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Evaluation of Marginal and Internal Fit of Metal-Ceramic Restorations Produced by Direct Metal Laser Sintering Method Before and After Porcelain Application: Experimental Study (*In Vitro* Material Study)

Direkt Metal Lazer Sinter Yöntemiyle Üretilen Metal Seramik Restorasyonların Porselen Uygulaması Öncesi ve Sonrası Marjinal ve İnternal Uyumlarının Değerlendirilmesi: Deneysel Çalışma (*İn Vitro* Materyal Çalışması)

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ABSTRACT Objective: Along with developing technology, digital methods have begun being used for the production of metal-ceramic systems. However, there are very few studies that investigate the changes of the marginal discrepancy during porcelain processes. The aim of the study is to compare the marginal discrepancy of metal-ceramic restorations produced by the direct metal laser sintering (DMLS) method using metal powders before and after the porcelain applying process. **Material and Methods:** A four-unit fixed restoration was designed at the right maxilla between the first premolar and second molar teeth. A total of 10 restorations were produced with the DMLS method. The marginal and internal gap was measured twice using the silicone replica technique, before and after the porcelain processes. Under a stereomicroscope, measurements were made from the mesial, occlusal, and distal surfaces, with 21 measurements from each sample. Statistical analysis was performed and $p<0.05$ was considered statistically significant. **Result:** At the molar tooth, a statistically significant increase in marginal discrepancy was observed at the mesial region ($p<0.001$) and at the occlusal region ($p<0.001$). At the premolar tooth, a statistically significant decrease in marginal discrepancy was observed at the mesial region ($p<0.001$), and an increase was observed at the occlusal region ($p<0.001$). **Conclusion:** The results of our study; It shows that 4-units metal-ceramic restorations, whose metal substructures are produced by the DMLS technique, can create marginal and internal discrepancy above clinically acceptable limits.

Keywords: Direct metal laser sintering; metal-ceramic crown; silicone replica technique; marginal discrepancy

ÖZET Amaç: Gelişen teknoloji ile birlikte metal-seramik sistemlerin üretiminde dijital yöntemler kullanılmaya başlanmıştır. Ancak marjinal uyumsuzluğun porselen uygulama öncesi ve sonrası arasındaki değişimini araştıran çok az sayıda çalışma bulunmaktadır. Bu çalışmanın amacı, direkt metal lazer sinter (DMLS) yöntemi ile üretilen metal-seramik restorasyonların porselen uygulama işlemi öncesi ve sonrası marjinal uyumsuzluklarının karşılaştırılmasıdır. **Gereç ve Yöntemler:** Sağ maksillada 1. premolar ve 2. molar dişleri arasında 4 üyeli sabit restorasyon tasarlandı. DMLS yöntemi ile toplam 10 adet restorasyon üretildi. Marjinal ve internal uyum silikon replika tekniği kullanılarak, porselen işlemlerinden önce ve sonra olmak üzere 2 kez ölçüldü. Bir stereomikroskop altında, her numuneden 21 ölçüm olmak üzere mesiyal, okluzal ve distal yüzeylerden ölçümler yapıldı. İstatistiksel analiz yapıldı ve $p<0,05$ istatistiksel olarak anlamlı kabul edildi. **Bulgular:** Molar diş, mesiyal bölgede ($p<0,001$) ve okluzal bölgede ($p<0,001$) marjinal uyumsuzlukta istatistiksel olarak anlamlı bir artış gözlendi. Premolar diş, mesiyal bölgede marjinal uyumsuzlukta istatistiksel olarak anlamlı bir azalma ($p<0,001$), okluzal bölgede artış ($p<0,001$) gözlendi. **Sonuç:** Çalışmamızın sonuçları; DMLS tekniğiyle metal alt yapıları üretilen 4 üyeli metal seramik restorasyonlarda klinik olarak kabul edilebilir sınırların üzerinde marjinal ve internal uyumsuzluğun olabileceğini göstermektedir.

Anahtar Kelimeler: Direkt metal lazer sinter; metal-seramik kron; silikon replika teknik; marjinal uyum

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Metal-ceramic crowns, which are popular in fixed prosthetic treatment due to their superior mechanical properties, have been determined to have high long-term clinical performance in the posterior region.[1,2] Long-term clinical performance of restorations depends on the opening between the substructure and the abutment tooth.[2] Internal and marginal adaptation are important issues in fixed prosthetic restorations.[1,2] An increase in marginal discrepancy causes disintegration of the cement, followed by secondary caries and periodontal diseases.[2]

Lost wax and traditional casting techniques are still used for metal substructure production. However, these methods have disadvantages such as complexity of production, long-term requirement, shrinkage of wax material, and irregularity of the metal substructure.[1,3] New systems have emerged with developing technology that can overcome these disadvantages.[2]

Computer-aided design/computer-aided manufacturing (CAD/CAM) and direct metal laser sintering (DMLS) technology are used in metal substructure production. In the CAD/CAM technology, the metal substructures are designed digitally (CAD) and manufactured by milling from blocks (CAM). In the DMLS technology, metal powders are melted layer by layer to create a 3-dimensional object by laser beams. Compared to the traditional casting method, the laser sintering method shows high metal-ceramic bond strength and better surface properties. These properties have made metal substructure production by laser sintering popular in recent years.[4]

There are many studies comparing the marginal discrepancy of metal, metal-ceramic and ceramic crowns produced by CAD/CAM technology and traditional casting methods.[5] In order for the marginal discrepancy to be acceptable, it must not be visible and must not be noticed in an examination with a probe. The ideally targeted marginal discrepancy value in the clinic has been suggested as 25 μm and shown as the maximum film thickness by the Dental Association Specification Association. But this marginal discrepancy has rarely been reported.[6]

Marginal discrepancy measurement methods differ in the previous studies. The researchers measured the thickness of the cement by cross-sectioning, or directly under the microscope, using micro-computed tomography (MCT) and the silicon replication method. However, there are disadvantages to this technique, such as destruction of substructures in the direct method, so sensitivity is required for microtomography. The silicon replication technique has eliminated the disadvantages of the other 2 techniques and has recently become the accepted method by many researchers for measuring marginal discrepancy.[1,4,5,7,8]

The aim of this study is to compare the marginal discrepancy of metal-ceramic restorations produced by DMLS before and after the porcelain process. The null hypothesis is that there will be no change between the conditions in the marginal and internal fit of metal-ceramic restorations before and after the porcelain application processes.

MATERIAL AND METHODS

The Frasaco-32 dental model was used to standardize the study. The first premolar and second molar teeth were removed from the dental model, and a 4-unit fixed restoration was designed between the right maxillary first premolar and second molar teeth. The abutment teeth with a 6° taper angle and 1 mm deep chamfer step were manufactured from chromium-cobalt alloy to prepared molar and premolar teeth. The prepared models were recorded on a computer with the help of a dental laboratory scanner (Dental Wings, Series 7, France). The metal substructures were designed with the help of CAD software (Dental Wings, Series 7, France).

The four-unit metal substructures were produced with a metal thickness of 0.5 mm and a cement thickness of 30 μm using metal powder (Co: 61.8-65.8, Cr: 23.7-25.7, Mo: 4.6-5.6, W: 4.9-5.9, Si: 0.8-1.2, Fe: 0.5, Mn: 0.1) (Bego Cobalt Chrome SP2; EOS GmbH, Germany) in accordance with the manufacturer's instructions with the laser sintering device (EOS M100, EOS, Germany). A Yb-fiber laser with 1.7 kW power, 900-1,200 nm wavelength, 20-200 mm/sec motion speed was used. The completed samples were sintered for a total of three hours at 750 °C with 45 minutes in accordance with the manufacturer's instructions. In total, 10 metal substructures with 4 units were obtained.

After production of the metal substructures, a compressed steam and sandblasting device was used for cleaning, a light-body type impression material (Variotime light flow Type 3, Kulzer GmbH, Germany) was applied to the metal substructures, and they were placed on the model (Figure 1a). Finger pressure was applied for 3 minutes during the polymerization of the impression material.

After polymerization of the impression material, the metal substructures were removed from the model. After applying the light-body type material to all samples, to stabilize the thin elastomer layer, which represented the discrepancy between the abutment and the restoration, a medium-body type of polyvinyl siloxane impression material (Variotime Heavy Tray, Dynamix Refill, Type 1, Germany) was applied (Figure 1b). Following polymerization of the impression material, silicon replicas were removed from the metal substructures (Figure 1c). All samples were subjected to the same procedures. Thin slices were obtained from the midlines of the replicas in the mesio-distal direction. The slices were marked to indicate the mesial direction (Figure 1d).

The samples were examined at 100x magnification under a stereomicroscope (Nikon Eclipse ME, 600; Nikon, US) (Figure 2). The marginal discrepancy size was measured with a micron ruler. A total of 21 measurements were obtained from each section, 7 measurements from each of the mesial, distal, and occlusal regions. Digital data was recorded on a computer as μm.

The porcelain application was made according to the manufacturer's instructions (Phoenix Quick Cool, Dentsply, USA). Oxidization firing was at 975 °C for 11 minutes. Following this stage, the first and

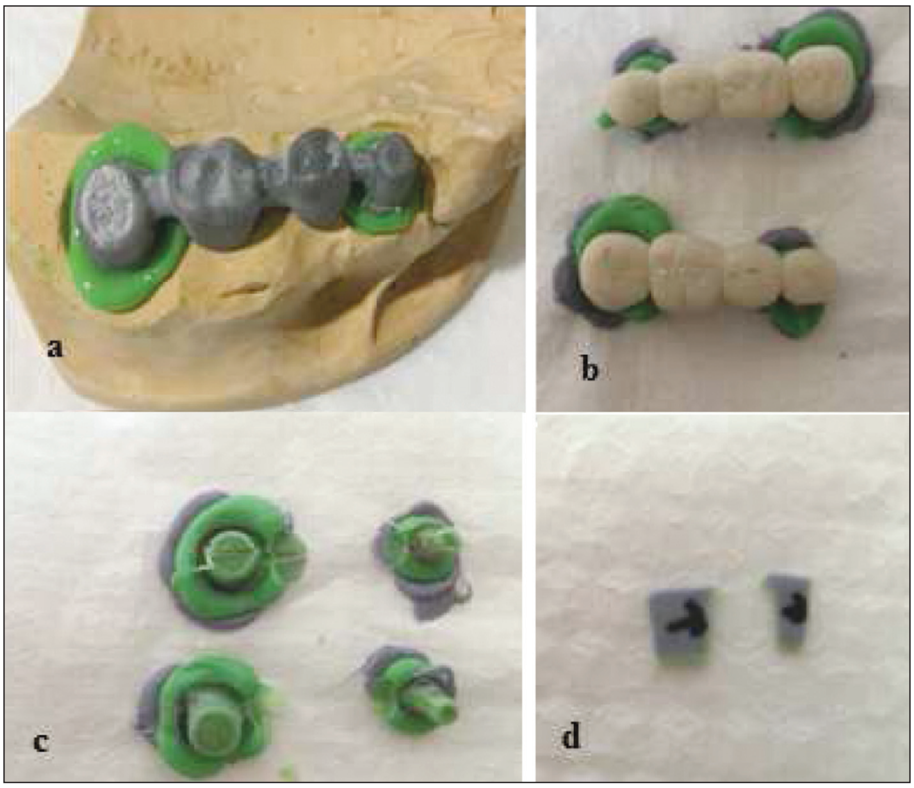

FIGURE 1: a) Making measurements with light body during the production of silicone replicas, **b)** After applying the material of the heavy body impression material, **c)** Removal of impression material from the restoration, **d)** Making sections from the samples.

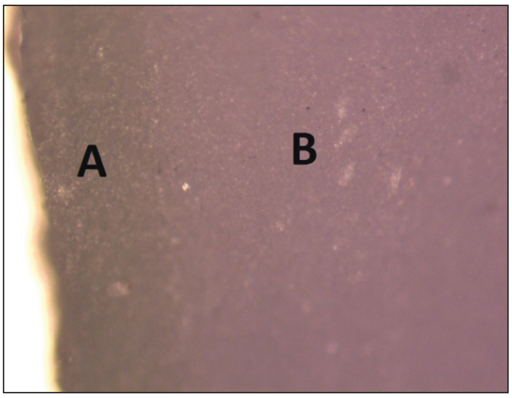

FIGURE 2: Microscope images of samples **A)** Flowable impression material (light body), **B)** Impression material with thick consistency (heavy body).

second opaque stages were fired at 950 °C for 12 minutes (Vita VMK Master, Vita, Germany). Dentin and enamel porcelain were processed at 920 °C for 17 minutes and the glaze was processed at 920 °C for 14 minutes (Noritake EX-3, Kuraray, Japan). The first 6 stages were made in a vacuum furnace and the last stage was made in a vacuum-free furnace. Silicon replica procedures were reapplied to the porcelain-applied samples in the same way as mentioned before. The samples were examined under a stereomicroscope. Digital data was recorded on a computer.

Statistical analysis of the data obtained in this study was evaluated with SPSS 20.0 software (SPSS Inc., Chicago, IL, USA). The mean values of the measurements were calculated separately as mesial, occlusal, and distal. Shapiro-Wilk tests were used to determine the homogeneity of the distribution of data. Paired t-test was used in the evaluation of data between the substructure and the superstructure in the same group. The level of $p<0.05$ was considered statistically significant.

RESULTS

The results obtained before and after the porcelain applying processes are shown in Table 1. Marginal discrepancy values were obtained in the mesial, distal, and occlusal regions in both molar teeth and premolar teeth, before and after porcelain application.

At the molar tooth, marginal discrepancies were 131.64 µm at the mesial region, 111.43 µm at the distal region, and 248.79 µm at the occlusal region before porcelain application. After porcelain application, marginal discrepancies were 139.07µm, 70.00 µm, and 306.50 µm, respectively. A statistically significant increase in marginal discrepancy was observed at the mesial region ($p<0.001$) and a statistically significant increase was observed at the occlusal region (Table 1, Figure 3) ($p<0.001$).

At the premolar tooth, marginal discrepancies were 111.57 µm at the mesial region, 115.57 µm at the distal region, and 174.71 µm at the occlusal region before porcelain application. After porcelain application, marginal discrepancies were 73.71 µm, 119.79 µm, and 196.36 µm, respectively. A statistically significant decrease in marginal discrepancy was observed at the mesial region ($p<.001$) and a statistically significant increase was observed at the occlusal region ($p<0.001$) (Table 1, Figure 3).

DISCUSSION

In this study, the marginal and internal fit of 4-unit metal restorations were evaluated before and after porcelain application when fabricated by the DMLS method, and the null hypothesis was rejected. In molar samples, a statistically significant increase was observed in the mesial and numerical decrease in dis-

TABLE 1: Before and after the porcelain applying processes marginal discrepancy values as µm (micrometer).

	Molar			Premolar		
	Before	After	p value	Before	After	p value
Mesial	131.64±3.851	139.07±3.167	0.000	111.57±3.279	73.71±2.366	0.000
Distal	111.43±5.914	70.00±4.099	0.741	115.57±3.015	119.79±2.595	0.053
Occlusal	248.79±6.241	306.50±8.475	0.000	174.71±7.760	196.36±5.395	0.000

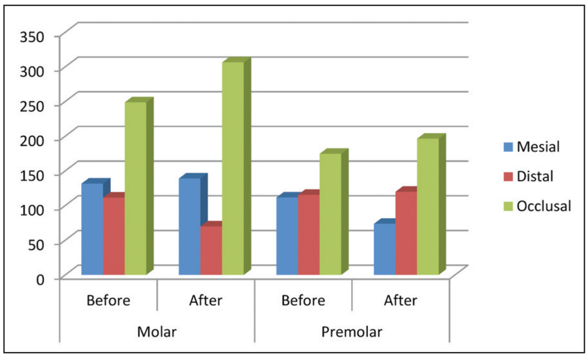

FIGURE 3: Before and after the porcelain applying processes marginal discrepancy.

tal after porcelain application. In premolar samples, a statistically significant decrease occurred in the mesial region and a numerical increase in the distal. Statistically increased occlusal surfaces of both molar and premolar samples were observed.

DMLS was used as the production method in this study. Metal ceramic restorations can be produced with the traditional casting method, CAD/CAM, or DMLS with developing technology. Compared to the traditional method, DMLS has advantages such as reducing production time, preventing practitioner error, protecting casting errors, and higher product density.[5] Xu et al. evaluated the marginal fit of the crowns produced by casting and laser sintering, and found the marginal gap (MG) value to be 102.86±40.54 µm in the laser-produced group. They measured a lower MG value in the laser-produced group than in the cast-produced group.[5] Örtorp et al. produced 3-unit restorations with 4 different methods in their study using Cr-Co infrastructure. They reported that crowns produced by the laser sintering method had lower marginal clearance than crowns produced by other methods.[8] On the other hand, there is a study stating that the marginal fit of the restorations produced by all three of the DMLS, CAD/CAM, and casting methods are similar and clinically acceptable.[1]

Previous studies have shown that high temperature in the porcelain firing stages leads to deterioration in the metal substructure, increasing or decreasing the marginal discrepancy of metal-ceramic crowns.[1,4,8-10] Buchanan et al. reported that this deterioration occurred due to the difference in heat expansion coefficients between the porcelain and the substructure during porcelain firing.[11] In this study, we think that the changes in marginal values may be caused by expansion between metal molecules due to the porcelain firing temperature.

In the literature, the marginal and internal fit between production methods are generally compared.[1,12] Akçin et al. evaluated the marginal discrepancy of an implant-supported multiunit framework with three, four, and five units, in different production methods.[12] Tamac et al. evaluated the marginal discrepancy of single-unit metal-ceramic restorations.[1] There are few studies on marginal discrepancy before and after porcelain application.[10] In the current study, the marginal discrepancy of metal-supported 4-unit restorations produced with the DMLS method before and after porcelain application was compared.

Some studies evaluate axial and occlusal marginal values separately; in others, the evaluation was made without discrimination.[1,9,12-15] Akçin et al. reported that there was a decrease in marginal discrepancy in three-unit restorations in areas far from the body at metal substructures.[12] Kim et al. also evaluated marginal discrepancy according to the production method and achieved similar results in restorations produced by DMLS.[9] Similarly, in this study, after porcelain processes, the marginal discrepancy values on surfaces far from the body decreased. This situation may be the movement of metal molecules toward the area where the mass is dense.

Some researchers have reported that marginal discrepancy values increase from the axial surface to the occlusal surface.[8,16,17] Son et al. in their study where they compared the marginal and internal range with 5 different methods, namely the cross-sectional method (CSM), silicone replica technique (SRT), triple scan method, MCT, and optical coherence tomography; reported that the highest values were found in the occlusal region in all methods.[18] Tamac et al. measured the highest marginal discrepancy value on the occlusal surface. They concluded that this high value may be due to the rounding of the sharp edges of the laser device as a result of not being able to measure clearly. This was explained by the different optical properties of the abutment tooth and the sensitivity of the camera.[1] In this study, the highest marginal discrepancy values were obtained on occlusal surfaces.

It has been reported in various literature that clinically acceptable mean marginal range values range from 50 µm to 180 µm.[19,20] Attar et al. also stated that the appropriate marginal range is 25-40 µm, but the acceptability of this range can be up to 120 µm.[21] According to McLean and Von Fraunhofer, the situation is similar and they stated in their study that a MG smaller than 120 µm can be considered clinically.[22]

Kim et al. in a study they have done; evaluated the marginal fit of three-member metal-ceramic restorations fabricated by the conventional lost wax technique (LW) and DMLS method. In this study, the cement thickness was accepted as 30 µm. And as a result, absolute marginal discrepancy, MG, and internal gap (IG) in the first molar were 83.3, 80.0, and 82.0 _m in the LW group; and 128.0, 112.0, and 159.5 _m in DMLS group, respectively.[9] Tamac et al. reported results as 96.23 µm in the marginal, 139.02, 188.12 in the axial, and 290.39 µ in the occlusal, respectively, in the DMLS group in the fit assessment of single-member metal-ceramic restorations produced by 3 different methods (CAD/CAM milling, DMLS, LW).[1] On the other hand, Akçin et al. reported the marginal and axial values of the restorations in the DMLS group within clinically acceptable limits in their study comparing different production methods.[12] There are conflicting results in the literature. In this study we have done, results similar to the studies of Kim and Tamac have emerged.[9] The values obtained are above the clinically accepted values.

Nawafleh et al. reported that the measurements made to evaluate the marginal adaptation of restorations may vary depending on the method used, whether it was an in vitro or in vivo study, the number of measurements made from each sample, and before and after porcelain firing. Sample size and the number of measurements per sample can affect the power of statistical analysis. The accuracy of the measurement means how close the mean is to the exact value.[23] In today's studies, there is no definite information in the literature regarding the number of measurements per sample. Groten et al. concluded that approximately 50 measurements along the crown margin provided clinically relevant information and gave a more accurate result regarding marginal clearance.[24] In our study, a total of 21 measurements were made from each sample, 7 from each region.

The assessment methods used in various studies may differ depending on the environment of the laboratory. There is still no standard protocol to assess the fitness of dental restorations. In addition; results should be interpreted with caution as in vitro methodologies vary and do not directly correlate with clinical conditions.[25] Son et al. reported in their study that they evaluated different methods in measuring marginal fit, there was a tendency of having similar marginal and internal fit in CSM and SRT, Therefore, the relatively simple and inexpensive SRT method can be an excellent alternative to CSM.[18] In this study, SRT was used to evaluate marginal and internal fit.

LIMITATIONS

- Four-unit restorations were evaluated in our study. No comparison of further units and complex restorations was made.
- This in vitro research needs to be supported by in vivo research.

CONCLUSION

1. In this study, during metal substructure and superstructure, changes were found in marginal discrepancy.

2. Marginal discrepancy between surfaces at mesial and distal surfaces was found to be lower than at the occlusal surface of both metal substructure and superstructure.

3. At the distal of premolar samples and the mesial of molar samples, there were increased

marginal discrepancy values after porcelain applications.

4. At the distal of molar samples and the mesial of premolar samples, there were decreased marginal discrepancy values after porcelain applications.

5. The results of our study; It shows that 4-units metal-ceramic restorations, whose metal substructures are produced by the DMLS technique, can create marginal and IG above clinically acceptable limits.

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Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

***Idea/Concept:** Server Mutluay Ünal; **Design:** Server Mutluay Ünal, Mehmet Biçer; **Control/Supervision:** Mehmet Biçer, Server Mutluay Ünal; **Data Collection and/or Processing:** Mehmet Biçer; **Analysis and/or Interpretation:** Mehmet Biçer, Server Mutluay Ünal; **Literature Review:** Mehmet Biçer; **Writing the Article:** Mehmet Biçer, Server Mutluay Ünal; **Critical Review:** Server Mutluay Ünal; **References and Fundings:** Afyon Kocatepe University BAP; **Materials:** Mehmet Biçer.*

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