https://doi.org/10.4047/jap.2024.16.4.221

Recording maximal intercuspation and border positions of the mandible with intraoral scanner using the acquisition software's multi-occlusion function

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PURPOSE. This *in vitro* study was conducted to investigate the accuracy of intraoral scanner (IOS) for recording maximal intercuspal position (MIP) and border positions of the mandible. **MATERIALS AND METHODS.** Maxillary and mandibular master casts were articulated in MIP, protrusive, and lateral interocclusal position sequentially on a semi-adjustable articulator. For each articulation relation, sites of occlusal contacts (SOCs) and sites of clearance (SCs) were identified on the master casts with articulating paper (reference sites). IOS was used to take full arch scans and nine virtual interocclusal records (VIRs) for virtual articulation of models. Virtual SOCs and SCs were detected with 3D processing software and compared to those identified with the articulating paper. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for each articulation relation. **RESULTS.** For MIP, IOS showed adequate sensitivity and NPV of 100%, and specificity and a PPV of 99%. For protrusive position, the IOS showed a sensitivity and a NPV of 100%, a high PPV of 86%, and a specificity of 83%. For lateral positions, the specificity and the PPV were high (93% and 79%, respectively), but the sensitivity and the NPV were below the clinically acceptable limits (28% and 56%, respectively). **CONCLUSION.** IOS displayed clinically acceptable accuracy for recording MIP and protrusive border mandibular position. However, IOS had less accuracy for lateral border mandibular position. [J Adv Prosthodont 2024;16:221-30]

KEYWORDS
Intraoral scanner; Mandibular position; Maximal intercuspal position; Occlusion; Virtual

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Received April 7, 2024 / **Last Revision** June 24, 2024 / **Accepted** July 1, 2024

INTRODUCTION

Complete digital workflow can help the operator work efficiently and enhance the patient comfort.[1] Moreover, digital acquisition and designing soft-

https://doi.org/10.4047/jap.2024.16.4.221

ware was improved by the manufacturers to meet the clinician needs. Some computer-aided design (CAD) software allows virtual articulation for occlusion analysis and fabrication of dental prostheses. However, this necessitates conventional mounting to a mechanical articulator to transfer the patient occlusion with an increased possibility of procedural errors.[2,3] Recently, some intraoral scanner (IOS) companies have introduced new functions to the IOS acquisition software. This function allows the IOS to capture the patient maximal intercuspal position (MIP) as well as the mandibular border positions for virtual articulation. This advancement eliminates the need for conventional articulation and aims to improve the articulation accuracy.[4]

Virtual articulation with the IOS is based on best-fit alignment of a virtual interocclusal record (VIR) on the digital scans of maxillary and mandibular arches by the scanner software. This process requires interocclusal landmarks to be used as reference points for the algorithm applied by the software.[1] Previous studies have reported that static virtual articulation with IOSs is a valid and reliable method when adequate occlusal stops are available.[5-13] On this basis, as few interocclusal stops exist at the lateral and protrusive mandibular border positions, the accuracy of the virtual articulation with IOS may be jeopardized. The virtual articulation accuracy can be assessed through the diagnostic accuracy for occlusal contacts. Diagnostic accuracy measures include sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). Sensitivity and NPV indicate the ability to identify or miss the occlusal contacts while specificity and PPV are related to introducing false contacts at sites of clearance during virtual articulation. A sensitivity of 70% and specificity of 90% have been considered the minimum for clinically acceptable registration. In addition, a NPV and a PPV as close as possible to 100% indicate a higher accuracy for detecting occlusal contacts.[8,14,15]

Currently available IOSs allow registration of dynamic occlusion with two different acquisition software functions. One software acquisition function is multi-occlusion function used in this research. This multi-occlusion function can record the mandibular border positions. Mandibular border positions describe the external limits of jaw movement in any direction and plane. Recording these border positions, which are clinically limited by the temporomandibular joint anatomy, is clinically significant as border positions are reproducible and closely associated with occlusal patterns.[16,17] Another IOS software function that can be used to record dynamic occlusion is recording the mandibular movements as videos. This function allows recording border and intra-border mandibular movements. However, this function was not applied in this study and can be addressed in separate research.

To the knowledge of the author, no studies have been conducted to evaluate the accuracy of recording mandibular border positions with IOS. Therefore, this study was conducted to investigate the accuracy of IOS for recording MIP and lateral and protrusive mandibular positions as VIRs. The accuracy was assessed by comparing the virtual sites of occlusal contacts (SOCs) and sites of clearance (SCs) to those identified by the articulating paper as reference sites. The study hypothesis was that virtual articulation with IOS would have clinically acceptable accuracy for all investigated interocclusal positions.

MATERIALS AND METHODS

The sample size was calculated based on the results of Arslan *et al*.[7] and Nemli *et al*.[18]; by using a software program (G*power 3.1.9.6; Heinrich-Heine-Universität, Düsseldorf, Germany), assuming an alpha error of 5%, a study power of 80%, and an effect size of 0.92, a minimum sample size of n = 9 per group was needed.

The protocol followed in this study is shown in Figure 1. Full dentate maxillary and mandibular 3D printed casts (Savoy dental model skin; Savoy digital systems, Hong Kong, China) were used as master casts in this study. The master casts were hand-articulated in MIP and mounted on a semi-adjustable articulator (Bio-Art-A7-Plus; Bio-Art Dental Equipment Ltda., Sao Paulo, Brazil). The articulator was programmed with average values (condylar inclination = 30 degrees; Bennett angle = 15 degrees).[3] The condylar elements of the articulator were locked to avoid any eccentric movements during registration of MIP with IOS. SOCs in MIP were identified with 12 µm articulating paper

(Bausch Arti-Fol metallic black/red BK 28; Bausch articulating papers Inc., Nashua, NH, USA). Occlusal adjustments were made to ensure bilateral evenly distributed SOCs (nine SOCs). After marking SOCs in MIP, Medit i700 IOS (Medit Corp., Seoul, Rep. of Korea) was used to make a full arch scan for the maxillary and the mandibular 3D printed casts. To articulate the virtual casts in MIP, a static load of 50 N was fixed on top of the articulator and bilateral posterior buccal scans in MIP were made with the IOS according to the manufacturer instructions. The maxillary and mandibular full arch scans were cloned using the IOS software (Medit Link; Medit Corp., Seoul, Rep. of Korea), the first VIR was deleted, and a new VIR was captured with the IOS in MIP to rearticulate the same virtual casts with a second VIR. The same process was repeated to produce nine articulated virtual casts in MIP saved as STL files.

For articulation in a protrusive border position, a customized incisal table was fabricated from DuraLay resin (Reliance Dental Mfg Co., Alsip, IL, USA) to create a stable and repeatable protrusive interocclusal position. First, the incisal table of the articulator was replaced with a 3D printed resin incisal table to ensure that the DuraLay resin would bond to it. Then, the condylar elements of the articulator were unlocked and the articulator was opened. The DuraLay resin was mixed according to the manufacturer's instructions and added to the incisal table of the articulator. The articulator was closed while the maxillary cast moved along the protrusive condylar path determined by the programmed condylar elements (condylar inclination = 30 degrees; Bennett angle = 15 degrees)[3] to obtain the protrusive border position. After complete setting of the DuraLay around the incisal pin, the achieved protrusive position was stabilized by the set DuraLay. If necessary, more duralay was mixed and added around the incisal pin to precisely adapt it in the custom incisal table. The articulation was fixed with an elastic band for 48 hours to ensure

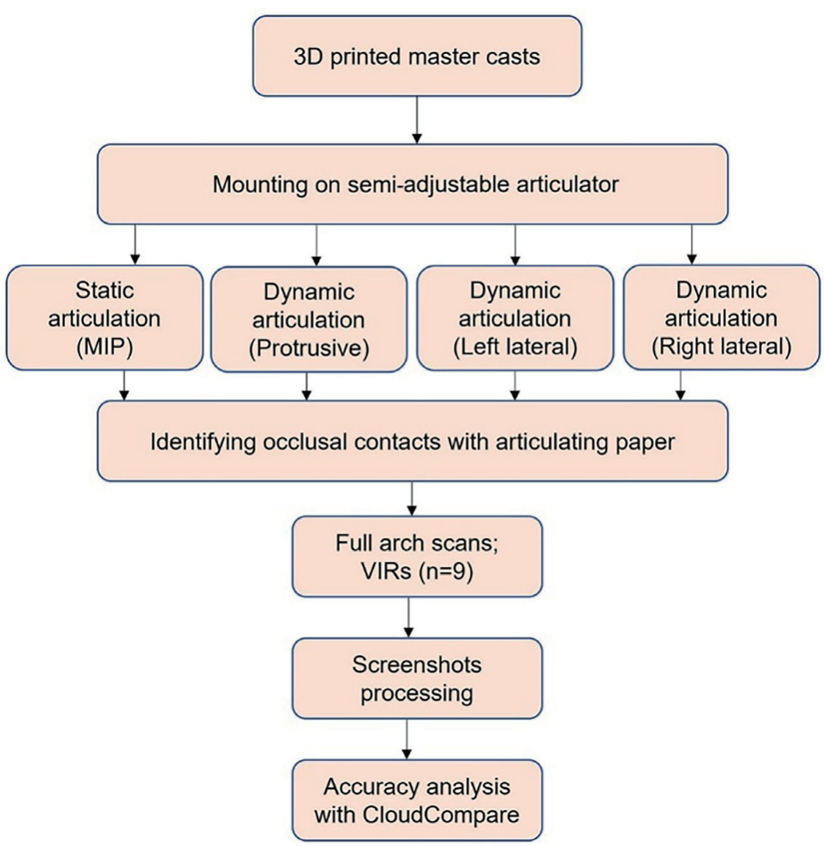

Fig. 1. Study protocol.

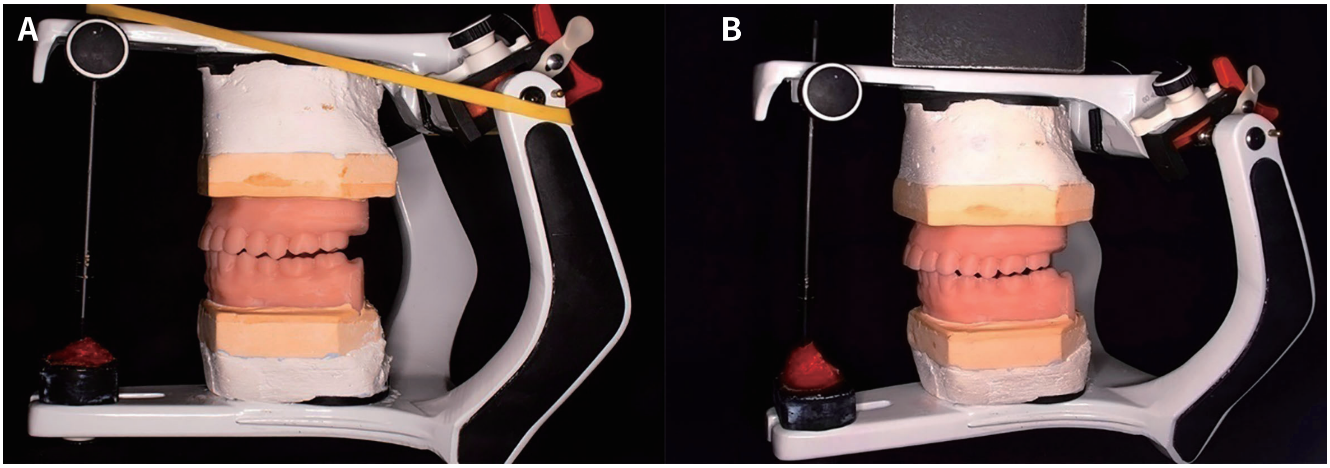

Fig. 2. Articulated casts with customized incisal table. (A) Protrusive position, (B) Lateral position.

its stability (Fig. 2).

SOCs in the protrusive interocclusal position were identified with the articulating paper. Adjustments were performed to ensure an even distribution of SOCs on the six anterior teeth only. The IOS was used to scan the full maxillary and mandibular arches. The virtual casts were articulated in the achieved protrusive interocclusal position with anterior interocclusal scans (from canine to canine) under 50 N load on top of the articulator. Nine articulated virtual casts were produced and saved as STL files.

For articulation in a left lateral interocclusal position, a customized incisal table was fabricated following the steps described previously. The duralay was mixed and added to a new 3D printed incisal table. The articulator was closed while the maxillary cast was moved along the programmed lateral condylar path to obtain the left lateral border position (Fig. 2). SOCs were identified with the articulating paper. Adjustments were performed to ensure an even distribution of SOCs on the left canine, left first and second premolars only. The IOS was used to scan the full maxillary and mandibular arches. The virtual casts were articulated in the obtained left lateral interocclusal position with left buccal scans (from canine to second molar) under 50 N load on top of the articulator. Nine articulated virtual casts were produced and saved as STL files.

Another custom incisal table was fabricated to articulate the casts in a right lateral interocclusal position. SOCs were identified with the articulating paper. Adjustments were performed to ensure SOCs on the right canine, right first and second premolars only. The IOS was used to scan the full maxillary and mandibular arches. The virtual casts were articulated in the right lateral interocclusal position with right buccal scans (from canine to second molar) under 50 N load on top of the articulator. Nine articulated virtual casts were produced and saved as STL files. All scans and VIRs in this study were conducted by a single operator with seven years of experience with intraoral scanners.

In this study, SOCs identified with the articulating paper were used as reference SOCs. Screenshots of the maxillary virtual cast from the occlusal view was captured from the IOS software to display the marked SOCs in each interocclusal position. The screenshots were saved as JPEG files and uploaded to an image processing program (Adobe Photoshop CS4; Adobe systems Inc., San Jose, CA, USA). SCs were selected and marked using the software on-screen tools to be used as reference SCs. The screenshots of the reference SOCs and SCs for each interocclusal position were saved as JPEG file to be used for comparison with the virtual occlusal contacts (Fig. 3).

To detect the virtual SOCs and virtual SCs, the articulated virtual casts were uploaded to a 3D processing software (CloudCompare v2.7; http://www.cloudcompare.org). The software measured the signed nearest neighbor distances between the opposing arches. A

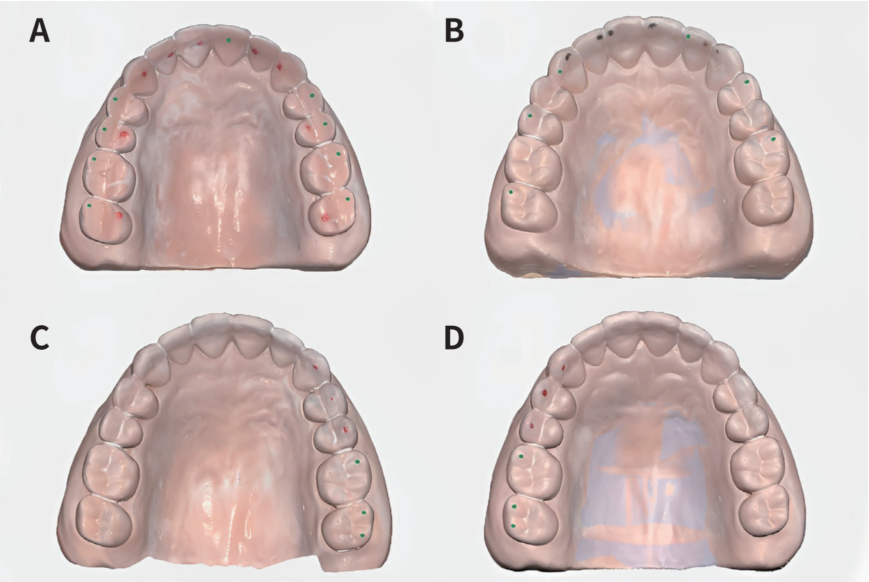

Fig. 3. Screenshots of reference sites of occlusal contacts (red and black) and reference sites of clearance (green). (A) Maximal intercuspal position, (B) Protrusive position, (C) Left lateral position, (D) Right lateral position.

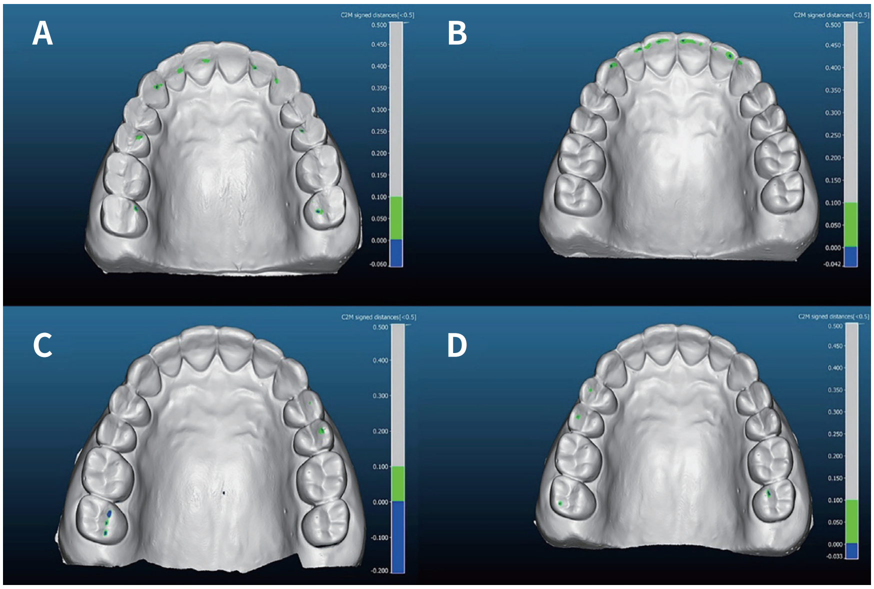

Fig. 4. Screenshots of CloudCompare software output. (A) Maximal intercuspal position, (B) Protrusive position, (C) Left lateral position, (D) Right lateral position.

color-coded map displayed areas with different interocclusal distances in distinct colors: green represented areas between 0 to 100 µm (sites of true occlusal contacts); blue represented areas < 0 µm (actual mesh perforations); and gray represented areas > 100 µm (sites of clearance) (Fig. 4).

The virtual SOCs and SCs were compared to the reference SOCs and SCs and scored as reported in similar studies.[1,8] For SOCs, virtual interocclusal area > 100 µm were scored as (0); areas between 0 and 100 µm were scored as (+); and areas < 0 µm were scored as (-). For SCs, virtual interocclusal area > 100 µm were scored as (0); and areas ≤ 100 µm were scored as (+). Consequently, for each interocclusal position,

https://doi.org/10.4047/jap.2024.16.4.221

true-positive (TP), true-negative (TN), false-positive (FP), and false-negative (FN) values were calculated. Sensitivity, specificity, PPV, and NPV were calculated representing the accuracy of the virtual articulation.

The following equations were used to calculate the diagnostic accuracy measures:[14,19,20]
Sensitivity = TP / (TP + FN);
and specificity = TP / (TP + FP)
PPV = TP / (TP + FP);
and NPV = TN / (TN + FN).

RESULTS

The results for analysis of SOCs and SCs are shown in Table 1, Table 2, and Table 3. The accuracy of VIRs in MIP, protrusive, and lateral interocclusal positions is summarized in Table 4. Virtual articulation in MIP with IOS showed clinically acceptable accuracy with a sensitivity and a NPV of 100%, and a specificity and a PPV of 99%. For protrusive interocclusal position, the IOS showed a sensitivity and a NPV of 100%, a high PPV of 86%, and a specificity of 83%. For lateral interocclusal position, the specificity and the PPV were high (93% and 79%, respectively), but the sensitivity and the NPV were below the clinically acceptable limits (28% and 56%, respectively). For all interocclusal positions, areas of mesh perforations (interocclusal distance below 0 µm) were detected between the articulated virtual casts. Perforations detected with lateral VIRs were up to 455 µm, while VIRs in protrusive position and MIP showed perforations up to 42 µm and 148 µm, respectively.

Table 1. Analysis of SOCs and SCs from CloudCompare output compared to similar reference sites in MIP

	SOCs								
VIR	Left second M MPC	Left second PM PC	Left canine	Left lateral	Right central	Right lateral	Right canine	Right second PM PC	Right second M MPC
1	-	-	+	-	-	+	-	-	-
2	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
4	-	-	+	-	+	+	-	-	-
5	-	-	+	-	+	+	-	-	-
6	-	-	-	-	+	+	-	-	-
7	-	-	-	-	+	+	-	-	-
8	-	-	-	-	+	+	-	-	-
9	-	-	+	-	+	+	-	-	-
	SCs								
VIR	Left second M MBC	Left first M MBC	Left second PM BC	Left first PM BC	Left central	Right first PM BC	Right second PM BC	Right first M MBC	Right second M MBC
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	+	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0

BC, Buccal cusp; MBC, Mesiobuccal cusp; M, Molar; MPC, Mesiopalatal cusp; PC, Palatal cusp; PM, Premolar; SOCs, Sites of occlusal contacts; SCs, Sites of clearance; VIR, Virtual interocclusal record

Table 2. Analysis of SOCs and SCs from CloudCompare output compared to similar reference sites in protrusive border position

VIR	SOCs						SCs					
	Left canine	Left lateral	Left central	Right central	Right lateral	Right canine	Left first M MBC	Left first PM BC	Left lateral	Right canine	Right second PM BC	Right second M MBC
1	+	-	-	+	-	-	0	0	+	0	0	0
2	-	-	-	-	-	-	0	0	+	0	0	0
3	-	-	-	+	-	-	0	0	+	0	0	0
4	-	-	-	+	-	-	0	0	+	0	0	0
5	-	-	-	+	-	-	0	0	+	0	0	0
6	-	-	-	-	-	-	0	0	+	0	0	0
7	-	-	-	+	-	-	0	0	+	0	0	0
8	-	-	-	+	-	-	0	0	+	0	0	0
9	+	-	-	+	-	-	0	0	+	0	0	0

BC, Buccal cusp; M, Molar; MBC, Mesiobuccal cusp; PM, Premolar; SOCs, Sites of occlusal contacts; SCs, Sites of clearance; VIR, Virtual interocclusal record

Table 3. Analysis of SOCs and SCs from CloudCompare output compared to similar reference sites in lateral border positions

VIR	SOCs						SCs					
	Left canine	Left first PM BC	Left second PM BC	Right canine	Right first PM BC	Right second PM BC	Left first M MBC	Left second M MBC	Left second M DBC	Right first M MBC	Right second M MBC	Right second M DBC
1	0	+	-	0	0	0	0	0	0	0	0	0
2	0	+	-	0	0	0	0	0	0	0	0	0
3	0	0	0	0	+	-	0	0	0	0	0	+
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	-	-	0	0	0	0	0	+
6	0	0	0	0	-	-	0	0	0	0	0	+
7	0	0	0	0	-	-	0	0	0	0	0	+
8	0	+	-	0	+	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0

BC, Buccal cusp; DBC, Distobuccal cusp; MBC, Mesiobuccal cusp; M, Molar; PM, Premolar; SOCs, Sites of occlusal contacts; SCs, Sites of clearance; VIR Virtual interocclusal record

Table 4. Accuracy analysis for virtual articulation in maximal intercuspal, protrusive and lateral border positions

Virtual articulation	TP	FP	TN	FN	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
MIP	81	1	80	0	100	99	99	100
Protrusive	54	9	45	0	100	83	86	100
Lateral	15	4	50	39	28	93	79	56

FN, False-negative; FP, False-positive; MIP, Maximum intercuspal position; NPV, Negative predictive value; PP, Positive predictive value; TN, True-negative; TP, True-positive

https://doi.org/10.4047/jap.2024.16.4.221

DISCUSSION

This study aimed to evaluate the accuracy of virtual articulation with IOS in MIP and mandibular border positions. The research hypothesis was partially accepted as only virtual articulation in MIP had clinically acceptable accuracy for all diagnostic measures. For protrusive VIRs, the IOS had sufficient sensitivity and NPV, indicating the ability of the IOS to detect occlusal contacts. In addition, the IOS had a specificity of 83% along with a high PPV of 86% indicating that the IOS did not tend to introduce false contacts at sites of clearance. For lateral VIRs, the IOS had adequate specificity and a high PPV. However, the sensitivity and NPV were low indicating that the IOS tended to miss the occlusal contacts instead of introducing false contacts.

Previous studies have reported the phenomenon of mesh perforation which occurs with virtual articulation because of the tilting effect on the virtual casts.[1,8] Perforated virtual casts after articulation will theoretically lead to designing and fabricating restorations with inaccurate occlusion. Although it is possible to eliminate such perforations through the CAD software, it is not clear how this attempt can affect the interocclusal relationship. In this study, mesh perforations were detected between the articulated virtual casts. For lateral VIRs, the perforations tended to occur at the last molars indicating a posterior tilting effect during virtual articulation, and this may explain the tendency of the IOS to miss SOCs. The tilting effect during articulation in dynamic lateral position might be exaggerated compared to static and protrusive positions, as less interocclusal reference points (only three SOCs) were present for virtual articulation by the IOS.

In this research, 12 µm articulating paper was used to identify the reference sites of occlusal contacts as described in similar studies.[3,9-11,19-21] In daily clinical practice, articulating papers have been used to analyze the occlusal contacts in the patient's mouth or in plaster casts.[9] However, articulating paper is liable to introduce false-positives and negatives as a result of variable biting force and presence of saliva. This study was conducted *in vitro*, and a static load was applied during making VIRs, which may reduce such limitations from the articulating paper. In this study, 3D printed models were selected as master models to ensure the stability of the master models throughout the study. In addition, this study used 3D printed models from photopolymer as in this study was validated by the American National Standards Institute and American Dental Association (ANSI/ADA) for assessing the accuracy of scanning systems *in vitro* to replicate the surface properties and optical characteristics of natural teeth.[22] For analysis of virtual occlusal contacts, CloudCompare 3D processing software was used because its method in measuring the interocclusal distance is known (measuring the nearest neighbor distance between mesh vertices).

The findings of the current research agree with those by Abdulateef *et al*.[8] who concluded that VIRs with IOS had acceptable accuracy although the IOS can miss occlusal contacts. In addition, the results of the current research are consistent with those by Arslan *et al*.[7] who concluded that decreased interocclusal reference points reduced the accuracy VIRs with IOS. Unfortunately, no studies on the accuracy of the IOS for dynamic articulation were available in the literature to compare the results of the current research.

Clinically, the accuracy of VIR can be affected by factors that include the body posture, psychological and physical status of the patient, time of the day, and the amount of biting force.[23-25] This study was performed *in vitro*, which does not simulate the oral environment and represents a limitation of the study. Moreover, small deviations in positioning the casts during physical articulation may impact the reference markings made with articulating paper, which might affect the subsequent comparisons to the virtual occlusal contacts. However, the physical articulation and marking of the occlusal contacts with the articulating paper were performed once after fixing the incisal pin with duralay for each assessed maxillomandibular relation to overcome this limitation. Using a single IOS system in this research is considered another limitation of the study and further research comparing different IOSs for dynamic VIRs accuracy is recommended.

CONCLUSION

Based on the findings of this *in vitro* study, it was concluded that VIRs with IOS in MIP and protrusive border position of the mandible displayed clinically acceptable accuracy for detecting occlusal contacts. For lateral border position of the mandible, VIRs had less accuracy where the IOS tested tended to miss interocclusal contacts rather than introducing false contacts. Further research is required before recommending IOS for dynamic virtual articulation.

ACKNOWLEDGMENTS

The authors would like to acknowledge Dr. Ahmed Menecy for his valuable participation in conducting the methodology of the study.

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