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CLINICAL REPORT

Cone beam computed tomography imaging as a primary diagnostic tool for computer-guided surgery and CAD-CAM interim removable and fixed dental prostheses

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ABSTRACT

This article describes a digital workflow using cone beam computed tomography imaging as the primary diagnostic tool in the virtual planning of the computer-guided surgery and fabrication of a maxillary interim complete removable dental prosthesis and mandibular interim implant-supported complete fixed dental prosthesis with computer-aided design and computer-aided manufacturing technology. Diagnostic impressions (conventional or digital) and casts are unnecessary in this proposed digital workflow, providing clinicians with an alternative treatment in the indicated clinical scenario. (J Prosthet Dent 2016;116:157-165)

Implant-supported complete fixed dental prostheses (ICFDP) have long been proposed as a predictable treatment for patients with edentulism.[1] When combined with immediate loading and an interim restoration, patient-centered evaluation reveals significant improvement in patient general satisfaction and self-perceived comfort, function, and esthetic outcomes during the phase of interim restoration.[2] The mandibular ICFDP, in particular, has shown high implant and prosthesis survival rates of more than 96% at 10 years.[3] Many clinical implant studies assessing the edentulous patient population have reported on the use of a mandibular ICFDP opposing a conventional maxillary complete removable dental prosthesis (CRDP).[4,5] The majority of patients were satisfied with the masticatory function and retention of maxillary CRDP, and only a few patients reported esthetic or phonetic problems.[4,5] In addition, when ICFDP oppose maxillary CRDP, screw-related complications are less prevalent, regardless of the patient's age and the cantilever length of the mandibular ICFDP.[6,7]

The first computed tomography (CT) scanner was developed by an English engineer, Godfrey Hounsfield in the early 1970s.[8,9] Different types of CT technology are available in craniofacial clinical practice and research, including the multidetector computed tomography (MDCT, commonly known as medical CT), cone beam computed tomography (CBCT), and microcomputed tomography, or micro-CT.[8,9] Because of the feature of image acquisition at a lower radiation dosage than MDCT, CBCT has been gaining in popularity since its development in the 1990s.[8] The current indications for the CBCT in dentistry include endodontic treatment planning and outcome assessment, detection of periapical lesions,[10] orthodontic analysis,[11] craniofacial applications,[12] forensic facial reconstruction,[13] and dental implant planning and treatment (preoperative analysis,

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computer-assisted treatment planning, and postoperative evaluation).[14-16] The limitations of CBCT are chiefly related to the limited contrast resolution for soft tissue assessment because of high scatter radiation during image acquisition and the misdiagnosis of pathologies due to inadequate training and improper equipment settings.[8,17,18]

Data acquisition with intraoral scanners and computer-aided design and computer-aided manufacturing (CAD-CAM) technology have gained in popularity since their inception in the 1980s.[19] Recently, several manufacturers have also developed CAD-CAM CRDP. However, this technique focuses mainly on improving the CAD-CAM process in fabricating the removable dental prosthesis (RDP), and conventional elastomeric impression materials are still required for making the definitive impression.[20] Although intraoral scans for edentulous jaws are feasible, the accuracy of such scans is still of concern.[21] The lack of definitive anatomic landmarks on the soft tissue seemed to cause problems for the point-and-click intraoral scanner systems.[22] Different clinical reports have provided proof of concepts for fabricating the implant-supported CRDP[23] and tooth-supported partial removable dental prosthesis (PRDP)[24] or obturator[25] with an intraoral scanner in which the dynamic registration of soft tissue is not as critical as for a conventional RDP.[23-25]

This article describes a digital workflow using CBCT imaging as the primary diagnostic tool in the virtual planning process to fabricate a CAD-CAM maxillary interim CRDP and mandibular interim ICFDP on immediately placed and immediately loaded dental implants.

CLINICAL REPORT

A 72-year-old white man with maxillary and mandibular partially edentulous dentition was referred to the Advanced Education in Prosthodontics, School of Dentistry, University of Louisville for the restoration of his missing teeth with implant-supported fixed dental prostheses. Partial edentulism and generalized chronic severe periodontitis of the remaining dentition was diagnosed. Three existing composite resin restorations were present on the maxillary left lateral incisors and canines and on the mandibular left second premolar. Radiographic findings showed that the maxillary right canine had been endodontically treated and that severe alveolar ridge atrophy had occurred in the maxillary posterior edentulous regions. The patient had no significant medical history that would contraindicate the dental restorative and surgical procedures. The patient accepted the treatment plan and because of financial considerations consented to a definitive maxillary conventional CRDP and a mandibular ICFDP supported by 5 dental implants. A maxillary interim CRDP was planned as an interim prosthesis after the removal of the remaining teeth. The patient's wish for an interim fixed dental prosthesis on the mandible would be satisfied with an interim ICFDP on immediately placed and immediately loaded dental implants.

An intraoral and extraoral examination was performed to confirm that the intended occlusal vertical dimension and stable maxillomandibular relationship could be achieved with the existing dentition (Fig. 1). In addition, the patient demonstrated no posterior occlusal interferences and showed coincidence of maximal intercuspal position and centric occlusion. The CBCT imaging (3D Accuitomo 170; J Morita USA) was performed at the existing maxillomandibular relationship (maximal intercuspal position, which coincided with centric occlusion in this patient) to complete the preoperative assessment. Digital Imaging and Communications in Medicine (DICOM) files generated from CBCT imaging and clinical digital photographs were then forwarded to a dental laboratory (nSequence Center for Advanced Dentistry) using a secure internet server.

The DICOM files were imported in a virtual implant planning software (Maven Pro; nSequence). Segmentation was performed in the software by the laboratory technician to identify the existing dentition (Fig. 2A) and to ensure that the obtained maxillomandibular relationship during CBCT imaging coincided with the desired occlusal position by comparing it with preoperative photography (Fig. 1A). Maxillary and mandibular virtual diagnostic tooth arrangements were created in the CAD-CAM software (Maven Pro; nSequence) using the existing dentition and clinical photographs as references (Fig. 2B). Virtual diagnostic tooth arrangements were made according to the recorded occlusal vertical dimension and maxillomandibular relationship. The design goal for the occlusal scheme on the interim prosthesis was to achieve bilateral, simultaneous occlusal contacts of the anterior and posterior teeth in centric relation. The occlusal contacts in the eccentric positions were to be confirmed during the surgical appointment.

Based on the virtual diagnostic tooth arrangements, simulated bone reduction was performed in the virtual implant planning software (Maven Pro; nSequence) to create adequate restorative space for the future mandibular interim and definitive ICFDP (Fig. 2C). A prosthetically driven implant surgical plan for computer-guided implant surgery was formulated based on virtual diagnostic tooth arrangements and simulated bone reduction (Fig. 2D). A proprietary design and method was used to create the 2-piece, CAD-CAM-fabricated, surgical templates (Bone Foundation Guide System, Guided Prosthetics; nSequence), incorporating a bone foundation guide and an implant placement template.

Figure 1. Pretreatment condition. A, Facial view. B, Smile.

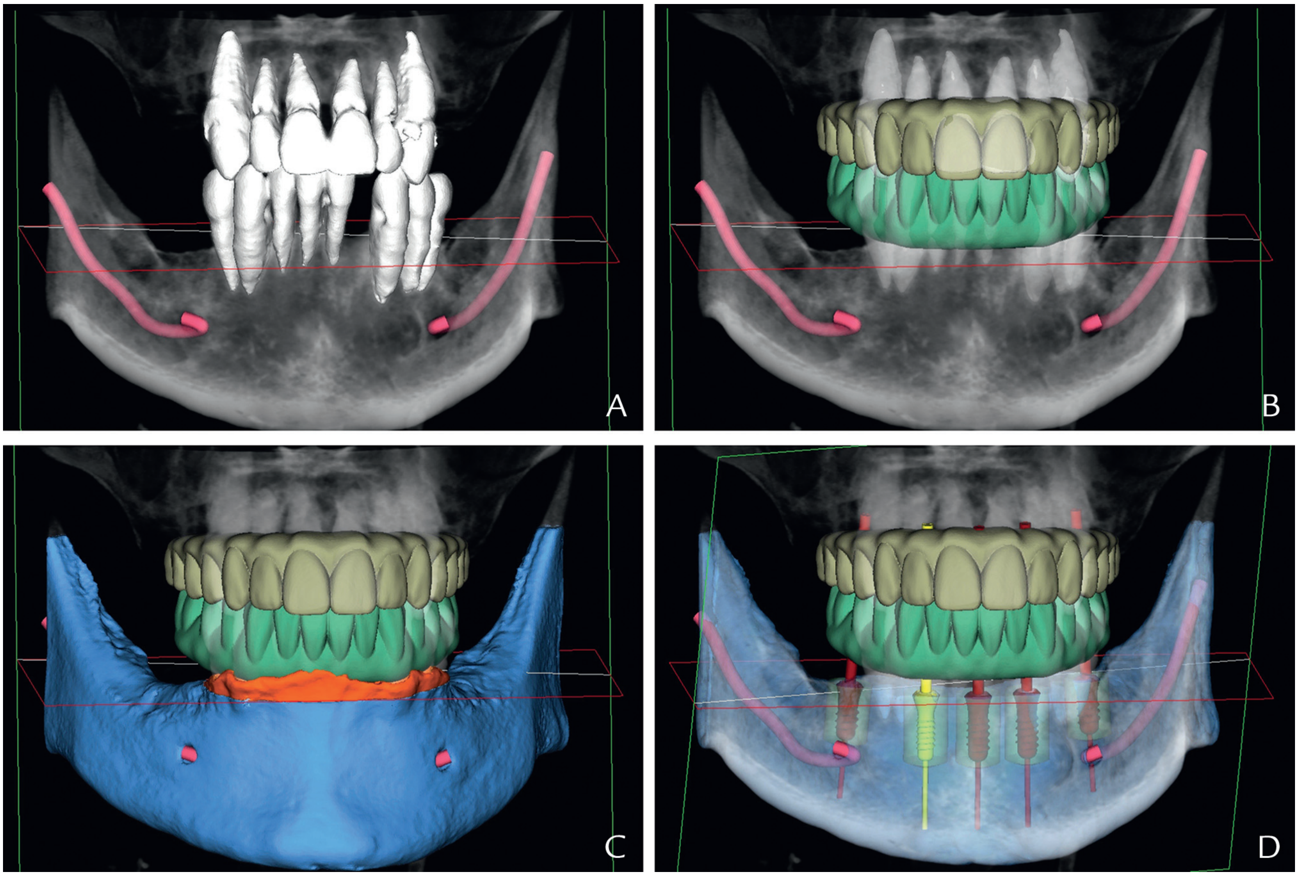

Figure 2. A, Existing dentition (represented by white color) segmented from DICOM files and used to confirm obtained maxillomandibular relationship. B, Yellow represents maxillary and green mandibular virtual diagnostic tooth arrangement. C, Simulated virtual bone reduction (represented by orange color) created according to virtual diagnostic tooth arrangement. D, Prosthetically driven implant surgical plan.

Using the DICOM files, the dental technician also identified and traced the soft tissue outline from the axial, coronal, and sagittal views of the CBCT volumetric data (Fig. 3A, B). The soft tissue outline tracings from various segments were then used to recreate a virtual diagnostic cast (with remaining dentition segmented and soft tissue recreated from the CBCT volumetric data) in the CAD-CAM software (Maven Pro; nSequence) (Fig. 3C, D). A virtual denture base was created to fit on the soft tissue of the virtual diagnostic cast, and the virtual diagnostic tooth arrangement was subsequently merged with this denture base in the CAD-CAM software (Maven Pro;

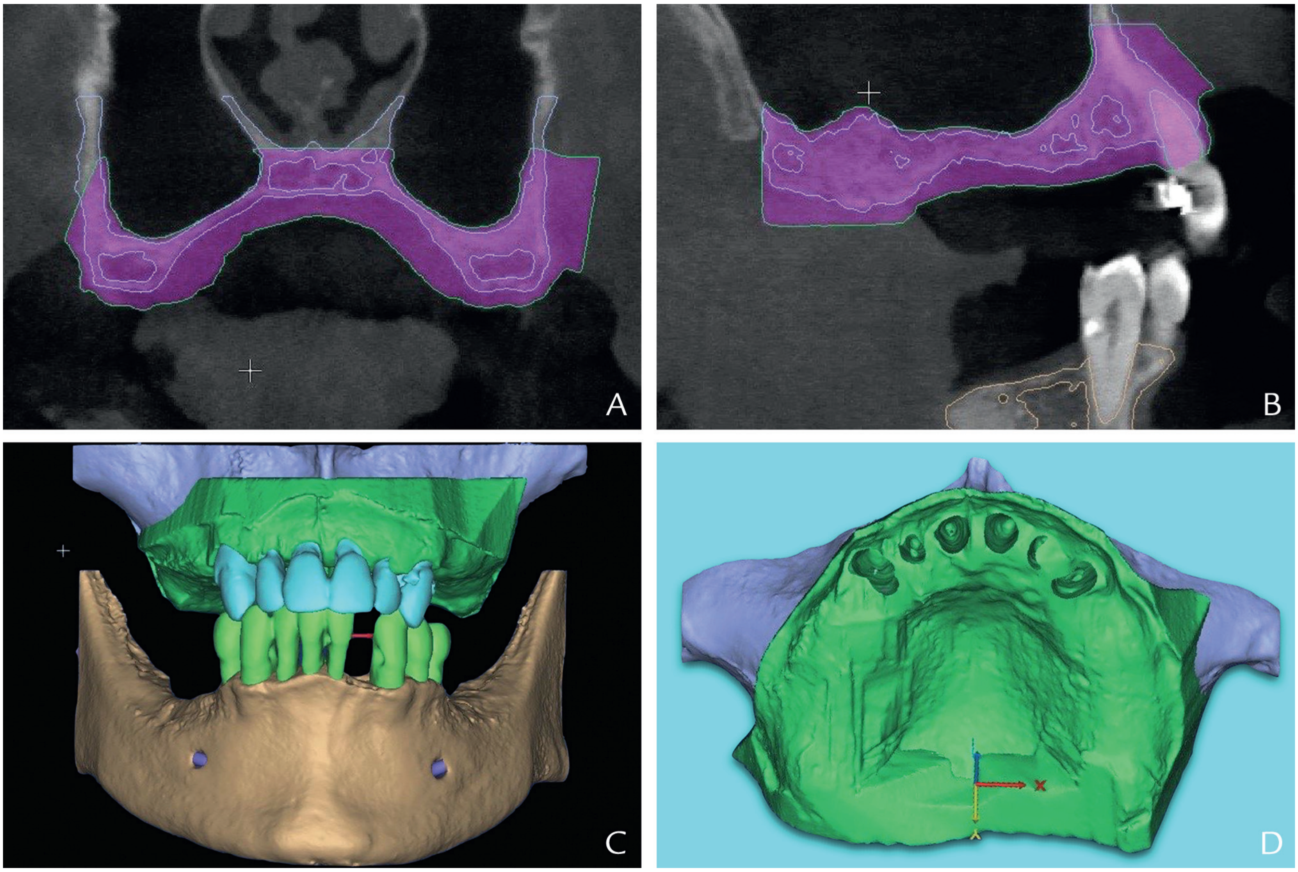

Figure 3. Identification of soft tissue outline from cone beam computed tomography volumetric data. A, Coronal view. B, Sagittal view; virtual diagnostic cast with segmented remaining dentition and reconstructed soft tissue profile. C, Facial view. D, Occlusal view.

nSequence) (Fig. 4A). The complete virtual design of the interim prostheses was exported from the CAD-CAM software (Maven Pro; nSequence) to a mill (Milling Unit M5; Zirkonzahn) to fabricate the CAD-CAM maxillary interim CRDP and mandibular interim ICFDP with prefabricated PMMA-based acrylate resin block (Temp Basic; Zirkonzahn) (Fig. 4B). The dental technician then layered the milled interim prostheses with light-polymerizing tooth-color and pink composite resin (Gradia System; GC America Inc) to enhance esthetics (Fig. 4C).

CAD-CAM 2-piece surgical templates (Bone Foundation Guide System, Guided Prosthetics; nSequence) and the interim prostheses (Guided Prosthetics; nSequence) were returned to the clinicians for presurgical evaluation. The first piece of surgical template, a bone foundation guide, was to be fitted on the alveolar ridges after extractions and stabilized with anchor pins (Guided Anchor Pin; Nobel Biocare). Three reposition jigs were designed to facilitate the correct seating of this bone foundation guide (Fig. 5A). The flat platform on the occlusal aspect of the bone foundation guide served as a reference plane for bone reduction (Fig. 5B). The second surgical template, an implant placement template, was to be assembled on the bone foundation guide after the completion of bone reduction and osseous recontouring. The assembly of the CAD-CAM 2-piece surgical template provided the guidance for implant placement according to the prosthetically driven implant surgical plan (Fig. 5C). After the implant placements, the implant placement template was removed from the bone foundation guide. The assembly of a prefabricated polyvinyl siloxane carrier and CAD-CAM mandibular interim ICFDP was fitted on the bone foundation guide for the subsequent immediate provisionalization procedure (Fig. 5D). The prefabricated polyvinyl siloxane carrier provided by the dental laboratory (nSequence Center for Advanced Dentistry) was usd to provide a block-out layer to prevent excessive autopolymerizing acrylic resin from contacting the dental implants. In addition, this carrier was designed to be a reposition template to seat the mandibular interim ICFDP on the bone foundation guide. The bone foundation guide was to be stabilized with anchor pins (Guided Anchor Pin; Nobel Biocare) and not removed from the bone reduction and osseous recontouring until the immediate provisionalization laboratory procedure had been completed; this was to ensure that the prosthetically driven implant surgical

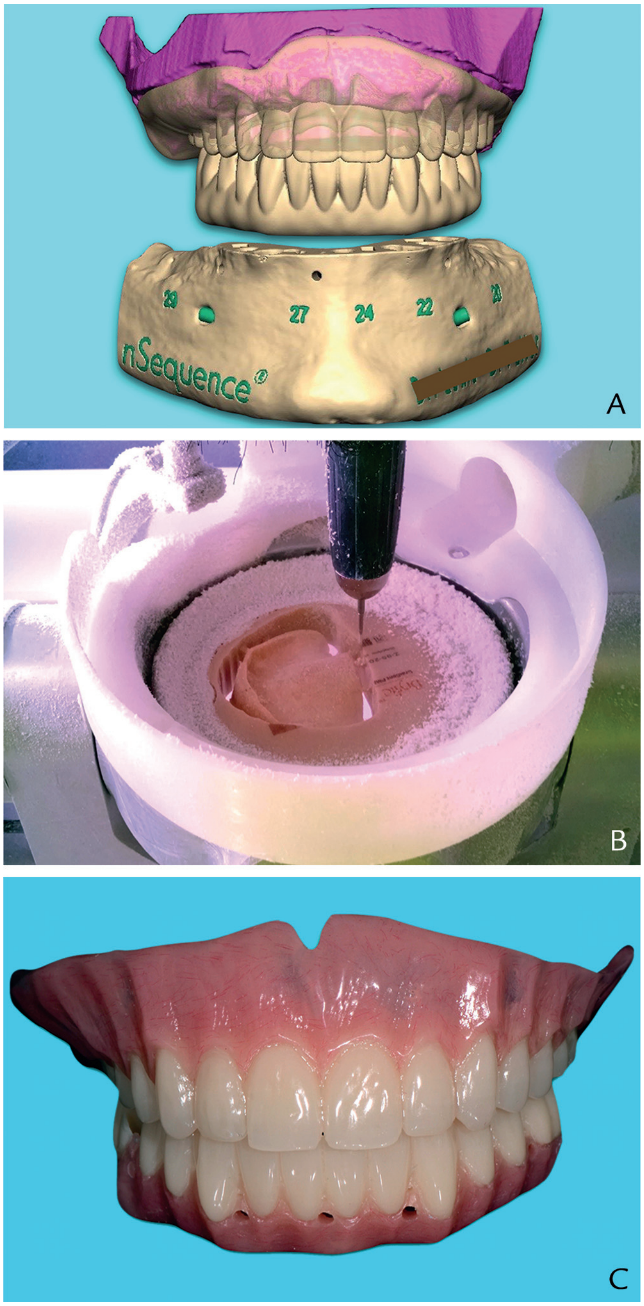

Figure 4. A, Design of CAD-CAM maxillary interim complete removable dental prosthesis and mandibular interim implant-supported complete fixed dental prostheses. B, Computer-aided manufacturing process. C, Light-polymerizing pink composite resin used to layer milled interim prostheses.

plan could be transferred and realized during the clinical procedures.

At the surgical appointment, the existing occlusal vertical dimension was measured and recorded from the base of the nasal septum to the inferior border of the chin with a ruler and tongue depressor as shown by Smith.[26] The remaining mandibular teeth were removed with an minimal trauma under local anesthesia and intravenous sedation to avoid excessive deformation of the alveolar ridge, which may have prevented the complete seating of the bone foundation guide after extraction. The bone foundation guide with 3 reposition jigs was fitted on the alveolar ridge after extractions and stabilized with anchor pins (Guided Anchor Pin; Nobel Biocare) (Fig. 6A). The planned osseous recontouring was completed with the guidance of the bone foundation guide (Fig. 6B). The implant placement template was then assembled on the bone foundation guide to provide the guidance of implant placements (Mandible: Straumann Soft Tissue Level, guided 4.1 mm × 8 or 10 mm and 3.3 mm × 10 mm; Institut Straumann AG) under a predetermined insertion torque of 35 to 45 Ncm (Fig. 6C). After the implant placement, interim abutments (RN synOcta post for temporary restorations, bridge; Institut Straumann AG) were attached to implants under a torque of 15 Ncm. The prefabricated polyvinyl siloxane carrier (nSequence Center for Advanced Dentistry) was seated on the bone foundation guide (Fig. 6D). Autopolymerizing composite resin (Quick up; VOCO) was used to connect the interim abutments and mandibular interim ICFDP (Fig. 6E). The assembly of the mandibular interim prosthesis and interim abutments was then removed from the implants. The bone foundation guide and anchor pins were removed from the alveolar ridge and the flaps were coronally repositioned with primary closure. The mandibular interim ICFDP was finished in the laboratory and secured to implants with 15 Ncm torque. All screw accesses were sealed with cotton pellets and a single-component resin sealing material (Fermit; Ivoclar Vivadent AG) (Fig. 6F).

The remaining maxillary teeth were removed under local anesthesia (Fig. 7A). The CAD-CAM maxillary interim CRDP was relined with interim soft liner (COE-Soft; GC America). During the relining procedure, the seated mandibular interim ICFDP was used to provide a stable plane of occlusion, and the pre-extraction record was used to confirm the desired occlusal vertical dimension. The patient's hard palate was used as a stable surface from which to apply pressure on the CAD-CAM maxillary interim CRDP to eliminate excessive interim soft reliner. The patient was subsequently guided with the bimanual manipulation technique into centric relation with the CAD-CAM maxillary interim CRDP and interim soft reliner (COE-Soft; GC America) in situ (Fig. 7B). The occlusal contacts in the eccentric position were adjusted intraorally to eliminate occlusal interferences, and group function was achieved with multiple occlusal contacts between the maxillary and mandibular teeth in lateral movements on the working side. The patient was satisfied with the clinical outcomes of the CAD-CAM, interim, maxillary CRDP and mandibular ICFDP (Fig. 7C, D). The patient was

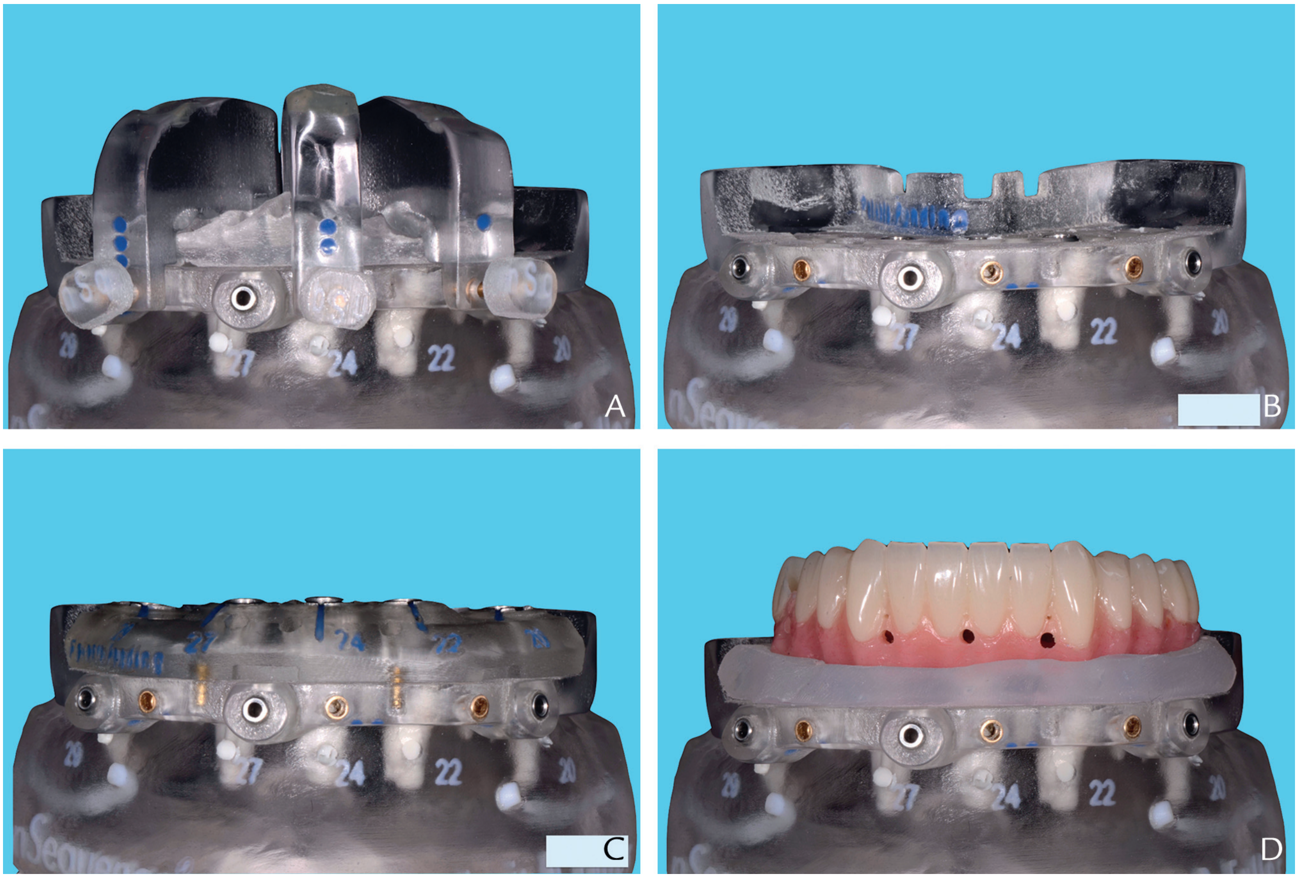

Figure 5. A, CAD-CAM bone foundation guide with 3 reposition devices repositioned on the CAD-CAM mandibular cast (simulation cast with postextraction alveolar ridge). B, CAD-CAM bone foundation guide on CAD-CAM mandibular cast (simulation cast with post-osseous recontouring alveolar ridge). C, Implant placement template assembled on bone foundation guide. D, Assembly of prefabricated polyvinyl siloxane carrier and CAD-CAM mandibular interim implant-supported complete fixed dental prostheses fitted on bone foundation guide for immediate provisionalization procedure.

then instructed in a home care regimen, including a soft diet and the use of a 0.12% chlorhexidine gluconate mouthwash (CHG Oral Rinse; Xttrium Laboratories), and scheduled for follow-up and treatment appointments. The patient was observed for 12 weeks with uneventful healing before the definitive impression appointment.

DISCUSSION

In the CBCT imaging process, metallic restorations can cause scatter and jeopardize its 3-dimensional volume rendering quality.[18] Although the scatter could be manually removed or segmented with an advanced software program/tool, it is a time-consuming step to ensure that real anatomic structures are not eliminated. In the virtual implant planning process, the STL files resulting from a diagnostic intraoral scan can often be imported and merged with the DICOM files in the virtual implant planning software. The intraoral scan can provide scatter-free surface profiles of soft tissue and remaining dentition.[18] The merged files will then contain clearly defined soft tissue and teeth contours to facilitate the treatment planning process and the subsequent fabrication of stereolithographic tooth-supported surgical templates. This process has been used for successful virtual implant planning in partially edentulous clinical scenarios, where existing metal ceramic restorations may cause scatter in the CBCT scans.[15,16]

Patient selection is important because predictable hard tissue anatomic landmarks and soft tissue mask in the CBCT volumetric data must be identified. In this clinical treatment, with few existing dental restorations, only minimal scatters were expected from the CBCT imaging, and CAD-CAM bone-supported surgical templates for subsequent computer-guided surgery were desired and planned. With these considerations in mind, CBCT imaging (with minimal scatters) was used as the primary diagnostic tool, and the DICOM files obtained were used in the virtual implant planning software for hard and soft tissue identification, virtual diagnostic tooth arrangement, virtual implant planning, design of CAD-

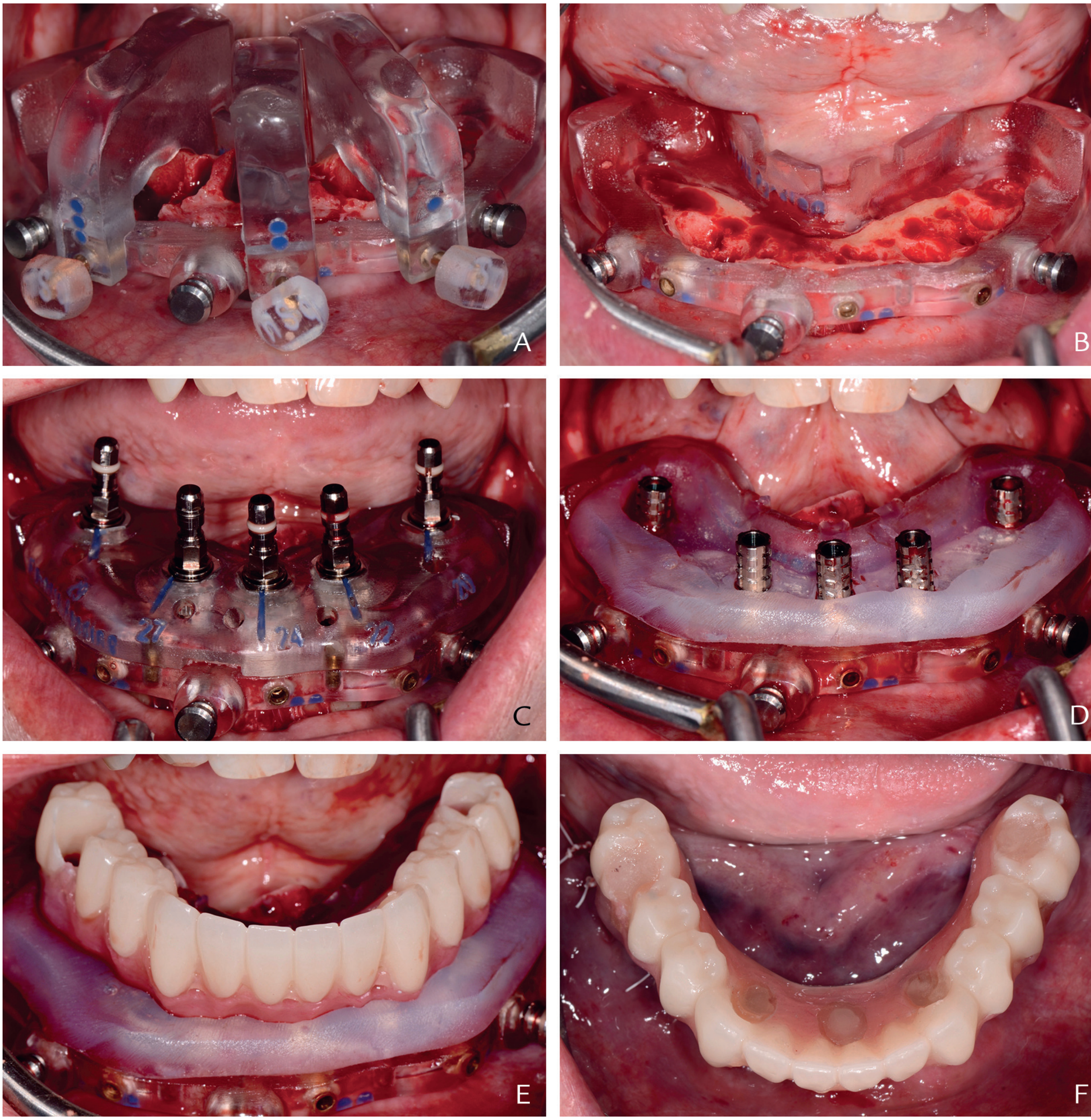

Figure 6. A, Bone foundation guide with 3 reposition jigs fitted on alveolar ridge after extractions and stabilized with anchor pins. B, Bone foundation guide used to complete planned osseous recontouring. C, Mandibular implants placed with assembly of CAD-CAM 2-piece surgical templates. D, Prefabricated polyvinyl siloxane carrier fitted over interim abutments and bone foundation guide. E, Interim abutments and CAD-CAM-fabricated mandibular interim implant-supported complete fixed dental prosthesis (ICFDP) prepared to be connected with autopolymerizing acrylic resin. F, Occlusal view of seated mandibular interim ICFDP.

CAM bone-supported surgical templates, a maxillary interim CRDP, and a mandibular interim ICFDP. The segmentation of the remaining dentition in the CBCT imaging was used to verify that the patient was in the desired occlusal vertical dimension (the existing occlusal vertical dimension was preserved in this patient) and maxillomandibular relationship (maximal intercuspal position, which coincided with centric occlusion in this patient) during the CBCT imaging process. In the obtained DICOM files, the existing tooth positions, the recorded occlusal vertical dimension, and the maxillomandibular relationship were then used as references for the virtual diagnostic tooth arrangement. Furthermore, the maxillary soft tissue identification on the

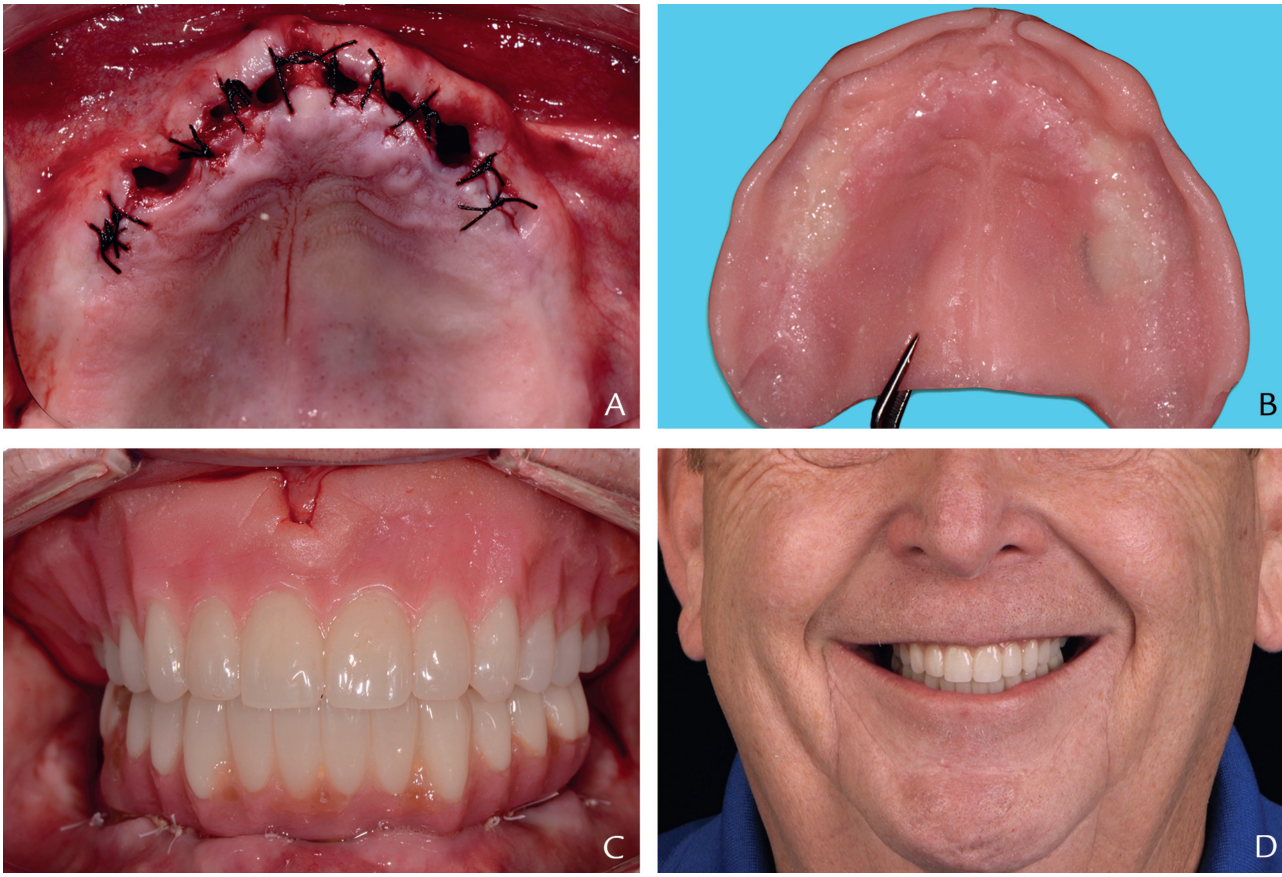

Figure 7. A, Remaining maxillary teeth removed. B, CAD-CAM-fabricated maxillary interim complete removable dental prosthesis relined with soft liner. C, Facial view of inserted maxillary and mandibular interim prostheses. D, Smile presentation of inserted interim prostheses.

DICOM files allowed the dental laboratory technician to trace the soft tissue profile from the axial, coronal, and sagittal views and to recreate the virtual diagnostic cast, containing information on the remaining dentition and soft tissue, for the fabrication of the maxillary interim CRDP.

The advantage of this proposed technique is that CBCT imaging is the primary diagnostic tool (without diagnostic impression and/or intraoral digital scan) for laboratory planning and preparation procedures, which can be performed in a single diagnostic appointment. There are a few limitations associated with this technique. The remaining dentition should only have a few existing dental restorations and minimal scatter in the CBCT imaging, and can maintain desired occlusal vertical dimension, and maxillomandibular relationship during the scanning process. If a desired and stable occlusal vertical dimension and/or maxillomandibular relationship cannot be achieved with the remaining dentition, a record base and occlusal rim with an interocclusal record could be used to maintain accurate maxillomandibular relations during CBCT imaging.

Because of the limitations of current technology and CAD-CAM software, the occlusal scheme on the virtual diagnostic tooth arrangements can only be designed in the centric occlusion position. The occlusal contacts of the inserted CAD-CAM interim prosthesis in the eccentric position still require intraoral adjustments to eliminate interferences. Bone-supported CAD-CAM-fabricated surgical templates should be designed and used, since the scatter-free surface profiles of soft tissue and remaining dentition were not obtained through diagnostic impression and/or intraoral digital scan. Although soft tissue identification and tracing on the DICOM files are feasible for the design and fabrication of CAD-CAM-fabricated maxillary interim CRDP, the accuracy of the denture intaglio surface and its adaptation to intraoral soft tissue need to be validated with further experimental studies. Interim soft liner was used in this study to facilitate the adaptation and insertion of the CAD-CAM maxillary interim CRDP.

SUMMARY

This clinical report provides a digital protocol for treating a patient with computer-guided surgery, a maxillary interim CRDP, and a mandibular interim ICFDP on immediately placed and immediately loaded dental

implants. CBCT imaging was used as the primary diagnostic data collection tool, and, with careful patient selection, the need for diagnostic impression (conventional or digital) and casts was eliminated.

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