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ACCURACY OF VIRTUAL INTEROCCLUSAL RECORDS FOR MULTIUNIT FIXED RESTORATIONS OF DIFFERENT SPAN LENGTH AND LOCATIONS

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ABSTRACT

INTRODUCTION: The procedural errors associated with conventional interocclusal records (CIRs) have been mitigated by the use of intraoral scanners (IOSs) for virtual interocclusal records (VIRs). However, in cases requiring multiunit fixed restorations the precision of (VIRs) is questionable.
OBJECTIVES: This in vitro study aimed to evaluate the precision of IOS for VIRs in maximal intercuspal position (MIP) for multiunit fixed restorations.
MATERIAL AND METHODS: Five pairs of 3-dimensionally (3D) printed master models represented five different clinical situations as follows: Full dentate (FD), short span posterior (SSP), long span posterior (LSP), short span anterior (SSA), and long span anterior (LSA). Fourteen pairs of interarch reference points were added to each set of master models to measure linear interarch distance. For MIP registration with VIRs, each pair of master models were scanned 10 times with Medit i700 IOS, and the virtual models were articulated with 10 VIRs. Digital linear interarch measurements on all virtually-articulated models were compared with reference measurements obtained with a digital caliper on master models.
RESULTS: All study groups had a mean value for interarch deviations less than 100 µm as follows: group FD: 9.21±6.04 µm, group SSP: 24.71±13.44 µm, group SSA: 12.79±5.35 µm, group LSP: 22.43±11.02 µm and group LSA: 29.43±33.67 µm. Groups SSP, LSP and LSA had significantly higher deviations in comparison to FD group ($P<0.05$), while SSA group did not show a significant difference from FD group ($p=0.054$).
CONCLUSION: The span length and location of prepared areas significantly impacted the accuracy of VIRs.
KEYWORDS: Intraoral scanners, Virtual interocclusal records, Conventional interocclusal records, Maximal intercuspal position, Multiunit fixed restorations.
RUNNING TITLE: Accuracy of virtual bites for multiunit fixed restorations.

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INTRODUCTION

The use of digital dental technology is increasingly becoming essential to contemporary prosthodontic practice. Compared to traditional procedures, it has been introduced to simplify and minimize the required steps to produce dental prosthesis. One of the many areas of dental digital technology that has seen notable advancement lately is virtual articulators (1).
The capacity to capture and replicate the maximal intercuspal position (MIP) is important to prosthetic workflows. Documenting the patient's occlusion and transferring it to the lab is important for fabricating an accurate fixed prostheses (2). Polyvinylsiloxane (PVS) interocclusal records are conventionally used for mounting stone casts in MIP (3). However, it has been reported that the existence of an interocclusal material causes errors in the reproduction of the static interocclusal relationship due to different properties of the material, operator manipulation of the material, variable biting forces of the patient, and compressibility of the record during mounting (4-6).

The "buccal image" technique is used in CAD/CAM systems to set virtual models into MIP. This technique involves direct buccal scanning of the mandibular and maxillary teeth at maximal intercuspation. Using the buccal scan image, the mandibular and maxillary virtual models are aligned in MIP (7-12). Consequently, the interocclusal record procedure is streamlined with more accurate results (13, 14). However, virtual articulation entails best-fit alignment of virtual models and buccal scan data Using regions of occlusal contacts as reference points. From a clinical perspective, the number of antagonistic contacts required for the buccal scan approach to produce a consistent and dependable VIR remains unclear (15).
Interocclusal records utilized in the production of fixed partial dentures (FPDs) are theoretically more difficult due to the presence of prepared abutments and edentulous areas (15, 16). When the conventional interocclusal record (CIR)

is used for FPD, it restores the tripod of the interocclusal vertical component that has been jeopardized by missing or prepared teeth (4). Similarly, as fewer interocclusal reference points are available during scanning, VIR for arches with prepared and missing dentition can be challenging (17).

A previous study by Ren et al. (18), reported that the accuracy of VIRs with IOS decreased in edentulous areas where three or more teeth are missing. In addition, Arslan et al. (14), reported that the accuracy of VIRs with IOS for arches with prepared 3-unit FPD were less compared to unprepared arches. This study aimed to assess the precision of VIR for articulation of arches prepared to receive multiunit fixed restorations of different span length and location in MIP based on linear interarch deviations. The null hypothesis was that the accuracy of the VIRs registration would not be affected significantly by span length and location of the prepared area.

MATERIAL AND METHODS

A pair of completely dentate maxillary and mandibular typodont models (KaVo EWL model teeth; KaVo Dental GmbH) was used to fabricate the master models for this study. The intraoral scanner (Medit i700, Medit Corp.) was used to scan the ivory models. The STL file of the obtained pair of virtual models was exported to a CAD software program (Exocad 2021, Exocad GmbH) and duplicated five times. The duplicated virtual models were modified using the CAD software to create the following five different configurations: full dentate (FD), short span posterior (SSP), long span posterior (LSP), short span anterior (SSA), and long span anterior (LSA) (18, 19). The teeth were removed, and the abutments were prepared virtually (20) by using the CAD software program tools as displayed in **Table 1 and Figure 1**.

Table (1): Representation of different Configurations of study master models

Master model configuration	Missing tooth/teeth	Prepared abutments
Full dentate (FD)	None	None
Short span posterior (SSP)	Maxillary right first molar	Maxillary right second molar and premolar
Long span posterior (LSP)	Maxillary right first molar and second premolar	Maxillary right second molar and first premolar
Short span anterior (SSA)	Maxillary right lateral incisor	Maxillary right central incisor and canine
Long span anterior (LSA)	Four maxillary incisors	Right and left canines

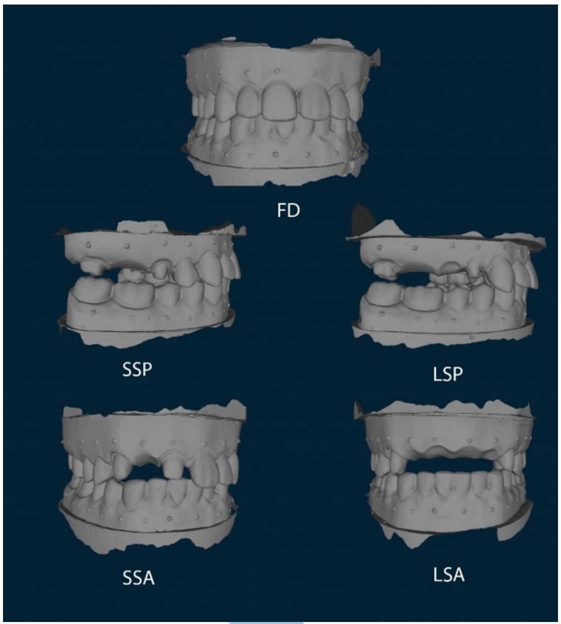

Figure (1): Configurations of study master models. FD, full dentate; LSP, long span posterior; LSA, long span anterior; SSA, short span anterior; SSP, short span anterior

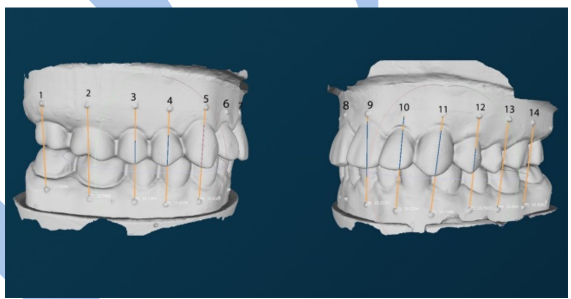

Figure (2): Reference points for measuring linear interarch distance

In order to measure the linear interarch distance in each pair of virtual models, the maxillary and mandibular models opposite to each tooth had 14 pairs of interarch reference points added using the CAD software. P1 was the interarch reference point opposite the right second molars, while P14 was the interarch reference point opposite the left second molars (18) **(Figure 2)**.

The five sets of virtual models were used to print five pairs of master models in a 3-dimensional (3D) printer (Anycubic photons; MAKTech 3D) using dental model resin (Savoy dental model skin; Savoy digital systems). Each pair of master models was mounted in a semi-adjustable articulator (Artex; AmannGirrbach AG) and the articulator eccentric movements were locked. During registration of interocclusal records, a static load of 5 kg was imposed on top of the articulator (21).

A digital caliper (INSIZE digital caliper; INSIZE Co., Ltd.) with a measurement accuracy of 0.02 mm was used to measure the vertical linear distance between each pair of reference points on the master models (1, 18). At each point, linear distance was measured 10 times by one operator (Y.E.) who was

calibrated to ensure that the measurements were consistent and the average data was recorded and used as a reference data.
Each pair of master models was scanned 10 times using a Medit i700 intraoral scanner following the manufacturer's scanning protocol in order to register MIPs with VIRs. Bilateral buccal scans were used to articulate the virtual models. In total 50 pairs of digital scans and 50 bilateral VIRs were obtained (n=10 for each master model). The sample size was calculated by using a software package (G*power 3.1.9.6; Heinrich-Heine-Universität) with study power 0.80 and alpha error 0.05 based on the results of the study by Ren et al (18).
For each master model, the virtually-articulated models were saved as STL files and exported to a 3D processing software (MeshLab; version 2016.12; National Research Council; Pisa; Italy). On each pair of virtual models, the linear interarch distance between the reference points was measured using the software on-screen tools (digital measurements) (12). Each distance was measured by the same operator 10 times and the average was recorded **(Figure 2)**.
To evaluate the accuracy of VIRs for each master model configuration, the differences (deviation) in interarch distance between digital measurements and reference manual measurements were calculated. The data were analyzed with a statistical package (IBM SPSS Statistics, v24.0; IBM Corp). The Shapiro–Wilk test and the Kolmogorov-Smirnov test assessed the normality of data. The deviations in linear interarch distance in each master model were averaged. A pairwise comparison was conducted between FD group and other study groups using paired t-test (α=.05).

RESULTS

Table 2 summarizes the mean differences in linear interarch distance for VIRs at each reference point for the five different configurations.

Table (2): Mean ±SD for deviations in linear interarch distance in µm at each reference point

	FD	LSA	SSA	LSP	SSP
P1	28.0±37.653	6.00±5.164	18.00±10.328	10.00±13.33	17.00±13.37
P2	9.0±5.676	20.00±10.541	9.00±8.756	9.00±9.94	33.00±24.97
P3	8.0±6.325	12.00±14.757	19.00±5.676	29.00±32.13	14.00±12.65
P4	9.0±7.379	28.00±22.509	12.00±11.353	19.00±21.32	59.00±34.79*
P5	9.0±7.379	9.00±11.005	7.00±6.749	28.00±35.53	26.00±29.51
P6	11.0±11.972	142.00±43.153*	13.00±11.595	45.00±38.66*	12.00±13.17
P7	6.0±8.433	21.00±18.529	11.00±11.005	17.00±20.03	22.00±15.49
P8	12.0±11.353	37.00±18.886	18.00±20.440	19.00±22.34	30.00±21.08
P9	8.0±4.216	34.00±20.111	18.00±10.328	22.00±10.33	41.00±33.15
P10	1.0±3.162	23.00±20.028	12.00±13.166	11.00±12.87	25.00±33.42
P11	6.0±5.164	23.00±16.364	8.00±6.325	43.00±24.06*	10.00±10.54
P12	8.0±4.216	24.00±16.465	6.00±5.164	18.00±15.49	25.00±18.41
P13	5.0±8.498	9.00±7.379	6.00±6.992	26.00±24.59	23.00±20.03
P14	9.0±15.951	24.00±17.127	22.00±22.998	18.00±17.51	9.00±8.76
Total	9.21±6.04	29.43±33.67	12.79±5.35	22.43±11.02	24.71±13.44

* FD, full dentate, LSA, Long span anterior; LSP, Long span posterior; P, Point; SSA, Short span anterior; SSP, Short span posterior; VIR, Virtual interocclusal record.

Table 3 displays the average of mean differences for each study group.
All study groups had a mean value for interarch deviations less than 100 µm. FD group had a mean value for interarch deviations of 9.21±6.04 µm, SSP group had a mean value for interarch deviations of 24.71±13.44 µm, SSA group had a mean value for interarch deviations of 12.79±5.35 µm, LSP group had a mean value for interarch deviation of 22.43±11.02 µm and LSA group had a mean value for interarch deviations of 29.43±33.67 µm. Group SSP, group LSP and group LSA had significantly higher deviations compared to FD group (P<0.05), while SSA group did not show a significant difference from FD group (p=0.054).

Table (3): Mean ± SD for linear interarch distance for different study groups in μm.

Total mean differences	FD group reference 9.21±6.04			
	LSA	**SSA**	**LSP**	**SSP**
	29.43±33.67	12.79±5.35	22.43±11.02	24.71±13.44
P value	0.045*	0.054	0.002*	0.002*

P was significant if < 0.05
* Significant difference at level 0.05

DISCUSSION

The aim of this study was to assess the accuracy of VIR with IOS for articulation of arches prepared to receive multiunit fixed restorations of different span length and location in MIP based on linear interarch deviations. The null hypothesis was rejected as the accuracy of the VIRs was significantly affected by the span length and location of FPD. The accuracy of VIRs in this study was evaluated by the mean differences between the manually recorded reference data and the digital measurements recorded from the virtually articulated models. Comparison between the total mean differences of reference points for each configuration with that of the full dentate group was used to evaluate whether the span and location of the prepared area would have significant effect on the accuracy of the VIRs (18). This finding agreed with the results of the Arslan et al who reported that non prepared full arch digital impression allow identification of correct virtual occlusal contacts (14).

Results obtained from group SSA revealed that anterior regions prepared to receive three units FPD didn't influence the accuracy of VIRs. In contrast, group SSP showed significant decrease in the accuracy of VIRs. This indicates that the location of the prepared area should be considered as a factor influencing the accuracy of VIRs.

In this study, deviations in interarch linear measurements were greater in group SSP than SSA. That finding might be explained by the tilting effect that might have occurred with absence of posterior interocclusal support which in turn might result in over articulation of the virtual models (19).

In groups LSA and LSP, the obtained data revealed that the presence of an extended prepared area both anteriorly and posteriorly significantly affected the efficacy of VIRs. This might be explained by the absence of landmarks in the edentulous area along with the scanner tip size limitations. Group LSA had the greatest deviation with a mean difference of (29.43 ±33.67) as a result of the presence of an extended edentulous area along with with the steep geometry of anterior abutments. In order to enhance clinical results, additional scan techniques like stitching markers on the dentulous area or VIRs scan aids were recommended by Ren et al (18, 22).

There is no consensus in the literature on the threshold of the acceptable values for deviations in virtual models. Deviations below 100 μm were reported by Ender and Mehl as a limit for virtual models (24). The reported results in this research were within the clinically acceptable limit for all studies clinical scenarios.

The results of this study agreed with the findings of Ren et al (18) who reported adequate accuracy of VIRs in situations where only one tooth is missed and that the presence of an extended edentulous anterior or posterior area reduced the efficacy of VIRs. Moreover, Iwaki et al (24) reported higher discrepancy for articulation with VIRs for arches prepared to receive FPDs.

The limitations of this study included the in vitro design of the study, the effect of some clinical factors such as saliva, muscular activity and patient position when registering the MIP was not considered (14). Moreover, the study was conducted with one IOS, as the IOS used was reported to affect the digital scanning accuracy (25).

Although the findings of this study can recommend the use of IOS for articulation of virtual models prepared to receive FPDs further investigations are needed to assess the accuracy of IOS for recording dynamic occlusion.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. VIRs had acceptable accuracy for recording MIP in full dentate and arches prepared to receive short span FPDs.
2. The location and span of the edentulous and prepared area significantly influenced the accuracy of VIRs.
3. Further investigations are required to assess the accuracy of IOS for recording dynamic occlusion.

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