

## CASE REPORT

# A Visional Method to Evaluate Mandibular Motion by Markerless Stereo Mandibular Tracking System

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**Objective:** The purpose of this case report is to describe a novel markerless stereo vision mandibular tracking system designed to record and display the patient's mandibular motion for the diagnosis and management of temporomandibular joint dysfunction (TMD).

**Overview:** This report compares traditional mandibular motion tracking methods, existing digital jaw tracking systems, and this stereo vision mandibular tracking system. The step-by-step illustration of the technique highlights the benefits of implementing the markless new method, such as convenience and reduced operational intervention.

**Evaluation and outcome:** Integrated with the 3-dimensional (3D) mesh model obtained from the intraoral scanner, the stereo vision mandibular tracking system was used to evaluate the patient's maxillomandibular relationship and occlusal condition (symptom evaluation).

**Conclusion:** The results provided by this novel digital mandibular tracking system can assist dentists in diagnosing and evaluating TMD. Its markerless implementation offers convenience in both setup and utilization, significantly enhancing its potential for widespread application in clinical trials.

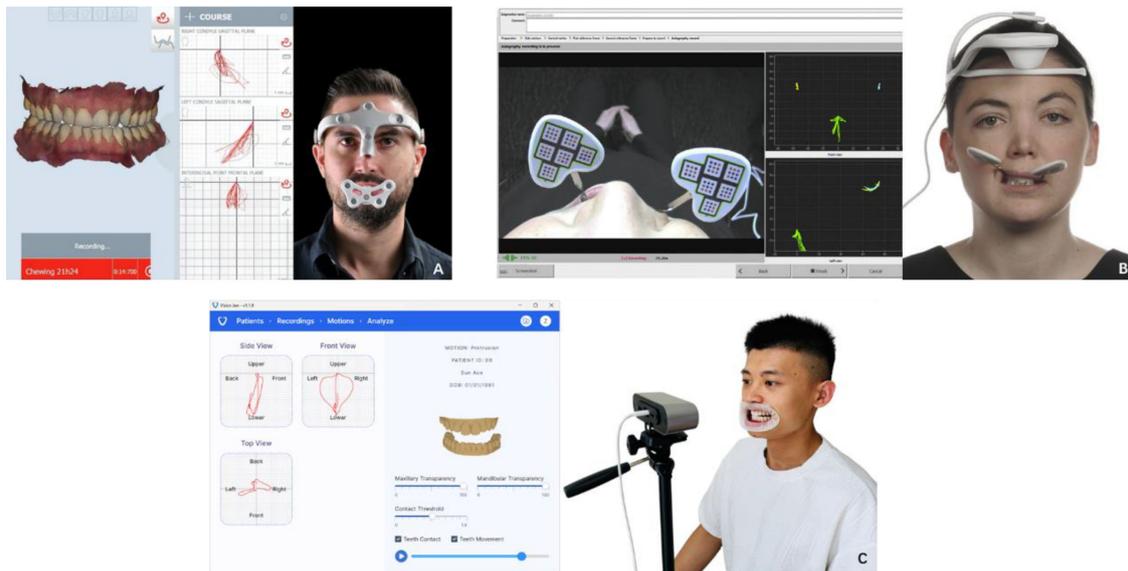
**Keywords:** digital mandibular tracking, markless, stereo vision, intraoral scanner, case report

## Introduction

Mandibular jaw tracking, a process that records dynamic relationships between maxillary and mandibular teeth during vertical, anteroposterior, and lateral motions, can assist in executing dental restorations, occlusal analysis, and fabricating prostheses. By using digital technologies, including mechanical devices (1), ultrasonic systems (2), photographic methods (3), magnetometry (4), and artificial intelligence (5), the mandibular motion trajectory and occlusal surface can be visualized for analyzing static and dynamic dental occlusion quantitatively. Combined with the virtual 3-dimensional (3D) models generated by intraoral

scanners, mandibular tracking techniques provide reliable access to virtually analyzing the mandibular motion by presenting dentists and physicians with diverse perspectives. The digital analysis and virtual visualization techniques adopted to mandibular tracking have effectively addressed the clinical restrictions, such as the inability to record real-life dynamic occlusion motion and limits of motion simulation due to the use of manufactured mechanical articulators (6).

Mandibular tracking is widely recognized as a crucial method assisting the analysis of temporomandibular joint dysfunction (TMD) (7), a dental term to describe a group of pathologies affecting the masticatory muscles, the temporomandibular joint (TMJ), and associated structures.



**FIGURE 1** | Examples of the mandibular tracking system with markers and without markers. (A) 4D motion capture system from modjaw (13). (B) Proaxis system from SDIMatrix (13). (C) Markerless stereo vision mandibular tracking system.

These occlusal variations and muscle tenderness can stem from the musculoskeletal disorder of hard and soft tissue structures of the TMJ, impacting more than 25% of the general population (8). For most TMD patients, the mechanical condition often involves deviations in the mandible movements, the limited range of mandibular motion, and unbalanced occlusal contacts (9). These typical symptoms can be recorded and measured during the designed TMJ movement patterns, such as vertical, anteroposterior, and lateral motions, with mandibular tracking techniques. This assists dentists in analyzing the condition of TMJs and evaluating the effectiveness of restorations.

While conventional methods simulate jaw motion using mounted mechanical articulators, modern procedures enable the replay of real-life dynamic motion via a virtual articulator simulation on a screen. However, dentists and physicians still face challenges due to uncertainties in environmental conditions, technological systems biases, patient-specific intraoral limitations, and the level of operator expertise. For instance, in the infrared optical camera system (10), the facebow (receiver and control unit) and a lower jaw sensor (transmitter unit) must be attached to the mandibular teeth, which remain bound to the inherent restraints of the mechanical device. Moreover, tracking and recording maxillomandibular motion using the Proaxis system from SDIMatrix (11) requires installing and calibrating the optical tracking camera and maxillary and mandibular passive trackers with multiple steps. Methods that involve the installation and calibration of mechanical devices tend to introduce human intervention and accumulate the systematic deviations, as well as the mechanical restrictions and extensive alignment time, which can negatively impact



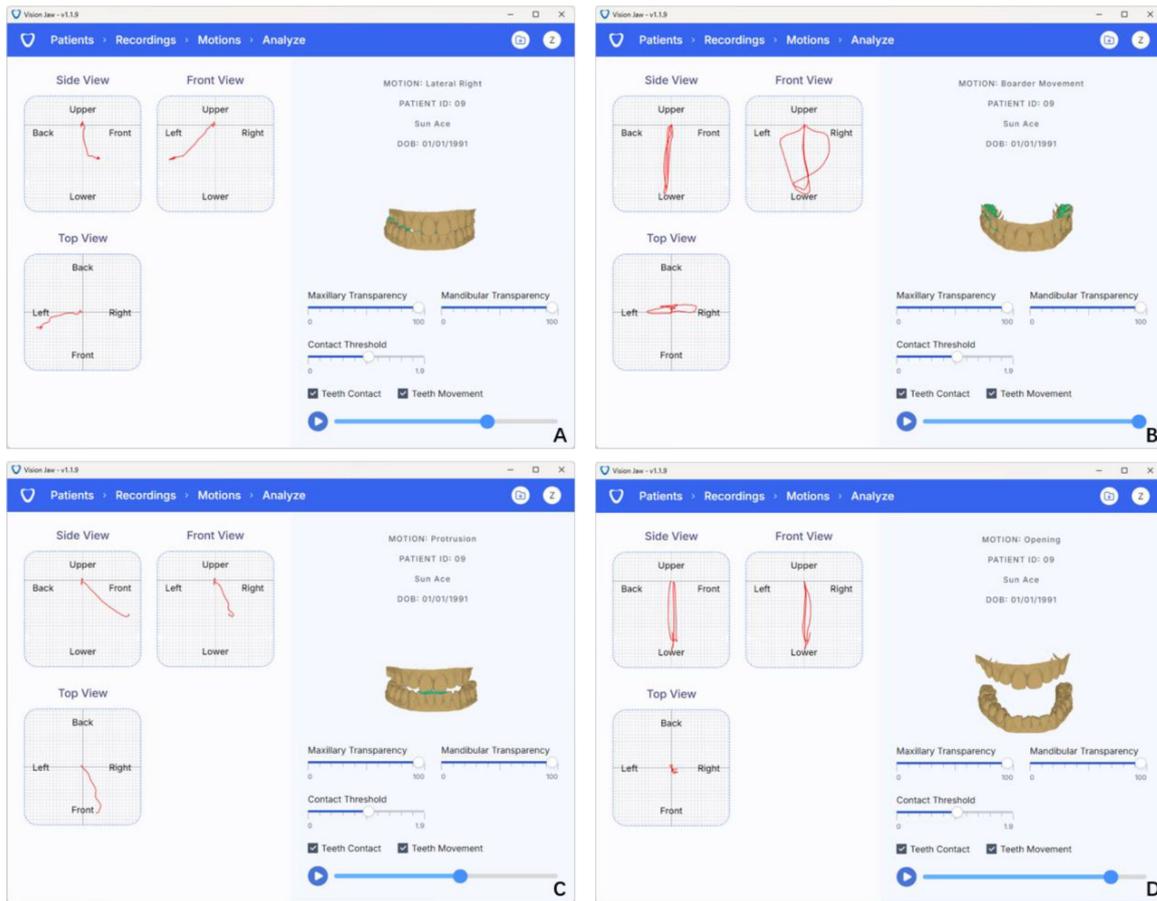
**FIGURE 2** | Component of markerless stereo vision system.

the patient's experience, which can be addressed and solved by the markerless method proposed in this study (Figure 1).

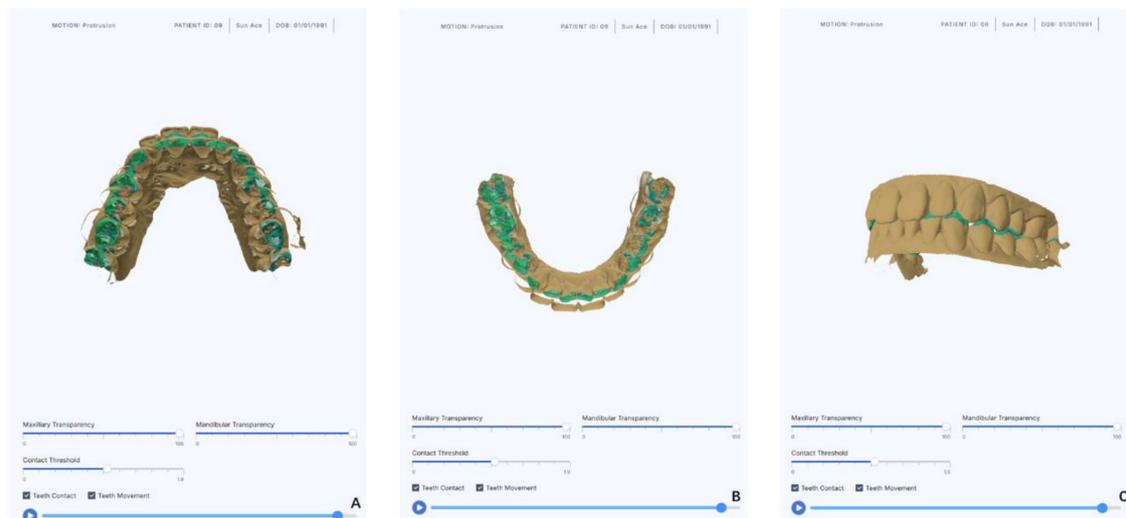
Considering the limited research on purely photometric mandibular motion tracking systems, an innovative markerless stereo vision technique for mandibular tracking, with a detailed, step-by-step guide for digital recording from the operator's perspective, is described. Without the need for intraoral markers or extraoral trackers, this technique utilizes a precisely aligned stereo camera system (Figure 2) to optically capture and record unrestricted motion trajectories, relative maxillomandibular spatial data, and occlusal surface during mandibular movements.

## Material and methods

The pre-procedure requirement involves obtaining the digital 3D mesh models of the participant's maxilla and mandible arches using an intraoral digital scanner (CEREC Primescan, Dentsply-Sirona). After alignment and transformation to the maximum intercuspal position (MIP) position, the digital mesh models are exported as two separate standard tessellation language format files for maxillary and mandibular arches.



**FIGURE 3** | Software interface for results display in the mandibular tracking system (vision Jaw, Vision Dentistry) for four example motions. (A) Lateral right motion results. (B) Boarder movement motion results. (C) Protrusion motion results. (D) Opening motion results.



**FIGURE 4** | Occlusal surface results displayed in the mandibular tracking system (vision Jaw, Vision Dentistry). (A) Bottom view. (B) Top view. (C) Side view.

The operator creates a patient profile on a markerless stereo vision mandibular tracking system (Vision Jaw, Vision Dentistry) and guides the patients through the recording procedures by following these steps:

1. **Model Upload:** Upload the upper jaw model and lower jaw model from local or import the existing jaw models to the system. Subsequently, the software lists all the names of default mandible movement patterns.

- 2. Patient Positioning:** Position the patient in an upright position on a distance of around 16 inches between the participant and the stereo camera system. Ensure the oral retractor is in place for better oral visibility. Adjust the patient's position to center the mouth within the frame of both cameras, ensuring the mouth is aligned with the main axis of the camera system.
- 3. Motion Recording:** Click on the motion name to start the video recording. Then guide the patient to perform the corresponding motion patterns, starting each motion from the MIP and moving slowly.
- 4. Result Analysis:** After confirming that the analysis is successfully processed in about 15 seconds, the corresponding motion results show in the Actions column (Figure 3). The results, including the side, front, and top views of the mandibular midpoint trajectory, tracked from the motion. Also, the software displays a real-life simulation of the maxillary and mandibular motion merged with the 3D model from the intraoral scanner. The real-time occlusal contact is highlighted in green (Figure 4).

## Discussion

The procedures for capturing the dynamic relationship between the maxilla and mandible, as well as the occlusal interface, have been described. This technique aims to reduce pre-preparation steps and simplify the procedures required for mandibular recording by using a markerless stereo vision mandibular tracking system. Additionally, by adjusting the software program variables, this mandibular tracking system enables more fine-tuning of the motion simulation results, making this system more practical for clinical applications.

Traditional methods for evaluating occlusal contacts and mandibular motion often rely on unreproducible direct visualization or simulations with manufactured articulators (11), which have mechanical restrictions. This innovative markerless stereo vision system records and presents digital results on a computer screen, including the mandibular midpoint trajectory from side, front, and top views; a virtual motion of the maxillary and mandibular 3D mesh models; and the highlighted occlusal surface during real-life motion. These results are digitally recorded for future replay and can be viewed from multiple perspectives. The combination of the mandibular midpoint trajectory from three views and the virtual motion simulation aids dentists and physicians in evaluating the causes of TMD problems and executing prosthodontic treatment plans. Additionally, the annotated occlusal surface data supports the evaluation of the occlusal condition in TMD patients, thereby assisting in the TMD management (12).

This technique offers several advantages. With the unique markerless tracing system powered by artificial intelligence,

it eliminates movement deviations caused by external mechanical attachments and erases intrusive discomfort to the patient. Meanwhile, with the camera's standalone equipment, it significantly reduces setup time to a few minutes. Last but not most least, this technique enhanced system accuracy through the use of artificial intelligence algorithms, which capture and analyze mandibular movement trajectories to ensure simulation accuracy. These improvements not only provide convenience to both patients and dental professionals but also have the potential to expand the application of this technique in clinical trials.

Based on the methodology of this technique, two limitations should be considered during clinical implementation: The oral retractor must be installed throughout the video recording to ensure oral visibility. Using a hard and oversized retractor can interfere with the patient's jaw movement. It is recommended to use a soft O-ring retractor, which has almost no impact on the jaw movement based on our studies and observation. Also, the quality of the virtual maxillomandibular motion simulation and occlusal contacts visualization depends on the 3D mesh jaw models obtained by the intraoral scanner, and the jaw models should be aligned in the bite position. If the input to the system is poor-quality jaw models or the models are not aligned in the bite position correctly, the jaw tracking results can be negatively affected.

## Summary

This article describes a novel approach for tracking and simulating the maxillomandibular relationship, including the moving trajectory, 3D mesh motion simulation, and occlusal interferences, using the markerless stereo vision mandibular tracking system. This technique can be utilized for the fabrication of prostheses as well as the diagnosis and treatment of TMJ disease through the analysis of mandibular motion trajectories. Unlike current methods, this approach does not require attachments or manufactured articulators, making it simpler, less operational intervention, and more convenient for patients. Additionally, the understanding of the maxillomandibular relationship could be further enhanced by integrating the patient's facial 3D point mesh into the dynamic virtual representation along with the mandibular motion in the future.

## Conflict of interest

The authors declare that they have no known conflicts financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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