



Optimized Er: YAG Laser Irradiation Distance to Achieve the Strongest Bond Strength Between Orthodontic Brackets and Zirconia-Ceramics

Seyyed Amir Hossein Mirhashmi¹, Mohammad Sadeq Ahmad Akhundi^{1*}, Saeed Mehdi Pour Ganji², Mehdi Allahdadi³, Mohammad Norouzi⁴, Nasim Chiniforush^{5,6*}

¹Department of Orthodontics, School of Dentistry, Laser Research Center of Dentistry, Dentistry Research Institute, Tehran University of Medical Sciences, Tehran, Iran

²Department of Periodontics, Faculty of Dentistry, Shahed University of Medical Sciences, Tehran, Iran

³Faculty of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran

⁴Department of Orthodontics, School of Dentistry, Ilam University of Medical Sciences, Ilam, Iran

⁵Dental Implant Research Center, Dentistry Research Institute, Tehran University of Medical Sciences, Tehran, Iran

⁶Department of Surgical Sciences and Integrated Diagnostic (DISC), University of Genoa, Genoa, Italy

*Correspondence to

Mohammad Sadeq Ahmad Akhundi, Professor, Department of Orthodontics, Faculty of Dentistry, Tehran University of Medical Sciences, Tehran, Iran. Email: ahmadakh@tums.ac.ir
Nasim Chiniforush, Assistant professor, Dental Implant Research Center, Dentistry Research Institute, Tehran University of Medical Sciences, Tehran, Iran. Email: n-chiniforush@farabi.tums.ac.ir

Published online June 21, 2020



Abstract

Introduction: In recent decades zirconium oxide has been introduced in the field of dentistry as a high-strength ceramic. Unlike its mechanical advantages, however, due to its inert chemical properties, it bonds poorly to other substrates, so improving bonding strength to an adhesive material is necessary.

Methods: In this experimental study, 70 ceramic zirconia blocks were prepared and distributed randomly among 7 groups. Then the shear bond strengths were determined and the samples were examined by a scanning electron microscope (SEM). Statistical analysis was performed by one-way ANOVA and multiple Tukey comparisons.

Results: One-way analysis of variance (ANOVA) showed that laser irradiation distance has a significant effect on orthodontics brackets bond strength to zirconia-ceramics. Based on the Tukey post hoc test, each group was compared with other groups and the contact mode and 2 mm distance groups showed significantly higher bond strength than other groups (P value <0.05).

Conclusion: Orthodontic bracket bond strength to zirconia-ceramics will be reduced by increasing Er: YAG laser irradiation distance from samples. The highest bond strength will be achieved when laser irradiation distance is 2 mm or when the laser beam is in contact with samples.

Keywords: Orthodontic bracket bond strength; Zirconia surface; Laser radiation distance; Er:YAG Laser.

Introduction

Recently, Zirconium-based ceramics have become a favorite choice for many dentists to manufacture dental prostheses due to their chemical stability, biocompatibility, proper compressive strength, and thermal expansion coefficient similar to the tooth structure. Zirconia also has a beautiful appearance and can cover patients' high esthetic demands.¹⁻³

In recent years, the number of adult patients for orthodontic treatment have been increased and clinicians have encountered the orthodontic bracket bonding process to dental crowns as a challenge. Orthodontic forces are applied through the bracket to the zirconia surface to induce orthodontic tooth movement, so reliable bonding is crucial to prevent bonding failure during the orthodontic treatment; on the other hand, when brackets

are debonded, damage to the restoration surface should be minimized.⁴

Different types of zirconia material have a different structure, different shape, size and composition of particle, and also different surface properties; therefore, surface preparation methods and the bond strength that will be achieved by each method are different.⁵

Due to the neutral surface of zirconia, bonding materials cannot effectively be attached to it without surface preparation, and surface modification is required to create an effective bond that can resist orthodontic forces. Various methods have been used to prepare the zirconia surface before bracket bonding, including surface wear by milling, sandblasting with Al₂O₃ particles, Er: YAG laser irradiation, and CO₂ laser irradiation. These methods can be followed by applying a coupling agent.⁶⁻⁸

Zirconia ceramics have a crystalline structure with less than 1% glass phase and a minimum amount of silicon dioxide so achieving a suitable micromechanical bond strength between resin cement and the zirconia surface with conventional surface preparation methods such as etching with HFA is incompetent and vain.⁹⁻¹² On the other hand, it has been proved new coupling agents, such as zirconia primer, increase surface wettability and improve bond strength.¹³

Various factors modify the effect of the Er:YAG laser on the target material, including the distance between radiation and the target material, the type of radiation, the wavelength of the radiation, radiation energy, radiation pulse frequency and presence of water in material texture, and cooling methods during operation.^{14,15}

In this study, we investigated the effect of Er: YAG laser irradiation distance on surface conditioning of a zirconia ceramic and shear bond strength between the zirconia ceramic surface and orthodontic brackets

Materials and Methods

In this experimental study, 70 samples of zirconia ceramic block (DD Bio ZS Zirconia) with 10 × 10 × 10 mm dimensions were prepared according to the manufacturer's instructions and distributed randomly among 7 groups:

- Group 1: Putting a thin layer of zirconia primer (Shofu AZ Primer) on the zirconia surface for 10 seconds - No laser radiation
- Group 2: Putting a thin layer of zirconia primer on the surface of the zirconia for 10 seconds/Er: YAG laser application (Contact mode, 10 s, 4 W);
- Group 3: Putting a thin layer of zirconia primer on the surface of the zirconia for 10 seconds/Er: YAG laser application (Distance 2 mm, 10 s, 4 W);
- Group 4: Putting a thin layer of zirconia primer on the zirconia surface for 10 seconds/Er: YAG laser application (Distance 4 mm, 10 s, 4 W);
- Group 5: Putting a thin layer of zirconia primer on the surface of zirconia for 10 seconds/Er: YAG laser application (Distance 6 mm, 10 s, 4 W);
- Group 6: Putting a thin layer of zirconia primer on the surface of the zirconia for 10 seconds/Er: YAG laser application (Distance 8 mm, 10 s, 4 W);
- Group 7: Putting a thin layer of zirconia primer on the surface of zirconia for 10 seconds/Er: YAG laser application (Distance 12 mm, 10 s, 4 W).

The groups were manually exposed to the Er: YAG laser (Smart 2940 Dplus, DEKA) (Frequency: 10 Hz, 4 W, 400 mJ, 10 s). Laser exposure was done by the same person in all groups with the spot scanning method.

Because of irradiation distance importance in this study, a dental probe was fixed to the laser tube so the distances were kept precisely and equally in the samples of each group.

From each group, one sample was taken to study the effect of laser exposure on the zirconia surface by a

scanning electron microscope (SEM).

After laser exposure, zirconia primer (Shofu, AZ Primer, Kyoto, Japan) was applied and after 10 seconds a thin layer of primer (Transbond XT, 3M, Unitek Monrovia, California, USA) was applied. Time was given for better penetration of the adhesive to create a resin tag and a better band. Then airflow was applied for 5 seconds and then light curing (Woodpecker, 1400 mW/cm²) was done for 20 seconds.

In the next step, the resin Adhesive (Transbond XT, 3M, Unitek Monrovia, California, USA) was applied to the base of brackets (Dentaurum, equilibrium2, design optimal, Germany), the brackets were placed and positioned on the surface of zirconia samples, and light curing with ultraviolet light (Woodpecker, 1400 mW/cm²) was done for 40 seconds. Additional light curing for 20 seconds was done to ensure complete polymerization.

Lastly, after sample preparation, the samples were incubated for 24 hours at 37°C to stimulate the oral environment.

After incubation, the samples were molded in a metallic template by self-cured acrylic resin (Acropars Co.) with the aid of orthodontic wire (0.19 "× 0.25") to do the shear test (Zwick, Roell 2050, Germany).

We used orthodontic wire for mounting of samples to ensure that the force in the Zwick machine would apply for all samples in the same direction.

The shear bond strength for each specimen was measured by means of a universal testing machine (Zwick, Roell 2050, Germany). Shear force was applied to the zirconia- bracket junction at a speed of 1 mm/min until the sample was debonded. Finally, specimens and brackets were collected and numbered to conduct an ARI (adhesive remnant index) test.

In 1984, Arthon and Bergland introduced the ARI Index that is defined as follows:

- Score 0: less than 10% of adhesive remains on the sample.
- Score 1: Less than 50% (10%-50%) of adhesive remains on the sample.
- Score 2: More than 50% (50%-90%) of adhesive remains on the sample.
- Score 3: More than 90% of adhesive remains on the sample.

In order to determine the ARI index for samples, a stereomicroscope with a magnification of at least 10 times was used and the amount of resin remained in the zirconia-bracket junction in the zirconia blocks after debonding was coded according to the aforementioned criteria.¹⁶

When the samples were examined under a microscope, we generally observed 3 types of bond failure:

Cohesive failure: Bond failure occurs inside the resin or ceramic

Adhesive failure: Bond failure occurs between ceramic and resin or bracket and resin.

Mixed failure: combination of adhesive and cohesive

To assess the ARI index, a stereomicroscope was used with a 3-megapixel digital camera connected to a computer (EZ4D, Leica). This device has a 7 LED light source that creates high-quality images. The debonded samples were placed on a block under the object lens and were magnified 10 times and examined by the same person twice to obtain the ARI index precisely.

All data were analyzed using SPSS 21 software. A one-way analysis of variance (ANOVA) was performed. The confidence level of this test was 95% and the test power was 80% and the significance level was assumed less than 0.05.

Results

The results showed that the shear bond strength to zirconia-ceramic after laser preparation was reduced by increasing laser beam distance and laser preparation did not statistically improve the bond strength between the orthodontic brackets and the zirconia surface, except when the laser was exposed in contact or at 2 mm distance from the zirconia surface.

The mean and 95% of confidence limit bond strengths in each studied group are shown in Figure 1.

The ARI index results did not show any significant differences among the groups. The results of the stereomicroscope examination are shown in Table 1. The ARI index is a qualitative scale so the ARI data were analyzed with the Kruskal-Wallis test and the results did not show significant differences among the groups ($P = 0.095$).

When checking the bond failure region, it was shown that the bond failure happened more in the adhesive in the conventional group (cohesive failure) and in other groups mostly mixed failure happened.

The zirconia blocks surface after preparation with the laser evaluated with SEM described in Figure 2A-G.

Discussion

Past studies have shown the Erbium laser is more suitable than other lasers such as CO_2 and Nd: YAG for making the zirconia-ceramics surface rough, because other lasers produce so much heat during operation that can have a negative effect on adhesion and mechanical properties of zirconia ceramics.¹⁷

Zirconium primer (AZ-Primer Shofu) was used in this study to prepare the surface of the samples. This primer is superior to other primers in conditioning the zirconia surface due to phosphoric acid monomer presence and it was previously proven by Kitayama et al in 2010.¹⁸

In our study, in addition to bond strength, the ARI index was evaluated and a significant relationship was observed between the ARI index and Shear bond strength that confirmed each other. In other words, in most of the samples, mixed type of bond failure was observed

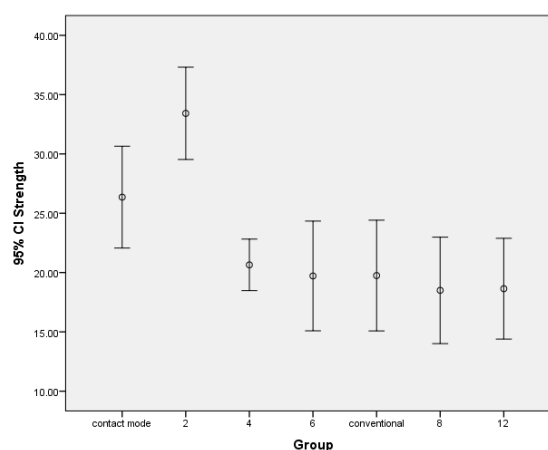


Figure 1. The Mean \pm Standard Deviation of Bond Strength Different Groups

which showed the bond strength is relatively strong and favorable, while in the control group, the most commonly registered code is zero based on the Arton and Bergland criteria, which indicated that the highest type of band failure (70% of the samples) was the adhesive type, implying weaker bond strength in this group.

As it is known, it is better to have more bond failure in the bracket-resin contactor inside the resin because if less adhesive remains on the enamel surface as a result of the bond failure in resin-enamel contact, more stress comes into the enamel surface.¹⁹

In a study done by Bařaran et al, enamel bond strength to orthodontic brackets that were conditioned by the erbium laser after etching decreased by increasing laser irradiation distance. This result is consistent with the result of our study except that we studied bond strength between zirconia-ceramics and brackets.²⁰

The Er: YAG laser is well absorbed in the presence of water and hydroxyapatite so the performance of the laser will enhance humidity.²¹

The bond strength in the group prepared with laser direct contact was lower than the bond strength in the group prepared with the laser from 2 mm distance. The reason is that for the performance of more Erbium lasers, water molecules are needed. When laser beam contact directly to the zirconia surface, water molecules are absent in the laser operation area so laser performance in zirconia surface conditioning is lower compared to zirconia surface conditioning from 2 mm distance.

We studied the samples prepared by the laser and the control group by the SEM microscope. Highest surface changes and roughness were observed in the group conditioned by direct contact laser exposure and in the group conditioned by laser exposure from 2 mm distance. Deeper cavities were produced in these two groups than the other groups. The groups that were prepared from 4 and 6 mm distance had almost identical surfaces, and

Table 1. Distribution of ARI Scores

		Distance*ARI Crosstabulation					Total
		ARI					
		0.00	1.00	2.00	3.00		
Distance	12 mm	Count	3	6	0	1	10
		% within distance	30.0%	60.0%	0.0%	10.0%	100.0%
	8 mm	Count	0	10	0	0	10
		% within distance	0.0%	100.0%	0.0%	0.0%	100.0%
	6 mm	Count	1	7	1	1	10
		% within distance	10.0%	70.0%	10.0%	10.0%	100.0%
	4 mm	Count	3	5	0	2	10
		% within distance	30.0%	50.0%	0.0%	20.0%	100.0%
	Contact	Count	1	9	0	0	10
		% within distance	10.0%	90.0%	0.0%	0.0%	100.0%
	2 mm	Count	2	8	0	0	10
		% within distance	20.0%	80.0%	0.0%	0.0%	100.0%
	Conventional	Count	7	2	1	0	10
		% within distance	70.0%	20.0%	10.0%	0.0%	100.0%
Total	Count	17	47	2	4	70	
	% within distance	24.3%	67.1%	2.9%	5.7%	100.0%	

the groups that were prepared from 12 mm and 8 mm distance had minimal changes and the surface texture was similar to the control group, and this finding was confirmed by the data that were collected from the shear bond strength test.

Further studies are needed to evaluate different distances of erbium laser with different parameters on

shear bond strength of brackets to ceramic surface.

Conclusion

The best results and highest bond strength between the zirconia-ceramics surface and the orthodontics brackets were achieved when the ER: YAG laser was exposed from 2 mm distance or when exposed in direct contact with

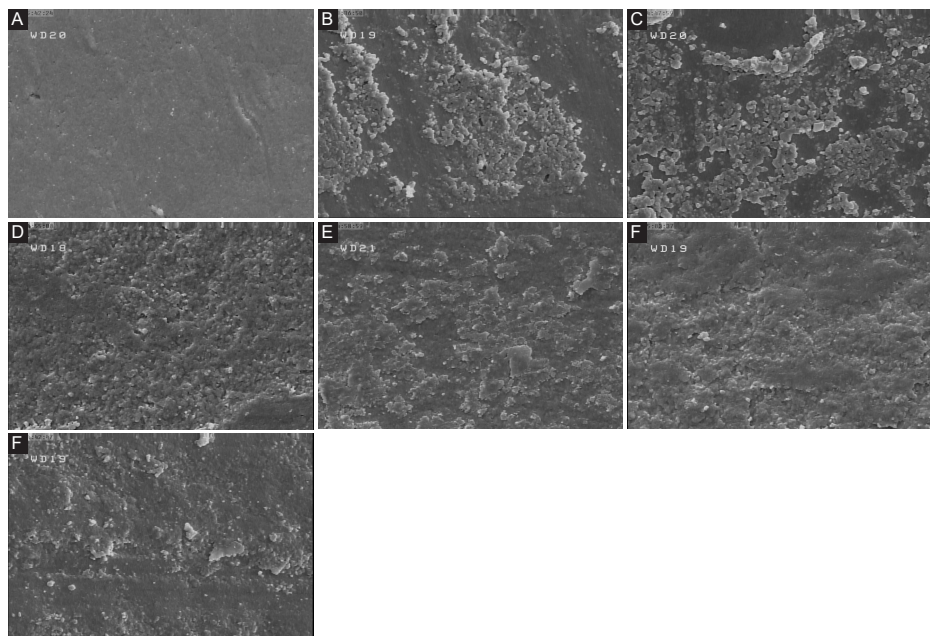


Figure 2. (A) Zirconia surface without preparation (laser radiation) is homogeneous, without any heterogeneity; actually similar to the surface of the control group samples. (B) Zirconia surface prepared with laser radiation in a contact mode which created a non-homogeneous surface with multiple deep cavities. (C) Zirconia prepared with laser radiation from 2 mm distance that created a non-homogeneous surface with multiple deep cavities. The heterogeneity degree in this group was greater and deeper than that in other groups. (D) Zirconia prepared with laser radiation from 4 mm distance, which formed a non-homogeneous surface with multiple cavities, and a low depth (lower than the previous group) was seen. (E) Zirconia prepared with laser radiation from 6 mm distance, which created a non-homogeneous surface with multiple cavities, and a low depth (as in the previous group) was seen. (F) Zirconia prepared with laser radiation from 8 mm distance and a nearly homogeneous surface with very shallow cavities was created. It was noted that in 5 times magnified surfaces, the texture was similar to the conventional group. (G) Zirconia prepared with laser radiation from 12 mm distance, and an approximately homogeneous surface with very shallow cavities was created. 5 times magnified images were similar to the conventional group.

the zirconia surface. As the distance between the zirconia surface and laser beam increased more than 2 mm, shear bond strength was reduced.

Ethical Considerations

Not applicable.

Conflict of Interests

The authors declare no conflict of interest.

References:

- Denry I, Kelly JR. State of the art of zirconia for dental applications. *Dent Mater.* 2008; 24(3):299-307. doi: 10.1016/j.dental.2007.05.007.
- Manicone PF, Iommetti PR, Raffaelli L. An overview of zirconia ceramics: basic properties and clinical applications. *J Dent.* 2007;35(11):819-26. doi: 10.1016/j.jdent.2007.07.008.
- Arami S, Hasani Tabatabaei M, Namdar F, Safavi N, Chiniforush N. Shear bond strength of the repair composite resin to zirconia ceramic by different surface treatment. *J Lasers Med Sci.* 2014;5(4):171-5.
- Yassaei S, Aghili HA, Davari A, Mostafavi SM. Effect of four methods of surface treatment on shear bond strength of orthodontic brackets to zirconium. *J Dent (Tehran).* 2015;12(4):281-9.
- Cavalcanti AN, Foxton RM, Watson TE, Oliveira MT, Giannini M, Marchi GM. Y-TZP ceramics: key concepts for clinical application. *Oper Dent.* 2009;34(3):344-51. doi: 10.2341/08-79.
- Paranhos MP, Burnett LH Jr, Magne P. Effect of Nd:YAG laser and CO₂ laser treatment on the resin bond strength to zirconia ceramic. *Quintessence Int.* 2011;42(1):79-89. doi: 10.2341/08-79.
- Akyil MS, Uzun IH, Bayindir F. Bond strength of resin cement to yttrium-stabilized tetragonal zirconia ceramic treated with air abrasion, silica coating, and laser irradiation. *Photomed Laser Surg.* 2010;28(6):801-8. doi: 10.1089/pho.2009.2697.
- Mirhashemi A, Chiniforush N, Jadidi H, Sharifi N. Comparative study of the effect of Er:YAG and Er:Cr:YSGG lasers on porcelain: etching for the bonding of orthodontic brackets. *Lasers Med Sci.* 2018;33(9):1997-2005. doi: 10.1007/s10103-018-2573-y.
- Özcan M, Vallittu PK. Effect of surface conditioning methods on the bond strength of luting cement to ceramics. *Dent Mater.* 2003;19(8):725-31. doi: 10.1016/s0109-5641(03)00019-8.
- Dérand P, Dérand T. Bond strength of luting cements to zirconium oxide ceramics. *Int J Prosthodont.* 2000;13(2):131-5.
- Della Bona A, Borba M, Benetti P, Cecchetti D. Effect of surface treatments on the bond strength of a zirconia-reinforced ceramic to composite resin. *Braz Oral Res.* 2007;21(1):10-5. doi: 10.1590/s1806-83242007000100002.
- Akgungor G, Sen D, Aydin M. Influence of different surface treatments on the short-term bond strength and durability between a zirconia post and a composite resin core material. *J Prosthet Dent.* 2008;99(5):388-99. doi: 10.1016/S0022-3913(08)60088-8.
- Piasek JR, Swift EJ, Braswell K, Stoner BR. Surface fluorination of zirconia: adhesive bond strength comparison to commercial primers. *Dent Mater.* 2012;28(6):604-8. doi: 10.1016/j.dental.2012.01.008.
- Pahlavan A, Mehmanchi M, Ranjbar Omrani L, Chiniforush N. Effect of Air Abrasion and Erbium-Doped Yttrium Aluminum Garnet (Er: YAG) laser preparation on Shear Bond Strength of Composite to Dentin. *J Lasers Med Sci.* 2013;4(3):127-30.
- Nokhbatolfoghahaie H, Chiniforush N, Shahabi S, Monzavi A. Scanning Electron Microscope (SEM) Evaluation of Tooth Surface Irradiated by Different Parameters of Erbium: Yttrium Aluminium Garnet(Er:Yag) Laser. *J Lasers Med Sci.* 2012; 3(2):51-5
- Artun J, Bergland S. Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. *Am J Orthod.* 1984;85(4):333-40. doi: 10.1016/0002-9416(84)90190-8.
- Usumez A, Aykent F. Bond strengths of porcelain laminate veneers to tooth surfaces prepared with acid and Er,Cr:YSGG laser etching. *J Prosthet Dent.* 2003;90(1):24-30. doi: 10.1016/s0022-3913(03)00235-x.
- Kitayama S, Nikaido T, Takahashi R, Zhu L, Ikeda M, Foxton RM, et al. Effect of primer treatment on bonding of resin cements to zirconia ceramic. *Dent Mater.* 2010;26(5):426-32. doi: 10.1016/j.dental.2009.11.159.
- Hashem-Hoseini M, Mahmood-Hashemi H, Soltan-Moradi F, Hooshmand T, Haririan I, Chalipa J, et al. Effect of fast curing lights, argon laser, and plasma arc on bond strengths of orthodontic brackets: an in vitro study. *J Dent Teh Uni Med Sci.* 2008;5(4):167- 72.
- Başaran G, Hamamcı N, Akkurt A. Shear bond strength of bonding to enamel with different laser irradiation distances. *Lasers Med Sci.* 2011;26(2):149-56. doi: 10.1007/s10103-009-0747-3.
- Visuri SR, Walsh JT Jr, Wigdor HA. Erbium laser ablation of dental hard tissue: effect of water cooling. *Lasers Surg Med.* 1996;18(3):294-300. doi: 10.1002/(SICI)1096-9101(1996)18:3<294::AID LSM11>3.0.CO;2-6.