 *Three-dimensional CT reconstruction of the maxilla.*

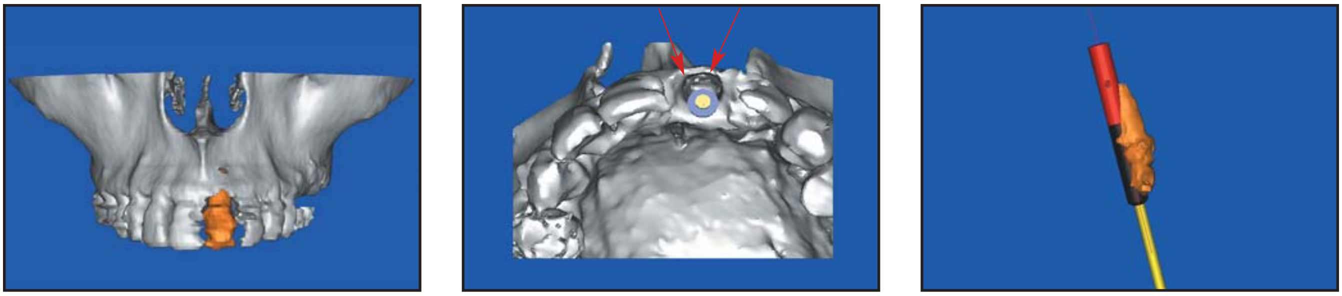

Fig 6a *A mask of the left central incisor has been created.*

Fig 6b *Occlusal view with the mask of the left central incisor toggled off. Note the positioning that will be required to stabilize the implant relative to the position of the natural alveolus. A discrepancy between the ideal implant position and facial alveolus* (red arrows) *will require a management decision.*

Fig 6c *Cross-sectional view without mask of the maxilla. Note optimal implant positioning* (red) *relative to the position of the natural tooth* (orange).

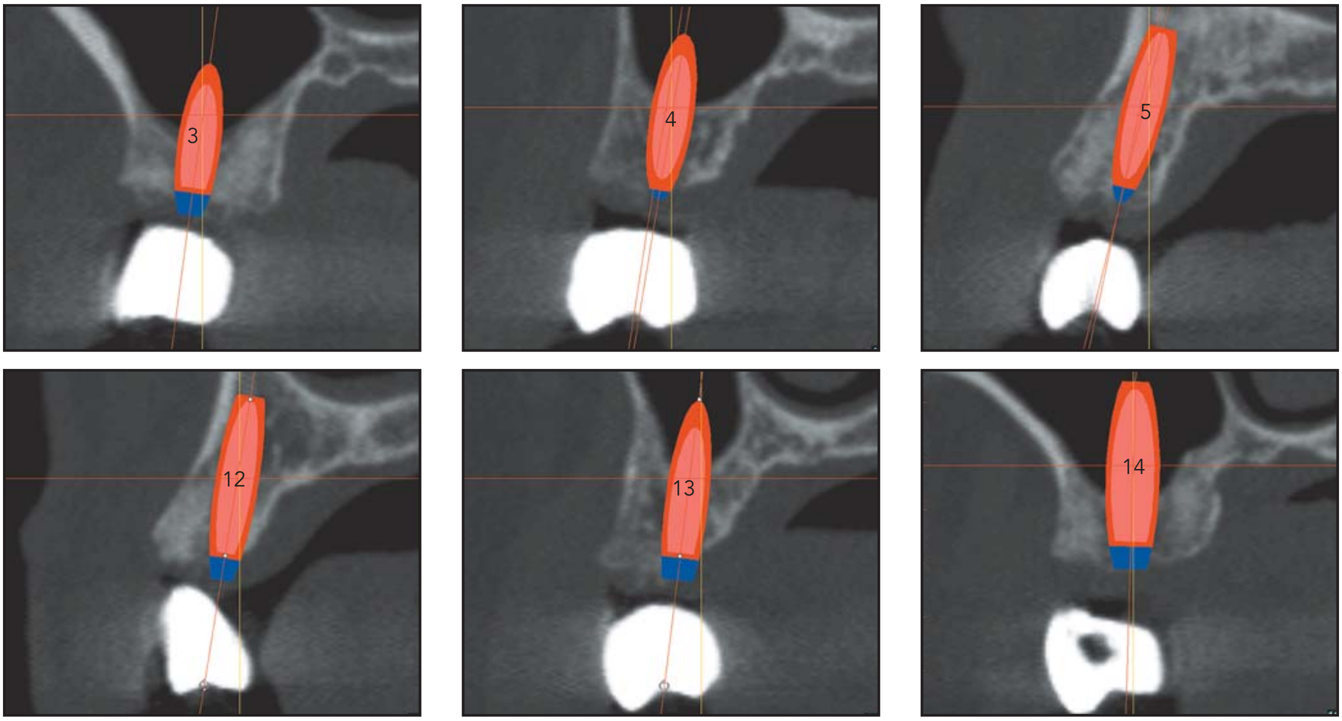

Fig 7 *Cross-sectional views of proposed implant postioning relative to optimal final tooth positioning.* (top left) *maxillary right first molar;* (top center) *right second premolar;* (top right) *right first premolar;* (bottom left) *left first premolar;* (bottom center) *left second premolar;* (bottom right) *left second molar.*

structures, it is possible to isolate both prosthetic and anatomic information (Fig 7; see also Figs 3b to 6).[26]

It is well documented that accuracy and precision are lacking with static or noninteractive radiography.[27,28] The inability to transfer the relevant prosthetically directed CT information directly to the patient has also been an obstacle. Perhaps the simplest way to understand the value of the technology is to understand that patient-specific information is embedded in the CT data set. The interactive software allows the treatment team to ask questions presurgically and retrieve the data necessary to determine what is required to produce the desired outcome.

Collaborative accountability

Because the prosthetic outcome has been defined by the restorative clinician, preoperative treatment planning establishes the surgical requirements that drive patient care. This provides the restoring clinician with an objective basis to assume a leadership role in defining treatment outcomes. Collaborative accountability represents a paradigm shift in the treatment of implant patients. The following points define collaborative accountability:

1. Prosthetic outcome determines surgical requirements, which the implant surgeon must follow. It also defines treatment limitations and costs preoperatively.
2. Preoperative, rather than intraoperative, planning drives treatment.
3. Stereolithographic modeling and surgical drilling guides (eg, SurgiGuide) reduce the surgical "talent gap." In other words, the placement of dental implants no longer relies on traditional "mental navigation" but rather on precise, computer-guided implant positioning that is planned presurgically.
4. The restorative practitioner assumes a leadership role in interdisciplinary collaboration by setting the treatment performance standards for those participating in patient care.
5. The collaborative process, by its nature, focuses on patient outcome.

Discussion

The most important aspects of patient care are accurate diagnosis and a treatment plan that addresses the needs and concerns of both the patient and the implant team. The ability to incorporate the prosthetic outcome into a CT data set marks a collaborative breakthrough between the surgeon and the restorative clinician. Roles and responsibilities can now be clearly defined.

The major benefit of this paradigm shift is the ability to determine the desired prosthetic outcome, along with the surgical requirements to achieve this outcome, before surgical intervention. The available technology allows the restorative clinician to have direct involvement in surgical accountability, giving him or her a leadership role in the outcome. Furthermore, the collaborative nature of this process ensures that all of the participants involved in interdisciplinary care are accountable to the final outcome. The accuracy and precision of computer-facilitated software for guided implant surgery dramatically supersede those of mental navigation.[10,26] Accurate presurgical treatment planning allows for interdisciplinary discussions, which should include the restorative clinician, surgeon, and laboratory technologist, thus resulting in a balanced and objective view of the treatment plan and surgical requirements. Perhaps its least appreciated benefit is the ability to conduct the process of informed consent in an atmosphere of complete disclosure.

The use of CT scanning technology need not be limited to so-called complex cases. Each and every implant surgery has unique nuances that affect treatment outcomes. The ability to interpret CT scans is proportional to familiarity, and its clinical application is related to experience.

Parts 2 and 3 of this series will address the use of rapid prototyping and stereolithographic medical modeling in the field of implant dentistry. It should be emphasized that this technology, while patient specific, is not dependent on a particular implant system.

Conclusions

1. Interactive CT technology allows the incorporation of prosthetic information into a CT study, which can be analyzed against the patient's regional anatomy before surgical intervention.
2. Collaborative accountability represents a leadership breakthrough for the restorative practitioner.
3. Surgical requirements can be established prior to treatment.
4. Minimally invasive surgical treatment is now feasible not only in general medicine, but also in the field of dentistry.
5. This technology allows for the process of informed consent to be conducted in an atmosphere of complete disclosure.

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