Cumhuriyet Dental Journal: 2020; 23(2)
e-ISSN 2146-2852
Doi:10.7126/cumudj.669621

Original research

SHEAR BOND STRENGTH OF ORTHODONTIC BRACKETS TO ZIRCONIUM OXIDE INFRASTRUCTURE TREATED WITH ER:YAG, ND:YAG, AND KTP LASERS: AN EXPERIMENTAL STUDY

ABSTRACT

Objective: The aim of the present study was to investigate the shear bond strength of orthodontic brackets to zirconium oxide infrastructures treated with erbium-doped yttrium aluminum garnet (Er:YAG), neodymium-doped yttrium aluminum garnet (Nd:YAG) and potassium titanyl phosphate (KTP) laser modalities in in vitro settings.

Materials and Methods: A total of 40 zirconium oxide infrastructures were prepared with CAD/CAM technology in accordance with ISO 11405 standard. The specimens were divided into 4 groups as following: Er:YAG, Nd:YAG, KTP, and control groups (n=10). Prior to the application of cementation of orthodontic brackets, the surfaces of the zirconium oxide infrastructures were irradiated using selected laser modailites. Shear bond strength tests were performed on each specimen by using a universal testing machine.

Results: The shear bond strength value of Er:YAG laser group was significantly higher than those of all other groups ($p<0.05$); although the bonding strength of Nd:YAG laser was higher than that of the KTP laser, this difference was not reached statistical significance ($p>0.05$). The bonding strength values of Nd:YAG laser group were significantly higher than that of the control group ($p<0.05$); and the the bonding strength values of KTP laser group were significantly higher than that of control group ($p<0.05$).

Conclusions: The bond strength between the orthodontic brackets and zirconium oxide infrastructures was improved upon using all the laser modalities in the present study, among which, application of the Er:YAG laser was the most successful.

Keywords: Er:YAG lasers, Nd:YAG lasers, KTP lasers, zirconium oxide, orthodontic brackets, shear strength.

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Received : 16.01.2020
Accepted : 27.03.2020

How to Cite: Ulgey M, Coban Buyukbayraktar Z, Gorler O, Hubbezoglu I. Shear Bond Strength of Orthodontic Brackets to Zirconium Oxide Infrastructure Treated with Er:YAG, Nd:YAG, and KTP Lasers: An Experimental Study. Cumhuriyet Dent J 2020;23:2;129-135.
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INTRODUCTION

Zirconium oxide ceramics have many benefits like biocompatibility, aesthetics, low cost, good fracture resistance, and accurate fabrication with CAD/CAM systems[1]; therefore, they are widely employed in posterior-localized teeth of adult patients. Orthodontic treatments have significantly increased in adult patients recently[2], which indicates how important bonding strength between orthodontic brackets and zirconium oxide ceramic crowns is.

Better adhesion properties are obtained by using surface treatment methods including airborne-particle abrasion[3], acid etching[4], tribochemical treatment[5], silanization[3,5] and laser treatment.[6,7] In the recent times, the number of studies investigating surface modifications with laser processing has significantly increased since highly automated workstations have been developed and lasers have affordable prices.[8] Crucial advantages of this process include the highly localized, clean nature of the process, low-distortion and high quality of finish.[9]

Attachment of brackets to zirconium oxide surface is required to be performed against orthodontic forces and exhibit a sufficient strength to avoid bonding failures.[10] Specialist orthodontic practitioners enhance bonding strength to both zirconium oxide and enamel surface through hydrofluoric acid prior to cementation of brackets.[11] But, the most common problem encountered in this process is the formation of micro-retention on smooth zirconium oxide surface using hydrofluoric acid.[12] However, the use of hydrofluoric acid prior to cementation may harm oral soft tissues and zirconium oxide restorations.[13] Therefore, application of laser surface treatment on ceramic surface can be a safe alternative method to increase the attachment of brackets to the ceramic surfaces.[11]

Although many studies were done to investigate the effect of surface treatment processes on ceramic surfaces on bonding strength, there are no studies examining the effects of Er:YAG, Nd:YAG and KTP lasers applied to zirconium oxide surface on bonding strength. The aim of the present study was to investigate the shear bond strength (SBS) of orthodontic brackets to zirconium oxide infrastructures treated with erbium-doped yttrium aluminum garnet (Er:YAG), neodymium-doped yttrium aluminum garnet (Nd:YAG) and potassium titanyl phosphate (KTP) laser modalities in in vitro settings. The null hypothesis was that the laser treatments would not alter the shear bond strength of the orthodontic bracket attached to the zirconium oxide infrastructures after surface modifications with Er:YAG, Nd:YAG, and KTP lasers.

MATERIALS AND METHODS

Specimen preparation

The study was approved by the Human Research Ethics Committee of Sivas Cumhuriyet University (No: 2020-02/32). The infrastructures were designed with the help of CAD Software (DWOS, Dental Wings, Canada) in accordance with ISO 11405 standards with a 7 mm-diameter and a 3-mm height. The designed samples were produced by milling pre-sintered zirconium oxide blocks (ST, Upcera, China) by using CAD/CAM milling device (Yenadent, Ankara, Turkey). Therefore, the disc-shaped specimens were removed from zirconium oxide blocks and sprue connections were eliminated. The sintering process of zirconium-oxide specimens were carried out in a high-temperature furnace (Protherm; B&D Dental Origin Milling, USA) in accordance to the manufacturer's instructions.

The specimens were randomly divided into 4 groups according to the surface treatment process to be applied (n=10). The specifications used during laser surface treatment procedures were as follows:

- Control group: No treatment.
- Er:YAG Laser Group: The Er:YAG laser (λ=2.940 nm) (Smart 2940D Plus; Deka Laser, Florence, Italy) was applied to zirconium oxide infrastructure with non-contact mode for 30 s using very short pulse mode. The laser settings were 3 W, 100 mJ, and 30 Hz (pulse/s).
- Nd:YAG Laser Group: The Nd:YAG laser (λ=1.064 nm) (Smarty A10, DEKA M.E.L.A. SRL, Italy) was applied to zirconium oxide infrastructure with contact mode for 30 s using short pulse mode. The laser settings were 3 W, 100 mJ, and 30 Hz (pulse/s).

- KTP Laser Group: The KTP laser (λ=532 nm) (Smartlite D, DEKA M.E.L.A. SRL, Italy) was applied to zirconium oxide infrastructure with contact mode for 30 s using pulsed mode. The laser settings were 3 W, 100 mJ, and 30 Hz (pulse/s).

After surface treatment processes, self-etch adhesive system (Transbond XT, 3M Unitek, USA) was applied to the base of orthodontic metal brackets (22-inch slot MBT prescription; American Orthodontics, USA) having the dimensions of 3x4 mm and brackets were bonded at the center of each treated zirconium oxide specimen. Overflowing cements were cleaned and polymerized with a light-curing device (Smartlite, Dentsply, USA) in each direction for a total of 40 s including 10 s for each direction. Before shear bond strength test, the specimens were kept at distilled water at 37±1 °C for 24 h.

After taken the specimens out of the distilled water, all specimens were fixed in the perpendicular position with the help of acrylic resin (Meliodent, Heraeus Kulzer, Germany) to cylindrical metal molds with a length of 2.5 cm and a diameter of 1.5 cm. The specimens were placed to a universal test machine (Lloyd LF Plus, Ametek Inc, UK) for shear bond strength test. The load was vertically applied through a 1-mm thick straight knife-edged blade for blunt cutting process in accordance with the ISO TR 11405 specification. The test was performed at 0.5 mm/min crosshead speed under laboratory conditions (Figure 2). The amount of load per unit area was calculated by recording loads at failure in newton (N) and converting them into Megapascal (MPa) values.

Figure 2. A representative image of control group.

Statistical Analysis

The data presented as the mean – standard deviation (SD) were assessed by using the analysis of variance followed by the post hoc Tukey test for pairwise comparisons after Kolmogorov–Smirnov normality test was performed. The data are shown with whisker plots including mean and SD lines and scatter dots presenting raw data. The value of 0.05 was accepted as statistical significance.

RESULTS

Figure 1 shows the shear bond strength values of zirconium oxide infrastructures and orthodontic brackets subjected to surface treatment procedures (Er:YAG, Nd:YAG, and KTP laser applications).

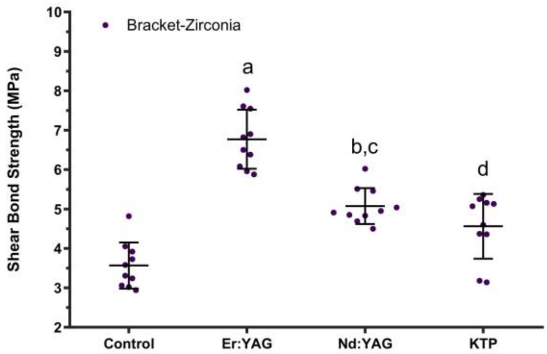

Figure 1. Values of shear bond strength between orthodontic brackets and zirconium oxide infrastructures treated with Er:YAG, Nd:YAG, and KTP lasers. Data were expressed as mean (midline) and SD (whiskers). [a]P<0.05, Er:YAG group vs. Nd:YAG, KTP, and control groups . [b]P>0.05, Nd:YAG group vs. KTP group. [c]P<0.05, Nd:YAG group vs. control group. [d]P<0.05, KTP group vs. control group.

ANOVA and t tests indicated that overall, all laser applications increased the bond strength of orthodontic brackets to zirconium oxide infrastructures. The SBS value was significantly higher in Er:YAG laser group compared to all other groups (p<0.05). The bonding strength was higher in Nd:YAG laser compared to the KTP laser; however, this difference was not statistically significant (p>0.05). The SBS values were significantly higher in Nd:YAG laser group compared to control group (p<0.05); whereas, KTP laser group had significantly higher SBS values than control group (p<0.05) (Table 1).

Table 1. Shear bond strength values (MPa) among all groups

Groups	Mean	Standard deviation	Minimum	Maximum
Control [a]	3.63	0.55	2.90	4.82
Er:YAG Laser [b]	6.77	0.74	5.88	8.02
Nd:YAG Laser [c]	5.07	0.45	4.50	6.02
KTP Laser [c]	4.56	0.82	3.14	5.36

*Different lower case letter represents statistical significant among groups, verified by one-way ANOVA and Tukey's test ($p<0.05$).

DISCUSSION

In this study, the null hypothesis, stating the laser treatments would not alter the shear bond strength of the orthodontic bracket attached to the zirconium oxide infrastructures after surface modifications with Er:YAG, Nd:YAG, and KTP lasers was rejected. Overall, these results indicated that while Er:YAG laser had the highest effectiveness in the zirconium oxide infrastructures than the other modalities, KTP laser had the least effectiveness in all the infrastructures.

Although the minimum bonding strength value is 6-8 MPa for orthodontic brackets to stand against orthodontic forces[14] , some authors have stated that a bond strength value of 2.86 MPa is clinically acceptable.[15,16] Since ceramics have inert surfaces, surface treatment applications can be useful to ensure attachment of brackets on ceramic surfaces.[13] Laser surface treatment applications can be an alternative method to hydrofluoric acid etching application used routinely in clinics due to their advantages such as not causing any pain or sensitivity, being applied in a short time and eliminating problems related to acid applications.[17]

Er:YAG laser is a laser at 2940 nm wavelength forming craters in anfractuous form leading microexplosions on the surface of dentin.[18] The use of Er:YAG laser to increase adhesion in dental materials may be an useful application. Hou *et al.*, examined different Er:YAG laser power settings in terms of the shear bond strength of different CAD/CAM ceramics. They determined that Er:YAG laser application provided a statistically significant increase in all groups when compared to the control group. The bond strength of IPS Empress CAD and IPS e.max CAD could be increased using certain power settings.[19] Sabuncuoglu *et al.*, made a comparison concerning the effects of different porcelain surface treatment methods on the shear bond strength and fracture mode of orthodontic brackets. They stated that laser etching with Nd:YAG or Er:YAG laser application was more effective and less time-consuming than both hydrofluoric acid and sandblasting for the treatment of deglazed feldspathic porcelain.[20] Yassaei *et al.*, assessed the shear bond strength of orthodontic brackets bonded to ceramic after etching with Er:YAG laser than 9.6% hydrofluoric acid (HF). They determined no significant difference between Er:YAG laser and acid etching applications. The authors also suggest that Er:YAG laser is a proper method for bonding of orthodontic brackets to porcelain surfaces.[13] Xu *et al.*, analyzed how Er:YAG laser conditioning bond strength of orthodontic brackets affected porcelain surfaces. They stated that porcelain surfaces etched by 250 mJ, 20 Hz of Er:YAG laser through hydrofluoric acid could have a sufficient bond strength and lower porcelain fracture rate for orthodontic bracket bonding.[21] Similarly, in the present study, Er:YAG laser application increased the bonding strength values.

Poosti *et al.*, examined shear bond strength of orthodontic brackets to porcelain surface after conditioning by Er:YAG and Nd:YAG laser by comparing with traditional methods. They determined that both Er:YAG at 2 W and 3 W and surface roughening alone showed significantly lower bond strengths than the Nd:YAG laser or 9.6% hydrofluoric acid-etching treatment ($p < 0.05$).[22] These results are different from results of the present study. This difference may be due to the difference in the infrastructure where the brackets are adhered.

The use of Nd:YAG laser in dental field, treatment of tooth hypersensitivity, cavity cleaning, tooth whitening and disinfection of dental tissues is preferred.[23] Nd:YAG laser is used in many studies for the purpose of increasing bonding strength.[24,25] Cevik *et al.*, assessed the shear bond strength of orthodontic brackets bonded to different kinds of ceramic surfaces after different surface conditioning methods. They determined that Nd:YAG laser treatment increased bonding strength values between porcelain systems to orthodontic brackets.[26] In their another study, Cevik *et al.*, assessed the effect of six different surface conditioning methods on the shear bond strength of ceramic brackets bonded to feldspathic porcelain. They determined that the Nd:YAG laser application on feldspathic porcelain surface statistically significantly increased compared to control group.[27] Akyil *et al.*, investigated the shear bond strength of a resin cement to zirconium oxide surfaces subjected to air abrasion, silica coating, CO_2, Er:YAG, or Nd:YAG laser irradiation, or irradiated by each laser after air abrasion. They determined that Nd:YAG laser irradiation after air abrasion is an alternative treatment method used to improve the bond strength between resin cement and Y-TZP material.[28] The results of the present study are compatible with the results of these studies.

For photochemical bleaching, absorption of chelate compounds is important and the best absorption is provided by argon laser (515 nm) and KTP laser (532 nm) due to their ideal wavelengths.[29] In addition, KTP laser is used in dental field; desensitization of cervical dentine, laser-enhanced fluoride uptake, periodontal pocket disinfection, root canal disinfection and minor soft tissue surgery processes.[30] In the dental literature, data about the investigating the effect of KTP laser on bond strength is limited. Kustarci *et al.* assessed the impacts of antimicrobial pretreatments [chlorhexidine gluconate (CHX), Clearfil Protect Bond (CPB), and potassium-titanyl-phosphate (KTP) laser] on microleakage under metal orthodontic brackets. They observed the lowest microleakage scores in the control group. CPB, KTP, and CHX groups did not show significant differences with the control group ($p > 0.05$).[31] In a study conducted in our laboratory, the shear bond strength (SBS) of ceromer and nanohybrid composite to direct laser sintered (DLS) Cr-Co and Ni-Cr-based metal infrastructures subjected to Er:YAG, Nd:YAG, and KTP laser applications was investigated. The results of that study indicated that Er:YAG, Nd:YAG, and KTP laser methods were effective in increasing bonding of these structures based on order of success, thus supported the bonding of ceromer and nanohybrid composite superstructures to the DLS and Ni-Cr based infrastructures.[32] The experimental work presented here provides one of the first investigations evaluating the effect of KTP laser on bonding strength of orthodontic brackets to ceramic infrastructures.

This study has some limitations in terms of the laser settings used. In this study, during the application of surface treatment to infrastructures, all laser parameters were set as 3W. We believe that this will be useful in the comparison of the effectiveness of lasers. In further studies, using different laser powers and measuring the bonding strengths of different ceramic systems will be useful in terms of comparing the attachments of orthodontic brackets to different infrastructures.

The main idea of the current study was to include different laser applications including Nd:YAG, Er:YAG, and KTP lasers, and investigation if the bond strength between zirconium oxide infrastructures and orthodontic brackets would be affected by different specifications of these laser modalities. These experiments suggested that laser treatments applied on zirconium oxide surface, especially the Er:YAG laser, can modify and enhance the bonding between zirconium oxide surface and orthodontic brackets.

CONCLUSIONS

Er:YAG, Nd:YAG, and KTP lasers may be considered as effective methods to increase bonding strength of orthodontic brackets to zirconium oxide infrastructures. Er:YAG laser has the highest effectiveness in the bonding strength of zirconium oxide infrastructures to orthodontic brackets. In present experimental setting; Er:YAG, Nd:YAG, and KTP lasers were more effective for improving the retention of orthodontic brackets to zirconium oxide infrastructures based on order of effectiveness.

ACKNOWLEDGEMENTS
None

CONFLICTS OF INTEREST STATEMENT
The authors declare that they have no competing interests.

Ortodontik Braketlerin Er:YAG, Nd:YAG ve KTP Lazer ile Pürüzlendirilen Zirkonyum Oksit Alt Yapılara Olan Makaslama Bağlantı Dayanımı: Bir Deneysel Çalışma

ÖZ

Amaç: *Bu çalışmanın amacı, Er:YAG, Nd:YAG ve KTP lazer ile pürüzlendirilmiş zirkonya altyapıların ortodontik braketlere olan bağlantı dayanımını in vitro olarak araştırmaktır.* ***Gereç ve Yöntemler:*** *Bu çalışmada, CAD/CAM teknolojisi kullanılarak ISO 11405 standartlarına uygun olarak üretilmiş 40 adet zirkonya örnek kullanıldı. Örnekler 4 gruba ayrıldı: Er:YAG, Nd:YAG, KTP ve kontrol grup. Ortodontik braketlerin simantasyonu öncesi, zirkonya alt yapıların yüzeyleri seçilen düzenleme yöntemlerine göre pürüzlendirildi. Makaslama bağlantı dayanımı testi, her örnek için universal test cihazında uygulandı.* ***Bulgular****: Er:YAG lazer grubunun makaslama bağlantı dayanımı, diğer tüm gruplara göre istatistiksel olarak anlamlı derecede yüksekti ($p<0,05$); Nd:YAG lazer grubunun bağlantı dayanımı değerleri KTP lazere göre yüksek olmasına rağmen, bu farklılık istatistiksel anlamlı değildi ($p>0,05$). Nd:YAG lazer grubunun bağlantı dayanımı değerleri, kontrol grubunun bağlantı dayanımına göre anlamlı derecede yüksekti ($p<0,05$). KTP lazer grubunun bağlantı dayanımı değerleri, kontrol grubuna göre anlamlı derecede yüksekti ($p<0,05$).* ***Sonuçlar:*** *Bu çalışmada ortodontik braketler ile zirkonya alt yapılar arasındaki bağlantı dayanımını tüm lazer uygulamaları arttırmıştır. Bunlar arasında Er:YAG lazer en başarılı uygulamadır.* ***Anahtar Kelimeler:*** *Er:YAG lazerleri, Nd:YAG lazerleri, KTP lazeri, zirkonyum oksit, ortodontik braketler, kayma mukavemeti.*

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