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Effect of digital bite registration condition and scanner type on the accuracy of 3D printed occlusal splints

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Abstract

Objective: The present study aimed to evaluate the accuracy of occlusal splints created at different bite registration conditions using two intraoral scanners.

Methods: Dental arches were mounted in the maximum intercuspation position and scanned using Trios 3 and Medit i700 scanners under three conditions: closed mouth position, and open bite to 4 mm with or without bite registration material. Eight splints were printed for each bite registration mode and scanner type (total=48), using a Phrozen 3D printer. The splints were placed on the model and scanned using a desktop scanner. The scans were superimposed on the digital file of the designed splint. The root mean square (RMS) deviation was calculated to represent the discrepancy between the designed and printed splints. The distance between the splint and the mandibular teeth was also measured. Data analysis was performed using a two-way ANOVA (α=0.05).

Results: Bite registration mode did not affect the RMS and the distance between the splint and the mandibular teeth (P>0.05). The scanner type did not influence the RMS values and posterior and total distance between the splint and the mandibular teeth (P>0.05). However, using the Trios 3 scanner led to a significantly greater distance between the splint and the mandibular teeth in the anterior region compared to that of the Medit i700 scanner (P=0.016).

Conclusions: Bite registration condition did not affect the accuracy of occlusal splints. Splints fabricated with the Medit i700 scanner had a better anterior fit than those scanned with the Trios 3 scanner.

Keywords: Bite registration, CAD-CAM, Oral scanner, Occlusal splints, Three-dimensional printing

Introduction

Temporomandibular disorders (TMDs) are a group of pathologies involving structural, functional, or physiological changes in the jaw joint and masticatory system. The management of TMDs has increasingly shifted toward minimally invasive or noninvasive approaches, including counselling, psychotherapy, physiotherapy, pharmacotherapy, low-level laser therapy (LLLT) and occlusal therapy (1-3).

Occlusal splints, also known as night guards or bite guards, are intraoral devices designed to stabilize the temporomandibular joint, improve occlusal conditions, and promote normal muscle function (4). Additionally, they protect teeth and supporting structures against attrition (5). For the effective function of these devices, precise occlusal contact with the opposing dentition is crucial, necessitating accurate bite registration (6).

Occlusal splints are traditionally fabricated by impression-making of both arches, then pouring stone models, and recording the mandibular position in centric relation (7). Various materials, including wax, acrylic resin, zinc oxide-eugenol, and elastomers, have been commonly used for bite registration (8). An ideal material should be accurate, dimensionally stable, easy to handle, and biocompatible (9, 10). However, the use of these materials is technique-sensitive and often requires significant clinical skill to ensure accuracy and reproducibility.

The advent of intraoral scanners has introduced a promising alternative to conventional impression techniques. Intraoral scanners capture digital impressions of the dental arches using narrow beams of light, enabling the creation of 3D digital models that can be stored electronically (13, 14). Digital scanning addresses many limitations of conventional impression materials, including dimensional instability and handling challenges, while offering comparable accuracy (15).

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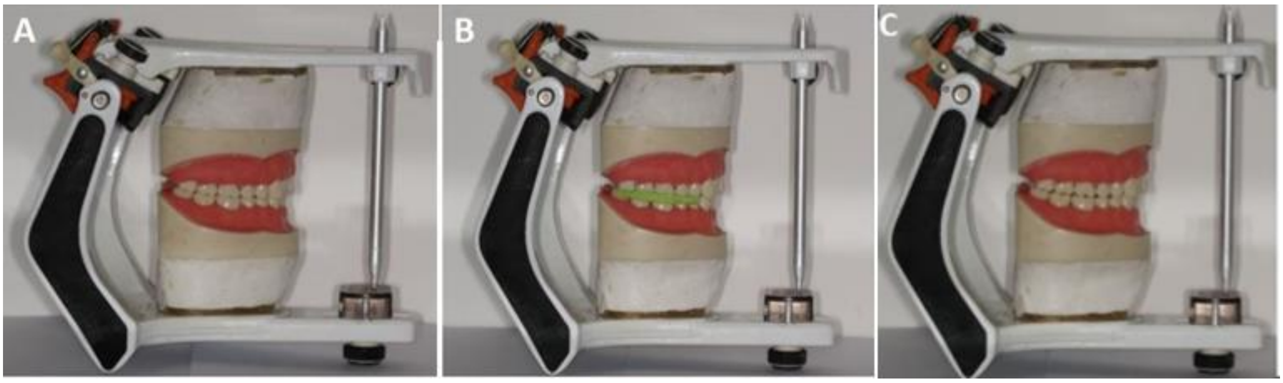

Figure 1. A-C) Different scanning modes: A) Closed mouth, B) Open bite with bite registration material, and C) Open bite without bite registration material

The digital workflow for occlusal splint fabrication typically involves capturing digital impressions of both arches, bite registration, and the use of computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies (4). Accurate bite registration is crucial for fabricating occlusal splints. Several factors can influence bite registration, including body posture, head position, the angle of the dental chair backrest, and the type of bite registration material used (16). Consequently, the bite registration process may be susceptible to various potential errors.

Some studies have reported that bite registration with intraoral scanners leads to a similar accuracy to conventional bite registration (17-19). Camcı et al. (20) also found that digital bite registration is a viable alternative to silicone materials. However, there is little evidence to show how the absence of bite registration material during increased vertical dimension (VD) adjustments impacts the accuracy of occlusal splints fabricated with intraoral scanners. Therefore, the present study aimed to evaluate the accuracy of occlusal splints created at an increased VD, with and without a bite registration material, using two intraoral scanners: Trios 3 and Medit i700.

Materials and methods

The protocol for the present study was approved by the ethics committee of Mashhad University of Medical Sciences (IR.MUMS.DENTISTRY.REC.1402.004).

Dental arch mounting

Maxillary and mandibular dental models were articulated in maximum intercuspation on a BioArt A7 plus articulator (São Carlos, São Paulo, Brazil), with the incisal pin set to the zero position. Complete scanning of the arches was performed using two intraoral scanners:

- Trios 3 (3 Shape Trios A/S, Copenhagen, Denmark).
- Medit i700 (Medit Inc., Seoul, South Korea).

Scanning of the buccal and lingual surfaces of both arches started from the maxillary second molar on the right side and proceeded sequentially to the maxillary second molar on the left side.

For bite registration, the buccal region arches were scanned under three conditions (Figure 1):

- Closed mouth position (Figure 1A).
- Open bite using polyvinyl siloxane bite registration material (Jet Blue Bite, Coltène, Switzerland; Figure 1B).
- Open bite without bite registration material (Figure 1C).

For the open bite conditions, VD was increased to 4 mm at the incisal pin, corresponding to approximately 2 mm in the posterior region. The bite registration material was directly applied to the occlusal surfaces using the spreader tip provided by the manufacturer.

For each condition, separate occlusal scans of the right and left quadrants were acquired, extending anteriorly to the incisor region of both arches. The scanners were calibrated before each scanning session according to the manufacturer's guidelines. One operator performed the scanning procedure.

Splint design

The scanned data were imported into the respective software platforms for designing occlusal splints. In the Medit Link software, the Medit Splint module was used to manually design splints. The maxillary scans were aligned to the occlusal plane, and the midline position was determined. A 2 mm separation between opposing posterior teeth was maintained, with an offset of 0.1mm and a retention value of 0.4 mm. Undercuts were blocked out automatically at a block-out angle of 0°, and the occlusion was manually fine-tuned to ensure uniform contact points between the buccal cusp tips of the mandibular teeth and the splint. Any red contact points were eliminated to achieve uniform green contact points. The finalized designs were saved in Standard Triangle Language (STL) format using the "Complete Splint Fabrication" function.

In the 3Shape Trios Design Studio, the "Splint Fabrication" module was used for designing splints. The maxillary scans were aligned to the occlusal plane, and the bite was adjusted to achieve a 2 mm opening in the posterior region. The retention value was set to 0.5 mm, the offset to 0.1 mm, and the splint thickness to 2 mm. Undercuts were blocked out at a block-out angle of 0°, and the occlusion was manually adjusted to establish uniform contact points, as explained previously. The final designs were saved in STL format.

3D printing

The STL files from both software platforms were imported into the Chitubox software, where they were positioned horizontally on the printing platform. The printing parameters included a layer height of 0.05 mm, a bottom layer count of 6, an exposure time of 7 seconds, a bottom exposure time of 25 seconds, and a transition layer count of 6, according to the splint resin manufacturer's instructions. A transparent resin (DETAX GmbH, Ettlingen, Germany) was used for splint fabrication following the manufacturer's guidelines. For each condition, eight splints were fabricated using a 3D printer (Phrozen 3D, Hsinchu City, Taiwan).

Once the splints were printed, the support structures were removed. The uncured resin was washed from the surface with isopropyl alcohol (IPA) 99% for three minutes using a washing machine, followed by a second IPA bath for two minutes. The 3D printed parts were then left for 30 minutes in a dark room for the evaporation of IPA. The polymerization was completed using a UV-polymerization machine with a wavelength of 405 nm at the light power intensity of 40 mW/cm^2.

Figure 2. Placing the fabricated splints on the maxillary teeth

Evaluating occlusal splints accuracy

After removing excess resin from the occlusal surfaces, each splint was repositioned on the model (Figure 2). The splints were scanned in occlusion using the Rainbow desktop scanner prime (Dentium, Suwon, Korea). All STL files were uploaded into the Medit Design software to evaluate the accuracy of splints (Figure 3).

In the software's alignment mode, the original design file for each splint served as the reference while the scanned STL file was designated as the target. The digital

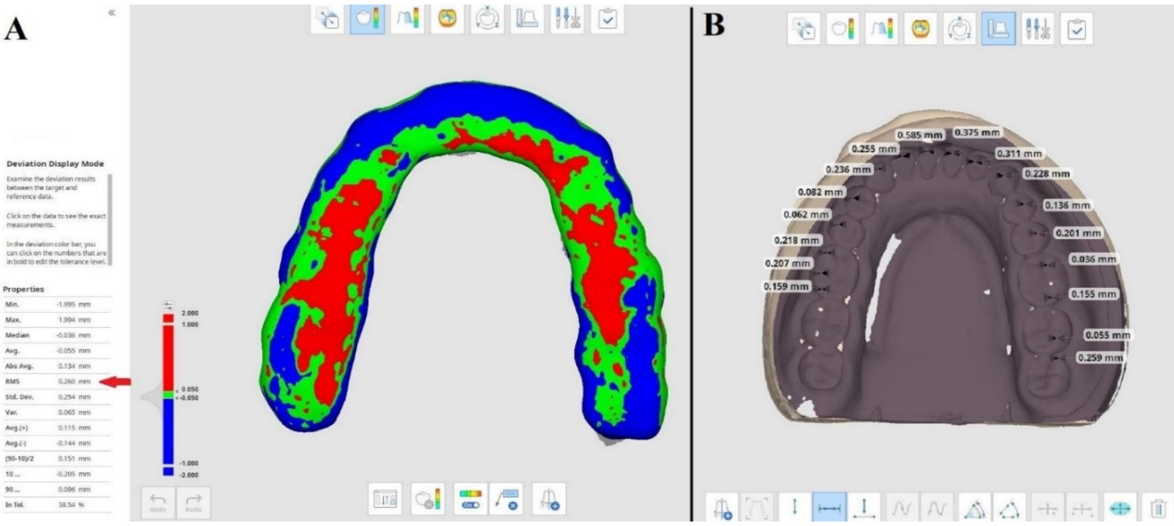

Figure 3. Evaluating splints accuracy: A) Superimposing of final scans and initial scans to measure the RMS deviation. Green areas indicate perfect alignment; B) measuring the distance of the mandibular buccal cusps from the splint. White points at the buccal cusps represent a contact between the splint and the mandibular teeth.

Table 1. The root mean square (RMS) values based on bite registration mode and scanner type

	Scanner	Bite registration mode			Total
		Closed bite	Open bite without bite registration	Open bite with bite registration	
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
RMS	Trios 3	0.31 ± 0.03	0.33 ± 0.03	0.29 ± 0.04	0.31 ± 0.03
	Medit i700	0.35 ± 0.06	0.30 ± 0.02	0.34 ± 0.12	0.33 ± 0.05
	Total	0.33 ± 0.05	0.31 ± 0.32	0.31 ± 0.08	
The effect of scanner type on RMS: P=0.51					
The effect of bite registration condition on RMS: P=0.87					
The interaction between the two factors: P=0.49					

files were manually superimposed by matching three reference points, including two on the canines and one on the first molar. Using the analysis software, the root mean square (RMS) value obtained from the color-difference map was used to quantify the deviation between the designed and printed splints, with values closer to zero indicating higher accuracy (Figure 3A).

Additionally, the distance between the printed splint and the mandibular teeth was measured at the buccal and incisal cusp tips, with a maximum of 22 measurement points per case (Figure 3B). A prosthodontist (A.M.) superimposed the files and evaluated the splints' accuracy.

Statistical analysis

The Kolmogorov-Smirnov test confirmed the normal distribution of the data (P>0.05). Statistical analyses were performed using SPSS software (version 26, IBM Corp., Armonk, NY, USA) with a significance level set at P<0.05. A two-way ANOVA was used to perform data analysis.

Results

Table 1 indicates the RMS values among the groups. The two-way ANOVA showed no statistically significant interaction effect between the bite registration condition and the type of the scanner on RMS values (P=0.49). Additionally, neither the bite registration condition nor the scanner type had a significant effect on RMS values (P>0.05; Table 1).

Table 2 shows the discrepancy between the printed splints and the functional cusp of mandibular teeth. The two-way ANOVA indicated no statistically significant interaction effect between bite registration condition

Table 2. The discrepancy (mm) between the printed splints and the functional cusp of mandibular teeth

		Bite registration mode			
Discrepancy	Scanner	Closed bite	Open bite without bite registration	Open bite with bite registration	Total
Posterior	Trios 3	0.33 ± 0.16	0.57 ± 0.09	0.39 ± 0.02	0.43 ± 0.14
	Medit i700	0.42 ± 0.25	0.44 ± 0.11	0.59 ± 0.25	0.49 ± 0.20
	Total	0.38±0.19	0.51±0.11	0.49±0.19	
The effect of scanner type on Posterior: P=0.50					
The effect of bite registration condition on Posterior: P=0.39					
The interaction between the two factors: P=027					
Anterior	Trios 3	1.17 ± 0.37	1.79 ± 0.39	1.44 ± 0.13	1.46 ± 0.38
	Medit i700	1.20±.51	1.02±.19	0.71 ± 0.46	0.97 ± 0.41
	Total	1.18±0.40	1.40±0.50	1.07 ± 0.46	
The effect of scanner type on Anterior: P=0.016					
The effect of bite registration condition on Anterior: P=0.32					
The interaction between the two factors: P=0.15					
Total	Trios 3	0.56±.21	0.90±.16	0.67 ± 0.04	0.71 ± 0.20
	Medit i700	0.63±.32	0.60 ± 0.13	0.62 ± 0.26	0.62 ± 0.22
	Total	0.60±0.25	0.75 ± 0.21	0.65 ± 0.21	
The effect of scanner type totally: P=0.37					
The effect of bite registration condition totally: P=0.46					
The interaction between the two factors: P=0.32					

and scanner type on anterior, posterior, or total discrepancies (P>0.05; Table 2). Moreover, the bite registration condition did not significantly affect anterior, posterior, and total discrepancy levels between the printed splints and the functional cusp of mandibular teeth (P>0.05; Table 2). The scanner type also was not influential on the posterior and total (P>0.05; Table 2). However, the Trios 3 scanner exhibited significantly higher discrepancy compared to the Medit i700 scanner in the anterior region (P=0.016).

Discussion

The present study evaluated the accuracy of occlusal splints created at an increased vertical dimension with and without a bite registration material, using two intraoral scanners, Trios 3 and Medit i700. Accuracy was assessed using the root mean square (RMS) error method, which is a widely used quantitative metric for assessing the trueness and precision of digital impressions (21).

In the present study, some deviations were observed between the designed and printed splints in all groups. The manufacturing and post-processing methods add deviation in the digital workflow. However, the intraoral environment allows for a degree of adaptation when the device is placed in the mouth. Therefore, these small deviations are not considered clinically significant (22).

In this study, no significant differences in RMS values were observed between the scanners. Similar to the present study, Ciocan et al. (23) reported comparable RMS values for the Medit i700 (174 µm) and Trios 3 (165 µm). However, their study did not include the fabrication of a physical appliance.

In the present study, the average RMS value of splints scanned with the Trios 3 in open bite mode with bite registration material was 0.29 ± 0.04 mm, while the Medit i700 yielded an average RMS value of 0.34 ± 0.12 mm. Blasi et al. (24) reported that the RMS values of splints fabricated with a digital workflow using the Trios 3 scanner and a milling machine were 0.14 ± 0.07 mm, which was lower than that of the present study. The difference could be due to using a Phrozen 3D printer for producing the splints in the current study. Milled appliances generally display superior accuracy compared to 3D-printed appliances (25, 26). The accuracy outcomes in this study were similar to the results associated with the analog workflow found in the study of Blasi et al. (0.23 ± 0.10 mm). Anitua et al. (22) emphasized that the 3Shape Trios 3 and Carestream CS 3800 are suitable for the digital manufacturing of occlusal splints.

When the printed splints were analyzed, the anterior region showed a significantly higher discrepancy in the Trios 3 than the Medit i700. The lower discrepancy of the Medit i700 in the anterior region might be due to its better maneuverability, slim profile, and slightly smaller tip size than the Trios 3 scanner (22.2 × 15.9 mm^2 versus 21.0 × 19.83 mm^2) (23). The difference in scanning technology may also affect the accuracy results. However, no significant differences were identified in the posterior region or the overall splint accuracy between the groups.

The Trios 3 scanner utilizes the confocal microscopy imaging principle. Confocal scanning technology is an optical imaging technique that creates high-resolution images using spatial filtering. It focuses a narrow beam of light at specific depths to capture 2D images, which are then reconstructed into a 3D structure of the scanned object through optical sectioning. Medit i700 uses triangulation scan technology. Triangulation is a non-contact optical imaging technique used to capture digital data of 3D objects. It involves projecting a laser spot onto the object's surface at a fixed angle, while a camera positioned at a known offset captures the reflected light. This setup forms a triangle between the laser emitter, the laser spot on the object, and the camera sensor, enabling precise calculation of the object's surface geometry (27).

The outcomes of this study are consistent with the results of Alharbi et al (31) who reported that Medit i700 had significantly higher accuracy than CEREC AC Omnicam, Trios 3, and iTero Element 2 in scanning the maxilla. In contrast, Osman et al. (27) reported that for scanning edentulous maxilla, the Trios 3 scanner displayed a higher trueness, precision, and scan time than the Medit i700. It should be noted that intraoral scanners have lower accuracy in impression-taking for edentulous patients compared to dentate patients (28, 29).

The results of this study demonstrated that digital impressions obtained with either scanner were comparable across all tested occlusions, including closed occlusion and open bite with and without bite registration material. Furthermore, the difference between the bite registration modes did not influence the accuracy of the printed splints.

In contrast to the outcomes of this study, Revilla-León et al. (16) reported that the scanning accuracy of the Trios 4 scanner is influenced by the interocclusal space. The authors adjusted the incisal pin of the articulator at 0, 1, 2, 3, and 4 degrees. They concluded that the smallest and largest available interocclusal space showed the worst and highest trueness and precision values, respectively. The authors declared that the reduced overlap between the maxillary and mandibular teeth enhances the performance of the intraoral scanner software's alignment algorithm. The variations in scanner models and CAD-CAM technologies may explain differences in results between the studies. Different CAD programs have distinct algorithms that might result in maxillomandibular discrepancies (32). Moreover, the prosthetic device was not printed in the study of Revilla-León et al. (16). Three-dimensional printing itself might cause errors, and printing the occlusal splints in the present study might also explain the different findings.

The outcomes of this study support the growing evidence indicating that virtual bite registration is a valid and efficient technique compared to conventional techniques with bite registration materials. Iwaki et al. (33) and Solaberrieta et al. (34), reported superior accuracy of digital bite registration compared to conventional methods for specific applications, such as single posterior crowns and virtual occlusion. Abdulateef et al. (35) reported that virtual records obtained using the CEREC Omnicam scanner had a sensitivity of 87% and a specificity of 95% compared to PVS bite registration material, which was clinically acceptable. Zarone et al. (36) highlighted the clinical reliability of virtual bite registration, emphasizing its potential to replace conventional methods.

The findings of this study suggest that omitting bite registration material during digital impression-taking does not compromise the accuracy of printed splints. This omission could simplify the clinical workflow, reduce chair time, and enhance patient comfort. This is particularly beneficial in cases where increased vertical dimension is required, as it minimizes potential errors associated with traditional bite registration materials. The observed discrepancies in the anterior region with the Trios 3 scanner highlight the need for carefully selecting scanners, especially for cases where recording the anterior occlusal relationship is critical. The Medit i700 scanner may be a more reliable option than the Trios 3 scanner in such cases.

The primary limitation of this study was its in vitro design. While the present results are promising, clinical conditions such as restricted access, patient movement, and edentulous areas may introduce additional challenges not accounted for in this study. Further clinical studies are suggested to validate the results obtained in the present study.

Conclusions

Within the limitations of this study, the following can be concluded:

- Different bite registration conditions and scanner types had no significant effect on the accuracy of printed occlusal splints based on RMS values.
- Bite registration condition did not affect the anterior, posterior and total discrepancy between the splint and the mandibular teeth.
- The anterior discrepancy between the splint and the mandibular teeth was significantly higher in scans obtained by the Trios 3 scanner compared to the Medit i700 scanner. However, no significant differences were observed in the posterior or overall discrepancies between the two scanners.

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Conflict of interest

The authors declare no conflict of interest.

Ethical considerations

The protocol of this study was approved by the ethics committee of the Mashhad University of Medical Sciences (Code: IR.MUMS.DENTISTRY.REC.1402.004).

Author contributions

A.M. and A.S.M. contributed to the study's conceptualization, design, and supervision and revised the manuscript. S.A.H. participated in data collection and analysis. M.H. participated in data collection and interpretation and prepared the manuscript draft. All authors have read and approved the final manuscript.

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