The success and durability of dental restorations depend on marginal fit, defined as the space between the tooth structure and restoration. Marginal discrepancy tends to accelerate cement breakdown and cause hypersensitivity, recurrent caries, periodontal diseases, pulpal lesions, and marginal staining. Thus, the marginal discrepancy of restorations should be minimized.

In the early 1900s, Taggart introduced the lost wax technique, which allowed the fabrication of crowns, inlays, onlays, and fixed partial dentures. This technique requires high precision, with the success of the definitive prosthesis relying on the skill of the dental laboratory technician.

Dental computer-aided design-computer-aided manufacturing (CAD-CAM) was developed as an automated system, which can be either subtractive, milling a solid block, or additive, the incremental deposition of material. In the subtractive method, a computer numerically controlled (CNC) machine is used to mill a workpiece out of a larger blank. The CAM software uses the CAD model to automatically generate a tool path for the CNC machine. In this...
Clinical Implications
Use of 3D wax printing technology for fabricating metal copings appears to be a promising method as the metal copings fabricated with this method exhibited excellent marginal fit.

The process, commands are computed to be transferred to the CNC system; the commands are sequencing, milling tools, and the direction and magnitude of the movement of the tool. The materials processed through subtractive milling are resins, alloys, ceramics, and waxes.

The additive manufacturing method is used in prosthodontics to make a pattern for a restoration in resin or wax which can be cast into a definitive prosthesis, or definitive restorations can be produced directly in metal, ceramic, or resin. The additive systems used in dentistry are stereolithography (SLA), 3D printing, and selective laser sintering or melting.

In SLA, a concentrated light beam or laser is focused onto the surface of a polymerizable liquid polymer reservoir and produces solid layers. Upon polymerization of the first layer, the platform is moved vertically a few micrometers to polymerize the next layer. It goes on repeatedly until the solid object is complete. Complete polymerization of the resin is achieved only after the object is washed with a solvent and processed in an ultraviolet unit.

In 3D printing, the material is expressed through a nozzle and solidified once deposited on the manufacturing platform. The horizontal movement of the nozzle and alternate material flow creates the layer pattern. Thereafter, the nozzle moves vertically to deposit the sequential layers. Three-dimensional printing can be performed with various materials that can pass through a heated nozzle and solidified right after extrusion (including thermoplastics such as resins, waxes, or fused filament). The procedure can also be carried out with liquid ceramic or resin materials with a binder, which solidifies upon deposition. Some systems even have a multicolor output.

Bae et al compared the additive and subtractive methods regarding the accuracy of inlay restorations. They reported that higher adaptation of dental restorations can be produced directly in metal, ceramic, or resin. The additive systems used in dentistry are stereolithography (SLA), 3D printing, and selective laser sintering or melting.

A standard machined brass die was designed and prepared by using a CNC lathe (CNC350; ARIX CNC Machines Co, Ltd) to mimic a metal-ceramic crown preparation. The die had the following characteristics: height of 6 mm, width of 6 mm at the finish line, circumferential chamfer margin (0.7 mm width, radius of 2 mm), taper of 6 degrees, and an axial antirotational design. Then, the die was fixed in an autopolymerizing acrylic resin block (Crown & Bridge Resin; Dentsply Sirona), and a dental surveyor (Ney Dental Surveyor; Dentsply Sirona) was used to ensure that the long axis of the die was perpendicular to the horizontal plane. This single die was used to make 30 copings.

To obtain a scannable surface, the master die was sprayed with a scan spray (Anti-Scan CAD-CAM Spray; Dr Jean Bausch GmbH & Co KG) and then scanned by using a 3D laser scanner (D810; 3Shape). The scanning data were transferred to the CAD software (CAD Design software; 3Shape), which is used to fabricate 30 patterns from the same CAD data.

Based on previous studies and by using a software program (G*Power, version 3.0.10; Heinrich-Heine-Universität Düsseldorf) with effect size=0.6, z=.05, and power=0.8, the sample size of each group was established at 10. Therefore, 30 patterns were fabricated with the 3 techniques: milling, SLA, and PolyJet. Accordingly, based on the same STL input, 10 resin patterns were milled out of polymethyl methacrylate blocks (PMMA disk; Yamahachi, Dental Mfg, Co) by using the milling unit (inLab MC XL; Dentsply Sirona), 10 resin patterns
The purpose of the present study was to evaluate and compare the marginal fit of metal copings cast by using 3 different fabricating methods. The findings showed the marginal fit of PolyJet printed copings was significantly different from that of the milling and SLA copings. Thus, the null hypothesis of the study was rejected.

Dental restorations can be produced by at least 3 methods: hand waxing, milling, and additive manufacturing. The main advantage of milling over the lost-wax technique is its higher speed and production.

Table 1. Descriptive statistics of vertical marginal gap of tested groups (μm)

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Mean ± Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milling</td>
<td>10</td>
<td>93.1 ±25</td>
<td>57.50</td>
<td>127.75</td>
</tr>
<tr>
<td>SLA</td>
<td>10</td>
<td>71.1 ±25</td>
<td>42.25</td>
<td>127.50</td>
</tr>
<tr>
<td>PolyJet</td>
<td>10</td>
<td>41.3 ±6</td>
<td>32.00</td>
<td>52.75</td>
</tr>
</tbody>
</table>

SLA, stereolithography.

The data were analyzed by using a statistical software program (IBM SPSS Statistics, v23; IBM Corp). The mean values and standard deviations were calculated in each group. The Shapiro-Wilk test was used to assess the normal distribution, and the Levene test was used to assess the equality of variances. One-way ANOVA test was performed to compare the mean differences among the 3 groups (α=.05). Post hoc analysis with the Games-Howell test was performed for multiple comparisons of the groups. The intraclass correlation coefficient (ICC) was used to find the relation between repeated measurements and the reliability of them.

RESULTS

Table 1 shows the mean and standard deviation of the marginal discrepancy in the milling, PolyJet, and SLA groups. Based on the results of the Shapiro-Wilk test, the distribution of the yielded values was normal (P>.05). One-way ANOVA test revealed statistically significant differences among the groups (P<.001). The Levene test showed that the variances were not equal (P=.004); therefore, the Games-Howell post hoc test was used, which indicated statistically significant differences among the groups. The lowest mean marginal gap was observed in the PolyJet group (41.3 ±6 μm), which was significantly different from that of the other groups (P<.05) (Table 2).

No statistically significant difference was detected between the milling and SLA groups (P=.158). According to the ICC, good agreement was observed between the evaluation of repeated marginal fit measurements (ICC=0.925 to 0.994).

DISCUSSION

The purpose of the present study was to evaluate and compare the marginal fit of metal copings cast by using 3 different fabricating methods. The findings showed the marginal fit of PolyJet printed copings was significantly different from that of the milling and SLA copings. Thus, the null hypothesis of the study was rejected.
volume that subsequently reduce costs. With this technology, there is no need to duplicate or trim a stone cast, and making a crown pattern can only take 7 minutes. Consequently, these improvements would reduce the turnaround time and increase the production volume. Among the shortcomings of the subtractive method is the dependency of the internal adaptation of the framework on the size of the smallest cutting tool. For that reason, in case the abutment is smaller than the tool in some areas, the internal precision would be negatively affected. Moreover, the cutting tools are not suitable for creating sharp internal angles. This issue would be resolved by considering a spacer parameter in the system of CAD-CAM or could be reconciled by removing the produced interfering areas by using a handpiece when fitting the restoration in the dental laboratory. However, both these strategies increase the internal gaps.

There are 2 milling methods: hard and soft milling. Hard milling is used for metal, densely sintered zirconia, and composite resin. Soft milling is particularly used for presintered zirconia. Milling is problematic when trying to create complex geometries, especially from metals that are difficult to machine (such as Co–Cr). These materials, wear of the cutting tools, noise, heat generation, and structure surface damage are to be expected. Another problem encountered with milling is the amount of recyclable waste. While milling produces waste as much as 96% of the material, additive techniques can lead to 40% less waste, of which 95% to 98% could be recycled. This might decrease the overall costs.

In the additive fabrication technique, printers can differ from each other in terms of the way the layers are built to produce objects. Therefore, this technique is quite flexible because several different machines and materials are available. By using this method, undercuts can be reproduced, and less raw material is wasted. However, similar to any other method, some additive techniques may cause certain problems, such as the staircase effect on the finished product due to the layer-by-layer technique, the nonhomogenous shrinkage, and the extensive postprocessing of the porous structures. Finally, in spite of improving the speed and precision of fabrication, many additive methods fail to provide the accuracy and reproducibility necessary for some dental restorations. Evidence has shown that increasing accuracy would slow the production speed. The accuracy of fabricated products has also been reported to be influenced by the thickness of the print layer and the printer model.

The present study found higher accuracy in restorations fabricated by wax printer methods than in those made with SLA. According to Munoz and Dickinson, the marginal fit was less in the copings made with a printed wax pattern than in those fabricated with a milled wax pattern. The present findings showed that the accuracy of printed wax patterns was more than that of milled resin blocks. Seemingly, the heat generated during the process of resin milling distorted the polymethyl methacrylate (PMMA). Moreover, the lower marginal fit in the milling group could be attributed to the limitations in the available cutting tool diameters that might cause positive and negative errors and make it difficult to design projection sites and sharp edges precisely.

Based on the findings of this study, marginal fit was less in the copings made by SLA than in those made by printed wax patterns. The authors relate it to the extensive postprocessing procedures of resin patterns. The extra steps in the process of pattern fabrication could possibly increase the discrepancies in the margins of copings.

Despite the risk of warpage or distortion upon standing, wax is still a desirable material because of the absence of residue on burn out compared with PMMA. Therefore, in the present study, the wax printing method showed the least marginal gap compared with the resin materials used in the SLA and milling method. Furthermore, the PolyJet technique was better than the other techniques despite the 25-μm thickness; possibly, 12-μm layers could be even more accurate.

The metal master die used in the present study precluded any appreciable wear of the die during seating and measuring. Moreover, as the copings were not cemented on the master die, the interfering factors such as the luting agent type, its viscosity, and seating forces during cementation were omitted. In the present study, the external surface of all copings were abraded with Al₂O₃ to simulate the clinical conditions. Performing this abrasion for the 3 groups affected the copings similarly, eliminating bias. Different studies assessed the marginal fit on various numbers of sites and reported different numbers as the optimal values. Although Nawafleh et al reported it to be 4 to 12 points, the measurement technique in the present study used 16 measurement points.

Marginal fit can be determined by 2D or 3D techniques. In the 2D method, photographic images are made and the thickness of the gap is assessed through image analysis. The discrepancy determination is performed by making images either from sections of a silicone replica of the gap volume or from cement layer cross-sections. The marginal discrepancy can also be measured by photography of external views of the cemented and noncemented restorations. Unlike 2D methods, in 3D techniques, the global thickness is determined at multiple points of the marginal and internal regions. The 3D fit measurements are
CONCLUSIONS

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

1. The 3D wax printer (PolyJet) method has less marginal discrepancy than the SLA and milling techniques.
2. The milling and SLA methods are not significantly different in terms of marginal fit.
3. The marginal gap resulting from the 3 CAD-CAM methods (<120 μm) suggests the restorations would be clinically successful.

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