THE JOURNAL OF PROSTHETIC DENTISTRY

CLINICAL REPORT

Integrating hinge axis approximation and the virtual facial simulation of prosthetic outcomes for treatment with CAD-CAM immediate dentures: A clinical report of a patient with microstomia

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ABSTRACT

This clinical report describes a digital workflow using extraoral digital photographs and volumetric datasets from cone beam computed tomography (CBCT) imaging to create a 3-dimensional (3D), virtual patient with photorealistic appearance. In a patient with microstomia, hinge axis approximation, diagnostic casts simulating postextraction alveolar ridge profile, and facial simulation of prosthetic treatment outcome were completed in a 3D, virtual environment. The approach facilitated the diagnosis, communication, and patient acceptance of the treatment of maxillary and mandibular computer-aided design and computer-aided manufacturing (CAD-CAM) of immediate dentures at increased occlusal vertical dimension. (J Prosthet Dent 2018;119:879-86)

Centric relation (CR) is a repeatable maxillomandibular relationship in which the mandible is directed superiorly and anteriorly and is restricted to a rotary movement about the transverse horizontal axis.[1] The transverse horizontal axis is often referred to as the hinge axis and is an imaginary line around which the mandible may rotate within the sagittal plane.[1,2] When in CR, the early phase of mandibular opening is a pure hinge movement, rotating about this axis for up to 15 to 20 mm.[3] The theory of hinge axis has made it possible to modify the occlusal vertical dimension (OVD) on a semiadjustable articulator without changing the articulation of dental casts.[4-6] Different clinical methods are available to locate the hinge axis, including the kinematic and arbitrary methods.[7-9] Early studies have suggested that the arbitrarily selected axis reference points are mostly within a 5-mm radius of those kinematically located.[10-12] With some substantial individual variations, authors have proposed that the actual anatomic location of the hinge axis is within the condylar head (such as the center of condyle head),[3,13-15] and some investigators have supported the idea of a hinge axis located outside of the condyle (such as behind and below the condylar head).[16-18]

Creating a 3-dimensional (3D) virtual patient with photorealistic appearance has many medical and dental applications. It can improve diagnostic quality,[19,20] facilitate the preoperative surgical and prosthetic planning process,[21-23] improve the simulation and prediction of the surgical outcome,[24-26] and improve postoperative surgical evaluation.[27] To create such a 3D virtual patient, a series of imaging methods are required to obtain the digital data of the craniofacial hard tissue, intraoral dentition and surrounding soft tissue, and extraoral facial soft tissue surface.[20,21] Craniofacial hard tissue can be imaged by cone beam computed tomography (CBCT) and stored or transferred in the Digital Imaging and Communications in Medicine (DICOM)

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Figure 1. A, Extraoral pretreatment condition at smile position from mid-facial and right and left 45-degree views. B, First CBCT imaging was completed under retracted view with cotton rolls and plastic retractor. CBCT, cone beam computed tomography.

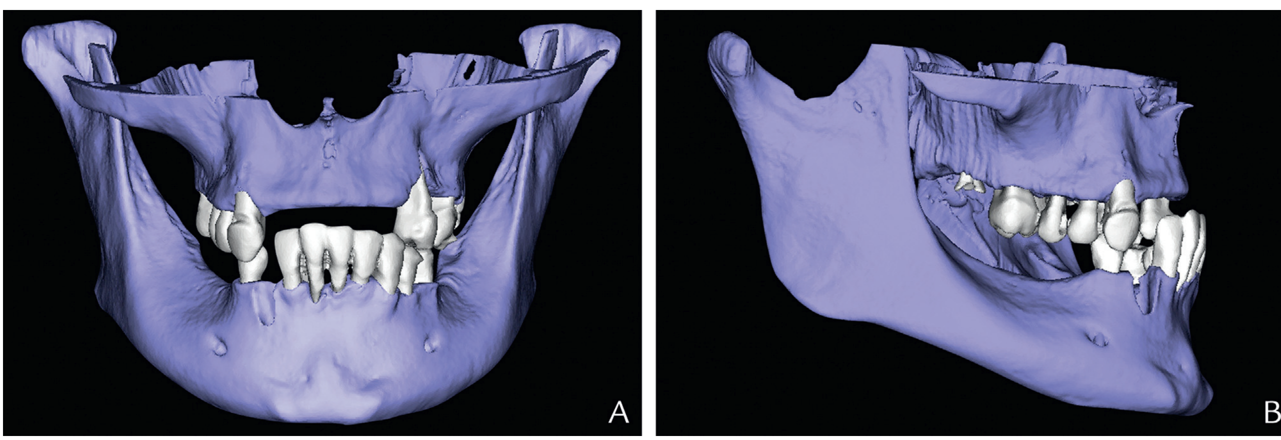

Figure 2. Craniofacial hard tissue and intraoral dentition segmented and identified from first CBCT volumetric data at patient's existing CO position and OVD. A, Frontal view. B, Lateral view. CBCT, cone beam computed tomography; CO, centric occlusion; OVD, occlusal vertical dimension.

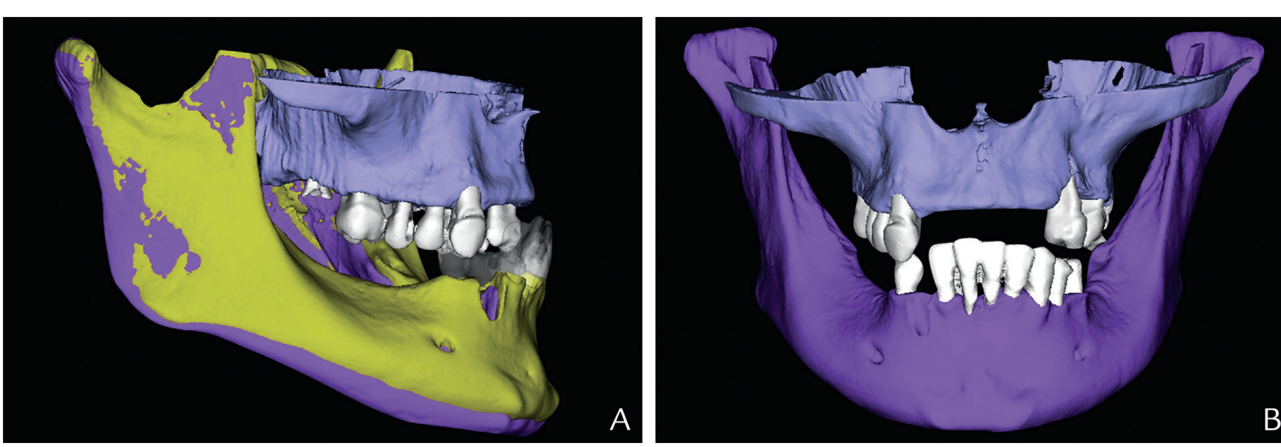

Figure 3. Using center of condyle head as approximated hinge axis, segmented mandible rotated clockwise to increase OVD by 3 mm in anterior region. A, Lateral view. Yellow indicates original position of mandible, and purple indicates rotated position of mandible. B, Frontal view. Craniofacial hard tissue and intraoral dentition at increased OVD position. OVD, occlusal vertical dimension.

file format.[28,29] The CBCT result has limited contrast resolution for soft tissue and is not capable of recording the surface texture and color of extraoral facial soft tissue.[30] Extraoral facial surface imaging methods, such as 2D photography[19] and 3D laser scanning or stereophotogrammetry,[31-34] can be used to obtain and

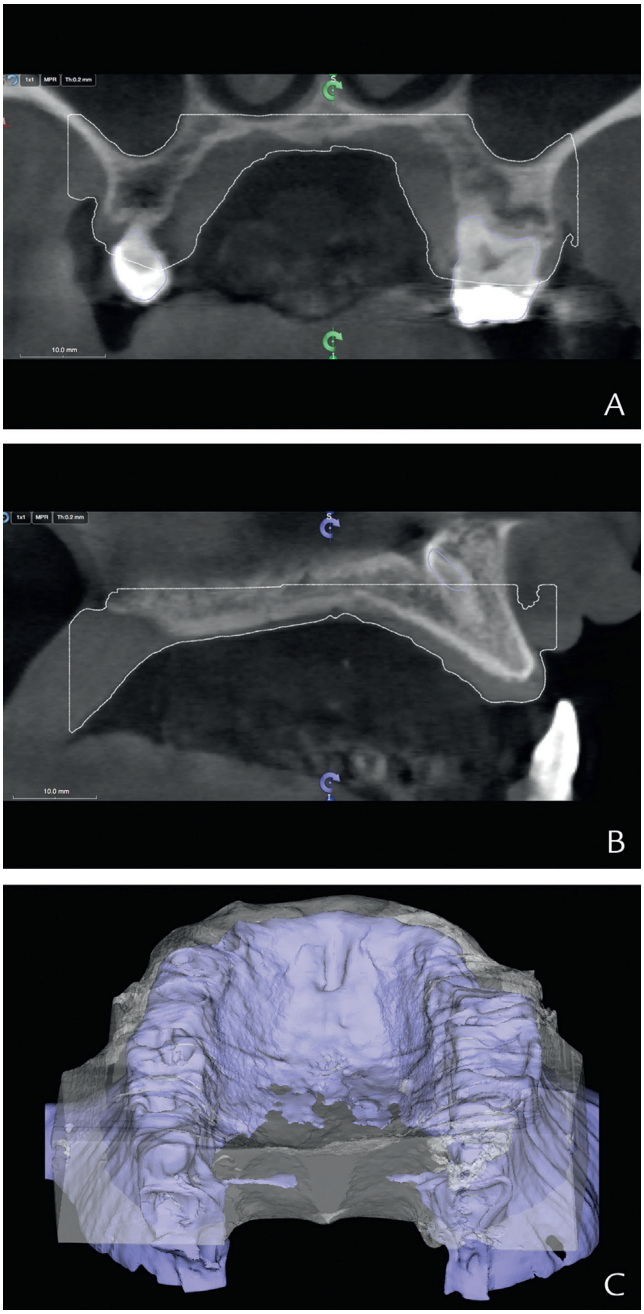

Figure 4. Identification of soft tissue outline from CBCT volumetric data. A, Coronal view. B, Sagittal view. C, Maxillary virtual cast with simulated postextraction alveolar ridge profile shown in transparent layer for visual comparison with underlying hard tissue. CBCT, cone beam computed tomography.

superimpose the facial surface texture data onto the 3D craniofacial volumetric rendering (digital model reconstructed from CBCT volumetric data) and create a 3D virtual patient with photorealistic appearance.

Microstomia or limited mouth opening is often a consequence of postoperative injury, surgical treatment of cancers, scleroderma, mucous fibrosis, trismus, cleft lips, or burns.[35-38] The prosthodontic procedures required for fabricating dental prostheses, such as impression making, recording of the maxillomandibular relationship, and trial insertion of the tooth arrangements, are all complicated by restricted mouth opening.[35-38]

This clinical report describes a digital workflow to treat a patient with microstomia with maxillary and mandibular computer-aided design and computer-aided manufacturing (CAD-CAM) immediate dentures.[39-42] Hinge axis approximation, increase of OVD, and soft tissue digital cast creation were completed in the 3D craniofacial volumetric rendering, and the desired prosthetic treatment outcome was simulated in a 3D virtual patient.

CLINICAL REPORT

A 30-year-old white woman presented to the University of Louisville School of Dentistry, Advanced Education Program in Prosthodontics Clinic, with microstomia resulting from second- to third-degree burns received in a housefire 3 years previously. The remaining dentition was diagnosed with generalized chronic severe periodontitis and dental caries. The clinical examination also revealed a loss of OVD of approximately 3 mm. The patient consented to the maxillary and mandibular CAD-CAM immediate dentures because her current financial situation did not permit dental implants. The patient also expressed a wish for maxillary and mandibular implant-retained overdentures in the future. She expressed the desire to have an opportunity to confirm the esthetics of the immediate dentures before extraction and consented to CBCT imaging for preoperative diagnosis and assessment.

A clinical examination was performed to confirm that a stable maxillomandibular relationship could be achieved in the centric occlusion (CO) position. An interocclusal record was made with a polyvinyl siloxane registration material (Futar D; Kettenbach GmbH & Co) in the CO position at the patient's existing OVD. Using the CO record to maintain the maxillomandibular relationship, digital extraoral photographs were made of an exaggerated smile from the mid-facial and right and left 45-degree views (Fig. 1A). The photographs were saved in the Joint Photographic Experts Group (JPEG) file format.

During the CBCT imaging (3D Accuitomo 170; J Morita USA), the CO record was used again to maintain a stable maxillomandibular relationship, and cotton rolls and a plastic retractor (Free Access II cheek and lip retractor, small; J Morita USA) were used to isolate the palate and buccal and lingual vestibules from the remaining intraoral structures (Fig. 1B). The patient was imaged under this retracted view using the following

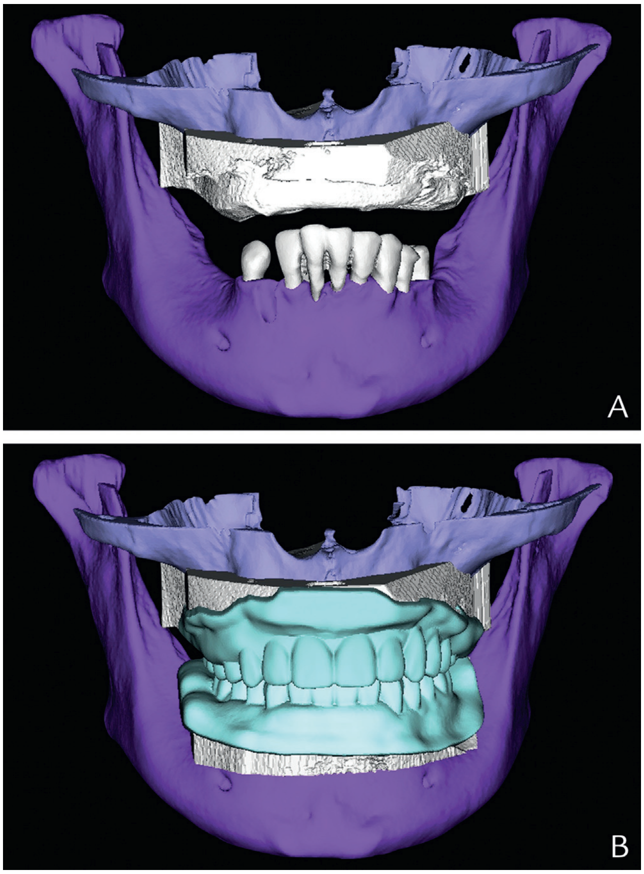

Figure 5. Virtual casts with simulated postextraction alveolar ridge profile, diagnostic tooth arrangement, and denture base recreated. A, Maxillary virtual cast. B, Complete maxillary and mandibular virtual prosthesis design.

exposure parameters: 90 KV, 5 mA, 360-degree High Fidelity mode, 30.8 second acquisition time, voxel size of 0.25 mm, effective dose of 378 μSv, and field of view (FOV) of 170×120 mm (3D Accuitomo170; J. Morita USA). The volumetric data generated from this retracted CBCT imaging was labeled DICOM #1.

The patient was then scanned a second time, without cotton rolls and plastic retractor, using a different CBCT unit (i-CAT Next Generation; Imaging Sciences Intl) with a larger FOV and lower effective dose scanning protocol. During the second CBCT acquisition, the patient was imaged with an exaggerated smile view with the following exposure parameters: 120 KV, 5 mA, 360-degrees, 8.9 seconds acquisition time, voxel size of 0.4 mm, effective dose of 74 μSv, and FOV of 230×172 mm (i-CAT Next Generation; Imaging Sciences Intl). The volumetric data generated from this smile CBCT image was labeled DICOM #2. Two sets of DICOM files (#1 and #2) and 3 digital extraoral photographs showing exaggerated smiles (mid-facial and right and left 45-degree views in JPEG file format) were sent to a dental laboratory (NDX nSequence). Segmentation of the CBCT

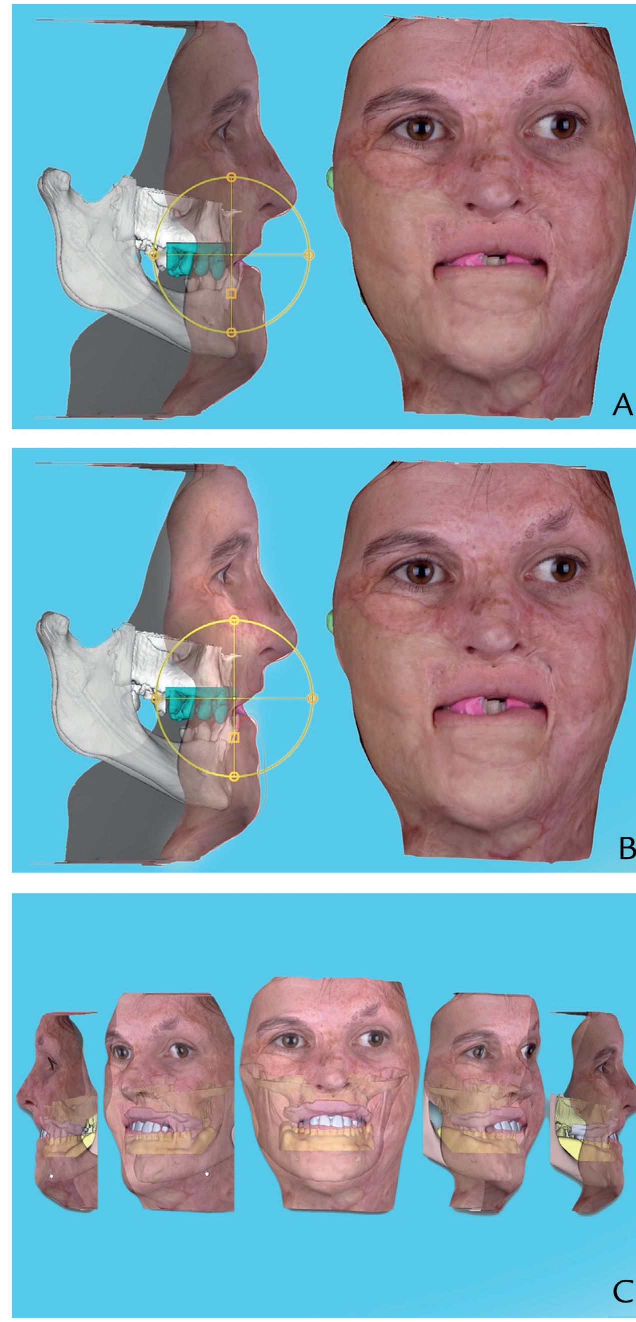

Figure 6. A, 3-dimensional virtual patient of photorealistic appearance at patient's original OVD. B, 3D virtual patient at increased OVD. C, Facial simulation completed in 3D virtual patient at increased OVD and complete maxillary and mandibular virtual prosthesis design in place. OVD, occlusal vertical dimension.

volumes was performed in a 3D medical image processing software (Mimics; Materialise).

From the DICOM file #1, the craniofacial hard tissue and intraoral dentition were segmented and identified (Fig. 2). Using CAD software (Geomagic Freeform; 3D Systems), the segmented mandible was rotated clockwise about the center of the condyle head (approximated

Figure 7. Optional CAD-CAM diagnostic casts and immediate dentures. CAD-CAM, computer-aided design and computer-aided manufacturing.

hinge axis) until the OVD was increased by 3 mm in the anterior region (Fig. 3).[6] From the axial, coronal (Fig. 4A), and sagittal (Fig. 4B) views of the CBCT volumetric data, the dental technician also identified and traced the soft tissue outline to create virtual maxillary and mandibular soft tissue casts. During the soft tissue outline tracings, the postextraction alveolar ridge profiles at the existing dentition area were estimated based on the soft tissue thickness at the adjacent area (Fig. 4C). Maxillary and mandibular virtual casts with simulated postextraction alveolar ridge profiles were then created from the segmented volumetric data (Fig. 5A).[43] A virtual diagnostic tooth arrangement and denture base were created on these virtual casts. Using existing dentition and clinical photographs as references, bilateral, simultaneous occlusal contacts were achieved in the virtual diagnostic tooth arrangement at the CO position (Fig. 5B). The dynamic occlusal contact at the eccentric position was to be confirmed during the surgical appointment.[43]

From DICOM file #2, the extraoral facial soft tissue surface was rendered using 3D simulation software (Dolphin 3D Surgery; Dolphin Imaging & Management Solutions). The digital extraoral photographs made with the patient's exaggerated smile were registered and wrapped to the surface digital volume of the extraoral facial soft tissue to create a 3D virtual patient with photorealistic appearance (at the patient's original OVD) (Fig. 6A). A second 3D virtual patient was also created at the 3-mm increased OVD in the 3D simulation software (Fig. 6B). The complete maxillary and mandibular virtual diagnostic tooth arrangement and denture base were registered to the second 3D virtual patient. The new extraoral facial soft profile was simulated in the software based on the increased OVD and the virtual prosthesis designs (Fig. 6C). After obtaining approvals from the clinicians (K.M.K., B.T.H., and W.S.L.) and the patient, the dental technician completed the maxillary and mandibular CAD-CAM immediate dentures.[43] Optional

Figure 8. A, CAD-CAM maxillary and mandibular immediate dentures relined with soft liner. B, Smile presentation of immediate dentures. CAD-CAM, computer-aided design and computer-aided manufacturing.

diagnostic casts were manufactured additively for the preoperative evaluation (Fig. 7).

The remaining teeth were removed under local anesthesia. The maxillary and mandibular CAD-CAM immediate dentures were relined with interim soft liner (COESoft; GC America) (Fig. 8A). The eccentric occlusion was adjusted intraorally on the relined immediate dentures to achieve group function with multiple working-side occlusal contacts during lateral movements. The patient was satisfied with the esthetic and functional outcomes and was scheduled for subsequent treatment appointments (Fig. 8B). No postinsertion complication has been observed associated with the increased OVD. The maxillary and mandibular CAD-CAM immediate dentures were scheduled to be relined with traditional laboratory procedures upon the maturation of the postextraction alveolar ridge. The clinical and laboratory procedures are presented in Figure 9 to summarize the digital workflow used in this clinical report.

DISCUSSION

This clinical report describes a digital workflow for fabricating CAD-CAM immediate dentures for a patient

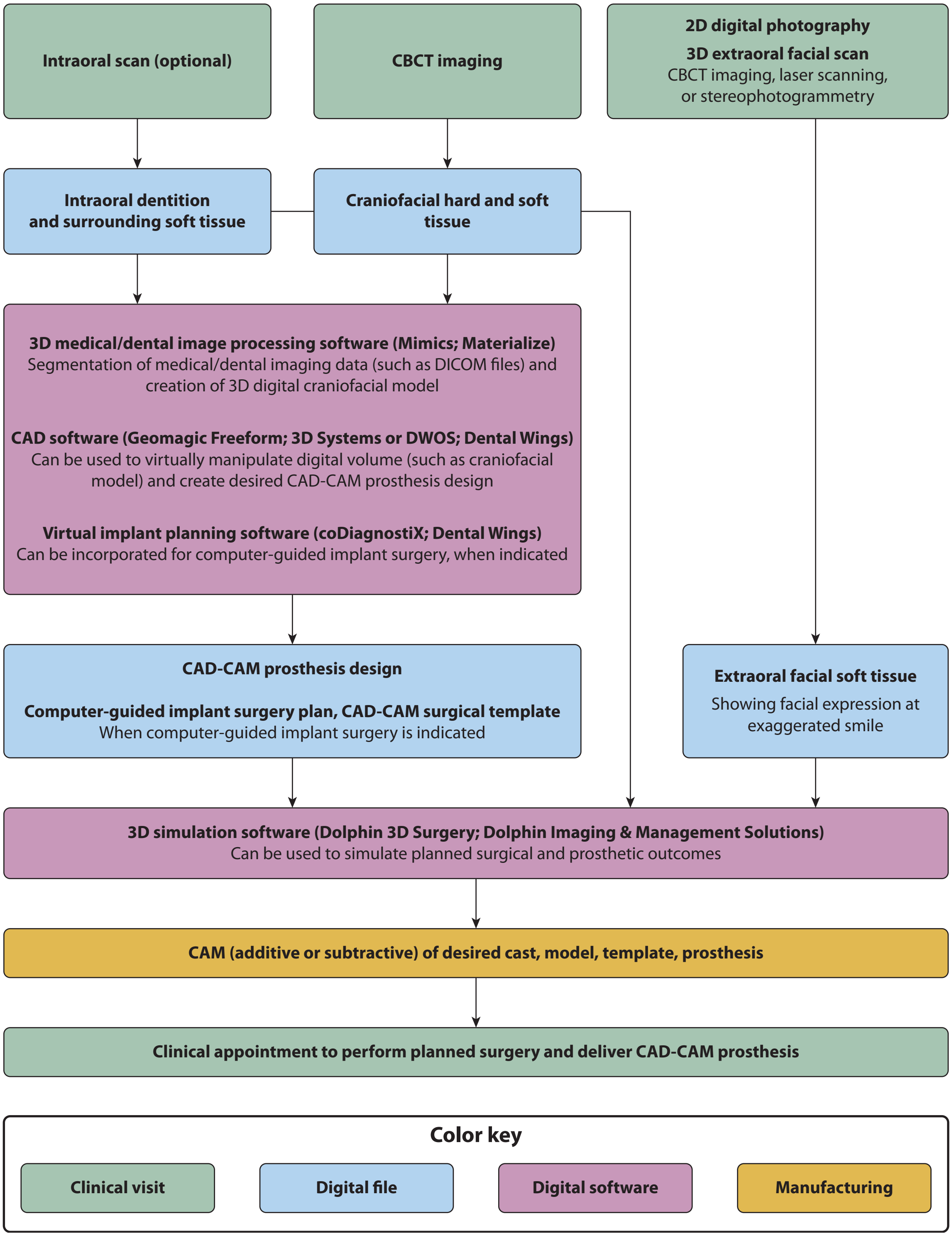

Figure 9. Digital workflow facially-driven edentulous prosthetic planning and simulation process for CAD-CAM prosthesis.

with microstomia. All the required diagnostic data (CBCT imaging and extraoral photographs) were collected in a single clinical visit. An approximate hinge axis was used to increase the OVD of the 3D virtual patient, and 3D simulation software was used to estimate the esthetic outcome of the prosthetic treatment in this virtual patient. The conventional methods of fabricating immediate dentures can involve multiple clinical visits and laboratory procedures. In a patient with microstomia, these prosthodontic procedures are all complicated by restricted mouth opening.[35-38] This digital workflow provided a comfortable and time-saving alternative for treating a patient with microstomia with CAD-CAM immediate dentures in a single clinical diagnostic visit. Furthermore, the esthetic outcome of immediate dentures fabricated using conventional methods could be difficult to verify and achieve in the dental laboratory, especially when the remaining dentition presents a nonoptimal cant of the midline and incisal plane.[41] This proposed digital workflow allows the preoperative simulation of a desired prosthetic esthetic outcome in a 3D virtual patient.

The proposed digital workflow has a few limitations which may limit its clinical application. The first set of CBCT images was used as a diagnostic tool to satisfy the patient's wish to explore future possibilities for maxillary and mandibular implant-retained overdentures. Cotton rolls and a plastic retractor were used to isolate the palate, buccal, and lingual vestibules and remaining dentition from the tongue and cheek. This process allowed for clearer visualization of the remaining dentition and intraoral soft tissue profile for the diagnosis, treatment planning, and creation of the virtual soft tissue cast. Although the soft tissue tracings on these DICOM files were used to create virtual soft tissue casts as denture-bearing areas for the CAD-CAM immediate dentures, their accuracy should be confirmed by future studies. In this clinical report, the resulting immediate dentures were relined with interim soft liner to achieve adaptation and proper denture extension with the postextraction alveolar ridge.

Retraction with cotton rolls and a plastic retractor distorted the facial profile during the first CBCT imaging and made it infeasible to use the same DICOM dataset for the preoperative prosthetic facial simulation. The second CBCT imaging was made to create a rendering of the extraoral facial soft tissue surface of the patient's exaggerated smile. The digital extraoral photographs were wrapped at this digital volume to create a 3D virtual patient with photorealistic appearance.[19,31,33] Although different medical/dental 3D surface scanners can be used to create a similar 3D virtual patient,[20-22,31-34] these scanners may be too expensive for many dentists.[32] This report presented a readily available CBCT imaging unit as an alternative for creating a 3D virtual patient for dental clinicians. However, the patient should be made aware of the additional radiation exposure (74 μSv for the second CBCT imaging, which was equivalent to 9 days of background exposure)[44] and associated cost and provided with proper protection during the entire imaging process.[29] Furthermore, a CBCT imaging unit and protocol with a lower effective dose should be considered to decrease the radiation risk for the patient.[29]

Additional precautions should be taken during diagnostic data acquisition (CBCT imaging and extraoral photographs) to ensure the patient's head position and expression are consistent in order to enhance the accuracy of the data acquisition and registration procedures.[22,23,31] In this clinical report, the patient did not wish to smile fully because of missing maxillary anterior teeth. Differences in facial expression throughout the treatment may affect the predictivity of the esthetic simulation. In this instance, the patient was more comfortable demonstrating an exaggerated smile after the insertion of CAD-CAM immediate dentures, and more maxillary anterior teeth were revealed in the actual treatment outcome than in the 3D simulation software. However, the patient was made aware of this limitation during the treatment-planning phase and was satisfied with the clinical outcome.

SUMMARY

This clinical report describes a digital workflow using a 3D virtual patient to provide maxillary and mandibular CAD-CAM immediate dentures for a patient with microstomia.

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Acknowledgments
The authors thank NDX nSequence (Reno, NV) for their assistance with this clinical treatment.