

Marginal Discrepancy of Single Implant-Supported Metal Copings Fabricated by Various CAD/CAM and Conventional Techniques Using Different Materials

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Eur J Dent 2019;13:563–568

Abstract

Objective Framework patterns can be formed using various materials such as wax, acrylic resin, or composite. Frameworks can be fabricated using either conventional or computerized techniques, using additive or subtractive method. This study aimed to compare the marginal adaptation of metal copings fabricated by two computerized technologies (milling and rapid prototyping) and additive conventional methods using different materials.

Materials and Methods Seventy-two fixture analogs were mounted vertically in acrylic resin. One-piece abutments with 5.5 mm in length and 6 degrees of convergence were secured into the analogs. The experimental frameworks were fabricated using either subtractive CAD/CAM milling (by wax, soft or hard metal), additive rapid prototyping (by wax), or conventional pattern fabrication (by wax [control] or acrylic resin). Wax and acrylic resin patterns were casted in Ni-Cr alloy. Marginal discrepancy was measured in 12 points by video measuring machine.

Statistical Analysis One-way ANOVA and posthoc tests were used to detect any significant difference among the groups at $\alpha = 0.05$.

Results There was a statistically significant difference among the marginal discrepancy of six groups ($p = 0.018$). The Tukey test indicated a significant difference between CAD/milling of soft metal and conventional wax pattern groups ($p = 0.011$); a significant difference was also reported between CAD/milling of wax patterns and control group ($p = 0.046$).

Conclusions Frameworks fabricated by conventional wax-up showed the largest marginal gaps, while the marginal gap created by frameworks made of soft metal CAD/milling were the smallest. In addition, frameworks fabricated by rapid prototyping showed clinically acceptable adaptations.

Keywords

- ▶ dental implants
- ▶ dental marginal adaptation
- ▶ dental materials
- ▶ computer-aided design
- ▶ metal ceramic alloys

Introduction

Marginal adaptation is one of the most important factors in the long-term success of implant restorations. An accurate adaptation between implant abutment and restoration is necessary for clinical success and prosthesis durability.¹

Lack of marginal adaptation may result in several biological and mechanical problems such as pain, marginal bone loss, plaque accumulation, increase in gingival index and periodontal pocket depth, abutment loosening, osseointegration loss, and even implant failure.²⁻⁴ The marginal adaptation of cement-retained implant restorations can be affected by



different factors including impression materials and techniques, restoration type, fabrication procedure, material used, technician expertise, cement type, and cementation process.⁵⁻⁹ Various techniques have been suggested for measuring marginal discrepancy, and one of the most common non-aggressive techniques is direct view;¹⁰⁻¹³ other methods include impression replica technique,¹¹ cross-sectioning technique,¹⁴ contact scanner technique,¹⁵ and laser videography.¹⁶ One of the acceptable processes is application of video measuring machine (VMM), which relies on non-contact video measurement of high resolution images. This system provides an inexpensive, accurate, and fast procedure to monitor critical dimensions of object without scarifying the specimen.¹⁷

The framework pattern of a restoration can be fabricated by either conventional, computerized, or a combination techniques using a variety of materials such as wax, composite, acrylic resin, and even directly by metal.^{18,19} After the introduction of computerized systems—for example, computer assisted design/milling (CAD/milling) and computer assisted design/rapid prototyping (CAD/RP)—fabrication of higher quality restorations became promising without the limitations of conventional methods.¹⁹⁻²¹ Computer-assisted procedures omitted several steps in fabrication flow,²² improved procedural reliability,²³ facilitated using new materials not applicable in conventional methods, reduced labor and cost, improved quality control, and increased production rate.^{19,24} However, transformation of point angles to smooth surfaces, and the limitation of finite resolution, leading to round edges are reported as disadvantages.²²

Recent studies have reported contradictory results for the marginal discrepancy of restorations made by different methods.^{23,25-36} Several studies reported greater marginal discrepancies in restorations fabricated by the CAD/CAM systems,^{23,25-29} while others showed greater values in restorations made by conventional methods,³⁰⁻³³ or even reported no significant differences³⁴ (►Table 1). The present study aimed to compare the marginal discrepancy of single implant-supported frameworks fabricated by different materials, using additive conventional/computerized and subtractive computerized methods. The null hypothesis was that there will be no significant differences between marginal adaptation of specimens made by different methods.

Materials and Methods

The sample size of 12 for each group was determined using a power analysis to provide statistical significance ($\alpha = 0.05$) at 80% power. Seventy-two implant analogues (Fixture Laboratory analogue, Ufit Dental implant system, South Korea) were mounted vertically in acrylic resin (Acrylic resin for patterns, GC America INC, Alsip, IL, USA). Impression coping was used on a dental surveyor (Ney Dental International, Bloomfield, CT, United State) as a guide to ensure the parallel mounting of each specimen. One-piece abutments (Solid abutment; Ufit Dental implant system, South Korea) of 5.5 mm length and 6 degrees of convergence were secured in the fixture analogues. Experimental groups ($n = 12$) were prepared

as follows by the same expert technician to prevent inter-operator bias (descriptive chart of prepared groups has been shown in ►Fig. 1). The conventional wax group was considered as the control group.

CAD/Milling Specimens (3 Groups)

Thirty-six abutments were sprayed (Scanspray; Renfert GmbH, Hilzingen, Germany) and scanned by a laser scanner (3Shape D810, 3Shape, Copenhagen, Denmark). Data was transmitted to a software program (3Shape's CAD Design software, 3Shape, Copenhagen, Denmark). The cement space was set at 30 μ starting 0.5 mm from the margin; the anatomic patterns were designed and milled using three different materials: wax, soft, and hard Cr-Co metal. Wax patterns (Yeti.; Dentalproduct GmbH, Engen, Germany) were milled by a milling machine (CORiTEC 350i; Imes-icore, Eiterfeld, Germany) using a T35-drill with a 2 mm diameter, invested in phosphate-bonded investments (Z4-C&B investment; Neiryck & Vogt, Schelle, Belgium), and cast by Ni-Cr alloy in a casting machine (Nautilus CC plus; Bego, Bremen, Germany). Soft metal Cr-Co patterns (Ceramil Sintron; Amann Girrnbach AG, Austria) were milled by Amann Girrnbach CAM system (Ceramil motion 2; Amann Girrnbach AG, Austria) using drill no. 760605 with 2.5 mm diameter, and sintered at 1300°C in vacuum oven (Argovent; Amann Girrnbach AG, Austria). Hard metal Cr-Co blocks were milled in a milling machine (CORiTEC 450i; Imes-icore GmbH, Eiterfeld, Germany) using a T40-drill with a 2.5 mm diameter. A silicone index was made from the first pattern to be used for standardization of the thickness/contour of conventional wax and acrylic resin patterns.

CAD/RP Specimens (1 Group)

After scanning the abutments and designing the patterns in the same way as CAD/milling models, wax patterns ($n = 12$) were prepared using a 3D printer (R66PLUS, Solidscape Inc, Merrimack, NH) by an Inkjet base system. The copings were invested in phosphate-bonded investments (Z4-C&B investment [and casted in Ni-Cr alloy (Nautilus CC plus)]).

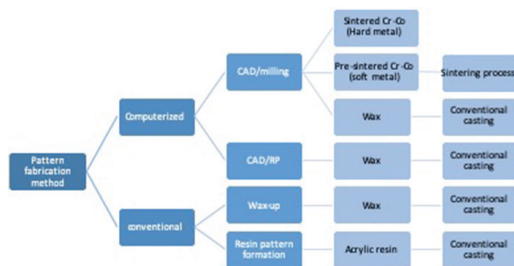
Conventional Specimens (2 Groups)

For wax patterns (control group), two layers of spacer (PICO-FIT; Renfert GmbH, Hilzingen, Germany) were applied to the abutments starting 0.5 mm from the margin, with a total thickness of approximately 30 μ m. After drying, a layer of separating medium (Picosep; Renfert GmbH, Hilzingen, Germany) was applied. The wax patterns were formed by inlay wax (GEO classic; Renfert GmbH, Hilzingen, Germany), and based on silicone index obtained from the first CAD/milling wax pattern. The marginal wax was reflowed before investing.

For acrylic patterns, two layers of spacer (Bredent; XPdent, Miami, United States) were applied on abutments starting 0.5 mm from the margin for an approximate total thickness of 30 μ m. Acrylic resin patterns (GC Corp; Tokyo, Japan) were formed based on the same silicone index. The wax and acrylic copings were invested in phosphate-bonded investments (Z4-C&B investment) and casted in Ni-Cr alloy (Nautilus CC plus). Casting sprues were separated from the models and the

Table 1 A summary of related studies

Study	Measurement method	Material	Fabrication method	Marginal discrepancy (μm)
Tan et al ²³	Direct view technique	Titanium blocks	CAD/CAM	79.43 \pm 25.46
		High noble	Conventional wax-up/CAM	73.12 \pm 24.15
			Conventional wax-up, casting	23.91 \pm 9.80
Farjood et al ²⁵	Cross-sectioning, digital microscope	Wax	CAD/RP wax/casting	89.8 \pm 8.3
			Conventional wax-up, casting	69.5 \pm 15.6
Han et al ²⁶	Cross-sectional	Wax titanium blocks	Conventional wax-up, casting	Shoulder: 55.2 (20.0) chamfer: 52.2 (14.2) Knife edge: 76.1(9.4)
			CAD/CAM hard metal	Shoulder: 67.0 (14.1) chamfer: 59.8 (14.9) knife edge: 80.7(10.4)
Vojdani et al	Cross-sectioning, digital microscope	Wax	CAD/CAM wax, casting	157.37 \pm 20.63
			Conventional wax-up, casting	69.54 \pm 15.60
Kim et al ²⁹	Micro CT imaging	Cr-Co	Conventional wax-up, casting	70.4 \pm 12.0
			CAD/CAM milling	123.5 \pm 32.1
			Selective laser melting	98.7 \pm 26.9
Nejatidanesh et al ³⁰	Replica technique	IPS e.max CAD	CAD/CAM	32.02 \pm 10.38
		Zirconia		34.26 \pm 11.41
		IPS e.max press	Conventional wax-up, press	74.99 \pm 24.51
		Base metal	Conventional wax-up, casting	59.19 \pm 17.81
Ghodsi et al ³¹	Replica technique	Wax	CAD/CAM	18.0 \pm 1.0
		Cr-Co blocks		176.07 \pm 53.54
Ng et al ³²	Direct view technique	Lithium disilicate	Conventional wax-up, pressing	74 \pm 47
			CAD/CAM	48 \pm 25
Xu et al ³³	Replica technique	Co-Cr	Conventional wax-up, casting	170.19
			Selective laser melting	102.86
Lalande et al ³⁴	Sectioning	Complete gold crown	Conventional wax-up, casting	52 \pm 31
			CAD/CAM acrylic, casting	45 \pm 27
Nesse et al ³⁵	Replica technique (3-unit)	Co-Cr	Conventional wax-up, casting	Good marginal fit
			CAD/CAM milling	Best marginal fit
			Selective laser melting	Poor marginal fit
Afify et al ³⁶	Direct view technique (3-unit)	Wax	CAD/CAM milling + casting	35.5 \pm 18.5
		Noble alloy	CAD CAM milling	18.7 \pm 20.4
		Noble alloy	Direct laser sintering	22.8 \pm 13.5

**Fig. 1** Descriptive chart of specimens.

internal surfaces of the copings were sandblasted (Basic master; Renfert GmbH, Hilzingen, Germany) by Al_2O_3 particles (50 μm) under 0.3 MPa pressure.

The internal surface of each coping was evaluated by a binocular loop (HEINE HR-C 2.5x, HEINE, Herrsching, Germany) and visible macro nodules were removed with a tungsten carbide bur (H71EF; Brasseler GmbH, KG, Komet, Siegel, Germany). Invisible nodules, irregularities, or pressure points were determined using a disclosing agent (Occlude indicator spray, Pascal International Inc, Seattle, Washington), and adjusted by round bur (Teezkavan; Tehran, Iran) up to the point that complete siting was confirmed by two prosthodontists blinded about materials/methods used for fabrication of the specimen. The copings were stabilized on abutments by pressure-indicating paste (GC fit checker, GC Corp, Tokyo, Japan), and the marginal discrepancy was measured in 12 points (middle of buccal, mesial, distal, and lingual surfaces, and two points between

each adjacent pair) marked on acrylic base. Marginal discrepancy was measured by a noncontact video measuring machine (AV350 + CNC; Starrett, Galileo Vision System, Birmingham, England) with Heidenhain 0.1 micron resolution scale and 3-axis stage with 350 × 350 × 200 mm XYZ travel (► Fig. 2). (SPSS Inc; Chicago, IL, United States) was used for statistical analysis. The discrepancy values were reported in millimeter scale and analyzed by one-way ANOVA and Tukey tests ($p < 0.05$).

Results

The (mean ± SD) for the marginal discrepancy of implant-supported frameworks fabricated from CAD/milling hard metal, CAD/milling soft metal, CAD/milling wax patterns, CAD/RP wax patterns, conventional wax patterns, and conventional acrylic pattern were 0.12 ± 0.07 mm, 0.09 ± 0.06 mm, 0.11 ± 0.06 mm, 0.11 ± 0.04 mm, 0.20 ± 0.12 mm, and 0.12 ± 0.07 mm respectively (► Fig. 3, ► Table 2). According to the one-way ANOVA test, there was a statistically significant difference among the marginal discrepancy in six groups ($p = 0.018$). The Tukey test indicated a significant difference

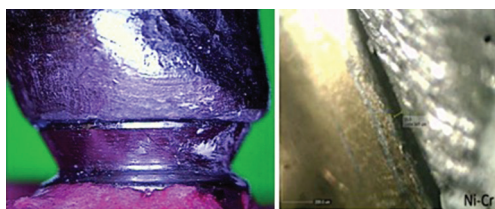


Fig. 2 VMM measurement of casted specimen. VMM, video measuring machine.

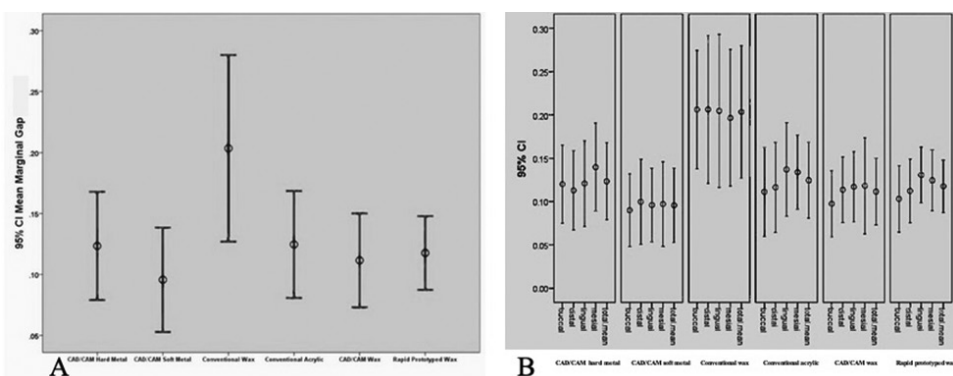


Fig. 3 Mean marginal discrepancy (A) in different groups; (B) separated by different measured points.

Table 2 Descriptive data of different evaluated groups

Specimen	n	Minimum (mm)	Maximum (mm)	Mean (mm)	Std. deviation
Conventional wax	12	0.040	0.471	0.2035	0.1204
Conventional acrylic	12	0.050	0.273	0.1246	0.0690
CAD/milling hard metal	12	0.000	0.225	0.1234	0.0698
CAD/milling soft metal	12	0.000	0.205	0.0957	0.0673
CAD/milling wax	12	0.000	0.215	0.1116	0.0605
Rapid prototyped wax	12	0.020	0.204	0.1176	0.0476

between CAD/milling soft metal and control group (conventional wax patterns) ($p = 0.011$); a significant difference was also reported between CAD/milling wax patterns and control group ($p = 0.046$).

Discussion

The present study was conducted to compare the marginal discrepancies in single-unit, implant-supported frameworks prepared by different methods/materials. The investigated groups were CAD/milling hard metal, CAD/milling soft metal, and conventional casting of patterns fabricated by CAD/milling wax, CAD/RP wax, and conventional hand-formed wax (control) or acrylic resin. The null hypothesis was rejected as there was significant difference between the specimens formed by different methods. Marginal discrepancy was significantly less in CAD/milling soft metal and CAD/milling wax compared with the control group. The sintering shrinkage of pre-sintered metal has been reported in approximately 11% of cases.³⁷ However, the milling system compensates for dimensional change by milling a larger pre-sintered coping; according to the result of the present study, it seems the compensation worked well and the soft metal group showed the least marginal gap ($95.7 \mu\text{m} \pm 0.0673$). Wax pattern fabrication is a time-consuming and labor-intensive step which is highly dependent on technician's skill. It is also claimed that removing wax pattern from a die with shoulder margin can lead to a margin opening of approximately $35 \mu\text{m}$. Moreover, wax color usually makes it difficult to detect small defects in wax patterns.³⁸ CAD/CAM restorations, on the other hand, reduce the effect of technician's expertise; however, their accuracy still

depends on the computer software design, milling material, and sintering shrinkage.^{39,40} According to the present study, CAD/milling wax caused significantly less marginal gap ($111.6 \mu\text{m} \pm 0.0605$) compared with hand-formed wax pattern group ($203.5 \mu\text{m} \pm 0.1204$). All the fabrication methods were made directly on the abutments to eliminate the effect of impression and pouring materials on the obtained results. Therefore, using the same material (wax) and process (conventional casting), the result confirms the significant effect of procedure (CAD/CAM vs. hand forming).

The present study result is inconsistent with the Vojdani²⁷ and Kim²⁹ studies. Furthermore, in a study by Farjood, the marginal discrepancy in the conventional wax group was significantly less than that of the CAD/RP group.²⁵ On the other hand, Nejatidanesh³⁰ and Xu³³ reported smaller marginal discrepancies in the CAD/CAM compared with conventional group which this study agrees with. Han²⁶ reported a significant difference between marginal adaptation in CAD/milling hard metal and conventional wax-up group, while there was no significant difference between these two groups in the present study. Conversely, Ghodsi reported that CAD/CAM technique for wax milling led to better marginal adaptation rather than milling metal blocks,³¹ while this study found no significant difference between these groups.

The controversial results could be explained by the effects of different factors on the accuracy and adaptation of computer- or hand-made models. Several studies confirm that different prostheses length,⁴¹ materials,^{31,42} finishing line configuration,^{26,43} and even framework design,⁴⁴ and measurement method³¹ could affect the accuracy obtained by different fabrication methods.

McLean and von Fraunhofer suggested that the clinically accepted marginal discrepancy is $120 \mu\text{m}$,⁴⁵ which means that the conventional wax patterns' marginal adaptation in the present study was not clinically acceptable; however, the marginal discrepancies in other groups were within the acceptable range.

Evaluating the accuracy of different methods will help the clinician in finding the best method according to the related situation in this growing world of science. The present study measured vertical marginal discrepancies. However, not cementing the specimens, not subjecting the specimens to thermal cycling or aging, and not performing layering stage could be mentioned as study limitations. It is suggested to consider horizontal marginal discrepancy and measure the adaptation both before and after cementation to compare the difference and assess the effect of cementation on marginal gap.

Conclusion

Keeping in mind the limitations of this study, it can be concluded that the framework fabricated by the conventional wax-up technique had, by far, the highest marginal gap compared with the other methods. We also found that the marginal fit of framework made by the CAD/CAM soft metal method was better than the other techniques. In addition, frameworks fabricated by the RP method showed acceptable adaptation on the abutment analogs.

Conflict of Interest

None declared.

Acknowledgment

The authors would like to thank the vice-chancellor of Tehran University of Medical Sciences and Health Services, Tehran, Iran, for supporting the research.

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