

Digital versus conventional techniques for pattern fabrication of implant-supported frameworks

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ABSTRACT

Objective: The aim of this experimental study was to compare retention of frameworks cast from wax patterns fabricated by three different methods. **Materials and Methods:** Thirty-six implant analogs connected to one-piece abutments were divided randomly into three groups according to the wax pattern fabrication method ($n = 12$). Computer-aided design/computer-aided manufacturing (CAD/CAM) milling machine, three-dimensional printer, and conventional technique were used for fabrication of waxing patterns. All laboratory procedures were performed by an expert-reliable technician to eliminate intra-operator bias. The wax patterns were cast, finished, and seated on related abutment analogs. The number of adjustment times was recorded and analyzed by Kruskal–Wallis test. Frameworks were cemented on the corresponding analogs with zinc phosphate cement and tensile resistance test was used to measure retention value. **Statistical Analysis Used:** One-way analysis of variance (ANOVA) and *post hoc* Tukey tests were used for statistical analysis. Level of significance was set at $P < 0.05$. **Results:** The mean retentive values of 680.36 ± 21.93 N, 440.48 ± 85.98 N, and 407.23 ± 67.48 N were recorded for CAD/CAM, rapid prototyping, and conventional group, respectively. One-way ANOVA test revealed significant differences among the three groups ($P < 0.001$). The *post hoc* Tukey test showed significantly higher retention for CAD/CAM group ($P < 0.001$), while there was no significant difference between the two other groups ($P = 0.54$). CAD/CAM group required significantly more adjustments ($P < 0.001$). **Conclusions:** CAD/CAM-fabricated wax patterns showed significantly higher retention for implant-supported cement-retained frameworks; this could be a valuable help when there are limitations in the retention of single-unit implant restorations.

Key words: Computer-aided design/computer-aided manufacturing, dental implant, retention, wax pattern

INTRODUCTION

Among various material options, metal ceramic restorations are still the most widely used options for fabricating implant-supported restorations.^[1] These restorations could be either screw or cement retained.^[2] Nowadays, cement-retained restorations are relatively popular because the rates of prosthetic complications and implant survival compare favorably with cement-retained prostheses.^[3,4] The

success of implant therapy depends not only on osseointegration of implants but also on prosthetic factors including maintenance of the restorations' integrity and retention.^[5]

The conventional way of fabricating metal substructure is lost wax technique.^[6] Wax has been chosen for this process because it can be well manipulated, precisely

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shaped, and completely eliminated from the mold by heating.^[7] Fabrication of wax pattern is the most crucial and labor-intensive step in making metal ceramic restoration. With the advent of computer-aided design/computer-aided manufacturing (CAD/CAM) and rapid prototyping (RP) technologies, human errors decreased, processes were simplified, and production rates increased.^[8,9] The introduction and application of CAD/CAM in finite element analyses provided valuable information on the pattern of stress distribution in complicate structures. With increasing application of computer in medicine, CAD/CAM base systems have been widely used in the surgical procedure and fabrication of precise equipment. These techniques have three steps of scanning the master model with a three-dimensional (3D) optical scanner, designing the pattern with specialized CAD software, and fabricating the wax model (using either RP techniques or milling machine in CAD/CAM system).^[10]

The application of CAD/CAM systems offers the advantages of high-quality restoration by using prefabricated blocks of material, reducing production cost, labor, and time,^[11] enhancing the accuracy, decreasing the errors,^[12] automatic accurate margin detection, and automatic restoration designing facilities.^[13] RP technology also has high production rate (up to 150 unit per hour), the quality control of wax framework, and reduction in material waste, spruing time, and finishing work needed on frameworks.^[10,14] Although CAD/CAM technology could be used for milling framework or monolithic restorations, using full digital workflow for long-span restorations is still with doubt.^[15-17] Therefore, conventional casting technique is still being in use in dental laboratories. Successful application of CAD/CAM or RP technologies for fabrication of removable partial denture frameworks has been confirmed. However, few studies have investigated the influence of wax pattern fabrication method on final fixed restoration properties.^[18,19]

As the biomechanical problems account for the major part of implant failures,^[20] controlling the stress distribution (compressive, tensile, or shear) and increasing the stability and preciseness of implant-supported restorations could guarantee the long-term clinical results. Finite element and von Mises analyses confirmed the effect of implant-abutment connection type (screw vs. cement),^[21] number and distribution of implant fixtures, size and type of individual components, abutment shape,^[22]

implant inclination,^[20] length, diameter, and surface characteristics,^[23] bone quantity and quality, and restorative materials,^[24] on stress distribution to implant and bone-implant interface.

Retention is one of the indices reflecting the precision and adaptation of a restoration on the related abutment. This characteristic has been investigated in several studies. The studies on the retention of implant- or tooth-supported crowns cemented with zinc phosphate (ZP) cement are summarized in Table 1.^[25-39] The effect of abutment height, diameter, and surface characteristics and cement type and thickness on the retention of implant- or tooth-supported restorations has been evidenced.^[25,40,41] The present study aimed at investigating if wax patterns fabricated by CAD/CAM or RP systems could improve retention value in implant-supported single-unit restorations compared to conventional wax-up method. The null hypothesis was that there was no significant difference in the quantity of retention among these three groups.

MATERIALS AND METHODS

By considering a standard deviation of 7.33 and significance level of 0.05, PASS 11 software (NCSS PASS, Statcon GmbH, Witzenhausen, Germany) (one-way analysis of variance [ANOVA]) was applied to determine the minimum sample size to achieve 86% power. Thirty-six acrylic resin (Cold-cure acrylic for repair, Acropars, Iran) cubes were fabricated in special metal molds and 36 implant analogs (Fixture Lab analogue, Ufit Dental implant system, South Korea) were mounted vertically in these cubes with acrylic resin (Acrylic resin for patterns, GC America Inc., Alsip, IL, USA). Straight abutments (Solid abutment, Ufit Dental implant system, South Korea) with 5.5-mm length and 6° of convergence were secured in the fixture analogs following manufacturer's recommendations. Impression coping was used on dental surveyor (Ney Dental International, Bloomfield, CT, USA) as a guide to ensure parallel mounting of each specimen. Based on wax pattern fabrication method, the specimens were randomly divided into three groups ($n = 12$). Two groups of the abutments were sprayed with scan spray (Powder scan spray, Vita, North America) and optically scanned (3Shape D810; 3Shape, Copenhagen K, Denmark) to make a digital model of abutments. For patterns fabrication, simulated die spacer was set at 30µm, started 0.5mm from the margin^[42] and patterns were designed in the software. Then, CAD/CAM wax patterns were produced (Yeti, Dentalproduct, GmbH, Engen, Germany) through a subtractive method in

Table 1: A literature review on the retention quantities of implant-/tooth-supported crowns with zinc phosphate cement

Reference	Abutment type	Fabrication method	Characteristic	Abutment height (mm)	Retention
Covey <i>et al.</i> ^[25]	Nobel Biocare	Gold cylinder	CeraOne	5	600 N
Kent <i>et al.</i> ^[26]	Nobel Biocare	Gold cylinder	CeraOne	5	599.19 N
Clayton <i>et al.</i> ^[27]	Nobel Biocare	Gold cylinder	CeraOne	3.7	452.2 N
Yeung <i>et al.</i> ^[28]	Nobel Biocare	Gold cylinder	CeraOne		344.21 N
Mayata-Tovalino <i>et al.</i> ^[29]	Nobel Biocare	Not mentioned	CeraOne	5.5	459.62 N
			Solid abutment		459.62 N
Li <i>et al.</i> ^[30]	Nobel Biocare, Steri-Oss	Conventional wax-up		3.8	0.731 MPa
Pan and Lin ^[31]	Nobel Biocare, Steri-Oss	Conventional wax-up		3.8	1.225 MPa
Tan <i>et al.</i> ^[32]	Biomet 3i	Conventional wax-up		7	158.8 N
Bernal <i>et al.</i> ^[33]		Conventional wax-up	30° taper	8	200.06 N
				4	105.91 N
			20° taper	8	374.61 N
				4	225.55 N
Matani <i>et al.</i> ^[34]	Uniti implant	Conventional wax-up	3.7 mm diameter	8	464.2 N
			6 mm diameter	8	667.4 N
Nejatidanesh <i>et al.</i> ^[35]	ITI solid abutment	Prefabricated burn-out cap	8° taper	5.5	267.62 N
Swift <i>et al.</i> ^[36]	Molar tooth	Conventional wax-up	4-8° taper		587 N
Mausner <i>et al.</i> ^[37]	Premolar tooth	Conventional wax-up	6-10° taper	5	383 N
Gorodovsky and Zidan ^[38]	Molar tooth	Conventional wax-up	8° taper	4.5	3.08 MPa
Darveniza <i>et al.</i> ^[39]	Molar tooth	Conventional wax-up	4-6° taper	3	207 N

milling machine (CORiTEC 450i; imes-icore GmbH, Eiterfeld, Germany). The RP wax patterns were also fabricated (Labcast wax, Solidscape material, Cimatrix, Montreal, Canada) in an additive inkjet-based process by R66PLUS system (Solidscape Inc., Merrimack, NH, USA).

To standardize the contour and thickness of wax patterns in all the three groups, a silicon index was made from the first CAD/CAM wax pattern and was used as an index for conventional wax-up method. Two layers of die spacer (Pico-fit; Renfert GmbH, Hilzingen, Germany) were applied directly on each abutment wall with a total thickness of 30 µ up to 0.5 mm from the finishing line. Dip wax technique was used for conventional wax-up procedure. Inlay wax (GEO classic, Renfert GmbH, Hilzingen, Germany) was added and shaped by electric waxing instruments (Waxelectric II, Renfert GmbH, Hilzingen, Germany) according to the index. A hook with an internal diameter of 5 mm was designed on the top of each specimen for attachment to universal testing machine for tensile resistance test.

All wax patterns were invested and cast by Ni-Cr Alloy (4all®, Ivoclar Vivadent, Schaan, Liechtenstein) with electric induction casting procedure. The internal surfaces of all frameworks were particle abraded with 50 µm particles of aluminum oxide (Basic master;

Renfert GmbH, Hilzingen, Germany) at a pressure of 0.3 MPa. Internal surfaces were evaluated by some binocular loupes (HEINE HR-C 2.5x, HEINE®, Herrsching, Germany) and visible nodules were removed with a tungsten carbide bur (No. H71EF; Brasseler GmbH and Co. KG, Komet, Siegel, Germany). A single expert-reliable technician performed all the laboratory procedures. In order to detect interferences, the internal surface of each framework was checked with a disclosing agent (Occlude indicator spray, Pascal International Inc., Seattle, Washington) and adjusted by the same reliable dentist. The adjustment times were recorded for each specimen and statistically analyzed with nonparametric Kruskal-Wallis test with the significance level of $P < 0.05$.

Frameworks were cemented on the corresponding abutments with ZP cement (Hoffmann Dental Manufacture GmbH, Halle, Germany) by standard procedure. Finger pressure was continued for 10 min for final setting of the cement. Excess material was removed by a dental explorer. In order to simulate oral condition and aging process, the framework/abutment/acrylic resin block assemblies were stored at 37°C and 100% humidity in an incubator machine for 24 h and thermocycled (TC-300, Vafaei industrial, Iran) for 5000 cycles, 5°C–55°C, with a 30-s dwell time equivalent to 6 months of clinical application. Universal testing machine

(Zwick/Roell ProLine Z050, Berlin, Germany) was set at a 0.5 mm/min crosshead speed, and pull-out test was used to evaluate retention of the individual restoration. The data were recorded in Newton (N). Statistical analysis was performed by ANOVA and *post hoc* Tukey test (the level of significance was set at $P < 0.05$).

RESULTS

The number of adjustment times for each specimen is shown in Table 2. The result of Kruskal–Wallis test showed significant difference among the three groups ($P < 0.001$). The CAD/CAM group required significantly more adjustments than the two other groups, while RP and conventional groups did not differ in needed adjustments according to median and interquartile range ($P = 0.986$).

The retention mean values were measured as 680.36 ± 21.93 N for CAD/CAM group, 440.48 ± 85.98 N for RP group, and 407.23 ± 67.48 N for conventional group. The interval plot for retention (95% confidence interval for the mean) is shown in Graph 1. One-way ANOVA test revealed significant differences among the groups ($P < 0.001$). The *post hoc* Tukey test showed that retention value in CAD/CAM group was significantly greater than that of the other groups ($P < 0.001$). There was no significant difference between RP and conventional wax-up groups ($P = 0.54$).

DISCUSSION

Evidence shows that the abutment properties, quantity of cement space, and type of cement affect retention values of implant- or tooth-supported restorations.^[25,40,41] This study was conducted to compare the effect of different methods of wax pattern fabrication on the retention value of implant-supported frameworks and showed that wax pattern fabrication method could also affect retention of related restorations. Therefore, the null hypothesis was rejected.

Several materials and methods have been introduced for fabrication of fixed dental or implant restorations,

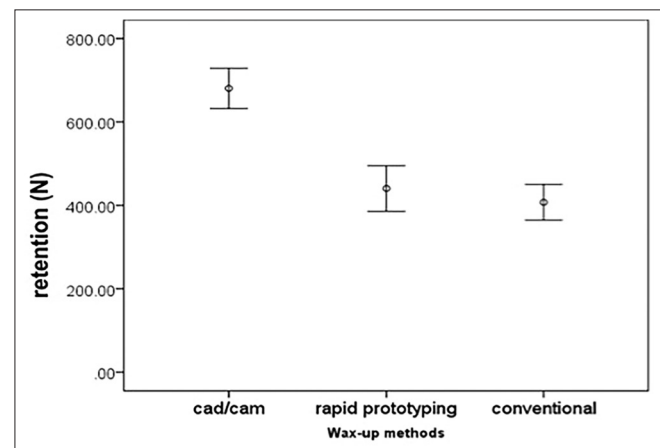
all aimed at improving the accuracy, velocity, and quality of final output. The conventional method is still the gold standard in marginal and internal adaptation according to Leong *et al.*, Harris and Wickens, Vojdani *et al.*, and Mansour *et al.*^[43–46] However, introduction of computerized methods, with their capacity to eliminate the human error, has affected dental practice. The present study showed no significant difference between retention of RP and conventional method ($P = 0.54$); however, frameworks fabricated with CAD/CAM-milled wax patterns had significantly higher retention values ($P < 0.001$). The results suggest that when the clinician decides to use cement-retained restoration on implant, and other clinical situations are not in favor of good retention, CAD/CAM waxing method is a reliable option. With the advancement of technology in the field of 3D printers, improving the results of RP system to profit the advantages of this new technology is promising. It has been shown that RP method decreased time and material waste compared to CAD/CAM milling.^[10,14]

ZP cement is a reliable, nonadhesive, conventional cement that exhibits good compression and tensile resistance when used at a thickness of 30 μm .^[40] The luting property of ZP cement is achieved mainly from mechanical interlocking.^[41] According to the scientific evidence, the retention of implant-/tooth-supported crowns cemented by ZP cement generally ranged between 200 and 600 N,^[25–27,36–39,47] and there is a little difference in retentive values between the implant or natural abutments. Dislodging forces in oral cavity have been reported to range from 60 to 200 N in anterior area and 300–800 N in posterior area.^[47] Therefore, ZP cement provides generally acceptable retention for implant-supported fixed restoration, even in decreased abutment height or increased

Table 2: Detailed statistics of adjustment times of three groups

Group	n	Mean	IQR	Minimum	Maximum
CAD/CAM	12	5	2	4	7
Rapid prototyping	12	1	1	0	3
Conventional	12	1	3	0	4

CAD: Computer-aided design, CAM: Computer-aided manufacturing, IQR: Interquartile range



Graph 1: The interval plot for the retention tests (95% confidence interval for the mean)

abutment taper.^[27,30,31,33,38,39] However, most of the investigations regarding retentive values are performed with conventional wax-up method, other than those applied prefabricated burn-out or gold cylinders. The present study compared different methods of wax pattern fabrication and showed that RP and conventional groups provided clinically acceptable retention quantities, while the CAD/CAM group showed considerably higher retention value.

Better fitness of CAD/CAM specimens necessitated more adjustment times that may be time consuming in clinical practice. Increasing the cement space may be considered rational, provided that the retention is not sacrificed. According to Torabi and Azarian,^[42] increasing the spacer thickness up to 40 μ would not cause significant change in retention. However, further studies are encouraged to evaluate the effect of cement space on the retentive value of computerized methods for fabricating dental restorations. Further studies are also suggested to evaluate the long-term clinical results of different fabrication methods and measure the retention under nonaxial forces that are the prominent types of exerted functional loads.

CONCLUSIONS

Within the limitation of this study, the following conclusions could be made:

1. By application of CAD/CAM technique for wax pattern fabrication, there was a significantly increased retention of implant-supported frameworks compared to conventional wax-up method ($P < 0.001$)
2. Retention of frameworks cast from CAD/CAM wax-up procedure was significantly more than those cast from rapid prototyped wax patterns ($P < 0.001$)
3. There was no significant difference in retentive values between frameworks cast from conventional and rapid prototyped wax patterns ($P = 0.54$)
4. The retentions achieved by all three groups were clinically acceptable
5. Frameworks cast from CAD/CAM waxing preparation required significantly more adjustments compared to conventional or rapid prototyped wax patterns ($P < 0.001$).

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Conflicts of interest

There are no conflicts of interest.

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