Purpose: To compare the accuracy of dentists with different levels of expertise in computer-aided design (CAD) and prosthodontics to digitally design single crowns.

Material and Methods: This in vitro study was conducted on 12 prepared teeth in 2 reference dental study models. The models were scanned using an intraoral scanner. Four dentists with different levels of clinical and CAD expertise (PROS: clinicians experienced in prosthodontics [n = 2]; CAD: experts in CAD [n = 2]) performed digital waxing on all prepared teeth using the same CAD software program. The resulting digital crown designs were compared to STL files of the original teeth to assess 3D deviations. The total cervical, distal, mesial, and occlusal surface deviations of the crowns from both groups were compared using paired *t* and Wilcoxon signed-rank tests (α = .05).

Results: The total median 3D deviation was 0.10 mm (range: 0.03 to 0.61 mm) for the PROS group and 0.14 mm (range: 0.07 to 0.58 mm) for the CAD group. The PROS group presented significantly smaller total 3D (P = .021) and cervical margin (P = .001) deviations. There were no significant differences between groups on the distal, mesial, or occlusal surfaces (P > .05). The CAD group performed digital waxing significantly faster (P = .001).

Conclusion: Within the limitations of this study, the present findings suggest that clinical experience has a higher impact on the accuracy of digital wax patterns of single crowns than CAD experience.
several advantages, such as enhanced data sharing and storage of digital files. Clinical outcomes of single crowns fabricated with a digital workflow are affected by both computer-aided design (CAD) and computer-aided manufacturing (CAM) methods. Single-crown restorations fabricated with poly-methyl methacrylate (PMMA) resin-based and ceramic CAD/CAM materials achieved satisfactory marginal fit and success rates. In this context, CAD/CAM dental prostheses have also been designed and fabricated in dental clinics using a chairside digital workflow. However, little is known about differences in accuracy of digital wax patterns created by dentists with varying levels of clinical and CAD expertise working with a chairside digital workflow.

Thus, the objective of this study was to compare the impact of different levels of clinical experience in prosthodontics and expertise in CAD on the accuracy of digital waxing of single crowns performed by dental clinicians.

**MATERIALS AND METHODS**

This in vitro study was conducted on two reference resin dental study models (Manequim Dental, P-Oclusal) with complete mandibular and maxillary arches. Both models were initially scanned using an intraoral scanner (TRIOS 4, 3Shape). Single-crown preparations were performed for a total of 12 teeth (3 in the anterior maxilla, 4 in the posterior maxilla, and 5 in the posterior mandible) by the same prosthodontist. All prepared teeth had sound antagonist and adjacent teeth. The models were then scanned using the same intraoral scanner. All resulting 3D virtual models were saved as standard tessellation language (STL) files and imported into a CAD software (Meshmixer, Autodesk), which was used to evaluate the integrity of each digital mesh.

For the purpose of assessing reproducibility, four dentists performed digital waxing for each prepared tooth using the same software (ChairsideCAD, exocad). Two dentists had more than 15 years of clinical experience in prosthodontics and basic CAD training (ie, a 1-week ChaisideCAD [exocad] software training course performed at a CAD/CAM training center [dOne3D, Ribeirão Preto, Brazil]; group PROS). The other two dentists were general practitioners with less than 5 years of clinical experience, but with at least a certificate in CAD/CAM and more than 5 years of experience using the software system of this study (DentalCAD, exocad) for approximately the same total experience time (group CAD).

Both groups performed the digital waxing following the same procedure. The first step was to import the STL files into another CAD software dedicated to dental treatment (ChairsideCAD, exocad) to initially outline the margin of the tooth preparation. Crown shapes of both groups were then chosen from the same software library to ensure that the comparison would be limited to the margins and the adjustments of the crown shape in the dental arch (eg, establishment of contact points with the adjacent and antagonist teeth). After defining the optimal insertion axis and emergence orientation of the crown positioned in the dental arch, the crown dimensions were digitally adjusted, taking into consideration the positions of the antagonist and adjacent teeth. Finally, the resulting digital crown design was saved as an STL file (Fig 1). The four dentists performed all digital waxing twice with an interval of 2 weeks between them to eliminate memory bias (Fig 2).

The STL files obtained from each digital wax pattern were aligned and superimposed on the respective control STL files (exported from the initial scan of the original teeth). Total and individual 3D mesh deviations were automatically calculated at each of the crown surfaces: (1) cervical margin at the coupling interface; (2) mesial; (3) distal; and (4) palatal/lingual/incisal for anterior teeth or occlusal for posterior teeth. These calculations were performed by using a 3D inspection and mesh-processing software (GOM Inspect 2019) following a previously described methodology. All deviation measurements were digitally recorded in millimeters within a 3D color map.
Since strong interobserver agreements were expected, sample size calculation was performed using the Noether formula considering a statistical power of 80% and a significance level of 5%. Normality of measurements was assessed using Shapiro-Wilk test. Intraobserver agreements were assessed with intraclass correlation coefficient (ICC). Parametric comparisons between groups were assessed with paired t test, whereas nonparametric comparisons were assessed with Wilcoxon signed-rank test. Comparisons among different crown surfaces (ie, cervical, distal, mesial, and palatal/lingual/incisal or occlusal) were performed using Kruskal-Wallis test. Finally, the mean times required by the two groups to perform digital waxing were compared using paired t test ($\alpha = .05$) using the same statistical software program (SPSS Statistics version 26, IBM).

RESULTS

Normality of the measurements performed by both groups was rejected for total 3D and occlusal surface deviations ($P < .05$) and accepted for cervical, distal, and mesial surfaces ($P > .05$). Descriptive results of this study are shown in Table 1. Statistical results for comparisons between operator groups and surfaces are available in Table 1 and Fig 3, respectively. Intraobserver agreement was confirmed for the four dentists, with ICC values ranging from 0.83 to 0.93 ($P < .001$).

The PROS group achieved significantly smaller total deviation ($P = .021$) and cervical margin ($P = .001$) deviations compared to the CAD group (Fig 4). However, there were no statistically significant differences between groups in distal, mesial, or occlusal deviations ($P > .05$, Table 1). Furthermore, Kruskal-Wallis test revealed a statistically significant difference in total 3D deviation results among all the crown surfaces analyzed ($P = .001$, Fig 3). Post hoc pairwise comparisons revealed that all surfaces were significantly different from each other ($P < .05$), with the exception of the pairwise comparison between distal and mesial deviations ($P = .769$).

Regarding the time required to perform digital waxing, normality was confirmed for both groups ($P > .05$). The mean times required to perform digital waxing were $14.69 \pm 4.33$ minutes for the PROS group and...
9.75 ± 2.12 minutes for the CAD group. A statistically significant difference was found ($P = .001$).

**DISCUSSION**

This in vitro study aimed to compare the accuracy of dentists with different levels of CAD expertise and clinical experience in performing chairside digital waxing of single crowns in relation to reference STL files of the respective original teeth. The results showed that the dental clinicians with more experience in prosthodontics digitally designed the cervical margins of the crowns significantly more accurately than the dentists who were CAD experts. This finding supports the fact that CAD/CAM technologies are tools for enhancing the predictability of treatments that follow the same principles of tooth morphology and clinical prosthodontics used in conventional workflows. On the other hand, there were no statistically significant differences for the other crown surfaces analyzed (distal, mesial, and incisal/occlusal). Of particular note is that the total median deviations obtained in this study were not higher than 0.14 mm (140 µm), which is still lower than marginal and internal gap values found in the literature for CAD/CAM single crowns.

A previous study reported strong intra- and interobserver agreements for 3D mesh deviation measurements between two observers with different levels of expertise, which contrasts with the present results. However, the aforementioned study was conducted on abutments embedded in individual resin dies. As a result, only digitally designed cervical margins were compared, since the crown shapes were not digitally adjusted in position in the dental arches. In this context, this is the first study on the precision of digital wax patterns assessing factors such as position of the crown in the dental arch, as well as contact points with the adjacent teeth and the antagonist arch in occlusion.

The present study supports previous evidence that professionals with experience in CAD/CAM are significantly faster in digital waxing than dentists with basic training. This finding is clinically relevant, since the advantages of digital workflows in dentistry include faster treatments and shorter chairside times. Such findings emphasize the importance of computer and CAD training for dental clinics and professionals striving to work solely with digital dentistry.

One of the limitations of this in vitro CAD study performed on dental models is that the impact of clinical factors affecting the 3D models could not be addressed (eg, saliva and limitation in mouth opening). The presence of such factors might affect the accuracy of intraoral scans of the tooth preparations. Furthermore, only two operators with each level of expertise were included in this preliminary study. Similarly, only one CAD software was used by these operators, and results could vary for different CAD software systems. Finally, this CAD study was restricted to the evaluation of 3D deviations of digital wax patterns. However, the clinical accuracy of the manufactured crowns could also be influenced by factors related to CAM. Therefore, future observational clinical studies are recommended to address the effect of knowledge of different CAD/CAM systems on the accuracy and precision of digital waxing procedures.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Descriptive Data and Comparisons Between PROS and CAD Groups</th>
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<tr>
<td>3D deviation</td>
<td>Central tendency</td>
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<tr>
<td>Total</td>
<td>Median (min–max)</td>
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<tr>
<td>Cervical</td>
<td>Mean ± SD</td>
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<tr>
<td>Distal</td>
<td>Mean ± SD</td>
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<tr>
<td>Mesial</td>
<td>Mean ± SD</td>
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<tr>
<td>Occlusal</td>
<td>Median (min–max)</td>
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Bolded values were statistically significant between groups.

*Paired $t$ test.

**Wilcoxon signed-rank test.

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CONCLUSIONS

Within the limitations of this study, the present findings suggest that postgraduate status in prosthodontics and clinical experience has a higher impact on the accuracy of digital wax patterns of single crowns than CAD experience. On the other hand, software training allows for faster digital waxing, which is clinically relevant for chairside digital workflows.

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REFERENCES


Literature Abstract

Attachment Systems for Mandibular Implant-Supported Overdentures: A Systematic Review and Meta-analysis of Randomized Controlled Trials

Although mandibular implant-supported overdentures have been highly recommended as a treatment option, consensus on the type of attachment system that can be used to increase implant and prosthesis survivability is lacking. The purpose of this systematic review and meta-analysis was therefore to compare different types of retention attachments by investigating outcome measures such as implant and prosthesis survival rates and biologic and prosthetic complications in patients with a mandibular implant-supported overdenture. The literature search was performed in the PubMed, Cochrane, Embase, and Scopus databases by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses criteria, and this article was registered with the International Prospective Register of Systematic Reviews (CRD42021253566). An analysis of associations between different attachment systems and implant and overdenture survival rates in randomized controlled clinical trials (RCTs) was conducted. The initial search indicated 477 studies, of which 25 RCTs were included for analysis. A total of 2,154 implants and 737 overdentures were analyzed in the meta-analysis. The main results indicated the failure rate for dental implants to be 2.0% (95% CI: 1.3 to 3.2) and for overdentures to be 4.2% (95% CI: 1.6 to 10.5). With regard to different attachment systems, similar failure rates were identified for bar-type retention (7.7% to 95% CI: 3.0 to 18.1), magnetic retention (7.6% to 95% CI: 2.2 to 22.7), and ball-type retention (6.8% to 95% CI: 3.0 to 14.3). No significant difference was found in biologic complications for splinted vs unsplinted implant overdentures (P = .902). Regarding prosthetic complications, the most favorable groups were LOCATOR attachments, followed by telescopic, Conus, bar, and ball attachments. Magnetic attachments had higher prosthetic complications (7.4 times) than the other attachments. Implants and implant-supported mandibular overdentures showed a high survival rate irrespective of the attachment system used. Splinting implants did not significantly affect the rate of biologic complications. Prosthetic complications were most common for magnetic attachments and least common for LOCATOR attachments.