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Journal of Esthetic and Restorative Dentistry

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CLINICAL ARTICLE

A Virtual Patient-Based Workflow for Mandibular Stabilization Using a Virtual Articulator and Digital Splint

Danal Moon[1,2,3] | Jae Hyun Park[4,5] | Jong Cheol Kim[6] | Sang Mi Lee[2,7,8] | Dong-Hwa Tom Chung[9] | Gye Hyeong Lee[1,10,11,12]

[1]Department of Orthodontics, School of Dentistry, Chonnam National University, Gwangju, South Korea | [2]Catholic University, Seoul, South Korea | [3]Private Practice, Gwangju, South Korea | [4]Postgraduate Orthodontic Program, Arizona School of Dentistry & Oral Health, A.T. Still University, Mesa, Arizona, USA | [5]Graduate School of Dentistry, Kyung Hee University, Seoul, South Korea | [6]Daegu MIR Dental Hospital, Daegu, Republic of Korea | [7]Graduate School of Dentistry, Chonnam National University, Gwangju, South Korea | [8]Private Practice, Goyang, South Korea | [9]Department of Orthodontics, College of Dentistry, Dankook University, Cheonan, South Korea | [10]Roth Orthodontic Society, Seoul, South Korea | [11]Kyung Hee University, Seoul, South Korea | [12]Private Practice, Yeosu, South Korea

Correspondence: Jae Hyun Park (jpark@atsu.edu)

Received: 29 August 2025 | **Revised:** 6 February 2026 | **Accepted:** 13 February 2026

Keywords: digital stabilization splint | digital workflow | mandibular stabilization | virtual articulator | virtual patient

ABSTRACT

Objectives: To present a fully digital workflow for mandibular stabilization that reproduces the conventional articulator-based process within a virtual environment, integrating patient-specific three-dimensional (3D) datasets and artificial intelligence (AI)-assisted alignment.

Clinical Considerations: The workflow involves registration of intraoral scans, cone-beam computed tomography (CBCT), and/or facial scans to construct a unified virtual patient. Mandibular casts are mounted in centric relation on a virtual articulator using reference best-fit alignment. A virtual face-bow transfer aligns the maxillary cast to the articulator orientation plane based on anatomical landmarks from CBCT or facial scans. Stabilization splints are digitally designed with adjustable condylar guidance and anterior ramp inclination and fabricated via liquid crystal display (LCD) 3D printing with optimized orientation and post-processing. Clinical follow-up includes repeated digital centric relation bite registrations to monitor condylar position and confirm mandibular stability.

Conclusions: The fully digital workflow achieves mandibular stabilization while maintaining the biomechanical objectives of conventional methods. AI-assisted alignment, computer-aided design (CAD)-based splint design, and validated 3D printing parameters enhance precision, reproducibility, and clinical efficiency.

Clinical Significance: This protocol provides a reproducible and clinically feasible approach to mandibular stabilization, bridging conventional occlusal principles with digital implementation, and establishing a foundation for future AI-integrated occlusion-centered therapy.

1 | Introduction

Mandibular stabilization is a foundational element across occlusion-driven disciplines such as prosthodontics, orthodontics, and restorative dentistry [1, 2]. It serves as the basis for full-mouth rehabilitation, occlusal equilibration, and temporomandibular joint (TMJ) assessment and therapy. By establishing a stable mandibular position, clinicians can design a functional and aesthetic occlusion on a reproducible occlusal platform [3–5].

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Conventional stabilization techniques typically involve mounting maxillary and mandibular casts on an articulator using a face-bow transfer and a centric relation (CR) bite registration, respectively. Occlusal analysis and stabilization splint fabrication are then performed on the mounted models [6]. While widely practiced, this analog approach has limitations, including operator dependency, time consumption, and the need for additional clinical and laboratory equipment.

With the ongoing advancement of digital dentistry, more efficient and precise methods have emerged to overcome these limitations [7–9]. This clinical article introduces a fully digital protocol for mandibular stabilization that integrates a virtual patient, a virtual articulator, and a digitally designed stabilization splint. The proposed workflow is grounded in the biomechanical and theoretical principles of conventional techniques and faithfully translated into a digital environment. This digital workflow offers improved accuracy, streamlined clinical procedures, and predictable treatment outcomes, positioning it as a potential new standard in occlusion-centered care.

2 | Mandibular Stabilization

2.1 | Clinical Case

Refer to Figures 1–3 for an overview of mandibular stabilization and subsequent orthodontic treatment procedures. In each case, informed consent was obtained.

2.2 | The Importance of Mandibular Stabilization in Occlusal Therapy

A fundamental goal of dental treatment is to establish a healthy masticatory system. This requires not only a favorable occlusion but also proper neuromuscular function of the masticatory muscles and a functionally stable TMJ [10]. When the mandible can repeatedly and predictably assume a consistent position under these conditions, the state is referred to as mandibular stabilization, which is regarded as the foundation and primary objective of all occlusal therapies [1].

For the masticatory muscles to remain physiologically stable, the condyles must articulate in an anterosuperior position against the posterior slopes of the articular eminences. This position corresponds to the CR [11]. It should be noted that this condylar position is considered physiologically stable when the articular disc is properly interposed and adapted within the joint space, without signs of intracapsular pathology. When occlusion is not influencing mandibular position, the combined vectors of the closing muscles—masseter, temporalis, and medial pterygoid—naturally guide the condyles into the CR position. Therefore, achieving maximum intercuspation (MIP) in the CR position is biomechanically the most favorable state for maintaining functional muscular balance [12]. Furthermore, when MIP occurs in CR, the occlusion is likely to be interference-free, enhancing overall occlusal stability [13].

If occlusal interference is present, closure into MIP requires compensatory contraction of the inferior lateral pterygoid, an opening muscle [14]. This introduces a nonphysiological protective co-contraction, which, when chronic, may alter the mandibular closing path. Consequently, the condyles may be displaced from CR during MIP, a condition known as CR-MIP discrepancy [15].

Electromyographic studies have shown that such occlusal interferences during closure increase masticatory muscle activity, leading to fatigue and pain due to the sustained co-contraction [16, 17]. Temporomandibular disorders (TMDs) can develop when this muscular hyperactivity exceeds the patient's adaptive capacity [18]. In a study involving orthodontic patients, most subjects exhibited measurable CR-MIP discrepancies. Notably, 96.9% of patients with TMD symptoms demonstrated condylar displacements that exceeded clinical thresholds (≥ 1.6 mm horizontally, ≥ 2.0 mm vertically, ≥ 0.5 mm transversely) [19]. In contrast, patients who underwent full-mouth rehabilitation to minimize such discrepancies experienced an 84% reduction in TMD symptoms posttreatment and significantly fewer signs of TMD compared to untreated controls [20]. These findings suggest that although some patients may adapt to substantial CR-MIP discrepancies, achieving MIP in the CR position represents a biomechanically favorable reference condition for maintaining functional muscular balance. Therefore, when occlusal modification is planned, the goal should be to provide a physiologically favorable and stable masticatory system throughout the patient's lifetime. Hence, minimizing this discrepancy is clinically advantageous.

In addition, mandibular stabilization is essential for accurate diagnosis in occlusal therapy. During orthodontic treatment or occlusal adjustment, the elimination of occlusal interferences or the loss of centric stops in restorative procedures may result in the disappearance of protective co-contraction. In such cases, the mandibular condyle may be moved toward CR under the influence of masseter, temporalis, and medial pterygoid activity [14, 21]. As the posterior teeth act as a fulcrum, this movement may induce clockwise mandibular rotation, altering the occlusal plane and occlusal relationships. These changes can necessitate modifications to the original treatment plan, underscoring the importance of verifying mandibular stabilization at the diagnostic stage [4].

2.3 | Essential Tools for Mandibular Stabilization: The Articulator and Stabilization Splint

To provide a physiologically stable masticatory system, the final mandibular position at the end of treatment should ideally bring the condyles close to CR while the patient is in MIP. To achieve this, occlusal analysis using an articulator throughout diagnosis and treatment is essential [1, 21–23]. The articulator allows clinicians to evaluate the occlusion in a position unaffected by protective neuromuscular reflexes. Although it does not perfectly replicate the intraoral environment, mounting the models in CR provides more clinically meaningful insights into occlusal discrepancies than MIP-based diagnosis [24].

To evaluate whether the masticatory system is functionally stabilized, clinicians must assess the CR-MIP discrepancy on the

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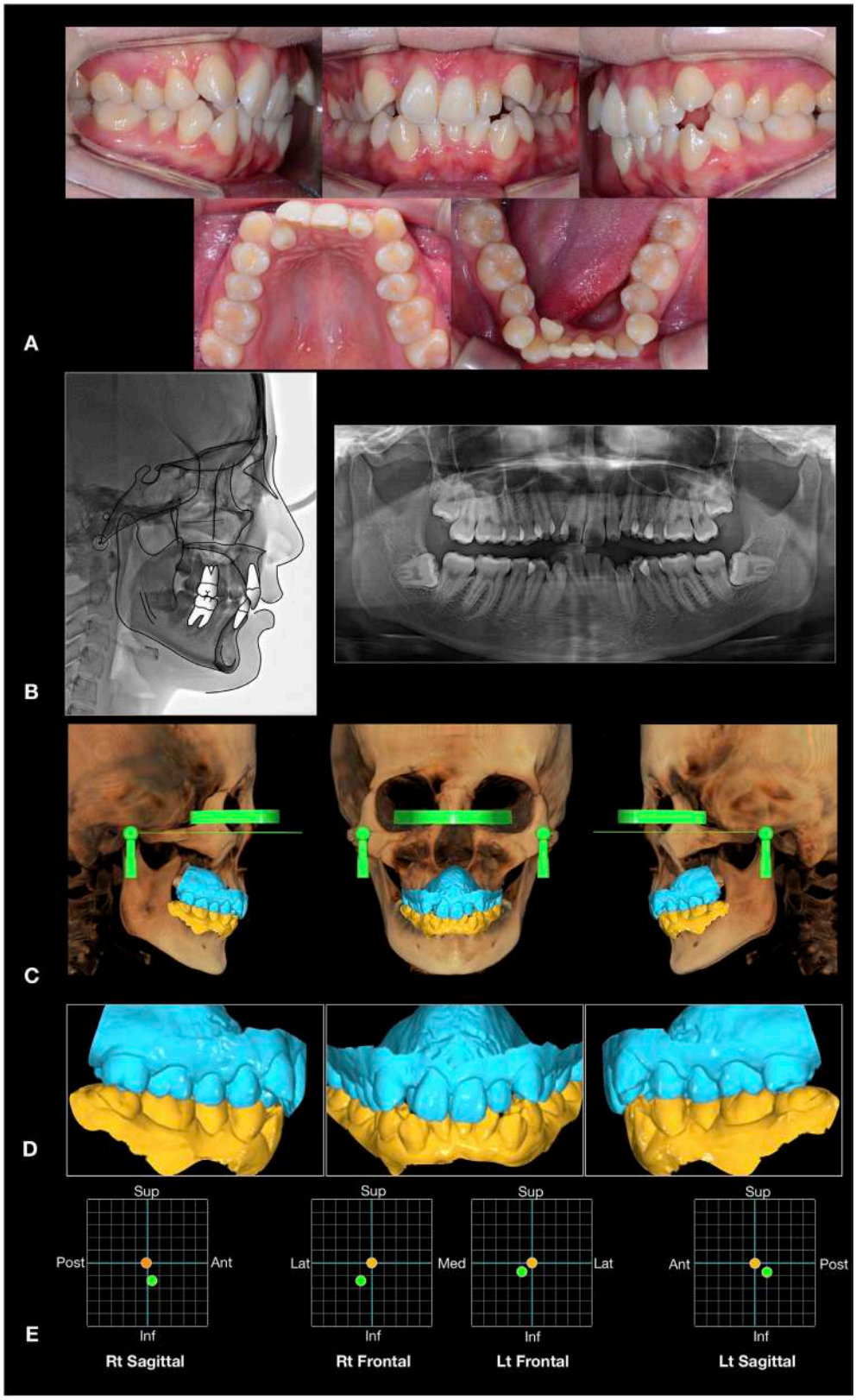


FIGURE 1 | (A) Pretreatment intraoral photographs; (B) pretreatment lateral cephalogram and panoramic radiograph; (C) pretreatment virtual articulator generated using CBCT scan data; (D) pretreatment CR occlusion observed on the virtual articulator; and (E) pretreatment centric relation-maximum intercuspal position (CR-MIP) discrepancy measured by the digital mandibular position indicator (MPI). Green indicates the condylar position at MIP, and yellow indicates the condylar position at CR. During the transition from CR to MIP, the right condyle shows an anteroinferior and rightward displacement of approximately 1.5 mm, while the left condyle demonstrates a posteroinferior and rightward displacement of approximately 1.0 mm.

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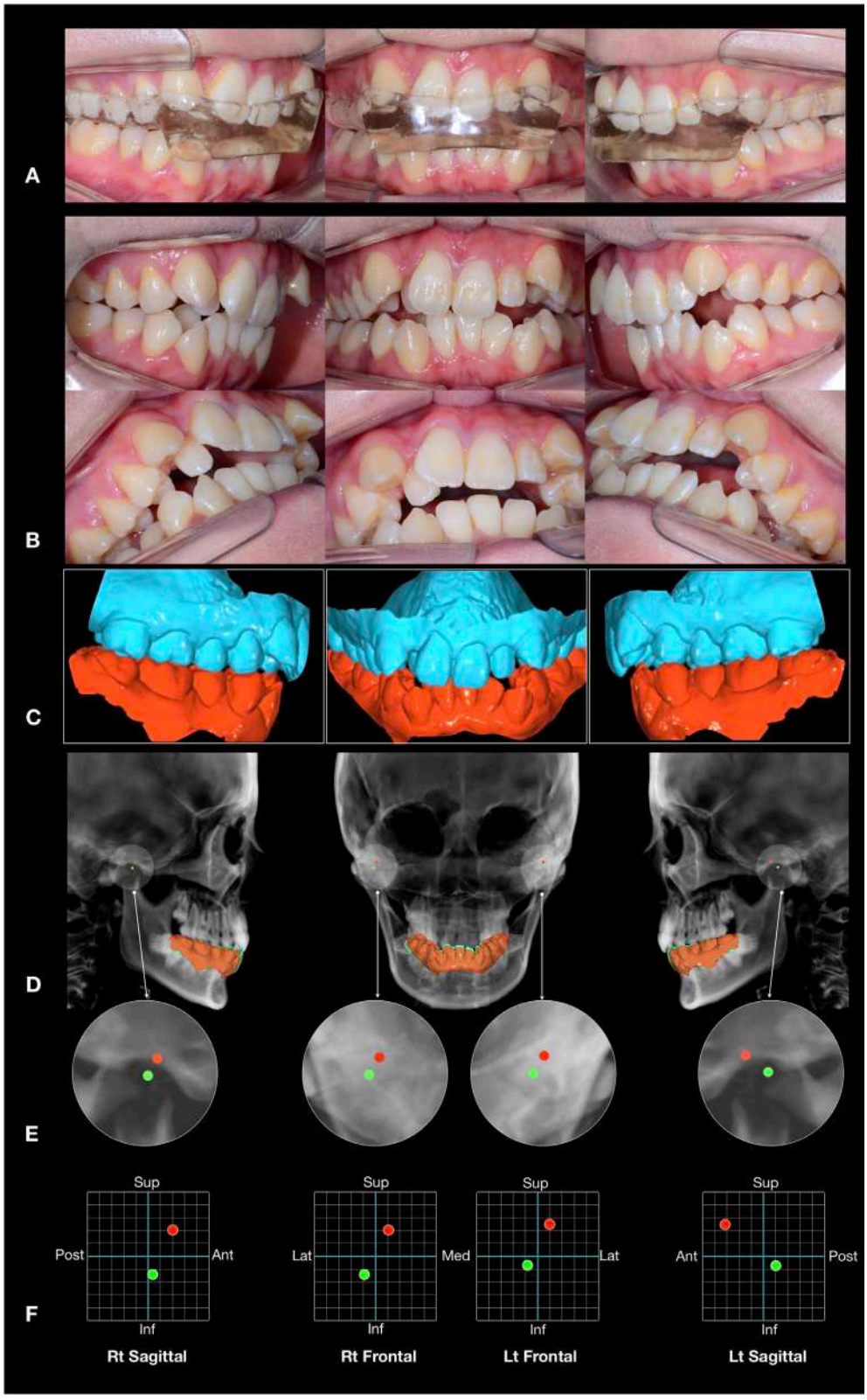


FIGURE 2 | (A) Digital stabilization splint in place; (B) poststabilization intraoral photographs; (C) poststabilization models virtually mounted in CR; (D) comparison of mandibular condylar points before and after stabilization (green dot: MIP, red dot: poststabilization CR); (E) magnified views of (D); and (F) difference between MPI data indicating changes in condylar positions after stabilization (green dot: MIP, red dot: poststabilization CR). After stabilization splint therapy, bilateral condylar positions showed displacement in an anterosuperior and leftward direction, indicating the condyles had moved into a more seated position.

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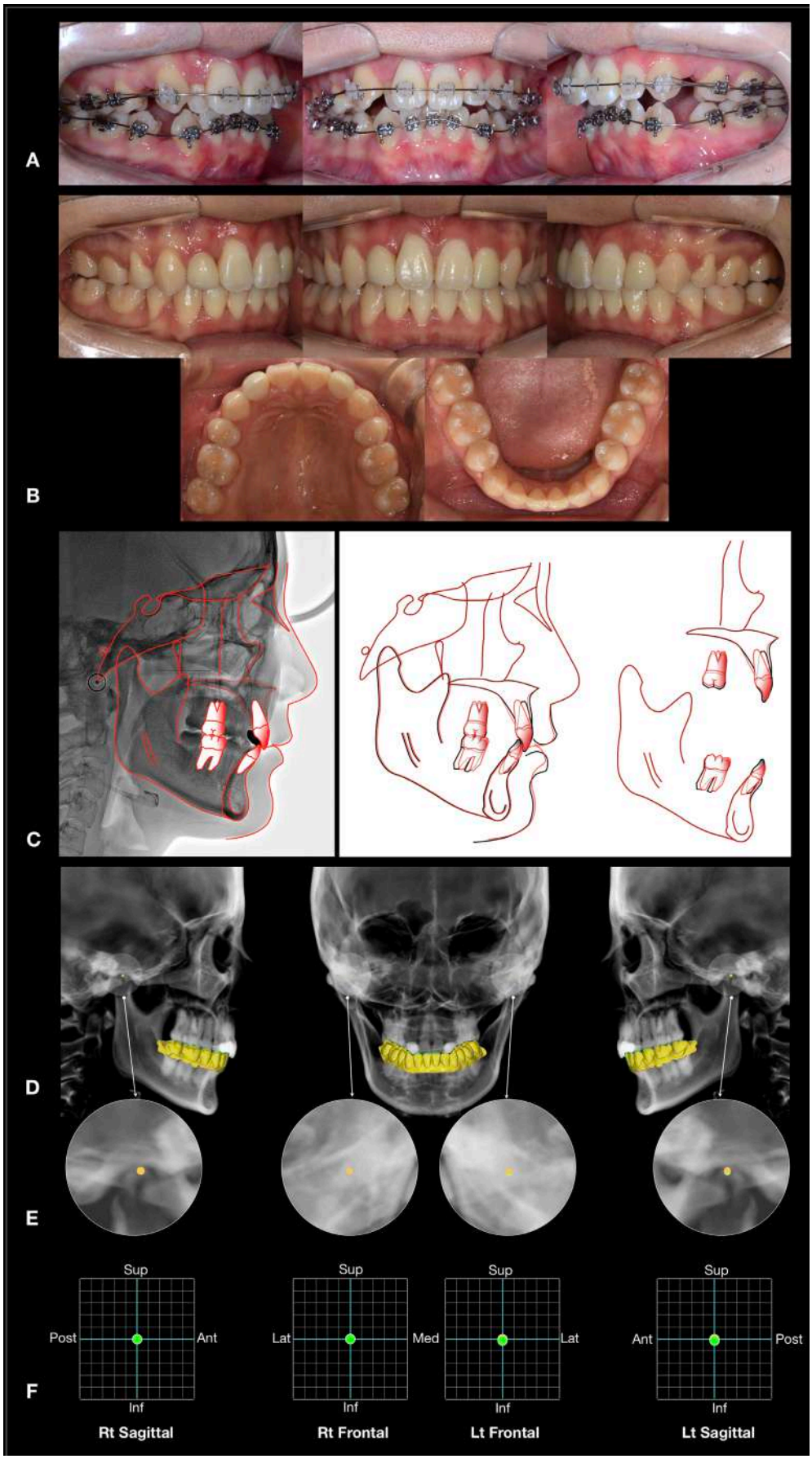


FIGURE 3 | Legend on next page.

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FIGURE 3 | (A) Intraoral photographs during orthodontic treatment; (B) posttreatment intraoral photographs; (C) posttreatment lateral cephalogram and cephalometric superimposition (black: pretreatment, red: posttreatment); (D) posttreatment CR-MIP discrepancy (yellow: CR, green: MIP); (E) magnified view of (D); and (F) posttreatment MPI sheet.

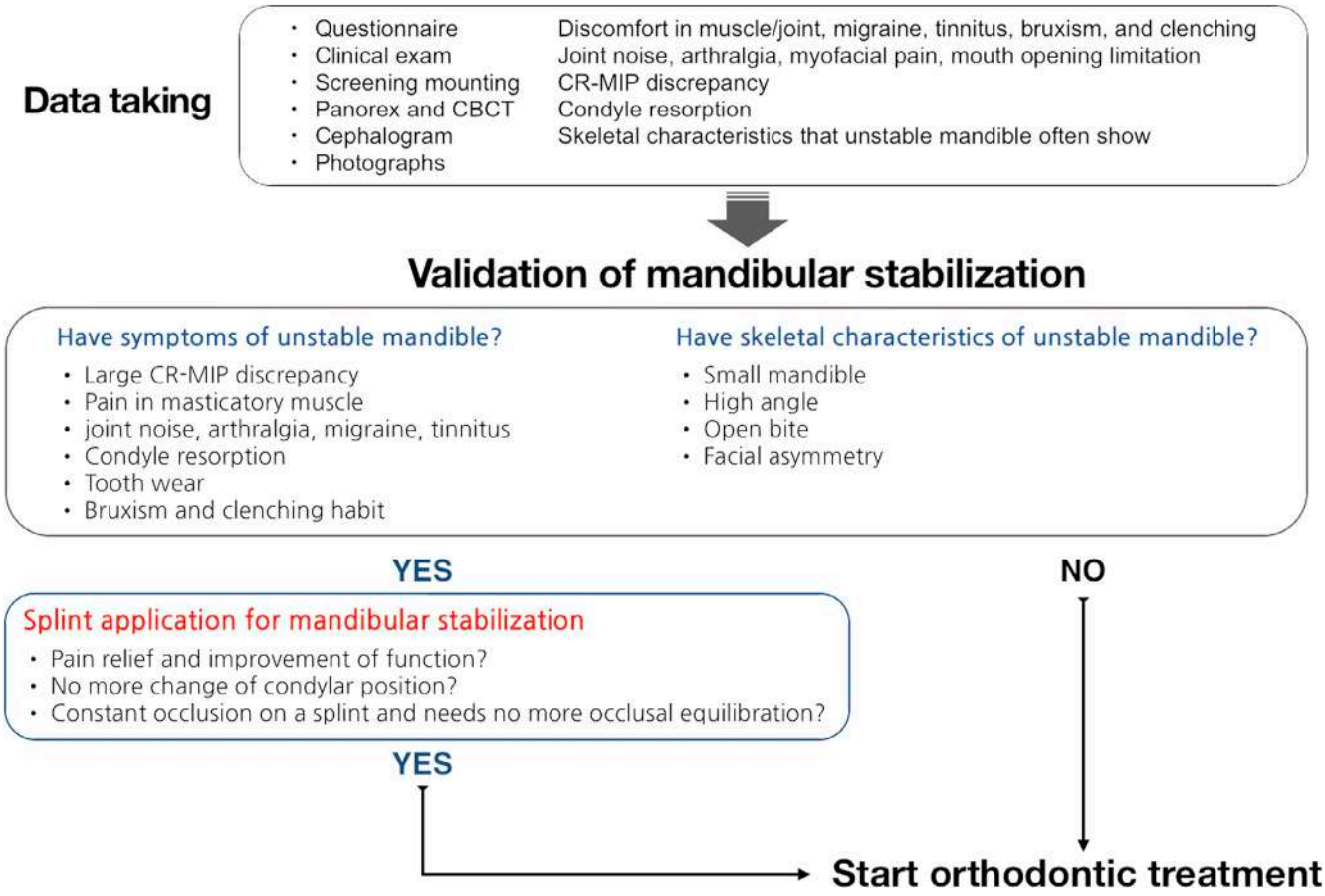


FIGURE 4 | Validation protocol for mandibular stability before orthodontic treatment.

articulator and evaluate condylar morphology using cone-beam computed tomography (CBCT). Panoramic radiographs may be used for preliminary assessment when indicated. Additionally, lateral and posteroanterior cephalograms are used to identify skeletal patterns associated with mandibular instability, including a small mandible, high mandibular plane angle, open bite, and facial asymmetry [25]. If mandibular instability is confirmed, stabilization using a stabilization splint should precede any orthodontic or prosthodontic intervention [1–5, 25–27] (Figure 4). Stabilization is not determined solely by symptom relief, as pain reduction may occur transiently even in the absence of true functional stability; rather, it is considered achieved when the patient exhibits no pain or dysfunction, with no further occlusal adjustments required on the splint for at least 3 months, and with no change in condylar position or occlusion during that period [1, 13, 26].

The stabilization splint alleviates protective co-contraction of the masticatory muscles, normalizes muscle activity, and physiologically stabilizes mandibular position [28]. It provides a reliable reference position for subsequent occlusal reconstruction [1, 3, 28]. Furthermore, it reduces loading on the TMJ [27], facilitating the formation of a pseudo-disc [29–31] and promoting bone remodeling between the condyle and articular fossa [32]. Adjustment of the anterior ramp inclination can improve mandibular movement patterns. In ultrasound-based joint motion analyses, patients with disc displacement exhibited more exaggerated and irregular lateral movements compared to healthy individuals [33]. When fitted with a stabilization splint featuring an anterior ramp inclined by approximately 50° to the axis–orbital plane, the patient's mandibular movement became more physiologically balanced [34].

Based on these findings, an effective stabilization splint should be designed so that all mandibular teeth simultaneously contact the occlusal surface of the splint when mounted on an articulator using a CR bite. The anterior ramp should be inclined by approximately 50° [6]. However, fabrication of such a precise splint requires accurate positioning of the maxillary cast using a face-bow transfer, CR-based mounting of the mandibular cast, and a high level of laboratory expertise—along with significant production time.

To overcome these limitations, recent efforts have focused on replacing the conventional stabilization process with a digital approach [7]. The following section introduces a fully digital protocol for mandibular stabilization, aimed at improving

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FIGURE 5 | Overview of the 3D digital data registration process. Several 3D digital datasets are prepared for use in this digital workflow.

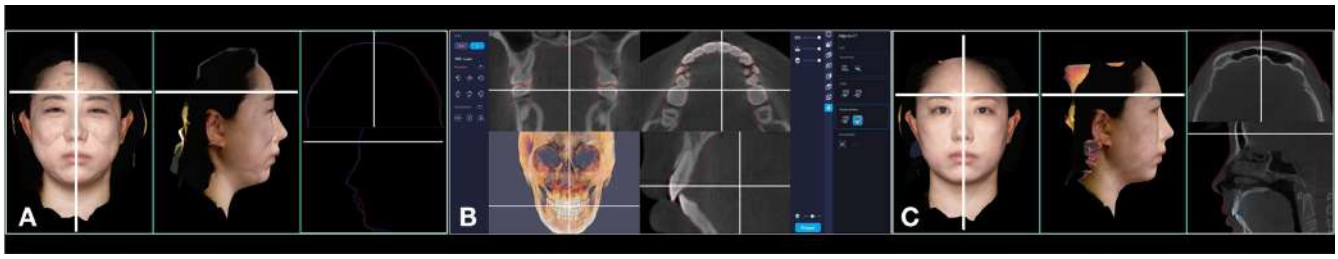


FIGURE 6 | Virtual patient construction. (A) Alignment of smile and lip-rest facial scans; (B) alignment of the digital maxillary cast with the CBCT scan; (C) final integrated virtual patient composed of facial scans, CBCT, and maxillary cast.

precision and efficiency through digital transformation of the traditional workflow.

3 | Digital Workflow for Mandibular Stabilization

The digital workflow for mandibular stabilization proposed in this study is a fully digital clinical protocol designed to replicate the traditional analog articulator-based treatment process within a virtual environment. This protocol involves the integration of patient-specific three-dimensional (3D) data to construct a virtual patient [35], followed by a virtual face-bow transfer and digital CR bite registration to mount the data on a virtual articulator. Based on this setup, a digital stabilization splint is designed and fabricated via 3D printing. All software and hardware used in this process are commercially available. The entire digital process consists of the following seven steps:

3.1 | Step 1: 3D Digital Data Registration (Figure 5)

The virtual patient is created using Rayface software (Ray America, USA), which registers the following 3D datasets:

- Intraoral scans: maxillary cast, mandibular cast, and CR bite registration.
- CBCT.
- And/or facial scans: captured under smile and lip-rest conditions.

3.2 | Step 2: Virtual Patient Construction (Figure 6)

Rayface software uses artificial intelligence (AI)-based auto-alignment to integrate diverse 3D datasets. The virtual patient is constructed through the following sequence:

1. Alignment of smile and lip-rest facial scans.
2. Alignment of the maxillary cast to the CBCT scan.
3. Integration of the two aligned datasets to produce a unified virtual patient incorporating the facial scans, CBCT, and maxillary cast.

After auto-alignment, a 3D cross-sectional inspection is performed to verify accuracy, and manual adjustments are made if necessary.

3.3 | Step 3: Virtual Articulator Mounting—Mandibular Cast Positioning (Figure 7)

The mandibular cast is positioned on the virtual patient using the CR bite as a reference. Rayface software employs a reference-based best-fit alignment protocol:

1. Align the CR bite scan to the maxillary cast.
2. Use the registered CR bite as a reference to position the mandibular cast.

This enables precise simulation of the mandibular position on the virtual articulator.

3.4 | Step 4: Virtual Face-Bow Transfer (Figure 8)

Rayface software uses AI-based auto-detection to identify orientation planes, such as the axis–orbital plane and Camper's plane, using anatomical landmarks like the hinge axis and orbitale. In this study, the virtual SAM articulator model from compuer-aided design (CAD) software (R2Gate, Megazen Implant, Korea) was imported and aligned to the auto-detected landmarks to perform the virtual face-bow transfer, with

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FIGURE 7 | Virtual articulator mounting process: Mandibular cast positioning. (A) Virtual patient with aligned maxillary cast; (B) alignment of the CR bite scan to the maxillary cast; and (C) mounting of the mandibular cast using the registered CR bite as reference.

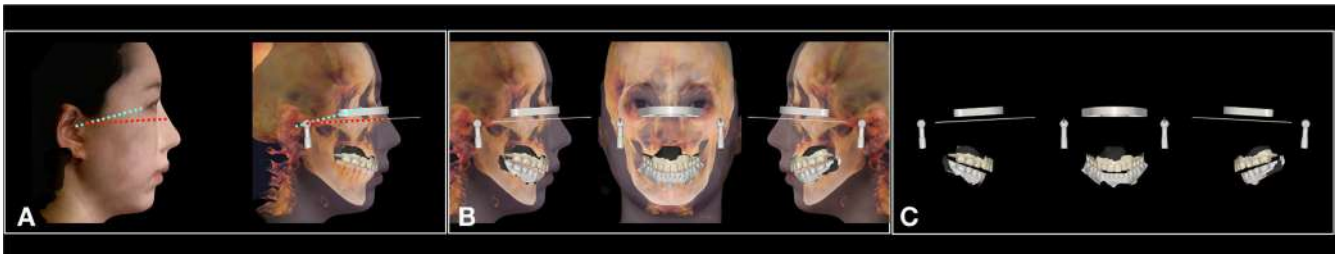


FIGURE 8 | Virtual face-bow transfer. (A) The articulator was imported and aligned to the reference plane based on the auto-detected landmarks; (B) completed virtual articulator mounting; (C) exported virtual articulator and CR mounted models.

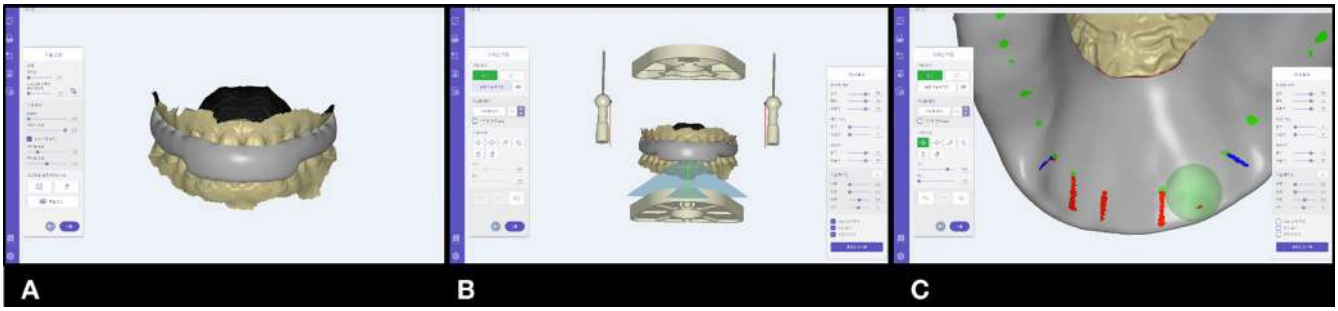


FIGURE 9 | Digital stabilization splint design process. (A) Initial splint outline generated by an AI-based design algorithm; (B) adjustment of condylar guidance and incisal table angles to simulate dynamic mandibular movement; and (C) refinement of the occlusal surface to achieve the desired occlusal scheme.

the axis–orbital plane serving as the reference for articulator mounting.

3.5 | Step 5: Digital Stabilization Splint Design (Figures 9 and 10)

The mounted virtual articulator dataset is transferred to the RAYDENT Splint (Raydent, Korea) CAD software for stabilization splint design. This software supports dynamic mandibular movement simulation, allowing the clinician to adjust the condylar guidance and incisal table inclination to achieve a target anterior ramp angle. The final design is optimized by simulating centric and eccentric occlusal contacts and anterior guidance to ensure the intended occlusal scheme prior to fabrication (Figure 10).

In this workflow, splint retention was managed in the RAYDENT Splint CAD environment by controlling the internal surface morphology. Given the relatively high rigidity of commonly used 3D printing resins, the software allows the clinician to selectively preserve minimal undercut regions in designated areas to fine-tune retention while avoiding excessive insertion resistance. This design-based approach enabled predictable retention in the digitally fabricated stabilization splint.

3.6 | Step 6: 3D Printing and Post-Processing (Figure 11)

The designed stabilization splint is imported into RAYDENT Studio (Raydent, Korea) for 3D printing preparation. The software offers automatic slicing and the generation of supportive structures. The printing orientation is set with the labial surface of the splint facing downward, and supportive structures are attached to this surface for easier post-processing. Printing is performed using an liquid crystal display (LCD) type 3D printer (RAM600, Ray America, USA) with Clear Splint Resin (ODS, Incheon, Korea). Approximate print time is 90 min.

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Post-processing steps include:

1. Removal of supportive structures.
2. Washing with isopropyl alcohol, including internal surfaces with a micro-brush.
3. Complete drying followed by post-curing using UV light in an RPC 500 unit (Ray America, USA).
   - Two cycles of curing are performed, rotating the splint between cycles.
   - This process improves strength, surface smoothness, and biocompatibility.
4. Final trimming and polishing of the cured splint.

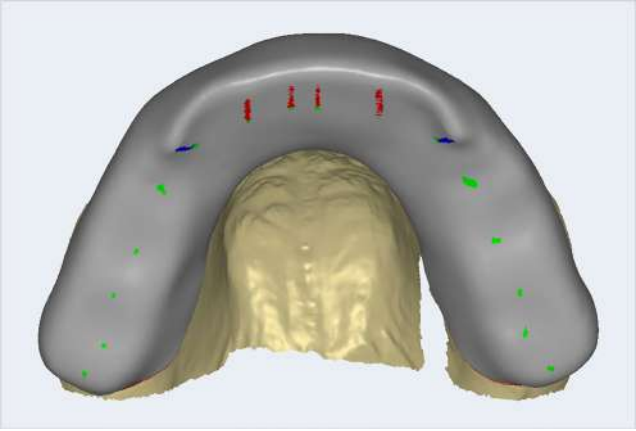


FIGURE 10 | Final digital stabilization splint design with centric and eccentric occlusal contacts visualized in the CAD environment. The posterior region of the appliance demonstrates contact only in CR. During lateral movements, only the mandibular canine exhibits laterotrusive contact on the appliance. During protrusive movement, even and simultaneous contact is observed on the mandibular incisors. These simulated contact patterns represent the intended occlusal scheme prior to fabrication.

3.7 | Step 7: Delivery and Follow-Up (Figures 12–14)

The stabilization splint is delivered to the patient and evaluated to ensure it guides the mandible into the intended occlusal scheme. Patients are recalled every two weeks for follow-up assessments, during which time the splint's occlusal surface may be adjusted. Additionally, the condylar position is monitored using intraoral scans of updated CR bite registrations, and positional changes of the condyles are assessed over time.

4 | Discussion

With the recent adoption of advanced 3D digital data acquisition technologies and the development of alignment algorithms, digital workflows are increasingly being applied across various dental fields. The full digital workflow for mandibular stabilization presented in this study is a clinical approach made possible by such technological advancements.

A virtual face-bow transfer refers to the process of aligning a digital maxillary cast to the articulator orientation plane (e.g., axis–orbital plane, Camper's plane) based on the patient's anatomical reference landmarks [36, 37]. This procedure utilizes CBCT or face scan data as reference, aligning the maxillary cast accordingly and matching the orientation plane of the virtual articulator to the same reference frame [8, 38].

Previous studies have reported that a virtual face-bow transfer using CBCT as a reference yields accuracy and precision comparable to conventional analog methods [39]. However, since a large field-of-view (FOV) CBCT is required, this approach results in significant radiation exposure and is thus not suitable for simple prosthodontic cases. Recently, the introduction of low-dose CBCT systems and the ability to perform virtual face-bow transfers using small FOV scans containing only the articulator orientation plane have made the technique clinically feasible without radiation-related concerns. This approach is particularly efficient in orthodontic or interdisciplinary treatment



FIGURE 11 | Printing and postprocessing. (A) LCD-type 3D printer used for splint fabrication; (B) 3D-printed stabilization splint; (C) postcuring machine used for final polymerization.

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FIGURE 12 | (A) Pretreatment intraoral photographs; (B) application of the stabilization splint; and (C) occlusion changes after splint therapy.

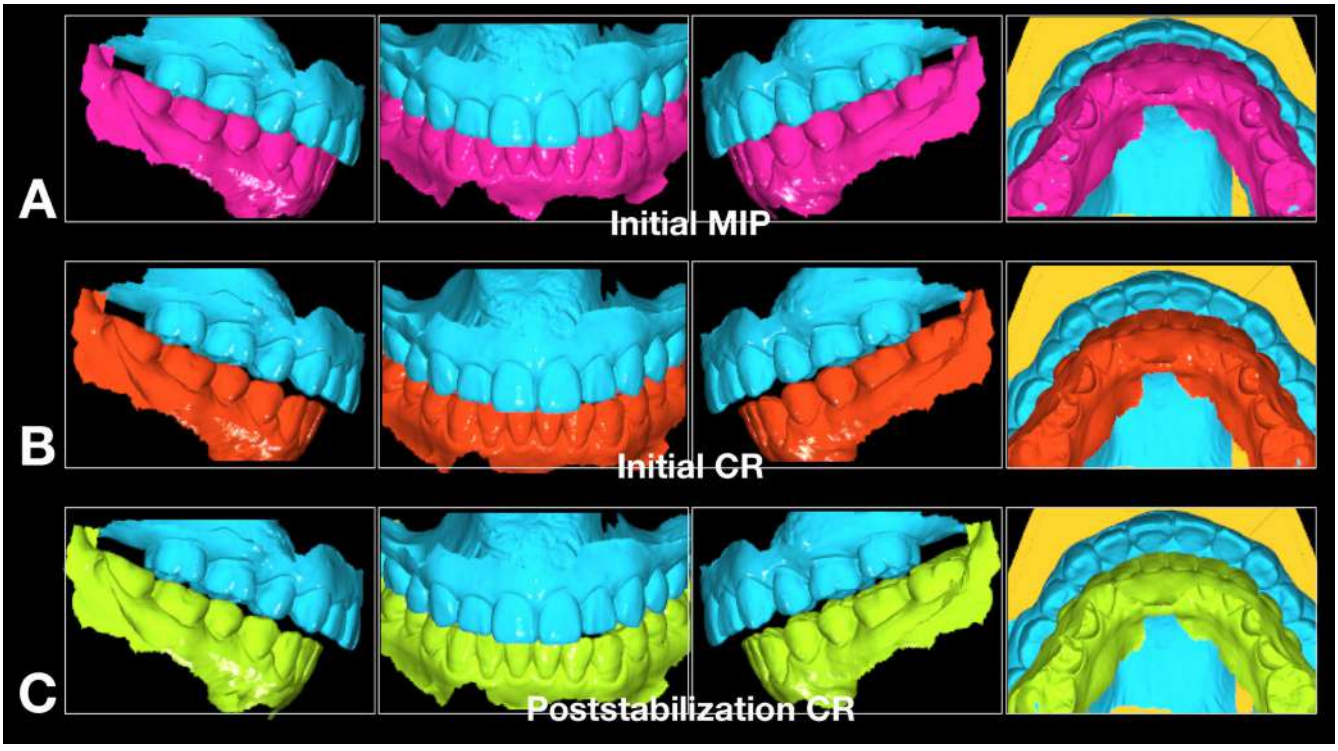


FIGURE 13 | Mounted models on a virtual articulator. (A) Pretreatment MIP mounted models; (B) pretreatment CR mounted models; and (C) poststabilization CR mounted models.

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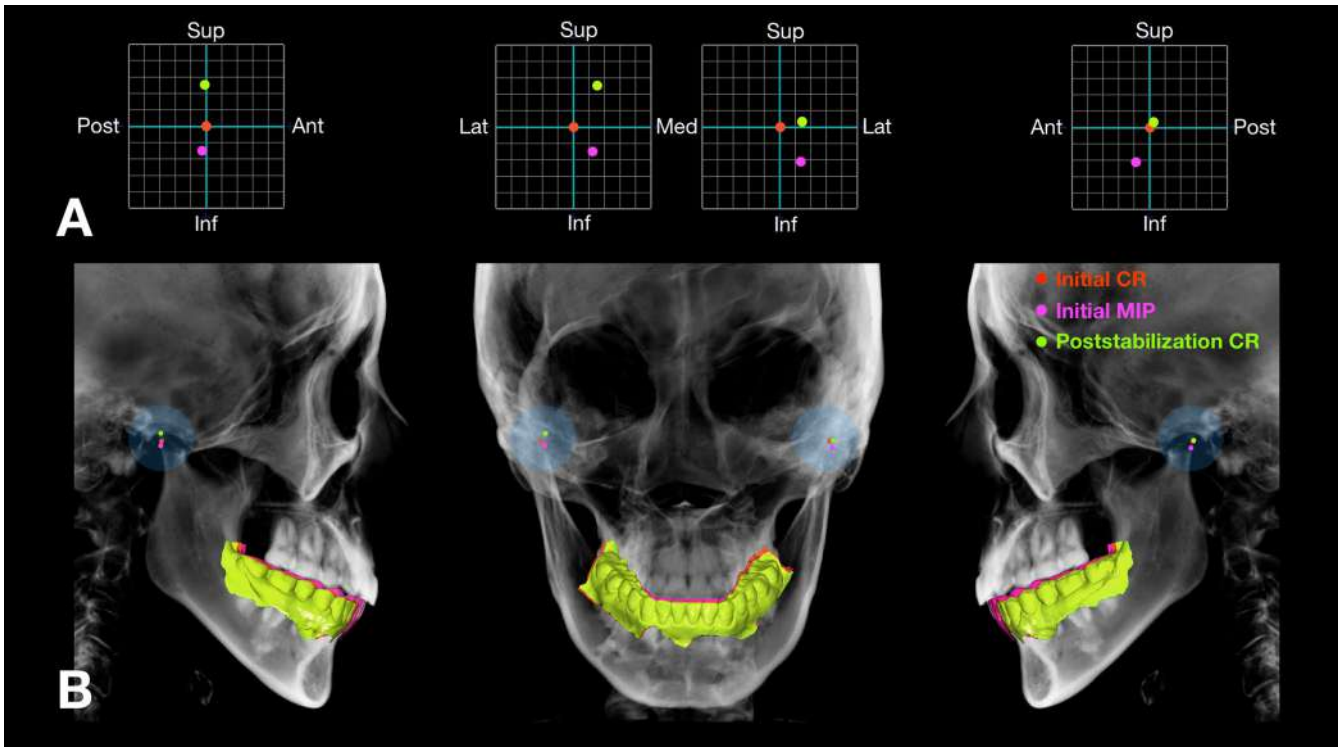


FIGURE 14 | Changes in condylar hinge position after stabilization splint treatment. (A) MPI data showing quantitative and directional information on condylar position changes after stabilization and (B) CBCT-based visualization of hinge point changes.

settings, where diagnosis and appliance design can be accomplished with a single CBCT scan [40].

Face scan data also contains true anatomical size information and is therefore valid for virtual face-bow transfers [8, 41]. However, because direct alignment between lip rest face scans and digital maxillary casts is not feasible, an indirect approach is required. The digital maxillary cast is first aligned with a smile face scan that exposes the maxillary anterior teeth, which is then aligned with the lip rest face scan. Previously introduced face scanners were unable to accurately capture the depth of maxillary anterior teeth, making it necessary to use scan bodies in this alignment process, thereby increasing complexity [42, 43]. In contrast, the hybrid-type face scanner used in this study accurately captures the depth of anterior teeth, allowing direct alignment between the smile face scan and the digital maxillary cast without a scan body [44]. The integrated dataset is then merged with the lip rest face scan, enabling full-face reference alignment. This entire procedure is rapidly and accurately executed using AI-based auto-alignment, followed by manual refinement through 3D sectional analysis.

Since an articulator positions the upper and lower casts based on the hinge axis to analyze occlusion, its use requires precise alignment of the virtual articulator's condylar ball centers with the patient's hinge axis in the reference data [13]. In this study, the Beyron point [45] on the face scan was automatically identified using AI auto-detection and used as the patient's hinge point for the virtual face-bow transfer (Figure 8). Recent studies have noted slight discrepancies in articulator orientation planes when using CBCT versus face scan data as reference [46]. To address this, our workflow incorporates a unified virtual patient integrating both CBCT and face scan data, allowing for verification of alignment accuracy between the two references.

A stabilization splint must provide simultaneous occlusal contact of the mandibular teeth on the splint surface while the condyles are in CR to eliminate protective co-contraction of the masticatory muscles and promote appropriate muscle activity and TMJ stabilization [6]. Achieving this requires highly accurate digital CR bite registration and precise virtual mounting of the mandibular cast [8]. While previous studies have shown digital bite registration to be more accurate than conventional interocclusal records [47–49], errors can occur in cases with incomplete occlusal contacts, such as with multiple preparations or edentulous areas, due to insufficient stitching data [50–56]. This issue is more pronounced in CR bites than in MIP bites, which inherently have spacing between maxillary and mandibular arches [8]. Some studies have reported that missing data in less-contacted regions may result in localized excessive spacing and compensatory tilting in other areas [57]. Thus, careful consideration is needed to take an accurate CR bite registration to fabricate a stabilization splint which can provide simultaneous occlusal contact of the mandibular teeth. Among various CR registration methods, using an anterior device (e.g., leaf gauge, deprogrammer, hard wax) to relax the lateral pterygoid muscle and activate the elevator muscles is a commonly employed strategy. However, in the digital CR bite registration process, this only anterior contact might increase the risk of a tilting error. Furthermore, the alignment algorithm significantly affects the accuracy of digital bite registration [58]. Common techniques include landmark-based best-fit, global best-fit, and reference best-fit alignment. Of these, reference best-fit—using the iterative closest point algorithm on a user-specified region—has

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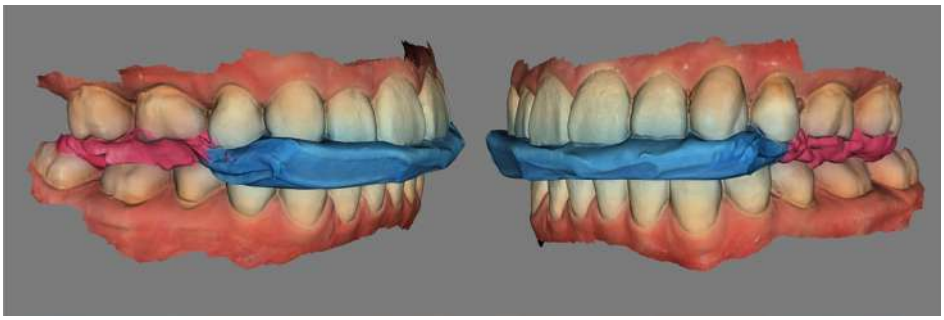


FIGURE 15 | CR bite registration was captured from the buccal surface with the occlusal record placed between maxillary and mandibular teeth using an intraoral scanner.

been reported as the most accurate method [59]. Accordingly, in this study, hard wax (Delar Bite-Registration Wax, Delar Corp, USA) was used in the anterior region, while a vinyl polysiloxane bite material was used posteriorly to ensure complete occlusal contact [60–62] (Figure 15). The mandibular cast was then mounted in CR using the reference best-fit alignment algorithm in Rayface software.

In both analog and digital workflows, the accuracy of mandibular mounting in CR is influenced by the hinge axis reference and the thickness of the interocclusal record. When an exact hinge axis is transferred, changes in vertical dimension do not alter the arc of closure. However, when an arbitrary or average hinge axis is used—as in most semi-adjustable articulator systems—alterations in vertical dimension may introduce rotational discrepancies during closure. To minimize such errors, the CR bite record in this study was obtained at a vertical dimension corresponding to the intended posterior splint thickness. By avoiding the opening or closing of the articulator after mounting, this approach reduces potential rotational error and facilitates simultaneous, even posterior occlusal contacts in the fabricated stabilization splint.

The slope of the anterior ramp in the stabilization splint can be adjusted to guide the mandible along a more physiologic functional pathway [63]. The RaySplint CAD software used in this study not only reproduces the current occlusal condition but also enables modification of anterior guidance by adjusting the condylar inclination and the incisal guide table within the virtual articulator, with dynamic mandibular simulation further enhancing splint design. In this context, the extent of extension of the anterior ramp and the amount of disocclusion were not defined by a fixed numerical value but were determined based on the functional objective of the stabilization splint. The anterior ramp was designed to provide immediate posterior disocclusion during excursive movements while maintaining stable and simultaneous posterior contacts in CR. This design aims to reduce posterior occlusal interferences, decrease loading on the TMJs, and guide mandibular movements along a physiologic pathway. By allowing controlled anterior guidance, the splint facilitates muscular relaxation and functional mandibular stability without introducing unnecessary lateral mandibular movements.

For fabrication, stereolithography (SLA), digital light processing (DLP), and LCD are the primary types of resin-based 3D printers used for splints. While SLA has been reported to offer the highest accuracy, the LCD printer we used in our study was sufficiently accurate for splint fabrication, with advantages of lower cost and faster print times, making it well-suited for clinical application. Print direction can also affect precision and accuracy. With SLA printers, printing splints at 0° yields the best internal fit and shortest printing time [64]. However, with LCD printers, previous studies have found no significant differences in accuracy based on orientation, and vertical orientation may even improve precision [65]. Additionally, post-processing ease should be considered when selecting print orientation. If support structures are located near occlusal contact areas or in thin sections, post-processing becomes difficult. Therefore, we oriented the splint nearly vertically and positioned the support structures on the outer labial surface of the splint, facing downward, to avoid critical contact areas.

In a digital workflow, it is equally important to verify that mandibular stabilization has been clinically achieved. Clinical symptoms alone cannot confirm mandibular stability; in addition to resolving pain and dysfunction, the absence of the need for occlusal adjustment and maintaining condylar position for at least 3 months should be evaluated. Serial digital CR bite registrations during splint use allow monitoring of condylar positional changes and assessment of mandibular stability [66].

Similar to other digital workflows, there exists a learning curve associated with virtual face-bow transfer and the fabrication of digital splints. However, compared with conventional analog articulator mounting and stabilization splint fabrication, which require highly experienced manual skill, the digital workflow offers a more structured and reproducible process. Step-by-step visualization, guided data registration algorithms, and reduced reliance on operator-dependent procedures can make mandibular stabilization protocols user-friendly.

The integration of AI technologies into clinical dentistry is accelerating. In this workflow, AI algorithms were utilized for 3D data alignment, facial landmark detection, block-out procedures, and splint base generation, thereby automating and simplifying the digital process. Further incorporation of AI at various stages will be essential to making mandibular stabilization using a digital workflow more efficient, accurate, and accessible.

5 | Conclusion

This clinical article presents a fully digital workflow for mandibular stabilization that integrates virtual face-bow transfer,

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digitally CR bite registration, virtual articulator mounting, and CAD-based fabrication of stabilization splints. The proposed protocol provides a clinically feasible and reproducible method for achieving and verifying mandibular stability while preserving established occlusal principles within a digital environment.

Author Contributions

Danal Moon contributed to the review and writing the case. Jae Hyun Park contributed to supervising overall project including writing. Jong Cheol Kim contributed to treating the case. Sang Mi Lee contributed to the review and writing the case. Dong-Hwa Tom Chung contributed to the review and writing the case. Gye Hyeong Lee contributed to treating the case including writing.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. R. H. Roth and D. A. Rolfs, "Functional Occlusion for the Orthodontist. Part II," *Journal of Clinical Orthodontics* 15 (1981): 100–123.

2. G. H. Lee, S. M. Lee, and J. H. Park, "The Role of Mandibular Stabilization in Orthognathic Surgery," *Seminars in Orthodontics* 25 (2019): 188–204.

3. D. Moon, J. H. Park, and G. H. Lee, "Orthodontic Treatment for a Patient With an Anterior Open Bite and Severe Condylar Resorption," *American Journal of Orthodontics and Dentofacial Orthopedics* 157 (2020): 392–407.e2.

4. G. H. Lee, J. H. Park, D. N. Moon, and S. M. Lee, "Protocols for Orthodontic Treatment of Patients With Temporomandibular Joint Disorders," *American Journal of Orthodontics and Dentofacial Orthopedics* 159 (2021): 373–388.

5. G. H. Lee, J. H. Park, S. M. Lee, and D. N. Moon, "Orthodontic Treatment Protocols for Patients With Idiopathic Condylar Resorption," *Journal of Clinical Pediatric Dentistry* 43 (2019): 292–303.

6. D. Moon, J. H. Park, S. M. Lee, et al., "Application of Stabilization Splint in Orthodontic Treatment," *Clinical Journal of the Korean Association of Orthodontists* 13, no. 3 (2023): 233–243.

7. K. C. Lee, J. H. Park, J. C. Kim, S. Lee, D. Moon, and G. H. Lee, "Digital Application of Three-Dimensional Diagnosis and Treatment With a Virtual Articulator," *Journal of Esthetic and Restorative Dentistry* 36, no. 5 (2024): 710–722.

8. D. Moon, J. H. Park, H. Kim, et al., "Evaluation of Occlusion Using 3D Digital Data: Virtual Articulator and Virtual Mandibular Positioning Indicator," *Clinical Journal of the Korean Association of Orthodontists* 13, no. 4 (2023): 308–318.

9. G. H. Lee, J. H. Park, Y. G. Park, D. Moon, and S. M. Lee, "Orthodontic Treatment of an Open Bite After Splint Therapy for a Patient With Idiopathic Condylar Resorption," *Journal of the World Federation of Orthodontists* 13 (2024): 38–47.

10. R. Roth, "JCO Roundtable: Diagnosis and Treatment Planning," *Journal of Clinical Orthodontics* 26 (1992): 585–606.

11. The Academy of Prosthodontics, "The Glossary of Prosthodontic Terms. 10th Ed," *Journal of Prosthetic Dentistry* 130 (2023): e1–e126.

12. J. P. Okeson, "Evolution of Occlusion and Temporomandibular Disorder in Orthodontics: Past, Present, and Future," *American Journal of Orthodontics and Dentofacial Orthopedics* 147 (2015): S216–S223.

13. P. E. Dawson, "Centric Relation," in *Functional Occlusion: From TMJ to Smile Design* (Mosby, 2007).

14. J. H. Park, S. M. Lee, D. N. Moon, and G. H. Lee, "Clinical Application of a Maximum Intercuspal Position-Centric Relation Occlusion Conversion of a Lateral Cephalogram in the Treatment of Orthodontic Patients," *American Journal of Orthodontics and Dentofacial Orthopedics Clinical Companion* 1 (2021): 127–135.

15. P. E. Dawson, "A Classification System for Occlusions That Relates Maximal Intercuspation to the Position and Condition of the TM Joints," *Journal of Prosthetic Dentistry* 75 (1996): 60–68.

16. S. P. Ramfjord, "Dysfunctional Temporomandibular Joint and Muscle Pain," *Journal of Prosthetic Dentistry* 11 (1961): 353–374.

17. E. H. Williamson and D. O. Lundquist, "Anterior Guidance: Its Effect on Electromyographic Activity of the Temporal and Masseter Muscles," *Journal of Prosthetic Dentistry* 49 (1983): 816–823.

18. J. P. Okeson, *Management of Temporomandibular Disorder and Occlusion*, 8th ed. (Elsevier, 2020).

19. F. E. Cordray, "Articulated Dental Cast Analysis of Asymptomatic and Symptomatic Populations," *International Journal of Oral Science* 8 (2016): 126–132.

20. S. D. Crawford, "The Relationship Between Condylar Axis Position as Determined by the Occlusion and Measured by the CPI Instrument and Signs and Symptoms of TM Joint Dysfunction," *Angle Orthodontist* 69 (1999): 103–116.

21. F. E. Cordray, "Three-Dimensional Analysis of Models Articulated in the Seated Condylar Position From a Deprogrammed Asymptomatic Population: A Prospective Study. Part 1," *American Journal of Orthodontics and Dentofacial Orthopedics* 129 (2006): 619–630.

22. F. E. Cordray, "Centric Relation Treatment and Articulator Mountings in Orthodontics," *Angle Orthodontist* 66 (1996): 153–158.

23. R. H. Roth, "Temporomandibular Pain-Dysfunction and Occlusal Relationship," *Angle Orthodontist* 43 (1973): 136–153.

24. D. Martin and R. Cocconi, "Orthodontic Dental Casts: The Case for Routine Articulator Mounting," *American Journal of Orthodontics and Dentofacial Orthopedics* 141 (2012): 8–16.

25. G. H. Lee, S. M. Lee, S. K. Yoo, and J. H. Park, "Chapter 41. Orthodontic Treatment of TMD Patients With Posterior Intrusion Using TADs," in *Temporary Anchorage Devices in Clinical Orthodontics*, ed. J. H. Park (Wiley, 2020), 415–431.

26. T. J. Dylina, "A Common-Sense Approach to Splint Therapy," *Journal of Prosthetic Dentistry* 86 (2001): 539–545.

27. J. H. Park, S. M. Lee, D. N. Moon, and G. H. Lee, "Orthodontic Treatment of a Patient With Severe TMD," *Journal of Clinical Orthodontics* 54 (2020): 537–550.

28. E. H. Dyer, "Importance of a Stable Maxillomandibular Relation," *Journal of Prosthetic Dentistry* 30 (1973): 241–251.

29. R. P. Scapino, "Histopathology Associated With Malposition of the Human Temporomandibular Joint Disc," *Oral Surgery, Oral Medicine, and Oral Pathology* 55 (1983): 382–397.

30. P. E. Dawson, "New Definition for Relating Occlusion to Varying Conditions of the Temporomandibular Joint," *Journal of Prosthetic Dentistry* 74 (1995): 619–627.

31. G. H. Lee, J. H. Park, S. M. Lee, and D. N. Moon, "New Definition for Relating Occlusion to Varying Conditions of the Temporomandibular Joint: Conditions of the Temporomandibular Joint Orthodontists Need to Know," *American Journal of Orthodontics and Dentofacial Orthopedics Clinical Companion* 1 (2021): 181–186.

17088240, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jerd.70139 by A.T. Still University Of The H, Wiley Online Library on [28/03/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

32. S. M. Ok, J. H. Lee, Y. I. Kim, J. Y. Lee, K. B. Kim, and S. H. Jeong, "Anterior Condylar Remodeling Observed in Stabilization Splint Therapy for Temporomandibular Joint Osteoarthritis," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology* 118 (2014): 363–370.

33. B. T. Choi, D. Y. Hwang, G. H. Lee, D. N. Moon, and K. M. Lee, "Computerized Ultrasonic Axiographic Evaluation of Condylar Movement in Patients With Internal Derangement of the Temporomandibular Joint," *Angle Orthodontist* 89 (2019): 924–929.

34. B. T. Choi and S. H. Baek, "Effect of Anterior Guidance Change on the Condylar Path in Skeletal Class I Young Adult Women Using a Splint With Flat or Steep Anterior Guidance," *Journal of Korean Dental Science* 5, no. 1 (2012): 29–36.

35. T. Joda and G. O. Gallucci, "The Virtual Patient in Dental Medicine," *Clinical Oral Implants Research* 26 (2015): 725–726.

36. M. Revilla-León, J. M. Zeitler, and J. C. Kois, "An Overview of the Different Digital Facebow Methods for Transferring the Maxillary Cast Into the Virtual Articulator," *Journal of Esthetic and Restorative Dentistry* 36 (2024): 1675–1686.

37. L. Lepidi, M. Galli, F. Mastrangelo, et al., "Virtual Articulators and Virtual Mounting Procedures: Where Do We Stand?," *Journal of Prosthodontics* 30 (2021): 24–35.

38. J. H. Park, G. H. Lee, D. N. Moon, J. C. Kim, M. Park, and K. M. Lee, "A Digital Approach to the Evaluation of Mandibular Position by Using a Virtual Articulator," *Journal of Prosthetic Dentistry* 125 (2021): 849–853.

39. H. Lin, Y. Pan, X. Wei, Y. Wang, H. Yu, and H. Cheng, "Comparison of the Performance of Various Virtual Articulator Mounting Procedures: A Self-Controlled Clinical Study," *Clinical Oral Investigations* 27 (2023): 4017–4028.

40. L. Lepidi, Z. Chen, A. Ravida, T. Lan, H. L. Wang, and J. Li, "A Full-Digital Technique to Mount a Maxillary Arch Scan on a Virtual Articulator," *Journal of Prosthodontics* 28, no. 3 (2019): 335–338.

41. N. Inoue, R. Scialabba, J. D. Lee, and S. J. Lee, "A Comparison of Virtually Mounted Dental Casts From Traditional Facebow Records, Average Values, and 3D Facial Scans," *Journal of Prosthetic Dentistry* 131, no. 1 (2024): 136–143.

42. J. H. Park, G. H. Lee, D. N. Moon, K. D. Yun, J. C. Kim, and K. C. Lee, "Creation of Digital Virtual Patient by Integrating CBCT, Intraoral Scan, 3D Facial Scan: An Approach to Methodology for Integration Accuracy," *Journal of Cranio-Maxillo-Facial Surgery* 33 (2022): e396–e398.

43. D. Moon, J. H. Park, K. C. Lee, et al., "3D Virtual Patient in Dentistry: Dental Avatar," *Clinical Journal of the Korean Association of Orthodontists* 13, no. 1 (2023): 78–90.

44. G. H. Lee, J. H. Park, J. J. Park, K. C. Lee, S. M. Lee, and D. Moon, "Key Considerations for Efficient 3-Dimensional Data Integration With a Face Scanner in the Digital Era: Product Review of the Hybrid Face Scanner," *AJO-DO Clinical Companion* 4 (2024): 351–359.

45. D. Raghav, K. Kapoor, A. Alqahtani, M. Kola, and F. Alqahtani, "Intricate Relations and Concepts of Reference Points in Prosthodontics: A Literature Review," *European Journal of Prosthodontics* 4 (2016): 1–6.

46. Y. Wang, X. Wang, L. Li, and M. Cao, "Evaluating Sagittal Condylar Inclination: A Comparative Analysis of Various Digital Workflow Measures," *Head & Face Medicine* 20 (2024): 69.

47. R. DeLong, C.-C. Ko, G. C. Anderson, J. S. Hodges, and W. H. Douglas, "Comparing Maximum Intercuspal Contacts of Virtual Dental Patients and Mounted Dental Casts," *Journal of Prosthetic Dentistry* 88 (2002): 622–630.

48. E. Solaberrieta, J. R. Otegi, N. Goicoechea, A. Brizuela, and G. Pradies, "Comparison of a Conventional and Virtual Occlusal Record," *Journal of Prosthetic Dentistry* 114 (2015): 92–97.

49. Y. Zheng, T. Zheng, Y. Liu, et al., "Evaluation Methods and Influencing Factors on Accuracy for Static Virtual Articulation Obtained by Intraoral Scanners: A Critical Review of the Literature," *Journal of Esthetic and Restorative Dentistry* 37 (2025): 378–399.

50. E. Solaberrieta, A. Arias, A. Brizuela, X. Garikano, and G. Pradiess, "Determining the Requirements, Section Quantity, and Dimension of the Virtual Occlusal Record," *Journal of Prosthetic Dentistry* 115 (2016): 52–56.

51. Y. Iwaki, N. Wakabayashi, and Y. Igarashi, "Dimensional Accuracy of Optical Bite Registration in Single and Multiple Unit Restorations," *Operative Dentistry* 38 (2013): 309–315.

52. S. Ren, D. Morton, and W. S. Lin, "Accuracy of Virtual Interocclusal Records for Partially Edentulous Patients," *Journal of Prosthetic Dentistry* 123, no. 6 (2020): 860–865.

53. A. Gintaute, A. J. Keeling, C. A. Osnes, N. U. Zitzmann, M. Ferrari, and T. Joda, "Precision of Maxillo-Mandibular Registration With Intraoral Scanners In Vitro," *Journal of Prosthodontic Research* 64, no. 2 (2020): 114–119.

54. S. Abdulateef, F. Edher, A. G. Hannam, D. L. Tobias, and C. C. L. Wyatt, "Clinical Accuracy and Reproducibility of Virtual Interocclusal Records," *Journal of Prosthetic Dentistry* 124 (2020): 667–673.

55. M. Revilla-León, A. B. Barmak, H. Tohme, B. Yilmaz, J. C. Kois, and M. Gómez-Polo, "Factors That Influence the Accuracy of Maxillomandibular Relationship at Maximum Intercuspation Acquired by Using Intraoral Scanners: A Systematic Review," *Journal of Dentistry* 138 (2023): 104718.

56. N. Chinam, M. Bekkali, M. Kallas, and J. Li, "Virtual Occlusal Records Acquired by Using Intraoral Scanners: A Review of Factors That Influence Maxillo-Mandibular Relationship Accuracy," *Journal of Prosthodontics* 32, no. S2 (2023): 192–207.

57. F. Edher, A. G. Hannam, D. L. Tobias, and C. C. Wyatt, "The Accuracy of Virtual Interocclusal Registration During Intraoral Scanning," *Journal of Prosthetic Dentistry* 120 (2018): 904–912.

58. X. Garikano, X. Amezua, M. Iturrate, and E. Solaberrieta, "Evaluation of Repeatability of Different Alignment Methods to Obtain Digital Interocclusal Records: An In Vitro Study," *Journal of Prosthetic Dentistry* 131, no. 4 (2024): 709–717.

59. M. Revilla-León, A. Gohil, A. B. Barmak, A. Zandinejad, A. J. Raigrodski, and J. Alonso Pérez-Barquero, "Best-Fit Algorithm Influences on Virtual Casts' Alignment Discrepancies," *Journal of Prosthodontics* 32, no. 4 (2023): 331–339.

60. S. O'Toole, C. Osnes, D. Bartlett, and A. Keeling, "Investigation Into the Accuracy and Measurement Methods of Sequential 3D Dental Scan Alignment," *Dental Materials* 35 (2019): 495–500.

61. Y. Arslan, M. B. Gungor, S. K. Nemli, et al., "Comparison of Maximum Intercuspal Contacts of Articulated Casts and Virtual Casts Requiring Posterior Fixed Partial Dentures," *Journal of Prosthodontics* 26 (2017): 594–598.

62. F. Beck, S. Lettner, L. Z. Cepic, and A. Schedle, "Comparison of Virtual Intersection and Occlusal Contacts Between Intraoral and Laboratory Scans: An In-Vivo Study," *Journal of Clinical Medicine* 12 (2023): 996.

63. G. Goldstein and C. Goodacre, "Selecting a Virtual Articulator: An Analysis of the Factors Available With Mechanical Articulators and Their Potential Need for Inclusion With Virtual Articulators," *Journal of Prosthodontics* 32 (2023): 10–17.

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64. M. T. Vasques and D. C. Laganá, "Accuracy and Internal Fit of 3D Printed Occlusal Splint, According to the Printing Position: A Technique Report," *Clinical Laboratory Research in Dentistry* 4 (2018): 1–6.

65. S. R. Cruz-Araújo, M. A. Sampaio-Fernandes, B. N. de Freitas, A. A. Simionato, M. H. Figueiral, and A. P. Macedo, "Accuracy of Occlusal Splints Printed in Different Orientations by Liquid Crystal Display Technology: An in Vitro Study," *Journal of Dentistry* 152 (2025): 105461.

66. J. H. Park, K. M. Lee, J. C. Kim, et al., "Evaluation of Mandibular Position for Splint Therapy Using a Virtual Articulator," *Journal of Clinical Orthodontics* 8 (2020): 466–472.

17088240, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jerd.70139 by A.T. Still University Of The H, Wiley Online Library on [28/03/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License