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ORIGINAL ARTICLE

Lithium di silicate ceramic surface treated with Er,Cr:YSGG and other conditioning regimes bonded to orthodontic bracket

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KEYWORDS

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Abstract *Aim:* To assess bond integrity and modes of failure of metallic brackets to lithium disilicate ceramics (LDC) conditioned with Er,Cr:YSGG laser (ECL).

Material and methods: Sixty LDC were arbitrarily allocated into six groups (n = 15) according to the type of ceramic surface conditioning treatment. Group 1 surface treated with silane (S) only, group 2 surface etched with hydrofluoric acid (HF)+ S, group 3 surface conditioned with HF+ ultrasonic bath (UB)+ S, group 4 sand blasting (SB) of glass ceramic surface with 50 μm Al_2O_3, group 5 surface conditioned with self-etch ceramic primer (SECP) and in group 6 surface treated with ECL + S. After conditioning, the specimens were positioned in a universal testing device for shear bond strength (SBS) testing. Adhesive Remnant Index (ARI) was used to determine sites of bond failure. Among experimental groups analysis of variance (ANOVA) and Tukey multiple comparison test was used at a significance level of ($p < 0.05$).

Results: The highest SBS values were observed in group 3 HF+ UB + S (18.21 ± 1.241) and the lowest SBS values were displayed group 1 surface treated with S only (5.21 ± 0.23). Specimens surface conditioned in group 2 with HF+ S (17.85 ± 1.25), group 3 HF+ UB + S (18.21 ± 1.241) and group 6 ECL + S (17.09 ± 1.114) unveiled comparable SBS values ($p > 0.05$).

Conclusion: LDC conditioned with ECL at (4.5 W and 30 Hz) has a potential to be used in clinical settings alternate to HF acid.

1. Introduction

With increasing dental awareness and improved facial aesthetics, more adults are opting for orthodontic treatment (Kim, 2017). It has become a common practice for orthodontists to bond orthodontic brackets to teeth already having amalgam, composite restoration or fixed dental prosthesis (i.e., bridge

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and crown) fabricated from lithium disilicate ceramics (LDC) (Winchester, 2014). LDC has gained popularity over the time due to better aesthetics, biocompatibility and translucency (De Kuijper et al., 2019; Albakry et al., 2004). However, efficiently bonding brackets to LDC is challenging for the orthodontist. Subsequently, available evidence suggests poor shear bond strength (SBS) of metallic brackets attached to LDC (Cochran et al., 1997).

To improve SBS, alteration in surface characteristics of LDC is proposed before bracket bonding. Available literature highlights different approaches for surface treatment of LDC which can either be chemical, mechanical or combination of both (Türk et al., 2006). Chemical methods for conditioning range from Silane (S) application, use of hydrofluoric acid (HF) acid and Self etch ceramic primer (SECP) (Siqueira et al., 2016). Whereas, mechanical preparation of LDC includes sand blasting (SB) with 50 µm Al_2O_3 and use of diamond burs (Pajares et al., 2009). Concurrently, HF acid along with silane application is gold standard in improving SBS by facilitating micromechanical retention (Bona et al., 2004) However, HF acid has a drawback of being corrosive, weakens ceramic surface, injurious to soft tissues, easily engrossed by the bones, blood and skin and surges the chance of lethal accidents in clinical settings (Huysmans et al., 2004).

Recently, laser application using photodynamic therapy (PDT) has been extensively and effectively used in dentistry (Al-Qahtani et al., 2018; Alkhudhairy et al., 2018b; Alkhudhairy et al., 2018a;' Alkhudhairy et al., 2019) Among lasers, Erbium yttrium scandium gallium garnet (Er: $Y_3Al_5O_{12}$) (Er,Cr:YSGG) laser (ECL) has gained admiration among orthodontists in enamel conditioning (Almoammar, 2019) and bleached enamel reversal (Khan et al., 2019) and the displayed results are convincing. Similarly, ECL has been used to repair zirconia and LDC and have unveiled encouraging outcomes (Miranda et al., 2014; Cho et al., 2012).

To the authors' knowledge and from scientific database, no studies have been conducted to assess the effect of ECL on LDC surface treatment bonded to orthodontic brackets. It is hypothesized, LDC conditioned with ECL will exhibit similar bond strength values to conventional HF acid. Therefore, the purpose of the contemporary study was to assess bond integrity and modes of failure after debonding of metallic brackets to LDC conditioned with ECL.

2. Materials and method

Ninety LDC (IPS Emax CAD, Ivoclar Vivadent AG Schaan, Lichtenstein) discs having dimensions of 10 mm diameter and 3 mm thickness were fabricated using lost wax technique by autopolymerisation of acrylic resin. The surface of the samples was made flat and smooth using automated polishing machine (Aropol 2 V, Arotec) at a speed of 450 rpm. For removal of residual debris from the surface the discs were kept in distilled water (Deerpark, Nestle, Switzerland) for 5 min followed by a rinse in 95% ethyl alcohol (C_2H_5OH) (Mitsubishi chemicals, Japan) for 2 min and air dried. The present study followed checklist for reporting invitro studies (CRIS) guidelines.

Now the samples were arbitrarily allocated into six groups (n = 15) according to the type of ceramic surface conditioning treatment. Group 1 surface treated with S only, group 2 HF + S (Control), group 3 HF + Ultrasonic Bath (UB) + S, group 4 SB the glass ceramic surface with 50 µm Al_2O_3, group 5 surface conditioned with SECP and in group 6 ECL + S on LDC. Surface treatment protocols were as follows:

Group 1 surface treated with S only: In accordance to manufacturer instructions S coupling agent (Monobond Plus ceramic primer Ivoclar, vivadent) was applied on LDC surface without roughening for 30sec and air dried for 60sec.
Group 2 HF + S (Control): HF acid at 9.5% (IPS ceramic etching gel Ivoclar, vivadent) was applied on LDC for 60 sec and then washed for 20 sec and air dried. S coupling agent (Monobond Plus ceramic primer Ivoclar vivadent) was applied in thin layer for 60sec and air dried.
Group 3 HF+ ultrasonic bath (UB) + S: 9.5% HF acid was applied on LDC surface as mentioned in group 2. Later, the samples were immersed in ultrasonic bath with distilled water (Deerpark, Nestle, Switzerland) for 120 sec and air dried. S was applied on the dried surface as mentioned in group 2 earlier.
Group 4 SB with 50 µm Al_2O_3: SB using 50 µm Al_2O_3 (Aluminium oxide Dentsply, Bohemia, USA) was performed on LDC surface from a distance of 1 mm under atmospheric pressure of 2.8 atm using a fine tip for a duration of 15sec. The SB was performed by a single operator in a circular motion. The samples were rinsed for 30 sec after SB and air dried.
Group 5 treated with SECP: LDC were surface conditioned with SECP (Monobond etch & prime, Ivoclar Vivadent, Schaan, Liechtenstein) using a micro brush for 60sec followed by water rinse for 20sec. Subsequently, the ceramic samples were air dried 10sec in accordance to the instructions of the manufacturer.
Group 6 ECL+ S: The samples were surface conditioned with ECL using (Biolase- Waterlase I-Plus) with power 4.5 W and frequency 30 Hz. The phototherapy of LDC was done in circular motion using tip MZ8 in a non-contact position 1 mm from the surface. After ECL on LDC, silane was applied to the surface as mentioned previously in group 2 and group 3.

After both mechanical and chemical conditioning method of LDC disks, maxillary central incisors brackets (Gemini bracket, 3M, Unitek) were positioned on the surface by Transbond XT (3M, Unitek) adhesive paste light cured for 20 sec (i.e., 10 sec each on mesial and distal direction) with a light intensity of 400 mW/cm^2. Excess composite from the periphery of the metallic bracket was removed with an explorer. Bonding procedure was done by a single operator to circumvent inter appointment variation.

After the procedure, initially the specimens were bathed in distilled water at room temperature 37 °C for five days. Then the samples were transferred to a thermocycler (MiniOpticon Real-Time PCR System, BioRad, USA) between 5 to 55 °C with a dwell time of 45 sec.

For SBS testing the LDC disk were positioned in a universal testing device (Zwick 1120, Ulm, Germany). Through the chisel downforce was applied with velocity of 0.5 mm/min between the metallic bracket and LDC interface. Bond strength values were calculated in megapascals (MPa).

Moreover, four pair of ceramic surfaces were examined under stereomicroscope at 40x magnification to check mode of failure using adhesive remnant index (ARI) (Årtun and Bergland, 1984). The mode of failure was categorized into adhesive, cohesive and admixed. Following are the interpretations of ARI

0 = No adhesive present on tooth surface,
1 = Less than half of adhesive on tooth surface,
2 = More than half of adhesive on tooth surface,
3 = All adhesive on tooth surface.

In accordance to Kolmogorov-Smirnov test SBS values displayed normal distribution. Data related to SBS was charted using statistical package software programme (SPSS version 21, Inc., Chicago, US). To compare the means and standard deviations (SD) among experimental groups analysis of variance (ANOVA) and Tukey multiple comparison test was used at a significance level of ($p < 0.05$).

3. Results

SBS values along with standard deviation (SD) are provided in Table 1.

The highest SBS values were observed in group 3 HF+ UB + S (18.21 ± 1.241) and the lowest SBS values were displayed group 1 surface treated with S only (5.21 ± 0.23). Specimens surface conditioned in group 2 with HF+ S (17.85 ± 1.25), group 3 HF+ UB + S (18.21 ± 1.241) and group 6 ECL + S (17.09 ± 1.114) unveiled comparable SBS values ($p > 0.05$). For SBS values analysis of variance (ANOVA) presented significant difference among the study groups ($p < 0.001$). In group 4 ceramic surface SB with 50 µm Al_2O_3 exhibited SBS values (14.91 ± 1.55) greater than group 5 (12.01 ± 1.29) SECP and group 1 S (5.21 ± 0.23) but less compared to group 2 HF+ S (17.85 ± 1.25), group 3 HF+ UB + S (18.21 ± 1.241) and group 6 ECL + S (17.09 ± 1.114). Similarly, ceramic surface conditioned with SECP group 5 (12.01 ± 1.29) showed significant difference compared to all other groups ($p < 0.05$). (Fig. 1)

The percentage of mode of failure among experimental group based on adhesive remnant index (ARI) is presented in Table 2. Admixed type of failure was displayed in group 6 ceramic surface conditioned with ECL + S. Whereas, in group 1 ceramic surface treated with S and SECP demonstrated adhesive type of failure. Cohesive failure was more pertinent in group 2 HF+ S, group 3 HF+ UB + S and group 4 SB 50 µm Al_2O_3.

Table 1 Means and SD for bond strength values among study groups using ANOVA and Tukey multiple comparisons test.

Experimental groups	Mean ± SD (MPa)	P value!
Group 1 Surface treated with Silane (S) only	5.21 ± 0.23^{A}	< 0.001
Group 2 Hydroflouric acid (HF)+ S (Control)	17.85 ± 1.25^{B}	
Group 3 HF + Ultrasonic bath (UB) + S	18.21 ± 1.241^{B}	
Group 4 Sand blasting (SB) 50 µm Al_2O_3	14.91 ± 1.55^{C}	
Group 5 Self-etch ceramic primer (SECP)	12.01 ± 1.29^{D}	
Group 6 Er,Cr:YSGG laser (ECL) + S	17.09 ± 1.114^{B}	

∞Different superscript capital alphabets denote statistical significant difference.
! Showing significant difference among study group (ANOVA). Tukey multiple comparison test.

4. Discussion

In the existing study, LDC was conditioned with both mechanical and chemical treatments and bonded to metallic bracket with same adhesive. The bond integrity of samples was assessed by SBS whereas, the modes of failures were evaluated using stereomicroscope. The present study was based on the hypothesis that LDC conditioned with ECL will exhibit comparable bond strength to glass ceramic surface treated with HF acid + S. Astoundingly, the hypothesis was accepted.

In clinical scenario, the acceptable bond strength of metallic brackets bonded to enamel is minimum of 8Mpa (Reynolds, 2016). Interestingly, all conditioned LDC exhibited SBS values higher than the clinical range except for group 1 surface treated with S. Since, the present study is of an in-vitro study design SBS values should be interpreted with extreme caution in clinical scenario as there are multiple factors that may influence SBS i.e., bracket base and type, kind of adhesive, form of material and light curing device (Abu Alhaija et al., 2010; Al-Hity et al., 2012). Nevertheless, in-vitro studies do provide a direction which is helpful in testing new methods before using them in-vivo.

In the current study, LDC conditioned with S demonstrated the lowest SBS values (5.21 ± 0.23). This finding was in concurrence with a study by (Türk et al., 2006) who found bond failures during thermocycling with low SBS values of LDC conditioned with S only. Similarly, (Barbosa et al., 1995) experienced an identical finding and explicated that high solubility of silane during thermocycling was the cause of low SBS values in S treated groups. Available evidence by (Özcan et al., 2004; Harari et al., 2003) advocates applying S only to LDC does not improve bond strength and that surface conditioning of LDC chemically or mechanically along with S is essential.

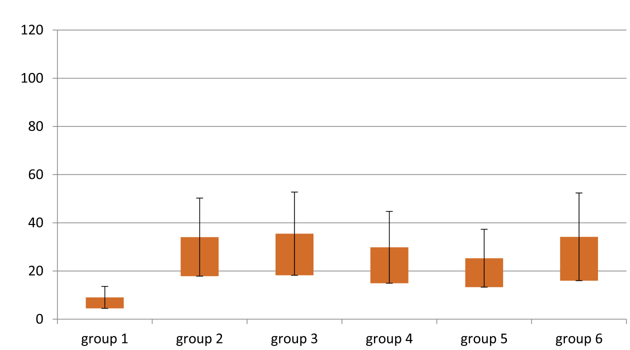

Fig. 1 Shear bond strength values among experimental groups.

Table 2 Percentages of mode of failures among trial groups using adhesive remnant index (ARI).

Experimental groups	0	1	2	3	n
Group 1					
Surface treated with Silane (S) only	90%	10%	–	–	8
Group 2					
Hydroflouric acid (HF)+ S (Control)	5%	5%	58%	32%	8
Group 3					
HF+ Ultrasonic bath (UB) + S	10%	10%	55%	25%	8
Group 4					
Sand blasting (SB) 50 μm Al_2O_3	7%	63%	20%	10%	8
Group 5					
Self-etch ceramic primer (SECP)	50%	20%	15%	15%	8
Group 6					
Er,Cr:YSGG Laser (ECL) + S	30%	25%	25%	20%	8

LDC in the current study was etched with 9.6% HF acid for 1 min and then application of S. However, different concentration and duration of HF acid proposed different results (Wolf et al., 1993). To attain standardization, in the present study 1 min conditioning of LDC with 9.6% HF acid was proposed as content of glass is less in LDC with smaller crystal size which improves bond strength values and micromechanical retention (Gonçalves et al., 2011). A study by (Zogheib et al.,2011) advocated that duration of HF acid increases the risk of ceramic fracture and reduces flexural strength of glass ceramic (Zogheib et al., 2011). HF acid etching of LDC is considered to be a gold standard but application of S is an extra step in clinical settings which invites inaccuracy (Alnassar et al., 2017). Moreover, corrosive nature of HF acid may cause harm to patients (Xiaoping et al., 2014).

In the existing study, SBS values of HF acid + UB + S was found to be highest (18.21 ± 1.241) compared to all other groups. A plausible explanation to this outcome is post etch cleaning by UB removing insoluble salts produced after conditioning of LDC with HF acid hindering S adhesion to glass ceramic (Bruzi et al., 2017). Even though, bond strength values were found to be maximum in this group, SBS value was statistically insignificant compared to the gold standard HF+ acid + S. In authors opinion, a possible description to this finding is micromechanical retention being the foremost mechanism generated by HF-etching to LDC and application of S not bringing benefit to the adhesion process. This narrative is supported by (Schmage et al., 2003)

It is also worthy-of-note that HF+ acid + S (17.85 ± 1. 25) and ECL+ S (17.09 ± 1.114) exhibited comparable bond strength values. ECL on repair bond strength of LDC has already been documented and have presented acceptable outcomes (Ebrahimi Chaharom et al., 2018). Similarly, different laser prototypes i.e., Nd-YAG, Er:YAG have shown contradictory results when conditioned to glass ceramic (Hosseini et al., 2015;Yassaei et al., 2013) This heterogenicity in outcomes can be accredited to different power and frequency, duration of phototherapy, distance of tip from ceramic surface, type of tip, irrigation, type of ceramic, number of thermocycles and bonding system. The author speculates that in the existing study, comparable bond strength in group 6 (17.09 ± 1.114) treated by ECL at (4.5 W 30 Hz) is due to formation of micro depths and micro abrasion on LDC surface making easy penetration of S therefore, improving SBS values.

Worthy of note was SBS values of LDC sandblasted with Al_2O_3 displayed higher SBS values (14.91 ± 1.55) compared to LDC conditioned with SECP (12.01 ± 1.29). A probable explanation to this argument is that sandblasting removes glazed surface from LDC which negatively effects bond strength values (Cevik et al., 2017). However, this method of conditioning is not appreciated as it is believed that cracks produced by deglazing fractures the glass ceramic itself (Schmage et al., 2003). Similarly, use of SECP to condition LDC is convenient, works in a single step and simplifies bonding procedures but it contains ammonium poly fluoride a milder acid compared to HF acid hence produces gentler, shallower etch pattern with weak SBS values (El-Damanhoury and Gaintantzopoulou, 2018) This argument parallels to the results of the present study.

Interestingly, according to ARI ECL on LDC presented admixed type of failure. In authors belief thermomechanical damage of LDC is a cause of this type of failure. Similarly, LDC conditioned with S only, SECP resulted in adhesive type of failure. This finding corresponds to low SBS scores in these groups. A mild gentler etching pattern by SECP and lack of chemical adhesion of S to LDC might be the reason for such results. Cohesive type of failure was displayed in HF acid + S, HF acid + UB + S and SB with Al_2O_3. A study by Thurmond et al., asserted that SBS values of LDC with metallic bracket equal or greater than 13 MPa are subjected to cohesive type of failure (Thurmond et al., 1994). This parallels the findings of the present study.

Within the limitations of the present study. More in-vitro and in-vivo studies are essential to confirm and substantiate the results of the existing study. These results are only applicable to the type of ceramic used, type of laser and laser parameters and adhesive. Future studies should be directed on surface profilometry, surface energy of LDC along with microleakage scores of metallic brackets bonded to lased LDC conditioned with ECL.

5. Conclusion

LDC conditioned with ECL at (4.5 W and 30 Hz) has a potential to be used in clinical settings alternate to HF acid.

Ethical statement

The research work detailed and discussed in the manuscript have not been previously published and is not been concurrently submitted elsewhere.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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