

Photosensitization of lithium di-silicate ceramic by Er, Cr: YSGG and fractional carbon dioxide laser bonded to orthodontic bracket

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ABSTRACT

Aim: To evaluate the shear bond strength (SBS) and modes of lithium disilicate ceramics (LDC) photosensitized by Er,Cr:YSGG (ECL) and fractional carbon dioxide (CO₂) laser bonded to metallic bracket compared to traditional conditioning methods.

Material and method: Fifty LDC discs were polished and randomly allocated into 5 groups (n = 10) each. Group 1 were photosensitized with ECL + Silane (S). Group 2 were irradiated using CO₂ laser + S. In group 3 LDC discs were treated with aluminium trioxide (Al₂O₃) air abrasion (AA). Moreover, samples in group 4 and 5 were conditioned with Hydrofluoric acid (HFA) + S (Control) and Self-Etch Glass Ceramic Primer (SEGCP). Following conditioning regimen fifty maxillary central incisor brackets were pasted on LDC using adhesive material. SBS testing was performed by mounting the specimens on a universal testing machine. After debonding, sheared surface was examined under stereomicroscope to classify failure mode using adhesive remnant index (ARI). Mean and standard deviation (SD) were compared by analysis of variance (ANOVA) and Tukey multiple comparison test at a significance level of p = 0.05.

Results: Among the conditioning groups the highest SBS values were presented by HFA + S (21.08 ± 1.06). The lowest SBS values were displayed by AA Al₂O₃ (12.61 ± 0.45). SBS of samples conditioned with SEGCP showed significant difference amongst all experimental groups (16.76 ± 0.81).

Conclusion: LDC photosensitized with CO₂ and ECL has a potential to be recommended in clinical settings alternate to HFA + S when bonded to metallic bracket.

1. Introduction

Demand of improve facial aesthetics has increased adults seeking orthodontic treatment. Multiple dental restorative materials such as amalgam, composites and different ceramics are offered by dentists to restore adult dentition [1,2]. However, LDC remains a leading choice for direct and indirect restorations due to better aesthetic appeal, diversity, higher fracture and bending resistance [3]. However, poor compatibility of bracket with LDC and high failure rate has been troublesome and challenging for the orthodontist [4,5]. Therefore, pre-treatment of ceramic surface is necessary through certain approaches to attain sufficient strength [4].

Various surface treatment modification of LDC has been proposed to improve bond strength. Chemical conditioning methods vary from hydrofluoric acid (HFA), phosphoric acid (PA), self-etch glass ceramic primer (SEGCP) to application of silane coupling agent. Whereas, mechanical roughing of LDC using diamond burs and sand blasting with

aluminium trioxide (Al₂O₃) are well documented [6,3]. At present, etching of LDC with HFA and silane is considered as a gold standard. HFA selectively dissolves glass matrix, improves surface energy and wettability for silane coupling agent thus improving SBS values [5,7]. However, use of HFA may result in acid burn, tissue necrosis and weakens the ceramic structure [8]. Moreover, it is advocated Al₂O₃ surface roughening imposes microcracks on LDC improving bond durability [6,1]. Recently, SEGCP has been introduced as single step LDC conditioner which is less technique sensitive and minimizes the toxic risk proposed by HFA [7]. Yet, a study by Lopes et al., and Hatem et al., proclaims SEGCP produces less pronounced etching pattern compared to HFA when applied on LDC compromising durable bonding [9,10].

In addition to the existing conditioning methods, laser irradiation using ECL on dentine, enamel surfaces and in various dental application have demonstrated overwhelming outcomes [11,12]. ECL works on a principal of micro abrasion at wavelength of 2790 nm and its use for photosensitization in zirconia and porcelain repair have revealed

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positive and convincing outcomes [13,14]. Similarly, effect of CO₂ laser on treating scars, wrinkles and warts has been successful [15,16] but its effect on LDC in improving SBS is still unexplored and unprecedented.

It is hypothesized that ECL and CO₂ photosensitization on LDC will exhibit comparable SBS to surface conditioned with HFA. Therefore, the aim of the present in-vitro study was to evaluate the SBS and modes of failure of LDC photosensitized by ECL and CO₂ bonded to metallic bracket compared to traditional conditioning methods.

2. Material and method

Fifty LDC (IPS e max Ivoclar, Liechtenstein) discs having 10 mm diameter 2 mm thickness were polished using 800 grit abrasive carbide paper (Wuxi, Yinli, Jiangsu, China) in an automated polishing machine (Aropol 2 V, Arotec) at 250 rpm and glazed before conditioning procedure. The discs were bathed in 99.9% ethyl alcohol (Jiangsu, Juming, China) to remove residual debris for 2 min and air dried.

Based on the surface treatment methods LDC discs were randomly allocated into 5 groups (n = 10) each. Samples in group 1 were photosensitized with ECL + Silane (S). Specimen in group 2 were irradiated using CO₂ laser + S. In group 3 LDC discs were treated with Al₂O₃ air abrasion (AA). Moreover, samples in group 4 and 5 were conditioned with HFA + S (Control) and SEGCP. Surface conditioning protocols for each group were as follows:

Group 1 Each specimen was photosensitized using ECL (Biolase-Waterlase I-Plus) under 60% water and 40% air in a non-contact circular motion using laser tip (MZ10) at 2 mm from the disc surface at 4.5 W and 30 Hz for a duration of 60 s. After laser surface treatment, S coupling agent (Monobond Plus ceramic primer Ivoclar, vivadent) in a thin layer was applied for 60 s and air dried.

Group 2 Each disc of LDC was photosensitized with a CO₂ fractional laser (Lumenis Ltd., UltraPulse, Israel) in a dynamic mode at 10 W, 200 Hz from 3 mm distance with an irradiation time of 60 s. The pulse duration was 1.75 ms. After surface treatment, S coupling agent was applied as described previously.

Group 3 Samples were sandblasted with Al₂O₃ using an intraoral grit blaster (Shibang Machinery Co. Shanghai, China) from 10 mm distance at a pressure of 2.8 MPa for 20 s. The tip of the sand blaster was kept perpendicular to the ceramic surface. The specimen was rinsed and air dried.

Group 4 9.6% HFA gel (IPS ceramic etching gel Ivoclar, vivadent) was applied on LDC disc for 60 s washed and air dried. S coupling agent was applied as explained earlier.

Group 5 SEGCP (Monobond etch & prime, Ivoclar Vivadent, Schaan, Liechtenstein) with the help of a micro brush was scrubbed on the glass ceramic disc for 10 s and left untouched for 40 s. The specimen was then washed with air-spray and air dried.

After performing conditioning regimen in all groups fifty maxillary central incisor brackets (Gemini bracket, 3 M, Unitek) with a surface area of 12.08mm² were pasted using composite (Transbond XT) with bracket pliers. The adhesive paste was light cured for 40 s 400 mw/cm² (Bluephase G2, Ivoclar, Vivadent) (20 s each distally and mesially) and excess was removed. Bonding procedure was completed by single operator to abate inter operator disparity. The specimens were kept in 0.9% NaCl solution for 24 h and then thermocycled (C1000 Touch, Thermal Cycler, Biorad) between 5C to 55C with a dwell time of 45 s. (Table 1).

2.1. Shear bond strength (SBS) testing

Shear Bond Strength (SBS) testing was performed by mounting the specimens in a jig of a universal testing machine (Zwick 1120, Ulm, Germany). A broad shearing edge of 1 mm and cross head speed of 0.5 mm/min external force was exerted between LDC and metallic bracket base. A software was used to record SBS in Megapascal (Mpa).

After debonding, sheared surface was examined under

Table 1

Name of Manufacturers and Materials used in the study.

Product	Manufacturer
Lithium Disilicate Ceramics	IPS e max Ivoclar, Liechtenstein
Silane coupling agent	Monobond Plus ceramic primer Ivoclar, vivadent
HF acid at 9.6%	IPS ceramic etching gel Ivoclar, vivadent
Self-etch glass ceramic primer	Monobond etch & prime, Ivoclar Vivadent, Schaan, Liechtenstein
Maxillary central incisors brackets	Gemini bracket, 3 M, Unitek
Composite	Transbond XT

stereomicroscope at 60x magnification to classify failure mode using ARI. The shear fracture was classified into cohesive, adhesive and admixed based on the interpretation of ARI.

SBS displayed normal distribution using Kolmogorov-Smirnov test. Using IBM SPSS Statistics (SPSS Inc., Chicago, IL, USA) mean and standard deviation (SD) were compared by analysis of variance (ANOVA) and Tukey multiple comparison test at a significance level of p = 0.05.

3. Results

Mean SBS values were demonstrated in Table 2. Among the conditioning groups the highest SBS values were presented by HFA + S (21.08 ± 1.06). The lowest SBS values were displayed by air abrasion Al₂O₃ (12.61 ± 0.45). SBS of samples conditioned with SEGCP showed significant difference amongst all experimental groups (16.76 ± 0.81). For bond strength values, analysis of variance (ANOVA) showed significant difference among study groups p < 0.05. Among, conditioning groups SBS values of ECL + S (20.11 ± 2.77), CO₂ laser + S (19.98 ± 2.94) and HFA + S (21.08 ± 1.06) were comparable p < 0.05 (Fig. 1).

Failure mode amongst different experimental groups were projected based on ARI. Admixed failure type was pertinent in lased and HFA groups. Group conditioned with Al₂O₃ and SEGCP majorly exhibited low number of scores between 0 and 1 (Table 3).

4. Discussion

The present study was based on the hypothesis that ECL and CO₂ photosensitization on LDC surface will exhibit comparable SBS to surface conditioned with HFA. Surprisingly, the hypothesis was accepted as SBS values between three groups i.e., LDC conditioned with HFA and photosensitized with ECL and CO₂ were comparable. SBS values of different experimental groups were evaluated using universal testing

Table 2

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 ECL + S	20.11 ± 2.77*	< 0.05
Group 2 CO ₂ laser + S	19.98 ± 2.94*	
Group 3 Air Abrasion (AA) Al ₂ O ₃	12.61 ± 0.45 [‡]	
Group 4 Acid Etching (Hydrofluoric acid HFA + S) (Control)	21.08 ± 1.06*	
Group 5 Self-Etch Glass Ceramic Primer (SEGCP)	16.76 ± 0.81 [‡]	

∞ Different superscript characters denote statistical significant difference.

!Showing significant difference among study group (ANOVA).

(Tukey multiple comparison test).

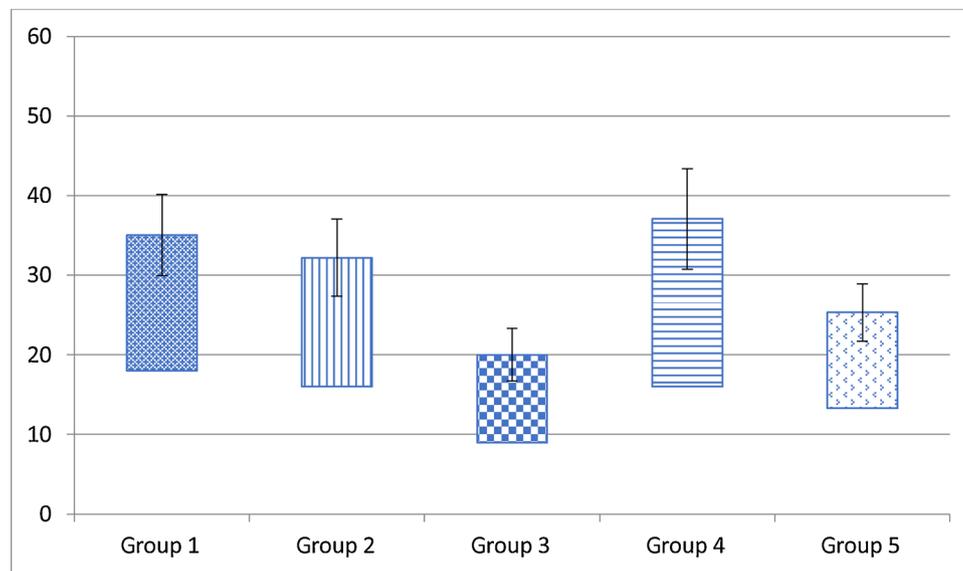


Fig. 1. Bond strength values among experimental groups.

Group 1 (ECL + S), **Group 2** (CO₂ laser + S), **Group 3** (Air Abrasion Al₂O₃), **Group 4** (Acid Etching [Hydrofluoric acid HFA + S] [Control]), **Group 5** (Self-Etch Glass Ceramic Primer [SEGCP]).

Table 3

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

Experimental Groups	0	1	2	3	n
Group 1 ECL + S	5%	40%	35%	20%	10
Group 2 CO ₂ Laser + S	10%	35%	40%	15%	10
Group 3 Air Abrasion (AA) Al ₂ O ₃	15%	60%	20%	5%	10
Group 4 Acid Etching (Hydrofluoric acid HFA + S) (Control)	15%	30%	35%	20%	10
Group 5 Self-Etch Glass Ceramic Primer (SEGCP)	25%	38%	7%	30%	10

machine. The technique is standardized, consistent and accounts for providing results and relate data among multiple groups simultaneously [17].

Two main ingredients of LDC are glass matrix composed of silica in tetrahedral arrangement and lithium oxide which works as a flux, maintaining the temperature when heated [5]. HFA on reaction with glass matrix form hexafluoro-silicate, exposing the crystalline structure making the surface rough for better micromechanical retention [18]. There are many in-vitro studies which are in favour of using HFA as surface conditioner on LDC as it improves bond strength [19,20]. However, study by Yen et al., and Ozcan et al., disapproves the use of HFA in clinical settings as HFA is corrosive and reduces flexural strength of ceramic [21,8].

In the current study the authors used laser parameters settings of (4.5 W and 30 Hz) for ECL and (10 W and 200 Hz) for CO₂ for photosensitization of LDC. At these settings, ECL exhibited comparable SBS (20.11 ± 2.77) to HFA (21.08 ± 1.06). Lately, different laser prototypes, Er:YAG and Nd:YAG have already demonstrated low fracture rate and improved bond strength values when used on ceramic surface [22]. However, a recent study by Ebrahimi et al., negates the narrative that ECL improves bond strength when irradiated on LDC [23]. Similarly, a study by Alkudhairy et al., supports the practise of ECL for photosensitization of LDC [7]. An inconsistency in results of the two studies can be attributed to the crystalline structure of LDC, frequency and power parameter, design of bracket, bonding system, light curing

devices and laser duration and distance [1,7].

It is worthy of note that CO₂ laser demonstrated comparable (19.98 ± 2.94) SBS to HFA (21.08 ± 1.06). Since, the use of CO₂ for photosensitization of LDC is unprecedented therefore, to compare the findings of present study with previous studies is not probable. Although there are studies by Zarif et al., and Giuliano et al., who claimed that CO₂ improved bond strength of zirconia and feldspathic porcelain when bonded to metallic bracket without damaging the surface [24,25]. In authors view, comparable bond strength of LDC photosensitized with CO₂ is due to thermomechanical effect of CO₂ providing a surface receptive for silanization hence improving mechanical retention and bond strength. Moreover, lased LDC in the present study displayed high standard deviation (SD) when compared to other groups. A credible reason for this outcome is sweeping motion of laser beam controlled manually displaying selective conditioning pattern [26].

The lowest SBS values were displayed by LDC surface conditioned by air abrasion AA (Al₂O₃) (12.61 ± 0.45). The results of the present study were in contradiction with the studies by Turk et al., [3] Schamag et al. [4], and Cevik et al. [6]. The high bond strength in former studies can be attributed to better deglazing process. However, Cevik et al. and Schamag et al. highlighted that high surface roughness was a disadvantage for the ceramic despite increase SBS [6,4]. Moreover, low bond strength in current study in AA group can be accredited to ineffective irregularities formed by (Al₂O₃) or deposition of particles hindering the interface between composite and LDC [27].

Interestingly, application SEGCP on LDC unveiled SBS values (16.76 ± 0.81) better than AA (Al₂O₃) (12.61 ± 0.45) but, a significant difference in bond strength was found among other experimental groups. Manufacturer claims SEGCP conditions and silanes LDC in a single step with less conditioning time and concentration compared to HFA as a conditioner [10]. SEGCP contains ammonium bifluoride (ABF), which is less toxic and less hazardous than HF with similar etching patterns to HFA [9]. These claims of the manufacturer were not in support to the findings of the present study. Our conclusions were in concurrent with a study by Swank et al. narrating that effect of SEGCP is negligible on LDC demonstrating less roughness and shallower pattern [28]. However, further studies are needed to warrant these conclusions.

A direct connection has been observed between ARI scores and SBS. High ARI scores correspond high SBS values [29]. In the present study,

majority of scores between (2 and 3) scores were observed in lased and HFA + S group. This is desirable in orthodontics as the interface between bracket and adhesive is considered safe [30]. Moreover, AA (Al_2O_3) and SEGCP exhibited low ARI scores consistent to low SBS score, displaying bond failure between LDC and adhesive interface.

Within the limitations of the present study, more in vitro studies focusing on surface profilometry, surface changes, quality of bond testing and surface free energy measurements should be performed to validate the conclusions of the present study. Moreover, future studies should be directed on different laser parameters of ECL and CO_2 and their effect on LDC. The findings of the current study are only applicable to the type of laser parameters, bracket, adhesive material and shear bond parameters.

5. Conclusion

LDC photosensitized with CO_2 and ECL has a potential to be recommended in clinical settings alternate to HFA + S when bonded to metallic bracket.

Declaration of Competing Interest

The author declares no conflict of interest.

References

- [1] B. Mehmeti, J. Kelmendi, D. Iljazi-Shahiqi, B. Azizi, S. Jakovljevic, F. Haliti, S. Anić-Milošević, Comparison of shear bond strength orthodontic brackets bonded to zirconia and lithium disilicate crowns, *Acta Stomatol. Croat.* 53 (2019) 17–27, <https://doi.org/10.15644/asc53/1/2>.
- [2] T. Topcuoglu, R. Oksayan, S. Topcuoglu, M.E. Coskun, N.E. Isman, Effect of Er:YAG laser pulse duration on shear bond strength of metal brackets bonded to a porcelain surface, *Photomed. Laser Surg.* 31 (2013) 240–246, <https://doi.org/10.1089/pho.2012.3463>.
- [3] T. Türk, D. Saraç, Y.S. Saraç, S. Elekdağ-Türk, Effects of surface conditioning on bond strength of metal brackets to all-ceramic surfaces, *Eur. J. Orthod.* 28 (2006) 450–456, <https://doi.org/10.1093/ejo/cj1010>.
- [4] P. Schmage, I. Nergiz, W. Herrmann, M. Özcan, Influence of various surface-conditioning methods on the bond strength of metal brackets to ceramic surfaces, *Am. J. Orthod. Dentofacial Orthop.* 123 (2003) 540–546, [https://doi.org/10.1016/S0889-5406\(02\)56911-0](https://doi.org/10.1016/S0889-5406(02)56911-0).
- [5] H. Özdemir, L.İ. Aladağ, Effect of different surface treatments on bond strength of different resin cements to lithium disilicate glass ceramic: an in vitro study, *Biotechnol. Biotechnol. Equip.* 31 (2017) 815–820, <https://doi.org/10.1080/13102818.2017.1334589>.
- [6] P. Cevik, N. Karacam, O. Eraslan, Z. Sari, Effects of different surface treatments on shear bond strength between ceramic systems and metal brackets, *J. Adhes. Sci. Technol.* 31 (2017) 1105–1115, <https://doi.org/10.1080/01694243.2016.1245074>.
- [7] F. Alkudhairy, M. Naseem, Z.H. Ahmad, A.N. Alnooh, F. Vohra, Efficacy of phototherapy with different conventional surface treatments on adhesive quality of lithium disilicate ceramics, *Photodiagnosis Photodyn. Ther.* 25 (2019) 292–295, <https://doi.org/10.1016/j.pdpdt.2019.01.015>.
- [8] M. Özcan, A. Allahbeickaraghi, M. Dündar, Possible hazardous effects of hydrofluoric acid and recommendations for treatment approach: a review, *Clin. Oral Investig.* 16 (2012) 15–23, <https://doi.org/10.1007/s00784-011-0636-6>.
- [9] G. Lopes, J. Perdigão, D. Baptista, A. Ballarin, Does a self-etching ceramic primer improve bonding to lithium disilicate ceramics? Bond strengths and FESEM analyses, *Oper. Dent.* 44 (2018) 210–218, <https://doi.org/10.2341/17-355-1>.
- [10] H.M. El-Damanhoury, M.D. Gaintantzopoulou, Self-etching ceramic primer versus hydrofluoric acid etching: etching efficacy and bonding performance, *J. Prosthodont. Res.* 62 (2018) 75–83, <https://doi.org/10.1016/j.jpor.2017.06.002>.
- [11] F. Vohra, N. Labban, P.G. Cert, A. Al-Hussaini, M. Al-Jarboua, R. Zawawi, A. Alrahlah, M. Naseem, Influence of Er:Cr:YSGG laser on shear bond strength and color stability of Lithium disilicate ceramics: an in vitro study, *Photobiomodulation Photomed. Laser Surg.* (2019), <https://doi.org/10.1089/photob.2018.4582>.
- [12] F. Alkudhairy, A. Alkheraif, M. Bin-Shuwaish, S. Al-Johany, M. Naseem, F. Vohra, Effect of Er:Cr:YSGG laser and ascorbic acid on the bond strength and microleakage of bleached enamel surface, *Photomed. Laser Surg.* 36 (2018) 431–438, <https://doi.org/10.1089/pho.2018.4437>.
- [13] F. Alkudhairy, M. Naseem, M. Bin-Shuwaish, F. Vohra, Efficacy of Er Cr: YSGG laser therapy at different frequency and power levels on bond integrity of composite to bleached enamel, *Photodiagnosis Photodyn. Ther.* 22 (2018) 34–38, <https://doi.org/10.1016/j.pdpdt.2018.02.019>.
- [14] P.V. Miranda, J.A. Rodrigues, A. Blay, J.A. Shibli, A. Cassoni, Surface alterations of zirconia and titanium substrates after Er,Cr:YSGG irradiation, *Lasers Med. Sci.* 30 (2014) 43–48, <https://doi.org/10.1007/s10103-013-1516-x>.
- [15] A. Mossaad, A. Kotb, M. Abdelrahman, H. Al Ahmady, Post-surgical repair of cleft scar using fractional CO_2 laser, *Open Access Maced. J. Med. Sci.* 6 (2018) 1231, <https://doi.org/10.3889/oamjms.2018.250>.
- [16] I. Majid, S. Imran, Efficacy and safety of fractional CO_2 laser resurfacing in non-hypertrophic traumatic and burn scars, *J. Cutan. Aesthet. Surg.* 8 (2015) 159, <https://doi.org/10.4103/0974-2077.167276>.
- [17] K. Sirisha, Y. Ravishankar, P. Ravikumar, T. Rambabu, Validity of bond strength tests: a critical review-part II, *J. Conserv. Dent.* 17 (2014) 420, <https://doi.org/10.4103/0972-0707.139823>.
- [18] L.V. Zogheib, A. Della Bona, E.T. Kimpara, J.F. McCabe, Effect of hydrofluoric acid etching duration on the roughness and flexural strength of a lithium disilicate-based glass ceramic, *Braz. Dent. J.* 22 (2011) 45–50.
- [19] P. Magne, K.R. Kwon, U.C. Belsler, J.S. Hodges, W.H. Douglas, Crack propensity of porcelain laminate veneers: a simulated operatory evaluation, *J. Prosthet. Dent.* 81 (1999) 327–334, [https://doi.org/10.1016/S0022-3913\(99\)70277-5](https://doi.org/10.1016/S0022-3913(99)70277-5).
- [20] O. Addison, P.M. Marquis, G.J.P. Fleming, The impact of hydrofluoric acid surface treatments on the performance of a porcelain laminate restorative material, *Dent. Mater.* 23 (2007) 461–468, <https://doi.org/10.1016/j.dental.2006.03.002>.
- [21] T.W. Yen, R.B. Blackman, R.J. Baez, Effect of acid etching on the flexural strength of a feldspathic porcelain and a castable glass ceramic, *J. Prosthet. Dent.* 70 (1993) 224–233, [https://doi.org/10.1016/0022-3913\(93\)90056-T](https://doi.org/10.1016/0022-3913(93)90056-T).
- [22] Z. Xu, J. Li, X. Fan, X. Huang, Bonding strength of orthodontic brackets on porcelain surfaces etched by Er:YAG laser, *Photomed. Laser Surg.* 36 (2018) 601–607, <https://doi.org/10.1089/pho.2017.4429>.
- [23] M.E. Ebrahimi Chaharom, F. Pournaghi Azar, N. Mohammadi, R. Nasiri, Effect of surface preparation with Nd:YAG and Er,Cr:YSGG lasers on the repair bond strength of Lithium disilicate glass ceramic to a silorane-based composite resin, *J. Dent. Res. Dent. Clin. Dent. Prospects* 12 (2018) 12–17, <https://doi.org/10.15171/joddd.2018.003>.
- [24] H. Zarif Najafi, M. Oshagh, S. Torkan, B. Yousefipour, R. Salehi, Evaluation of the effect of four surface conditioning methods on the shear bond strength of metal bracket to porcelain surface, *Photomed. Laser Surg.* 32 (2014) 694–699, <https://doi.org/10.1089/pho.2014.3782>.
- [25] C. Giuliano, D. Selaj, E. Manzon, D. Pasqualini, E. Berutti, N. Scotti, Bonding to zirconia and lithium-disilicate: analysis of different chemical treatments, *Dent. Mater.* 30 (2014) e22, <https://doi.org/10.1016/j.dental.2014.08.045>.
- [26] S. Üşümez, M. Orhan, A. Üşümez, Laser etching of enamel for direct bonding with an Er,Cr:YSGG hydrokinetic laser system, *Am. J. Orthod. Dentofacial Orthop.* 122 (2002) 649–656, <https://doi.org/10.1067/mod.2002.127294>.
- [27] F. Ahriari, A. Boruziniat, H.S. Mohammadipour, M. Alirezai, The effect of surface treatment with a fractional carbon dioxide laser on shear bond strength of resin cement to a lithium disilicate-based ceramic, *Dent. Res. J. (Isfahan)* 14 (2017) 195–202.
- [28] H.M. Swank, N.C. Motyka, C.W. Bailey, K.S. Vandewalle, Bond strength of resin cement to ceramic with simplified primers and pretreatment solutions., *Gen. Dent.* 66 (n.d.) 33–37.
- [29] É. Faria-Júnior, R.D. Guiraldo, S.B. Berger, A.B. Correr, L. Correr-Sobrinho, E.F.R. Contreras, M.B. Lopes, In-vivo evaluation of the surface roughness and morphology of enamel after bracket removal and polishing by different techniques, *Am. J. Orthod. Dentofacial Orthop.* 147 (2015) 324–329, <https://doi.org/10.1016/j.jajodo.2014.10.033>.
- [30] Fernanda de Souza Henkin, Érika de Oliveira Dias de Macêdo, Karoline da Silva Santos, Marília Schwarzbach, Susana Maria Werner Samuel, Karina Santos Mundstock, In vitro analysis of shear bond strength and adhesive remnant index of different metal brackets, *Dental Press J. Orthod.* 21 (2017) 67–73, <https://doi.org/10.1590/2177-6709.21.6.067-073.oar>.