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Subtractive versus additive indirect manufacturing techniques of digitally designed partial dentures

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PURPOSE. The purpose of this *in vitro* study was to evaluate the accuracy of digitally designed removable partial denture (RPD) frameworks, constructed by additive and subtractive methods castable resin patterns, using comparative 3D analysis. **MATERIALS AND METHODS.** A Kennedy class III mod. 1 educational maxillary model was used in this study. The cast was scanned after modification, and a removable partial denture framework was digitally designed. Twelve frameworks were constructed. Two groups were defined: Group A: six frameworks were milled with castable resin, then casted by the lost wax technique into Co-Cr frameworks; Group B: six frameworks were printed with castable resin, then casted by the lost wax technique into Co-Cr frameworks. Comparative 3D analysis was used to measure the accuracy of the fabricated frameworks using Geomagic Control X software. Student's t-test was used for comparing data. P value $\leq .05$ was considered statistically significant. **RESULTS.** Regarding the accuracy of the occlusal rests, group A (milled) (0.1417 ± 0.0224) showed significantly higher accuracy than group B (printed) (0.02347 ± 0.0221). The same results were found regarding the 3D comparison of the overall accuracy, in which group A (0.1501 ± 0.0205) was significantly more accurate than group B (0.179 ± 0.0137). **CONCLUSION.** In indirect fabrication techniques, subtractive manufacturing yields more accurate RPDs than additive manufacturing. [J Adv Prosthodont 2021;13:327-32]

KEYWORDS
Milling; 3D printing; Removable partial dentures (RPDs); Accuracy

INTRODUCTION

RPDs will likely remain an important treatment option. Thus, it is mandatory to keep up with the development in materials and technologies associated with RPDs to overcome the additional costs related to the oral and systemic

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health consequences of wearing these devices.[1]

Traditionally, the fabrication of removable partial dentures (RPDs) was limited to manual design, wax-up, and casting. It involves conventional impressions of the oral structures and production of stone models, geometric characterization of the teeth and soft tissues, and careful designation of RPD components using a direct waxing method. Then, fabrication of the metallic framework was completed by traditional casting of the wax patterns.[2,3]

The lost wax technique (LWT) has been serving for centuries in construction of RPD frameworks with good outcomes reported in literature. However, it has been modified many times in order to improve the performance and accuracy as well as to overcome the technique sensitivity associated with this procedure.[4]

Current digital software enables the design of RPD components on 3-dimensional (3D) representations of the patient's oral structures instead of stone casts by using geometric analysis tools that create designs of micrometer-level accuracy that can be viewed in cross section. The virtual patterns are designed digitally and manufactured by milling or printing castable wax or resin patterns for casting metal frameworks or by direct printing or milling of metal, resin, or ceramic frameworks.[5]

In subtractive manufacturing, 5-axis machines are suitable for producing complex shapes such as acrylic denture bases, partial denture frameworks, and screw retained implant prosthesis. For dental applications, the quality of the restoration is independent of the number of axes; instead, it reflects the accurate matching of the need with the proper manufacturing method and material.[6,7]

Digital light projection (DLP) is an additive manufacturing process based on the use of a light source for the solidification of liquid photopolymer\copolymer resins. It allows simultaneous exposure of the entire workspace, and the construction speed of a layer is constant regardless of the complexity of the geometry. Each layer is displayed as square pixels, and the successive layers of the print are comprised of rectangular bricks known as voxels.[8,9]

Few studies evaluated the accuracy of the RPD frameworks constructed by digital techniques. Thus, this study aimed to evaluate the accuracy of RPD frameworks constructed indirectly from milled and printed castable resin patterns. The null hypothesis was that no differences would be found among different manufacturing techniques.

MATERIALS AND METHODS

This study was applied on a Kennedy class III mod. 1 educational maxillary stone model. Occlusal rest seats were prepared on the abutments bilaterally (first premolars and the second molars).

The modified model was duplicated using silicone base duplication material (REPLISIL 22 N, dent-e-con, Lonsee, Germany). The duplicate cast was optically scanned using the 3shape D850 desktop scanner (3Shape Dental System, Copenhagen, Denmark).

The scanned model was automatically surveyed by the partial denture module in the 3shape software (3Shape Dental System™, Copenhagen, Denmark) according to the chosen path of insertion, and the undercuts were presented in the form of a colored scale.

The denture bases and the major connector were drawn by placing points and connecting them together until the proper form was reached. Akers clasp assembly was designed by applying the occlusal rest and adapting it to the rest seat preparation. The retentive and reciprocal arms were designed on three abutments where the right first premolar was excluded. The design was finalized using the sculpt tool.

Finally, an standard tessellation language (STL) file of the framework design was produced by the software and used to construct the partial denture frameworks.

Co-Cr metallic frameworks were constructed by two different indirect manufacturing techniques. Thus, two groups were defined: Group A: six Co-Cr metal frameworks were constructed by milling a castable resin which was casted into metal by the lost wax technique; Group B: six Co-Cr metal frameworks were constructed by 3D printing a castable resin, which was casted into metal by the lost wax technique.

In group A, the six frameworks were milled from castable resin blanks (YAMAHACHI dental MFG, Gamagori, Japan). 15 mm blanks of castable resin were used after installing the STL file into the milling machine (K5 - Five-Axis Dry Milling, vhf®, Ammerbuch, Germany) (Fig. 1). Each framework took three and half hours to complete the milling procedure using burs of two different diameters (2 mm and 1 mm).

For group B, six frameworks were 3D printed using castable resin (NextDent Cast, Vertex-Dental B.V, The Netherlands). The STL file of the design was imported to the Creation Workshop software to create the supporting arms generating a new STL file of the framework with its supporting arms (Fig. 2).

The new STL file was imported to the 3d printing machine (MOGASSAM Dent2 3D Printer, Mogassam, Cairo, Egypt), which is a digital light projection (DLP) device used to fabricate the printed castable resin frameworks. A digital projector screen of resolution 1280 × 800p was used to flash a single image of each layer across the entire platform, generating XY resolution of 90 microns and adjusted Z resolution of 100 microns. Each framework was oriented parallel to the platform. The printing process of each framework lasted for 45 - 60 minutes.

The printed castable frameworks were rinsed twice in a 96% ethanol solution in an ultrasonic bath. Then they were inserted in a post curing unit for 30 minutes. Finally, the supporting arms were separated by air turbine, and the outer surface of the frameworks was finished.

Each framework was sprued and invested with a special phosphate bonded investment material (Sheravest, SHERA GmbH & Co.KG, Lemförde, Germany) and casted using cobalt-chromium alloy (WIRINIUM®, BEGO GmbH & Co.KG, Bremen, Germany).

For evaluation of accuracy, all partial denture

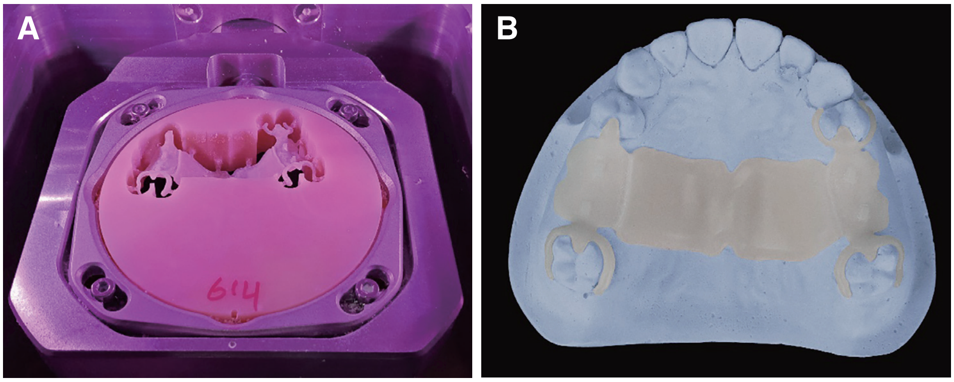

Fig. 1. The milled castable framework (A) the framework after being milled in the 5-axis milling machine, (B) the milled framework adapted on the stone model.

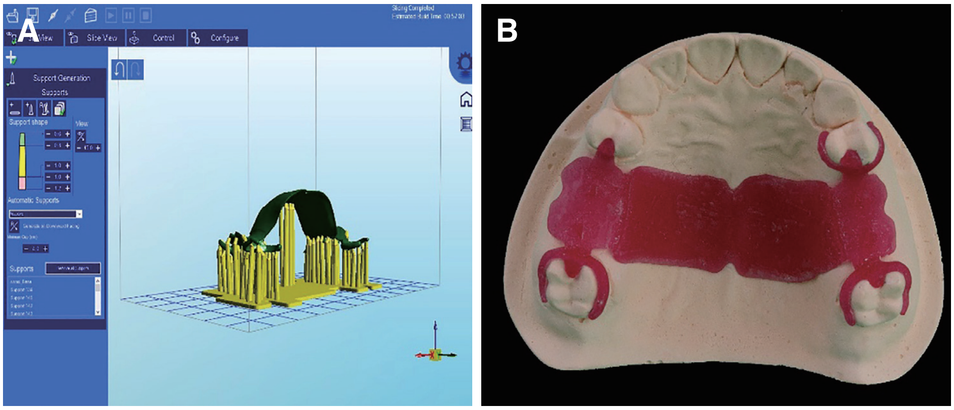

Fig. 2. (A) Creation Workshop used to create supporting arms for the printed framework, (B) the printed castable framework adapted on the stone model.

frameworks of each group were scanned using the 3Shape desktop scanner. The STL file of each of the scanned frameworks was superimposed with the initial STL file of the design using surface matching software (Geomagic® Control X, 3D systems, Rock Hill, SC, USA) (Fig. 3).

Evaluation of the accuracy of the frameworks was performed at the apex of the occlusal rests and at the 3 axes X, Y, and Z for overall 3D analysis (Fig. 4, Fig. 5).

The data were collected, tabulated, and statistically analyzed. Statistical Package for Social Science software computer program version 26 (SPSS Inc., Chicago, IL, USA) was used. The data were presented as mean and standard deviation of the root mean square deviation (RMSD) values. Student's t-test was used for comparing data. *P* value ≤ .05 was considered statistically significant.

RESULTS

RMSD is the square root of the mean square of error/deviation values. RMSD is always non-negative, and a value of 0 is almost non-practical indicating a perfect fit to the data. Therefore, a lower RMSD is better than a higher one.[10]

Regarding the accuracy of the occlusal rests, group A (milled) (0.1417 ± 0.0224) showed less deviation indicating higher accuracy than group B (printed) (0.2347 ± 0.0221) ($P < .001$) and this difference was statistically significant (Table 1).

Concerning the overall 3D analysis, group A (milled) showed less deviation indicating higher accuracy (0.1501 ± 0.0205) than group B (printed) (0.1790 ± 0.0137) ($P = .017$) and the difference was statistically significant.

The Y and Z axes showed higher accuracy in group A (milled) (0.0987 ± 0.0200 & 0.1137 ± 0.0261) successively than group B (printed) (0.1481 ± 0.0278 & 0.1832 ± 0.0201) ($P < .05$), and the values were statistically significant.

On the other hand, regarding the X axis, group B (printed) showed less deviation than group A (milled). However, the difference was statistically insignificant (Table 2).

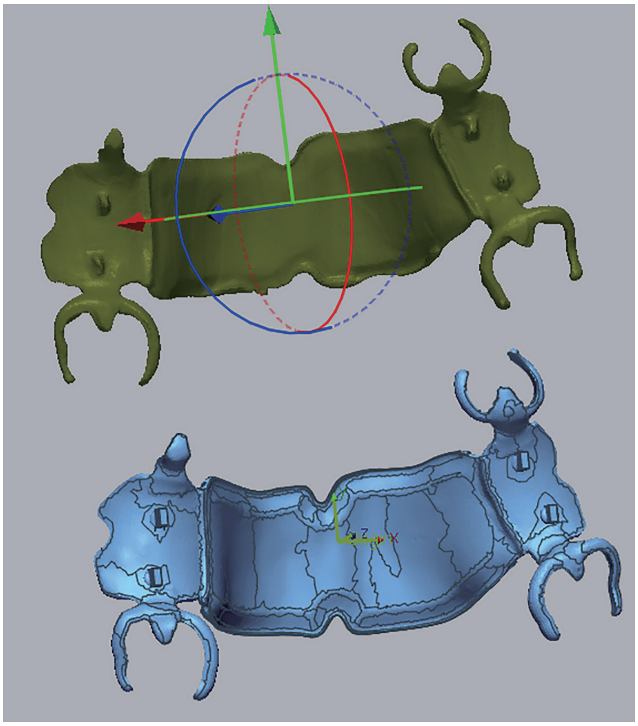

Fig. 3. Alignment of the designs, the original design and the generated one from the scanned framework.

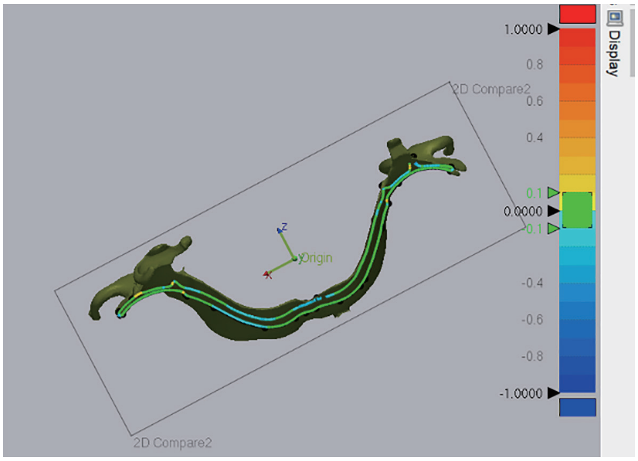

Fig. 4. The Y axis comparison.

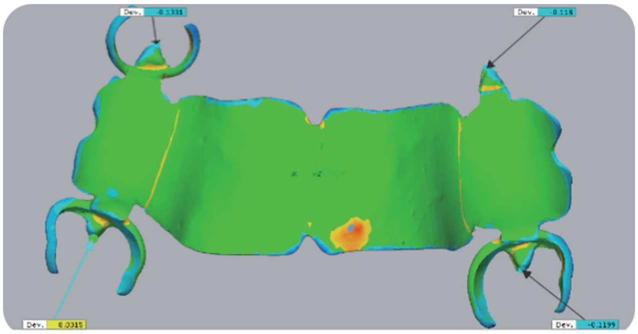

Fig. 5. The Point comparison.

Table 1. Mean, standard deviation, and *P* value of student's t-test for the point comparisons between the two groups

	Group A (Milled)	Group B (Printed)	*P* value
Mean ± SD	0.1417 ± 0.0224	0.2347 ± 0.0221	< .001*

Table 2. Mean, standard deviation, and *P* value of student's t-test for the 2D & 3D comparisons between the two groups

	Group A (Milled)	Group B (Printed)	*P* value
x-axis	0.2001 ± 0.0273	0.1832 ± 0.0301	.33
y-axis	0.0987 ± 0.0200	0.1481 ± 0.0278	.005*
z-axis	0.1137 ± 0.0261	0.1832 ± 0.0201	< .001*
3D	0.1501 ± 0.0205	0.1790 ± 0.0137	.017*

DISCUSSION

In this study, RPD frameworks were fabricated by two different indirect manufacturing techniques. The Co-Cr frameworks were casted from resin patterns designed and constructed by different CAD-CAM techniques (3D milling and printing). The two manufacturing techniques showed a significant difference in accuracy, and thus the null hypothesis was rejected.

Casting the digitally designed and constructed resin patterns omits the need of conventional waxing up of the refractory casts, and therefore the inaccuracies due to wax distortion are avoided.[11-13] The resin patterns were casted in chrome cobalt without the need of refractory casts using phosphate bonded investment material and rubber investment rings. Several studies utilized this technique to avoid the dimensional changes of refractory casts and to simplify the procedure of construction.[14,15]

The Geomagic Control X software was used to measure the accuracy of fit using surface matching and best-fit algorithms to adapt the frameworks with the initial design allowing digital measurements to be recorded which are more accurate than the traditional physical measurements. Accurate measurement and fast analysis of the manufactured parts and assemblies was done.[16] The apex of each occlusal rest was selected for evaluation of accuracy by point comparisons for standardization of the measurements. 3D and detailed comparisons were done to detect the overall deviation of the fabricated frameworks from the original design.[12,15]

The statistical data of this study revealed that there was significant difference in the accuracy of the fabricated frameworks of both groups. Geomagic Control x software showed less deviation indicating higher accuracy in group A (milled) than group B (printed) at the apex of the occlusal rest and in the overall 3D analysis.

These results may be attributed to utilization of unpolymerized resins for printing the castable patterns. During the 3D printing workflow, polymerization shrinkage is theoretically possible, as the patterns are not completely polymerized. An additional final light-polymerization step is required to complete the process. The deformation can also occur while separating the partially polymerized pattern from the building platform.[17]

Fine errors might have occurred after separation of the support arms or during the surface refinement process.[18] The use of ultraviolet light curing may be another cause of distortion due to sunlight-related degradation. To avoid this effect, the patterns should be rapidly invested after printing.[19] On the hand, the use of pre-polymerized resin blanks for milling and the lesser number of supporting arms overcome the disadvantages of shrinkage and distortion of the liquid resins used for 3D printing.[17]

Parallel results were obtained by Arnold *et al*.[11] who studied that the clasp assemblies of the frameworks fabricated by rapid prototyping showed more discrepancies than those of directly or indirectly milled frameworks. A study by Örtorp *et al*.[20] showed that frameworks fabricated by the conventional LWT had higher values of distortion than those casted from milled patterns using the LWT.

CONCLUSION

Based on the findings of this *in vitro* study, the following conclusion was drawn: in indirect fabrication techniques, subtractive manufacturing yields more accurate RPDs than additive manufacturing.

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