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Evaluation the Effect of Trichloroethylene on the Metal-Ceramic Bonding

Trikloroetilenin Metal-Seramik Bağlanmasına Olan Etkisinin Değerlendirilmesi

Nurten BAYSAL[1] [ID], Barış Filiz EROL[1] [ID], Simel AYYILDIZ[1] [ID]

[1]Department of Prosthodontics, Faculty of Gülhane Dentistry, University of Health Sciences, Ankara, Türkiye.

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Correspondence: Nurten Baysal; PhD, Department of Prosthodontics, Faculty of Gülhane Dentistry, University of Health Sciences, Ankara, Türkiye. E-mail: nurtenerdogan7@hotmail.com

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Abstract

The aim of the study is to evaluate the effect of trichloroethylene (TCE) on the metal-ceramic bond of additively manufactured and casting Co-Cr alloys. For this purpose, 84 disc-shaped (r=12 mm, h=1 mm) specimens were prepared for two experimental groups (n=42) with different fabrication techniques; casting and additively manufactured with Co-Cr. Before ceramic application, the disc specimens divided into two subgroups (n=21): Casting and cleaned with TCE (CT), casting and not cleaned with TCE (C), additively manufactured and cleaned with TCE (AT), additively manufactured and not cleaned with TCE (A). Ceramic (h=4 mm, r=6 mm) was applied to the disc specimens (n=20) and their shear bond strength (SBS) was measured. The surface morphology of disc (n=1; for each subgroup) specimens before and after TCE application was analyzed with a scanning electron microscope (SEM). Results were statistically analyzed with 1-way ANOVA and the Bonferroni multiple comparisons tests ($\alpha=0.05$). Significant differences were found in SBS of the CT, C, AT, and A groups. CT group (21.74±1.66 MPa) showed a significantly higher SBS value than the C (18.65±2.11 MPa), AT (19.07±1.75 MPa) and A (18.52±1.94 MPa) groups ($p<0.001$). In conclusion the application of the TCE increased the metal-ceramic bond of casting Co-Cr alloy. Although the results were not statistically significant the TCE also increased the bond of additively manufactured Co-Cr alloy.

Keywords: Trichloroethylene, Co-Cr alloy, Ceramic, Shear bond strength.

Özet

Çalışmanın amacı trikloroetilenin (TCE) eklemeli ve döküm yöntemleri ile üretilen Co-Cr alaşımlarının metal-seramik arasındaki bağlanmaya olan etkisinin araştırılmasıdır. Bu amaçla, Co-Cr alaşımı kullanılarak döküm ve eklemeli üretim teknikleri ile iki deney grubu (n=42) için 84 adet disk şeklinde (12 mm çapında, 1 mm kalınlığında) örnek elde edildi. Seramik uygulamasına başlamadan önce örnekler iki alt gruba (n=21) ayrıldı: Döküm yöntemi ile üretilip TCE ile temizlenen (CT), döküm yöntemi ile üretilip TCE ile temizlenmeyen (C), eklemeli yöntem ile üretilip TCE ile temizlenen (AT) ve eklemeli yöntem ile üretilip TCE ile temizlenmeyen (A). Sonrasında örneklere (n=20) seramik (h=4 mm, r=6 mm), uygulanıp makaslama bağlanma direnci testi (*shear bond strength*, SBS) yapıldı. Örnek (n=1; her bir alt grup için) yüzeylerindeki TCE uygulaması öncesi ve sonrası değişim taramalı elektron mikroskobu (SEM) ile incelendi. Sonuçlar istatistiksel olarak 1-way ANOVA ve Bonferroni Çoklu karşılaştırma testleri ile değerlendirildi ($\alpha=0.05$). CT, C, AT ve A gruplarının SBS değerleri arasında istatistiksel olarak anlamlı farklılıklar bulundu. CT grubunun (21.74±1.66 MPa) SBS değeri, diğer gruplara göre; C (18.65±2.11 MPa), AT (19.07±1.75 MPa), A (18.52±1.94 MPa) anlamlı derecede yüksek

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bulundu ($p<0.001$). Sonuç olarak, TCE uygulaması döküm Co-Cr alaşımlarının metal seramik bağlantısını önemli derecede arttırmıştır. İstatistiksel olarak anlamlı olmamakla beraber, TCE uygulaması sonrası eklemeli imalat yöntemi ile üretilen Co-Cr alaşımlarının metal seramik bağlanma direnci de artmıştır.

Anahtar Kelimeler: Trikloroetilen, Co-Cr alaşımı, Seramik, Makaslama Bağlanma direnci.

Introduction

Ceramic-fused-to-metal restorations have been the most favored options for dental treatments from past to present due to their long-term clinical success [1-4]. Although the researchers have improved new materials for substructures of the fixed partial dentures (FPD) such as zirconia or Ti alloys [2,5], Co-Cr alloys are the most preferred ones because of their well-known mechanical and biological properties in addition with the low cost [2-4,6-9].

Conventional casting method has been most known and commonly used technique for producing metal substructures [9]. However, the technical casting procedures are difficult in practice and time consuming. Therefore, with the development of the technology computer aided systems such as milling and additive techniques become prevalent in dentistry [6,9,10]. The additive techniques produce the materials with layer-by-layer technique with nanoscaled powders that minimizing material consumption and decreasing labor costs [6,10].

The bonding mechanism which is achieved from micromechanical forces and chemical factors between the metal and veneering ceramic is need to be strong enough for long-term clinical success of the FPDs [1,2,8,11]. There have been many studies about the improvement of the bond strength between substructure material and veneer ceramic, but still fractures of veneer ceramic occur in functional using [12]. Many reasons have been reported for these failures such as; inappropriate coefficient of thermal expansion between the metal alloys and veneer ceramics, incomplete wetting of the veneer ceramic to the metal alloys, and firing conditions [3,7,8,13,14]. Wetting of the metal substructure with the veneer ceramic has an important effect on the bonding mechanism. And the surface treatment of the metal substructure is a critical factor providing wetness of the metal with ceramic [15]. There are four types of surface preparations including: detergent, solvent, chemical, and mechanical. The preference of these, are dependent on the bonding strength required [16].

Different surface treatment procedures have been reported for cleaning metal surfaces before ceramic application, air-borne particle abrasion with Al_2O_3 particles [6,10,15,17], 70/100 isopropyl alcohol [6,17], steam cleaning [18], trichloroethylene [8,19], and water rinsing [1,8,16]. Trichloroethylene (TCE; C_2HCL_3) is a solvent that is used in industrial degreasing operations, in printing inks and paints, and as an anesthetic or analgesic [20,21]. Cold cleaning with TCE is a type of degreasing which can be applied by wiping, spraying, and dipping [20]. The metal industry is commonly using TCE as a metal cleaning solvent [20]. However, the information about the cleaning effect of this solvent on shear bond strength of metal-ceramic bonding is lacking. The purpose of this study was to investigate the effect of TCE application on the bond strength of ceramic to cast and additively manufactured Co-Cr alloys. The null hypothesis was that the TCE application would be increased the metal-ceramic bond of the differently manufactured Co-Cr alloys.

Material and Method

A total of 84 disc specimens (r=12 mm, h=1 mm) were produced for 2 study groups (n=42) to analyze the shear bond strength (SBS). Casting discs specimens were produced in a standard dimension with using specially designed molds [8]. The standard wax patterns (Denta Wax 665, Alpsa Dental) were obtained by these molds, and they were invested by phosphate-bonded investment (Bellavest SH, Bego). After wax elimination process the 42 patterns cast from Co-Cr (Remanium star, Dentaurum) alloy according to the manufacturers' instructions by using an induction-casting machine (INF-2010, Mikrotek Dental).

In the additively manufactured groups, the 3-dimensional shapes of specimens were digitized with a special design program (3-Matic, Materialise, Leuven, Belgium). Data was transferred to the production department and Co-Cr metal alloy (Remanium star CL) powder used to produce specimens (n=42) with a laser metal sintering method (Direct Metal Laser Sintering) (M2 Cusing, Concept Laser GmBH) as mentioned in the previous study [8].

After the manufacturing process, one surface of the both casting and additively manufactured specimens was finished with a low-speed air-turbine rotary hand piece using a pink stone medium bur. Then the all specimens were airborne-particle abraded with 110-μm Al_2O_3 particles (Korax, Bego), at a pressure of 0.5 MPa applied for 10 seconds at a distance of 15 to 20 mm. The specimens were ultrasonically cleaned in distilled water with a 5-minute dwell time and then steam cleaned for 15 seconds.

After the ultrasonic cleaning procedure, the additively manufactured and casting specimens were divided in 2 subgroups (n=21). Then the first group of specimens (CT and AT) exposed to trichloroethylene for 5 seconds to clean the surface perfectly before ceramic application (Figure 1). The surfaces on which the ceramic would be applied were protected from all kinds of contact until the ceramic application. Then the ceramic was applied to all groups of the disc specimens (h=4 mm, r=6 mm) (n=20) by using custom-made liquid silicone molds according to the manufacturer's instructions [8].

All ceramic applied specimens were subjected to the aging, as the aging procedure of the previous study [8] by using the same weathering machine (Xenotest 150 S+, Atlas Material Testing Technology, Chicago, IL, USA) under the same conditions for 200 h.

The all ceramic-applied-specimens were embedded separately in auto-polymerized acrylic resin (Imicryl, Imicryl Dental) using female silicone molds (internal volume of 13×13×13 mm^3). The shear force was conducted to the metal-ceramic interface until failure occurred with a universal testing instrument (L-loyd Instruments LRX). A standard notched was used at a crosshead speed of 1 mm/min. Peak force values at failure were recorded in Newtons (N) and the peak force values were divided by the surface area to obtain the SBS (MPa = N/mm^2).

One specimen from each group was examined with scanning electron microscope (SEM). After airborne-particle abrasion and ultrasonic cleaning and the application of TCE one specimen was randomly selected from each group to analyze the surface differences and the cleaning effect of TCE. SEM (JSM 6060LV; Jeol Ltd, Tokyo, Japan) photomicrographs were then obtained from the selected specimens at different magnifications.

Statistical analysis was performed using the IBM SPSS program (v25; IBM Corp, Armonk NY, USA). The data was examined by means of Kolmogorov-Smirnov test for normality. The results of the SBS were statistically analyzed with 1-way ANOVA and Bonferroni multiple comparison tests (α=0.05).

Results

The results of the 1-way ANOVA test for determining the effect of TCE on the SBS of the study groups are listed in Table 1. The descriptive statistics and mean values of SBS are shown in Table 2 and Bonferroni multiple comparison test results shown in Table 3. According to the Bonferroni multiple comparison test results (Table 3) CT (21.74±1.66) group showed the significantly highest SBS values compared with C (18.65±2.11 MPa), AT (19.07±1.75 MPa) and A (18.52±1.94 MPa) groups ($p<0.001$) (Figure 2). No significant differences were seen between the C, AT, A groups.

Figure 3 demonstrates the SEM images of the experimental groups. As seen in Figure 1 (a: C group) and (c: A group) there are particles on the surface of the group C and A specimens (indicated by arrows). In the Figure 3 (b: CT group) and (d: AT group) demonstrate the CT and AT specimen groups which have been exposed to the TCE. There are not any particles seen on the surface of these specimen groups. SEM examinations at ×500 magnification indicated that the surface of C and A specimen groups show different roughness patterns as seen in Figure 4 (a, b, c, d). The surface additively manufactured specimens demonstrate a smoother surface than casts.

Table 1. One-way ANOVA results for shear bond strength (SBS) of specimen groups.

SBS (MPa)	*df*	Sum of square	Mean square	F	*p*
Between groups	3	137.83	45.94	13.04	<0.001
Within groups	76	267.88	3.53		
Total	79	405.71			

MPa: Megapascal.

Table 2. Descriptive statistics for SBS (MPa) of the experimental groups.

	Group	n	Mean ± SD	Minimum	Maximum
SBS	CoCr-CT	20	21.74±1.66	18.05	23.92
	CoCr-AT	20	19.07±1.75	16.66	22.94
	CoCr-C	20	18.65±2.11	15.54	22.45
	CoCr-A	20	18.52±1.94	15.86	21.69

Table 3. Bonferroni multiple comparisons test.

(I) Group	(J) group	Mean difference (I-J)	Standard error	Significance	95% Confidence Interval	
					Lower bound	Upper bound
CoCr-CT	CoCr-AT	2.6760000*	0.5936959	0.000	1.067636	4.284364
	CoCr-C	3.0930000*	0.5936959	0.000	1.484636	4.701364
	CoCr-A	3.2180000*	0.5936959	0.000	1.609636	4.826364
CoCr-AT	CoCr-CT	-2.6760000*	0.5936959	0.000	-4.284364	-1.067636
	CoCr-C	0.4170000	0.5936959	1.000	-1.191364	2.025364
	CoCr-A	0.5420000	0.5936959	1.000	-1.066364	2.150364
CoCr-C	CoCr-CT	-3.0930000*	0.5936959	0.000	-4.701364	-1.484636
	CoCr-AT	-0.4170000	0.5936959	1.000	-2.025364	1.191364
	CoCr-A	0.1250000	0.5936959	1.000	-1.483364	1.733364
CoCr-A	CoCr-CT	-3.2180000*	0.5936959	0.000	-4.826364	-1.609636
	CoCr-AT	-0.5420000	0.5936959	1.000	-2.150364	1.066364
	CoCr-C	-0.1250000	0.5936959	1.000	-1.733364	1.483364

*The mean difference is significant at the 0.05 level.

Figure 1. Application of trichloroethylene (TCE) to the specimens.

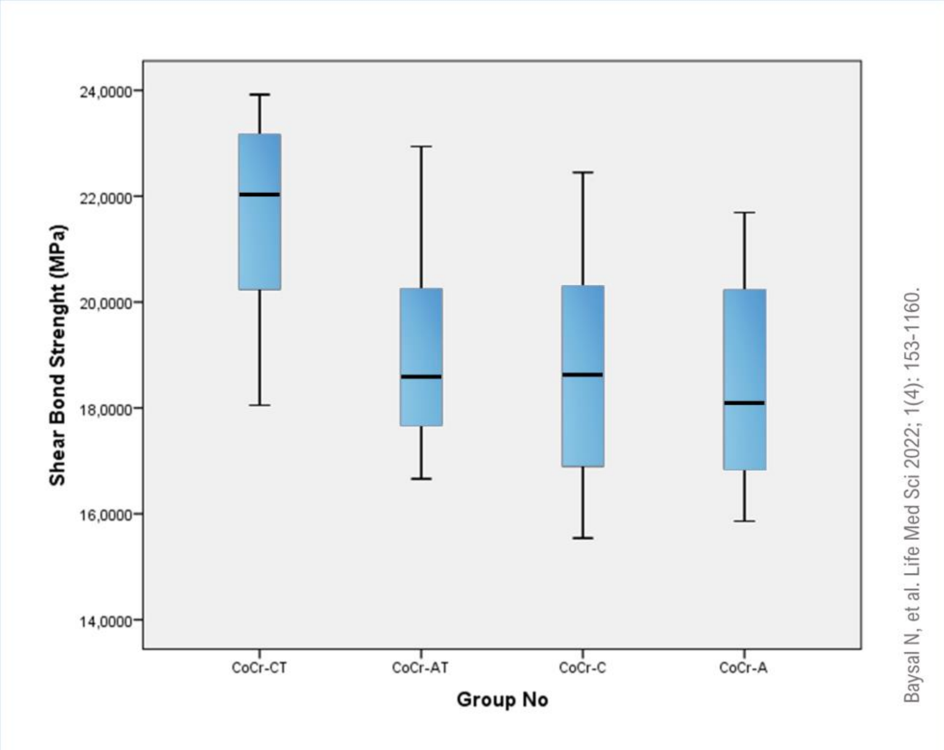

Figure 2. Shear bond strength (SBS) of CT, AT, C, and A experimental group. The box plot shows the distribution and average values of the SBS within the groups.

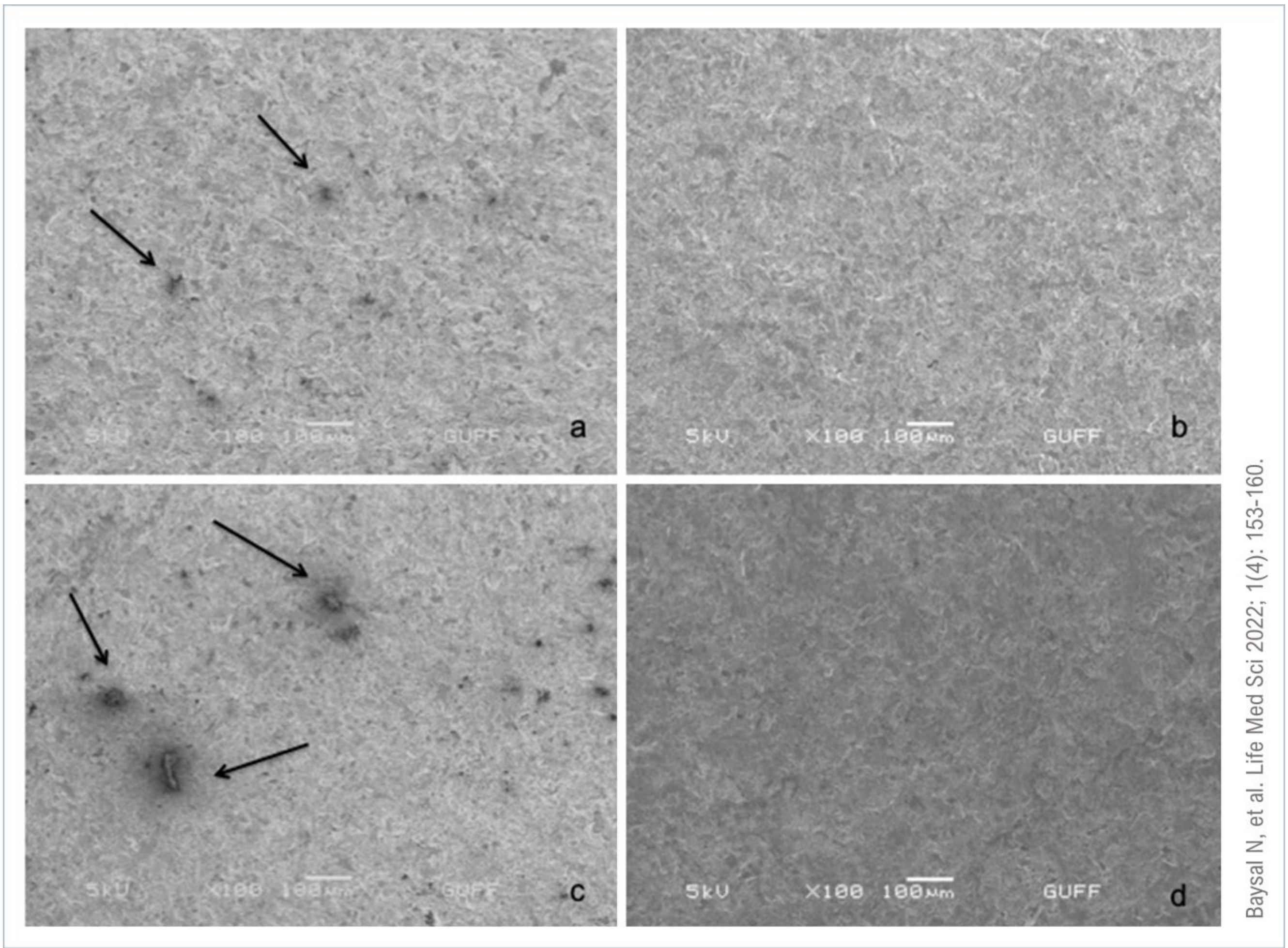

Figure 3. Scanning electron microscope (SEM) images show top surfaces of the cast and additively manufactured Co-Cr alloys before and after TCE application. The letters show the groups; a:C, b:CT c:A, and d:AT.

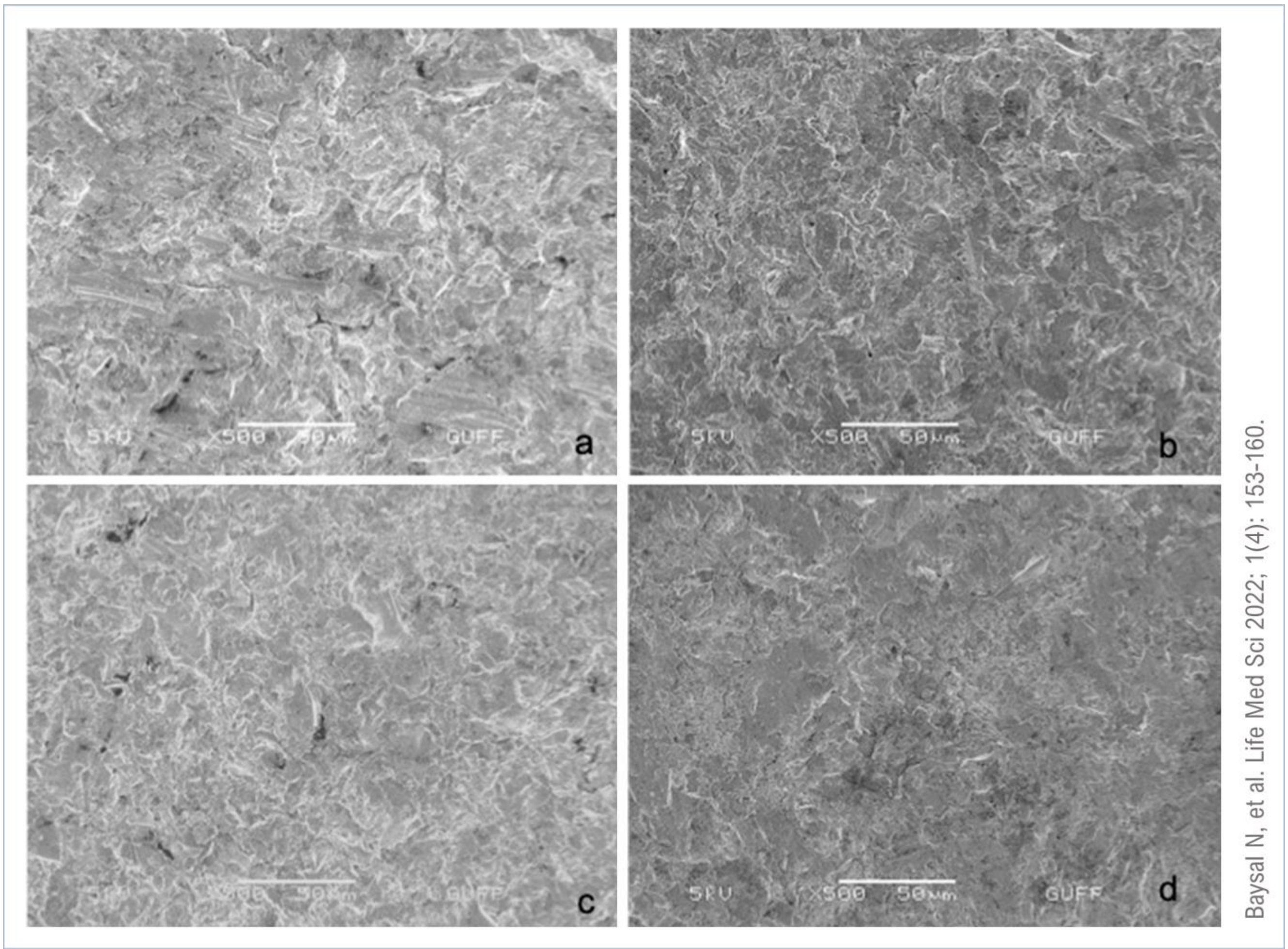

Figure 4. Scanning electron microscope (SEM) images show top surfaces of the cast and additively manufactured Co-Cr alloys before and after TCE application. The letters show the groups; a:C, b:CT c:A, and d:AT.

Discussion

The aim of this in-vitro study was to evaluate the effect TCE application on the bond strength of ceramic to cast and additively manufactured Co-Cr alloys. The null hypothesis that the TCE application would be increased the metal-ceramic bond of the differently manufactured Co-Cr alloys was accepted for cast Co-Cr alloy groups. However, there was no statistically significant difference in SBS of the additively manufactured Co-Cr alloy groups after surface cleaning with TCE.

Chipping and delamination of veneering ceramics in ceramic fused to base and noble metals or zirconia restorations are causing functional and esthetics problems for patients [15,17]. To avoid these problems, the bond strength between ceramic and substructure material is need to be provided perfectly. It has been reported that the oxide layer thickness of the metal [3,11,12,17,22], manufacturing technique of the framework material [6], alloy type [17], aging [4,12], surface treatments [1,12,15,17], affect bond strength. In the present study, two different manufacturing techniques were used to produce metal frameworks. The same experiment procedures were applied for specimen groups except the application of TCE to see the effect of surface cleaning on bond strength. As a result of this application the SBS of the CT group showed a significant increase compared with the C, A, and AT groups ($p<0.001$). As seen in the SEM images (Figure 3: b and d) the application of TCE had removed all particles from the specimen surface when compared to non-applied specimen. Also, the mean SBS of the AT group specimen demonstrated an increase after the application of TCE while the result was not statistically significant. However, when we examine the SEM images of the A and AT specimens' surfaces, there were also seen that the TCE clean the particles from the AT specimen group too.

Different manufacturing techniques may affect the microstructure and hardness of the material [18]. Wu et al. [18] reported that SLM manufacturing provides dense and defect-free microstructure Co-Cr alloy, that results in excellent mechanical properties, than casting. Baysal et al. [8] reported that the additively manufactured Co-Cr alloy Vickers Hardness value was higher than casting (Co-Cr casting: 327.6±26.6 HV1/Co-Cr additively manufactured: 507.2±20.9 HV1). Therefore, it is considered that the surface of the casting (C, CT) specimen group may be more affected from the AL_2O_3 particles, and the surface roughness may be higher than additively manufactured group. As a result of these situations the SBS of the casting group specimens showed higher values than additive specimen groups.

Despite the statistical differences the mean SBS values of the all groups were lower than the 25 MPa bond strength value that was accepted by the International Standard (ISO9693) for the metal-ceramic restorations [9,10,15]. This may be explained by the fact that in the present study a 1-week aging process that corresponded to 1 year of clinical use was performed for all specimen groups. The aging processes have a decrease effect between the bond strength of the metal and ceramic. Although the aging methods are different this situation reported as a result in the literature [9,15].

TCE had been used for surface cleaning of the metal specimens before ceramic application [8,19]. However, this is the first study that assesses the effect of TCE on the SBS of metal-ceramic restorations. The results of the present research demonstrated that TCE had a favorable influence on increasing the bond between metal and ceramic. However, the limitation of this research is that to explore the chemical effects of the TCE to the Co-Cr alloys, the EDS analysis needs to be done. Also, the surface roughness measurements should be done before and after TCE application to the Co-Cr alloys. Additionally, it should be kept in mind that this solvent may have carcinogenic effects and should be used very carefully [20].

Conclusion

The findings of this in vitro study reached the following conclusions. The application of the trichloroethylene increased the metal-ceramic bond of casting Co-Cr alloy. Although the results were not significant statistically, the trichloroethylene also increased the bond of additively manufactured Co-Cr alloy. Therefore, the trichloroethylene could be a preferable surface cleaning agent for casting and additively manufactured Co-Cr alloys.

Conflict of interest: The authors declare that there is no conflict of interest. The authors alone are responsible for the content and writing of the paper. **Financial disclosure:** There is no financial support for this study. **Ethical considerations:** The study was conducted in accordance with the Declaration of Helsinki.

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