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A digital technique for fabricating a diagnostic occlusal device using mandibular motion tracking

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ABSTRACT

Objective: To present a fully digital workflow for fabricating diagnostic occlusal devices using intraoral scanning and digital mandibular motion tracking.

Methods: A clinical method was applied involving intraoral scanning of dental arches in maximum intercuspation (TRIOS 5). A second maxillary scan, using a rebased fork, was imported into SDI MATRIX software for digital facebow transfer. The prosthetic plane was recorded in natural head posture using a central marker. Lateral markers were placed on canines, and mandibular movements were recorded with an optical axiograph. Functional motions, including opening, closing, excursions, and mastication, were analyzed to determine the utility position. This position was exported into CAD software for articulator configuration and splint design. The final device was milled in PMMA and assessed clinically.

Results: The digital workflow provided stable, reproducible mandibular recordings. The diagnostic position differed from maximum intercuspation by 3.8 mm anteriorly and 9 mm vertically. The digitally fabricated splint showed excellent fit without the need for occlusal adjustments. Follow-up motion tracking confirmed functional alignment. The patient reported no discomfort or occlusal interferences.

Conclusions: This technique allows for the accurate fabrication of diagnostic occlusal devices by integrating dynamic mandibular data into the design process, improving clinical precision.

Clinical Significance: By capturing functional mandibular movements digitally, this workflow enhances diagnostic reliability, minimizes chairside adjustments, and supports prosthetic planning based on real jaw dynamics.

1. INTRODUCTION

Digital techniques for fabricating occlusal devices, such as CAD/CAM workflows, have demonstrated notable advantages over traditional methods. For instance, studies indicate that not only do digital procedures enhance manufacturing efficiency, but also improve material properties and patient acceptance [1]. The use of intraoral scanners and 3D printing technologies allows for precise reproduction of interocclusal relationships, which is critical for the effectiveness of occlusal devices [2-3]. Furthermore, digital workflows have been shown to reduce the need for occlusal adjustments during the delivery of devices, thereby decreasing chair time and improving patient comfort [4]. The ability to quickly produce duplicate splints and the high-quality material outcomes further highlight the benefits of digital fabrication systems [2, 5-7]. Among these advanced digital solutions, CAD/CAM Diagnostic Esthetic Functional Splints (DEFS) have emerged as high-tech diagnostic tools that serve as removable prosthetic appliances to test in the medium-term the functional and esthetic acceptance of the rehabilitation [8]. These splints not only facilitate precise functional and esthetic assessments but also enable clinicians to test occlusal schemes and patient adaptation before proceeding with definitive restorations [8]. Also, tracking systems allow the design and production of occlusal splints, interim and definitive prostheses [7, 9-12].

Conversely, conventional techniques, while often perceived as less efficient, still hold relevance in specific clinical scenarios. Traditional methods typically involve physical impressions and the use of materials such as heat-cured acrylics, which have been shown to yield high occlusal accuracy under certain conditions [13]. For example, the accuracy of restorations fabricated using conventional impressions can sometimes be more efficient compared to digital systems, particularly when considering occlusal relationships [14]. Moreover, the tactile feedback and experience of dental professionals using conventional techniques can contribute to the quality of the final product, especially in complex cases involving multiple missing teeth [14].

The integration of mandibular motion tracking into the fabrication process further enhances the precision of occlusal devices. Digital intraoral scanning technologies can capture dynamic mandibular movements, allowing for a more comprehensive understanding of occlusal relationships during functional activities [3]. This capability is essential for creating devices that not only fit well but also function properly in clinical conditions. Moreover, the recent advancements in artificial intelligence are paving the way for automated design processes that can fit individual patient needs, potentially revolutionizing the field of occlusal device fabrication [5].

Optical jaw tracking systems, such as Modjaw and similar 4D capture platforms, have demonstrated the ability to record mandibular motion with high temporal resolution, enabling clinicians to visualize and utilize the patient's functional envelope of motion, including centric relation (CR), excursive paths, and mastication cycles, for prosthetic planning [15]. When combined with intraoral scanners, these systems offer a comprehensive digital workflow that enhances both diagnostic accuracy and the functional adaptation of occlusal appliances [16]. Several studies have validated the effectiveness of digital jaw tracking in capturing repeatable centric relation (CR) and excursive movements. Compared to conventional methods involving jigs and facebows, digital workflows offer faster acquisition times, reduced inter-operator variability, and easier data transfer to CAD software [16-17]. Furthermore, the ability to design splints or mouthguards that accommodate the patient's natural jaw motion is clinically significant for patients with temporomandibular disorders (TMD), parafunction, or complex occlusal schemes. However, challenges persist. While 3D printing and digital manufacturing have allowed for rapid prototyping and high customization, issues such as scanner accuracy, patient movement during acquisition, and system calibration remain critical factors influencing clinical success [6]. Moreover, despite the growing use of digital workflows, long-term clinical validation and standardization of protocols are still limited.

In summary, both digital and conventional techniques for fabricating diagnostic occlusal devices show their unique advantages and challenges. Digital methods offer efficiency, precision, and improved patient outcomes, while conventional techniques provide reliability and tactile feedback that can be crucial in complex cases. The future of occlusal device fabrication will likely involve a hybrid approach that takes advantage of the strengths of both methodologies, particularly with the incorporation of advanced technologies like mandibular motion tracking and AI-driven design.

The present article describes a fully digital workflow for fabricating a customized diagnostic occlusal device (bite splint). The method involves the use of intraoral scanners for arch digitization and a digital axiograph for recording mandibular movements. The innovative aspect lies in determining the diagnostic intermaxillary relationship by analyzing free mandibular movements and identifying a diagnostic position. This position is then exportable to a CAD software program for the subsequent design and fabrication of the diagnostic occlusal device.

2. MATERIALS AND METHODS

1. Make intraoral scanning of the dental arches in maximum intercuspation using an intraoral scanner (IOS) (e.g., TRIOS 5, software v. 3Shape Unite 24.1, 3Shape, Copenhagen, Denmark) (Fig.1A).
2. Perform an additional scan of the maxillary arch using a specific fork rebased with addition silicone material (e.g., Occlufast Rock, Zhermack, Rovigo, Italy) (Fig. 1B). Subsequently, export STL or PLY files to the SDI MATRIX software program (SDI MATRIX, Zurich, Switzerland). This step enables the transfer of the maxillary arch using the digital facebow SDI MATRIX.

3. Use the central marker, a wireless electronic device, to record the prosthetic plane relative to the horizon. Attach the marker to the previously rebased fork. Position the patient in the natural head posture (NHP) and record the maxillary position. This data can be exported directly to CAD software programs (Fig. 2A).

4. Attach lateral markers with composite material to the right maxillary canine and left mandibular canine. Subsequently, fit the patient with an axiograph equipped with an optical tracking system and record mandibular movements, including opening, closing, lateral excursions, and protrusion, both constrained (along occlusal surfaces) and free movements (Figs. 2B-C).

5. Perform basic movement analysis (opening, closing, lateral, and protrusive motions) and mastication cycle analysis. Ensure muscle relaxation before identifying the intermaxillary relationship and record the maxilla mandibular utility position (Fig. 3) [18]. Import the XML file containing mandibular movement coordinates into the CAD software program (Fig. 4).

6. Import the maxillary position and articulator programming data, and input condylographic data to configure the articulator's digital condylar paths (Fig. 5). Avoid deflective trajectories that might compromise the device's functionality.

7. Fabricate the diagnostic occlusal device by using milled resins (Fig. 6). Deliver the device to the clinic for patient trials (Fig. 7). Conduct a follow-up axiography session to verify the device's diagnostic effect.

Informed consent has been acquired from the patient for collecting data and for displaying the patient's figures.

3. RESULTS

The digital workflow was successfully implemented in a clinical case involving the fabrication of a diagnostic occlusal device thanks to the integration of jaw motion data. The resulting digital models of the dental arches were precise and stable, supporting reliable integration into CAD software. The maxillary position, recorded in natural head posture, demonstrated consistency across repeated acquisitions. All tracking markers remained stable during mandibular motion recording, and signal integrity was maintained throughout.

Jaw motion data allowed complete programming of the virtual articulator, yielding the following parameters: Balkwill angle of 21.7°, sagittal eminence angles of 62.0° (left) and 62.1° (right), Bennett angles of 12.1° (left) and 13.5° (right), and immediate side shift of 1.7 mm (left) and 1.4 mm (right). Functional mandibular movements and chewing cycles produced smooth, reproducible traces. Mean values for free movements included 9.6 mm of protrusion, 8.2 mm of left excursion, and 7.8 mm of right excursion.

The intermaxillary utility position, determined from muscle-relaxed functional recordings, differed from maximum intercuspation by approximately 3.8 mm anteriorly and 9 mm vertically. The occlusal splint, digitally designed and milled in PMMA, exhibited a passive and stable fit upon clinical delivery, with no occlusal interferences detected.

A follow-up session confirmed the repeatability of mandibular movements with the device in place. The patient experienced no discomfort or functional disturbances during use, and the device's performance remained stable over time.

4. DISCUSSION

The proposed digital technique represents a significant advancement in the fabrication of diagnostic occlusal devices. Accurate calibration of the tracking system is crucial to avoid distortion of mandibular motion data. As noted in previous studies, even small errors in tracker positioning or patient movement during recording can lead to discrepancies in the recorded jaw path [15-16]. To mitigate these risks, the present workflow employed repeated acquisitions, careful marker stabilization with composite resin, and motion cycle repetition to ensure data consistency. Another challenge lies in the integration of movement data into CAD software. While many jaw-tracking systems export XML motion files, compatibility and functionality within CAD platforms can vary. Some systems, such as those described by Kois et al. and Ntovas et al., allow for precise mapping of the hinge axis, path of closure, and excursive vectors. In the present workflow, this integration enabled not only static positioning but also dynamic motion visualization, supporting the design of a device tailored to the functional "utility" position [16-18]. Comparatively, traditional methods, such as centric relation records using the Lucia jig or Kois deprogrammer, are limited in their ability to account for functional motion. While these analog techniques can yield stable bite registrations, they rely on static records that may not capture nuances of patient-specific kinematics. Furthermore, semi-adjustable articulators, while widely used, fall short in replicating the full envelope of mandibular motion [16]. Other digital techniques, such as the 3D printed workflow by Waldecker et al., demonstrate the feasibility of fully digital occlusal splint production using CR records and vertical dimension adjustments [6]. However, these do not fully integrate functional movement data. In contrast, workflows like that of Ntovas et al. for sports mouthguards incorporate both static and dynamic occlusion through optical jaw tracking to achieve balanced occlusion across excursive paths [17].

The integration of mandibular motion tracking enhances the precision of intermaxillary relationship registration, reducing manual errors and ensuring accurate reproduction of mandibular movements [3].

This level of precision is particularly relevant given the increasing reliability of CAD/CAM technologies, which have been shown to improve efficiency, material properties, and patient acceptance [1, 4]. Moreover, the ability to seamlessly integrate mandibular movement recordings into CAD software programs bridges the gap between gnathological planning and prosthetic design, ensuring a functional and esthetic balance [8]. A key advantage of this workflow is the reduction in clinical and laboratory time, as digital methodologies have been demonstrated to minimize the need for occlusal adjustments and chairside modifications [4]. Additionally, the ability to analyze free mandibular movements enables the creation of highly personalized devices that align with the patient's unique functional dynamics [10-11]. The capacity to digitally replicate these movements not only optimizes treatment predictability but also facilitates communication between clinicians and dental laboratories. Despite the advantages, certain limitations must be acknowledged. First, the initial investment in equipment and the associated learning curve can be significant barriers for clinicians unfamiliar with digital workflows [5]. Moreover, hardware and software compatibility issues may pose logistical challenges, particularly in clinics with limited access to advanced digital tools [7]. Another critical consideration is that digital mandibular movement tracking assumes that all relevant functional dynamics can be accurately captured and replicated, yet some complex occlusal conditions may require additional manual adjustments [14]. The digital workflow faces challenges such as motion artifacts and patient variability, which can affect recording accuracy. Proper calibration and repeated sessions help improve reliability. Success also depends on patient compliance, with factors like limited mouth opening or joint issues potentially impacting outcomes. Broader clinical validation is needed to confirm its consistency and general use.

5. CONCLUSION

The described digital workflow was effective and clinically reliable for fabricating a diagnostic occlusal device, capturing stable scans, and reproducible jaw movements. Functional mandibular tracking allowed the identification of a diagnostic position, which was used to design a well-fitting occlusal device. The splint required no adjustments and was comfortable in function. Follow-up confirmed consistent jaw motion with the device in place.

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LEGENDS TO FIGURES

Figure 1. A, intraoral scan in maximum intercuspation; B, Scan of the maxillary arch using a specific fork rebased with addition silicone material.

Figure 2. A, use of the central marker; B, lateral markers from the camera on the head; C, lateral markers in frontal view.

Figure 3. Maxilla mandibular utility position.

Figure 4. XML file with mandibular movement coordinates.

Figure 5. Articulator programming data.

Figure 6. Design of the diagnostic occlusal device.

Figure 7. Device delivered to the patient.

Figure 8. Schematic workflow diagram summarizing the digital workflow.

FIGURES

Figure 1.

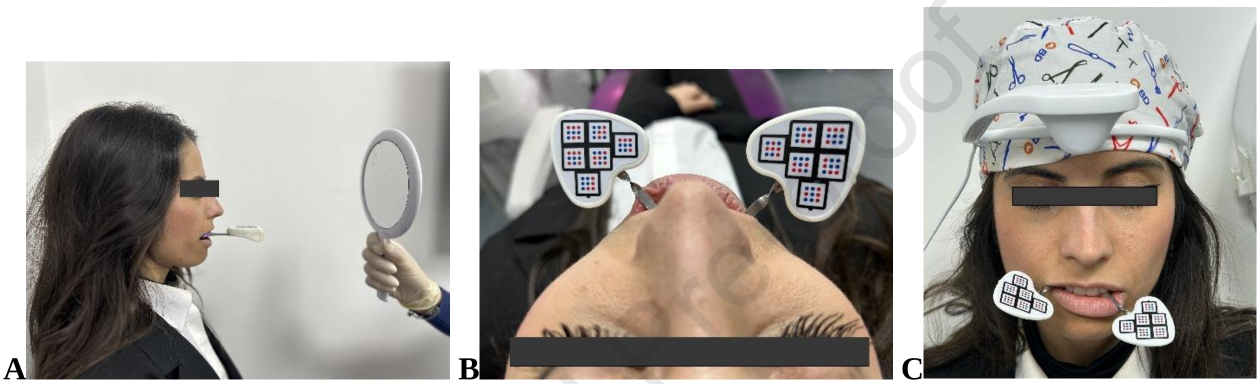

Figure 2.

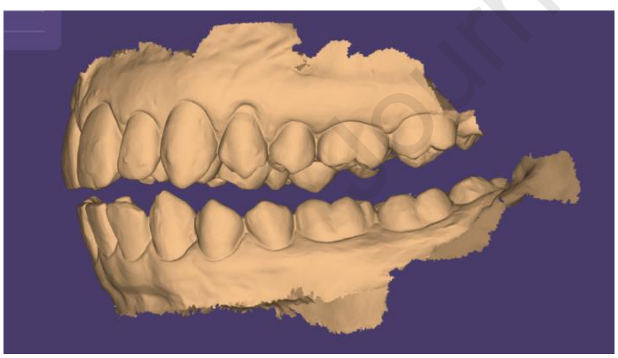

Figure 3.

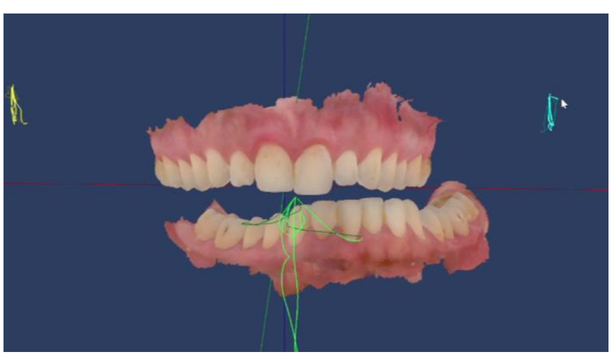

Figure 4.

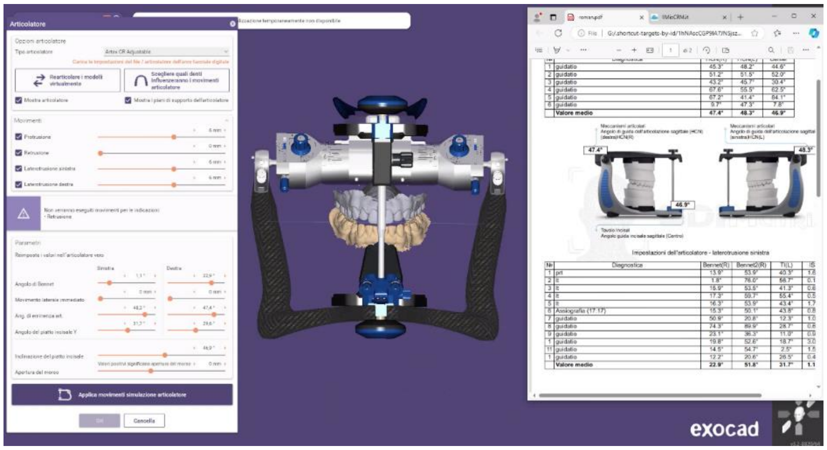

Figure 5.

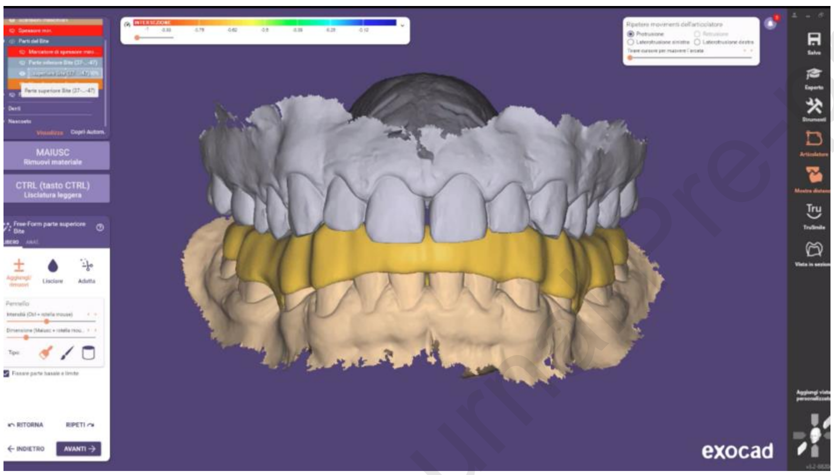

Figure 6.

Figure 7.

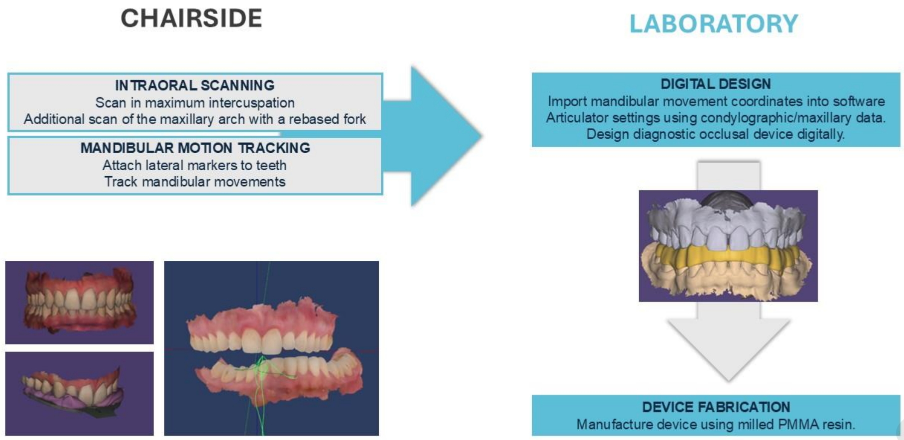
CHAIRSIDE
LABORATORY
INTRAORAL SCANNING
Scan in maximum intercuspation
Additional scan of the maxillary arch with a rebased fork
MANDIBULAR MOTION TRACKING
Attach lateral markers to teeth
Track mandibular movements
DIGITAL DESIGN
Import mandibular movement coordinates into software
Articulator settings using condylographic/maxillary data.
Design diagnostic occlusal device digitally.
DEVICE FABRICATION
Manufacture device using milled PMMA resin.

Figure 8.

Declaration of interests

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

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: