Analyzing the Accuracy of a Cross-Mounting Technique Utilizing Digital Occlusal Registrations

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Accessibility
Analyzing the Accuracy of a Cross-Mounting Technique Utilizing Digitized Occlusal Records

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Previously presented at:

First Place, Resident Research Poster Presentation Competition
Presented at: 105th Annual Session of the Academy of Prosthodontics, Naples, FL, May 2023

Second Place, Scientific Poster Presentation Competition
Presented at: 52nd Annual Session of the American College of Prosthodontists, Austin, TX, November 2022

Grant Provider: Greater New York Academy of Prosthodontics
Presented at: 68th Scientific Meeting of the Greater New York Academy of Prosthodontics, New York, NY

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ABSTRACT

Objective: To compare the accuracy of a partially digital cross-mounting workflow of direct scans of interocclusal records to that of a conventional workflow by analyzing the deviations of sequentially cross-mounted casts.

Materials and Methods: A set of reference casts, comprising maxillary and mandibular full-arch prepared casts and interim prostheses, was articulated, mounted, and scanned to generate four reference casts for cross-mounting. In the conventional approach, 15 sets of these four casts were printed. Polyvinyl siloxane (PVS) interocclusal records were made using the reference casts and utilized for sequential cross-mounting. In the partially digital group, the same PVS interocclusal records were scanned and used for digital cross-mounting via design software program. The mean deviations of both groups from the reference cast were analyzed using a 3D inspection software program. Statistical tests, including paired t-test and analysis of variance (ANOVA), were conducted to compare the average discrepancies between the two groups and to evaluate discrepancies in the anterior and posterior regions (α = .05).

Results: The range of discrepancies was similar in both the conventional and partially digital groups. The final set of related casts had a mean deviation of 201.58 ±136.98 μm in the conventional workflow and 248.69 ±164.71μm in the partially digital workflow. No statistically significant difference was found between conventional and partially digital groups (P=.091). Error propagation was examined by comparing discrepancies at each step within the cross-mounting process. In the conventional group, no significant difference was found (P=.148), but a significant difference was found among groups in partially digital group at each step of sequential mounting (P<.001). A significant difference was observed between anterior
and posterior deviations in the partially digital group \((P < .001)\), but not in the conventional group \((P = .143)\).

**Conclusions:** The study reveals that there is no statistically significant difference between conventional and partially digital cross-mounting workflows. However, within the partially digital group, a significant difference in deviation emerges across cross-mounting steps, with increased deviation in the anterior region.

**KEYWORDS:** Cross-mounting, Accuracy, Articulation, Digital scan.

**INTRODUCTION**

Cross-mounting is an important procedure in restorative and full-mouth rehabilitation cases, involving the sequential mounting of provisionalized and prepared casts in an articulator. This process theoretically ensures a perfect interchangeability of the maxillary and mandibular casts relationships.\(^1\) Once mounted in an articulator, clinician can evaluate the occlusion and function by stimulating the patient’s jaw movement, while aiding dental laboratories transferring precise information from provisional to final restorations for a proper fit and ultimate function.\(^2\)

In conventional cross-mounting procedure, several factors can introduce inaccuracies.\(^3\) These factors involve issues with impression materials and stone expansion that can contribute to cast distortions.\(^4, 5\) Some impression materials may fail to capture all the fine details of the dental arches, resulting in inaccuracies.\(^6, 7\) Furthermore, the dimensional inaccuracies in the dental stone affect the ability to mount the casts accurately. According to the American Dental Association’s Specifications No. 25, gypsum-based materials display linear setting expansion ranging between 0.06% to 0.5% and continue to expand for up to 120 hours.\(^3\)

Digital methods in dentistry are increasingly popular, aiming to replace conventional techniques. Several articles have demonstrated that digital scanned models are either superior to
or equally accurate as poured models obtained through conventional methods.\textsuperscript{8-10} Utilizing a digital workflow in cross-mounting can be a precise method for transferring information from provisional to permanent prosthesis.\textsuperscript{11} One such digital technique involves a buccal bite scan utilizing an intraoral scanning device. Studies have shown that digital cross-mounting using buccal bite scan can achieve high accuracy, with errors ranging from 10 to 100 microns.\textsuperscript{12-14}

While buccal bite scans for cross-mounting may offer greater accuracy and efficiency compared to conventional techniques, there are some limitations that make digital cross-mounting challenging.\textsuperscript{15,16,17} The accuracy of the buccal bite scan can be affected by patient-related factors such as jaw tremors, spasms, or twitching during the scanning process, leading to inaccuracies.\textsuperscript{18} Alternatively, rigid polyvinyl siloxane (PVS) registration materials provide more stable records, making them preferable in scenarios where challenges such as movements during scanning procedures occur or with a limited number of contacting teeth in intercuspal position after crown preparations. Therefore, integrating PVS registration into the digital cross-mounting process is crucial to address these specific objectives and ensure optimal outcomes.

This study aimed to compare the accuracy of a partially digital cross-mounting workflow, using direct scans of interocclusal records, with a conventional workflow by analyzing the mean deviations of sequentially cross-mounted models. The null hypotheses were as follows: no significant difference between partially digital and conventional cross-mounting groups; no significant difference in deviations at each step of sequential cross-mounting; and no difference in deviations between anterior and posterior regions for each group.

**MATERIALS AND METHODS**

The project was conducted in five stages: reference cast generation, interocclusal record generation, cross-mounting, data collection, and analysis (\textit{Fig. 1}).
**Reference Casts Generation**

A dental typodont was used to replicate a full-mouth rehabilitation scenario. A set of reference casts were prepared, which included 3D printed (Promaker LD20, Prodways Tech., Paris, France) full-arch maxillary and mandibular prepared casts (referred to as MxPp, MnPp) and a set of designed and milled (WX-52D - 5-Axis Milling Machine, Roland DGShape Corp., Shizuoka, Japan) full-arch maxillary and mandibular interim restorations (MxIn, MnIn). These interim restorations were securely placed onto maxillary and mandibular preparation casts, manually articulated, and mounted in an articulator (Artex CR, Amann Girrbach AG, Koblach, Austria) using type III gypsum (Whip Mix Mounting stone, Whip Mix Corp., Louisville, KY). For reference, the Bonwill triangle served to establish the occlusal plane. Following this preparation, the reference casts were scanned using a laboratory scanner (E3, 3Shape A/S, Copenhagen, Denmark) to generate a reference set of standard tessellation language (STL) files. Four sets of casts were created: maxillary (MxPp) and mandibular (MnPp) preparation casts, along with maxillary (MxIn) and mandibular (MnIn) interim restoration casts. In total, 15 sets of these four casts were produced using a 3D printer for utilization in the conventional cross-mounting group.

**Interocclusal Record Generation**

In the conventional method, 15 sets of three interocclusal records were made using PVS bite registration material (Blu-Mousse, Parkell Inc., Edgewood, NY) on the reference cast. The sequence of PVS interocclusal records captured was as following: maxillary interim opposing mandibular interim (MxIn-MnIn), maxillary preparation opposing mandibular interim (MxPp-MnIn), maxillary preparation opposing mandibular preparation (MxPp-MnPp). In the partially digital method, the same 15 sets of three PVS interocclusal records were used to create digital
interocclusal records (Fig. 2). The initial step involved converting the master models into impression models using 3Shape software (3Shape Trios, 3Shape Dental Manager, Copenhagen, Denmark) and saving each converted model as single STL file. Within the 3Shape Trios software, an order was created utilizing impression mode, which included two single trays and a bite registration. Subsequently, the STL files of the converted models of maxillary interim, mandibular interim, and scanned PVS interocclusal record were imported into 3Shape software. The next step consisted of aligning the scanned PVS interocclusal records with maxillary interim and mandibular interim models utilizing 3-point alignment feature. The resulting STL file was then exported as MxIn-MnIn digital interocclusal record. The same sequence was repeated for the maxillary preparation opposing mandibular interim, maxillary preparation opposing mandibular preparation, and maxillary interim opposing mandibular preparation, resulting in MxPp-MnIn, MxPp-MnPp, and MxIn-MnPp digital interocclusal records, each subsequently exported as an STL file.

**The Cross-Mounting Procedure**

In the conventional method, a facebow preservation jig was created by mounting the MxIn reference cast with a facebow and PVS interocclusal registration material using Type III gypsum. MnIn was hand articulated with the MxIn and mounted in the articulator. The MxPp cast was then mounted against the MnIn cast using PVS interocclusal records, while the MxPp cast was mounted against the MnPp cast using corresponding PVS interocclusal record. The last pair, MxIn and MnPp, was oriented based on previous mountings rather than having its own interocclusal record. The mounted casts were then scanned and exported for analysis. A 19.6-N load was applied on the articulator over a 15-minute period to facilitate the setting of the stone
for each mounting. Subsequently, 15 sets of the four related casts were placed in the articulator and scanned to generate STL files for analysis in inspection software (Fig. 3).

In the partially digital method, the 3Shape Dental System program was used to upload STL files of the reference casts and one set of digital interocclusal records, aligning them through a 3-point alignment feature. The alignment process was done in the following sequence: the MxIn cast was aligned with MxIn-MnIn digital interocclusal record; the MxIn-MnIn digital interocclusal record was aligned with MnIn; the MnIn was aligned with MxPp-MnIn digital interocclusal record; the MxPp-MnIn digital interocclusal record was aligned with MxPp; MxPp to MxPp-MnPp digital interocclusal record; and MxPp-MnPp digital interocclusal record was aligned with MnPp. Subsequently, a new order was initiated with the next set of digital interocclusal records while utilizing the same STL files of reference casts. The 15 sets of four digitally related STL files were then exported for analysis in inspection software.

**Data Collection and Analysis**

Each related STL file was imported into the inspection (Geomagic Control X, 3D Systems, Rock Hill, SC) software program and superimposed over the corresponding reference STL file. In the MxIn-MnIn, MxPp-MnPp, and MxIn-MnPp casts, the deviations were measured on the mandibular cast, while in MxPp-MnIn casts, they were measured on the maxillary cast. Deviations from the reference casts were measured and analyzed at 4 specified points: the center of the buccal surfaces of #24 and #26, the center of buccal cusp of #19 and #30 (Fig. 4). All maxillary models were positioned within the same coordinate system.

The collected data was analyzed using statistical software (IBM SPSS Statistics, v22; IBM Corp) program with a significance level of α=0.05. The paired t-test was used to compare the average overall deviation between the partially digital and conventional groups and
deviations between anterior and posterior regions within both groups. ANOVA was used to evaluate the average deviations at each step of the cross-mounting process for each group.

RESULTS

Table 1 provides the mean ±standard deviation values depicting the comparison between reference casts and experimental casts within the partially digital and conventional groups. The range of discrepancy is similar in conventional and partially digital workflows. The conventional group demonstrated a mean ±standard deviation of 201.58 ±136.98 μm and the partially digital group showed a mean ±standard deviation of 248.69 ±164.71 μm (Fig. 5). There was no statistically significant difference between partially digital and conventional groups (P =.091). Therefore, the null hypothesis is not rejected at the significance level (α=.05).

The error propagation was investigated by comparing the amount of discrepancy at each step within the cross-mounting process. There was no significant difference found among groups in conventional (P=.148) (Fig. 6), but a significant difference was found among groups in partially digital (P<.001) at each step of sequential mounting (Fig. 7).

The mean anterior and posterior deviations in the partially digital and conventional groups were analyzed with the results outlined in Table 2. Significant difference was observed between anterior and posterior deviations in the partially digital group (P<.001), but not in the conventional group (P=.143). The mean ±standard deviation in partially digital group was at 333.34 ±152.65 μm anteriorly and 164.05 ±130.66 μm posteriorly. The mean ±standard deviation in conventional group was at 175.56 ±119.20 μm anteriorly and 227.60 ±150.22 μm posteriorly.

DISCUSSION
A previous study showed that digital cross-mounting, using a buccal bite scan, offers higher accuracy compared to the conventional method. Nevertheless, the accuracy of the buccal bite scan can be affected by patient-related factors, particularly uncontrolled muscle activity. In cases where patients are unable to maintain a consistent bite due to jaw tremors, spasms, or twitching during the scanning process, potential inaccuracies can arise. To address these challenges, our study introduces an alternative method by incorporating PVS interocclusal records and converting them into a digital format. The use of the rigid PVS interocclusal record ensures a stable bite particularly beneficial for patients with uncontrolled muscle activity. By integrating the benefits of digital technology and utilizing converted PVS interocclusal records, this workflow is designed to overcome limitations encountered in both conventional and fully digital approaches.

This study compared the accuracy of a partially digital cross-mounting workflow utilizing direct scans of PVS interocclusal records to a conventional workflow. There was no statistically significant difference between partially digital and conventional groups. Therefore, the null hypothesis of the study was not rejected. The results indicate that the partially digital workflow achieves a comparable level of accuracy to the conventional workflow. This suggests that the proposed approach can be a viable alternative, capable of delivering accurate results especially in challenging clinical scenarios.

When comparing anterior and posterior deviations in the conventional and partially digital groups, a statistically significant difference was observed in the partially digital group with increased deviation observed in the anterior region. Consequently, the null hypothesis was rejected for the partially digital group. The limitation in the current software alignment method utilizing a three-point feature may contribute to these results. Notably, only one of these three
points was used for aligning the anterior region, potentially leading to less accurate alignment of
the anterior teeth and contributing to the observed deviations. This indicates that using more than
one data point in the anterior region could improve the accuracy of the data collection by the
software in the future. Additionally, the greater anterior deviation could be attributed to
limitations within the software algorithms. Wong et al observed the differences in how the
software aligns and compares the digital models of the anterior and posterior regions.6 His
findings showed that certain software programs may be better optimized for the posterior region,
possibly yielding more accurate outcomes in that region.

In our study, we examined error propagation in both partially digital and conventional
cross-mounting groups. While no significant difference was found when comparing the range of
discrepancies at each of mounting step within conventional group, a significant difference was
found within the partially digital group. Therefore, the null hypothesis was rejected for the
partially digital group.

One of the contributing factors to the error propagation within the partially digital
workflow was related to the method used to align casts in MxIn-MnIn. In the conventional
group, the initial step of mounting the maxillary interim restoration with mandibular interim
restoration was conducted using manual hand articulation. However, in the partially digital
group, this initial alignment of MxIn-MnIn necessitated an interocclusal registration.
Consequently, using the MxIn-MnIn digitized interocclusal record may have contributed to the
error propagation observed within partially digital workflow.

In the conventional group, known errors such as expansion of the gypsum model stone
and polymerization shrinkage of PVS material, were carefully compensated for, resulting in
errors that were equally distributed and consistent within each cross-mounting step. Without such compensation for the expansion and shrinkage of these physical dental materials in the partial digital group, the inaccuracies accumulated to a greater from one step to the next. However, in the partially digital workflow, although certain errors inherent to conventional methods may not directly apply, there are unique sources of deviation that require consideration and compensation. In this context, potential inaccuracies can arise during digital scanning or printing stages. Additionally, registration errors during digital cross-mounting and discrepancies arising from manipulating digital data within the software design may occur. This further emphasizes the need for more research to answer questions regarding the accuracy of digital manufacturing processes. While conventional methods involve established protocols for error compensation, the digital method requires careful attention to sources of deviation and thorough calibration protocols to mitigate these errors.

By acknowledging the limitations of workflows and addressing patient-related factors, practitioners can optimize the accuracy and reliability of digital cross-mounting workflows in dental applications. With the prospect of conducting more similar studies in the future, this tailored approach ensures that workflow aligns with the patients’ needs and minimizes the potential challenges during the treatment. Further research and refinement of these processes can lead to improved clinical outcomes and more efficient workflows.

CONCLUSIONS

This study reveals no significant difference between conventional and partially digital cross-mountings. This proposed partially digital workflow of cross-mounting, utilizing direct scans of PVS registration records, offers an alternate solution for cross-mounting. Although, the
partially digital workflow is a viable method, offering benefits like increased efficiency and reduced reliance on physical models, the clinical impact is yet to be determined.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Mr. Jack Jeong, and 3DBioCAD/B&B Dental Lab (Seattle, WA) for technical expertise, Mr. Joel Pollet from Cimquest Inc. (Sterling, MA) for technical assistance, and Mr. Charles Mwele from Harvard School of Dental Medicine (Boston, MA) for the laboratory support.
REFERENCES


**Figures and Tables**

**Figure 1.** Study design of conventional and partially digital workflows: reference cast fabrication, interocclusal records, cross-mounting, data collection and analysis.

<table>
<thead>
<tr>
<th>Reference Casts</th>
<th>Interooclusal Records</th>
<th>Mounting</th>
<th>Data Collection and Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conventional Workflow</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Reference casts | 3D intraoral records  | Mounts | Digital 
Medial  
Medial |
| **Partially Digital Workflow** | | | |
| Reference casts | 3D intraoral records  | Mounts | Digital 
Medial  
Medial |

![Diagram showing study design](image-url)
Figure 2. Conversion of PVS interocclusal registrations into digital interocclusal records. A: MxIn-MxIn, B: MxPp-MnIn, C: MxPp-MnPp.
Figure 3. Sequence of conventional cross-mounting.
Figure 4. Data analysis in a 3D inspection software. Point 1: Tooth #30, Point 2: Tooth #26, Point 3: Tooth #24, Point 4: Tooth #19.
Figure 5: Boxplot of mean deviations in partially digital and conventional cross-mountings at the final cast relation (MxIn-MnPp).
Figure 6: Boxplot of the deviations at each mounting step in the conventional cross-mounting workflow.
**Figure 7:** Boxplot of the deviations at each mounting step in the partially digital cross-mounting workflow.
Table 1. Mean ±Standard Deviation in conventional and partially digital cross-mounting groups at the final step.

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Partially Digital</th>
<th>P value</th>
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<tbody>
<tr>
<td>201.58 ±136.98</td>
<td>248.69 ±164.71</td>
<td>.091</td>
<td></td>
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*P<.05
Table 2: Mean anterior and posterior deviation ±standard deviation (mm) in conventional versus digital cross-mounting groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Anterior</th>
<th>Posterior</th>
<th>P</th>
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<td>Conventional</td>
<td>175.56 ±119.20</td>
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<td>.148</td>
</tr>
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<td>Partially Digital</td>
<td>333.34 ±152.65</td>
<td>164.05 ±130.66</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

*P<.05