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RESEARCH AND EDUCATION

Effect of varying levels of expertise on the reliability and reproducibility of the digital waxing of single crowns: A preliminary in vitro study

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ABSTRACT

Statement of problem. The digital waxing of single crowns can be affected by the quality of intraoral scans and use of computer-aided design (CAD) software programs. However, clinical outcomes of the resulting crowns are also affected by computer-aided manufacturing (CAM) methodologies. Studies on the effect of different levels of expertise on digital waxing are lacking.

Purpose. The purpose of this in vitro study was to assess the impact of different levels of expertise on the reliability and reproducibility of margin outlining during digital waxing.

Material and methods. Thirty analogs of implant stock abutments (Ø4.8×4 mm) were embedded into resin blocks. To simulate different clinical situations, abutments were divided into 3 groups: 10 abutments (group GOS) received artificial gingiva and were scanned with an open system intraoral scanner, while 10 abutments with (group GIS) and 10 abutments without artificial gingiva (group IS) were scanned with an intraoral scanner within an integrated CAD-CAM system. All resulting standard tessellation language (STL) files were used by 2 different observers (an experienced CAD professional and a clinician with basic CAD knowledge) to digitally design a left mandibular central incisor in the same software program. All resulting digital crown designs were exported to STL files to assess crown margin accuracy at the coupling interface by superimposition with the control STL file of the scan body designed for the same abutment by the manufacturer. For this purpose, a CAD software program was used to automatically calculate median, minimum, and maximum deviations of margins in millimeters. Statistically significant pairwise differences among groups and between observers were assessed with the Wilcoxon signed-rank test (α=.05).

Results. For the CAD professional, median deviations between designed crown STL files and the control STL of the scan body were 0.08 mm (range: 0.04 to 0.15) for group GOS; 0.10 mm (range: 0.06 to 0.18) for group GIS; and 0.05 mm (range: 0.03 to 0.08) for group IS. For the clinician, median deviations were 0.08 mm (range: 0.04 to 0.12) for group GOS; 0.11 mm (range: 0.07 to 0.17) for group GIS; and 0.05 mm (range: 0.04 to 0.11) for group IS. There were no significant differences between observers (P>.05). However, statistically significant differences were found between group IS and the other 2 groups (P=.001) but not between groups GOS and GIS (P>.05).

Conclusions. The present findings suggest that a digital wax pattern made with a dental CAD software program is not affected by varying levels of expertise but might be affected by subgingival margins. (J Prosthet Dent 2020;■:■-■)

Advances in computer-aided design and computer-aided manufacturing (CAD-CAM) technology have increased the number of clinical applications of the digital workflow in dentistry, including the virtual prosthetic planning from intraoral scans, which can be achieved by designing digital wax patterns of crowns or other prostheses with a CAD software program.[1] The resulting digital prostheses can then be 3D-printed as interim or milled as definitive

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Clinical Implications

Digital wax patterns appear to be highly reproducible even for dentists with basic CAD software training. Furthermore, while different intraoral scanners lead to comparable digital wax pattern results, subgingival finish lines around tooth preparations and abutments should always be exposed before obtaining intraoral scans.

CAD-CAM prostheses, generally with satisfactory precision and accuracy.[2,3]

One of the factors that may affect a digital wax pattern is the intraoral scanning procedure.[4] As compared with conventional impression making, intraoral scanning presents advantages such as improved patient acceptance, less distortion than with impression materials, and reduced chairside time.[5,6] However, intraoral scanners may vary in accuracy for scanning tooth preparations[7] and stock implant abutments.[8]

In addition to the intraoral scan, a digital wax pattern also depends on variables such as the CAD software program used and the expertise of the dental laboratory technician with CAD knowledge to reproduce a 3D representation of a prosthesis.[9] Although satisfactory results have been reported,[10,11] digital waxing conditions may affect marginal adaptation of CAD-CAM crowns.[12,13] Furthermore, little is known about the influence of varying software programs with different tools and interfaces on the precision and accuracy of digital waxing procedures. Similarly, studies that compared digital waxing results from professionals with different levels of expertise on CAD procedures are lacking.

Therefore, the purpose of this preliminary in vitro study was to compare the reliability and reproducibility of margin outlining during the digital waxing of single crowns from professionals with different levels of expertise. The null hypotheses were that different intraoral scanners would lead to similar digital wax patterns for both observers and that experienced observers with expertise on CAD procedures would generate similar digital wax patterns.

MATERIAL AND METHODS

Analogs of titanium implant stock abutments (RN analog for solid abutment, Ø4.8×4 mm; Institut Straumann AG) (N=30) were individually embedded in epoxy resin and considered test abutments of this study. To simulate different clinical situations, abutments were divided into 3 groups: 10 abutments (group GOS) with subgingival finish line underwent intraoral scanning with an open system scanner (TRIOS3; 3Shape A/S), while 10 abutments with (group GIS) and 10 abutments without subgingival finish lines (group IS) underwent intraoral scanning with a scanner within an integrated CAD-CAM system (CEREC Omnicam; Dentsply Sirona). To simulate subgingival finish lines, groups GOS and GIS received artificial gingiva (Gingifast Rigid; Zhermack SpA) with margins located approximately 1 mm higher than abutment finish lines. For this purpose, positioning cylinders of conventional transfer copings of the same abutment were used during artificial gingiva application to orientate its position around the abutment while protecting the extension of the finish line (Fig. 1) by following a previously described methodology.[14]

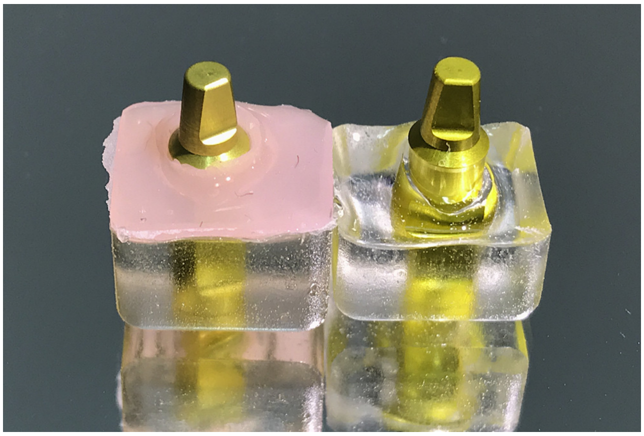

Figure 1. Test abutments with and without artificial gingiva.

All resulting intraoral scanning images were saved as standard tessellation language (STL) files and imported to a CAD software program (Meshmixer; Autodesk Inc) which was used to evaluate each digital mesh to ensure that the entire abutment had been scanned completely and without distortions from irregular light reflection from the metal surface. Next, the STL files were imported to another CAD software program dedicated to dental treatment (ChairsideCAD; exocad GmbH) to digitally fabricate a wax pattern. The finish line of the abutment was initially outlined to digitally design the crown margin of a left mandibular central incisor, with the shape chosen from the same digital library (exocad; exocad GmbH) for all waxings. Further position adjustments were not made (that is, just pressing the "next" button in all further steps until the whole crown shape was automatically designed by the software program). The resulting digital crown designs were saved as STL files (Fig. 2). All procedures (Fig. 3) were performed in random order (using a computer-generated randomized list) by 2 observers (A.S., J.N.C) with different levels of expertise (an experienced CAD professional and dentist with 5 years of experience in digital wax pattern and digital restorative dentistry using the software program of this study and an inexperienced dental clinician with basic CAD knowledge and basic training in the software

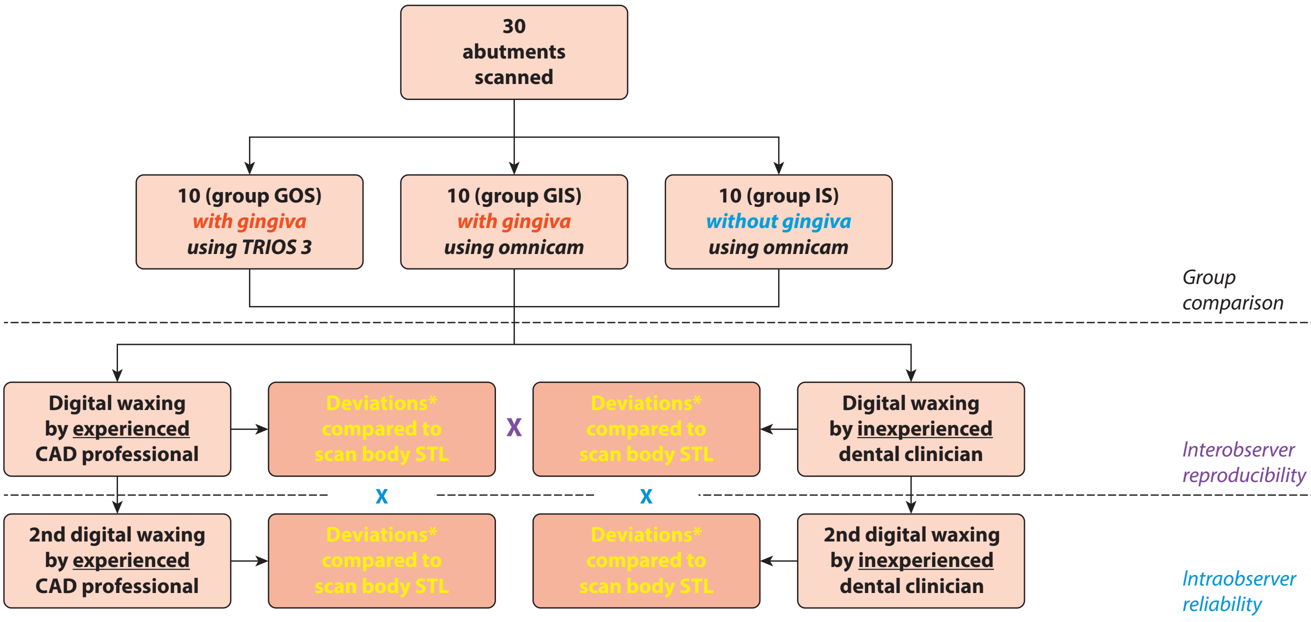

Figure 2. Study flowchart. *3D deviations between STL meshes, assessed at the crown margin level. CAD, computer-aided design; STL, standard tessellation language.

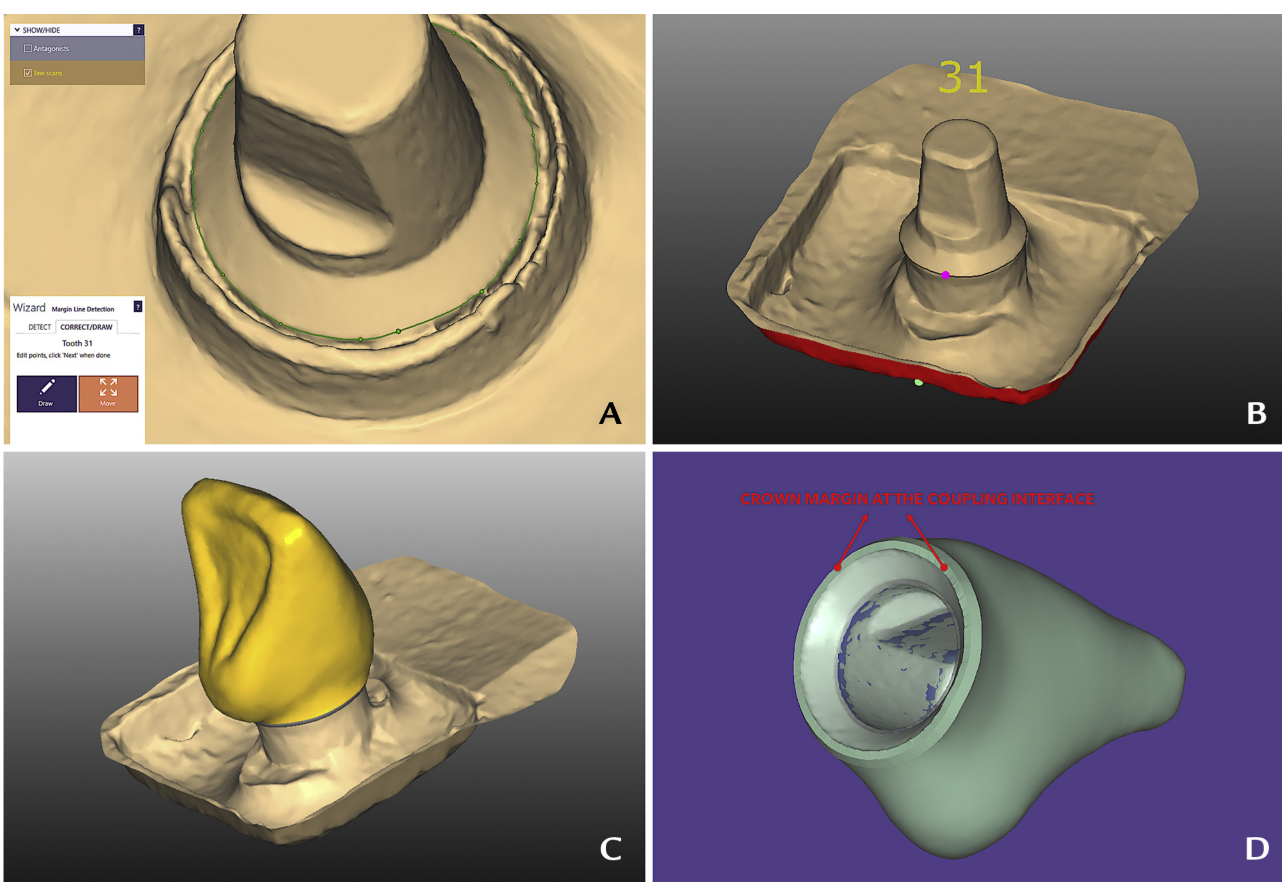

Figure 3. Digital waxing steps using CAD software program. A, Crown margin outlining procedure in test abutment with subgingival finish lines. B, Crown margin outlining procedure in test abutment without subgingival finish lines. C, After crown margin outlining, crown design automatically created from software library. No further adjustments performed. D, Digital crown design result after exporting to STL file. Area of crown margin at coupling interface considered STL analyses (*red arrows*). CAD, computer-aided design; STL, standard tessellation language.

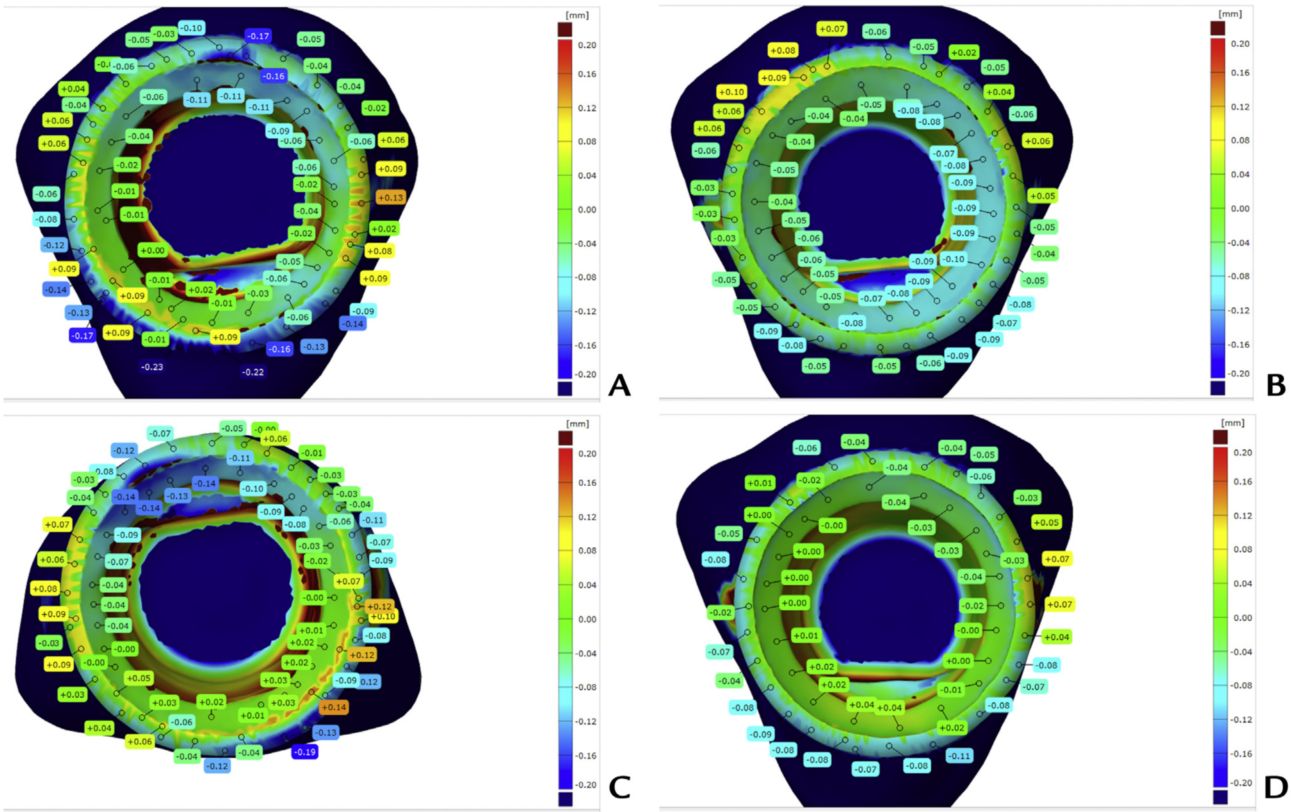

Figure 4. Software output results of 3D deviation measurements of crown margins obtained from STL superimpositions. A, CAD professional result for test abutment with subgingival finish line. B, CAD professional result for test abutment without subgingival finish line. C, Dental clinician result for test abutment with subgingival finish line. D, Dental clinician result for test abutment without subgingival finish line. CAD, computer-aided design; STL, standard tessellation language.

program of this study). Both observers performed their measurements twice at intervals of 2 weeks to eliminate the memory bias. In addition, the time required to perform each digital waxing procedure was also recorded in seconds for both observers.

Each STL file from the digital waxing procedures was imported into a software program dedicated to 3D measurement data (GOM Inspect 2019; GOM GmbH), aligned, and superimposed on the control STL file (the STL of the scan body designed by the manufacturers to fit the abutment used) at the margin level by following previously described methodologies for STL comparison in specific areas using the same software program.[15,16] Deviation values were then automatically calculated for the crown margins at the coupling interface area. All measurements were digitally recorded in millimeters within a 3D color map. Median, minimum, and maximum margin deviations were then obtained from the data in the software program and used in the statistical analyses.

For statistical analysis, the normality of 3D deviation and time measurements were assessed by using the Shapiro-Wilk test. Since the same type of stock implant abutment was analyzed in all groups, intraobserver reliability and interobserver reproducibility of 3D deviations, as well as statistically significant differences from pairwise comparisons among the 3 groups, were calculated by using the Wilcoxon signed-rank test for repeated measurements. Finally, mean times required by different observers to perform digital waxing in the 3 groups were compared with the paired *t* test (α=.05) using a statistical software program (IBM SPSS Statistics, v26; IBM Corp).

RESULTS

Normality of 3D deviation measurements was rejected for both observers (P<.05). For the CAD professional, median 3D margin deviations between designed crown STL files, and the control STL of the scan body were 0.08 mm (range: 0.04 to 0.15) for group GOS; 0.10 mm (range: 0.06 to 0.18) for group GIS (Fig. 4A); and 0.05 mm (range: 0.03 to 0.08) for group IS (Fig. 4B). For the dental clinician, median deviations were 0.08 (range: 0.04 to 0.12) for group GOS; 0.11 (range: 0.07 to 0.17) for group GIS (Fig. 4C); and 0.05 (range: 0.04 to 0.11) for group IS (Fig. 4D).

Table 1. General pairwise comparisons of 3D deviation measurements

Analysis	Observer(s)	Group(s)	P*
Group comparison	–	Group GOS×GIS	.122
	CAD Professional	Group GOS×IS	**.001**
	–	Group GIS×IS	**.001**
	–	Group GOS×GIS	.097
	Dental Clinician	Group GOS×IS	**.001**
	–	Group GIS×IS	**.001**
Interobserver reproducibility	–	Group GOS	.109
	CAD Professional×Dental Clinician	Group GIS	.157
	–	Group IS	.226
Intraobserver reliability	–	Group GOS	.354
	CAD Professional×CAD Professional	Group GIS	.302
	–	Group IS	.455
	Dental Clinician×Dental Clinician	Group GOS	.257
		Group GIS	.318
		Group IS	.516

*Significance according to Wilcoxon test (***P*<.05** indicates significant differences).

Table 2. Mean pairwise comparisons of total time required to perform digital waxing

Analysis	Observer(s)	Group(s)	P*
Time comparison among groups	–	Group GOS×GIS	**.010**
	CAD Professional	Group GOS×IS	**.001**
	–	Group GIS×IS	**.001**
	–	Group GOS×GIS	**.001**
	Dental Clinician	Group GOS×IS	**.001**
	–	Group GIS×IS	**.001**
Time comparison between observers	–	Group GOS	.092
	CAD Professional×Dental Clinician	Group GIS	**.001**
	–	Group IS	.144

*Significance according to Paired *t* test (***P*<.05** indicates significant differences).

Regarding the time required to perform digital waxing, normality was confirmed for both observers (*P*>.05). The mean ±standard deviation times required by the CAD professional to perform digital waxing procedures were 60.85 ±8.57 seconds for group GOS, 96.33 ±11.78 seconds for the group GIS, and 43.38 ±7.67 seconds for group IS. For the dental clinician, mean times required were 64.22 ±10.26 seconds for group GOS, 174.81 ±12.38 seconds for group GIS, and 50.11 ±8.17 seconds for group IS.

Statistical comparison results for 3D deviation and time required to perform digital waxing are presented in Tables 1 and 2. Intraobserver reliability and interobserver reproducibility were confirmed for the 3D measurements as there were no statistically significant differences between the 2 sets of measurements from each observer, or between both observers for 3D deviation (*P*>.05) in any of the groups; group GIS, however, presented a significant difference between observers for the time required (*P*=.001). In addition, statistically significant differences in 3D deviation were found between group IS and the other 2 groups (*P*=.001) but not between groups GOS and GIS (*P*>.05) for both observers. Finally, statistically significant differences in time required were found among the 3 groups (*P*<.05) for both observers.

DISCUSSION

This study aimed at comparing the accuracy of professionals with different levels of expertise in designing the finish line of single crowns during digital waxing. According to the present findings, both null hypotheses tested were accepted. Therefore, margin outlining during the digital waxing of single crowns can be considered highly reliable and reproducible by using a dental CAD software program, which is consistent with the previous satisfactory marginal fit results of CAD-CAM crowns.[12,13,15] Furthermore, the finding that no significant differences would be found between results from the 2 intraoral scanners tested for situations with subgingival finish lines (groups GOS and GIS) is also consistent with those of previous similar studies on different intraoral scanners.[6-8]

Although the present study has clinically relevant implications for single-tooth preparations, this in vitro experiment was conducted on analogs of stock implant abutments. In order to perform digital implant-prosthetic planning, either an implant scan body can be scanned intraorally to transfer the implant position to the CAD software or the implant abutment can be directly scanned, which is considered more appropriate for acquiring images of the actual soft tissue profile.[17,18] The fact that the present results were not affected by irregular light reflection from metal exposure is consistent with a previous study performed with intraoral scans of stock implant abutments.[8] Although results may vary among different intraoral scanners, satisfactory trueness and precision can be obtained by directly scanning stock implant abutments.

According to the present findings, there were statistically significant differences between 3D deviation and time results for test abutments without artificial gingiva (group IS) and those from the other 2 groups with artificial gingiva (groups GOS and GIS). Such findings suggest that subgingival finish lines may affect intraoral scans of stock implant abutments, leading to larger 3D deviations of digital wax patterns as compared with the control STL file of the abutment scan body. Such results are consistent with those of previous studies that suggested that the intraoral scanning of subgingival margins might be challenging.[14,19,20]

Limitations of this in vitro study performed on test abutments included that the impact of clinical factors that could affect 3D deviations and times required to perform digital waxing such as occlusion and the proximity to adjacent teeth could not be addressed. Similarly, the present study adopted a previously described in vitro method of preventing the artificial gingival material from obscuring the finish line.[14] As a result, the clinical implications of using gingival displacement techniques such as cords to expose subgingival finish lines were not tested. Furthermore, only 1 CAD software program was used, whereas the digital workflow may involve 2 or more CAD software programs for the treatment planning of a patient.[21] Therefore, future prospective clinical studies are recommended to address the impact of different CAD-CAM systems on the trueness and precision of digital waxing procedures.

CONCLUSIONS

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

1. Margin outlining during the digital waxing of single crowns can be performed with high reliability and reproducibility and is not affected by varying levels of expertise.
2. However, the results might be affected by the presence of subgingival margins.

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