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Evaluation of Marginal Fits of Crown Substructure Designs in Implant-Supported Abutments

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Statistical Analysis C
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Background: The purpose of this clinical study was to compare the marginal adaptation of infrastructure design with 4 different techniques.

Material/Methods: Forty tissue-level implant abutments (NTA, Shorter) were inserted on implant analogs. The samples were placed randomly in the wax blocks in the arch form of the upper jaw so that there would be 10 in each group. Test samples were obtained using the conventional casting method (CC), milling from metal blocks method (MB), direct metal laser sintering method (LS), and Noritake Alliance (NA) system. Data were analyzed by ANOVA with *t* tests.

Result: After porcelain oven-drying, marginal gaps of metal substructures obtained by using conventional casting and milling methods were observed to decrease. The smallest value of the marginal gaps was found in the Noritake (NA) system, and the largest value in the milling (MB) method before and after oven-drying. The marginal gap of the direct metal laser sintering method was not significantly different from the change in the marginal gap of other metal substructures ($p>0.05$).

Conclusions: The marginal gap of the substructures obtained using the direct metal laser sintering method was not significantly different from the change in marginal gap of other metal substructures ($p>0.05$).

MeSH Keywords: **Dental Abutments • Dental Implant-Abutment Design • Dental Marginal Adaptation • Dental Restoration, Permanent**

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Background

Dental reconstruction with fixed prostheses needs to be esthetic, biocompatible, and sufficiently strong to withstand the stress of the physiological masticatory function. The long-term success of fixed dental restoration is greatly influenced by the marginal accuracy of the restoration. Improper marginal adaptation of the restoration induces microbacterial deposits on the plaque, which initiates decay and periodontal disease and leads to failure of the restoration [13]. Microleakage through the dentinal tubules to the pulp chamber may lead to endodontic inflammation. In addition, the restoration itself can be affected by the poor margin, as variation in the fitting can create stress concentrations that may reduce the strength and long-term success of the restoration.

In spite of careful tooth preparation and extremely controlled fabrication process for fixed dental restoration, inaccuracy still remains between the margins of the restorations and the finishing lines of the prepared abutments, which predisposes the tooth abutment to caries and periodontal disease [4,5]. The more precisely the margin of the restoration adapts to the finishing line of the prepared tooth, the less the marginal gap manifests and the less the cement film is exposed to oral fluid. It is generally agreed that a marginal fit below 120 μm is clinically acceptable for conventional fixed dental restorations [6,7].

The fabrication method for Co-Cr restorations has been conventional casting with the lost-wax method. The many steps in the production increase the number of variables that can cause discrepancies in the final product. Dental technicians, for instance, commonly use a die-spacer to make room for the cement when waxing the restorations. The thickness of the spacing layer is difficult to standardize, which explains some of the variation in the internal fit of cast restorations [7–9]. A technology that involves fewer manual steps in the manufacturing process and that can reduce some of the errors is the computerized system, computer-aided design/computer-aided manufacturing (CAD/CAM). However, the following factors can also affect the fit of CAD/CAM restorations: scanner precision, transformation of the scanning data into 3-dimensional models, and precision of the milling machine. The disadvantages of this method are expensive milling tools, time-consuming processes, waste products, and wear of equipment. Selective laser melting uses a high-temperature laser to sinter a metal powder, which is then fused together layer by layer. The add-on production method is cost-effective, produces little waste, and does not wear the equipment [10–14].

All-ceramic restorations are becoming increasingly popular because of their high esthetic potential and outstanding biocompatibility. Zirconia unites all of the positive characteristics of ceramics, although it has limited esthetics due to its high opacity.

Noritake Alliance (Noritake Dental Supply Co. Ltd., Japan) is one of the CAD/CAM systems capable of making production from zirconia blocks containing 94.4% ZrO_2 and 5.4% Y_2O_3 [15–17].

Therefore, the aim of this clinical study was to compare the marginal adaptation of conventional casting method (CC), milling from metal blocks method (MB), direct metal laser sintering method (LS), and Noritake Alliance (NA) system.

Material and Methods

Forty tissue-level implant abutments (NTA, Shorter) were inserted on implant analogs and subsequently tightened to 30 N using the manufacturer's torque driver.

To determine the vestibules sides of the samples and thus to provide a single entryway for the crown, notches were opened in the metal samples to determine their labial sides. The prepared samples were placed randomly in the wax blocks in the arch form of the upper jaw so that there would be 10 in each group. Measurements were taken from the prepared blocks by using the Wash technique, using polyvinyl siloxane type measuring material (Elite P&P, Zhermack, Italy), and models were obtained.

Test samples were obtained using the conventional casting method (CC), milling from metal blocks method (MB), direct metal laser sintering method (LS), and Noritake Alliance (NA) system.

Preparation of metal substructures obtained through traditional casting

One layer of 10- μm -thick die-spacer (Yeti Dental, Germany) was applied on a plaster model so as to be 1 mm away from the margin, and it was allowed to dry for 60 s. The modeling of the wax sample was completed using wrapping and dripping methods and connected to the casting sprue and casting cone (Waxwire, Bego, Germany). Surface tension-reducing agent (Aurofilm, Bego, Germany) was applied to the samples. The phosphate-bound revetment (Bellavest-T, Bego, Germany) was prepared in accordance with the manufacturer's instructions. The prepared fluent revetment was filled into a flask mold. Then, the revetment mold was held on a vibrator for 1 min to allow the air bubbles to rise to the surface.

The prepared molds were placed in a preheating furnace (Infratherm-II AT, GMG Electronics, Turkey) for wax elimination with ceramic casting crucibles while the casting channels were facing down; wax burn-out and preheating processes were completed.

Figure 1. Sub-structures obtained using the: (A) CC (conventional casting method); (B) LS (direct metal laser sintering method); (C) MB (metal blocks method); (D) NA methods (Noritake Alliance method).

The flask and the casting crucible that were removed from the furnace with the help of tongs were placed in a centrifugal induction-heating casting furnace (Mikrotek, Turkey) without delay. The required amount of Cr-Co metal alloy nuclei (Microlite Heat, Schütz Dental Group, Germany) was placed in the ceramic casting crucible for casting. For metal substructures, 100% pure metal alloys were used in each casting.

The lid of the induction casting furnace was closed, and the heating and casting process was started. The oven was heated to 1400°C in 1 min in accordance with the manufacturer's instructions. The metal alloy nuclei were cast in a centrifuge for 20 s after they were melted. After cooling, revetment residues were cleaned by sandblasting with 50-µm aluminum oxide

particles (Korox 50, Bego, Germany). Considering the material losses that may occur during the cleaning of revetment, the samples were checked using calipers to see if they were 0.5 mm thick after the leveling process. Samples that did not meet the standards were not included in the study, and new samples were cast. Thus, 10 Cr-Co cast substructures were prepared (Figure 1).

Preparation of Cr-Co metal substructures fabricated by using milling technique

One layer of 10-µm-thick die-spacer (Yeti Dental, Germany) was applied on a plaster model so as to be 1 mm away from the margin, and it was allowed to dry for 60 s. The models

were transferred to a computer environment with a 3D optical scanner (Dental Wings, Inc, Montreal, Canada). Metal substructures of 0.5 mm thickness were designed with the aid of a design program (DWOS software, Dental Wings Inc, Montreal, Canada) and were milled from a Cr-Co-based metal block (Whitepeaks Dental Systems GmbH & Co., Germany) by using a milling machine (Fedi 18, Mariotti & C. Attrezzatura Dentale, Italy). The thicknesses of the samples were checked by calipers to be adjusted to 0.5 mm, and samples that did not meet the standards were not included in the study and were replaced with new ones (Figure 1).

Preparation of Cr-Co metal substructures obtained by using direct metal laser sintering (DMLS)

One layer of 10- μ m-thick die-spacer (Yeti Dental, Germany) was applied on a plaster model so as to be 1 mm away from the margin, and it was allowed to dry for 60 s. The plaster model was scanned using a laser scanner (Indian-Els Scanner, Indian-Els DentaCAD Systeme Germany) and transferred to a computer. The design process was carried out using a design program (DWOS software, Dental Wings, Inc, Montreal, Canada). Data generated in the computer environment were transferred to the production department, and substructures were prepared from Cr-Co metal alloy powder (SINTTECH, Clermont-Ferrand, France) by using the laser metal sintering method (EOSINT M 280, EOS GmbH Electro Optical Systems, Germany). The thicknesses of the substructures were calibrated to 0.5 mm by measuring with calipers, and those that did not conform to the standards were not included in the study and were replaced with new ones.

Preparation of substructures obtained by using Noritake Alliance Y-TZP method

One layer of 10- μ m-thick die-spacer (Yeti Dental, Germany) was applied on a plaster model so as to be 1 mm away from the margin, and it was allowed to dry for 60 s. The plaster model was scanned (Optical Scanner S600), and the substructures to be prepared were designed. Ten substructures were obtained by designing the samples using the Noritake Alliance (Noritake Dental Supply Co. Ltd., Japan) Y-TZP blocks that were predefined in the Dental Wings (Montreal, Canada) CAD system within the Ata Dental Prosthesis Laboratory (Figure 1A–1D).

The half-sintered disc obtained for zirconia substructures was sintered in a total of 8 h using the conventional method (Protherm, HLF 100, Ankara, Turkey) based on the recommendations of the manufacturer. Samples were ultrasonically cleaned (Ultrasonic Cleaner SUC-110, Shofu, Kyoto, Japan) with distilled water for 15 min and air-dried.

Figure 2. Application of a constant load after cementation.

Marginal fit measurements

The marginal fit measurements of the prepared substructure samples were made on the metal abutments obtained from the main models. While measurements were being made, one surface of the crown was treated with temporary cementation without eugenol (Cavex Temporary Cement, Cavex, The Netherlands) so that the substructures did not move on the metal abutments. The cemented substructure and abutment were placed in a special setup for 10 min in accordance with the manufacturer's instructions (Figure 2).

While measuring the reference points on the metal abutments, a block of transparent acrylic (Paladent RR, Heraeus Kulzer GmbH, Germany) was prepared with the aid of a silicone mold, which also carried the measuring assembly on it to ensure that the substructures did not move and were under a stable pressure. Lining was applied to the housing where the metal abutment was to be placed using a texture-restorative material (Visco-gel, Dentsply, Germany) to ensure that the abutment was constrained in the housing.

On each of the abutments, 14 points were marked using a permanent marker (Faber-Castell, Germany). Measurements were made from the regions where these marks were located. Before marginal fit measurements of the acrylic block, photographs were taken with a ruler to minimize the error margin of the image obtained using a stereomicroscope- and a microscope-integrated digital camera (Canon 25 $\times$, Japan), and the appropriate magnification value and location were determined. Measurements were taken from the reference points on the samples with a digital camera attached to the upper part of the microscope at $\times 40$ magnification before and after the oven-drying process. The photographs that were taken were saved on a computer

Table 1. The marginal gap values of the methods before and after oven-drying.

Method	Oven-drying	Marginal gap values μm
LS	Before	55.47 $\pm$ 31.63
	After	56.57 $\pm$ 25.51
CC	Before	87.52 $\pm$ 16.93
	After	68.12 $\pm$ 10.95
MB	Before	96.68 $\pm$ 26.24
	After	90.71 $\pm$ 11.84
NA	Before	17.70 $\pm$ 3.5
	After	19.60 $\pm$ 4.41

LS – direct metal laser sintering method; CC – conventional casting method; MB – metal blocks method, NA – Noritake Alliance method.

and evaluated using a professional photo editing program (Photoshop CS4, Adobe Systems Software, USA). Marginal gap measurements were determined by measuring the distance between the crown margin and the notch prepared on the metal abutment. Measured values were recorded in micrometers (μm).

Results

Comparison of marginal gaps

Comparison of marginal gaps prior to oven-drying

ANOVA was used to examine the difference in marginal gaps between the methods of all groups prior to oven-drying ($p < 0.05$).

Paired t tests were used to determine whether the differences between the marginal gaps before and after oven-drying were statistically significant.

The marginal gap values of the substructures before oven-drying were measured as 17.70 $\pm$ 3.5 μm in the Noritake system, 55.47 $\pm$ 31.63 μm in the direct metal laser sintering group, 87.52 $\pm$ 16.93 μm in the conventional casting method, and 96.68 $\pm$ 26.24 μm in the milling metal group. The marginal gap values of the substructures after oven-drying were measured as 19.60 $\pm$ 4.41 μm in the Noritake system, 56.57 $\pm$ 25.51 μm in the direct metal laser sintering group, 68.12 $\pm$ 10.95 μm in the conventional casting method, and 90.71 $\pm$ 11.84 μm in the milling metal group. The distributions of the marginal fit measurements before and after oven-drying are shown in Table 1.

The smallest value of the marginal gaps was found in the Noritake (NA) system and the largest value was found in the milling (MB) method before and after oven-drying (Table 2).

Results of the t test with $p < 0.05$ indicate that the oven-drying process in the relevant method produces a statistically significant difference in marginal gap values. The oven-drying process resulted in a statistically significant reduction in the marginal gap values of conventional casting (CC) methods, whereas the decrease in the milling metal (MB) group was not statistically significant. The largest increase in the marginal gap was observed in the Noritake (NA) system (Table 3).

Discussion

The purpose of this study was to compare the marginal gaps of materials obtained before and after oven-drying by applying different methods to the crown substructure designs in implant-top abutments. The marginal gap values of the substructures

Table 2. Descriptive statistics of the methods before and after the oven-drying processn.

Method	Oven-drying	Average	Median	Standard deviation	p
LS	Before	55.47001	44.5394	31.63691	0.660
	After	56.57613	47.7142	25.51265	
CC	Before	87.52544	87.2969	16.93443	0.001
	After	68.12313	69.8308	10.9583	
MB	Before	96.68714	101.278	26.24048	0.325
	After	90.7119	91.4521	11.84039	
NA	Before	17.70054	18.28	3.507712	0.111
	After	19.601	21.1025	4.418854	

LS – direct metal laser sintering method; CC – conventional casting method; MB – metal blocks method; NA – Noritake Alliance method.

Table 3. t-Test results of the methods before and after the oven-drying process.

	Mean differences	Standard deviation of the differences	t	p	
LS	-1.1061164	7.68971406	-0.455	0.660	
CC	19.4023093	13.2705087	4.623	0.001	p<0.05
MB	5.9752343	18.15873	1.041	0.325	
NA	-1.9004586	3.40067467	-1.767	0.111	

before oven-drying were measured as 17.70 ± 3.5 μm in the Noritake system, 55.47 ± 31.63 μm in the direct metal laser sintering group, 87.52 ± 16.93 μm in the conventional casting method, and 96.68 ± 26.24 μm in the milling metal group. The marginal gap values of the substructures after oven-drying were measured as 19.60 ± 4.41 μm in the Noritake system, 56.57 ± 25.51 μm in the direct metal laser sintering group, 68.12 ± 10.95 μm in the conventional casting method, and 90.71 ± 11.84 μm in the milling metal group.

In our study, the marginal gap of the substructures obtained using the direct metal laser sintering method was not significantly different from change in the marginal gap of other metal substructures ($p > 0.05$). The oven-drying process resulted in a statistically significant decrease in marginal gap values of conventional casting (CC) methods ($p < 0.05$).

The success of a restoration depends on several factors, including the marginal fit of the restoration. The lack of adequate fit is a potentially harmful factor for both dental and periodontal tissues, as it causes cement dissolution and plaque retention. For the restoration to be durable in the biological environment of the oral cavity, the fixed prosthetic edge must be firmly adapted to the abutment margin [18–20].

Several studies have reported that marginal discrepancy values greater than 120 μm are clinically unacceptable [9–11,17,18]. In the present study, no specimen showed a mean marginal discrepancy value greater than 120 μm ; therefore, all methods were found to be successful in terms of marginal fit [21,22]. The direct microscopy method is the most straightforward, least time consuming, most easily repeated, and least expensive of the 4 methods, but the precision of measurements is lower, and selection of measurement points is more challenging. Thus, in the present study, the direct microscopy method was used to evaluate all margins [23–25].

Kim et al. evaluated the marginal accuracy of 4 fabrication methods (casting, milling, selective laser melting, and milling-sintering) and 2 different alloy systems specific to each fabrication method. In contrast to our results, they concluded that metal-ceramic crowns prepared by using the laser

milling-sintering method exhibited the best marginal fit [24]. This disagreement may be due to the different metal alloys used.

Rosentritt et al. reported that fabrication methods did not significantly affect the adaptation of metal-ceramic crown, and the mean clinical marginal adaptation of finished crowns before luting ranged from 80 to 71 μm [9]. Tamac et al., who measured the fit of Co-Cr restorations produced by casting or milling, found no significant difference between the marginal discrepancies of the cast (75.92 μm) and the milled groups (86.64 μm) [7]. May et al. emphasized that marginal gaps of cemented restorations should in theory be between 25 and 40 μm , but they reported that this was rarely observed clinically [26].

In our study, the marginal gap values before oven-drying were measured as 17.70 ± 3.5 μm in the Noritake system, 55.47 ± 31.63 μm in the direct metal laser sintering group, 87.52 ± 16.93 μm in the conventional casting method, and 96.68 ± 26.24 μm in the milling metal group. The marginal gap values of the substructures after oven-drying were measured as 19.60 ± 4.41 μm in the Noritake system, 56.57 ± 25.51 μm in the direct metal laser sintering group, 68.12 ± 10.95 μm in the conventional casting method, and 90.71 ± 11.84 μm in the milling metal group. The minimum marginal gap was found in the Noritake CAD-CAM system, whereas the maximum marginal gap was found in the conventional casting method.

Witkowski et al. [27] reported that fitting in CAD-CAM systems significantly reduced the marginal gap, which agrees with our findings.

The restoration itself can be affected by the poor margin, as variation in the fitting can create stress concentrations that may reduce the strength and long-term success of the restoration. Dental implants have a high survival rate, and implant therapy is considered highly successful [1,2]. However, implant-associated infections also occur regularly. Colonization of the submucosal peri-implant area starts immediately after installation of the implant or the abutment. Takanashi et al. studied colonization of dental implants in patients without a history of periodontitis and demonstrated that *P. gingivalis* and

Prevotella intermedia are intra-orally transmitted from dentate to peri-implant sites [28]. This could indicate that placement of dental implants favors the formation of a submucosal bio-film that supports colonization by this pathogen and may explain the frequent detection of this pathogen in peri-implantitis lesions [29].

These colonies already exist in the mouth, no matter how good the marginal gap; therefore, the restoration needs to be done as harmoniously as possible.

Niwut et al. reported that the marginal fit of metal casting and zircon substructure obtained by using conventional methods is clinically acceptable [2]. The results in our study are also clinically acceptable.

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Conclusions

- After porcelain oven-drying, marginal gaps of metal substructures obtained by using conventional casting and milling methods were observed to decrease.
- There was a 1.1-µm change in the marginal gap of the substructures obtained by using the direct metal laser sintering method. This amount of change was not statistically significant in comparison to the change in the marginal gap of other metal substructures ($p>0.05$).
- Lower values were obtained in all our test samples than the clinically acceptable marginal gap of 120 µm.

Conflict of Interest

None.