THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Accuracy of virtual interocclusal records for partially edentulous patients

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ABSTRACT

Statement of problem. Intraoral scans and virtual interocclusal records (VIRs) are widely used for contemporary prosthodontic treatment of patients with partial edentulism. The accuracy of VIRs in various clinical conditions is unclear.

Purpose. The purpose of this in vitro study was to investigate whether the span and location of edentulous areas affect the accuracy of VIRs.

Material and methods. Five sets of master stone casts were duplicated from a typodont model (Prosthetic Restoration Jaw Model; Nissin Dental) and then assigned into 5 study groups. Six pairs of interarch markers were placed on the master stone casts as reference points for measurements. The 5 study groups were group 1-Post: 1 posterior tooth missing; group 3-Post: 3 posterior teeth missing; group 6-Ant: 6 anterior teeth missing; group Bil-Post: bilateral posterior teeth missing; and group Dent: completely dentate arch. Master stone casts along with VIRs were scanned 10 times in each group by using an intraoral scanner (IOS) (Dental Wings Intraoral Scanner; Dental Wings Inc). Digital measurement of distances between the interarch markers was obtained on all digitally articulated casts and compared with the manual measurements (with electronic calipers with an accuracy of 0.02 mm). In addition, the differences (absolute values) between the digital and manual measurements were calculated at the edentulous locations for the groups 1-Post, 3-Post, 6-Ant, and Bil-Post and were compared with the corresponding interarch marker positions in the group Dent. Two-sample *t* tests were used for the statistical analysis (α=.05).

Results. The overall differences (mean ±standard deviation) between digital and manual measurements were group 1-Post: 0.10 ±0.19 mm, group 3-Post: 0.28 ±0.63 mm; group 6-Ant: 0.19 ±0.20 mm; group Bil-Post: 0.28 ±0.25 mm; and group Dent: 0.05 ±0.18 mm. Group Dent was the only group with no significant differences between digital and manual measurements at all 6 interarch marker positions and was used as the reference to analyze the measurements in the edentulous areas. No statistical difference was found (P=.237) at the group 1-Post's edentulous area when compared with the group Dent. In the group 3-Post, the edentulous areas showed statistically significant difference when compared with those of the group Dent (P=.002 and P=.003). In the group 6-Ant, the edentulous areas showed statistical differences when compared with those of the group Dent (P=.019 and P=.008). In the group Bil-Post, only 1 side of the edentulous areas showed statistical differences when compared with group Dent (P=.006 and P=.034).

Conclusions. The span and location of edentulous areas impact the accuracy of VIRs. For a single missing posterior tooth, VIRs could achieve a high level of accuracy comparable with that of the dentate condition. Unilateral and bilateral extended edentulous spans with 3 or more missing posterior teeth and the extended edentulous span in the anterior region all affected the accuracy of VIRs. (J Prosthet Dent 2020;123:860-5)

Traditional prosthodontic treatment with conventional impressions, stone casts, and a physical articulator is being replaced by digital technology.[1-4] An intraoral scanner (IOS) allows immediate capture of intraoral hard- and soft-tissue anatomy, and a virtual interocclusal record (VIR) is used to articulate virtual dental casts in the computer-aided design and computer-aided manufacturing (CAD-CAM) software program.[4,5] The

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Clinical Implications

When only 1 single posterior tooth in a partially edentulous arch is missing, VIRs obtained from an IOS can achieve a high level of accuracy; however, the presence of an extended edentulous space (3 teeth or more) in the anterior or posterior area decreases the accuracy of VIRs.

IOS and CAD-CAM prosthesis fabrication enable a completely digital restorative workflow, offering advantages including eliminating the need to store analog dental casts, straightforward prosthesis replication from existing CAD files, and lower fabrication costs.[6,7]

The accuracy of IOS and CAD-CAM restorations has been evaluated[8-11]; however, research on the accuracy of VIR is lacking.[12,13] Accurately transferring the interocclusal relationship into the CAD-CAM software program is essential for providing clinically acceptable restorations with accurate occlusal morphology and decreasing the need for chairside occlusal adjustment. AVIR is one or several 3D records that capture the relationship between the maxillary and mandibular dentition in the proposed occlusal position, including maximum intercuspation position (MIP) or centric occlusion (CO). With VIRs, digital maxillary and mandibular casts obtained from IOS can be repositioned in the CAD software program according to a best-alignment algorithm which orients various 3D files by pairing corresponding data.[14] Most IOSs require bilateral VIRs to locate the relative position of maxillary and mandibular digital casts,[14,15] and each VIR includes opposing maxillary and mandibular dentition.[16-18] However when teeth are absent, the process of occlusal alignment for digital casts becomes problematic.[19-23]

The purpose of this in vitro study was to investigate whether the span of missing teeth or location of edentulous areas influences the accuracy of VIRs in different simulated partially edentulous situations. The null hypotheses were that the accuracy of VIRs would not be affected by the span or location of the edentulous areas.

MATERIAL AND METHODS

Five sets of master study casts were duplicated from a complete dentated typodont (Prosthetic Restoration Jaw Model; Nissin Dental) with Type IV dental stone (ResinRock; Whip Mix Corp) and were articulated in a semiadjustable articulator (Model 2240 Articulator; Whip Mix Corp) in MIP. The articulation of the master study casts was verified with an 8-μm-thick articulating film (Shimstock Occlusion Foil; Almore Mfg Co). The semiadjustable articulator was locked in the hinge movement during opening and closing to minimize unintentional lateral movement. To simulate different partially edentulous scenarios, the master study casts were modified as follows: group 1-Post: 1 posterior tooth missing; group 3-Post: 3 posterior teeth missing; group 6-Ant: 6 anterior teeth missing; group Bil-Post: bilateral posterior teeth missing; and group Dent: completely dentate arch (Table 1). Six pairs of interarch markers for each group were marked by using a laboratory tungsten carbide rotary instrument (H71E.HP.027; Komet USA LLC) on the master stone casts as reference points for subsequent measurements. The interarch markers were positioned at similar locations in each group, located at the areas close to the maxillary and mandibular first molars, first premolars, and lateral incisors (Fig. 1).

Two measurement methods, manual and digital, were used to measure the distance between corresponding interarch markers. The manual method measured the distance between interarch markers on the master study casts by using electronic calipers with a measurement accuracy of 0.02 mm (ABSOLUTE Digimatic Caliper Series 500; Mitutoyo America Corp). One operator (S.R.) was calibrated to ensure the manual measurements were consistent, and the test-retest reliability was greater than 0.9. Subsequently, the same operator (S.R.) measured all 6 pairs of interarch markers for each study group 10 times in a controlled laboratory environment.

The digital method was used to measure the distance between interarch markers on the articulated digital study casts. Maxillary and mandibular scans and bilateral VIRs were made 10 times for each group by using an IOS (Dental Wings Intraoral Scanner; Dental Wings Inc). The same operator (S.R.) carried out all the scans according to the manufacturer's instructions in the controlled laboratory environment. VIRs were used to align maxillary and mandibular scans with the autoalignment function in the IOS. Standard tessellation language (STL) files, including maxillary and mandibular digital casts and VIRs, were exported from the IOS and imported into a surface-matching software program (Geomagic Control 2016.2.1; 3D Systems Inc) (Fig. 2). The distance between corresponding interarch markers was measured using the software program's linear distance-measuring tool. The same operator (S.R.) went through the calibration process to ensure the digital measurements were consistent, and the test-retest reliability was greater than 0.9. Subsequently, the same operator (S.R.) measured all 6 pairs of interarch markers for each articulated digital study cast under a controlled laboratory environment.

A statistical software program (SAS version 9.4; SAS Institute Inc) was used for the statistical analysis. A 2-sample *t* test was used to compare means from digital and manual measurements in each group at each interarch marker position. In addition, digital and manual measurements at each interarch marker position were paired. The differences (absolute values) between digital

Table 1. Group assignment and representation of clinical scenarios

Study Group	Clinical Situation	Missing Tooth or Teeth
Group 1-Post	Single posterior tooth missing	Maxillary right first molar
Group 3-Post	3 Posterior teeth missing	Mandibular right premolars and first molar
Group 6-Ant	6 Anterior teeth missing	Mandibular incisors and canines
Group Bil-Post	Bilateral posterior teeth missing	Maxillary and mandibular premolars and molars
Group Dent	Complete dentate	None

and manual measurements were calculated at the edentulous locations for the groups 1-Post, 3-Post, 6-Ant, and Bil-Post and were compared with the corresponding interarch marker positions in the group Dent with the 2-sample *t* test. The intraclass correlation coefficient (ICC) was used to assess agreement between all paired digital and manual measurements (α=.05 for all tests).

RESULTS

Strong agreement was found among the measurement methods indicated by the ICCs, ranging from 0.91 to 0.99, suggesting excellent measurement reliability. The overall mean difference ±standard deviation (SD) between digital and manual measurements was as follows: group 1-Post: 0.10 ±0.19 mm, group 3-Post: 0.28 ±0.63 mm; group 6-Ant: 0.19 ±0.20 mm; group Bil-Post: 0.28 ±0.25 mm, and group Dent: 0.05 ±0.18 mm. Group Dent was the only group with no significant differences between digital and manual measurements at all 6 interarch marker positions and was used as the reference to further analyze the measurements in the edentulous areas. The mean differences (absolute values) between the digital and manual measurements were calculated at the edentulous locations for the groups 1-Post, 3-Post, 6-Ant, and Bil-Post and were compared with the corresponding interarch marker positions in the group Dent. These results are summarized in Table 2.

In the group 1-Post, at the interarch marker position 1, the mean ±SD difference between the digital and manual measurements was 0.27 ±0.24 mm. When compared with the measurement difference at the same interarch marker position in the group Dent (0.17 ±0.13 mm), no statistical difference was found (*P*=.237). In the group 3-Post, the edentulous areas were at the interarch marker position 1 and 2. The group 3-Post had significantly greater mean differences between the digital and manual measurements (0.87 ±0.52 mm and 0.44 ±0.29 mm) than the group Dent (0.17 ±0.13 mm and 0.06 ±0.05 mm; *P*=.002 and *P*=.003). In the group 6-Ant, the edentulous areas were at the interarch marker positions 3 and 4. The group 6-Ant had significantly greater mean differences between the digital and manual measurements (0.29 ±0.17 mm and 0.34 ±0.11 mm) than the group Dent (0.13 ±0.11 mm and 0.19 ±0.12 mm; *P*=.019 and *P*=.008).

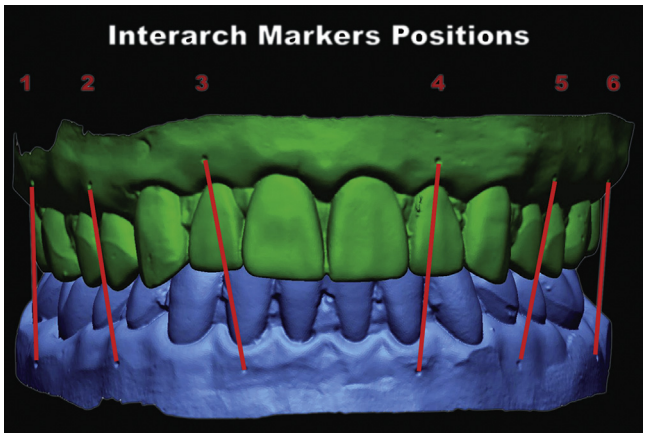

Figure 1. Six pairs of interarch markers marked in each group on master stone cast.

In the group Bil-Post, the edentulous areas were at the interarch marker positions 1, 2, 5, and 6. At the interarch marker positions 1 and 2, the group Bil-Post had significantly greater mean differences between the digital and manual measurements (0.44 ±0.24 mm and 0.17 ±0.13 mm) than the results from the group Dent (0.17 ±0.13 mm and 0.06 ±0.05 mm; *P*=.006 and .034). However, at the interarch marker positions 5 and 6, the mean difference between the digital and manual measurements in the group Bil-Post (0.28 ±0.18 and 0.47 ±0.49 mm) was not significantly different from that of the group Dent (0.22 ±0.13 and 0.20 ±0.18 mm; *P*=.367 and *P*=.137).

DISCUSSION

The null hypothesis was accepted for the group 1-Post, as a single missing posterior tooth did not affect the accuracy of VIRs. However, the null hypotheses were rejected in the group 3-Post, group 6-Ant, and group Bil-Post, as extended edentulous spans in the anterior and posterior regions affected the accuracy of VIRs. In this study, the VIR error was represented by mean differences between the digital and manual measurements. These mean differences from the group Dent were used as the references and compared with the mean differences from the remaining groups at the corresponding interarch marker positions. This comparison was used to investigate the effects of the span and location of edentulous areas on the accuracy of VIRs. The results from the group 1-Post showed a single missing posterior tooth did not affect the accuracy of VIRs in the edentulous area (0.27 ±0.24 mm); this finding implies that a complete digital workflow may be indicated in a missing single posterior tooth in clinical practice.

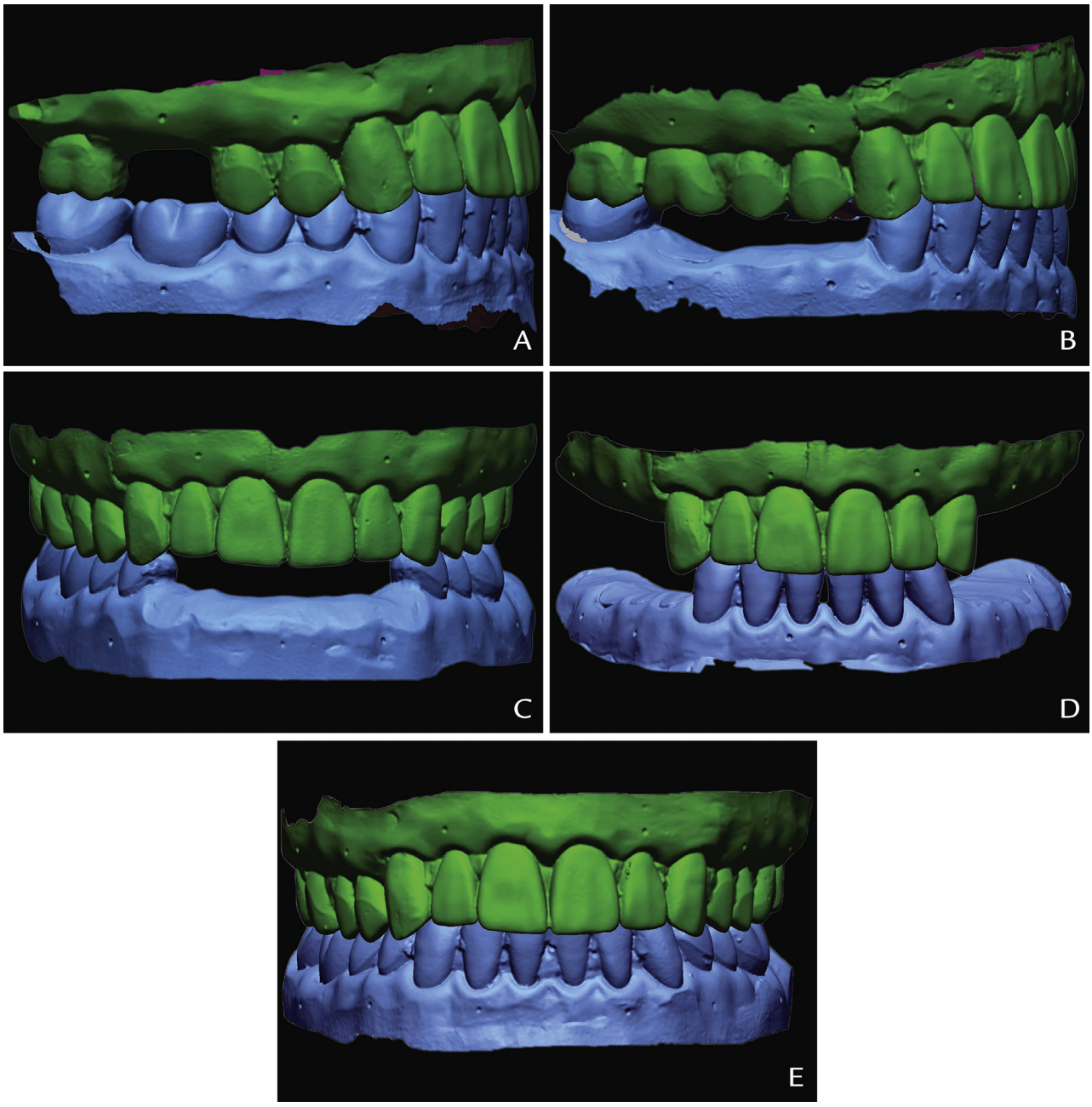

Figure 2. Representative standard tessellation language files as imported into surface-matching software program for digital measurements. A, Group 1-Post. B, Group 3-Post. C, Group 6-Ant. D, Group Bil-Post. E, Group Dent.

In the group 3-Post, group 6-Ant, and group Bil-Post, the results suggested that an extended edentulous span in the posterior and anterior regions all affected VIR accuracy. However, with an anterior edentulous span, although the accuracy level (mean) decreased, the reproducibility (standard deviation) of VIRs remained at a higher level. When the edentulous spans were in the unilateral or bilateral posterior areas, both the accuracy and reproducibility of VIRs decreased. These findings imply that the use of a completely digital workflow with extended edentulous space might not be a predictable practice. The decision of whether to use VIRs in these situations depends on factors such as the type of prosthesis and its error tolerance in terms of occlusion. Traditional prosthodontic laboratory steps including manually articulated CAD-CAM milled or printed casts can be considered to correct the occlusal deviation from VIRs.

The trueness and precision of digital scans for either a complete dentate arch or partial edentulous arch have been reported to range between 0.06 mm and 0.20 mm.[10,18,19] The accuracy of VIRs in the 1-missing-tooth

Table 2. Mean differences ±standard deviation (mm) between digital and manual measurements calculated at edentulous interarch marker positions in groups 1-Post, 3-Post, 6-Ant, and Bil-Post and compared with corresponding positions in group Dent

Study Group	Group 1-Post	Group 3-Post	Group 6-Ant	Group Bil-Post	Group Dent
Interarch marker position 1	0.27 ±0.24	0.87 ±0.52[a]		0.44 ±0.24[a]	0.17 ±0.13
Interarch marker position 2		0.44 ±0.29[a]		0.17 ±0.13[b]	0.06 ±0.05
Interarch marker position 3			0.29 ±0.17[b]		0.13 ±0.11
Interarch marker position 4			0.34 ±0.11[a]		0.19 ±0.12
Interarch marker position 5				0.28 ±0.18	0.22 ±0.13
Interarch marker position 6				0.47 ±0.49	0.20 ±0.18

Using group Dent as reference for comparisons, in same row (at same interarch marker position). [a]Statistical difference at $P<.01$. [b]Statistical difference between 1 group and group Dent at $P<.05$.

situation has been reported to be between 0.02 mm and 0.471 mm.[13,16] The findings from the present study are within this reported range. A few clinical studies have reported that using a complete digital workflow with VIRs to restore single implant–supported crowns required little or no clinical adjustment and was a feasible treatment option.[7,20,21] Kollmuss et al[23] reported that clinicians spent 68 to 129 seconds on an occlusal adjustment of about 0.2 mm for CAD-CAM crowns. Overall, a complete digital workflow including VIRs could be considered a suitable and effective clinical practice for single-unit restorations. The authors are unaware of a previous experimental study or clinical trial that validated the complete digital workflow for a partially edentulous arch that had 1 or more missing posterior teeth.

In addition to the span of the edentulous area (1 missing tooth versus 3 missing teeth), the present study also found that the location (anterior versus posterior or unilateral versus bilateral) of the edentulous area affected the accuracy and reliability of the VIRs. Therefore, additional scan strategies such as stitching markers on edentulous area or VIRs scan aids can be considered to improve clinical outcomes.[11]

This study did not replicate all clinical scenarios and had limitations. Only one IOS system was used, and future studies should investigate the system-specific scan strategy that may affect the accuracy and reliability of different VIRs. In addition, the in vitro study did not account for all the clinical variables, such as the presence of saliva, need for soft-tissue management, and patient movement during scanning, factors that could impact the scan process and the accuracy of VIRs. Finally, the study simplified partial edentulous areas, with no presence of recognizable dental structures such as an implant scan body or healing abutment; these recognizable dental structures may facilitate and improve the accuracy of VIRs. In addition, the simplified edentulous area did not include prepared abutment teeth, which may also offer more distinguishable anatomic structures to be captured and registered for the VIRs. Future clinical investigations are required to broaden and validate the indications of complete digital workflow with VIRs.

CONCLUSIONS

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

1. The span and location of edentulous areas affected the accuracy of VIRs.
2. A single missing posterior tooth did not affect the accuracy of VIRs, and a complete digital workflow may be recommended in this scenario.
3. Unilateral and bilateral extended edentulous spans with 3 or more missing posterior teeth and the extended edentulous span in the anterior region all affected the accuracy of VIRs. The use of a complete digital workflow in the clinical scenarios with extended edentulous space might not be a predictable practice.

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Acknowledgments:
The authors thank Jeff Rogers from Advance Visualization Lab in the Indiana University for his technical instruction and support in this research and George J. Eckert from the Indiana University School of Medicine for his statistical consultation.

https://doi.org/10.1016/j.prosdent.2019.08.013