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Original research

The Effects of Er,Cr:YSGG laser on shear bond strength of orthodontic lingual brackets to CAD/CAM ceramic systems

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Purpose

The aim of this study is to compare the bond strength of lingual brackets bonded to resin-matrix and lithium disilicate based-ceramic crowns following various surface treatments.

Materials and Methods

Sixty ceramic crowns (IPS Emax and Cerasmart) were fabricated by CAD/CAM. Er,Cr:YSGG laser, sandblasting with aluminium oxide and hydrofluoric acid treatment effects on ceramics was tested (n=10/group). A light-cure orthodontic adhesive was used to bond lingual brackets to the ceramic surfaces. Bond strengths of the brackets to ceramics were assessed by shear bond test. The remnant adhesive on bracket and ceramic surfaces was inspected with a light microscope and adhesive remnant index scores were recorded. The data were analyzed statistically using the Kruskal–Wallis test followed by the Mann–Whitney U-test.

Results

Cerasmart ceramic specimens showed lower shear bond strength values than IPS Emax ceramic specimens ($p<0.05$). The statistical analysis of the surface treatment groups regarding bond strength were ranked as follows: Laser ≤ Hydrofluoric acid ≤ Sandblasting ($p=0.058$). While laser-treated Cerasmart ceramic group displayed the lowest SBS (9.39 MPa), hydrofluoric acid-treated IPS Emax group had the highest (16.8 MPa) bond strength value.

Conclusion

The use of Er,Cr:YSGG lasers for etching of CAD-CAM ceramics could be a promising alternative to “conventional techniques”, to improve bond strength of lingual brackets to IPS Emax and Cerasmart ceramics.

Keywords: *Lingual bracket, ceramic, shear bond strength, Er,Cr:YSGG laser*

Introduction

The increasing aesthetic demand of adult patients has contributed to a marked increase for lingual fixed orthodontic treatment in recent years (1-3). While invisible brackets offer higher aesthetic gain than conventional techniques; speech dysfunctions, mastication problems, and oral discomfort are the main adverse effects of this technique (4,5). Besides, adults receiving orthodontic therapy might have various types of ceramic restorations, and bonding of orthodontic appliances to ceramic surfaces could be classified as a challenge compared to bonding to dental structures (1,6).

In adult patients, commonly used tooth-colored materials could be leucite- and lithium disilicate-reinforced glass, zirconia, and hybrid ceramics (7). Lithium disilicate glass-ceramics (IPS Emax, Ivoclar Vivadent AG, Schaan, Liechtenstein) have high mechanical strength, favorable translucency, shade variety, aesthetics, and etchability (8). Moreover, dif-

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ferent microstructure, processing techniques and materials such as resin-matrix ceramics and polymer-infiltrated-ceramic network materials have been developed (9). Amid the diverse spectrum of bond resin ceramics, CAD/CAM nanohybrid-composite (Cerasmart, GC Corp, Tokyo, Japan), a high-density composite material containing inorganic ceramic fillers (silica and barium glass filler by weight), has become popular for its positive features combining ceramics and resin composites (7,9).

Since different microstructure and processing techniques of ceramics might influence the adhesion properties of brackets, preparation of the surfaces is essential for improving bond strength of brackets to ceramics (1,10). Recently, hydrofluoric acid, diamond bur, or sandblasting were used for etching the ceramic surfaces in orthodontics (11). Hydrofluoric acid and chair-side intraoral sandblasting might have possible hazardous effects. Besides, laser etching technology offers an alternative for etching surfaces to reinforce the bond between orthodontic brackets and restorative materials or dental tissues (6,10). The most commonly used lasers in dental applications are Er:YAG and Er,Cr:YSGG lasers. Since Er,Cr:YSGG laser has minor thermal side-effects on vital tissues of the tooth, it is preferred both for soft and hard-tissue applications (11-13).

Recently, studies about lasers have focused on the effectiveness of laser treatments on bonding of labial brackets to surfaces (14,15). There is only one study in the literature evaluating the effects of laser (Nd:YAG) on the shear bond strength (SBS) of lingual brackets (16). Thus, the present study aimed to decide an ideal surface treatment method for bonding of lingual brackets to resin-matrix and lithium disilicate glass ceramic crowns. The null hypotheses were that first, the SBS of brackets to ceramics would not be improved by Er,Cr:YSGG laser treatment of lingual brackets and second, the type of ceramic would have no influence on the bracket bonding success.

Materials and Methods

Specimen preparation

Sixty maxillary right first premolar ceramic crowns (IPS Emax (Ivoclar Vivadent AG, Schaan, Liechtenstein) and Cerasmart (GC Corp, Tokyo, Japan) were fabricated by CAD/CAM (Cerec In Lab MC XL; Sirona Dental Systems, Charlotte, USA) (Table 1). Then, the crowns were grouped according to surface treatment methods randomly as follows:

1. Er,Cr:YSGG laser treatment (n=20) (Waterlase; Biolase Technology, Irvine, CA, USA) was performed with the power output of 3.5 W. The distance of laser tip was approximately 1 mm and perpendicular to the ceramic surface (65% air and 55% water spray) with a pulse duration of 140 µs. In addition, the crowns were irradiated with a wavelength of 2.780 nm. Furthermore, the average exposure time was set at 10 s and 20 Hz repetition rate.

2. Sandblasting with aluminium oxide particles (50 µm diameter) (n=20) was performed at 2.5 bar for 4 s at a distance of 1 cm.

3. Hydrofluoric acid (HF) (n=20) (%9.6, Pulpdent, Watertown, Mass, USA) was applied to the surface for 2 min and rinsed with deionized water for 2 min.

Afterwards, the metal brackets (Protect, Zhejiang Protect Medical Equipment Co, China) were bonded on crowns with a light-cure adhesive (Transbond XT, 3M Unitek, Monrovia, USA). Then, the specimens were polymerized with a LED (Elipar S10, 3M ESPE, St Paul, USA) for 20 s from distal and mesial side of the bracket. A compressive force (300-g) was applied on the brackets (force gauge, Correx Co, Bern, Switzerland) for 10 s and with a sharp scaler all of the visible resins around the brackets was removed. Following storage in distilled water at 37°C for 24 h, the specimens were embedded in an auto polymerizing acrylic resin (Meliodent, Heraus Kulzer, Hanau, Germany) using a cylindrical plastic mold.

Shear bond strength test

Specimens were loaded in shear mode of the universal testing machine (Lloyd Instruments, Fareham Hants, UK) with a cross-head speed of 0.5 mm/min. The bond strength values were recorded in Newtons (N), was divided by the surface area of the bracket base to calculate the SBS in MPa.

Failure mode analysis

The failure modes were evaluated with a stereomicroscope (40X, Leica Microsystems, Milan Italy) and classified according the modified adhesive remnant index (ARI). The ARI scoring index was ranked from 0 to 4 as follows (17):

Score 1. No adhesive was left on the ceramic surface.

Score 2. Less than half of the adhesive remained on the bracket base.

Score 3. More than half of the adhesive remained on the bracket base.

Score 4. All adhesive was left on the ceramic surface with a clear impression of the bracket mesh.

SEM analysis

Representative specimens of the ceramics from each group were exposed to different surface treatment methods and scanning electron microscopy (SEM; Carl Zeiss NTS, Oberkochen, Germany) was carried out to identify the surface variations of the ceramics.

Table 1. *Materials tested in the present study.*

Material	Trade name	Shade	Lot no	Manufacturer	Composition
Lithium disilicate	IPS Emax	A1-HT	V46006	Ivoclar Vivadent AG, Schaan, Liechtenstein	SiO_2 %57 – 80 Li_2O 11.0 – 19.0 K_2O %13 P_2O_5, %11 ZrO_2 %8 ZnO, %8 Al_2O_3 %5 MgO, %5 Color oxides
Nano hybrid ceramic	GC Cerasmart™	A1-HT	008512	GC Corp, Tokyo, Japan	Bis-MEPP, UDMA, DMA, %71 silica (20 nm), barium glass (300 nm) nano particles by weight

Statistical analysis

Since data were not normally distributed according to Shapiro Wilk test, the statistical significance was determined by the Kruskal–Wallis followed by Mann–Whitney U-test (SPSS v11.5, Chicago, USA) with the level of significance set at $p < 0.05$. The chi-square test was used to detect the presence of statistical differences in the ARI results of the tested groups. Pearson's correlation statistical analysis was performed to define the correlation between SBS and ARI ($p < 0.05$).

Results

The means SBS and standard deviations of the tested groups are presented in Figure 1. The results of the statistical analysis indicated no significant differences among the bond strength values of the tested groups ($p<0.05$).

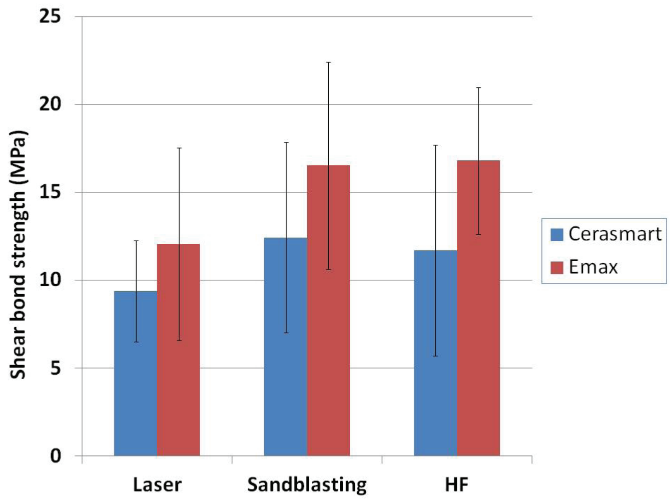

Figure 1. *Shear bond strength and standard deviation values of the tested groups.*

Table 2. *Failure analysis of the tested groups (%).*

Surface Treatment	Groups	Score 1	Score 2	Score 3	Score 4
Laser-treated	IPS Emax	0	20	80	0
	Cerasmart	0	0	75	25
Sandblasted	IPS Emax	20	30	50	0
	Cerasmart	10	20	50	20
HF-treated	IPS Emax	11,1	55,6	33,3	0
	Cerasmart	30	20	50	0

The Cerasmart ceramic specimens exhibited significantly lower bond strength values than IPS Emax ceramic specimens ($p<0.05$). In addition, the statistical ranking of the surface treatment groups was observed as follows: Laser ≤ HF ≤ Sandblasting ($p = 0.058$). While laser-treated Cerasmart ceramic group had the lowest bond strength (9.39 MPa), HF-treated IPS Emax group had the highest (16.8 MPa). Besides, laser-treated Cerasmart ceramic group demonstrated a significantly lower bond strength value than sandblasted and HF–treated IPS Emax groups ($p<0.05$).

ARI analysis revealed that the majority of the specimens presented scores 2 and 3 (%80.65) (Table 2, Figure 2). Furthermore, no significant correlation was observed between bond strength and ARI scores of the groups. SEM analysis demonstrated microstructural variations between the ceramic surfaces (Figure 3).

Discussion

The present study showed that surface treatment of ceramics had no effect on the SBS of lingual brackets, leading to the acceptance of the first null hypothesis. In the present study, SBS test was applied to find a suitable etching method for effectively bonding of lingual brackets to resin-matrix and lithium disilicate glass ceramics. To our knowledge, this is the first report evaluating the effect of Er,Cr:YSGG laser on SBS of lingual brackets. The bond strength values of HF for 2 min, sandblasting with Al_2O_3 for 4 s, and 3.5 W Er,Cr:YSGG laser treatment groups were obtained between 9.39 MPa-16.53 MPa in the present study. As previously reported, in vitro bond strength of 6 MPa to 8 MPa is considered as a gold standard and "clinically acceptable" (18). Therefore, all surface treatments tested in the present study could be considered sufficient etching procedures for clinical applications.

The laser-treated groups also exhibited clinically acceptable SBS values (Cerasmart-laser: 9.39 MPa and IPS Emax-laser: 12.07 MPa). However, laser-treated Cerasmart group showed significantly lower SBS value than HF-treated and sandblasted IPS Emax groups ($p<0.05$). Since there is no study to our knowledge in the literature evaluating the SBS of lingual brackets to lithium disilicate and hybrid ceramics, it is difficult to compare the present results with previous studies. A study by Sfondrini *et al*. investigated the SBS values of different lingual bracket base designs and reported SBS values ranging approximately from 16 to 20 MPa (5). In addition, a previous report evaluated the effect of surface treatment methods on SBS of indirectly bonded lingual appliances and reported values ranging between 13.17 MPa and 16.42 MPa. The difference in the bond strength values between the results of the present study and others may be related to the bonding substrates (19).

The ceramic type affected the bond strength of lingual brackets, necessitating the rejection of the second null hypothesis. This finding could be related to the size of particles and crystalline structure of the ceramics and processing techniques of the ceramic systems. While Cerasmart has barium and glass fillers, IPS Emax ceramic is a glass-ceramic with a 70% crystal volume incorporated in a glass matrix and a fine-grained size of approximately 1.5 µm (9). Therefore, the higher bond strength of IPS Emax ceramic than Cerasmart ceramic could be attributed to the micro-porosities

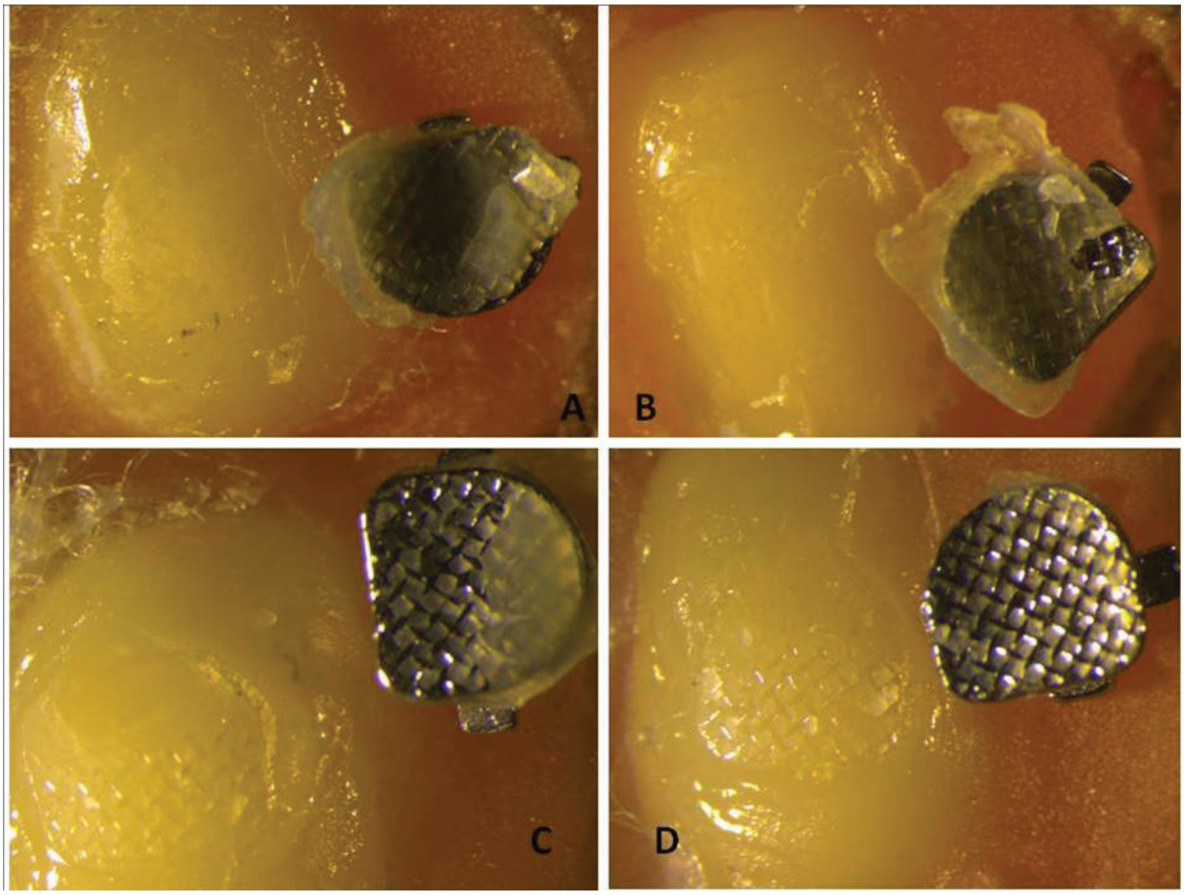

Figure 2. *Stereomicroscopic images showing representative ARI groups; A: All adhesive remained on the bracket base; B: More than half of the adhesive remained on the bracket base; C: Less than 50% of the adhesive remained on the bracket base; D: No adhesive remained on the bracket base. Original magnification x40, bar= 1 mm.*

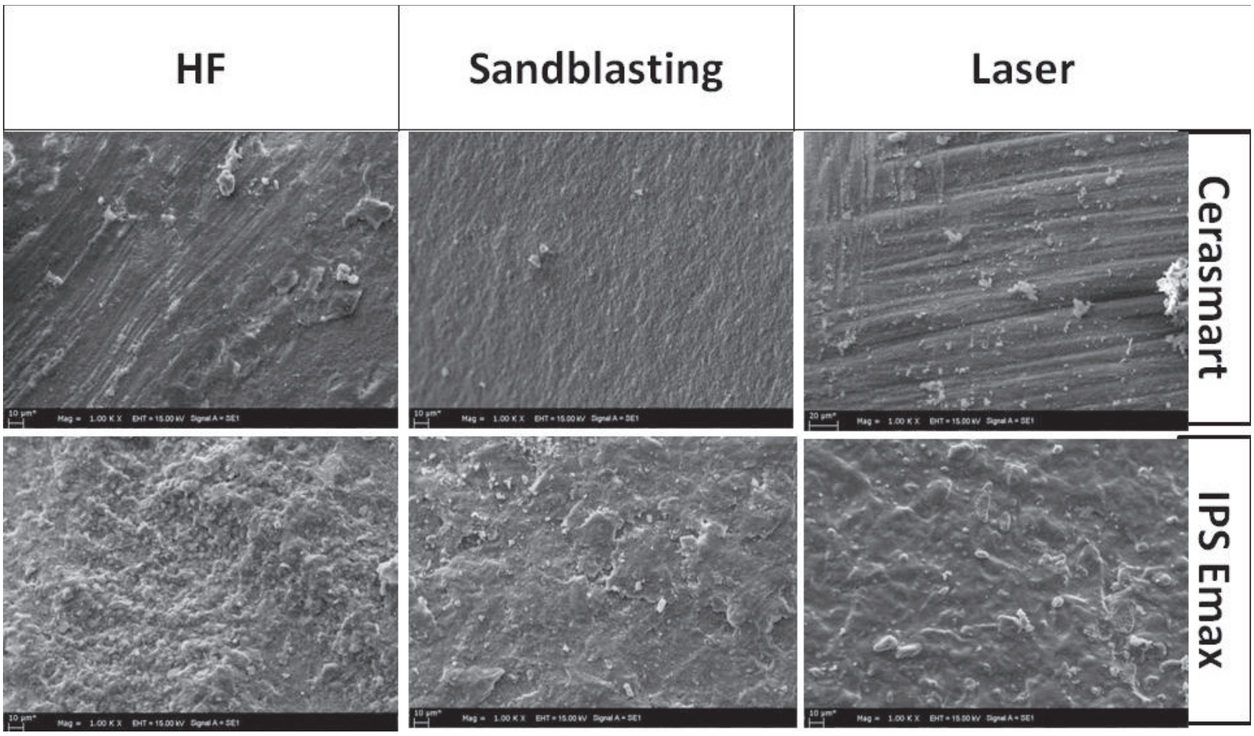

Figure 3. *SEM photomicrographs of HF-treated, sandblasted, and laser-treated ceramic surfaces (Original magnification: 1000x, bar = 10 µm).*

created by the dissolution of the glass phase of this ceramic. Similarly, Abu Alhaija *et al*. compared the bond strength of stainless steel brackets to different ceramics. The researchers also observed significant differences between the SBS values of brackets to feldspathic porcelain, In-Ceram, and IPS-Empress (20). Furthermore, a previous study investigated two surface-conditioning methods' effects on the SBS of metal brackets bonded to three different all-ceramic materials (feldspathic, leucite-reinforced and fluoro-apatite ceramic) (21). In accordance with the present study, that previous study reported significant differences between all ceramics.

Since possible harmful effects could be possible with the use of strong HF acids, different surface treatment methods have been evaluated instead of HF acid previously (22,23). Likewise in the current study, Er,Cr:YSGG laser treatment was performed and its effect on SBS of lingual brackets to ceramics was compared with routine etching procedures. To our knowledge, there are no standard Erbium laser irradiation settings in literature for ceramic etching. Therefore, a previous setting of the Er,Cr:YSGG laser was used in the present study (11). Yassei *et al*. compared the effect of HF acid and Er-YAG laser (1.6, 2, and 3.2 W) on the SBS of orthodontic brackets to porcelain. The authors reported that there was no significant difference between these surface treatments (24). Similarly, another study examined the influence of different lasers (Er:YAG and Er,Cr:YSGG) on bonding of resin composite to labial brackets. They concluded that 3W or 2 W Er,Cr:YSGG laser application can be suggested instead of other etching processes (12). Moreover, a previous study investigated whether the Er:YAG (3W) or Er:CrYSGG (3W) laser affects the SBS of brackets to dental porcelain or not. They concluded that Er:YAG laser is not a suitable substitute to HF etching. Although HF etching performed significantly higher than Er:CrYSGG laser, the bond strength required for orthodontic brackets has been achieved for the laser groups (25).

The optical microscope photographs of the ARI analysis indicated that the ceramic-adhesive interface bond failures were mostly detected (Table 2, Figure 2). The adhesive was bonded to bracket surface better than the ceramic surface (Scores 1 and 3) except HF-treated Emax group (majority of the failures were Score 2). Besides, no destruction of the ceramic surfaces in any group has been observed. Furthermore, this could be a clinical advantage since less adhesive should be removed from the ceramic surface after bracket debonding, as reported previously (26). A previous study reported that the morphology of the base design might have a positive effect on the penetration of the composite material to the bracket (2).

In the current study, the percentage of score 3 in the laser-treated Cerasmart group was % 75 (Figure 2B), indicating the lowest bonding results in all tested groups. In HF-treated IPS Emax groups (Figures 2C and 2D), the percentage of scores 2 increased. This result could be due to higher bond strength results of the lingual brackets to IPS Emax ceramic specimens than Cerasmart specimens. In addition, this result indicated that the adhesive bonded IPS Emax ceramic better than the bracket. However, no correlation was observed between bond strength and ARI scores.

The statistically non-significant bond strength results of the groups were supported by the SEM observations. Besides, there were structural variations in the surfaces of the Cerasmart and IPS Emax restorative materials following surface treatments. In addition, it should be pointed out that IPS Emax specimens displayed distinct surface irregularities, creating a micro-retentive features compared to Cerasmart specimens (Figure 3).

The first limitation of this study was its small sample size. Second limitation is the absence of aging procedures simulating clinical situations. Further investigations are necessary to determine the long-term adhesion of lingual brackets to all ceramics under clinical conditions. Additional trials were also needed to compare these findings with labial orthodontic appliances.

Conclusion

IPS Emax ceramic crowns are more likely to demonstrate higher bond strength than Cerasmart ceramic crowns. Besides, Er,Cr:YSGG laser could be an effective method for etching of resin-matrix and lithium disilicate-ceramic based CAD/CAM crowns before bonding lingual brackets to them.

Türkçe özet: *Ortodontik lingual braketlerin CAD/CAM seramik sistemlere makaslama bağlanma dayanımı üzerine Er,Cr:YSGG lazerin etkisi. Amaç: Çalışmanın amacı, farklı yüzey işlemleri sonrasında rezin matriks ve lityum disilikat bazlı seramik kronlara bağlanan lingual braketlerin, bağlanma dayanımlarını karşılaştırmaktır. Gereç ve Yöntem: 60 adet seramik kron (IPS Emax ve Cerasmart) CAD/CAM ile hazırlandı. Er,Cr:YSGG lazer, alüminyum oksit ile kumlama ve hidroflorik asitlerin seramikler üzerine etkileri test edildi (n=10/grup). Lingual braketleri seramik yüzeylere yapıştırmak için, ışıkla sertleşen ortodontik adeziv kullanıldı. Braketlerin seramiklere bağlanma dayanımı, makaslama bağlanma testi ile değerlendirildi. Braketler ve seramik yüzeyler üzerinde kalan artık adezivler, ışık mikroskobu ile gözlendi ve adeziv artık indeksi kaydedildi. Veriler istatistiksel olarak, Kruskal-Wallis testini takiben, Mann-Whtiney U testi ile analiz edildi. Bulgular: Cerasmart seramik örnekler, IPS Emax seramik örneklerden daha düşük makaslama bağlanma dayanımı gösterdi (p<0.05). Yüzey işlem grupları istatistiksel olarak bağlanma dayanımı değerlerine göre şu şekilde sıralanmaktadır: Lazer ≤ Hidroflorik asit ≤ Kumlama (p=0.058). Lazerle işlem gören Cerasmart seramik grubu en düşük iken (9.39 MPa), hidroflorik asit ile işlem gören IPS Emax (16.8 MPa) en yüksek bağlanma dayanımı değeri göstermiştir. Sonuç: Lingual braketlerin IPS Emax ve Cerasmart seramikler üzerine bağlanma dayanımını geliştirmek için, CAD-CAM seramiklerin pürüzlendirilmesinde Er,Cr:YSGG lazerlerin kullanımı, konvansiyonel tekniklere göre umut verici bir alternatiftir. Anahtar kelimeler: lingual braket, seramik, makaslama bağlanma dayanımı, Er,Cr:YSGG lazer.*

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Informed Consent: Not required.

Peer-review: Externally peer-reviewed.

Author contributions: EK, GE, ICN participated in designing the study. FE participated in generating the data for the study. FE participated in gathering the data for the study. FE participated in the analysis of the data. ICN wrote the majority of the original draft of the paper. EK, GE, SY, ICN participated in writing the paper. FE has had access to all of the raw data of the study. EK, ICN have reviewed the pertinent raw data on which the results and conclusions of this study are based. EK, ICN have approved the final version of this paper. EK, ICN guarantee that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

Conflict of Interest: The authors declared that they have no conflict of interest.

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