Presurgical Implant-Site Assessment and Restoratively Driven Digital Planning

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KEYWORDS

• Cone beam computed tomography • Presurgical virtual implant planning
• Three-dimensional imaging • Digital registration

KEY POINTS

- Cone beam computed tomography imaging and 3-dimensional (3D) computer software allow for greatly enhanced visualization of bone, critical anatomy, and restorative plans. These systems allow clinicians to alter and process patients' 3D images and restorative templates, facilitating dental implant planning.
- Effective assessment of proposed implant sites requires that clinicians interpret implant sites for many factors related to successful implant restorations, including adequate bone volumes, distance away from teeth/implants, sufficient prosthetic space for restoration, and precise implant placement.
- The combination of soft-tissue and occlusal separation, digital registration of patient scans with prosthesis, and soft-tissue scans greatly enhances the ability to visualize planned restorative outcomes and accommodating implants within these outcomes.
- Crown-down digital implant treatment planning permits clinicians to have more control over the implant treatment plan by creating ideal, virtual restorations and managing implant positions based on the virtual plan.
- 3D treatment flow significantly improves on the traditional workflow by supplementing more complicated and expensive diagnostic information with simpler and equally effective treatment protocols.

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INTRODUCTION

Proper dental implant placement for single crowns, multiple fixed partial dentures, implant-retained overdentures, or fixed implant–supported restorations relies on adequate pretreatment visualization of the proposed bone recipient site, evaluation of bone density, and assessment of restorative goals. Radiographic visualization of facial and cervical tooth positions, bound restorative space, and bone configuration is a necessary step in the treatment sequence and planning of implant restorations. The ultimate success of the dental implant relies on this radiographic assessment in combination with proper restorative evaluation to ensure that the final outcome is compatible with expected outcomes.[1–3]

Many imaging options are available for the assessment of dental implant sites, and their use depends on several factors:

- Availability
- Experience of the clinician
- Amount of radiation exposure
- Restorative planning goals
- Cost

Although these factors affect the decision of the clinician to request a certain radiographic approach, the patient is typically concerned most about the radiation exposure and cost. The advent of digital 3-dimensional (3D) imaging in conjunction with cone beam computed tomography (CBCT) allows for a maximum amount of information available to the clinician and laboratory while minimizing the amount of radiation exposure.[4] Furthermore, popularization of CBCT imaging and moderate growth into the private practice group imaging sector has allowed an increase in availability of digital scanning to patients while reducing cost. Recent advancements in software development have allowed for greater visualization of implant sites, complete control of restorative plans, and fabrication of precise computerized surgical guides. The purpose of this article is to describe methods of preoperative assessment of implant sites based on a philosophy of crown-down digital implant treatment planning, using CBCT scanning and 3D digital imaging.

TWO-DIMENSIONAL VERSUS 3D IMAGING

Traditional 2-dimensional (2D) radiographic imaging of dental implant sites typically involve the use of periapical radiographs for partially dentate patients, with single implant sites and panoramic radiographs for edentulous patients and multiple implant sites.[5] In combination with calibration markers, such as ball-bearing spheres of a known diameter, the clinician is able to estimate maximum height and mesiodistal width of implant sites (**Figs. 1** and **2**). Although this approach has historically allowed the clinician the ability to rapidly visualize potential implant sites, it gives little information in regards of buccal-lingual bone width, configuration, or density. In addition, these methods of radiographic imaging are also subject to angulation discrepancies between the planned implant position, where the radiograph indicates there is adequate bone volume, and the resultant implant site.[6] When an implant is to be placed in proximity to a vital structure, such as a nerve, artery, or sinus cavity, with 2D radiography only limited information with which to properly assess the distance is possible. The resulting errors from the reliance on the traditional imaging leads to potential complications, including prosthetic complications, soft-tissue insufficiency, implant failure, and paresthesia.[7,8] Complications may lead to an unsatisfactory patient outcome, referral to other specialists, and medicolegal claims.[9,10] These

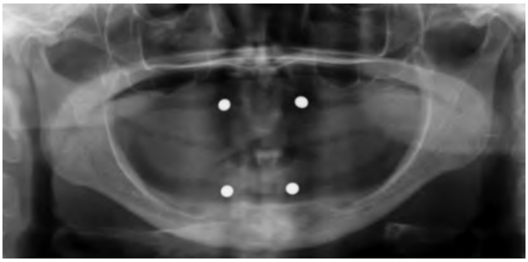


Fig. 1. Panoramic radiograph of a patient with calibration ball bearings in positions of possible implant sites.

complications can potentially be greatly reduced with the utilization of additional imaging techniques for implant-site assessment.

The use of CBCT imaging allows for 3D evaluation, increasing the visualization of critical anatomic structures and providing a superior amount of information.[4,11,12] The radiographic visualization of the alveolar ridge, tooth position, and the restorative plan are necessary steps in assessment of a potential implant site, and the treatment sequence and planning of implant restorations. The rapid visualization of bone contour and configuration allows for more precise treatment planning and presurgical preparation.

The clinical reality of most edentulous ridge sites is that they are not as even and as favorable as the 2D radiograph portrays (**Fig. 3**). Essential presurgical assessment should include an evaluation of the mesiodistal, occlusal-gingival, and buccal-lingual conformation of the proposed bone recipient site. Relying on 2D imaging may lead the clinician to believe that the ridge volume will accommodate a traditionally

Fig. 2. Periapical radiograph with a calibration ball bearing.

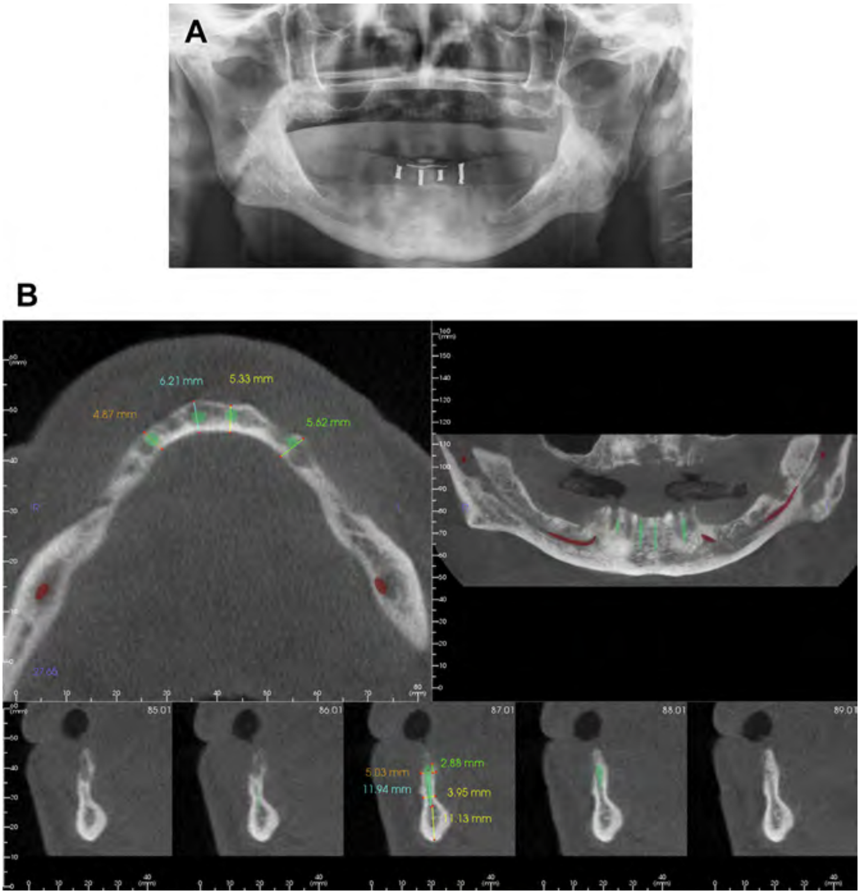


Fig. 3. Panoramic radiograph of an edentulous patient showing sufficient bone height for dental implants in the anterior mandible (*A*), and cone beam computed tomography (CBCT) arch section of the same patient illustrating a cross section through the bottle-shaped mandibular anterior ridge (*B*).

larger-diameter implant. Whereas some surgeons keep large inventories of implants for many clinical scenarios, many only order the implants when the case has been planned. After surgical access has been obtained, it is possible to encounter bone volume that cannot accommodate implants of traditional size, causing the unprepared clinician to abort the surgical procedure (**Fig. 4**A). Ultimately the surgical site must be entered a second time, and increased surgical morbidity is possible. After initial analysis, the clinician can accurately visualize the 3D bone contour of a patient and make determinations about surgical entry, implant diameter and length, and prosthetic requirements before the surgical procedure (see **Fig. 4**B, C).

CBCT IMPLANT PLANNING SOFTWARE

Various software packages are available for the interpretation of Digital Imaging and Communications in Medicine (DICOM) files generated from CBCT scans. Most imaging software packages allow for cross-sectional implant-site analysis, nerve mapping, thresholding control, and planning of virtual implants (**Fig. 5**). Although the individual

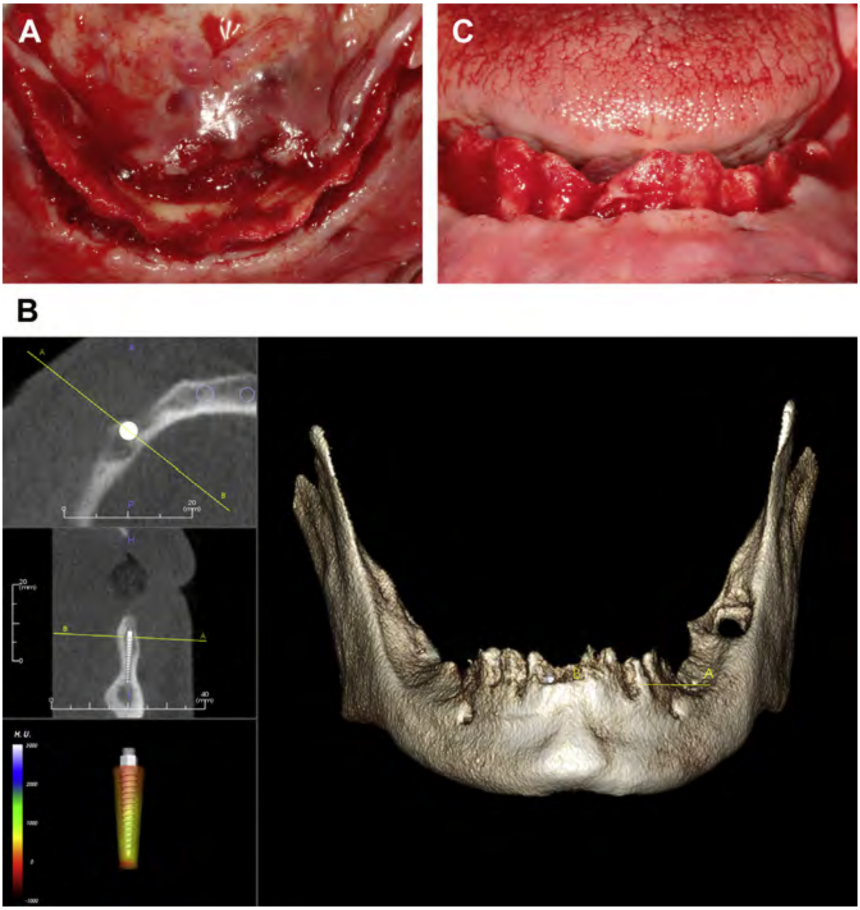


Fig. 4. (*A–C*) Surgical access of patient illustrated in Fig. 3. The clinical reality of many patients is a thin, knife-edge anterior ridge (*A*). Volumetric CBCT imaging allows for better visualization and preparedness for the surgical procedure (*B, C*). Once accessed, the 3-dimensional (3D) rendering is substantially more realistic and lifelike than visualizing the 2-dimensional panoramic radiograph illustrated in Fig. 3A.

software packages do have various features that differ from each other, these essential controls allow the user to assess an implant site and virtually plan the surgical placement of the implant (Table 1).

The computer software allows the user to use the CBCT DICOM data and, through various methods of data interpretation, permit rendering of the bone volumes before surgical procedures. The clinician can easily visualize virtual implant bodies present in the bone volume rendering, allowing for more precise implant-site measurements based on visualization (see Fig. 5). Clinicians typically visualize the bone profile, make measurements, and use these measurements when preparing for surgical procedures. Though relatively simple, these controls are effective when the virtual implant outline is shown, allowing immediate visualization of the proposed implant position within the bony contours.

Many of the computer software packages allow for assessment of the relative bone densities of the implants in the proposed implant site; for example, Invivo Dental

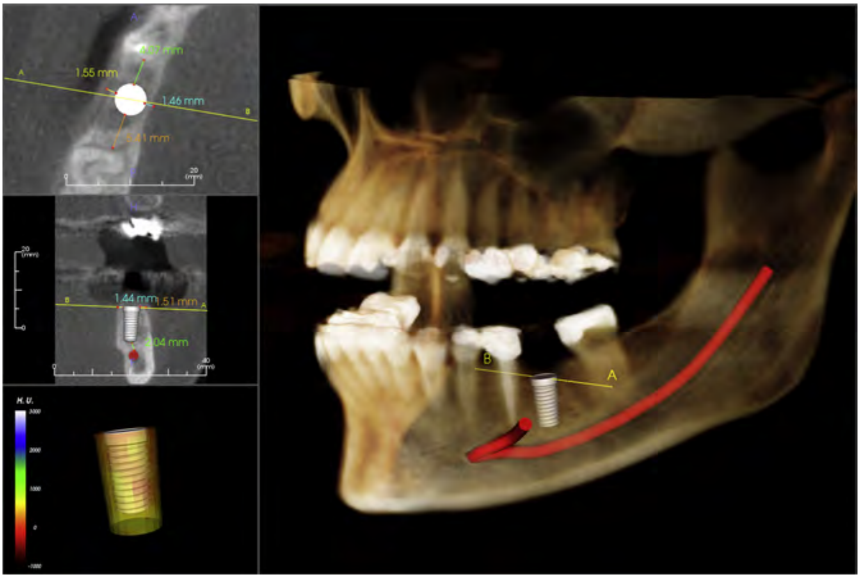


Fig. 5. Most 3D CBCT software allows for nerve mapping, virtual implant placement, and measurement tools to provide a digital assessment of the implant site in virtual rendering of the bone (Invivo Dental; Anatomage, San Jose, CA).

(Anatomage, San Jose, CA). Evaluation of bone density values allows for prediction of the implant insertion torque and primary stability. Although this measurement is a relative measure based on gray values, machine calibration, and software interpretation, it often provides a more predictable assessment of proposed bone density. Although not fool-proof, this is a valuable preoperative measurement that allows the clinician to modify surgical drilling protocol, surgical access, and implant-thread configuration. During implant planning and virtual visualization, cool tones such as green and blue indicate higher-density bone, and hot tones such as yellows and reds indicate lower-density bone (Fig. 6A, B). This example illustrates the first molar sites on 2 separate patients: one CBCT scan (see Fig. 6A) is predicting much lower bone density than the second CBCT scan (see Fig. 6B). As a result of these scans, a different implant with a more aggressive thread design was chosen for the patient with lower-density bone to allow for increased immediate primary stability. In addition, implants using a tapered drilling protocol typically do not allow for an undersized osteotomy in lower-density bone. If a lower bone density profile is predicted, choosing an implant that allows for a cylindrical drilling protocol and the ability to slightly undersize the last osteotomy before implant placement may allow for increased primary stability of the implant during surgical procedures.

Some of the software packages allow for visualization of implant abutments in addition to implant bodies; for example, OnDemand3D (Cybermed, Irvine, CA). Visualization of implant abutments are important when considering angulation of implants with full-arch restorations such as All-on-4 (Fig. 7). The clinician can alter abutment angulation, rotation, and the height of the gingival emergence form. These controls are essential with implants tilted or angled during the initial assessment phase because they give a full-featured restorative-based visualization of the proposed implant position within the bony contours. Complete visualization including abutment positions

Table 1
CBCT implant planning software

Software	Features											
	Automatically Converts DICOMS	Requires DICOM Conversion	DICOM Conversion Fee	Automatic Thresholding and 3D Rendering	Imports STL Files	Nerve Mapping	Implant Site Measure-ment Tools	Virtual Implant Library	Implant Abutment Library	Surgical Guide Fabrication	Radiology Reporting Service	Software Cost
Anatomage Invivo Dental	✓	—	—	✓	✓	✓	++	+	+	+	+	$
Cybermed onDemand3D	✓	—	—	—	✓	✓	++	+	++	++	++	$
Materialise Simplant Planner	—	✓	$$	—	—	✓	++	++	++	++	—	$
Materialise Simplant Pro	✓	—	—	—	✓	✓	++	++	++	++	—	$$
Nobel Clinician	✓	—	—	—	—	✓	+	+	++	+	+	$$
Straumann coDiagnostix PPP	—	✓	$	—	✓	✓	+	+	++	+	—	$
Straumann coDiagnostix PPG	✓	—	—	—	✓	✓	+	+	++	+	—	$$
Keystone EasyGuide	✓	—	—	—	—	✓	+	+	+	+	—	$
BlueSky Plan	✓	—	—	✓	✓	✓	+	+	+	+	—	—

Key: ✓, available; —, not available; +, partially featured; ++, fully featured; $, moderately expensive; $$, very expensive.

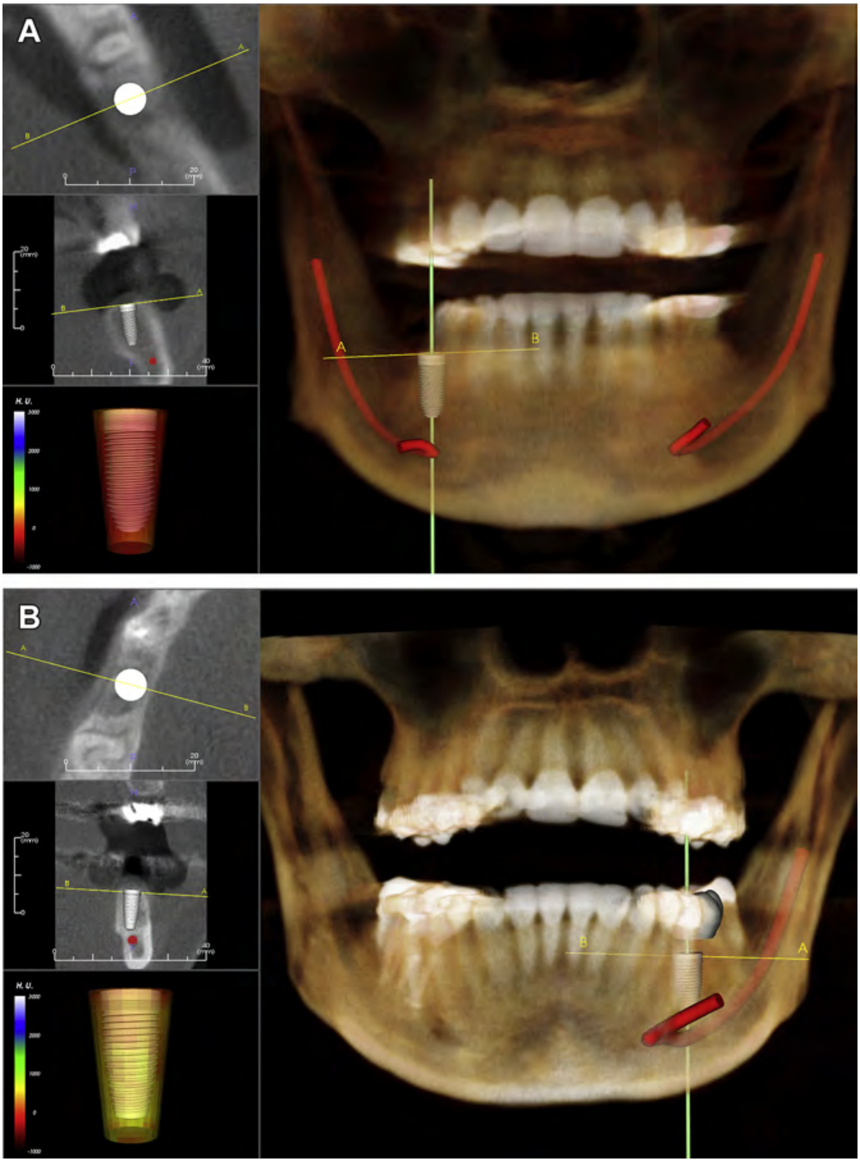


Fig. 6. (*A*, *B*) Patients with hotter colors in predictive bone-density profiles tend to have lower insertion torque. If a 1-stage surgical procedure is desired, an implant should be chosen with a more aggressive thread pattern and the ability to undersize osteotomies (*A*) rather than in sites with higher bone densities represented by cooler colors (*B*).

allows a substantially improved implant plan, and allows for accurate presurgical ordering of applicable implant parts. Having software control of all aspects of the implant plan also allows for more precise computer-generated surgical guides, leading to implants being placed in ideal positions relative to bony contours and to each other, with correct timing and rotation.

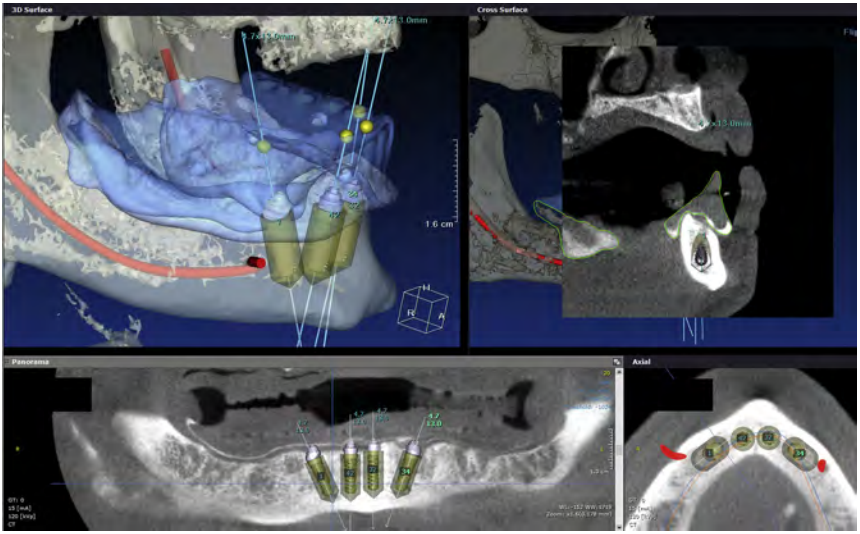


Fig. 7. Full virtual abutment libraries allow for complete control of angulation and rotation to precisely plan implant position for tilted implant protocols (All-on-4).

IDEAL IMPLANT POSITIONING

Proper evaluation of 3D tooth position, angulation, and restorative space is essential during treatment evaluation for preoperative assessment of implant sites. Positioning of single implants within the dental arch is challenging considering the proximity to adjacent tooth roots, vital structures, occlusal plane, and relative position within the arch. Falling within certain defined guidelines, recommendations are based on generally accepted criteria (Box 1, Figs. 8 and 9).[13–16]

When positioning an implant within the arch, digital software will allow the user to place a virtual analog of the proposed implant and measure the optimum distance between the previously mentioned structures (see Fig. 8). This visualization allows for rapid site analysis and predictable treatment planning whereby the surgeon can order specific implant diameters and sizes, healing abutments, and provisional crowns. Once the implant and healing abutment is placed during the surgical procedure, restorative procedures are relatively straightforward with minimal compromise (Fig. 10).

For multiple implants in an edentulous arch, ideal implant positioning is relative to the final restoration goals and configuration. Knowledge of the proposed restorative plan and space is essential in implant-site assessment before initiating the radiographic analysis. This restorative space is bound by the proposed occlusal plane, mesial-distal distance between teeth, denture-bearing tissues of the edentulous ridge,

Box 1
Recommended minimum distances (mm) for single implants

Implant to tooth	1.5
Implant to vital structure	2.0
Implant to implant (fixed restorations)	3.0
Implant to facial/lingual bone	>1.5

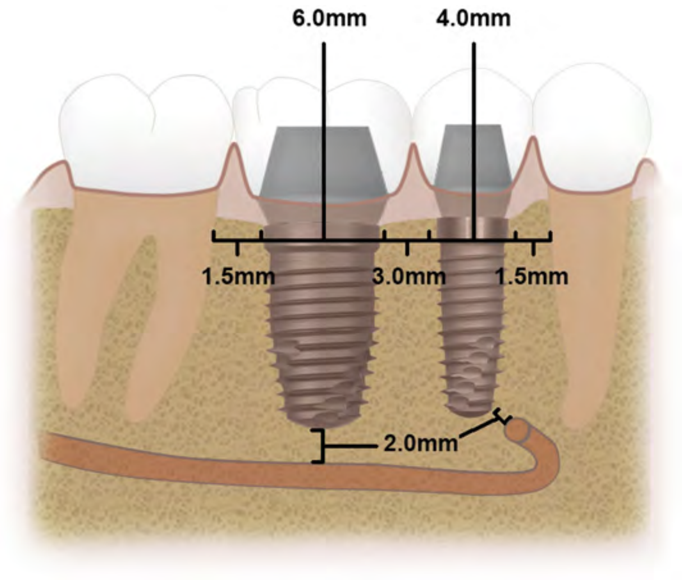


Fig. 8. Recommended distances from implants to adjacent teeth and vital structures to maintain safety and restorative success.

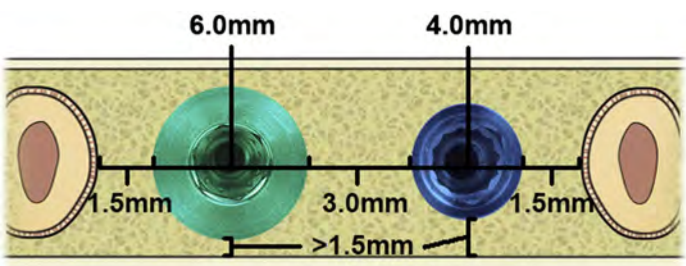


Fig. 9. Maintaining minimum distances away from implant surface to facial/lingual bone allows for long-term success of the dental implant and ideal tissue health.

Fig. 10. Predictable implant surgical procedures based on digital assessment.

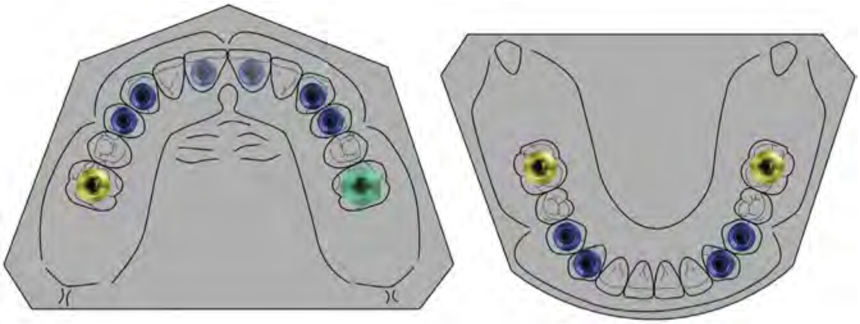


Fig. 11. Strategic implant positions for full-arch reconstruction include canines, first premolars, and first molars. The maxillary central incisors may also be considered strategic positions.

and orofacial tissues.[17] To facilitate full-arch reconstruction of implant cases, certain implant positions exist where the practitioner can reliably restore patients to near complete function. These strategic positions include the canines, first premolars, and molars (**Figs. 11** and **12**). In addition, some investigators advocate that in the maxillary arch, the central incisors are also strategic positions. Available restorative space is the amount of space available to retain an implant abutment, retentive mechanism, and any other parts necessary to properly fabricate the prosthesis. Generally recommended criteria for hybrid and overdenture restorations in edentulous patients are given in **Box 2**, and **Fig. 13**.[18–20]

Using this information, the clinician can measure the amount of prosthetic space by using a caliper to measure the distance between the intaglio surface of the denture and the incisal edge of the prosthesis (**Fig. 14**A). During this initial assessment of a patient's dental prosthesis, estimates can be made regarding potential alveolar ridge reduction to increase the amount of prosthetic space for the final implant prosthesis. Besides this simple and effective method of measuring the denture prosthetic space, the listed recommended measurements also include 1 to 3 mm of tissue depth, which should be added to the caliper measurement. Once the CBCT scan is made, the estimate can

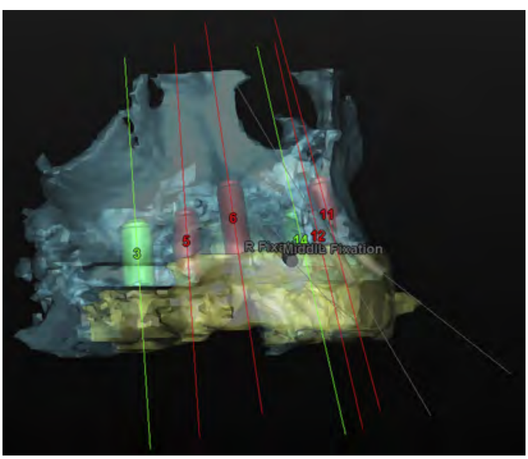


Fig. 12. Digital treatment plan of a patient requiring maxillary reconstruction with 6 implants in strategic positions.

Box 2
Recommended minimum distances (mm) for overdenture and hybrid restorations

Implant to implant (overdenture)	5.0
Implant to incisal edge (overdenture)	9–11
Implant to implant (hybrid)	>1.5
Implant to incisal edge (hybrid)	15–18
Implant to vital structure	2.0

be verified and the implant positions and proposed bone reduction digitally planned (see Fig. 14B). Bone-reduction computerized surgical templates provide precise guidance for the amount of alveolar recontouring necessary before implant placement (see Fig. 14C). This recontouring will allow for an increase in the amount of restorative space necessary once the implant body is in place. After completion of this procedure, the implants may be predictably placed according to the preoperative implant treatment plan using a computerized surgical guide (see Fig. 14D). This proposed treatment flow is only possible with careful attention to the preoperative implant-site assessment and treatment plan, using implant planning software programs.

Inadequate attention to analyzing the restorative space can lead to problems such as an overcontoured restoration, artificially opened occlusal vertical dimension, and the need to perform additional surgical and restorative procedures (Fig. 15).[21–24] This example illustrates an implant case that was seemingly well executed with implants that appear integrated; however, the patient reported she was unable to wear the denture since the surgical appointment 5 years prior. The patient immediately

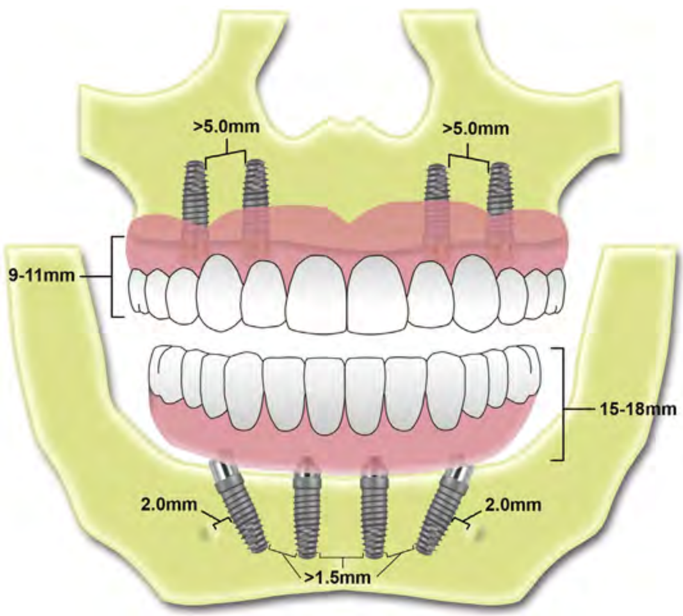


Fig. 13. Minimum distance measures between implants and vital structures, and from implant surface to superior portion of restoration for overdentures (*top*) and for fixed hybrid restorations (*bottom*).

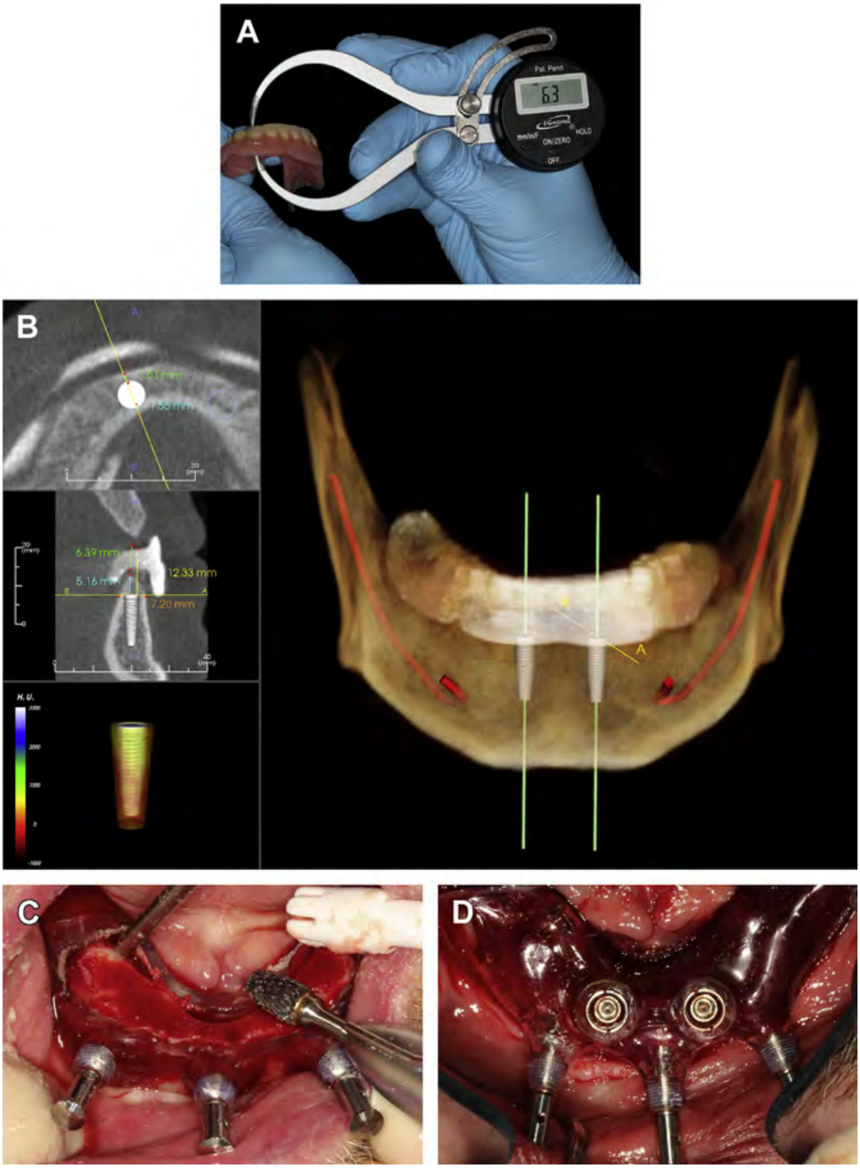


Fig. 14. A caliper can be used to measure prosthetic space from the intaglio of the denture to the incisal edge and adding 1 to 3 mm for tissue depth (*A*), and correlate the measurement to the 3D digital plan to give a definitive bone-reduction plan (*B*). After the plan has been made, a bone-reduction computerized surgical guide can be fabricated and placed intraorally (*C*), followed by an implant computerized surgical guide to place implants with precision (*D*).

reported signs of excessive vertical dimension; she was unable to speak adequately, with extreme gag reflex and temporomandibular joint strain. Alterations to the existing complete denture allowed the vertical dimension to be corrected, but resulted in inability to use the dental implants for retention. The availability of smaller-diameter

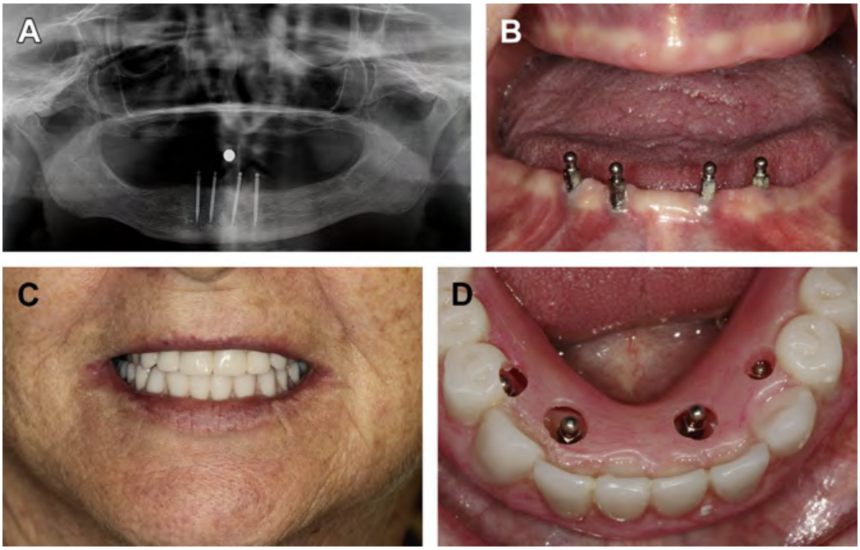


Fig. 15. Panoramic radiographic showing 4 small-diameter implants (*A*), and intraoral evaluation shows some signs of minor tissue changes but overall healthy appearance (*B*). Evaluation of the vertical dimension illustrates that the patient is excessively opened and cannot speak effectively (*C*). Holes were made exposing the retentive head of the implant bodies to allow the patient to be comfortable at an appropriate vertical dimension; reducing the vertical dimension allowed her to be comfortable and speak well (*D*).

implants combined with flapless techniques has allowed for more patients to benefit from implant therapy with reduced morbidity. Inadequate visualization of the restorative space, however, for any implant design will cause a restorative challenge.

RADIOGRAPHIC TEMPLATES AND VISUALIZATION

Various methods of radiographic visualization of proposed restoration methods are available, and typically fall within categories radiographic template and virtual restorative wax-up. Radiographic templates are typically fabricated by duplicating the existing or proposed restoration or waxing on a dental cast, duplicating the diagnostic cast, and fabricating a separate template based on the wax-up.[25–28] Many of these radiographic guides contain radiopaque markers such as gutta percha,[29–31] ball bearings,[32,33] metal tubes,[26] metal strips,[6,34] and barium sulfate.[25–27,35,36] These markers can reliably act as restorative markers indicating buccolingual position, occlusal surface configuration, denture base contour, tooth angulation, and proposed screw-access channel (Fig. 16A).

Before the CBCT scan, the fit of the radiographic guide is tested to verify complete adaptation to the teeth or tissues. The patient wears the radiographic guide during the scan, and it is easily visualized during software analysis and treatment planning (see Fig. 16B). Traditional radiographic guides are effective for rapid assessment of restorative features necessary for implant-site assessment and treatment planning. Although visualization can be achieved with this approach, some choose not to fabricate radiographic guides because of the extra steps and costs involved. The clinician needs to make an impression, pour a cast, and send the cast to the dental laboratory before making a CBCT scan. Although these procedures may be completed by the

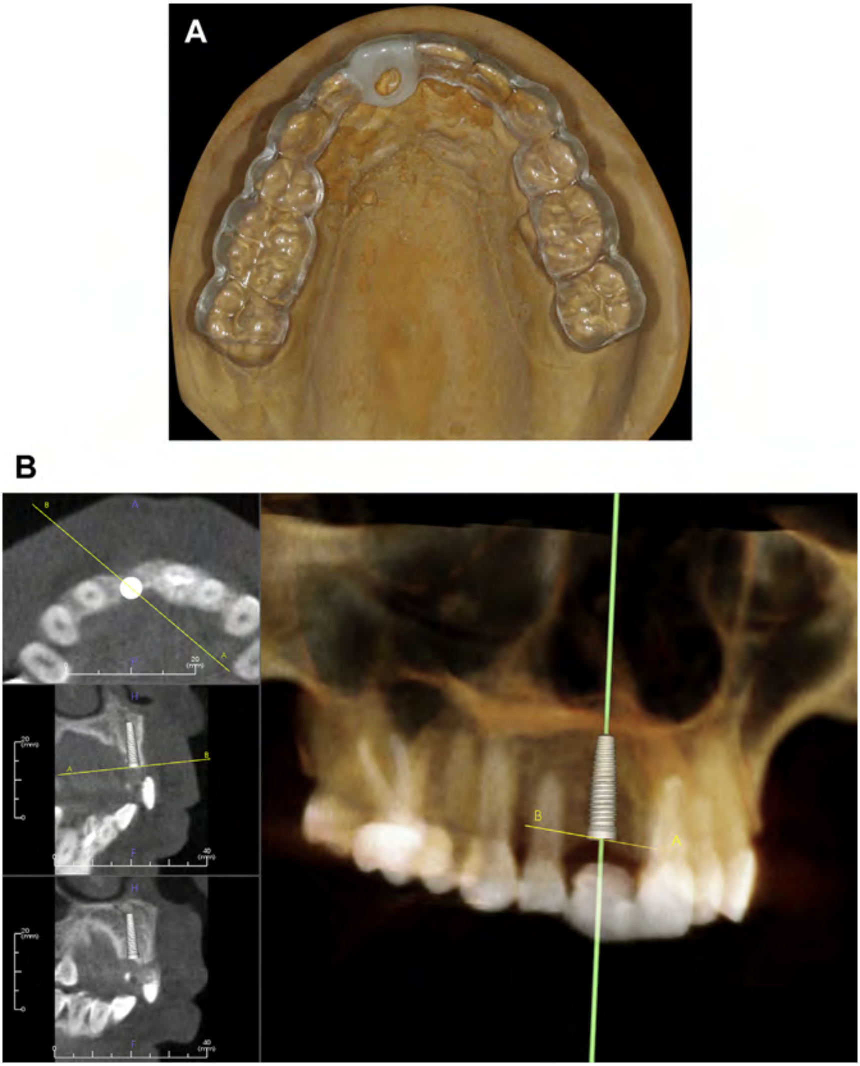


Fig. 16. Traditional barium sulfate radiographic template based on a laboratory wax-up (*A*). In the mouth the radiographic appearance is distinct and easily recognized (*B*).

dentist or a dental assistant, most clinicians refer out these procedures rather than fabricate them in their own offices. A second clinical appointment is typically necessary to try the prosthesis to confirm an adequate fit before the CBCT scan. Even with this extra effort, voids and inaccuracies may arise from the fabrication process, resulting in improper visualization of the restorative profile or inadequate adaptation to the soft tissues (Fig. 17).

THE ROLE OF AIR SPACE IN 3D IMAGING

CBCT scans made with a dental prosthesis such as a denture, or with natural teeth in occlusion, are traditional methods used to evaluate bone volumes for implants.

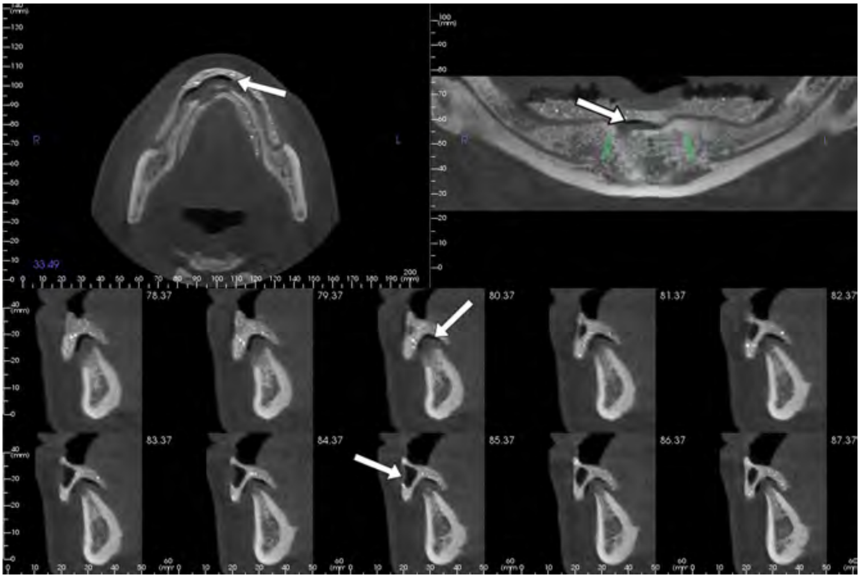


Fig. 17. CBCT scan of a patient wearing a barium sulfate duplicate of the existing complete denture, illustrating potential for voids and misfit between guide and soft tissues (*arrows*).

Protocols using cotton rolls or tongue depressors placed between the occlusal surfaces of the teeth while the patient applies biting pressure may assist in visualizing the occlusal surface detail of the remaining teeth (Fig. 18). The creation of air space around the occlusal surfaces allows for greater visualization of surface detail and facilitates visualization of restorative treatment (Fig. 19).

CBCT scans that are made without creation of air space through soft-tissue separation provide little information other than the amount of residual bone present for the implant site. Even though a patient may be wearing complete dentures during a CBCT scan, little information is present regarding restorative goals if soft tissues are allowed to intimately contact the surfaces of the dentures (Fig. 20A). The radiodensity of cortical bone (1700 Hounsfield units [HU]) allows it be easily discernible on CBCT

Fig. 18. Cotton rolls added to separate tongue, cheeks, and lips, allowing for a creation of air space around dentition and periodontal tissues.

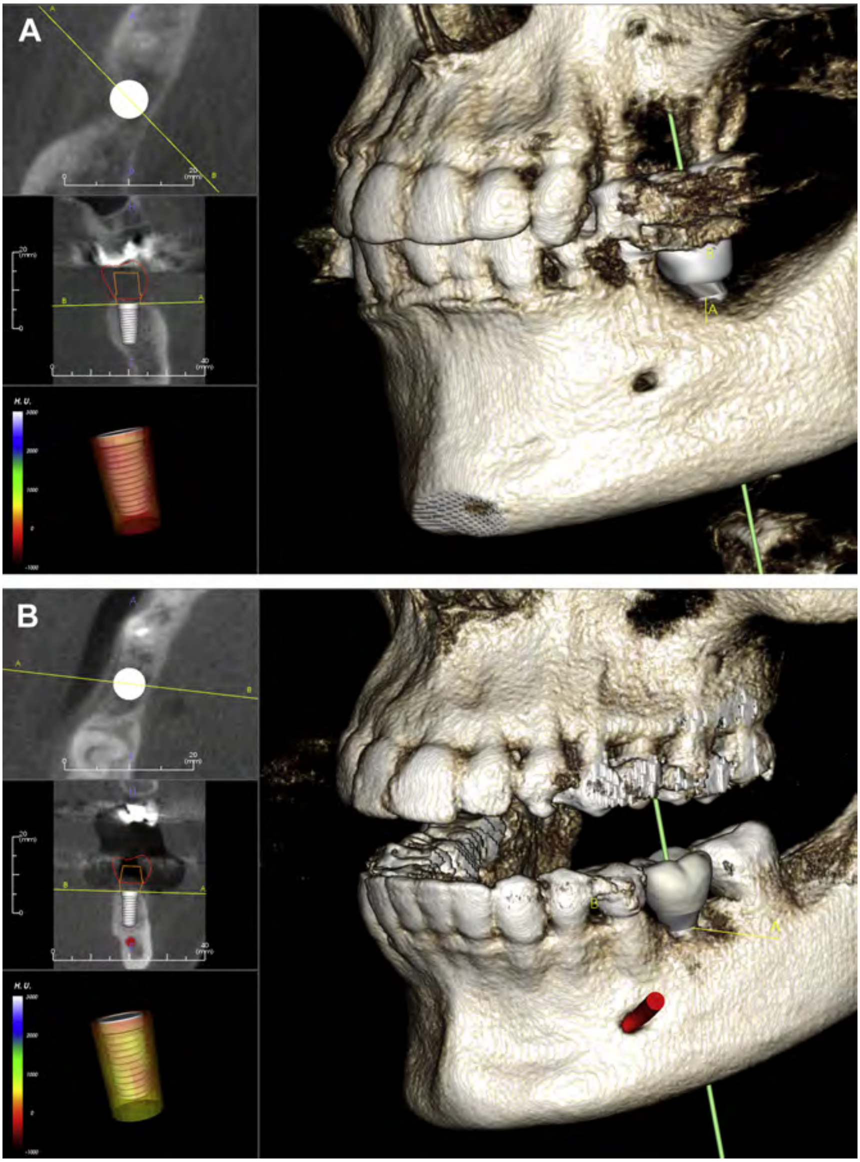


Fig. 19. CBCT scans are often performed without occlusal separation, making the occlusal analysis difficult because of potential areas of backscatter from dental restorations (*A*). Making CBCT scans with occlusal separation improves the visualization of the occlusal surfaces, even when areas of backscatter are present (*B*).

radiographs in comparison with air (−1000 HU) and tissues (50 HU).[37] The comparison of tissue radiodensity and that of denture acrylic resin (70 HU), however, makes it more difficult to discern the differences between the resin and tissues.[37]

Separation of tissues and creating air space around acrylic resin allows the radiodensity of air to contrast with that of acrylic resin (see Fig. 20B). When used in combination with a well-fitting and clinically acceptable denture, this approach therefore

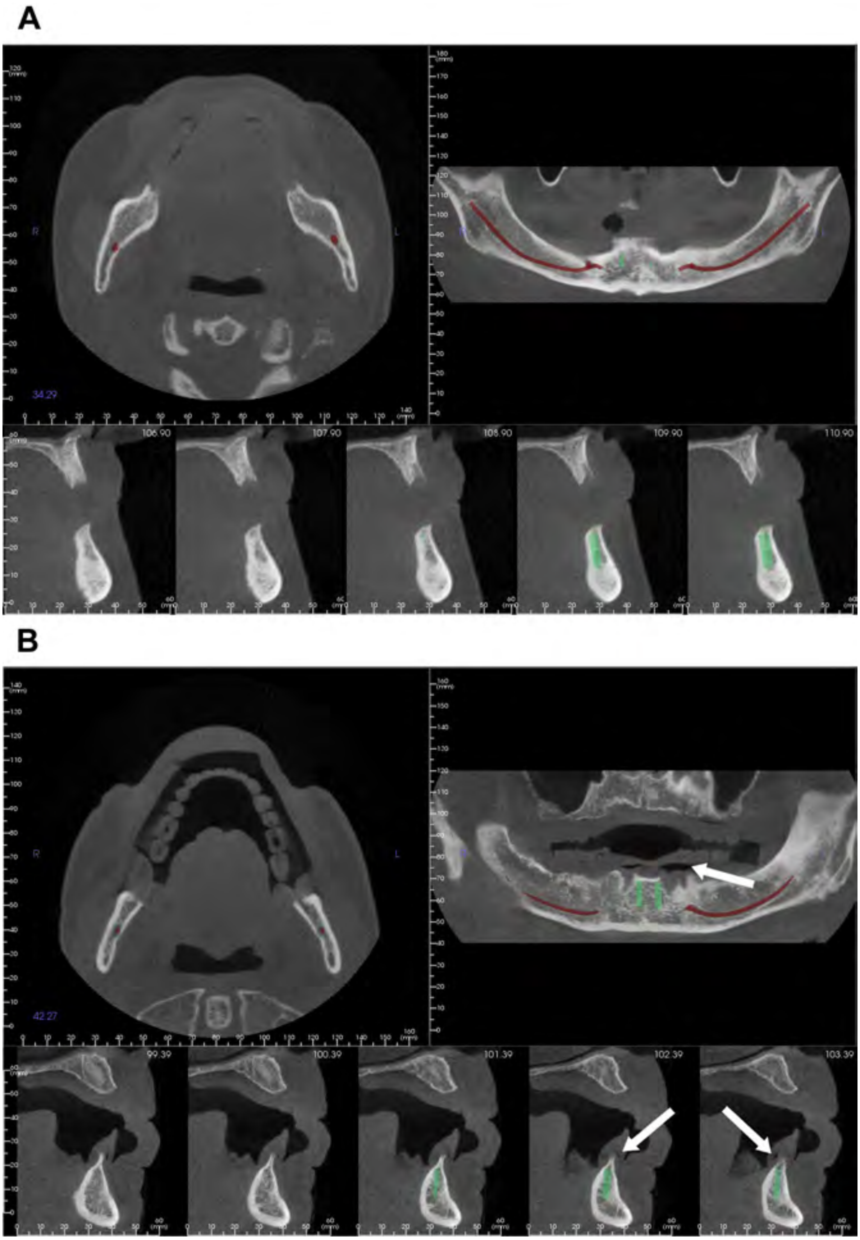


Fig. 20. CBCT scan of a patient wearing maxillary and mandibular dentures in occlusion without regard to separation of soft tissues (*A*), contrasted by a CBCT scan showing a patient wearing complete dentures with soft tissue and the denture surfaces separated by cotton rolls placed lingually, buccally, and occlusally (*B*). White arrows indicate areas of the mandibular denture not fully adapted to the soft tissues because of ridge resorption.

allows visualization of the restorative plan without having to fabricate a distinct radiographic template. This approach is also effective when using a diagnostic wax-up on acrylic resin denture bases created specifically for evaluating the restorative plan.

USING FIDUCIALS AND DIGITAL REGISTRATION

Most contemporary CBCT software packages allow for visualization of dental casts, soft-tissue replicas, and virtual wax-ups digitally superimposed over the 3D rendering of DICOM files. Typically this visualization is referred to as digital registration or superimposition, and involves the use of 2 to 3 CBCT scans in combination with an optical scan of the dental cast or patient.[38] The CBCT scans and optical scans join together with the use of fiducial markers such as gutta percha points, ceramic or metallic spheres, hollow tubes, and flat patterns or lines, embedded into an object with an algorithm to recognize the marker (**Fig. 21**A). The marker contains unique, recognizable features that allow the object to be detected and analyzed via a computer algorithm. The algorithm will allow for digital reorientation based on CBCT and optical scans that contain identical fiducial markers (see **Fig. 21**B). This marker-based registration method results in superimposition of a virtual layer that the user can toggle on and off to assess restorative space, implant position and trajectories, and abutment choices (see **Fig. 7**).

Although some studies have shown that the marker-based methods of digital registration historically are considered more accurate, newly developed surface registration algorithms have greatly enhanced registration methods.[39–42] These new algorithms allow the clinician to use readily available dental surface markers such as occlusal surfaces, denture and wax borders, and tissue profiles to facilitate the digital registration. Optical scanning technology of a dental cast or intraoral scans allow the clinician to export stereolithography (STL) files representing digital images of the physical cast or dentition. This STL file format can be imported into the CBCT interpretation software, allowing the clinician to superimpose on the patient scan based on surface-based algorithms.

Digital registration of CBCT scans of partially dentate patients is facilitated by the use of occlusal surface markers and soft-tissue surface profiles. In many partially dentate patient CBCT scans, increased amount of scatter may interfere with the ability to create a virtual diagnostic assessment of the implant site, resulting in possible planning errors (**Fig. 22**A). It is possible to minimize these effects by digitally registering the patient cast with an optical STL file to the original patient CBCT scan, and creating a superimposition layer in the computer software (see **Fig. 22**B). This layer can be toggled on and off, providing a clear assessment of the dental implant site within the original bone volume contours, and also lining up with the expected position within the proposed dental cast. If an optical scanner is not available, some of the software packages permit digital registration of a CBCT scan of the patient cast to the patient CBCT scan (see **Fig. 22**C). If the clinician prefers to routinely make CBCT scans of the patient cast, it is recommended that an optical scan is also performed for the first few cases to calibrate the CBCT scanner. Once the digital registration is complete, a virtual wax-up can be added to the combined scan, allowing for more precise digital assessment of the proposed implant site and its relationship to bone volume and the proposed restorative goal (see **Fig. 22**D).

Digital registration with edentulous patients is similar to that of partially dentate patients; however, it requires a method of isolating soft tissue to aid in the registration. Traditional methods of digital registration of edentulous patients include the use of 6 to 8 fiducial markers impregnated within the contours of a clear acrylic resin duplicate

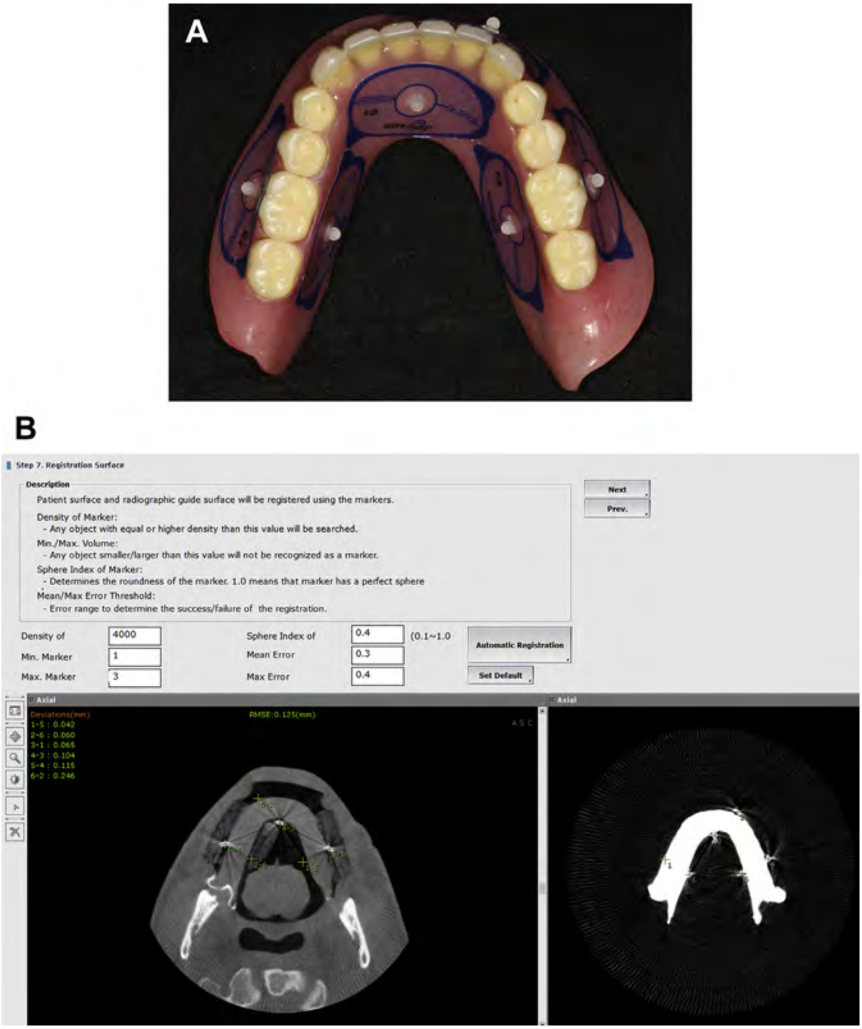


Fig. 21. Spherical markers can be applied to existing dental prostheses and diagnostic wax-ups before scanning (*A*) to facilitate digital registration of the denture scan to the patient scan (*B*).

of the proposed restorative plan, and superimposed over the CBCT patient scan bone volume (Fig. 23). Although this method is effective, it requires an additional laboratory expense and 2 clinical visits to confirm adequate adaptation to the soft tissues. A contemporary and simpler approach involves the use of a patient's existing complete denture that is deemed adequate, and placing a radiopaque polyvinyl siloxane (PVS) liner on the tissue-bearing surface (Green-Mousse; Parkell, Edgewood, NY) (Fig. 24A). Using cotton rolls placed buccal and lingual to the dentures, and occlusal separation with cotton rolls or a tongue blade, a CBCT of the patient with the dentures in the mouth is made (see Fig. 24B). Visualization of the dentures is improved using this approach, which allows ideal presurgical assessment of implant positions with respect to bone contours and restorative space. Radiographically the PVS liner will

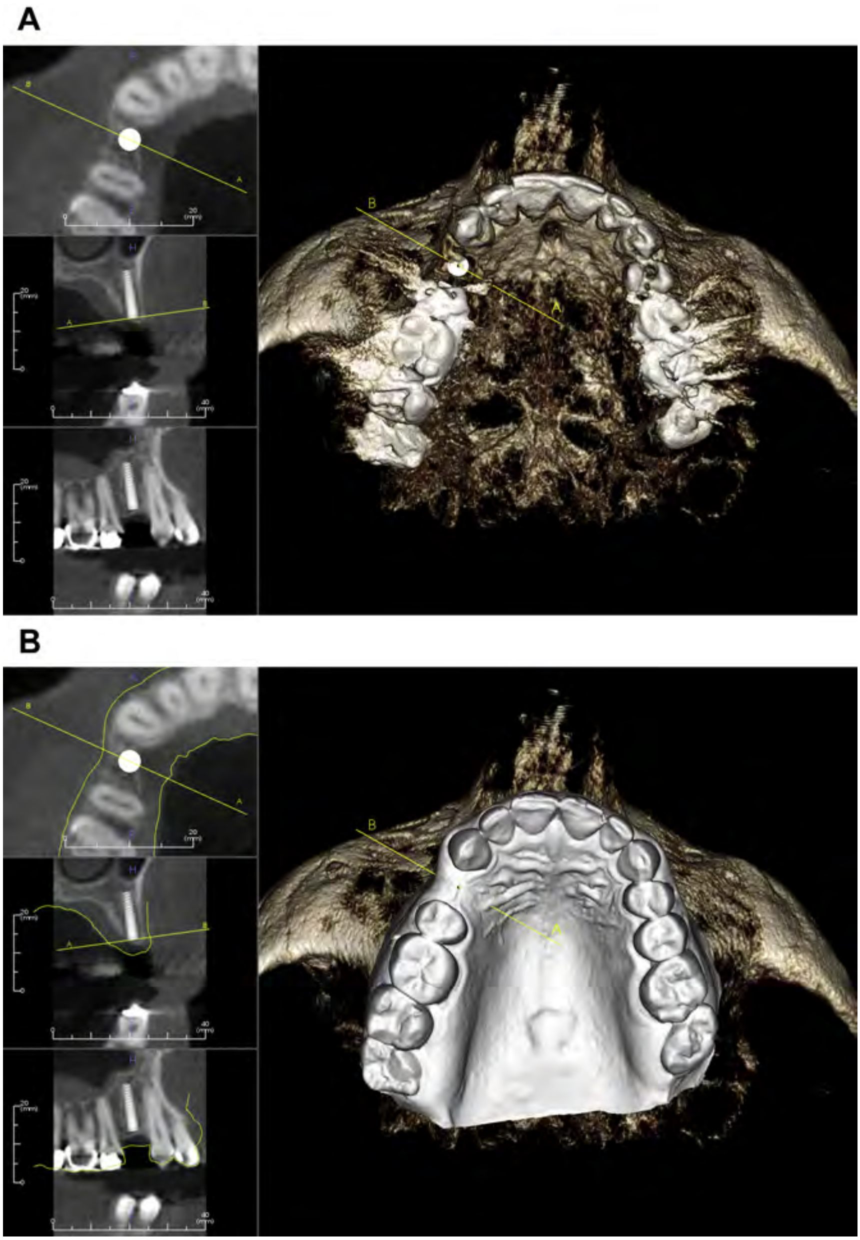


Fig. 22. Backscatter around existing dental restorations makes it difficult to properly evaluate surfaces of the existing dentition (*A*). Superimposing an optical scan of the patient or dental cast can greatly improve visualization of the adjacent teeth in relation to the proposed implant site (*B*). Alternatively, a CBCT scan of the dental cast can be performed and superimposed on the patient scan (*C*). Once the superimposition is completed, a virtual diagnostic wax-up can be added to assess the proposed implant position in relation to the adjacent dentition (*D*).

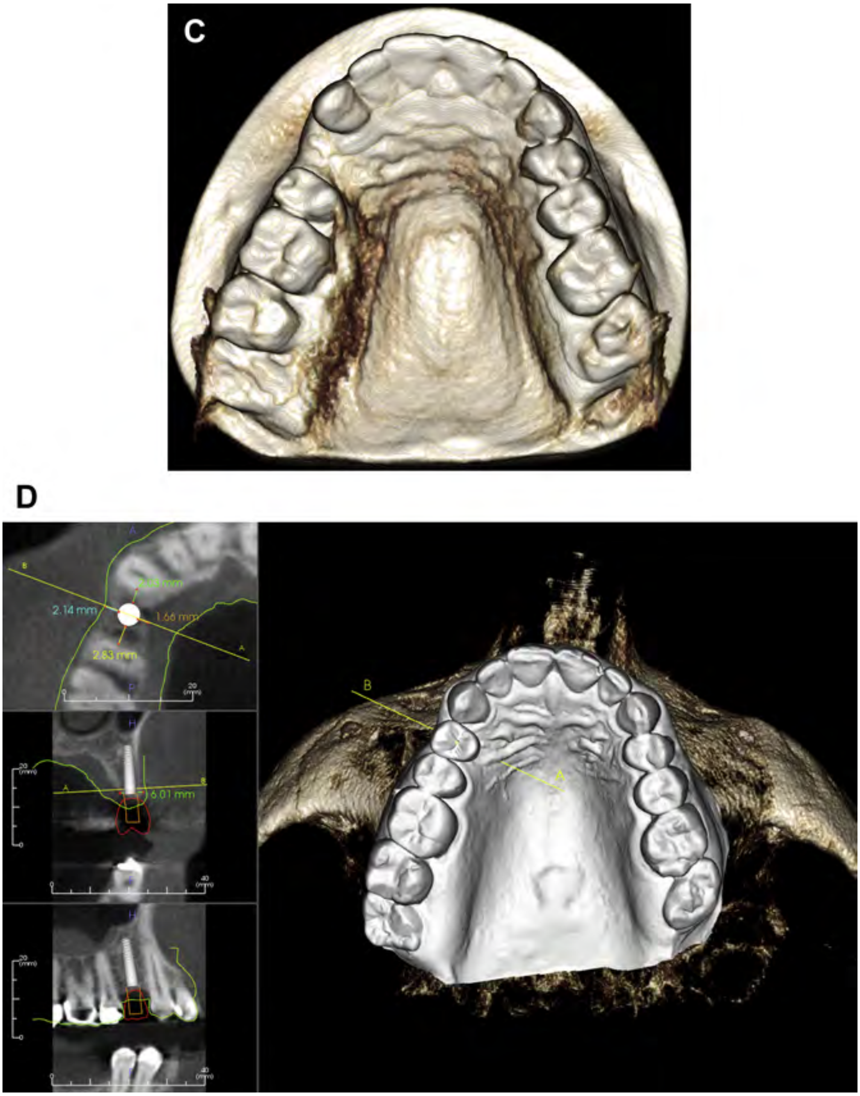


Fig. 22. (*continued*)

appear as a white line and the denture will appear as a gray shadow, and denture outlines in areas of insufficient soft-tissue separation will not be discernible from oral tissues (see **Fig. 24**C). Two additional scans are made of the each of the patient's dentures separately and in the same approximate orientation as that scanned in the mouth suspended with a radiolucent foam block. For example, a maxillary complete denture should be facing forward, tooth side down, and a mandibular denture should be facing forward, tooth side up.

Digital registration is performed and, instead of using 6 to 8 fiducial points, an algorithmic best-fit analysis and registration is completed using an iterative closest-point algorithm.[43] This method compares closest points in each of the 2 data sets, identifying a least-square rigid-body transform, continuously repeated until each match is

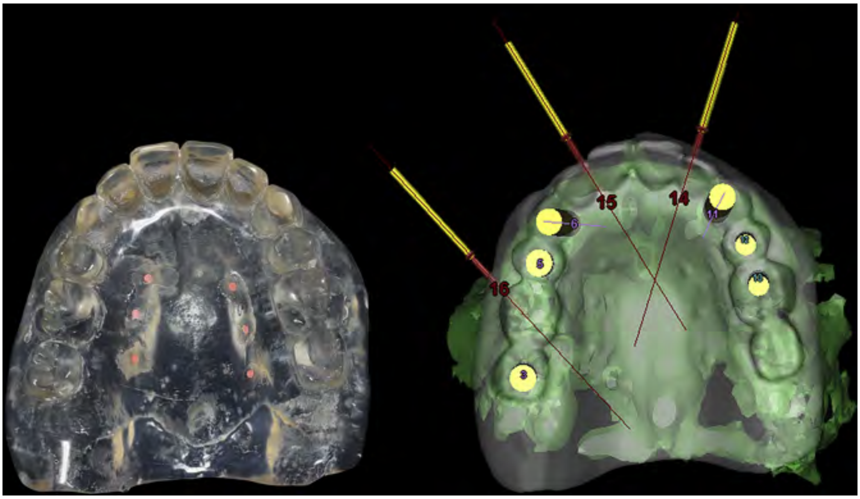


Fig. 23. Duplicate of a diagnostic wax-up in clear orthodontic resin with gutta percha fiducial markers superimposed on a patient's CBCT scan.

better than a given threshold.[39] As a result, the 2 CBCT scans are combined based on the surface fiducial markers present within the radiopaque PVS liner and the marker-based fiducial markers on the borders of the denture and the cusps of the denture teeth. Although this approach is possible without soft-tissue separation, accuracy is greatly enhanced when using a combination of surface-based registration and marker-based registration methods.[39–42] If soft-tissue separation is not performed, registration methods based on denture cusp tip and acrylic base contour markers would be limited without the use of a distinct radiographic template or modification of the denture to include traditional fiducial markers. Once completed, the clinician can readily view the prostheses superimposed on the patient CBCT scan, and make decisions regarding implant position, restorative space, and placement of anchor pins necessary for computer-guided surgical guides (see Fig. 24D).

CROWN-DOWN PREOPERATIVE ASSESSMENT OF IMPLANT SITE

As described previously, implant-site assessment of patients who are missing single or multiple teeth involves many clinical factors. A highly effective method of rapid computerized assessment involves a philosophy known as crown-down treatment planning. This method involves the following procedure:

1. Making 1 to 3 CBCT scans of the patient, denture, and/or dental cast
2. Importing DICOM files into 3D CBCT computer software
3. Making initial assessments of bone volumes and vital structures
4. Placing a virtual implant in an initial position based on the best fit in the bone volume
5. Adding a restorative plan such as a virtual wax-up or superimposed prosthesis
6. Adjusting the implant position, trajectory, and angulation based on the restorative assessment, and making assessments regarding the necessity for bone grafting, implant design modification, or prosthesis modification

Patients Missing Single Teeth

Many clinicians encounter patients in their practices with missing teeth that may be bound by teeth mesial and distal to the edentulous site (Fig. 25A). To ensure accuracy

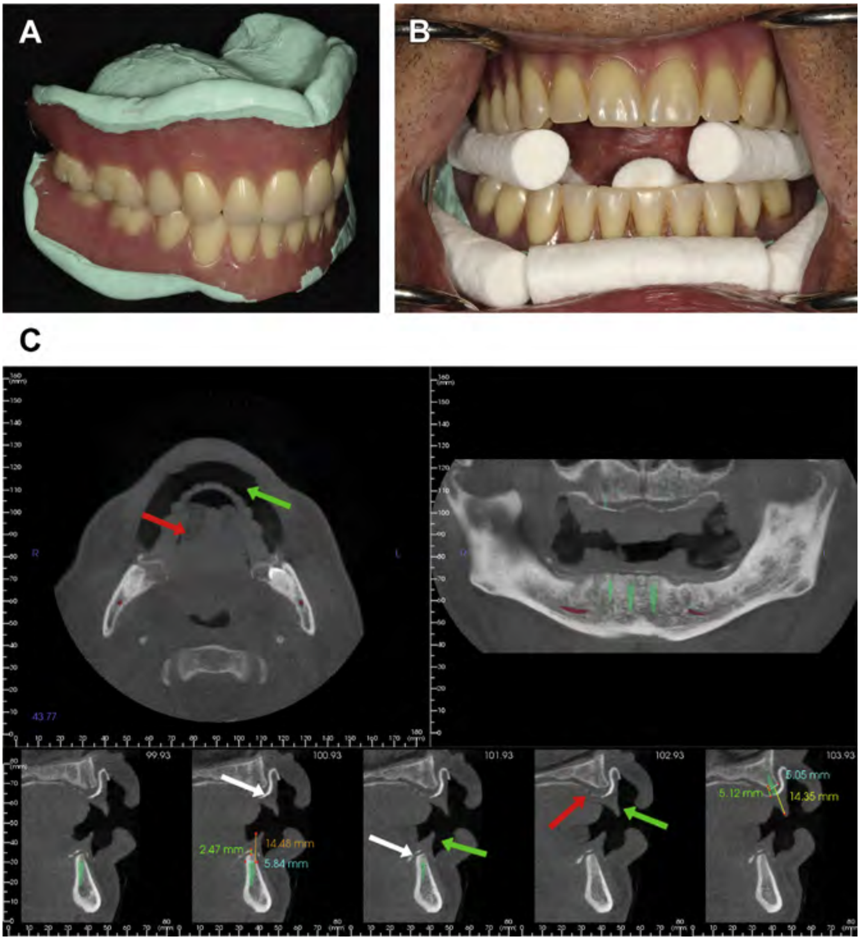


Fig. 24. Dentures relined with radiopaque polyvinyl siloxane (PVS) before a CBCT scan (*A*) is placed in the mouth, with cotton rolls used to separate the lingual and buccal soft tissue and occlusal surfaces (*B*). This method allows for implant-site assessment without having to fabricate a radiographic template (*C*). Green arrows indicate acceptable areas of soft-tissue separation, and red arrows indicate insufficient separation. Superimposition of the individual CBCT scans of the complete dentures allow for visualization of the restorative space in relation to the alveolar volume (*D*).

with digital registration methods previously described, it is recommended that the clinician make a PVS impression and pour a cast in die-stone (see Fig. 25B). Alternatively, an intraoral optical impression can be made with any optical scanner than can convert scans to STL files, rather than having to fabricate a dental cast. A traditional CBCT scan is made at 0.3-mm voxel resolution with cotton rolls placed on the occlusal surfaces of the teeth and with the patient biting down on the cotton rolls to slightly separate the occlusal plane. The DICOM data are imported into the CBCT software for analysis and interpretation. Fig. 25C shows this procedure using Invivo software (Anatomage). Before placing implants, the maxillary cast is scanned using a laboratory

D

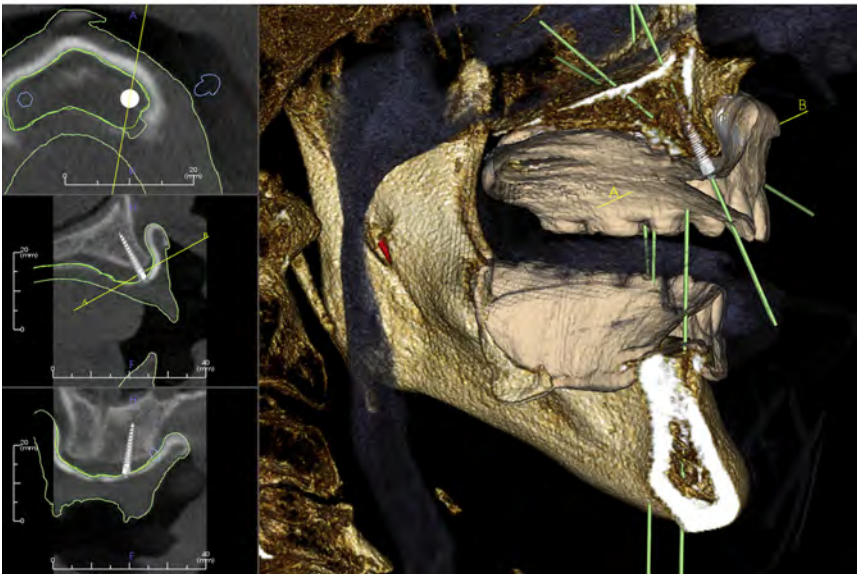


Fig. 24. (*continued*)

optical scanner to generate an STL file; this can be accomplished at a local dental laboratory or can be mailed to a scanning center for processing. The maxillary cast is digitally registered to the scan using cusp tips, line angles, and soft-tissue markers in combination with a digital algorithm (see Fig. 25D).

An implant is selected from the library with diameter, length, and tooth number chosen based on the availability of bone present in the 3D view. The implant is tentatively placed according to available bone volume with regard to positioning with adjacent dentition and root proximity (Fig. 26A). A virtual restoration and abutment is added to the implant, and the software automatically designs the restoration according to the proposed implant angulation and position, without regard to adjacent teeth on the dental cast overlay. Modifications are made relative to buccal-lingual and mesial-distal positioning and restoration width to fit within the dental cast overlay by using the software's adjustment widget (see Fig. 26B). In addition, side views allow the clinician to modify mesiodistal tilting and incisal-gingival positioning to allow creation of a natural tooth emerging from below the gingiva (see Fig. 26C, D).

After fabricating an ideal virtual restoration, attention must be paid to the angulation and positioning of the implant body. Ideally the long axis of the implant should be through the central portion of the restoration, and for screw-retained restorations the retaining screw is best configured in the central pit of the restoration. Modification of implant angulation a common step after completion of the ideal restorative plan (Fig. 27A). Final assessment of the implant site can be visualized using measuring tools; additionally the user can check the fit of the surgical guide and verify that the proposed implant position is compatible with surgical guide master sleeves (see Fig. 27B). Occasionally, modifications to the implant position to allow proper surgical guidance may be required. Once the implant plan is completed, a computerized

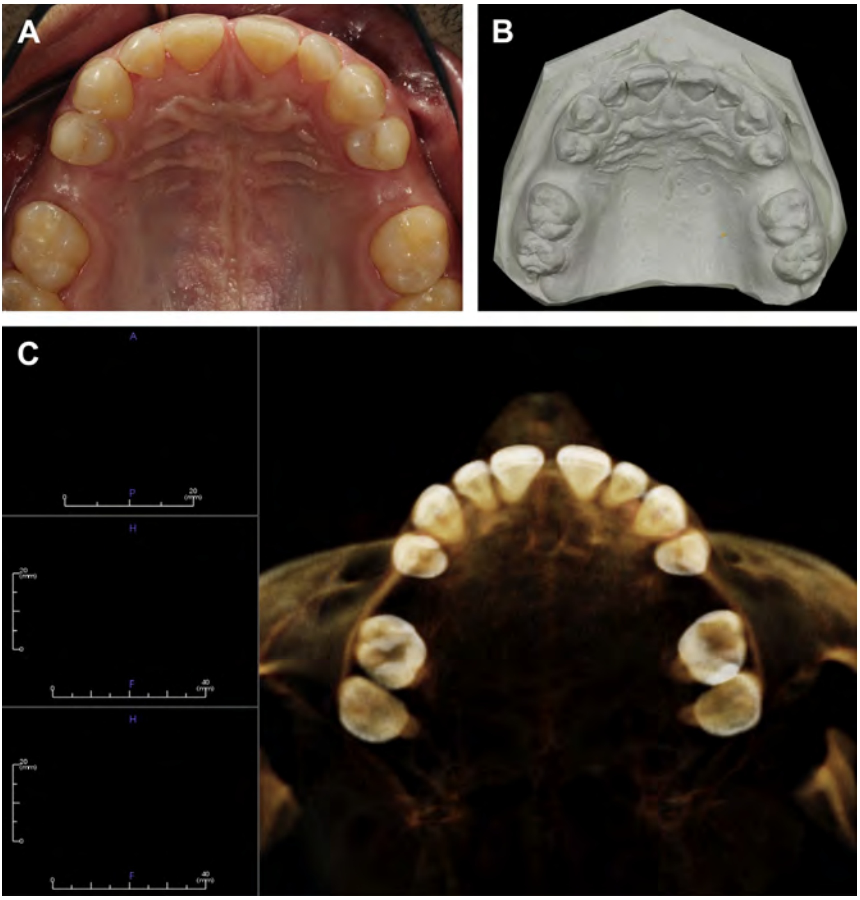


Fig. 25. (*A–D*) Illustration of a patient congenitally missing second premolars (*A*). A high-detail dental cast is made from a PVS impression (*B*) and is optically scanned to create an STL file. The STL file is imported into the computer software, which will allow the CBCT patient scan (*C*) to be combined with the optical scan of the patient cast (*D*).

surgical guide can be ordered and placed in the mouth, allowing precise implant placement based on the final planned restorative outcome (see Fig. 27C, D). This approach can also be applied to multiple missing teeth adjacent to each other, such as a distal edentulous ridge.

Edentulous Patients

3D imaging and treatment assessment for fully edentulous patients traditionally requires a slightly more involved approach; previously mentioned techniques and methods help to expedite this assessment. Effective visualization of a patient's denture or diagnostic tooth assessment is facilitated by using soft-tissue separation in combination with radiopaque PVS. Many edentulous patients who have been wearing dentures for a moderate period of time often present with a well-healed edentulous ridge with abundant keratinized tissues (see Fig. 28A). It is essential to verify that

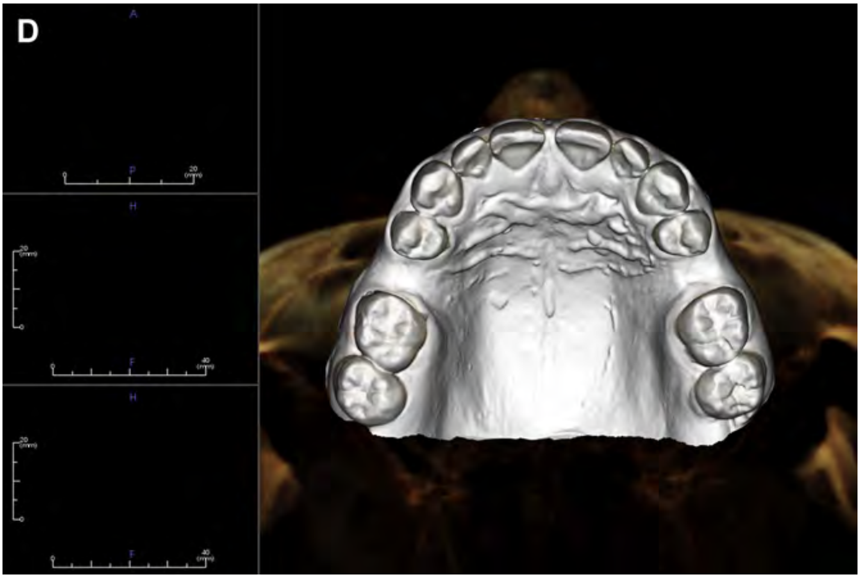


Fig. 25. (*continued*)

such a denture is acceptable before using it for the CBCT scan, using readily available methods for verification of denture criteria.[44]

Fabrication of computerized surgical guides requires fiduciary markers to register the patient scan to the denture scan. Using a radiopaque PVS impression material (Green-Mousse) to reline the intaglio of a complete denture will allow computer systems to recognize the fiducials present within the PVS material (see Fig. 28B, C). The patient is scanned at 0.3-mm voxel resolution wearing the relined denture, using soft-tissue and occlusal separation (see Fig. 24B). Once the patient scan is completed, the denture is removed and scanned separately at 0.2 to 0.3-mm voxel resolution, suspended on a foam block (see Fig. 28D). A dental cast is poured into the intaglio of the denture containing the radiopaque PVS material and is scanned in using an optical scanner to create an STL file. Similar to the aforementioned, this can be accomplished at a local dental laboratory or can be mailed to a scanning center for processing. After the completion of the second scan and pouring of the dental cast, the radiopaque PVS liner can easily be removed and the denture returned to the patient without having to irreversibly modify the denture.

The CBCT scan of the denture and optical scan of the edentulous ridge is digitally registered to the scan using denture cusp tips and edentulous ridge soft-tissue markers in combination with a digital algorithm (Fig. 29A). Implants are selected from the library, with diameter and length chosen based on the availability of bone present in the 3D view. Once the bone volume is analyzed, implant position and depth are chosen according to the amount of available prosthetic space and in relation to critical anatomic structures (see Fig. 29B). The combination of the registration of the denture, edentulous ridge, and implant plan allows for a more complete assessment of the proposed implant site. Using this assessment the clinician can make

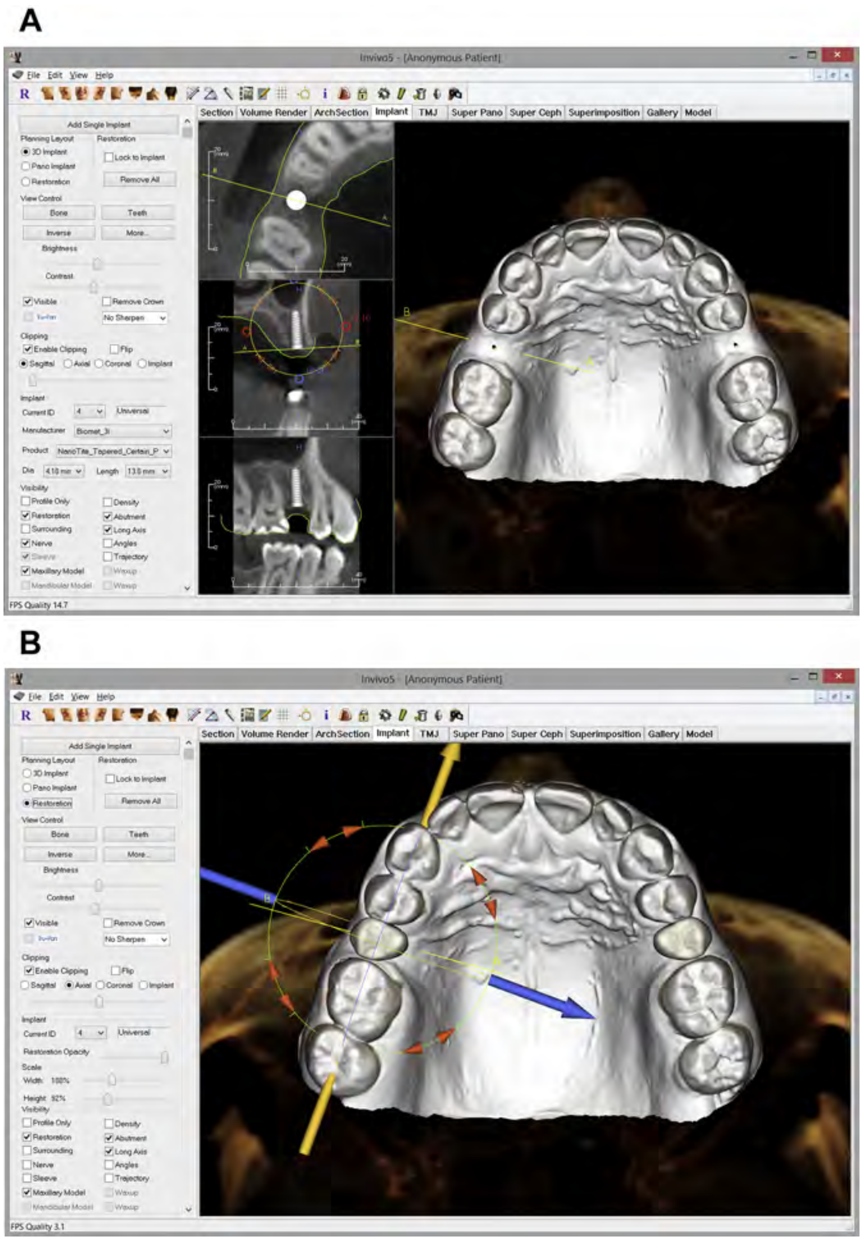
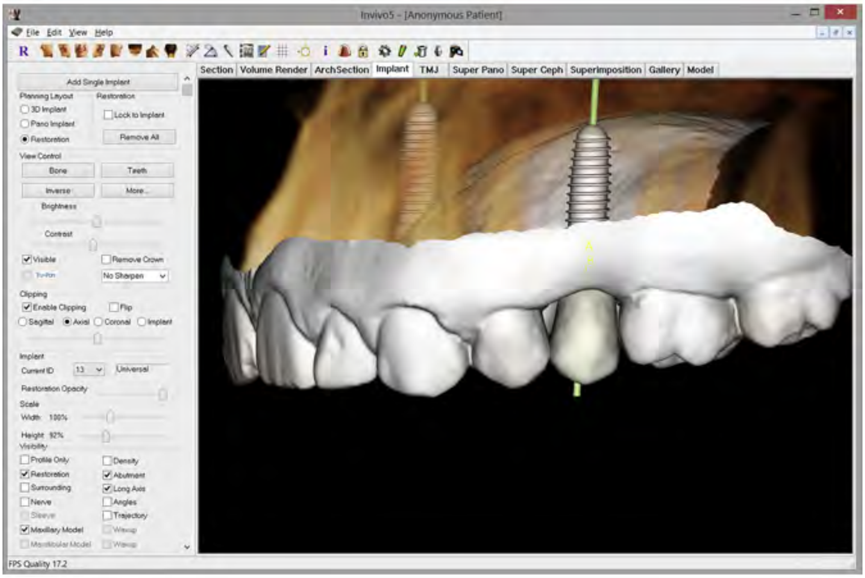


Fig. 26. Implants are initially placed according to the best fit to the bone volume within the recommended implant-positioning guidelines (*A*). Virtual restorations are added to the implants (*B*) and using the computer software's widget controls, and the restorations are modified to fit ideally within the superimposed dental cast (*C*, *D*).

C



D

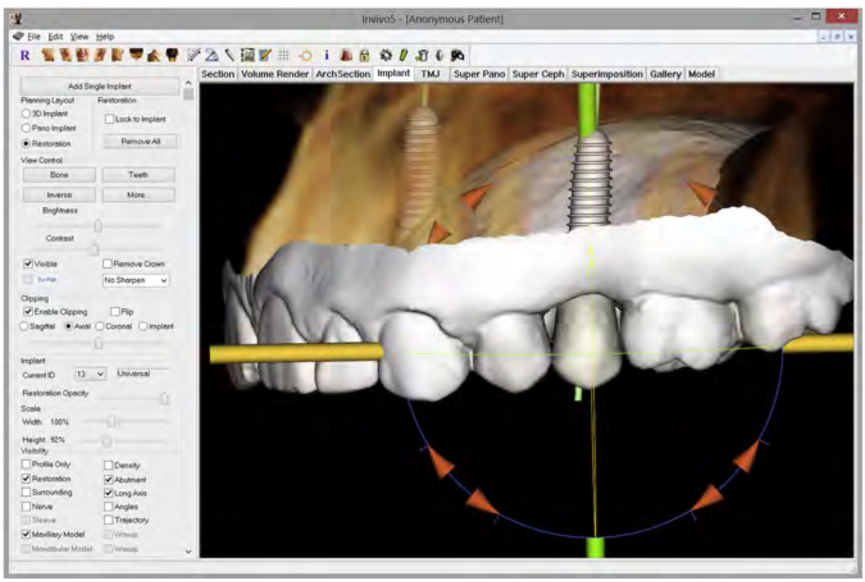


Fig. 26. (*continued*)

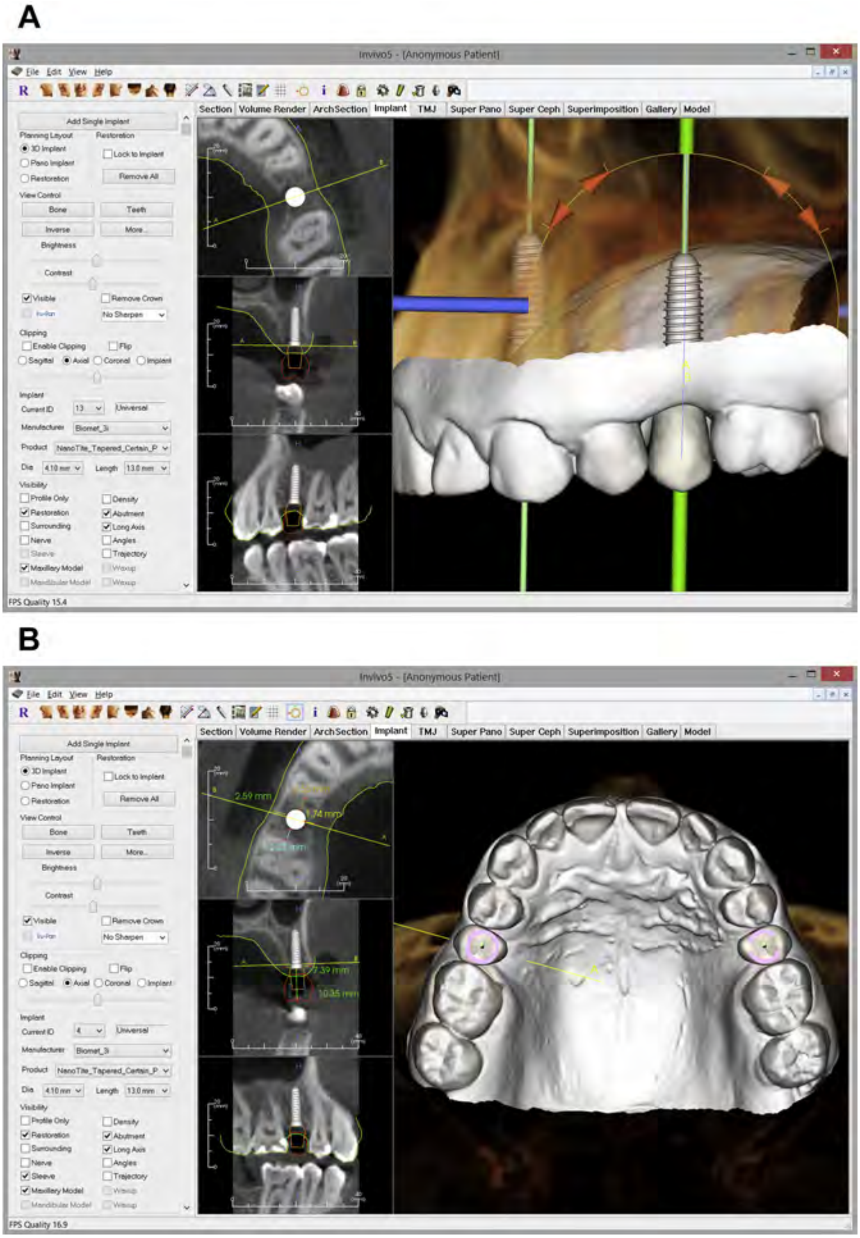


Fig. 27. The implants are tilted or moved to fit within the desired restorative contours and long-axes whenever possible (*A*). Using superimposed dental casts also illustrates the fit of the surgical guide master sleeve to ensure adequate surgical clearance (*B*). A computerized surgical guide can be fabricated (*C*), and surgical procedures provide precise control of the final implant position with minimal intraoperative trauma (*D*).

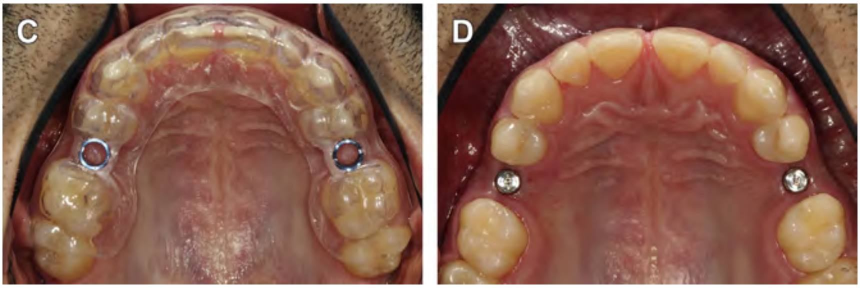


Fig. 27. (*continued*)

decisions regarding whether bone recontouring, alveolectomy, or additive grafting procedures are required during surgical placement of the implant. A computerized surgical guide can be fabricated, and implants placed according to a precise surgical plan (Fig. 30).

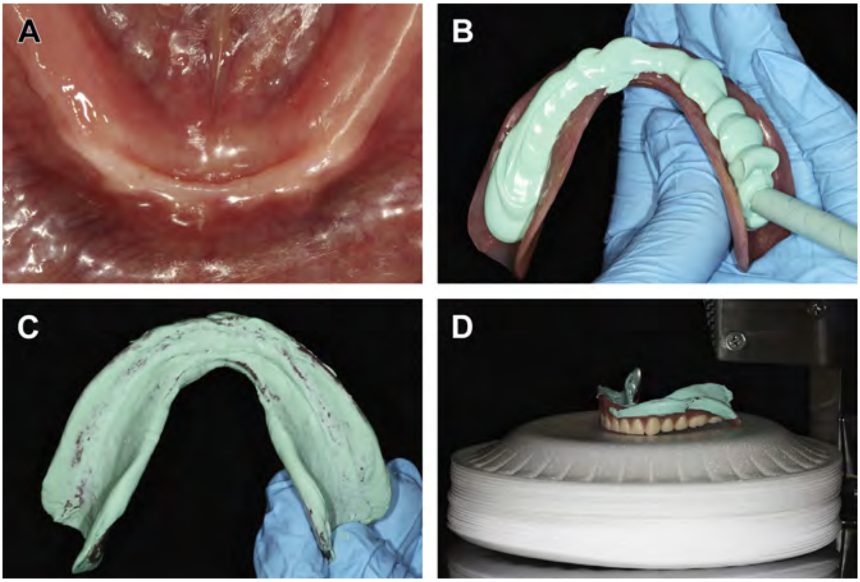


Fig. 28. Edentulous ridges often appear healthy with adequate keratinization if the patient has been edentulous for a period of time (*A*). Injecting a radiopaque PVS material (Green-Mousse; Parkell, Edgewood, NY) into the intaglio surface of the denture (*B*) and placing onto the ridge using a reline approach will provide an impression of the edentulous ridge (*C*). After the patient scan, the denture is removed and placed on a foam block, and a CBCT scan is made of the denture with the liner (*D*).

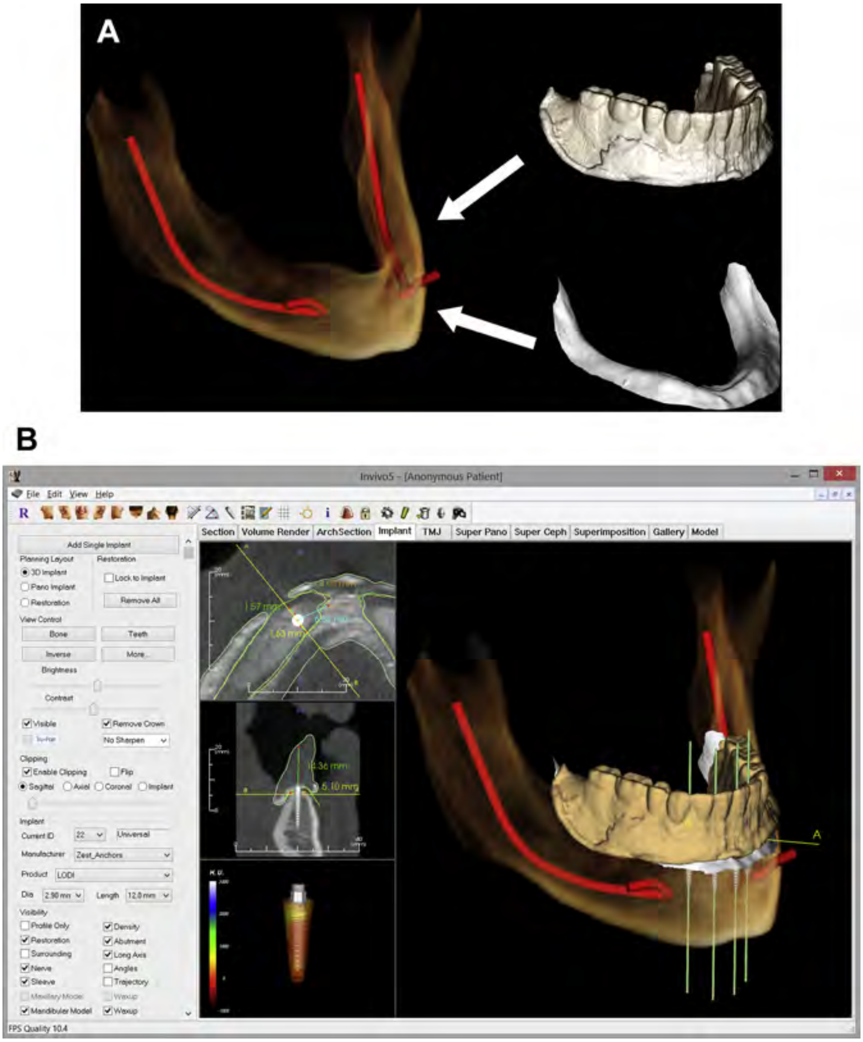


Fig. 29. The CBCT scan of the complete denture and the optical scan of the edentulous ridge are digitally registered to the CBCT scan of the patient (*A*) using fiducial markers present in all 3 scans. The final assessment of the implant positions within the bone volume is made using the combined scans, verifying that the restorative and surgical parameters are compatible (*B*).

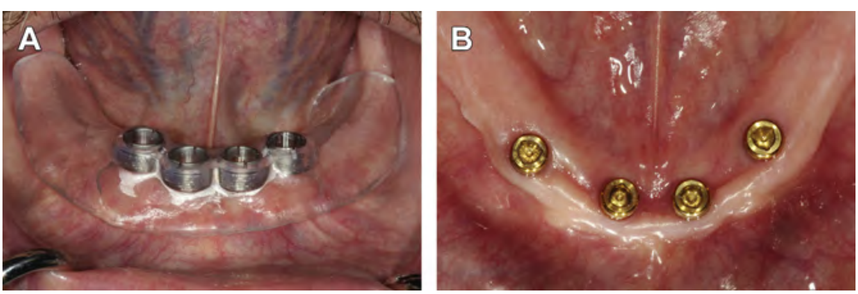


Fig. 30. A computerized soft-tissue supported surgical guide can be fabricated based on the combined scans in Fig. 29 (*A*) and implants predictably placed with minimal trauma according to the digital plan (*B*).

SUMMARY

CBCT imaging and 3D computer software allow for greatly enhanced visualization of bone, critical anatomy, and restorative plans. These systems allow clinicians to alter and process patient 3D images and restorative templates, facilitating dental implant planning. Effective assessment of proposed implant sites requires that clinicians interpret implant sites for many factors related to successful implant restorations, including adequate bone volumes, distance away from teeth/implants, sufficient prosthetic space for restoration, and precise implant placement. The combination of soft-tissue and occlusal separation, and digital registration of patient scans with prosthesis and soft-tissue scans greatly enhances the ability to visualize planned restorative outcomes and to accommodate implants within these outcomes. This article highlights the utilization of contemporary methods of digital assessment with traditional restorative philosophies to allow the clinician to plan implant positions based on clinical requirements.

Crown-down digital implant treatment planning permits clinicians to have more control over the implant treatment plan by creating ideal, virtual restorations and managing implant positions based on the virtual plan. This 3D treatment flow significantly improves on the traditional workflow by supplementing more complicated and expensive diagnostic information with simpler and equally effective treatment protocols.

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