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COMPARISON OF MARGINAL ADAPTATION OF DIFFERENT FRAMEWORK MATERIALS BEFORE AND AFTER CEMENTATION: AN IN VITRO STUDY

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Research Article

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Abstract

This study aimed to compare the marginal adaptation of different framework materials polyetheretherketone (PEEK), zirconia, and cobalt-chromium (Co-Cr) through direct metal laser sintered (DMLS) and conventional casting (CC) in fixed prosthetic restorations. A total of 80 stainless steel dies were embedded in silicone molds, and the master models obtained were divided into four groups (n=20): PEEK, zirconia, Co-Cr through DMLS and CC frameworks. The vertical marginal gap was measured by stereomicroscope at ×20 magnification. In addition to descriptive statistics in the evaluation of data, one-way ANOVA was used with the post hoc multiple comparison test Tamhane's T2, as the data were normally distributed, and variances differed according to the Kolmogorov–Smirnov and Shapiro–Wilk tests. There was a statistically significant difference in vertical marginal gap before and after cementation in all groups ($p<0.05$). Before and after cementation, vertical marginal gap values of laser sintered Co-Cr, zirconia, and PEEK frameworks were clinically acceptable.

Key Words: PEEK, Marginal Adaptation, Laser Sintered Co-Cr, Zirconia, Framework

Özet

Bu çalışmada, CAD/CAM teknolojisi ile üretilen PEEK (Polietereterketon), zirkonya, direkt metal lazer sinter (DMLS) Co-Cr, ile konvansiyonel olarak üretilen metal alt yapıların marjinal adaptasyonlarının karşılaştırılması amaçlandı. Toplamda 80 adet paslanmaz çelik güdük silikon kalıplara gömülerek ana model elde edildi ve bu ana modeller üzerinden CAD/CAM teknolojisi üretilen PEEK, Zirkonya ve DMLS Co-Cr alt yapılar ile konvansiyonel olarak üretilen döküm metal alt yapılar (n=20) olmak üzere 4 gruba ayrıldı. Marjinal gap, stereo mikroskop ile x20 büyütmede ölçüldü. Verilerin değerlendirilmesinde tanımlayıcı istatistiklerin yanı sıra, ikili grupların karşılaştırılmasında, veriler Kolmogrov–Smirnov ve Shapiro-Wilk testlerine göre normal dağıldığından ve varyantları farklılık gösterdiğinden Post Hoc çoklu karşılaştırma testi Tamhane's T2 ile tek yönlü ANOVA kullanıldı. Konvansiyonel döküm metal, Laser sintered CoCr, CAD/CAM milling Zirkonya ve CAD/CAM PEEK alt yapı materyallerinin yüzey özelliklerini taramalı elektron mikroskobu ile incelendi. Tüm gruplar arasında simantasyon öncesi ve sonrasında marjinal gap mesafelerinde, istatistik analizleri ile yapılan değerlendirmeler sonucu anlamlı fark görülmüştür ($p<0.05$). Simantasyondan önce ve sonra, lazerle sinterlenmiş Co-Cr, zirkonya ve PEEK çerçevelerinin dikey marjinal boşluk değerleri klinik olarak kabul edilebilirdi.

Anahtar Kelimeler: PEEK, Marjinal Adaptasyon, Lazer Sinter Co-Cr, Zirkonya, Çerçeve

1. Introduction

Fixed prosthetic restorations can be prepared by conventional or computer aided design/computer aided manufacturing (CAD/CAM) methods. The most common metal–ceramic restorations in fixed prosthodontics can be prepared by conventional casting, CAD/CAM milling, or direct metal laser sintered (DMLS) methods. The physical, mechanical, and aesthetic properties are superior in metal–ceramic restorations produced by CAD/CAM, compared to those prepared by conventional methods. In addition, it is advantageous to visualize the restorations in three dimensions before they are produced and to make necessary corrections in the digital environment. In the DMLS method, because the material is produced by stacking instead of removing material from the main part, the cost is considerably reduced, compared to CAD/CAM systems. Metal frameworks produced by the DMLS method have better dimensional stability than those obtained by conventional casting (Joda et al., 2017; Raigrodski et al., 2012; Chaar et al, 2020).

Due to zirconia's characteristics, such as rigidity, abrasion resistance, aesthetics, and biocompatibility, it is frequently used in the framework of fixed prosthetic restorations, implant body and abutment material, endodontic post, and telescopic holders. Yttria-stabilized tetragonal zirconium polycrystal (Y-TZP) is frequently preferred to other zirconia types due to its physical and mechanical properties. However, the mechanical properties of Y-TZP affect the amount of stabilizer Y_2O_3, the size and shape of the zirconia particles, the etching and surface applications, temperature, humidity, time, and macro and micro cracks in the material (Larsson et al., 2014; Sailer et al., 2015; Sundh et al., 2005). The hardness of zirconia depends on the production process and the degree of sintering of the zirconia blocks. Currently, semi-sintered zirconia materials are used for milling the zirconia frameworks with the CAD/CAM system. The most common problems with zirconia restorations are fractures in the zirconia framework, delamination, and chipping in the veneering ceramic (Raigrodski et al., 2012). Although framework fracture is the most common complication in bridge restorations, it is less common in Y-TZP frameworks. According to Silva et al, while zirconia as a framework material shows performance similar to the metal framework, it is also better than other ceramic systems (Silva et al., 2012).

Polyetheretherketone (PEEK) is a high-tech polymer that is biocompatible, highly abrasion-resistant, low elastic modulus, corrosion resistant, and light weight. PEEK material is easier for repairs than ceramics; its mechanical properties do not change during the preparation stage. Furthermore, it is subject to minimal wear in the mouth, increasing its suitability for use in fixed prosthetic restorations. In addition, despite its low modulus of elasticity and hardness, its high abrasion resistance makes it a material that can compete with metal alloys. Due to these properties, PEEK material is used for implant and abutment, end crown, temporary crown-bridge and as a framework for implant-supported restorations. Prosthetic frameworks are produced from PEEK material by injection molding or CAD/CAM methods (Tekin et al., 2019; Zeighami et al., 2019; Ghodsi et al., 2018).

Clinical success and the quality of the restoration depend on factors such as anatomical form, marginal adaptation, color matching, marginal coloration, secondary caries, surface roughness, integrity of the restoration, and post-operative tooth sensitivity and retention. Of these, especially marginal adaptation, it includes other factors that affecting clinical success and the quality of the restoration. Clinical failure is inevitable when marginal adaptation is not good. Marginal adaptation is affected by many other factors, including the type of restoration and the cement, tooth preparation design, impression material and method, the laboratory processes, the viscosity of the luting cement, and the physicochemical characteristics acting on the luting cement and the tooth-restoration (humidity, heat, and load applied during cementation). Marginal incompatibility in dental restorations affects long-term clinical success by causing microleakage and secondary caries (Conrad et al., 2007; Hickel et al., 2010). Although acceptable vertical marginal gap values are not clearly expressed in the literature for fixed prosthetic restorations, it has been reported by some authors that the vertical marginal gap value should be 80–120 µm for long-term clinical success (McLean et al., 2007; Boitelle et al., 2014). The American Dental Association (ADA) recommends that marginal adaptation be between 25 and 40 µm (American Dental Association; Chicago 1970). As these values are rarely achieved clinically, it is difficult to determine their parameters. CAD/CAM manufacturers provide dental restorations among these values. In the literature, quite different marginal adaptation values for adaptations in fixed prostheses have been reported (Papadiochou et al., 2018; Huang et al., 2015). The reason for this disparity in the studies is due to the use of different techniques and variables, such as in vivo or in vitro testing conditions, values for before or after cementation, cement types, finished line design, the number of specimens and number of measurements per specimen, the measurement methods, and measurement localization. While the same crown system has excellent marginal adaptation in one study, it may not be within acceptable limits in another (Papadiochou et al., 2018; Nawafleh et al., 2013; Groten et al. 2000)

This study aimed to compare the marginal adaptations of conventional cast metal, laser sintered Co-Cr, CAD/CAM-milled zirconia, and CAD/CAM PEEK framework materials before and after cementation. The null hypothesis is that there will be no differences in marginal adaptation among these framework materials, before and after cementation.

2. Material and Methods

Stainless steel dies representing the tooth prepared for crown restoration were designed in a professional drawing program (Solidworks, 2019; Dassault Systèmes Solid Works Corporation Waltham, Massachusetts, USA) with 6 mm occlusal–gingival length, 3,8 mm occlusal diameter, 1 mm wide chamfer finishing line, and a 6-degree angle of convergence of the axial walls (similar to prepared mandible premolar tooth). Eighty stainless steel dies were prepared on CNC devices (Takisawa Machine Tool Co., Okayama, Japan). One side of each stainless-steel die was prepared flat to determine the buccal–lingual surfaces and to create a single entryway for the crown (Figure 1). Each ten stainless steel dies were then placed into a specially prepared polyvinyl silicone (Elite HD+, Zhermack, Rovigo, Italy) mold. A different restorative option was established for each group: conventional cast metal (Wironit extra hard, Bego, Germany) (control group), DMLS Co-Cr (Eos Cobalt Chrome SP_2; Eos Optical Systems, Germany), zirconia (DD cubeX^2 ML, Dental Direct, Spenge, Germany), and PEEK frameworks (BioHpp, Bredent, Senden, Germany). Preparation of each group of specimens (n = 20) was done as follows.

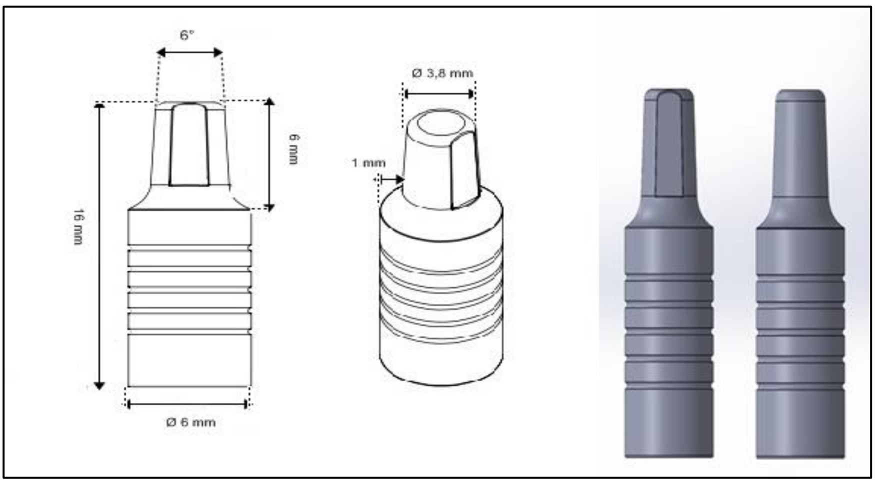

Figure 1. Drawing of stainless-steel die models with computer program

In the preparation of metal frameworks (Control Group) with conventional casting technique, a 25 µm thick die-spacer (ISOLANT / C.M.S. Dentsply, USA) was applied on the master plaster model, 1 mm away from the edge finishing limit. Metal frameworks were produced using Co-Cr metal alloy cores (Wironit extra hard, Bego, Germany) by casting with conventional lost wax technique in accordance with the manufacturer's instructions. Throughout levelling and modelling, the metal surface was measured with a caliper at 1 mm homogeneous thickness in order to detect the loss of substance that may occur on the metal surface. Unsuitable specimens were not included in all groups and new specimens were obtained.

For the preparation of DMLS Co-Cr, zirconia, and PEEK frameworks, the master plaster models were transferred to the computer by scanning a laser scanner (Dental Wings 3 Series, Straumann Group Brand, Germany). A design program (Exocad Dental CAD, Darmstadt, Germany) was created with the cement at 1mm from the edge end border and 25 µm width; the frameworks were 1 mm thick. The data processed and created in the computer environment were transferred to the production stage. DMLS Co-Cr frameworks were obtained from Co-Cr metal alloy powder (Eos Cobalt Chrome SP2; Eos Optical Systems, Germany). Zirconia frameworks were obtained from Y-TZP zirconium oxide blocks (DD cubeX^2, Dental Direkt, Spenge, Germany) with a copy/milling device (Yena Dent 15, Istanbul, Turkey), and full sintering process (Sirona inFire HTC Speed, Bensheim, Germany) was applied to the frameworks at 1,450ºC for 4.5 h. PEEK frameworks were prepared from PEEK blocks (BioHpp, Bredent, Senden, Germany) with a CAD/CAM device (Redon Hybrid, Istanbul, Turkey). No internal or marginal adjustment was performed on the specimens before marginal measurements for each group. The marginal adaptation measurements of the frameworks were evaluated at 30 reference points in stainless steel die models, performed before and after cementation. Images obtained with a stereomicroscope (×20, ZeissStemi 508, Carl Zeiss Microscope, Germany) camera were transferred to the computer, and vertical marginal gap measurements were taken digitally (Zen 2 lite, Carl Zeiss Microscope, Germany). After precementation measurements, the specimens were permanently cemented under constant pressure with self-adhesive resin cement (Panavia SA Cement Plus Automix, Kuraray Noritake Dental, Japan). After cementation, vertical marginal gaps were measured again (Figure 2).

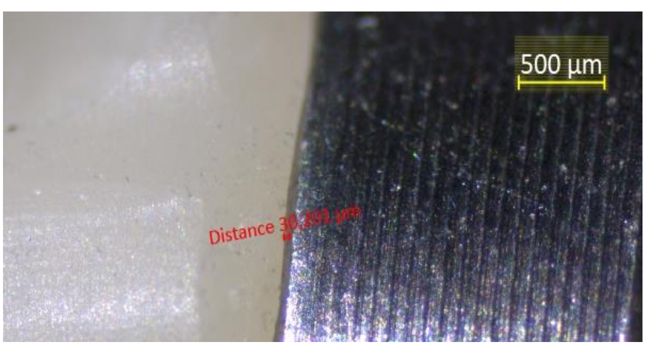

Figure 2. Measurement of marginal gap values of zirconia framework on the preobtained stereomicroscope image with image analysis program

The surface properties of the prepared specimens were examined with a scanning electron microscope (magnification 7× –5000× at 20 keV, Hitachi Regulus 8200, Japan). Before analysis, non-conductive specimens were coated with gold with a device for insulating material coating (Quorum SC7620, QuorumTech, UK) to make it suitable for imaging.

3. Results

Statistical analysis of the data obtained was done with SPSS 22 software (SPSS Inc, Chicago, IL, USA). In addition to descriptive statistics (mean, standard deviation) in the evaluation of the data, one-way ANOVA was used with post hoc multiple comparison test Tamhane's T2, as the data were normally distributed, and variances differed according to the Kolmogorov–Smirnov and Shapiro–Wilk tests. In comparisons between the processes, the paired t-test was used. Results were considered significant at $p < 0.05$. Multiple comparison results after cementation are shown in Table 1 ($p<0.05$). Vertical marginal gap values and standard deviations of the frameworks before cementation were conventional cast metal (188.03 ± 48.03 µm), PEEK (108.74 ± 21 µm), zirconia (43.62 ± 4.06 µm) and DMLS Co-Cr (33.27 ± 4 µm).

Table 1. Multiple comparison table before cementation

					95% Confidence Interval	
Group	**Group**	**Mean Difference**	**Sdt. Error**	**P Value**	**Lower Bound**	**Upper Bound**
CM	**PEEK**	27,03140	16,58074	,561	-24,7962	78,8590
	ZR	77,18690*	15,24579	,004	26,2908	128,0830
	DMLS	85,23130*	15,24412	,002	34,3350	136,1276
PEEK	**CM**	-27,03140	16,58074	,561	-78,8590	24,7962
	ZR	50,15550*	6,76700	,000	27,8907	72,4203
	DMLS	58,19990*	6,76323	,000	35,9359	80,4639
ZR	**CM**	-77,18690*	15,24579	,004	-128,0830	-26,2908
	PEEK	-50,15550*	6,76700	,000	-72,4203	-27,8907
	DMLS	8,04440*	1,80401	,002	2,7171	13,3717
DMLS	**CM**	-85,23130*	15,24412	,002	-136,1276	-34,3350
	PEEK	-58,19990*	6,76323	,000	-80,4639	-35,9359
	ZR	-8,04440*	1,80401	,002	-13,3717	-2,7171

CM=Casting metal, PEEK= Polyetheretherketone, ZR= Zirconia, DMLS =Direct metal laser sintered

Multiple comparison results after cementation are shown in Table 2 ($p<0.05$). Vertical marginal gap values and standard deviations of the frameworks after cementation were: conventional cast metal (196.02 ± 48.40 µm), PEEK (119.23 ± 22.02 µm), zirconia (49.99 ± 3.24 µm), and DMLS Co-Cr (28.86 ± 5.04 µm) (Table 2). When Table 3 was examined, it was seen that there was a statistically significant difference between the groups in vertical marginal gap after cementation ($p<0.05$). Tamhane's T2 multiple comparison test was selected from the post hoc tests to examine whether methods were different.

Table 2. Multiple comparison table after cementation

					95% Confidence Interval	
Group	**Group**	**Mean Difference**	**Sdt. Error**	**P Value**	**Lower Bound**	**Upper Bound**
CM	**PEEK**	24,85880	16,81846	,659	-27,5182	77,2358
	ZR	78,59760*	15,34251	,004	27,3079	129,8873
	DMLS	85,75760*	15,39111	,002	34,4727	137,0425
PEEK	**CM**	-24,85880	16,81846	,659	-77,2358	27,5182
	ZR	53,73880*	7,04052	,000	30,4033	77,0743
	DMLS	60,89880*	7,14581	,000	37,5407	84,2569
ZR	**CM**	-78,59760*	15,34251	,004	-129,8873	-27,3079
	PEEK	-53,73880*	7,04052	,000	-77,0743	-30,4033
	DMLS	7,16000*	1,89592	,011	1,4425	12,8775
DMLS	**CM**	-85,75760*	15,39111	,002	-137,0425	-34,4727
	PEEK	-60,89880*	7,14581	,000	-84,2569	-37,5407
	ZR	-7,16000*	1,89592	,011	-12,8775	-1,4425

CM=Casting metal, PEEK= Polyetheretherketone, ZR= Zirconia, DMLS =Direct metal laser sintered

A paired t-test was used to determine whether the differences between vertical marginal gap before and after cementation were statistically significant (Table 3). There was a statistically significant difference between the averages of measurements before and after cementation in all groups ($p<0.05$). Considering Table 3, the lowest value of vertical marginal gap before and after cementation was in DMLS Co-Cr, and the highest was in conventional cast metal. In all groups, an average increase after cementation was observed ($p<0.05$). All values resulting from-tests showed a statistically significant difference in the vertical marginal gap from the cementation procedure in the relevant method. The highest increase in vertical marginal gap was observed in the PEEK framework before and after cementation.

Table 3. Results of paired t-test and marginal gap values of framework materials before and after cementation

Group	Cementation	Marginal Gap Value (µm) Min	Max	Mean(µm)	Standard Deviation	P Value
CM	Before	50,323	188,036	113,1030	48,03972	,000
	After	57,896	196,021	121,3072	48,40889	
PEEK	Before	50,323	108,748	86,0716	21,00943	,000
	After	58,896	119,235	96,4484	22,02691	
ZR	Before	30,210	43,625	35,9161	4,06536	,000
	After	37,976	49,992	42,7096	3,24105	
DMLS	Before	21,312	33,273	27,8717	4,00215	,000
	After	28,864	43,651	35,5496	5,04389	

CM=Casting metal, PEEK= Polyetheretherketone, ZR= Zirconia, DMLS =Direct metal laser sintered, Min=minima, Max=maxima

Surface properties of conventional cast metal, DMLS Co-Cr, zirconia, and PEEK framework materials were examined with a scanning electron microscope. Laser sintered Co-Cr frameworks were observed to have a layered characteristic surface with wavy edges (Figure 3). A more homogeneously dispersed micro-well surface was observed in zirconia frameworks (Figure 4). In cast frameworks, a non-homogeneous recessed surface was observed (Figure 5). The surface structure of PEEK frameworks, on the other hand, was more homogeneous and flatter, compared to other groups, although layers appeared at certain distances (Figure 6).

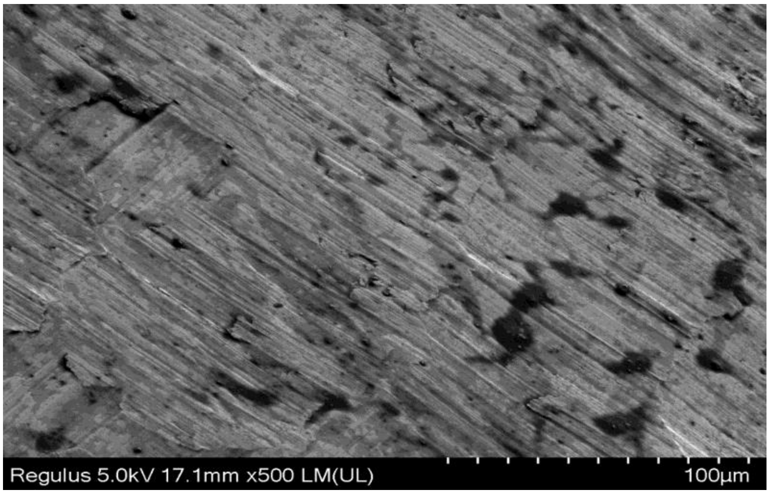

Figure 3. Images with×500 magnification of (A) laser sintered Co-Cr framework surface

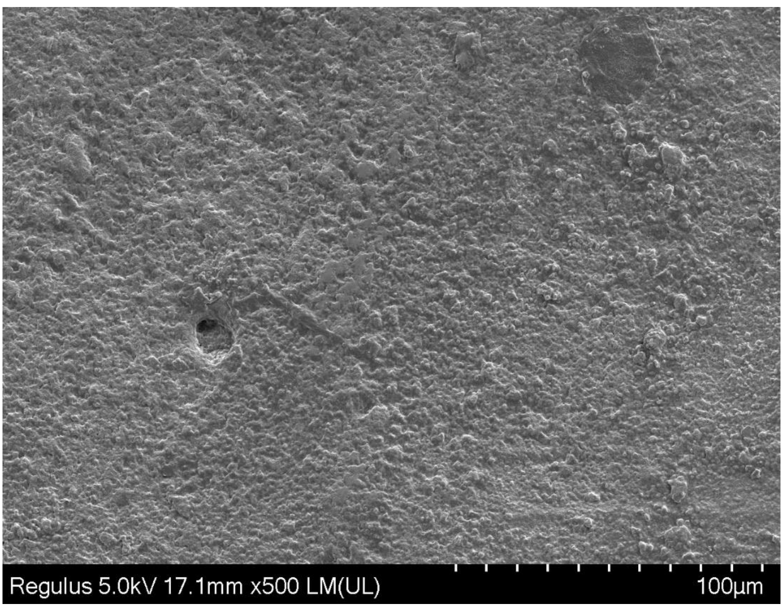

Figure 4. Images with×500 magnification of (A) zirconia framework surface

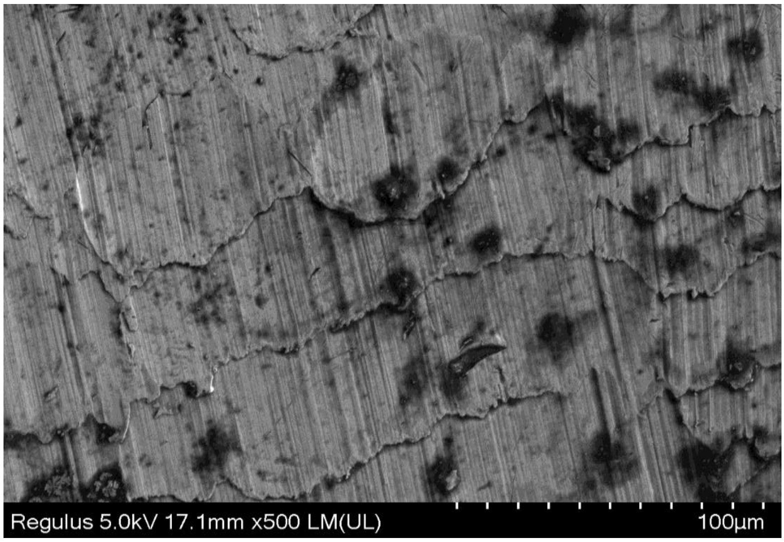

Figure 5. Images with×500 magnification of conventional cast metal framework surface

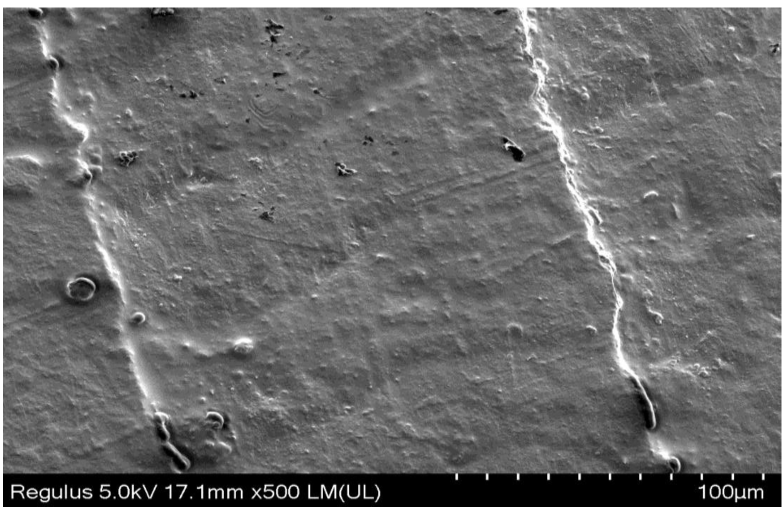

Figure 6. Images with×500 magnification of (A) PEEK framework surface

4. Discussion

From the data obtained, the null hypothesis was completely rejected. Significant differences were observed in the comparison of the vertical marginal gaps of the test groups before and after cementation. There were also significant differences in the vertical marginal gap values in comparing the groups.

In studies investigating marginal adaptation, reference points and terms used for measurements differ among researchers. To clarify this issue, Holmes et al. (1989) examined many points between the restoration and dental tissue and defined the terms used. The vertical measurement between the inner surface of the restoration and the axial wall of the tooth is known as the “internal gap.” When the same measurement is made at the restoration edge, it is referred to as the “marginal gap.” Parallel to the exit direction of the restoration, “vertical marginal discrepancy” and the vertically “horizontal marginal discrepancy” are measured. The angular combination of horizontal and vertical marginal discrepancy has been called the “absolute marginal discrepancy” (Holmes et al., 1989; Karaman et al., 2015). In these previous studies, inconsistency remains between the reference points used for measurement and the terms used.

Clinically, the intra-oral environment, dental preparation, the impression, and cementation procedures complicate the studies performed, causing deviations from ideal conditions, and making in vivo studies more difficult than in vitro studies. In vitro studies can provide optimal and standardized conditions experimentally which are very difficult to replicate in vivo (Nawafleh et al. 2013). In our study, although an in vivo environment was not created exactly, it was performed in vitro to create optimal and standardized experimental conditions.

In previous studies conducted, the number of measurements per specimen varies. Gassino et al., (2004) considered 18 measurements per sample sufficient in experimental studies while Gonzalo et al. (2009) found 30 measurements per sample (n=10) to be sufficient from the vestibule and oral surfaces. Karaman et al. used 10 points (n=20) per sample in their in vitro marginal adaptation study (Karaman et al., 2015). Groten et al., (2011) reported that the number of points to be measured should be at least 20–25 in studies in which marginal compliance measurements will be made, and that if this number is increased, more reliable results will be obtained. Also, the number of samples should be increased when measuring at 4–12 points. In our study, measurements were made from 30 different points (n=20), in view of all the studies.

In the examination of marginal adaptation, methods with the most important morphological criteria are preferred, and the measurement method with an indirect technique is the most preferred of these (Nawafleh et al., 2013). This method, because there is no replica that imitates the tooth or cement gap, is cheaper than other techniques, and there is no error due to replication. However, this method can only be applied in in vitro research. In addition, standardization of reference points is difficult in direct examinations, and imaging errors may also occur (Contrepois et al., 2013). This study used a stereomicroscope in vitro for standardization and ideal measurements.

Although there are studies in which the cementation process increased the marginal gap values of fixed restorations (Gonzalo et al., 2009; Contrepois et al., 2013; Att et al., 2009; Ural et al., 2010) there are other studies in which marginal gap values decreased after cementation (Karaman et al., 2015; Zeighami et al., 2019) In this study, a significant difference was observed in marginal gap values after cementation in all analysed groups. This may be related to cement spaces forming in conventional and digital impression techniques. In addition, while the preparation of all frameworks was used plaster models; marginal gap measurements were examined on stainless steel dies. Gonzalo et al., (2009) reported that zirconia frameworks were more successful in marginal adaptation than conventional cast metal frameworks and that vertical marginal gaps do not make a significant difference, even though they increase after cementation.

Zeighami et al., (2019) evaluated those marginal adaptations of PEEK, zirconia, and composite frameworks and reported that absolute marginal discrepancy of all frameworks after cementation was significantly reduced, and that the marginal gap values of zirconia and composite frameworks were within the limit of acceptability. In addition, zirconia frameworks showed better marginal adaptation before and after cementation than PEEK frameworks. In another study, Ghodsi et al., (2018) reported that zirconia and composite frameworks were evaluated for marginal gap with the replica technique, and the zirconia frameworks had better marginal adaptation than others. Jin et al., (2019) reported that marginal adaptation of PEEK frameworks is clinically acceptable and may be an alternative to metal frameworks. Among the PEEK frameworks in our study, the values of 86.07±21 µm before cementation and 96.44 ± 22.02 µm after cementation are similar to the studies performed that concluded these as being clinically acceptable.

Dahl et al., (2018) reported that zirconia 39±32 µm and DMLS Co-Cr 63 ± 24 µm frameworks had acceptable marginal adaptation values in their study in which they compared single-crown prostheses with different framework materials. In our study, zirconia 35.91±4.06 µm and DMLS Co-Cr 27.87±4.0 µm frameworks were similar to their marginal adaptation values.

In the study by Yildirim et al., (2019), conventional cast metal and DMLS Co-Cr frameworks showed better marginal adaptation compared to zirconia frameworks. In a study by Nelson et al.,

(2017) comparing conventional cast metal, milled zirconia, CAD/CAM zirconia, and DMLS Co-Cr frameworks, the DMLS Co-Cr frameworks were reported to have the best marginal adaptation. In most studies comparing conventional metal frameworks with laser sintering Co-Cr frameworks in terms of marginal adaptation, the laser sintering Co-Cr frameworks were found to be more successful (Chaar et al., 2020; Kocaağaoğlu et al., 2016; Xu et al., 2014; Huang et al., 2015).

As the limitations of this study, in vitro and in vivo failure to fully reflect the experimental environment, stainless steel dies do not fully reflect the tooth anatomy and physiology, the lack of an accepted standard regarding the localization of marginal adaptation measurements, the method of preparation and use of the cement type of PEEK material can be counted. In addition, clinical studies are needed to confirm these results.

5. Conclusion

Within the limitations of this in vitro study, the following conclusions were drawn:

1. A significant difference was found between the marginal adaptation values of different framework materials before and after cementation.
2. Vertical marginal gap values of laser sintered Co-Cr, zirconia, and PEEK frameworks were clinically acceptable.
3. Laser sintered Co-Cr and zirconia frameworks had better marginal adaptation than conventional cast metal and PEEK frameworks.
4. Although the use of PEEK polymer as a framework materialise promising, more extensive clinical research is needed, especially in view of the scarcity of clinical studies on marginal adaptation.

Conflicts of interest

The authors declare that there are no potential conflicts of interest relevant to this article.

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