Virtual facial simulation of prosthetic outcome for static computer-aided implant surgery and CAD-CAM prostheses

Short title: Virtual facial simulation for implant surgery and CAD-CAM prostheses

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INTRODUCTION:

Although some common features determine human beauty, the perception of attractiveness is often influenced by the self-perception in the beholder's mind and the continually changing norms of a society.[1,2] This is important in dental treatment. To achieve ideal dental treatment outcomes for patients, clinicians should seek harmony among classical definitions of beauty, current cultural trends, and the patient's personal preferences.[3-5] Studies have shown that the esthetics outcome is the decisive factor for the patient's emotional acceptance of tooth loss and dental prostheses.[6,7]

The developments in 3-dimensional (3D) imaging technology allow clinicians to generate a volumetric virtual patient consisting of the surface texture of the face, craniofacial skeletal structure, and intraoral soft tissue, dentition, and its occlusion.[8] Different developed and emerging 3D surface acquisition technologies, including laser and optical-based surface imaging, that can be used to capture realistic 3D surface textures and colors of extraoral facial soft tissue.[9,10] Although cone beam computed tomography (CBCT) allows the 3D imaging of the craniofacial hard tissue, it only has a limited field of view and contrast resolution for facial soft tissue. The 3D craniofacial hard tissue reconstructed from CBCT volumetric data can then be superimposed with the extraoral facial soft tissue texture and color data to create a 3D virtual patient with a photorealistic appearance.[9-12] The virtual patient can be used to assist the clinical diagnosis and treatment planning process[11,13] and simulate the patient's post-operative facial appearance after orthognathic surgery.[14-16] Notably, studies have suggested limited accuracy in the prediction outcomes, and these computer simulation programs should be used with caution to prevent unrealistic patient expectations and dissatisfaction.[15-17]

Static computer-aided implant surgery (s-CAIS) and computer-aided design and computer-aided manufacturing (CAD-CAM) complete fixed dental prosthesis have become a predictable treatment modality for patients.[18-20] This clinical report describes a digital workflow using a 3D virtual patient for s-CAIS and CAD-CAM prostheses. In addition, the facial simulation of post-treatment prosthetic outcomes was used to facilitate the communication and treatment planning process among the patient and clinical treatment team members.

CLINICAL REPORT:

A signed, written informed consent for the use of digital images, photographs, and radiographs was obtained from the patient for publication of this clinical report. A 62-year-old woman with a partially edentulous maxilla and mandible was referred to the Prosthodontics Clinic. The clinical and radiographic examination showed recurrent dental caries associated with direct and indirect dental restorations, periapical pathology, generalized mild horizontal alveolar bone loss, retained residual roots, and root canal therapy on the remaining dentition. Two existing dental implants were present at the right maxillary canine and the right mandibular central incisor sites, and significant bone loss was noted for both implants (Fig. 1A). After the esthetic and functional assessment, it was also revealed that the patient lost an occlusal vertical dimension (OVD) by approximately 3 mm. A removable mandibular occlusal splint was provided to the patient to evaluate the possibility of increasing OVD. During eight weeks of wearing the occlusal splint, no post-insertion complication associated with the increased OVD of 3 mm was observed (Fig. 1B).

After the treatment plan discussion, the patient accepted the option of a maxillary removable complete denture (RCD) and mandibular implant-supported fixed complete denture (IFCD) with five dental implants.

The mandibular occlusal splint was used to maintain the patient in the centric occlusion (CO) position while collecting all diagnostic data, including digital extraoral photographs, intraoral scanning, and CBCT imaging. Intraoral scans were taken with an intraoral scanner (iTero; Align Technology) (Fig. 2A). A series of digital extraoral photographs were made at an exaggerated smile view from the mid-facial, right and left 45-degree views, and right and left 90-degree views (Fig. 2B). Two sets of CBCT imaging were taken for the patient. The patient was first scanned at a retracted view using cotton rolls and a plastic retractor (Free Access II cheek and lip retractor - small; J Morita USA) to obtain clear visualization of the alveolar ridge profile and remaining dentition.[8] The first scan was completed with an effective dose of 378 μSv and a field of view (FOV) of 170 x 120 mm (3D Accuitomo170; J. Morita USA). The second scan was completed under an exaggerated smile view, with a low effective dose of 74 μSv and large FOV of 230 x 172 mm (i-CAT Next Generation; Imaging Sciences Intl).[21]

All digital diagnostic data were forwarded to a dental laboratory (NDX nSequence; Reno, Nevada) to compose a complete 3D virtual patient with realistic facial soft tissue at an exaggerated smile view (Fig. 3A). In the CAD software program (Maven Pro; NDX nSequence), the tooth arrangement was completed using the remaining dentitions and digital photographs as references, providing the patient a smile design that harmonized with facial esthetics (Fig. 3B).[11] In a 3D simulation software (Dolphin 3D Surgery; Dolphin Imaging & Management Solutions), the patient's post-operative facial profile was simulated based on the diagnostic tooth arrangement (Fig. 4A and 4B). The 3D virtual patient with a simulated post-operative facial profile was then used as a communication medium to obtain the patient's approval for the proposed prostheses designs. Upon receiving the patient's approval, a prosthetically-driven s-CAIS plan and CAD-CAM surgical templates, a maxillary interim RCD, and a mandibular interim IFCD were designed and manufactured (Guided Prosthetics; NDX nSequence) (Fig. 5A, 5B, and 5C).

The existing maxillary and mandibular dental implants and dentition were removed under local anesthesia. The CAD-CAM surgical templates were used in the mandibular s-CAIS to guide the bone reduction and the implant placements (Straumann Tissue Level, Regular Neck, Standard Plus, SLActive, guided 4.1 mm × 8 mm, 4.1 mm × 10 mm and 4.1 mm × 12 mm; Institut Straumann AG) (Fig.6A and 6B). The distal implant at the left mandibular first molar region did not reach pre-determined insertion torque of 35 Ncm and was excluded from the immediate loading procedure. The auto-polymerizing acrylic resin (Jet Tooth Shade Acrylic; Lang Dental) was used to connect the interim abutments (Regular Neck, Temporary post, bridge; Institut Straumann AG) and mandibular interim IFCD. The mandibular interim ICFDP was finished and polished in the laboratory and secured to the dental implants under the torque of 15 Ncm. A maxillary interim RCD was relined with soft reliner (Coe-Soft; GC America) in the centric occlusion position (Fig.6C).

After 12 weeks of post-operative observation (Fig.6D), the patient was scheduled for the subsequent appointments for the fabrication of a definitive maxillary RCD and a mandibular IFCD. After obtaining the definitive polyvinyl siloxane impressions (Virtual XD Heavy Body and Extra Light Body; Ivoclar Vivadent Inc), the facebow and maxillomandibular relation record were used to articulate the maxillary and mandibular definitive casts on an articulator (Stratos 300; Ivoclar Vivadent Inc). A trial insertion was completed to confirm the desired esthetic and functional outcomes, and the diagnostic tooth arrangements were sent to a dental laboratory (Roy Dental Laboratory) for the mandibular CAD-CAM titanium framework (DWOS; Dental Wings Inc). The autopolymerizing injection-molded acrylic resin (Ivobase High Impact; Ivoclar Vivadent Inc) was used to process the maxillary and mandibular definitive prostheses. The complete finished and polished definitive prostheses were returned to the clinicians for the insertion. The patient was instructed to follow a home care regimen and scheduled for periodic maintenance appointments at six-month intervals for two years (Fig.7A, 7B, and 7C).

DISCUSSION:

A pre-operative prediction of a post-operative facial profile and prosthetic treatment outcome could be challenging to verify and achieve in a dental laboratory, especially under the circumstances in which the remaining dentition cannot be used as references for the diagnostic tooth arrangement. A digital process of using a 3D software program (Dolphin 3D Surgery) to simulate a patient's post-operative prosthetic treatment outcome was described in this clinical report. The integrated surgical and prosthetic treatment plan and prediction of the post-operative prosthetic treatment outcome visualization in a virtual 3D patient serve as a powerful diagnostic, treatment planning, communication, and education tool among dental clinicians, technicians, and patients. The use of CAD-CAM surgical templates and dental prostheses can facilitate accurate translation of a virtual treatment plan into clinical procedures. Although post-operative outcome predictions have been commonly utilized for orthognathic surgery,[14-16] the 3D prediction of a post-operative facial profile from the dental prostheses proposed in this clinical report can further expand the usage of 3D simulation software programs in a prosthodontics application.

The first limitation with the proposed digital process was that two sets of CBCT imaging were needed to compose a virtual 3D patient with realistic facial soft tissue at an exaggerated smile view. In the first set of CBCT imaging, a cotton roll and a plastic retractor were used to create air space separation around the remaining dentition and surrounding intraoral soft tissue for clear visualization of regions of interest in the s-CAIS planning process. The second set of low effective dosage, large FOV CBCT imaging was used to create an extraoral facial soft tissue profile at an exaggerated smile view.[11,21] Although two different CBCT imaging units were used in this report, clinicians may utilize available equipment in their practices. The important selection criteria are that the first scan should provide clear and sufficient 3D volumetric data for prosthetically-driven s-CAIS planning. The second scan should provide a large FOV to capture an adequate amount of the patient's facial profile for the esthetic assessment and facial simulation. Also, the second scan should only possess a low effective dose to decrease the radiation exposure for the patient. Nevertheless, patients should understand the risks of additional radiation exposure (74 μSv for the second CBCT imaging, which was equivalent to nine days of natural background exposure)[21] and should be provided with proper protection during all CBCT imaging procedures.

Although different laser and optical-based surface imaging technologies could capture surface texture and color of extraoral facial soft tissue, these scanners may be resource-prohibitive for dental clinicians. In addition, during the data registration process, the constant anatomic landmarks are essential to formulate an accurate 3D virtual patient. If a surface scanner was used to capture the patient's facial profile, only the facial soft tissue landmarks and remaining dentition could be used to register CBCT volumetric and surface scan datasets. These anatomic landmarks may not be adequate to register all datasets correctly, especially in a clinical condition in which the patient has a low smile line with minimal remaining dentition exposure at an exaggerated smile view. The second set of CBCT imaging was used in this report to capture the patient's soft tissue profile, and the underlying craniofacial hard tissue was used as constant anatomic landmarks to register two sets of CBCT volumetric data.

During the diagnostic data acquisitions, such as CBCT imaging and clinical photographs, the patient's head position, facial expression, and maxillomandibular relationship should be consistent to ensure the accuracy of subsequent data registration procedures. Particularly, the second set of CBCT imaging was used to obtain the patient's facial profile, and great caution should be paid to ensure the patient smiled fully. Repeated radiographic exposure is not warranted if the required patient profile at an exaggerated smile view could not be obtained during the second set of CBCT imaging. Various commercial 3D simulation software programs are commonly used in maxillofacial surgery to provide a pre-operative prediction of post-operative facial profiles for the patient and clinician. Although some studies have shown that various 3D simulation software programs have topological errors of less than 2 mm,[14,16] the clinical application has not been validated for usage in the prosthetic outcome simulation. Future studies should be developed and focus on the 3D simulation software program's application in prosthodontics.

SUMMARY

This clinical report describes a digital process of using a 3D virtual patient and simulation software to estimate the patient's post-operative prosthetic treatment esthetic outcome.

LIST of ABBREVIATIONS

3D: 3-dimensional

s-CAIS: static computer-aided implant surgery

CAD-CAM: computer-aided design and computer-aided manufacturing

CBCT: cone beam computed tomography

OVD: occlusal vertical dimension

RCD: removable complete denture

IFCD: implant-supported fixed complete denture

CO: centric occlusion

FOV: filed of view

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Captions to figures

Figure 1. A, Pre-treatment panoramic radiograph. B, Occlusal splint was used to assess desired centric occlusion (CO) and occlusal vertical dimension (OVD) increase.

Figure 2. Digital diagnostic data collection at pre-treatment condition. A, Intraoral scans at increased occlusal vertical dimension (OVD). B, Extraoral digital photographs demonstrating patient’s exaggerated smile and facial profile.

Figure 3. A, Static 3-dimensional (3D) virtual patient with realistic facial soft tissue at exaggerated smile. B, Virtual diagnostic tooth arrangement.

Figure 4. Lateral views of virtual patient demonstrating facial profiles. A, Pre-treatment facial profile. B, Virtual simulation of prosthetic outcome based on the diagnostic tooth arrangement.

Figure 5. A, Prosthetically-driven plan for static computer-aided implant surgery (s-CAIS). B, Computer-aided design and computer-aided manufacturing (CAD-CAM) surgical templates. C, CAD-CAM maxillary interim removable complete denture (RCD) and mandibular interim implant-supported fixed complete denture (IFCD).

Figure 6. A, Surgical template fitted over alveolar ridge to complete planned osseous recontouring. B, Implants placed under the guidance of surgical template. C, Maxillary and mandibular interim prostheses. Distal implant at left side was excluded from interim prosthesis due to insufficient primary stability. D, Extraoral digital photographs demonstrating facial prosthetic outcome from interim prostheses.

Figure 7. Two-years post-treatment outcomes. A, Frontal view of definitive prostheses. B, Post-treatment panoramic radiograph. C, Extraoral digital photographs demonstrating facial prosthetic outcome from definitive prostheses.

Figure 1A

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Figure 1B

Figure 2A

Figure 2B

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Figure 3A

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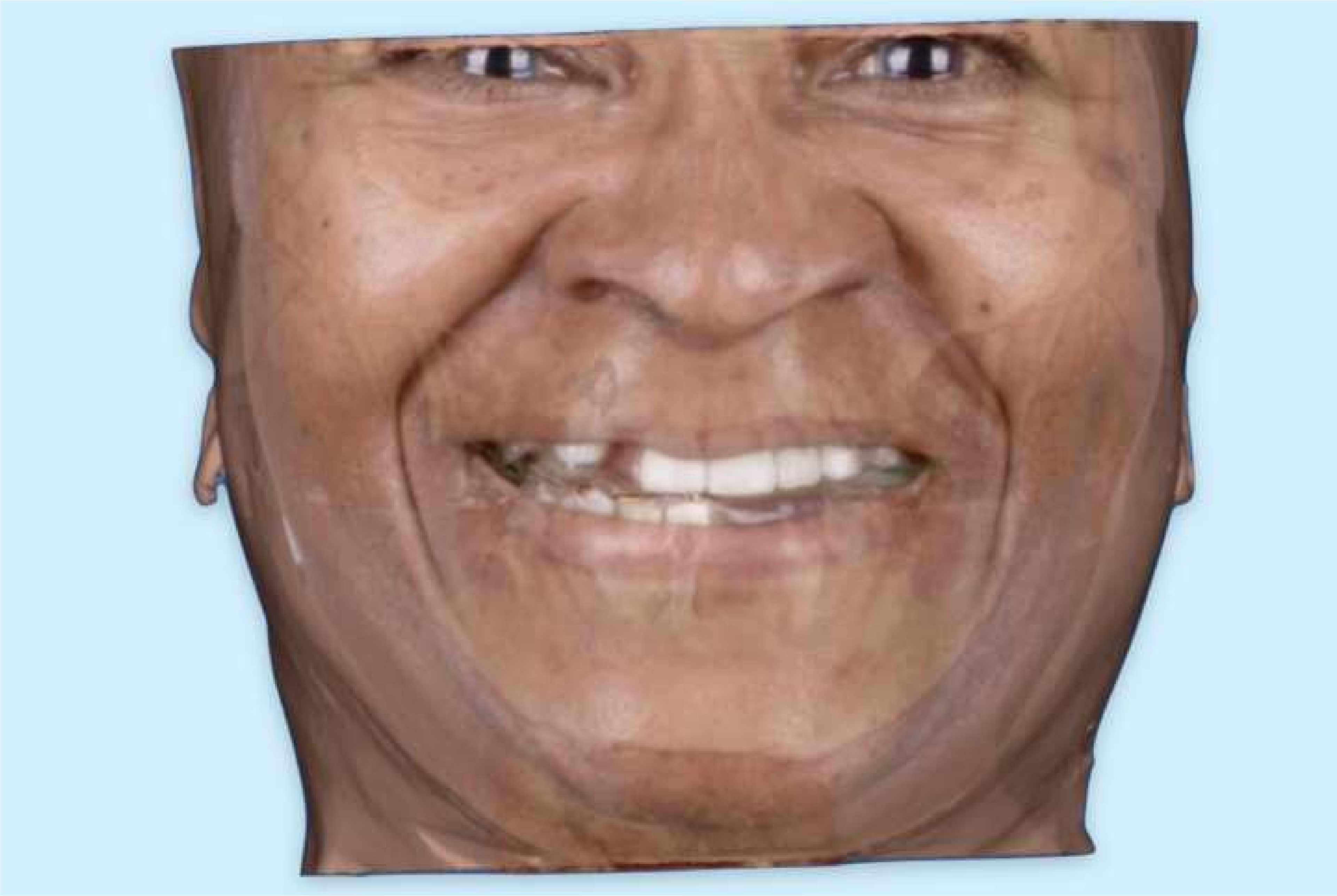

Figure 3B

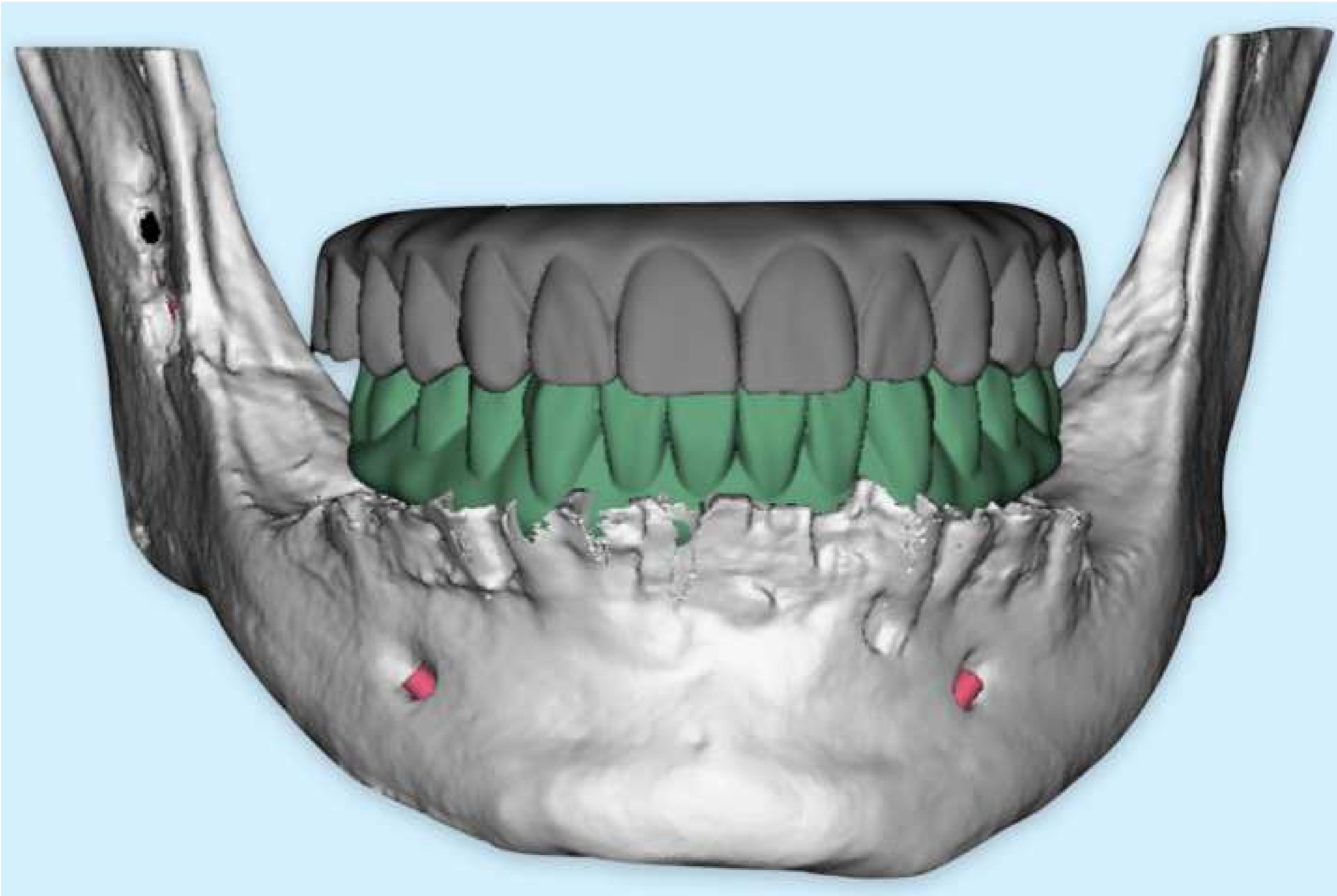

Figure 4A

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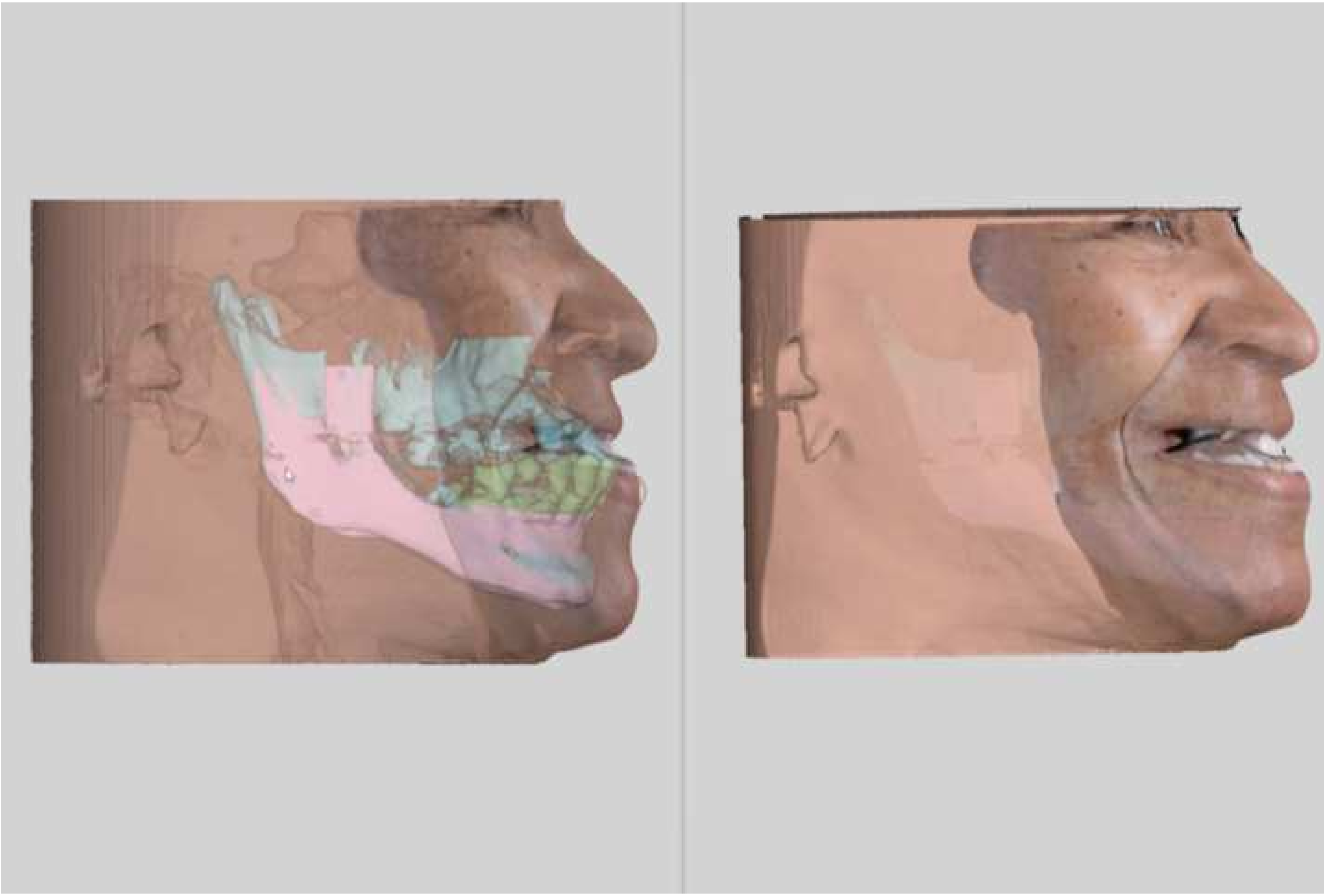

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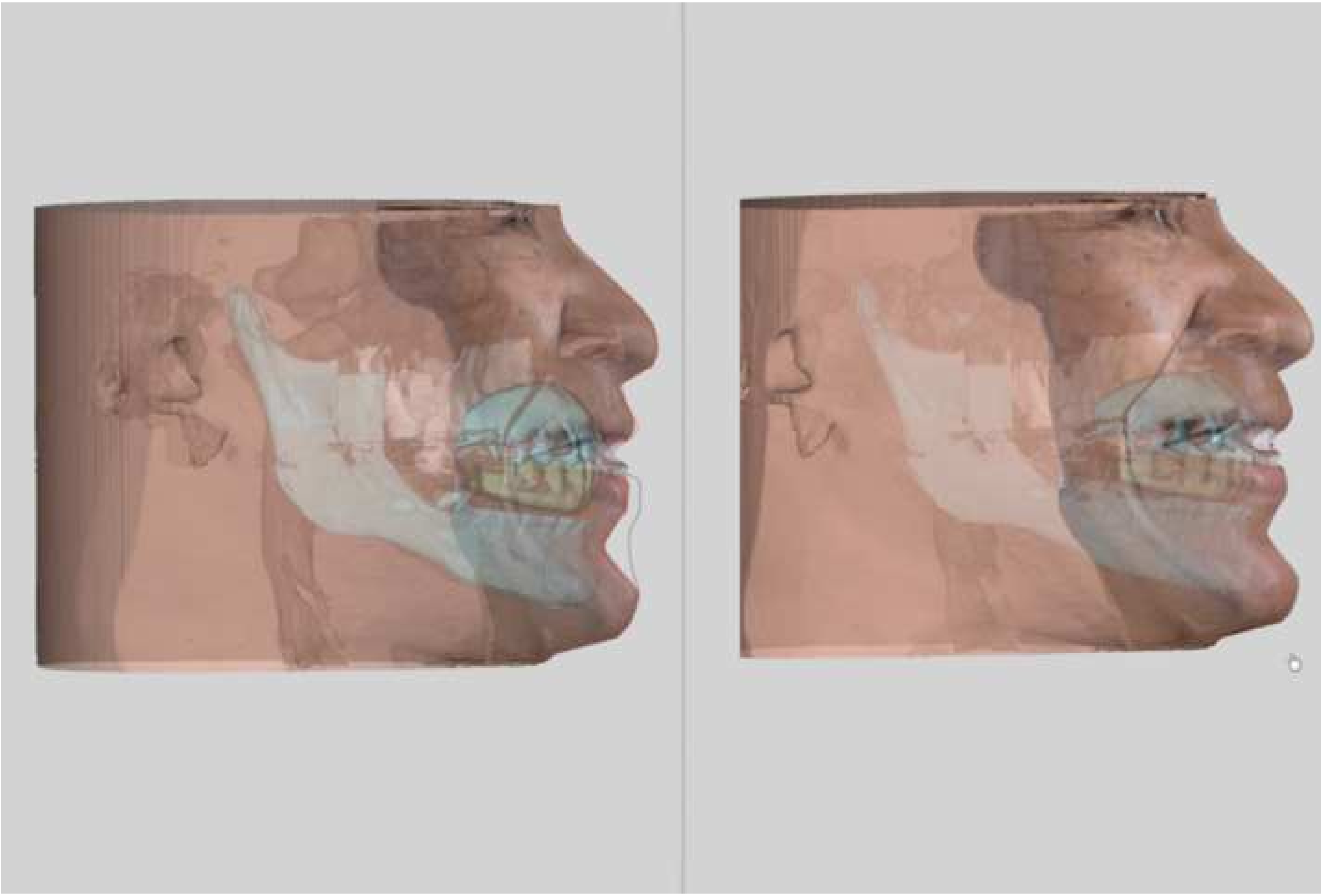

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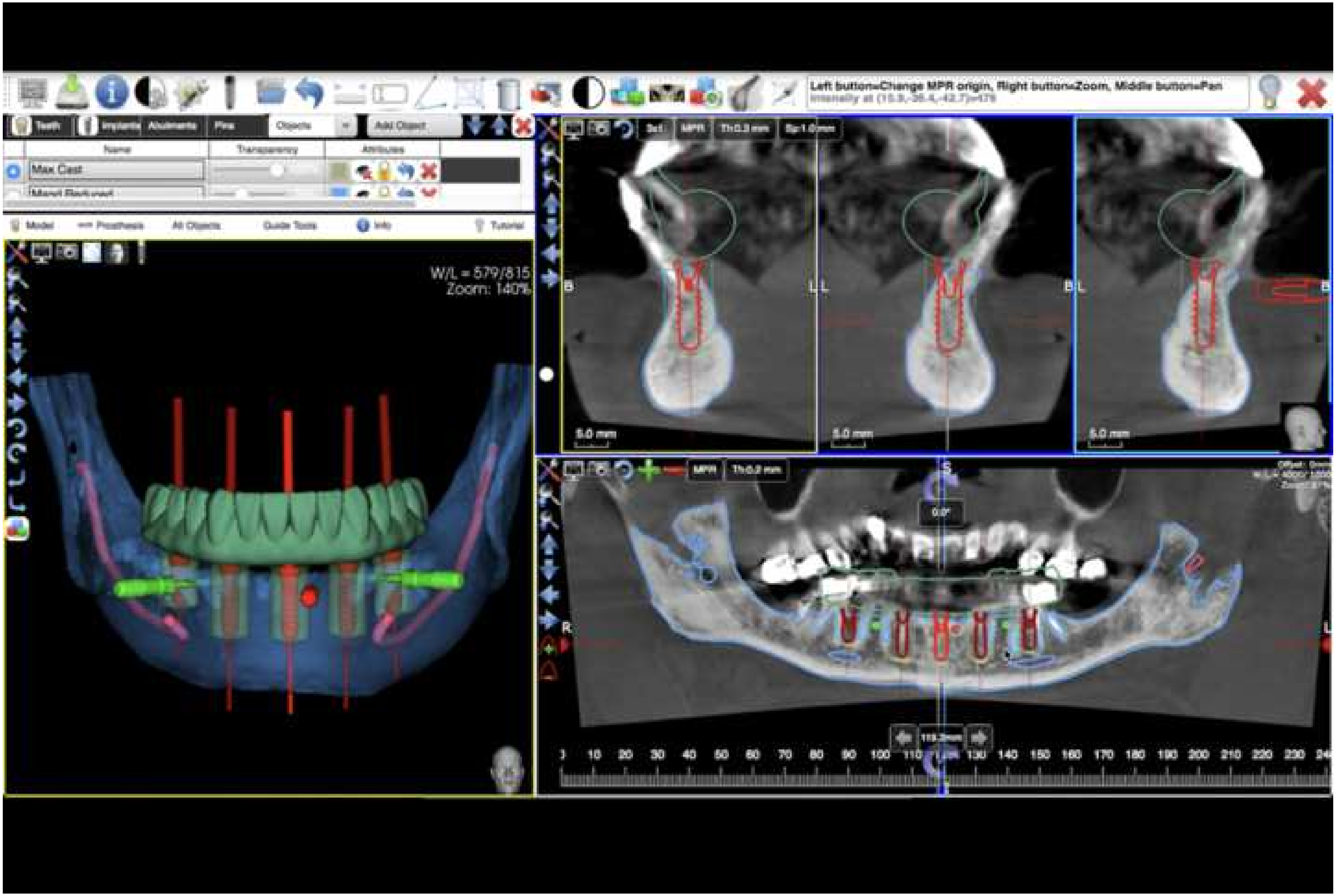

Figure 5B

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Figure 5C

Figure 6A

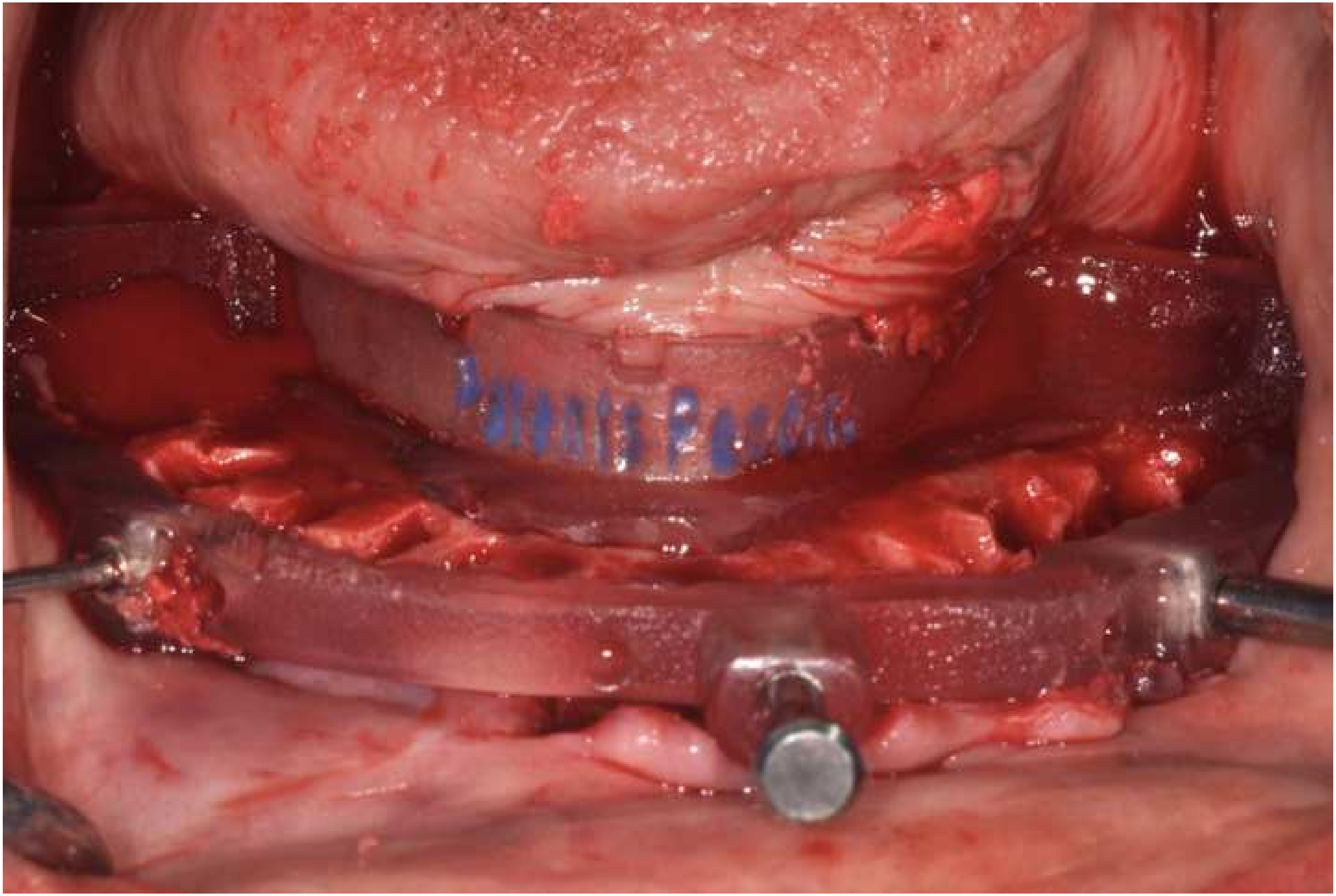

Figure 6B

Figure 6C

Figure 6D

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Figure 7A

Figure 7B

Figure 7C

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