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CLINICAL REPORT

Creation of a 3-dimensional virtual dental patient for computer-guided surgery and CAD-CAM interim complete removable and fixed dental prostheses: A clinical report

Bryan T. Harris, DMD,[a] Daniel Montero, DDS,[b] Gerald T. Grant, DMD, MS,[c] Dean Morton, BDS, MS,[d] Daniel R. Llop, CDT,[e] and Wei-Shao Lin, DDS[f]

ABSTRACT

This clinical report proposes a digital workflow using 2-dimensional (2D) digital photographs, a 3D extraoral facial scan, and cone beam computed tomography (CBCT) volumetric data to create a 3D virtual patient with craniofacial hard tissue, remaining dentition (including surrounding intraoral soft tissue), and the realistic appearance of facial soft tissue at an exaggerated smile under static conditions. The 3D virtual patient was used to assist the virtual diagnostic tooth arrangement process, providing patient with a pleasing preoperative virtual smile design that harmonized with facial features. The 3D virtual patient was also used to gain patient's pretreatment approval (as a communication tool), design a prosthetically driven surgical plan for computer-guided implant surgery, and fabricate the computer-aided design and computer-aided manufacturing (CAD-CAM) interim prostheses. (J Prosthet Dent 2016;■:■-■)

Creating a 3-dimensional (3D) virtual patient may provide advantages in dental and medical treatment, including a noninvasive simulation of planned treatment procedure, potential treatment outcomes, and effective communication among patient, technician, and clinician.[1,2] Essential tissues required to create a 3D virtual patient include the craniofacial hard tissue, the remaining dentition (including surrounding intraoral soft tissue), and the extraoral facial soft tissue.[1-3] Although cone beam computed tomography (CBCT) can provide accurate 3D volumetric views of craniofacial hard tissue in the Digital Imaging and Communications in Medicine (DICOM) file format, dense intraoral metallic restorations are often in the field of view of most CBCT scans of dental patients and can compromise the image quality with various scatter artifacts.[4] In contrast, intraoral optical scans can provide scatter-free contours of the dentition and surrounding soft tissue profiles in the stereolithography (STL) file format. STL files can be merged with DICOM files to augment information from the artifact in the computer-aided design and computer-aided manufacturing (CAD-CAM) or virtual implant planning software.[5,6]

CBCT has limited contrast resolution for soft tissue because of the high scatter radiation during image acquisition; therefore, the high-resolution surface detail and optical properties of extraoral facial soft tissue (the surface texture and color of face) cannot be recorded.[7,8] In the past 2 decades, laser- and optics-based (structured light, passive and active stereophotogrammetry imaging systems) and extraoral 3D surface acquisition technologies have been used to capture the realistic appearance of facial soft tissue and have been integrated into the dental and medical fields.[9-13] Studies have shown that 3D volumetric data from the CBCT (hard tissue) and extraoral 3D facial surface acquisition (soft tissue) can be merged to create a 3D composite virtual craniofacial model, allowing the concurrent assessment of both hard and soft tissues.[14,15] Imaging management

[a]Associate Professor, Advanced Education in Prosthodontics, Department of Oral Health and Rehabilitation, School of Dentistry, University of Louisville, Louisville, Ky.
[b]Assistant Professor, Department of Oral Health and Rehabilitation, School of Dentistry, University of Louisville, Louisville, Ky.
[c]Professor, Department of Oral Health and Rehabilitation, School of Dentistry, University of Louisville, Louisville, Ky.
[d]Professor, Department of Prosthodontics, Indiana University School of Dentistry, Indianapolis, Ind.
[e]President, nSequence, Center for Advanced Dentistry, Reno, Nev.
[f]Associate Professor, Division of Prosthodontics, Department of Oral Health and Rehabilitation, University of Louisville School of Dentistry, Louisville, Ky.

systems and treatment planning software have also been re-engineered to incorporate the 3D composite virtual craniofacial model into the treatment options, including the design and fabrication of maxillofacial prostheses,[16,17] diagnosis, patient education, and virtual postoperative soft tissue simulation in computer-based maxillofacial surgical planning.[18-20]

Conventionally, several clinical appointments and labor-intensive laboratory procedures were required to collect necessary diagnostic information and prepare for the computer-guided surgery and immediate visualization.[21,22] Technology developed for implant dentistry, including 3D imaging modalities (CBCT, intraoral, and extraoral scanning), virtual implant planning software, and CAD-CAM surgical templates/prostheses, has afforded the dental clinician an opportunity to plan and execute computer-guided surgery and immediate visualization in a predictable manner.[23-25] Dental implants placed with computer-guided surgery have been reported to have a 97.3% survival rate with at least 12 months of follow-up.[26] When different surgical approaches are used in conjunction with immediate visualization, no differences in clinical outcomes are observed between computer-guided versus conventional options.[27]

This article describes a digital workflow using digital photographs and a low-cost extraoral 3D scanner to acquire a facial soft tissue profile for creating a 3D virtual patient with realistic facial soft tissue at the exaggerated smile. This was used in conjunction with CBCT volumetric data to augment the required diagnostic information in the digital treatment planning and a virtual smile design (VSD) process for computer-guided implant surgery and CAD-CAM interim complete fixed and removable dental prostheses.

CLINICAL REPORT

A 48-year-old woman was referred to the Dental Associates, School of Dentistry, University of Louisville, with partially edentulous dentition of the maxilla and mandible; the chief complaint was missing teeth. The clinical and radiographic examination showed generalized chronic severe periodontitis with mobility of the remaining teeth. Missing maxillary and mandibular left central incisors were restored with interim resin-bonded fixed dental prostheses. Different treatment options and associated costs, risks, and benefits were presented and discussed with the patient. The patient accepted the definitive treatment plan of a conventional maxillary complete removable dental prosthesis (CRDP) and mandibular implant-supported complete fixed dental prosthesis (ICFDP) with 4 dental implants. She also accepted the proposal of a mandibular interim ICFDP on immediately placed and immediately loaded dental implants. An immediate maxillary interim CRDP was also planned after the removal of remaining maxillary dentition.

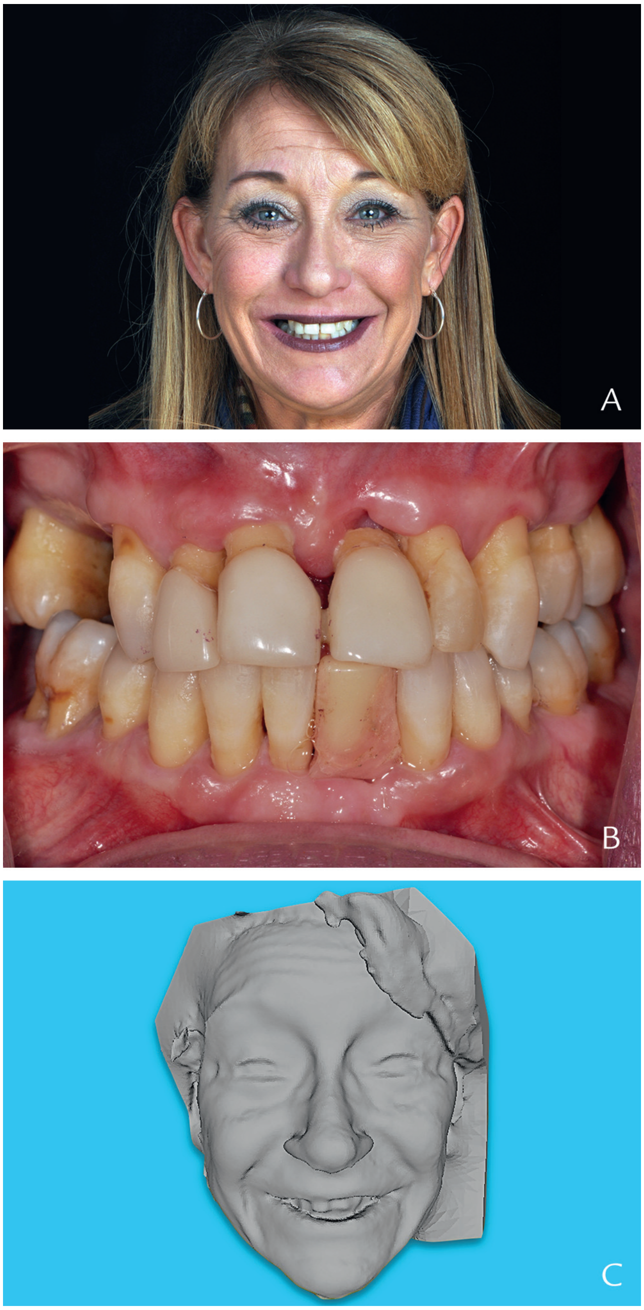

Figure 1. Pretreatment condition. A, Full-face view extraoral digital image demonstrating patient's exaggerated smile. B, Intraoral digital photograph showing patient in centric occlusion. C. 3D extraoral facial scan at patient's exaggerated smile.

Extraoral and intraoral digital photographs were made to preserve preoperative diagnostic information. The patient was instructed to demonstrate an exaggerated smile during photography, and the maxillary lip position and gingival display were recorded with full-face

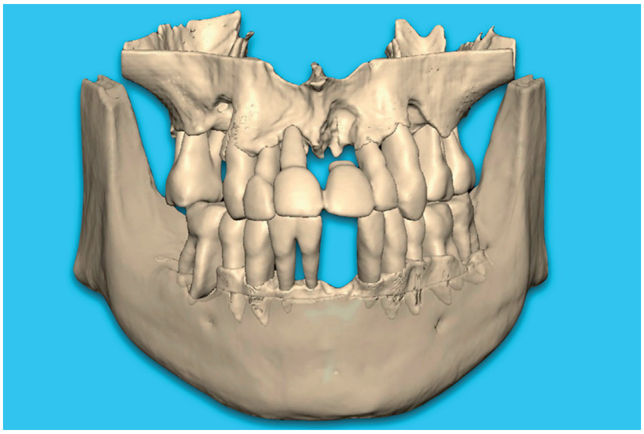

Figure 2. 3-Dimensional volumetric data of craniofacial hard tissue and remaining dentition (skeletal and dental) rendered from DICOM files. DICOM, Digital Imaging and Communications in Medicine format.

extraoral digital photographs (Fig. 1A). The patient was guided in the centric occlusion position while making the intraoral digital photographs (Fig. 1B). All extraoral and intraoral digital photographs were exported in a Joint Photographic Experts Group (JPEG) file format. A low-cost extraoral 3D scanner (Sense 3D scanner; 3D Systems) was used to capture the facial soft tissue profile at the patient's exaggerated smile (Fig. 1C), and the captured data were exported as Polygon File Format (PLY) files. The CBCT imaging (3D Accuitomo 170; J. Morita USA) was performed in the patient's existing centric occlusion position, and the CBCT imaging data were exported as DICOM files.

All digital diagnostic information (JPEG files of intraoral and extraoral digital photographs, PLY files of 3D extraoral facial scan, and DICOM files of CBCT imaging) was forwarded to a dental laboratory (nSequence Center for Advanced Dentistry, Reno, Nevada) through a secure internet server. First, from the DICOM files, the 3D volumetric data of craniofacial hard tissue and remaining dentition (skeletal and dental) (Fig. 2) were segmented and rendered in virtual implant planning software (Maven Pro; nSequence) and exported as an STL file. Second, the PLY file of 3D extraoral facial scan (from the extraoral scanner) and the JPEG file of 2D extraoral digital photographs were imported into CAD software (not disclosed as part of proprietary laboratory development process; nSequence). The laboratory technician merged the 2D and 3D files until best fit between data sets was found in this surface-based merging process (Fig. 3A),[2] which used constant soft tissue landmarks (glabella, nasion, endocanthions, pronasale, subnasale, alares, and pogonion) as merging markers. A virtual patient was created with realistic facial soft tissue at the exaggerated smile (Fig. 3B). Third, the STL file of the 3D volumetric data of craniofacial hard tissue and remaining dentition from CBCT imaging (skeletal and dental) were merged to this virtual patient by using the remaining dentition as the merging markers (Fig. 3C). A complete 3D virtual patient with realistic facial soft tissue (data obtained from extraoral scanner and digital camera), craniofacial hard tissue (data obtained from CBCT imaging), and remaining dentition (data obtained from CBCT imaging) was then created at the patient's exaggerated smile under static conditions.

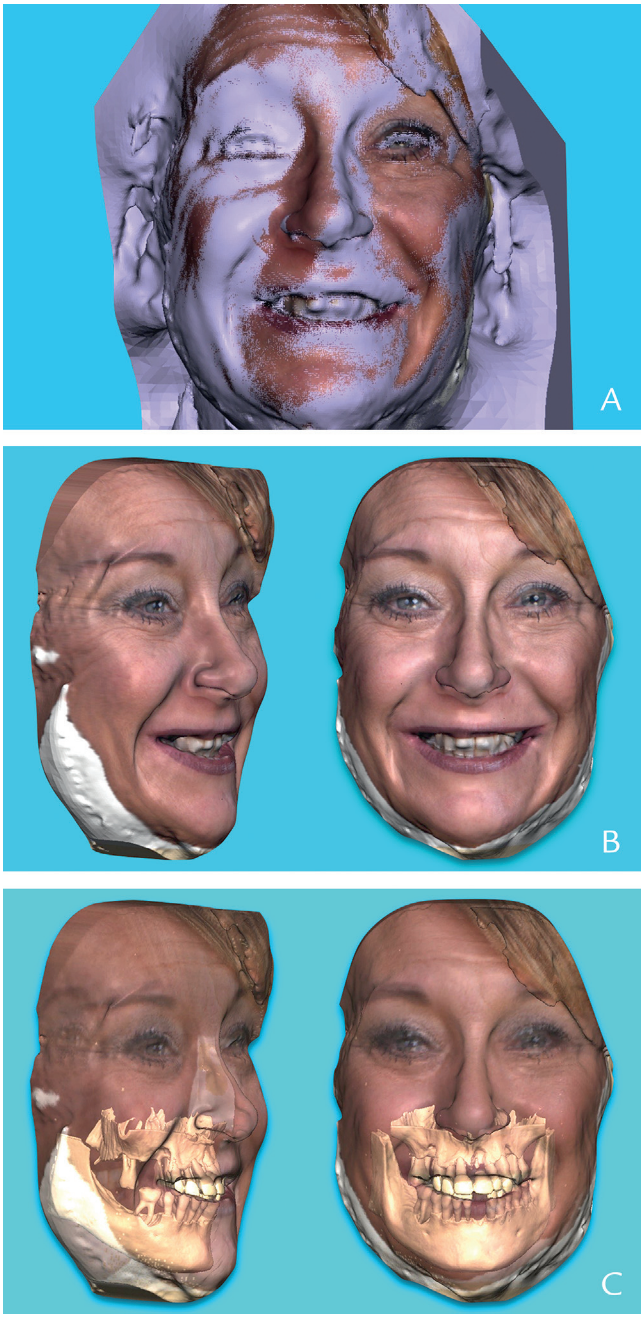

Figure 3. A, Merged 2D and 3D files of extraoral facial soft tissue. B, Lateral, 45-degree view and front view of 3D virtual patient with photorealistic appearance of facial soft tissue at exaggerated smile. C, 3-Dimensional volumetric data of craniofacial hard tissue and remaining dentition (skeletal and dental) was also registered to virtual patient.

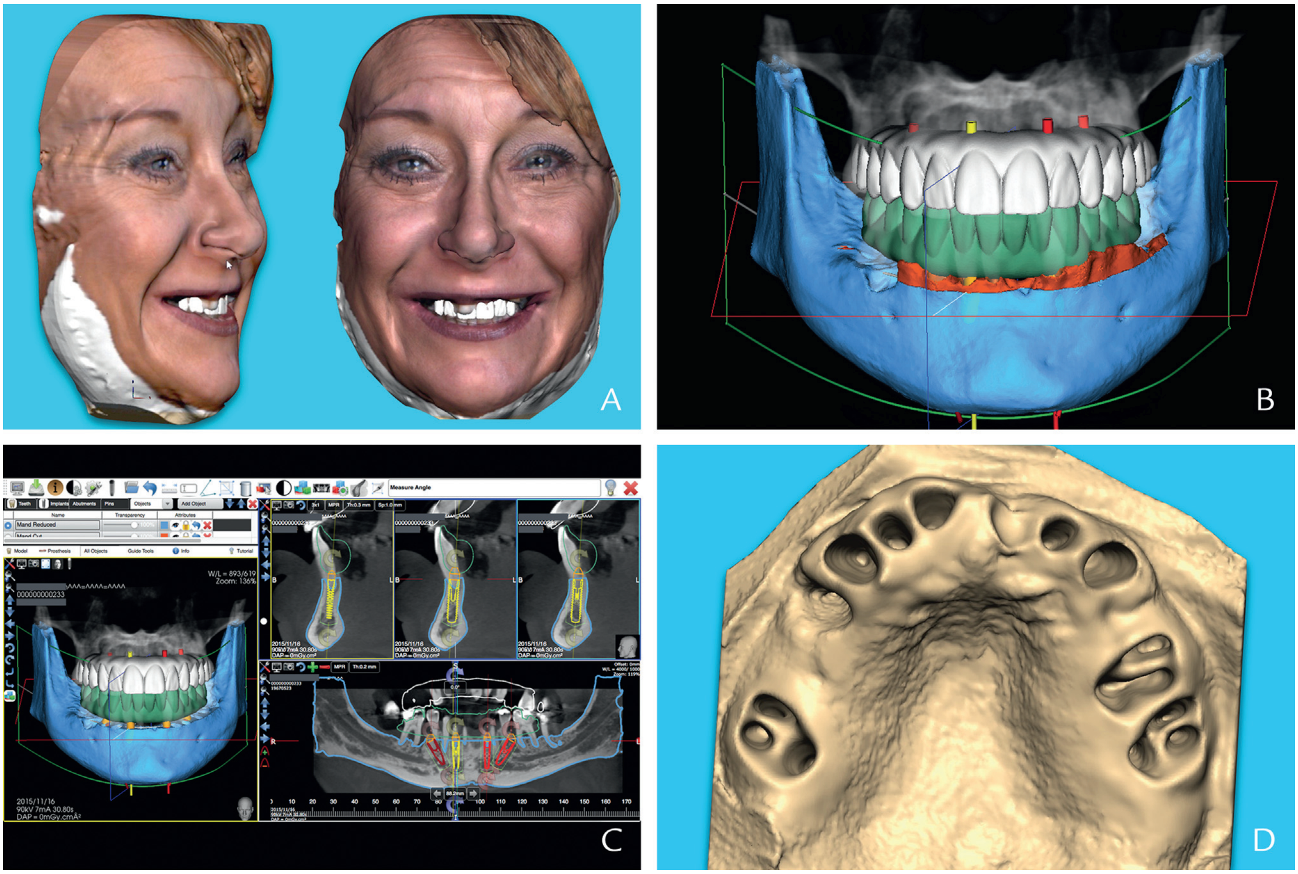

Figure 4. A, Proposed virtual diagnostic tooth arrangement was registered to virtual patient and was provided to patient for approval. B, Complete maxillary and mandibular virtual diagnostic tooth arrangement. Orange represents simulated virtual bone reduction. C, Prosthesis-driven implantation surgical plan. D, Occlusal view of virtual diagnostic cast with simulated postextraction alveolar ridge and reconstructed soft tissue profile.

The 3D virtual patient was used to assist in the subsequent treatment planning and VSD process, providing the patient with a tooth arrangement which harmonized with facial esthetics.[28-30] The facial profile and midline was used to assist in the selection of virtual maxillary anterior teeth[31] and the arrangement of the dental midline.[32] In addition, because the patient's pupils were symmetrical, the interpupillary line was used as the horizontal reference plane for the maxillary occlusal plane.[33] A maxillary virtual diagnostic tooth arrangement was created in the CAD-CAM software (Maven Pro; nSequence) and registered to the 3D virtual patient (Fig. 4A). After obtaining approvals from the clinicians and patient, the dental technician completed the maxillary and mandibular virtual diagnostic tooth arrangement (Maven Pro; nSequence) (Fig. 4B). A prosthetically driven implant surgical plan for computer-guided implant surgery was completed in the virtual implant planning software (Maven Pro; nSequence) (Fig. 4C). A virtual cast with a simulated postextraction alveolar ridge and soft tissue profile was recreated from the CBCT volumetric data in the CAD-CAM software (Maven Pro; nSequence) in preparation for the CAD-CAM maxillary interim CRDP (Bone Foundation Guide System, Guided Prosthetics; nSequence) (Fig. 4D). Two-piece surgical templates (incorporating a bone foundation guide and an implant placement template) (Fig. 5A, B), mandibular interim ICFDP (Fig. 5C), and maxillary interim CRDP (Fig. 5D) were created based on the implant surgical plan.[6]

At the surgical appointment, the bone foundation guide was fitted over the postextraction alveolar ridge and stabilized with anchor pins (Guided Anchor Pin; Nobel Biocare) (Fig. 6A) to provide guidance for complete planned bone reduction. The implant placement template was fitted onto the bone foundation guide and used to perform the computer-guided surgery for the 4 mandibular implants (Straumann Bone Level, guided 3.3×14 mm and 4.1×14 mm; Institut Straumann AG) under a predetermined insertion torque of 35 to 45 Ncm (Fig. 6B). The definitive abutments (Narrow CrossFit [NC] screw-retained abutments; titanium alloy [TAN]: straight 0°; dimension [D]: 4.6 mm; gingival height [GH]: 2.5; and Regular CrossFit [RC] screw-retained abutments; TAN: angled 30°; D: 4.6 mm; GH: 2.5 mm; Institut Straumann AG) were attached to the implants under 35 Ncm torque.

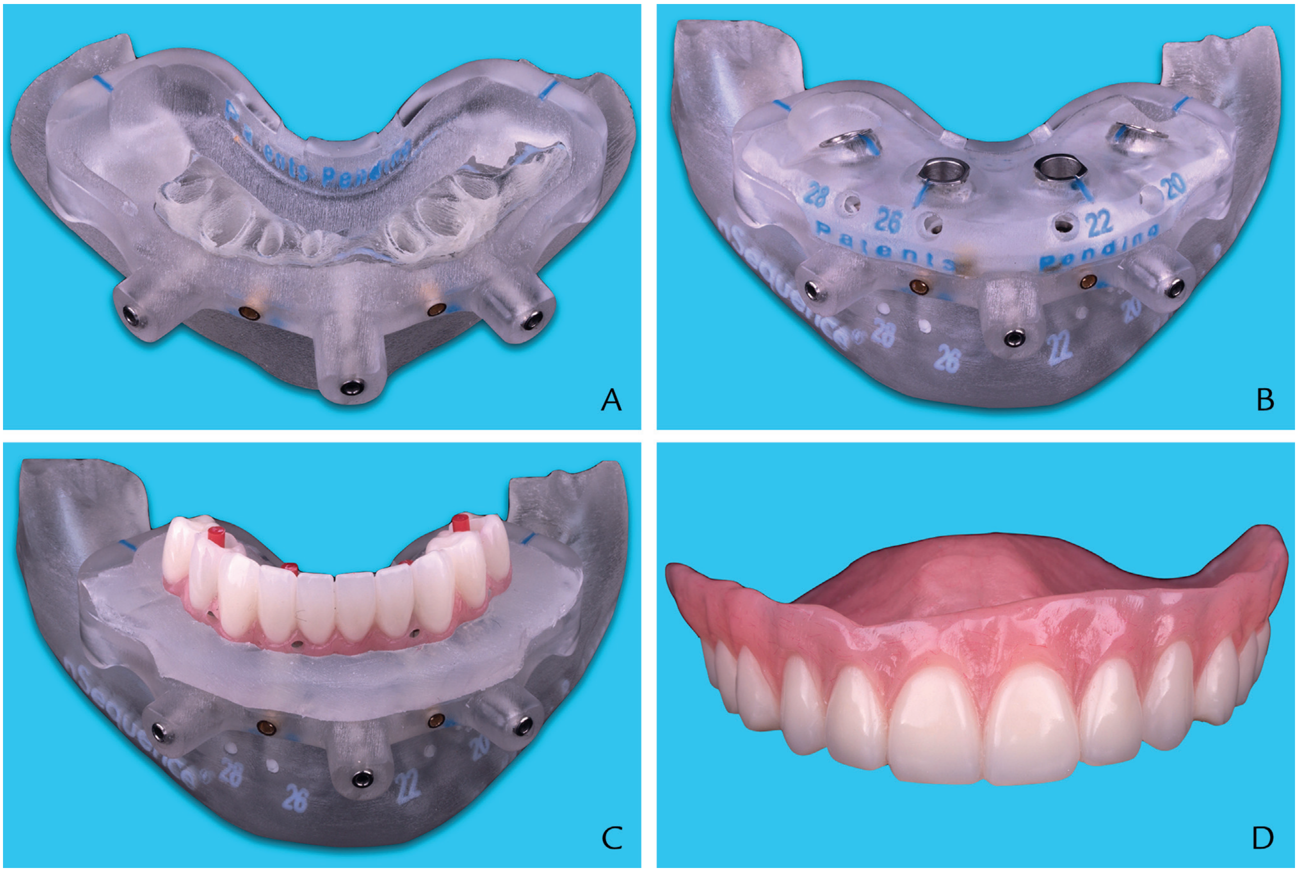

Figure 5. A, CAD-CAM bone foundation guide fitted on mandibular cast with simulated postextraction alveolar ridge. B, Implant placement template assembled on bone foundation guide. C, Prefabricated polyvinyl siloxane carrier and CAD-CAM mandibular interim ICFDP assemble on bone foundation guide. D, CAD-CAM maxillary interim CRDP. CRDP, complete removable dental prosthesis; ICFDP, implant-supported complete fixed dental prosthesis.

The interim copings (NC/RC coping for screw-retained abutment, Ti, bridge; D: 4.6 mm) were then attached to the definitive abutments with a torque of 15 Ncm. An autopolymerizing acrylic resin (Jet Tooth Shade Acrylic; Lang Dental) was used to connect the interim copings and mandibular interim ICFDP (Fig. 6C). The mandibular interim ICFDP was finished and polished in the laboratory and secured to the definitive abutments with a torque of 15 Ncm. Cotton pellets and a single-component resin sealing material (Fermit; Ivoclar Vivadent AG) were used to seal all screw accesses.

Under local anesthesia, the maxillary teeth were removed, and the CAD-CAM maxillary interim CRDP was relined with soft reliner (Coe-Soft; GC America) (Fig. 7A) in the centric occlusion position. The occlusal contacts in the centric and eccentric position were adjusted intraorally to eliminate occlusal interferences. The patient was instructed to follow a postoperative home care regimen including soft diet and the use of a 0.12% chlorhexidine gluconate mouthwash (CHG Oral Rinse; Xttrium Laboratories) and scheduled for follow-up appointments (Fig. 7B, C). The patient was observed for 12 weeks with uneventful healing before the definitive impression appointment.

DISCUSSION

A 3D virtual patient with an accurate composite virtual craniofacial model can be an effective diagnostic, planning, communication, and educational tool among dental technicians, clinicians, and patients.[1-3] The successful creation of a 3D virtual patient requires the superimposition of 3 digital data sets of different file formats. According to a recent systematic review,[2] although it is feasible to create a virtual patient under static conditions, only 2 reported feasibility studies (case reports) integrated all 3 of the digital data sets. This clinical report describes the digital workflow in creating a 3D virtual patient at exaggerated smile under static conditions to assist in the treatment planning process of computer-guided implant surgery and CAD-CAM interim fixed and removable dental prostheses.

The smile design considers different scientific and artistic principles to create a pleasing smile for patients and

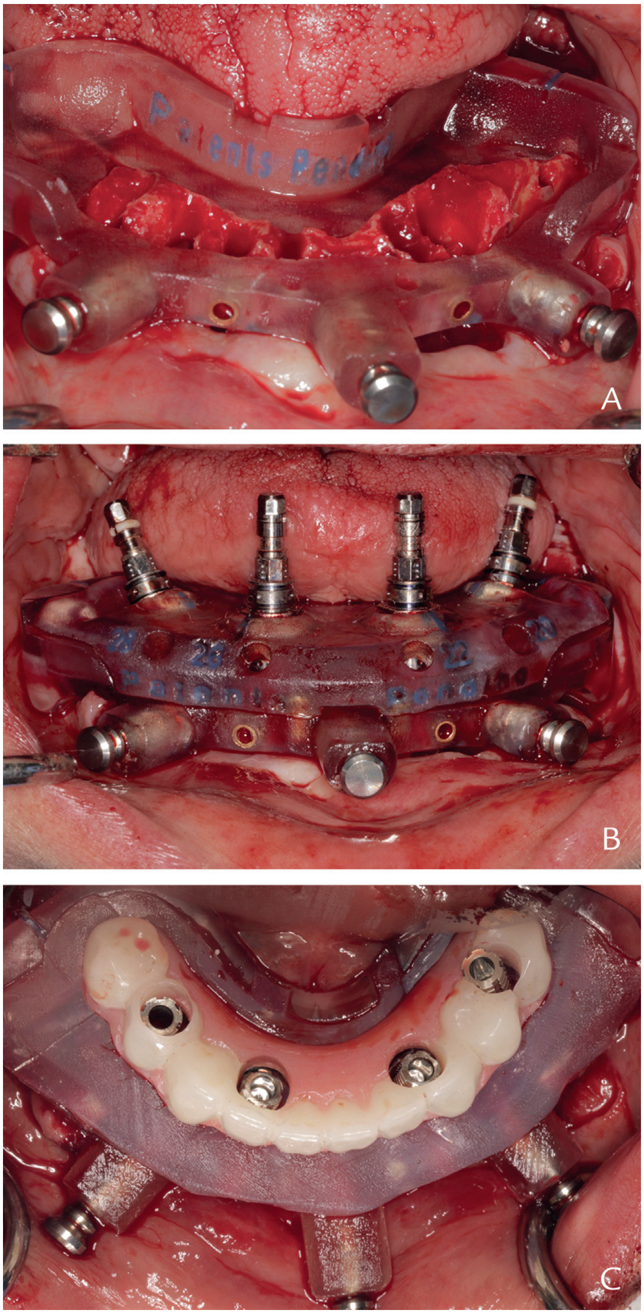

Figure 6. A, Bone foundation guide fitted over post-extraction alveolar ridge to complete planned osseous recontouring. B, Implant placement template use to guide mandibular implant placement. C, Interim copings and CAD-CAM mandibular interim ICFDP prepared to be connected with autopolymerizing acrylic resin. ICFDP, implant-supported complete fixed dental prosthesis.

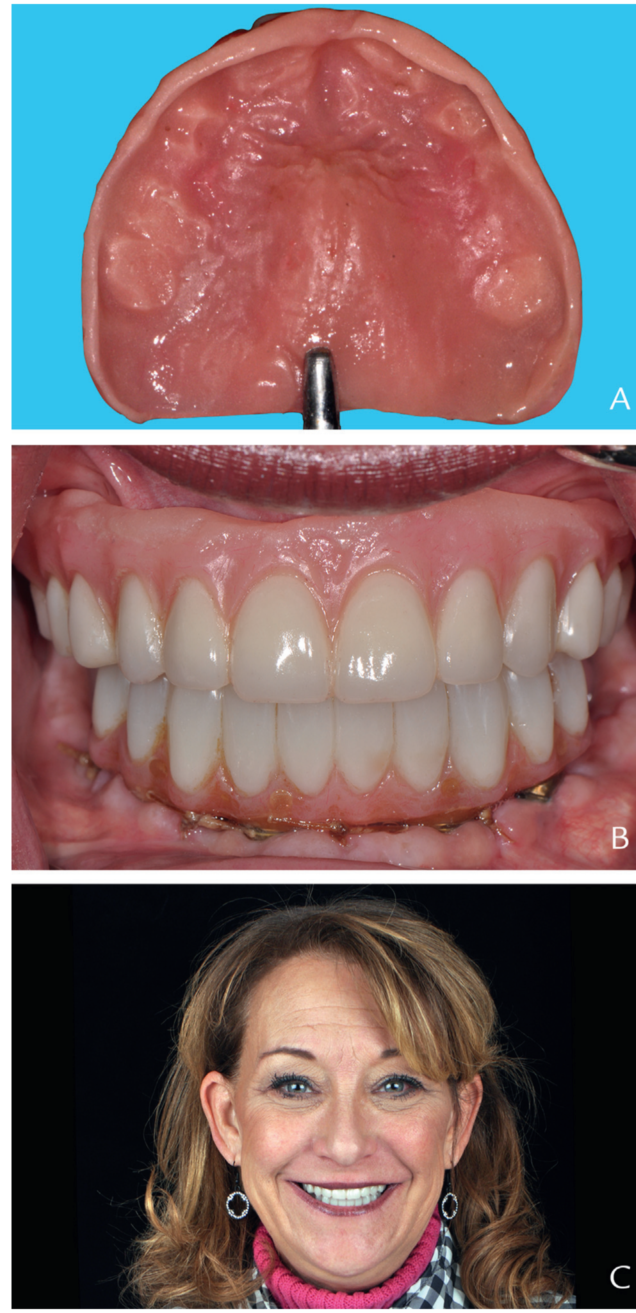

Figure 7. A, CAD-CAM maxillary interim CRDP relined with soft reliner. B, Facial view of inserted maxillary and mandibular interim prostheses. C, Smile presentation of inserted interim prostheses. CRDP, complete removable dental prosthesis.

often requires the evaluation of the patient's intraoral hard and soft tissue (teeth and gingival display) and their relationship to the facial features and smile.[28-33] The main advantage of this proposed clinical treatment workflow was to eliminate the need for dental clinicians to obtain expensive dental/medical extraoral 3D surface imaging systems and to incorporate a 3D virtual patient with realistic appearance into the preoperative diagnostic and treatment planning process, the VSD in particular. A portable low-cost extraoral 3D scanner (Sense 3D scanner; 3D Systems) was used to conveniently and efficiently capture the facial soft tissue profile at chairside. This provides a practical alternative to the more expensive, resource-consuming extraoral 3D surface imaging systems, especially for private practitioners. Although the quality of the scanned data from the portable extraoral 3D scanner was not comparable to that from a professional system, a 2D extraoral digital photograph and CAD software were used to augment the surface detail and optical properties of the 3D virtual patient. Additional laboratory cost is required for the dental technician to merge/register all the digital data and compose the 3D virtual patient.

Some limitations are associated with the proposed digital workflow. Because various digital data sets are used to compose a 3D virtual patient, all the digital data sets should be merged or registered at a clinically acceptable level of accuracy. The 3D virtual patient was created at the patient's exaggerated smile to obtain the diagnostic information of the patient's maxillary lip position and gingival display. The head positioning and facial expression need to be fairly consistent during the acquisition process of 3D extraoral facial scanning and digital photography. Differences in head positioning and facial expression between the data acquisitions can result in a registration error. Because facial soft tissue landmarks and remaining dentition were used as the registration markers to merge all the data sets, additional attention must be paid in obtaining adequate details in these registration markers during the entire data acquisition process. In addition, the facial soft tissue of the 3D virtual patient does not change corresponding to the position or placement of the diagnostic tooth arrangement. Although various computational strategies have been used to perform 3D virtual soft tissue simulations/prediction in the treatment of dentofacial deformities with orthognathic surgery,[18,20] the effect on lip support from the virtual diagnostic tooth arrangement could not be simulated in this clinical report because of current software limitations. Maxillary lip support is known to be subjective and difficult to quantify, and the patient's input is important in determining acceptable lip projections.[33] Although a clinically acceptable result was achieved without preoperative virtual soft tissue simulations, 3D planning software could provide a more predictable postoperative esthetic outcome in the future.

The 3D virtual patient was created in a static position, and the phonetics or other functional outcomes could not be simulated in the 3D planning software. For future research and development, 4D facial imaging should be considered to obtain further diagnostic information and create a 3D virtual patient in motion.[1,2] Four-dimensional facial imaging is defined as a sequence over a period of time of 3D virtual patient of facial animations, and the dynamics of facial expressions and functional movements can offer important information in diagnosis, surgical planning, and postoperative assessment in dental or craniofacial treatment.[11] Although different motion capture stereophotogrammetric systems are available to capture realistic dynamics of facial expressions and movements as opposed to creating only a virtual patient under static conditions, no commercial imaging and virtual planning system is yet available to merge and register a 4D sequence of facial expressions and movements to the DICOM files of CBCT imaging and/or STL files of 3D intraoral/extraoral scans for dental treatment.[11,12]

SUMMARY

This clinical report describes a digital workflow using digital photographs, a low-cost extraoral 3D scanner, and CBCT imaging to create a 3D virtual patient with craniofacial hard tissue, remaining dentition (including intraoral soft tissue), and realistic appearance of facial soft tissue at exaggerated smile, under static conditions. The 3D virtual patient was used in the VSD and treatment planning process of computer-guided implant surgery and CAD-CAM interim fixed and removable dental prostheses.

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Corresponding author:
Dr Wei-Shao Lin
University of Louisville
501 South Preston St
Louisville, KY 40292
Email: WeiShao.Lin@Louisville.edu