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DENTAL TECHNIQUE

Jaw motion tracking with open-source tools: A dental technique

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ABSTRACT

A method is described for the cost-effective tracking of mandibular movements using an open-source software program (Blender v. 4.3; Blender Foundation) in combination with video recordings and intraoral scans. Semispherical resin markers serve as reference points, synchronizing virtual cast movements from intraoral scanning. These data can be integrated into a CAD software program with facial scanning and cone beam computed tomography. (J Prosthet Dent xxxx;xxx:xxx-xxx)

The accurate tracking and analysis of mandibular movements can improve diagnostic capabilities and enable clinicians to design treatments tailored to individual functional dynamics.[1,2] Several jaw-tracking systems have been developed using technologies such as ultrasonic, infrared, and digital cameras, and axiography.[3] Currently, a scientific consensus on the best method of tracking mandibular movements is lacking.[4–7] Additionally, algorithms driven by artificial intelligence can simulate occlusion and articulation.[8,9] Intraoral and facial scans can be integrated with jaw-tracking systems to provide static and dynamic occlusal data[10,11]; however, they face challenges such as restricted ranges of motion and the need for software program improvements to optimize real-time tracking.[12–14] This approach marks the rise of the 4-dimensional virtual patient, which incorporates jaw-tracking systems into treatment planning, to align with the actual patient dynamics.[7,15–17] Despite their potential, these digital technologies remain expensive, limiting widespread adoption, especially for dental practices with restricted resources. A possible solution may be a target tracking system that combines a smart device with an open-source software program like Blender (Blender Foundation) developed for 3-dimensional (3D) modeling, animation, rendering, and motion tracking.[18,19] Because of its flexibility and cost-efficiency, Blender has been widely used in industries such as animation, game development, and scientific visualization.[18,19] Its motion tracking capabilities allow for the integration of video-recorded motion data with 3D virtual casts, facilitating the analysis of articular kinematics without the need for expensive equipment.[18,19] Moreover, Blender supports motion tracking and CAD dental functions through systems like BDental 4D, an external open-source add-on, and Blender for Dental, a paid plug-in. However, its motion tracking feature still lacks validation and involves additional costs and setup complexity, requiring extraoral reference markers like 3D printed boards or facebows.[17]

This article describes a method that integrates video recordings of mandibular movements with virtual casts from intraoral scanning using a free, open-source, software program.

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TECHNIQUE

1. Fix 8 semi-spherical markers made of light-polymerizing flowable composite resin (LC Block-Out; Ultradent Products, Inc), approximately 2 mm in diameter, on the labial surfaces of the anterior teeth (Fig. 1A). Do not etch or bond the enamel for straightforward removal after the procedure.
2. Record the patient's closure path, protrusive, and lateral mandibular movements with a smartphone with a 60-fps camera in 4 K resolution (Xiaomi 11T Pro; Xiaomi Inc). Capture the video in landscape mode, hand-held, with the Android Camera app, by using the built-in stabilization and distortion correction features. Place the smartphone at approximately 30 cm focal distance, ensuring that only the mouth movements are captured. Use lip retractors (OptiView; Kerr Corp) to enhance visibility. Calibrate the lens with a focal length of 23 mm, aperture of f/1.9, and field of view of approximately 80 degrees. Export the video in Moving Picture Experts Group 4 (MP4) format.
3. Make optical scans of the patient's maxillary and mandibular teeth with the resin markers in place by using an intraoral scanner (Omnicam AF, SW 5.2.9; Dentsply Sirona Inc) (Fig. 1B).

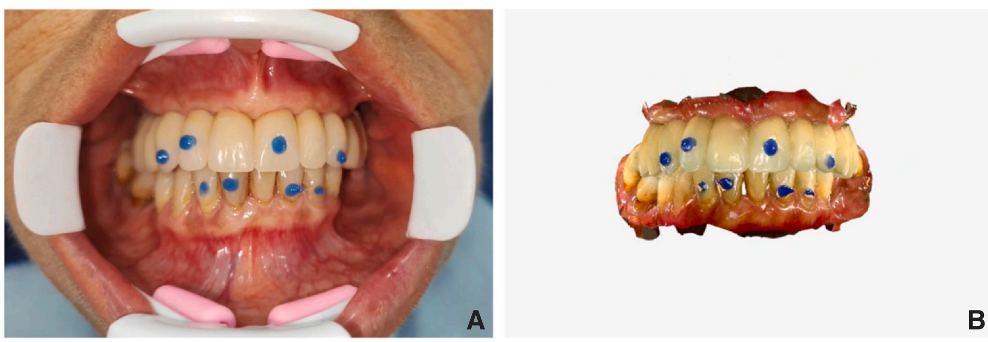

Figure 1. A, Reference markers placed on labial tooth surfaces. B, Intraoral scans (Omnicam AF v. 5.2.9; Dentsply Sirona Inc).

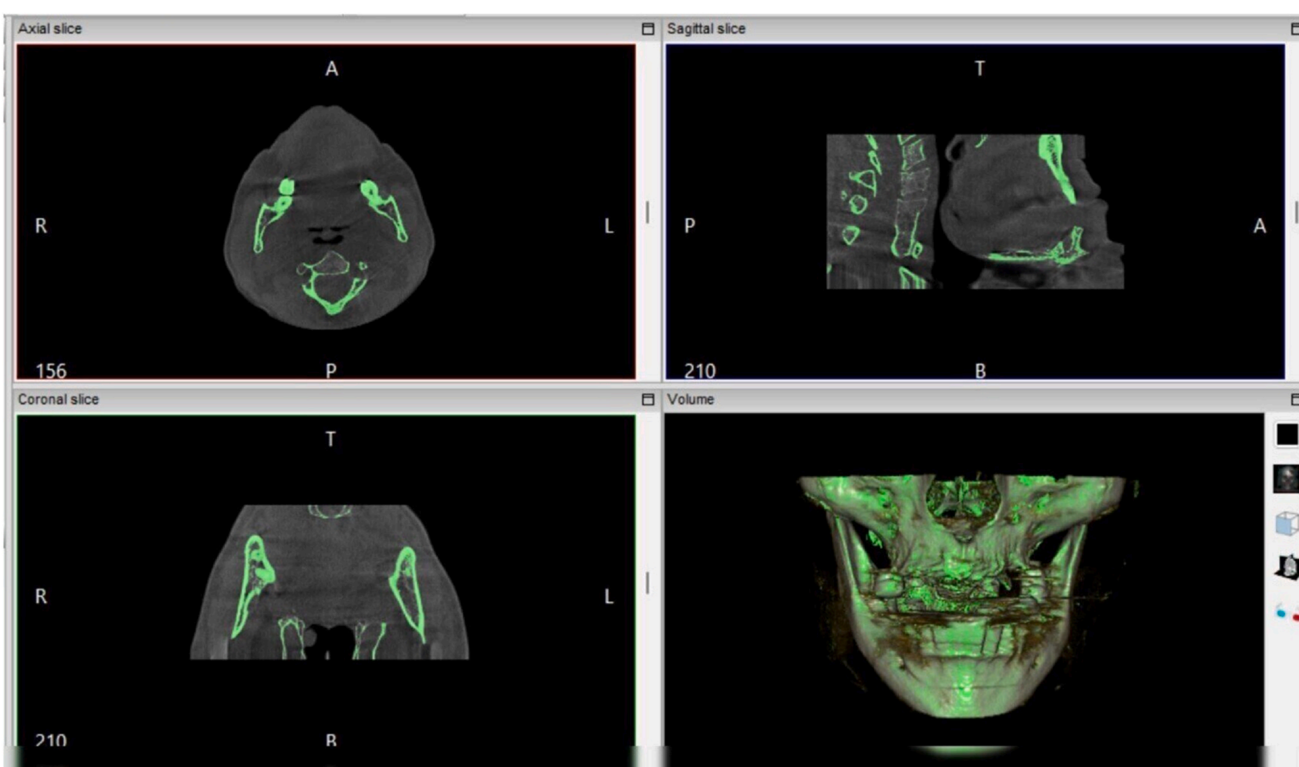

Figure 2. Conversion of DICOM to STL file format (Invesalius v. 3.1.1.; CTI Renato Archer). DICOM, digital imaging and communications in medicine file; STL, standard tessellation language.

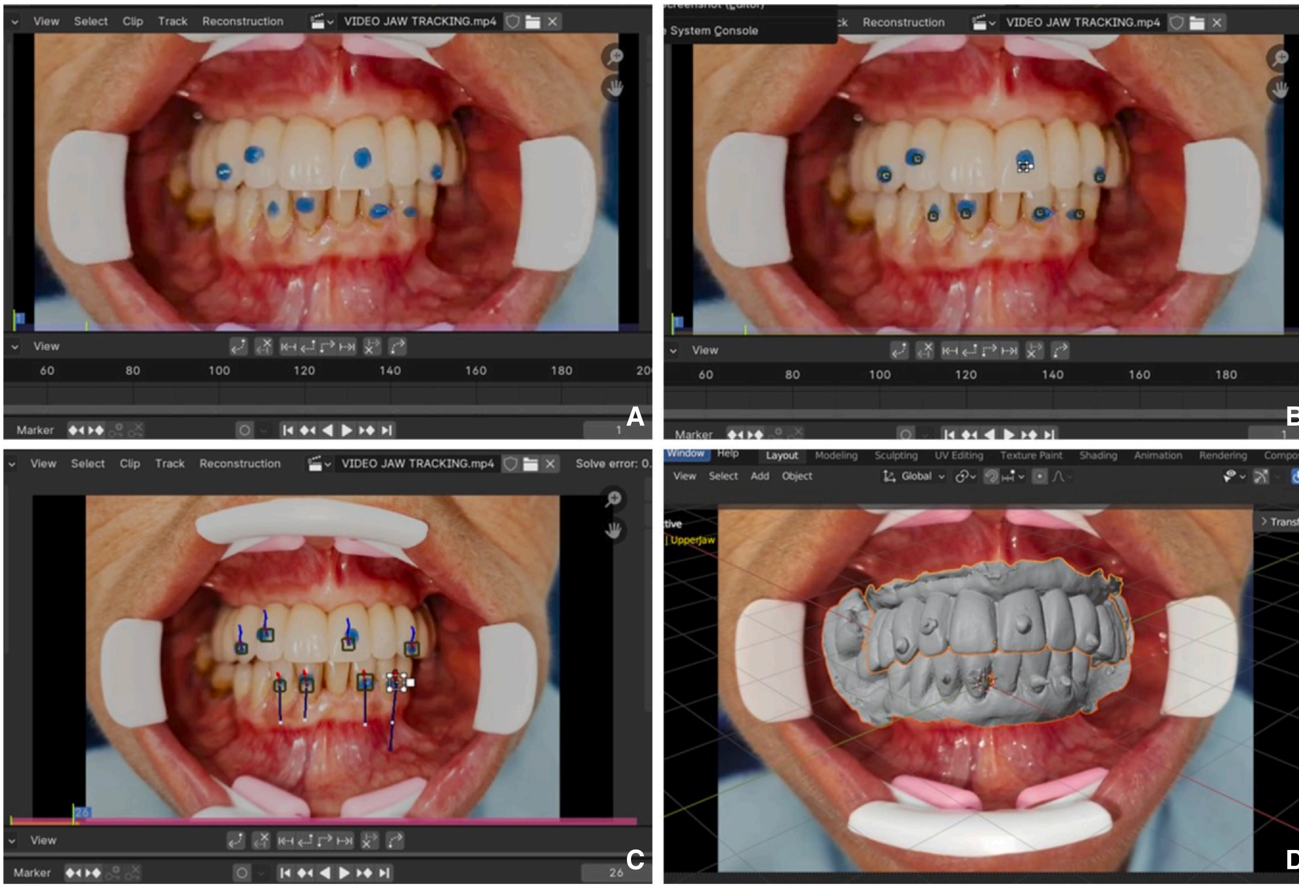

Figure 3. Integration of video footage of mandibular movements. A, Video data imported. B, Tracking points identified. C, Frame-by-frame adjustment. D, Video footage aligned to intraoral scans.

4. Detach the markers with a spatula (Heidemann N.1; ASA Dental SPA). Polish off any residual resin using a rubber polisher (Komet 94026F; Komet Dental SRL).
5. Make a cone beam computed tomography (CBCT) scan (Sirona GALILEOS; Sirona Dental Systems GmbH) with the jaws separated. Set the field of view at 15×15 cm. Convert the digital imaging and communications in medicine file (DICOM) into standard tessellation language (STL) with a software program (InVesalius v. 3.1.1.; CTI Renato Archer) (Fig. 2).
6. Make a facial scan with a dedicated application (Polycam app v. 2.0.2; Polycam Inc) on the smartphone with the patient smiling in an upright position.
7. Import the video file into a free open-source software program (Blender v. 4.3; Blender Foundation). Use the “Movie Clip Editor” tool and select the video file (Fig. 3A).
8. Manually set tracking points on the resin markers in the first frame, ensuring the pattern size covers them (Fig. 3B), and then track their movements automatically frame by frame (Fig. 3C).
9. Import intraoral scans in polygon file (PLY) format, align them with motion data in "3D Viewport," create an "Empty Object," and attach the motion data to link video movement to intraoral scanning data (Fig. 3D). Refine alignment with "Transformation Tools" and verify synchronization by replaying the animation (Fig. 4).
10. Export the animation in Filmbox (FBX) or Graphics Library Transmission Format (glTF) for use within Blender and its specialized add-ons or plug-ins (such as OrtogOnBlender, Blender for Dental, or BDental 4D), which extend its functionalities for diagnostic or educational purposes.
11. Digitally remove the resin markers from the virtual casts with sculpting or editing tools.
12. Import CBCT, facial, and intraoral scanning data into Blender, align them by using teeth as landmarks, and visualize the combined data (Figs. 5 and 6).

DISCUSSION

This technique integrates mandibular motion tracking with virtual casts from intraoral and facial scanning and CBCT by using an open-source software program. The

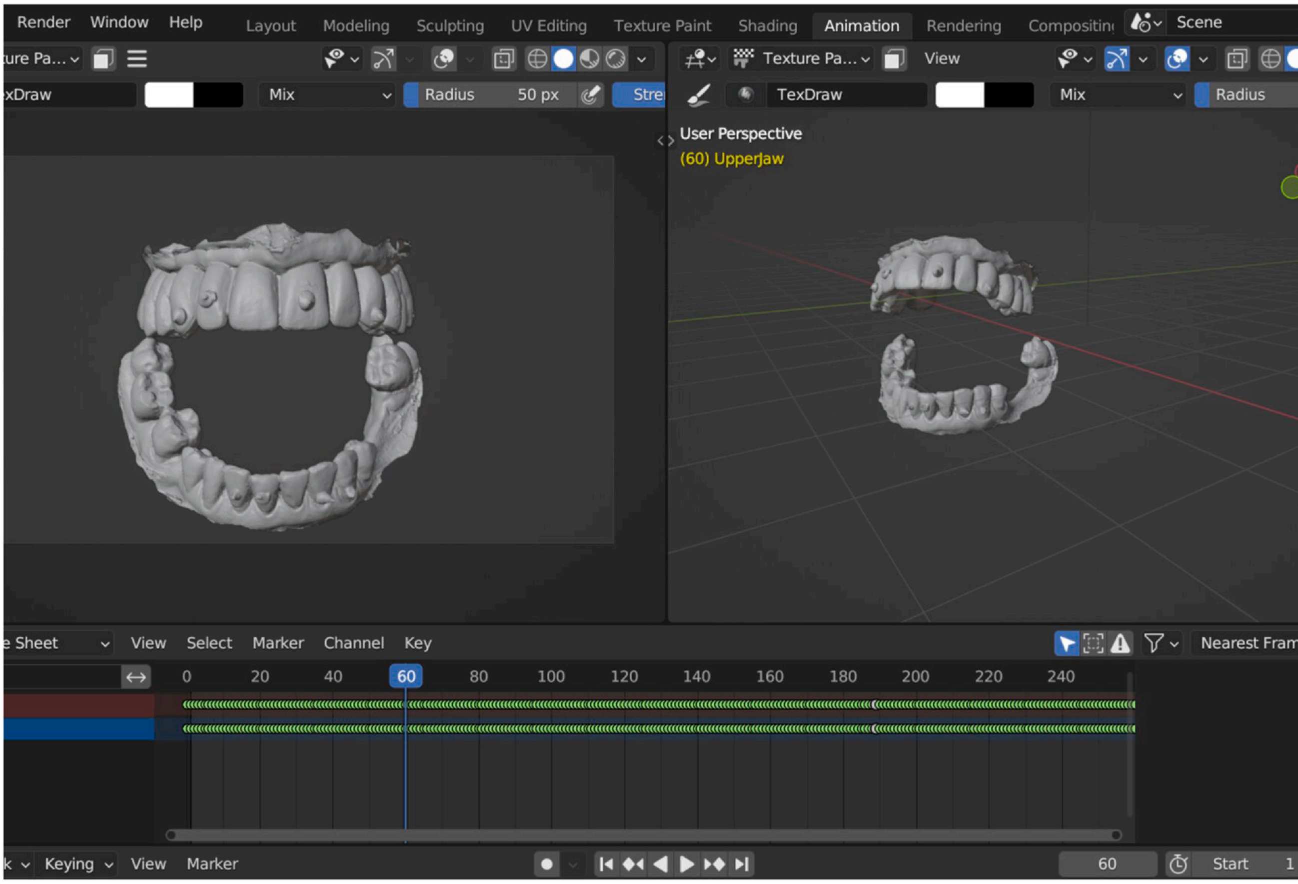

Figure 4. Frame-by-frame synchronization in timeline.

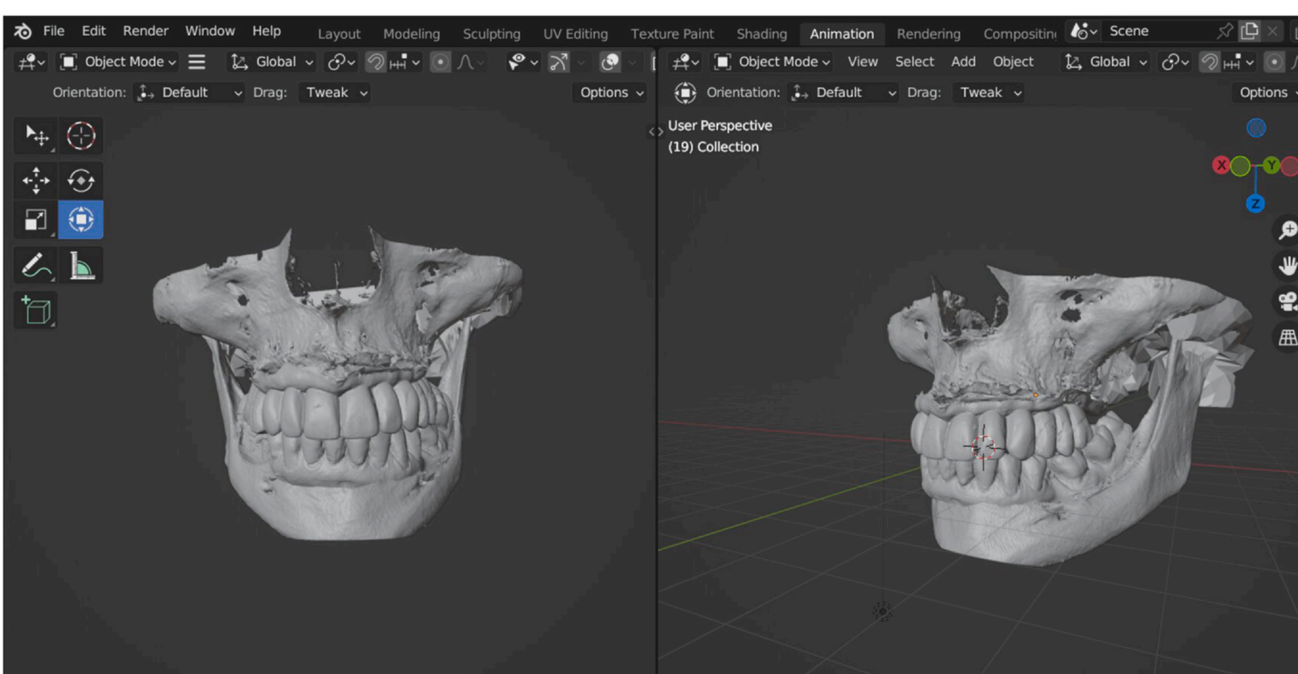

Figure 5. Superimposition of CBCT data onto intraoral scans. CBCT, cone beam computed tomography.

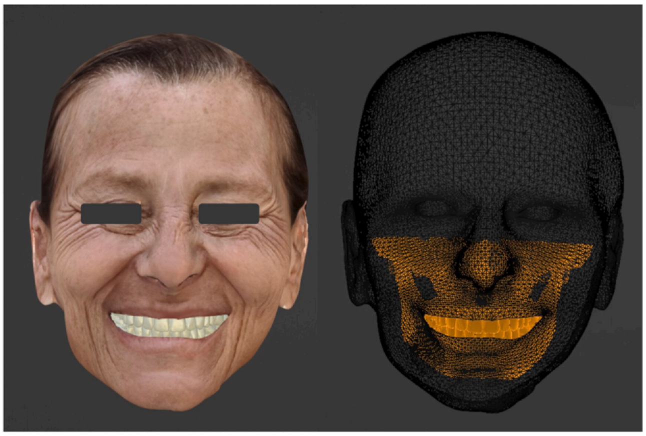

Figure 6. Face scan data integration. Left, face scan superimposed to intraoral scan. Right, CBCT superimposed to intraoral scan. CBCT, cone beam computed tomography.

face scan remained static, aiding intraoral scanning data refinement and virtual prosthesis visualization, enhancing its versatility. No scaling was needed for CBCT and intraoral scanning casts, only for the face scan to ensure alignment. The operator (G.R.) had 2 years of experience with jaw-tracking systems in digitally assisted dentistry. Before refining the protocol, he trained on 5 treatments with Blender's motion tracking module to ensure proficiency. The development of a mandibular motion tracking workflow with Blender offers a cost-effective approach to integrating dynamics into 3D virtual patients for visualization and fast animations. Unlike expensive ultrasound and optical motion capture systems, this Blender-based workflow is accessible by using standard video cameras and intraoral scans, making it useful for small practices and resource-limited research. Current marker technologies are often bulky and inconvenient, prompting the adoption of simplified tracking systems.[11,17] Some researchers have developed adhesives for placing resin markers on the labial surfaces of teeth.[11] This technique further simplifies the process and enables seamless alignment with facial scans and video footage for target tracking (Figure 1). At least 6 flowable resin markers, preferably green or blue, are recommended for better tracking. The methodology uses small intraoral resin markers, easily applied directly to the teeth, eliminating the need for external markers. These markers align automatically with intraoral scans, removing the need for calibration, 3D-printed boards, or commercially available facebows, reducing costs and enhancing patient comfort. Additionally, unlike BDental 4D (external add-on) and Blender for Dental (commercial plug-in), this approach is fully integrated into Blender's native environment, offering a cost-effective and independent solution. The described jaw-tracking system has the potential to support dental applications like prosthetic planning and design, treatment monitoring, and analysis of temporomandibular disorders. It is possible to work with this mandibular movement tracking system on the prosthetic project or the trial prosthesis (Supplemental Video 1, available online). Also, virtual casts can be adjusted per frame for precise contact evaluation and customization. Future improvements could automate marker detection and alignment for better usability and consistency. Integrating real-time tracking through plug-ins could enhance competitiveness with proprietary systems. Limitations include operator training and lack of standardization. The smartphone-based monovision system may reduce anteroposterior accuracy because of parallax, limiting depth estimation versus stereo-vision.[20,21] Lip retractors aid visibility but restrict movement, and resin markers may be obscured by a deep vertical overlap or anatomy. Systematic evaluation across clinical treatments is needed to confirm reliability and establish guidelines.

SUMMARY

Blender provides a cost-effective workflow for animating mandibular movements with video data and intraoral scans. Its 3D design and motion tracking capabilities could democratize advanced dental technologies, though validation is needed to match established systems.

APPENDIX A. SUPPORTING INFORMATION

Supplemental data associated with this article can be found in the online version at doi:10.1016/j.prosdent.2025.03.032.

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