Effect of pattern fabrication methods on retentive strength in three-unit implant-supported frameworks: A comparative analysis

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Abstract

Objective

Given the significant role of retention in the long-term success of implant-supported prostheses, this study aimed to compare the retentive strength of three-unit implant-supported frameworks manufactured using the conventional, subtractive milling, and 3D printing methods.

Methods

In this in-vitro study, two fixture analogs were placed in the mandibular right first premolar and first molar region of a Dentiform model, and two prefabricated abutments were secured in the fixture analogs. A total of 27 three-unit frameworks were fabricated utilizing wax patterns prepared through conventional, milling, and 3D printing techniques (n = 9 per group). The frameworks were cemented with zinc oxide eugenol and subjected to thermocycling. The retentive strength of each specimen was evaluated through a pull-out test conducted with a universal testing machine. The data were analyzed using one-way ANOVA and Tukey’s post hoc test (P < 0.05).

Results

The three groups were found to be significantly different (P = 0.01). While the 3D printing and milling groups were not significantly different (P = 0.99), they yielded significantly higher retentive strength compare to the conventional group (P = 0.02 for 3D printing and P = 0.03 for milling group).

Conclusion

The utilization of 3D printing and milling technique for wax pattern preparation significantly increased the retention of the implant-supported framework, with no statistically significant difference between the two methods.

1. Introduction

Dental implant prostheses have emerged as a promising option for dental restorations, exhibiting superior survival rates of over 90% in 10 to 15 years compared to fixed partial dentures with a mean lifespan of 5 to 13 years [1, 2]. Metal ceramic restorations, whether screw- or cement-retained, are widely utilized for implant-supported restorations [3–5]. Cement-retained restorations are particularly popular due to their favorable esthetics, occlusion control, and cost-effectiveness. However, it is important to note that cement-retained restorations lack retrievability [6]. The success of implant therapy relies not only on the osseointegration of implants, but also on critical prosthetic factors such as the integrity and retention
of the restoration [7]. Retention in implant-supported restorations is influenced by the same factors as in natural teeth including abutment taper, surface area, height, surface finish, and roughness [5, 8].

The conventional method for fabrication of dental restoration pattern involves hand waxing, which has inherent limitations such as the requirement for skilled technicians and potential inaccuracies due to material shrinkage or expansion [9–11]. Dental CAD-CAM technology was developed to overcome these challenges by providing cost and time efficiency, enhanced accuracy, and predictable outcomes [10–12]. CAD-CAM systems scan a master model, design through a specialized software, and fabricate a wax model through either rapid prototyping or milling machines [13–15].

While subtractive milling is faster, it has limitations when it comes to achieving optimal internal adaptation, sharp angles, and complex geometries [16]. On the other hand, additive manufacturing techniques such as 3D printing, stereolithography, selective laser sintering, and selective laser melting provide an alternative approach that offers greater flexibility in dealing with complex geometries and generates less waste. However, additive manufacturing methods may have challenges such as the staircase effect and non-homogeneous shrinkage [17–19].

Numerous previous studies have evaluated the impact of framework fabrication methods and cement types on marginal integrity and internal fit [20–22]. However, limited research has specifically investigated their influence on the retentive strength of crowns [23, 24]. Alikhasi et al. [23] found that the fabrication of wax pattern through milling method resulted in significantly higher retention values when compared to both the conventional and 3D printing methods. Cesmeci et al. [24] reported that in single-unit implant-supported crowns, the CAD-CAM additive method exhibited the lowest retention among the plastic burn-out coping, CAD-CAM milling, and conventional techniques. Given the inconsistencies observed in previous studies and the lack of research evaluating the impact of pattern fabrication methods on the retention of three-unit implant-supported prostheses, the present study aimed to compare the retentive strength of such frameworks manufactured using the conventional, subtractive milling, and 3D printing methods. The null hypothesis was that the pattern fabrication method would not affect the retentive strength.

2. Materials and methods

This in-vitro study was approved by the Ethics Committee of Shiraz University of Medical Sciences (IR.SUMS.DENTAL.REC.1400.116).

2.1. Die preparation

Two fixture analogs (Fixture Lab analogue, DIO UFII Implant, South Korea) were placed in the Dentiform model to simulate the mandibular right first premolar and first molar regions. To ensure parallelism and perpendicularity to the horizontal plane, a parallel meter (Paraskop M; Bego GmbH, Bremen, Germany) was used during the positioning of the fixture analogs. Straight abutments (Solid abutment, DIO UFII
Implant, South Korea) with a length of 6 mm and a convergence angle of 6° were attached to the fixture analogs following the manufacturer’s instructions (Fig. 1).

Figure 1. Placement of fixture analogs and abutments in the Dentiform

2.2. Wax pattern preparation

A silicone index was created from the initial CAD-CAM wax pattern to standardize the contour and thickness of the wax patterns, and subsequently as a guide in the conventional wax-up method. The thickness of the copings was verified to be 0.5 mm using a thickness gauge (POCO 2N; Kroeplin, Schluchtern, Germany).

2.2.1. Milling and 3D printing wax pattern

The Dentiform model was coated with an anti-scan spray (Dr. Jean Bausch GmbH & Co KG, Köln, Germany) before being scanned by a 3D laser scanner (UP400; UP3D, Shenzhen, China) connected to CAD software (CAD Design; Exocad GmbH, Darmstadt, Germany). For the milling and 3D printing groups, CAD-CAM patterns were designed with a thickness of 0.5 mm, a cement space of 40 µm incorporated on the occlusal and axial surfaces, and no cement space included at the margin. Appropriate emergence profiles resembling dies were chosen. The CAD-CAM wax patterns were then fabricated using CAM systems. In the milling group, the wax patterns were milled from wax blocks (Dental Wax Disc Block; Wieland, China) using a milling unit (CORiTEC 350i series; imes-icore GmbH, Eiterfeld, Germany). In the 3D printing group, the wax patterns were fabricated using a 3D printer (Guider 3 Plus; FlashForge, Zhejiang, China) with Print2Cast Wax Filament (MachinableWax.com, Michigan, USA).

2.2.2. Conventional wax pattern

By using a brush, the abutments walls were directly coated with two layers of die spacer (Pico-t; Renfert GmbH, Hilzingen, Germany) with a thickness ranging from 40 µm to 0.5 mm from the finishing line. The bottles were securely closed between applications and the brush was regularly cleansed with a thinner agent. Once the die spacer dried, the abutments were coated with a thin layer of separating medium (Picosep; Renfert GmbH, Hilzingen, Germany). The dip wax technique used for the conventional wax-up procedure involved adding inlay wax (Polywax; Bilkimya, Izmir, Turkey) and shaping it using electric waxing instruments (Waxelectric II, Renfert GmbH, Hilzingen, Germany) based on the silicone index mentioned earlier. To facilitate the connection of the crown to the testing machine, a waxed ring with a diameter of 5 mm was created on the center of the occlusal surface of each pattern (Fig. 2).

Figure 2. Wax patterns fabricated through different methods: A) conventional, B) milling, and C) 3D printing

2.3. Cobalt-chromium frameworks

The fabricated patterns were equipped with wax sprues and invested in phosphate-bonded investment material (Hinrivest RP investment; ERNST HINRICHS Dental GmbH, Goslar, Germany) at a ratio of 20 mL
to 100 g to reduce wax contraction.

The wax patterns were eliminated in a preheating furnace at 950°C (Magma; Renfert GmbH, Hilzingen, Germany), and cast (Ducatron casting machine; KFP-Dental Co., Tehran, Iran) with Cobalt-Chromium alloy (Damcast NB; China). After devesting, the copings’ outer surfaces were abraded with 50-µm aluminum oxide (Basic master; Renfert GmbH, Hilzingen, Germany) at 300 kPa pressure. The sprues were removed using a separating disk (Dentaurum GmbH & Co KG; Ispringen, Germany) and the copings were inspected for defects such as nodules, fins, or porosities (Fig. 3).

**Figure 3.** Cobalt-chromium frameworks fabricated through different methods: A) conventional, B) milling, and C) 3D printing

To check for interferences, the internal surface of each framework was examined after applying a disclosing agent (Occlude indicator spray; Pascal International Inc., Seattle, Washington, United States). All laboratory procedures were performed by a single skilled dental technician following a standardized protocol.

The frameworks were cemented onto the respective abutments using zinc oxide eugenol cement (Kerr; Romulus, MI., USA) following standard procedure. Finger pressure was maintained for 10 minutes to ensure complete cement setting. Excess cement was removed using a dental explorer.

### 2.4. Artificial aging process

The framework-abutment-acrylic resin block assemblies were incubated at 37°C and 100% humidity for 24 hours. Subsequently, they underwent 5000 thermal cycles (TC-300 machine; Vafaei Industrial, Iran), ranging from 5°C to 55°C and a 30-second dwell time, equaling 6 months of clinical use [25].

### 2.5. Retentive strength measurement

The retentive strength of each restoration was evaluated using a pull-out test on a universal testing machine (Zwick/Roell ProLine Z050; Berlin, Germany) at a crosshead speed of 0.5 mm/min (Fig. 4). The force required to detach the specimens was measured in Newton. The pull-out tests were conducted by a blinded operator.

**Figure 4.** Universal testing machine used to perform the pull-out test

### 2.6. Statistical analysis

The data were analyzed using SPSS software (version 26; SPSS Inc. USA). Mean ± standard deviation (SD) was used to report the descriptive statistics. The normal distribution of the data was evaluated using the Shapiro-Wilk test, and the equality of variances was assessed using Levene's test. One-way ANOVA and Tukey’s post hoc test were performed for comparison. A significance level of \( P < 0.05 \) was considered statistically significant.
3. Results

Normal distribution and homogeneity of variances were confirmed \((P > 0.05)\) (Table 1).

<table>
<thead>
<tr>
<th>Pattern fabrication method</th>
<th>Normality</th>
<th>Homogeneity</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D Printing</td>
<td>0.35</td>
<td>0.87</td>
</tr>
<tr>
<td>Milling</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>0.65</td>
<td></td>
</tr>
</tbody>
</table>

The results of One-way ANOVA revealed that the three pattern fabrication methods yielded specimens with significantly different retentive strengths \((P = 0.01)\) (Table 2 and Fig. 5).

<table>
<thead>
<tr>
<th>Pattern fabrication method</th>
<th>Retention force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D printing</td>
<td>(150.60 \pm 4.63^{A*})</td>
</tr>
<tr>
<td>Milling</td>
<td>(149.93 \pm 4.18^{A})</td>
</tr>
<tr>
<td>Conventional</td>
<td>(132.14 \pm 16.19^{B})</td>
</tr>
</tbody>
</table>

* Different superscript letters show significant difference between the groups

Subsequent multiple comparisons showed no significant difference between the 3D printing and milling groups \((P = 0.99)\). However, they had significantly higher retentive strength than the conventional group \((P = 0.02\) for 3D printing and \(P = 0.03\) for milling group) (Fig. 5).

**Figure 5.** Mean ± standard deviation of the retentive strength in the study groups

4. Discussion

The obtained results rejected the null hypothesis as the retentive strength was significantly affected by the fabrication methods. The 3D printing and milling methods showed similar and significantly higher retentive strength compared to the conventional method, making them excellent alternatives for achieving greater retention in implant-supported frameworks.

Retention plays a crucial role in the effectiveness and success of cement-retained restorations including implant prostheses. Various factors, such as abutment preparation, taper, height, and surface area can
influence retention [26, 27]. Aside from the preparation design, retention can be influenced by every step of the fabrication process of copings including implant misalignment, impression technique, wax contraction, alloy composition, type of investment, framework design, casting and veneering method, luting procedure, and the technician's experience [28]. A critical step in making porcelain-fused-to-metal crowns is the wax-up fabrication, which highly relies on the technician's skill and may consequently have inherent inaccuracies when made via conventional methods. In contrast, CAD-CAM technology provides several benefits such as cost and time efficiency, improved accuracy, and predictable outcomes [9–11].

The crown-abutment gap and internal fit accuracy play a significant role in determining the retention strength of implant-supported frameworks. A poor internal fit can increases cement thickness and negatively impact retention [29]; while, a precise fit enhances retention strength [30]. Advanced fabrication methods like 3D printing and milling provide high precision and accuracy in producing implant-supported frameworks [31]. These techniques employ digital workflows, reducing human errors and ensuring consistency in fabrication, thereby resulting in consistent and reliable retentive strength [31]. In contrast, the conventional method is more susceptible to errors, particularly related to technician's skills [32]. However, a previous study reported better internal fit in conventional wax-up compared to milled or laser-sintered cobalt-chromium frameworks [33].

An implant-supported prosthesis with multiple elements is particularly prone to interferences, increasing the risk of error in the implant platform and connection design [32]. However, a 2019 systematic review and meta-analysis found that CAD-CAM and conventional methods were not significantly different regarding the marginal misfit of implant-supported frameworks in cement-retained or screw-retained systems [32].

The dislodging force in the oral cavity ranges from 60 to 200 N in the anterior and 300 to 800 in the posterior region [34]. Several studies that used zinc phosphate cement and conventional wax-up method reported higher retentive strength compared to the present study [35–40]. This can be due to the type and height of the abutment and the type of cement.

Limited studies have investigated the impact of pattern fabrication methods on the retentive strength of implant-supported frameworks, some of which align with the findings of the current study. Alikhasi et al. [23] conducted a tensile resistance test to compare the retention of frameworks cast from wax patterns fabricated by CAD-CAM milling, 3D printing, and conventional techniques in one-piece abutments. The results showed that the CAD-CAM-milled wax patterns exhibited significantly higher retention compared to the other two groups. However, the milling group required more adjustments than the other two groups. The study concluded that milled wax patterns could be a beneficial option when retention cannot be easily achieved in single-unit implant restorations. Nasr Mostafa et al. [41] reported that compared to the conventional method, the implant-supported overdenture frameworks made by using CAD-CAM showed significantly less retention loss over a period of 3, 6, and 12 months.

On the other sides, some studies obtained results that contrast those of the current and above-mentioned studies. Cesmeci et al. [24] compared the marginal and internal fit as well as retention of crowns
fabricated using four different castable pattern production methods: plastic burn-out coping, CAD-CAM milling, CAD-CAM additive (stereolithography), and conventional technique. The findings revealed that the prefabricated plastic burn-out coping technique exhibited superior retention values compared to the other methods. The CAD-CAM additive group showed the lowest retention. However, the retention was not significantly different between CAD-CAM (milling or additive) and the conventional method. Such a contrast can be attributed to the type of CAD-CAM additive method (stereolithography vs. 3D printing) and cement type.

Lövgren et al. [42] reported no significant difference in the retentive strengths of cobalt-chromium single-crown copings fabricated through CAD-CAM milling, CAD-CAM additive (laser sintering), and the conventional method. Gap et al. [43] found no significant difference in the internal fit accuracy of frameworks fabricated using conventional, milling, and 3D printing wax-up methods. However, it was only slightly better in 3D printing group. This disagreement in findings could be due to the artificial aging of samples in the present study, variations in the type of employed cement and the specific CAD-CAM additive methods (laser sintering vs. 3D printing).

The choice of cement is another crucial factor affecting the misfit of a prosthesis [44]. Studies have demonstrated improved marginal sealing with resin-modified glass ionomer and urethane-based cements [45, 46].

This in-vitro study had limitations including the evaluation of only three pattern fabrication methods and the exclusion of the effect of porcelain veneering and cement type on retentive strength of implant frameworks. Future long-term clinical studies are recommended to investigate the combined effect of pattern fabrication method, cement type, and abutment preparation on retentive strength. Such studies would provide valuable insights for selecting appropriate fabrication methods and improving the success of implant-supported restorations.

5. Conclusions

In conclusion, within the limitations of this study, both 3D printing and milling technique for wax pattern preparation significantly improve the retention of three-unit implant-supported frameworks compared to the conventional method. Importantly, there was no statistically significant difference between the 3D printing and milling methods in terms of improving the retentive strength, suggesting that both methods are similarly effective in enhancing retention.

Abbreviations

3D
three dimensional
CAD-CAM
computer-aided design / computer-aided manufacturing
Declarations

Ethical Approval

This in-vitro study was approved by the Ethics Committee of Shiraz University of Medical Sciences (IR.SUMS.DENTAL.REC.1400.116).

Consent for Publication

Not applicable.

Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing Interests

The authors declare that they have no competing interests.

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Authors’ Contribution

All authors contributed to the study conception and design. Literature review was done by RG and MB. The experiments were performed by MB and supervised by RG. Data analysis and curation was done by MR and RG. The manuscript was drafted by MB and edited by RG. All authors reviewed and approved the final manuscript.

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References


Figures
Figure 1

Placement of fixture analogs and abutments in the Dentiform

Figure 2

Wax patterns fabricated through different methods: A) conventional, B) milling, and C) 3D printing
Figure 3

Cobalt-chromium frameworks fabricated through different methods: A) conventional, B) milling, and C) 3D printing
Figure 4

Universal testing machine used to perform the pull-out test
Figure 5

Mean ± standard deviation of the retentive strength in the study groups

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- RawData.xlsx