

Investigation of the Effect of Different Surface Treatments on Shear Bond Strength in the Fabrication of Metal-Ceramic Dental Restorations

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ABSTRACT

Aim: The bond strength between metal and porcelain is an essential factor for the success of metal-ceramic restorations. Therefore, this study evaluated the shear bond strength (SBS) between ceramic and cobalt-chromium (Co-Cr) alloys after oxidation treatment.

Material and Methods: A total of 150 Co-Cr samples, 50 samples each, were produced from casting, laser sintering, and milling techniques. The primary group samples produced were divided into five subgroups. One of the subgroups is sandblasted with 110 μm Al_2O_3 , and the others are ground with carbon separator disc, sintered diamond bur, tungsten carbide bur, and pink stone in one direction. SBS test was applied after the oxidation and veneering process. After debonding, digital microscopy investigated the surface characterizations of Co-Cr alloys. For the normality distribution of SBS measurements, the Kolmogorov-Smirnov test was used. According to the results, non-parametric tests were used in the study because the distribution was not suitable for the normal distribution, and the number of samples within the group was low in the subgroups. Kruskal Wallis and All pair-wise post hoc test ($\alpha = 0.05$) were used for analysis.

Results: There was a statistical difference between the laser sintering and milling groups according to the fabrication techniques. The highest SBS value was found in the Al_2O_3 laser group (34.35) and the lowest in the Al_2O_3 casting group (17.68). Surface treatments significantly altered ceramic adhesion. Almost all subgroups exhibited mixed failure. All of the SBS values found in this study were almost clinically acceptable.

Conclusion: As different abrasives in the leveling and finishing of metal substructures may affect the metal-ceramic bonding, care should be taken in their use as much as possible.

Keywords: Shear bond strength; metal ceramic alloy; chromium-cobalt alloys; metal ceramic restorations.

Metal-Seramik Diş Restorasyonlarının Üretiminde Farklı Yüzey İşlemlerinin Makaslama Bağlanma Dayanımına Etkilerinin Araştırılması

ÖZ

Amaç: Metal ve porselen arasındaki bağ gücü, metal-seramik restorasyonların başarısı için önemli bir faktördür. Bu nedenle, bu çalışmada, oksidasyon işleminden sonra seramik ve kobalt-krom (Co-Cr) alaşımları arasındaki makaslama bağlanma dayanımı (MBD) değerlendirilmiştir.

Gereç ve Yöntemler: Döküm, lazer sinterleme ve frezeleme tekniklerinden her biri 50 örnek olmak üzere toplam 150 Co-Cr örnek üretildi. Üretilen ana grup örnekleri beş alt gruba ayrıldı. Alt gruplardan biri 110 μm Al_2O_3 ile kumlandı, diğerleri tek yönde karbon separe disk, sinterlenmiş elmas frez, tungsten karbür frez ve pembe taş ile taşlandı. Oksidasyon ve veneering işleminden sonra MBD testi uygulandı. MBD ölçümlerinin normallik dağılımı için Kolmogorov-Smirnov testi yapıldı. Sonuçlara göre dağılımın normal dağılıma uygun olmadığı, alt gruplarda ise grup içi örneklem sayılarının az olması nedeni ile çalışmada parametrik olmayan testler kullanıldı. Analiz için Kruskal Wallis ve All pair-wise post hoc testi ($\alpha = 0,05$) uygulandı.

Bulgular: Lazer sinterleme ve frezeleme grupları arasında fabrikasyon tekniklerine göre istatistiksel fark vardı. En yüksek MBD değeri Al_2O_3 lazer grubunda (34,35), en düşük ise Al_2O_3 döküm grubunda (17,68) bulundu. Yüzey işlemleri seramik yapışmasını önemli ölçüde değiştirdi. Neredeyse tüm alt gruplar karışık başarısızlık sergiledi. Bu çalışmada bulunan MBD değerlerinin tümü, klinik olarak hemen hemen kabul edilebilirdi.

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Geliş Tarihi / Received: 03.12.2021, Kabul Tarihi / Accepted: 22.07.2022

Sonuç: Metal alt yapıların tesviye ve bitimlerinde farklı aşındırıcıların kullanılması metal-seramik bağlantısını etkileyebileceğinden, kullanımlarında mümkün olduğunca dikkatli olunmalıdır.

Anahtar Kelimeler: Makaslama bağ dayanımı; metal seramik alaşım; krom-kobalt alaşımları; metal seramik restorasyonları.

INTRODUCTION

Although the trend towards metal-free restorations is increasing in modern dentistry, metal-ceramic restorations that combine the excellent mechanical properties of alloys with the excellent aesthetic properties of porcelain are still frequently used for fixed partial dentures and single crowns (1). The production of metal-ceramic restorations has increased due to the high cost of base metal alloys such as cobalt-chromium (Co-Cr) and nickel-chromium (Ni-Cr), noble metal alloys (2). These base metal alloys are superior to noble metals in various aspects, such as their low density, excellent hardness, and tensile strength (3). Today, biocompatible Co-Cr alloys are preferred instead of Ni-Cr alloys due to adverse effects such as allergy to nickel and beryllium (4).

The Co-Cr substructure can be produced by conventional casting methods, computer-aided design/computer-aided milling manufacturing (CAD/CAM), or laser sintering technologies (5). The most widely used technique is lost wax casting. However, base metal alloys are more difficult to cast than noble metal alloys because base metals have higher melting points and are more vulnerable to oxidation during casting. In addition, the high hardness of the resulting casting requires more time for finishing (6). In CAD/CAM alloys, procedural errors such as foreign matter and deformation caused by heat treatment are less and show higher corrosion resistance than cast alloys (7). The bond strength between metal and ceramic affects the survival of metal-ceramic restorations (8). The metal-ceramic bond results from chemical bonding, mechanical retention, van der Waals forces, and compressive bonding (9). The presence of an oxide layer of appropriate thickness on the metal surface is essential for chemical bonding to porcelain. The bond strength is weakened due to the oxide layer that is too thin or too thick. A thick oxide layer is easily formed on the base metal alloys (10).

A strong metal-ceramic bond is obtained with an oxide layer of suitable thickness. The effects of different oxidation heat treatments on the oxide layer have been investigated in various studies. However, the results of the studies in the literature are insufficient regarding the optimal oxidation processes of Co-Cr alloys. Few of these studies have focused on other aspects of the porcelain bond strength of Co-Cr alloys, such as the use of thermal and mechanical cycling, laser sintering technology, airborne particle abrasion, and different opaque layer firing temperatures (11).

Opaque porcelain adheres to micro irregularities on the metal surface by flowing during veneering. Sandblasting increases the total surface area, eliminates surface irregularities and improves mechanical adhesion. The effect of mechanical retention on bonding is limited. A rough surface is not required for the metal-ceramic bond. It is believed that the polished surface will provide better ceramic adhesion (12). However, some surface roughness

is effective in increasing adhesion (13). In metal-ceramic restoration production, technicians prepare the alloy for ceramic veneering. The grinding process increases the metal roughness. Leveling and finishing operations can be performed under high force with rough burs during prosthesis production. Due to pressure and mechanisms, the porcelain structure may be affected during the grinding process. However, grinding can weaken the restoration during the setting stage. Few studies have been conducted on the effect of post-grinding oxidation treatment on metal-ceramic adhesion. The result of sanding metal-porcelain restorations, especially before firing the porcelain, is still unknown.

Although many studies evaluate the bond strength of ceramics to Co-Cr alloys, there is currently a lack of scientific literature on the bond strength of Co-Cr alloys obtained with three different techniques to ceramics. This study aims to evaluate the bond strength between ceramic and five pre-treated and oxidized Co-Cr alloys fabricated by different manufacturing techniques (casting, laser sintering, and milling). The null hypothesis was that the SBS would be independent of fabrication and surface pretreatment methods.

MATERIAL AND METHODS

The Co-Cr framework was designed virtually with Sketchup 3D design program (Trimble Company, CA, USA) (Figure 1A).

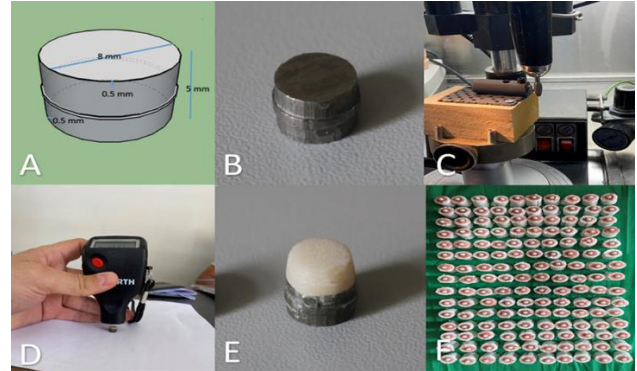


Figure 1: A: Virtual design of the metal framework, B: Fabricated Co-Cr sample, C: Grinding of a sample, D: Measuring the opaque layer, E: Prepared sample, F: Samples embedded in acrylic

In calculating the sample size, Hamza et al. (14) study was taken as reference, and power analysis (effect size 0.5 at 80% power and type I error level 0.05) was performed with the G*Power (version 3.1.9.2, Düsseldorf, Germany) program. A total of 150 Co-Cr alloy samples were fabricated using the STereolithography file of this design: 50 cast samples, 50 laser-sintered samples, and 50 milled specimens (Figure 1B). Cast samples were milled from MillStar Waxblank wax discs (S&S Scheftner GmbH, Mainz, Germany). Starbond CoS Co-Cr powder (S&S Scheftner GmbH, Mainz, Germany) was used for the conventional casting method. Laser sintering samples were manufactured with the Eosint E270 laser sintering system (Eos GmbH, Krailing, Germany) and Starbond CoS 30 Co-Cr powder (S&S Scheftner GmbH, Mainz, Germany). Milled samples were fabricated from

prefabricated Starbond Easy Co-Cr disk (S&S Scheftner GmbH, Mainz, Germany) with a computer-controlled five-axis Yenascan milling machine (Yenadent, Istanbul, Turkey). Dimensions were measured with a digital caliper (Hengliang, Shanghai, China) with an accuracy of 0.02 mm to precisely confirm the final dimensions of the samples before the porcelain veneering. The samples were air-drying and cleaned ultrasonic device and separated into groups for five different surface treatments.

According to production techniques, the samples were divided into five subgroups (Groups I, II, III, IV, V). Surface treatments were performed on these samples, as shown in Table 1.

The grinding operations were carried out by a single operator, as stated by other authors (15,16), with the bur shaft parallel to the specimen surface using a System-sigma DEL090 milling machine (Eleksan, Istanbul, Turkey). Grinding of samples was carried out at 20.000 rpm/min in one direction. (Fig. 1C). Sandblasting was carried out using 110 μm Al_2O_3 at a pressure of 0.2 MPa from approximately 1 cm at an angle of 45 ° for 15 seconds. The treated samples were then ultrasonically cleaned in distilled water, followed by steam cleaning.

After the pretreatment, one sample's surface morphology and elemental composition from each group were evaluated using a Lapsun digital microscope (Lapsuntech, Hongkong, China) with a 5 MP video camera. The oxidation was carried out in a Programat P300 ceramic furnace (Ivoclar Vivadent, Schaan, Liechtenstein) at 980°C (heating rate: 80°C/min) for 5 minutes under vacuum as recommended by the manufacturer.

According to the manufacturer's recommendations, the opaque and body porcelains were applied and fired in two stages by the same dental technician. First, A2 shade Ceramco 3 powder opaque paste (Densply Sirona, NC, USA) was thinned with Ceramco 3 Modifier opaque liquid (Densply Sirona, NC, USA). The surfaces of the samples were wetted with the first coat of OP using B-260 opaque porcelain brushes (BK-Medent Co., Ltd, Buk-gu Daegu, South Korea). Baking was carried out under vacuum with Ivoclar Programat P300 porcelain furnace (Ivoclar Vivadent, Schaan, Liechtenstein). The samples were masked with a more viscous OP and baked in the second step. An opaque porcelain (OP) layer with a thickness of 0.2 mm was obtained. After the OP application was completed, the OP thicknesses were measured with the Würth Dual ultrasonic measuring device (UMD) (Adolf Würth GmbH, Künzelsau, German) (Figure 1D) as stated by Pişkin et al. (17). Calibration was done according to the device's foil standards. After calibration, the same operator performed three measurements for each sample. Samples with an unsuitable OP layer thickness ($0.2 \pm 0.01\text{mm}$) were excluded from the study and reproduced.

The body porcelain veneer process was performed in two stages. In the application steps, the thickness of the body porcelain layer was ensured to be equal. Porcelain veneering with a thickness of 2.5 mm was applied at every application stage, and firing shrinkage was considered. Teflon matrix was used for standardization in body porcelain application. The body porcelain layers were fired in a Programat P300 porcelain furnace (Ivoclar Vivadent Inc, NY, USA). Porcelain thickness was standardized to be 4 mm for each sample (Figure 1E). The glazing step was

not performed in this study. A single technician performed all procedures.

Prepared samples were embedded in an auto-polymerized resin and mounted on a shear tester (Figure 1F). SBS testing was performed with a universal testing machine with a 5.0 kN load cell (AGS-5kNG, Shimadzu Corp., Kyoto, Japan) at a 1.0 mm/min crosshead speed until debonding failure. A single bevel chisel made of stainless steel was used to generate the shear force parallel to the metal-ceramic interface. SBS was calculated as Mpa by dividing the maximum load (N) by the bond surface area (mm^2).

Statistical Analysis

After oxidation and veneering, the SBS test was applied. The surface properties of Co-Cr alloys were also examined with a digital microscope after debonding. The conformity of the distributions of the SBS measurements to the normal distribution was made using the Kolmogorov-Smirnov test. According to the results, non-parametric tests were used in the study because the distribution was not suitable for the normal distribution and the number of samples within the group was small in the subgroups. Kruskal Wallis and All pair-wise post hoc test ($\alpha = 0.05$) was used in the study. Table values are given in the tables as Median and IQR. Data were analyzed using SPSS software (version 25, IBM Corporation, NY, USA).

Type of failure analyses

The failure surface of each sample was analyzed at x20 magnification with a digital microscope (Lapsun, Lapsuntech, Hongkong, China). The failure modes were categorized as a (Figure 2):

- (A) Adhesive: between metal and ceramic,
- (B) Cohesive: entirely within ceramic,
- (C) Mixed: including adhesive and cohesive failure.



Figure 2: Failure modes; A: Adhesive, B: Cohesive, C: Mixed

Mixed-type adhesion failure was observed in almost all samples, and cohesive failure was rare (Table 2).

Microscopic evaluation of the sample surfaces

The surface of the cast specimen contained typical black cast porosity. Cast specimens exhibit a dense dendritic microstructure formed due to different solidification temperatures. Dendrites are the dark metallic phase in the figures, while the light parts correspond to the intermetallic phase. Black dots represent endogenous pores. External pores appear as longer broad lines. Two details of laser-sintered samples differ significantly from cast samples. Thick wavy lines are seen at the top.

Table 1. Surface treatments and groups

Co-Cr Samples Main Groups		<i>n</i>	Casting (CG)	Sintering (LG)	Milling (MG)
Surface treatments (Subgroups)	I : Sandblasting (Korox 110, Bego, Bremen, Germany) (control group)	10	CA	LA	MA
	II : Carborundum disk (Dentaurum GmbH & Co. KG, Ispringen, Germany) grinding	10	CC	LC	MC
	III : Diamond fine bur (Hager & Meisinger GmbH, 879S Pink, Neuss, Germany) grinding	10	CF	LF	MF
	IV : Tungsten carbide hard bur (Hager & Meisinger GmbH, HM 251FX, Neuss, Germany) grinding	10	CH	LH	MH
	V : Pink stone (Hager & Meisinger GmbH, 743S Pink, Neuss, Germany) grinding	10	CP	LP	MP

Table 2. Debonding failure types of subgroups

Groups	Adhesive n (%)	Cohesive n (%)	Mixed n (%)
CA	0 (0%)	0 (0%)	10 (100%)
CC	0 (0%)	0 (0%)	10 (100%)
CF	2 (20%)	0 (0%)	8 (80%)
CH	2 (20%)	0 (0%)	8 (80%)
CP	0 (0%)	0 (0%)	10 (100%)
LA	0 (0%)	0 (0%)	10 (100%)
LC	0 (0%)	0 (0%)	10 (100%)
LF	0 (0%)	0 (0%)	10 (100%)
LH	0 (0%)	0 (0%)	10 (100%)
LP	0 (0%)	0 (0%)	10 (100%)
MA	1 (10%)	0 (0%)	9 (90%)
MC	0 (0%)	0 (0%)	10 (100%)
MF	2 (20%)	3(30%)	5 (50%)
MH	0 (0%)	1 (10%)	9 (90%)
MP	0 (0%)	0 (0%)	10 (100%)

This amorphous structure is probably due to the sudden increase in viscosity during the sintering process. In general, laser sintered samples are much more homogeneous and compact than those produced by casting. CAD/CAM milled specimens have a uniform, homogeneous dense microstructure. There are tiny pores in a smooth mesh structure (Figure 3).

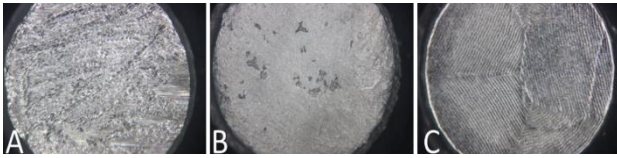


Figure 3: Microscopic examination of the sample surfaces (x180)

While the Co–Cr samples exhibited different surface properties before surface treatment, they were almost identical for each group after treatments. Surface treatments produced significant changes in sample surfaces. Changes occurred in the metal surface depending on the abrasive material used, the particle structure, and the bur cutting surface properties (Figure 4).

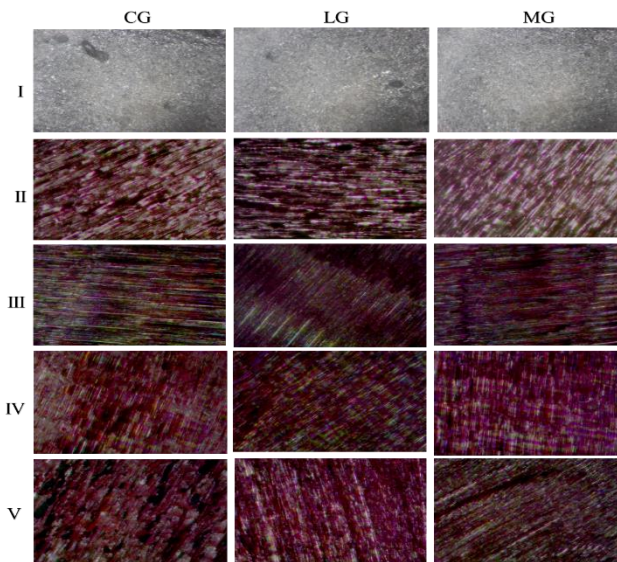


Figure 4: Microscopic examination of the treated surfaces (x360)

The alloy's microstructure was important in the microscopic examination of the failure areas (Figure 5). Following the surface treatments, the metal surface exhibited the same topographic structure and showed differences according to the microstructural structure and the applied surface treatment. It is understood that the debonding areas where the indentations on the surface benefit the retention are the regions where there is more stress concentration (shiny areas). It is seen that the thickness of the formed oxide layer (green areas) changes according to the material microstructure and the surface treatment. The failures are more in regions where the oxide layer is very little or thick.

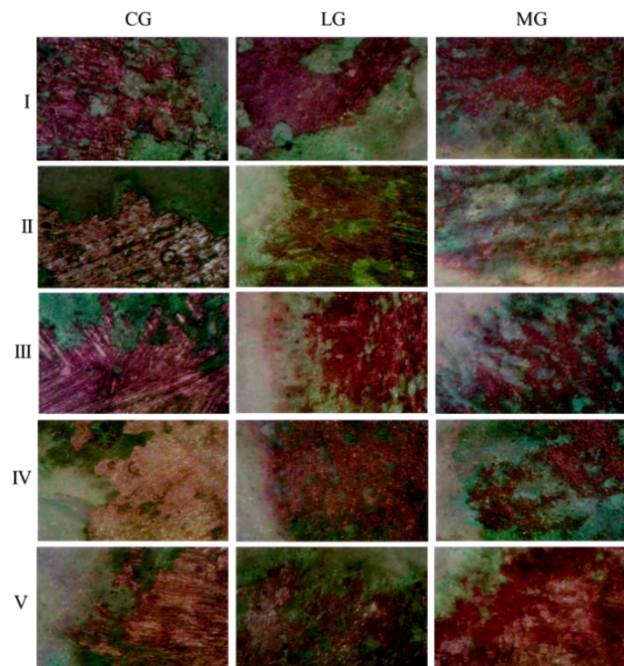


Figure 5: Microscopic examination of the failure areas (x360)

RESULTS

The frequency and percentage rates of debonding failure types are given in Table 2. In Table 3, it was determined that the sub-levels of SBS values were different according to the subgroups ($X^2=39.351$, $p=0.001$, $p<0.05$).

Table 3. General mean SBS values of all subgroups (according to surface treatments)

Subgroups	μ -IQR	p***	post hoc**
CA	17.68-20.94		
CC	22.35-22.68		CA-CF
CF	31.03-19.96		p=0.018*
CH	24.86-14.54		CA-LP
CP	25.96-25.84		p=0.008*
LA	34.54-19.50		CA-LA
LC	20.32-9.84		p=0.001*
LF	20.55-21.24		MA-CF
LH	27.48-24.86	0,001*	p=0.012*
LP	30.49-19.38		MA-LP
MA	18.26-28.02		p=0.018*
MC	20.84-24.06		MA-LA
MF	28.37-14.30		p=0.002*
MH	22.96-19.18		MP-LA
MP	22.24-20.58		p=0.002*
			MC-LA
			p=0.002*

***Kruskal Wallis H test, **All pair-wise comparison level.

It was observed that the difference was because the SBS levels of the CA and MA groups were lower than those of the CF, LP, and LA groups. In addition, LA levels were higher than MP and MC levels ($p < 0.05$). There was no significant interaction between other subgroups ($p > 0.05$). In Table 4, it was determined that the lower SBS levels were different according to the main study groups ($X^2 = 19.422$, $p = 0.001$, $p < 0.05$). It was determined that the difference was due to the lower levels of SBS in the LG group compared to the MG group ($p = 0.006$). In addition, there was no significant interaction between the CG-MG ($p = 0.211$) and LG-CG ($p = 0.628$) groups ($p > 0.05$).

Table 4. General mean SBS values of main groups (according to fabrication techniques)

Groups	μ -IQR	p***	post hoc**
CG	24.25-32.60		
LG	22.91-28.02	0.002*	LG-MG $p = 0.006^*$
MG	27.42-33.44		

***Kruskal Wallis H test, **All pair-wise comparison level.

DISCUSSION

Strong SBS at the metal-ceramic interface provides more prolonged metal-ceramic restoration survival. There is no definitive method to evaluate metal and ceramic SBS in the literature. The shear test is highly reliable in SBS evaluation due to minimal experimental variables and less residual stress (14). This is why the SBS test was used in this study. Since all metal surface treatments used in this study significantly changed ceramic bonding to the Co-Cr alloy, the study's null hypothesis was rejected. The formation of a suitable oxide layer on the metal surface increases the metal-ceramic bond (18). It is necessary to add a small base metal to noble metal alloys for optimum oxide layer formation. This oxide layer formed provides adhesion between porcelain and metal in porcelain firing. Nonprecious metal alloys form an over-oxidized layer and reduce adhesion (4). To this problem, metal conditioners have been used in nonprecious metal-ceramic alloys. They react with metal oxides and form a new interface on the alloy surface that protects against further oxidation. Thus, they prevent the formation of a thick oxidized layer and fuse the opaque porcelain well (19). This study used no metal conditioner.

Multidirectional grinding can reason surface irregularities that can cause gas bubbles to form at the metal-ceramic interface. The resulting residues may not be removed from the surface during multidirectional grinding. These gases and residues can reduce ceramic adhesion. Therefore, one-way grinding is recommended during the preparation of metal substructures. Theresa M. et al. examined the effect of metal finishing and sandblasting on porosity formation and shear bond strength at the metal-ceramic interface. They stated that the grinding direction does not affect the metal-ceramic adhesion, but the sandblasting process significantly affects the adhesion (20). Generally, a metal-ceramic adhesion value of at least 25 MPa is considered sufficient (21). Although the lowest value was found in the

CA group (17.68) in this study, the mean values for grinding and blasting samples were close to this value. Although the predicted value is 25 MPa, some previous studies have reported adhesion values below 10 MPa, which is lower than the expected 25 MPa value for dental alloys and composite resins (22). Such information should be considered in determining the minimum desired clinical values and converting specifications into laboratory tests. The results are similar in microscopic analysis studies evaluating adhesion defects between ceramic and metal. There is no significant difference in the bonding error type classifications. The test groups had almost the same mixed error type, but the SBS values were different. Previous studies investigated the relationship between metal-ceramic bond strength and failure categories, and no relationship was found. The results of this study are similar to the results of previous studies (23).

Chemical bonding occurs with the diffusion of metal oxides into opaque porcelain. This metal oxide layer is directly affected by the elements that make up the alloy (24). The fact that most of the values obtained in this study are close to 25 Mpa can be attributed to the same oxidation process. In the first images before the surface treatments, the surfaces of the cast samples were seen to be rougher, while the surfaces of the samples after the treatment had a similar appearance. Close SBS values can be attributed to the samples' fundamental structures and surface properties. Microscopic examination of the fracture stages revealed that the nut area was more than cohesive. There was a porcelain layer on the opposite side of the direction in which the shear force was applied (25). In this study, while cohesive failure was widespread, adhesive failure was infrequent. This is similar to the study results, which reported that the porcelain layer remained on the force applied side, where cohesive failures are common. The cohesive failure is due to the existing problems in the porcelain structure (26). These problems are usually caused by applicator error during porcelain veneering. No such failures occurred in this study.

In the microscopic images of the separation surfaces of the metal-ceramic, the ceramic piece in contact with the metal is located on the upper surface of the sample, in the contact area of the shear force. Adhesive failure counts as a specific failure mode in SBS tests, but this is not easy to interpret. Thermal cycling or fatigue loading was not applied to the samples In this study. Vojdani et al. found that mechanical cycling affects metal-ceramic bond strength, and this effect was similar for each of the tested metal-ceramic systems (27).

Lee et al., Serra-Prat et al., Li et al., and Rosenstiel et al.'s studies reported that the fabrication method of Co-Cr alloy does not affect the bond strength with ceramic. Co-Cr alloys produced with the latest techniques exhibit metal-ceramic bond strength comparable to castable alloy. However, Wang et al. and Mhaske Prasad et al. revealed that the fabrication technique significantly affected the bond strength between porcelain and base metal alloys and mentioned that alloys produced with contemporary methods are better than those produced by traditional casting. The results of this study also support this view. These results may be due to methodological differences as they compare Co-Cr alloys produced by casting to those

produced by computer numerical controlled milling and selective laser melting techniques (14).

The alloy surface treatments had a statistically significant effect on the SBS values in this study. Several authors have reported similar results regarding the effect of surface treatment on porcelain-to-metal bond strength (11,28–30). Different studies reported opposite results (3,20,31,32). These differences may be related to the different surface treatment protocols followed in the research studies and the different base metal alloys tested. There are numerical differences between sandblasting and the different grinding processes that need to be discussed. The highest SBS value among the groups was recorded in the sandblasting group regardless of the production technique. Sandblasting with 110 µg Al₂O₃ caused different changes in the surface texture than grinding treatments, as shown in the microscopic images. A similar result was found by Kunt et al. concluded that base metal alloys were maximally roughened by blasting more than any other surface treatment tested (14).

It is reported that rough metal surfaces have a superior ceramic wetting ability than smooth surfaces. The metal surface roughness provides the micromechanical grip when the ceramic moves on the irregularities on the metal surface, thus strengthening the metal-ceramic bond. In addition, metal surface roughness increases bond strength by expanding the bond surface area. It has been shown that the metal-ceramic bond strength increases significantly by sandblasting the metal surface with 50 and 110 µg Al₂O₃ (28,29,33).

The results are consistent with other studies that mention that blasting improves SBS across different surface treatments (28,29). In contrast, Deepak et al. found that laser surface treatment achieved better SBS values than sandblasting (3). Differences in results may refer to the different blasting protocols used in both studies; they used Al₂O₃ with 50 µm particle size while 110 µm was used in our research.

The surface treatment results differed significantly from sandblasting regardless of the manufacturing technique. Similar oxidation properties and chemical bonding may explain these results for the three alloys. Microscope images supported these results, as both the treated and oxidized samples showed similar morphological patterns. Contrary to our findings, some researchers noted that the oxidation heat treatment did not significantly affect SBS (3). This consistency may be due to using the same oxidation protocol as those used in this study.

CONCLUSION

According to the general average SBS values, the metal-ceramic bond of the laser-sintered and milled samples is significantly different from the cast samples. Grinding and sanding processes for all three metal alloys improve the metal-ceramic bond. SBS value differs depending on the surface properties of the bur used in grinding. Stress fields that occur during grinding affect the metal-ceramic bond. Choosing the burs to be used during the leveling and finishing operations depending on the metal's production technique may be beneficial in improving the metal-ceramic bond. The microstructure of the metal alloy directly affects the metal-ceramic adhesion.

Authors's Contributions: Idea/Concept: R.K.; Design: R.K.; Data Collection and/or Processing: R.K.; Analysis and/or Interpretation: R.K.; Literature Review: R.K.; Writing the Article: R.K.; Critical Review: R.K.

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