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Influence of Various Laser Surface Modifications on SBS of Titanium and Zirconium Oxide Substructures

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Abstract. In prosthodontics, to increase the bonding of metals with porcelain by several means including laser surface treatments is still an important research topic. The current study was undertaken to evaluate the influence of surface treatment with Ho:YAG, Er:YAG, and Nd:YAG lasers on the shear bond strength (SBS) of low fusion dental porcelain to titanium and zirconium oxide substructures. Titanium (n=70) and zirconium oxide (n=70) specimens were categorized into 7 study groups (n=10): sandblasting, Er:YAG 1.5W and 2.5W, Nd:YAG 1.5W and 2.5W, and Ho:YAG 4W and 10W. Their surface morphology was examined with under scanning electron microscopy (SEM) after surface treatment. After application of low fusion dental porcelain, the SBS test was performed applying a universal testing machine. In the titanium specimens, the SBSs of the Nd:YAG laser 2.5W and 1.5W were significantly higher than those of the sandblasting and other lasers, respectively ($p<0.05$); In the zirconium oxide specimens, the SBSs of the sandblasting, Nd:YAG 1.5W and Nd:YAG 2.5W lasers were significantly higher than those of the other lasers, respectively ($p<0.05$); In the titanium specimens, Er:YAG 1.5W, Nd:YAG 2.5W, and Ho:YAG 10W lasers provided significantly higher SBSs compared to those in the zirconium oxide specimens ($p<0.05$). To increase SBS of low fusion porcelain with titanium and zirconium oxide substructures, Nd:YAG laser is more successful compared to Er:YAG and Ho:YAG lasers. The laser applications provide different SBS results although there are no obvious differences among their surfaces by SEM; this requires further research in order to clarify the mechanism of these differences.

Keywords: Ho:YAG laser, Nd:YAG laser, Er:YAG laser, shear bond strength, titanium, zirconium, low-fusion dental porcelain, CAD/CAM

Zirkonyum Oksit ve Titanyum Metal Alt Yapıların SBS Üzerine Farklı Lazer Yüzey Uygulamalarının Etkisi

Özet: Protetik diş tedavisinde lazer yüzey uygulamalarını da içeren birçok yöntem, porselen alt yapı ile metalin bağlantısını arttırmak için halen önemli bir araştırma konusudur. Çalışma; titanyum ve zirkonyum oksit alt yapılara uygulanan düşük ısı porseleninin makaslama bağlantı dayanımına (SBS); Ho:YAG, Er:YAG ve Nd:YAG lazer ile yüzey şartlandırmalarının etkisini geliştirmeyi amaçlamıştır. Titanyum (n=70) ve zirkonyum oksit (n=70) örnekler 7 çalışma grubuna ayrılmıştır (n=10): Kumlama, Er:YAG 1.5 W ve 2.5 W, Nd:YAG 1.5 W ve Er:YAG 2.5 W, ve Ho:YAG 4W VE 10 W. Yüzey morfolojileri, şartlandırma sonrasında taramalı elektron mikroskobu (SEM) altında incelenmiştir. Dental düşük ısı porseleninin uygulanmasından sonra SBS testi universal test makinesi kullanılarak yapılmıştır. Titanyum örneklerde Nd:YAG lazer 2.5 W ve 1.5 W SBS sırasıyla kumlama ve diğer lazerlerden önemli ölçüde yüksektir ($p<0.05$). Zirkonyum oksit örneklerde Kumlama, Nd:YAG 1.5W and Nd:YAG 2.5W lazerler sırasıyla diğer lazerlerden önemli ölçüde yüksektir. Titanyum örneklerde Er:YAG 1.5W, Nd:YAG 2.5W, ve Ho:YAG 10W lazer zirkonyum oksit örnekler ile karşılaştırıldığı zaman SBS önemli derecede üstünlük sağlamıştır ($p<0.05$). Titanyum ve zirkonyum oksit alt yapılar ile düşük ısı porseleninin SBS artırmak için Nd:YAG lazer Er:YAG ve Ho.YAG ile karşılaştırıldığı zaman daha başarılıdır. SEM vasıtasıyla yüzeyleri arasında

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belirgin bir fark olmamasına rağmen lazer uygulamaları farklı SBS sonuçları sağlamıştır ; bu durum bu farkların işleyişini açıklamak için daha fazla araştırmayı gerektirmektedir.

Anahtar Kelimeler: Ho: YAG Lazer, Nd: YAG Lazer, Er:YAG Lazer, Makaslama Bağlantı Dayanımı, Titanyum, Zirkonyum Oksit, Dental Düşük Isı Porseleni , CAD/CAM

1. INTRODUCTION

Metal-ceramic restorations are recently preferred in prosthodontics since they harmonize the esthetic properties of dental ceramic materials with the high strength of metals to increase the long-term satisfaction of patients [1-3]. In this context, titanium and zirconium oxide are the leading metals which were introduced for dental applications as a core materials suitable for veneering with dental porcelain in combination with CAD/CAM techniques [4]. The most common clinical failures of dental prostheses is fracture of porcelain material at the interface between metal and porcelain [5, 6]. Sufficient bond strength among the veneering dental porcelain and the framework materials is therefore the main factor determining their long-term clinical success of fixed dental prostheses.

Although several methods had been introduced to improve the mechanical bonding between metal and ceramic, bonding in zirconium- and titanium- porcelain systems compared to the conventional metal-porcelain systems is not still as expected for the successful performance of veneer/framework bilayered restorations [6-9]. The bonding of ceramic to a metal substructure is developed by many factors between porcelain and metal. The quality of mechanical bonding is related to the degree of roughness in the metal surface. Therefore, interfacial bond strength can to be optimized by the surface pretreatment of the metal substracture to increase the surface roughness of metal before the ceramic application [6, 10]. To improve the surface roughness effect of titanium and zirconium, many methods had been introduced, including sandblasting with Al_2O_3 particles [11], and laser applications [11, 12].

The emergence of lasers with variable wavelength and their ability to be used for various purposes make their applications an important reseach topic [11, 12] Among those surface treatments, laser etching has a potential to produce a controlled micro-topography of metal surface [13] There is a need for a standardized and optimized method of laser surface treatment for increasing the shear bond strength (SBS) of metal surfaces. Among the lasers used in dentistry, Ho:YAG, Nd:YAG, and Er:YAG lasers have a wavelength of 2940, 1064, and 2100 nm, respectively [14]. We aimed to determine the SBSs of the low-fusion dental porcelain bonded to the CAD/CAM-fabricated titanium and zirconium substructures after surface modifications with Ho:YAG, Er:YAG, and Nd:YAG lasers in vitro settings. The null hypothesis was that the laser treatment modalities would not change the SBSs of the low-fusion dental porcelain bonded to the CAD/CAM-fabricated titanium and zirconium substructures after surface modifications with Ho:YAG, Nd:YAG, and Er:YAG and lasers.

2. MATERIALS AND METHODS

Preparation of samples

In this study, the SBS values of low temperature porcelain with zirconium oxide and titanium metal substructure applications were examined.

By choosing the SBS as the main numeric variable of the study and assuming a difference of 18.5 MPa with 14.9 MPa standard deviation of experimental data, based on the findings from similar studies published in the literature, the number of samples (i.e. sample size=10) tested for each group was computed with the “Sample Size for Analysis of Variance Program” module of the online Computer

Program to Calculate Sample Size Requirement in the Analysis of Variance (http://www.statstodo.com/SSizAOV_Pgm.php) after setting of desired statistical power at 90% ($1-\beta = 0.90$) at a significance level of 1% ($\alpha < 0.01$).

140 samples in total were milled. Zirconium oxide (Alliance ring block) and Titanium (Copra-Ti ring block) substructures were prepared in the final dimensions of 7 mm in diameter and 3 mm in thickness in line with ISO 11405 standard in CAD/CAM (Yenadent DC-40, Turkey) device, and surface sandblasting (Mikrotek MKK-975 pen sandblasting device) was applied to all samples. Then the laser process was applied in two different output powers for 20 seconds in the presence of water (Table 1).

Table 1. Settings of applied laser modalities.

Lasers	Er:YAG		Nd:YAG		Ho:YAG	
Power (W)	1.5	2.5	1.5	2.5	4	10
Pulse energy (mJ)	150	250	150	250	500	1000
Repetition rate (Hz)	10	10	10	10	8	10
Duration (sec)	20	20	20	20	20	20

Table 2. Distribution of samples according to the groups (SB: Sandblasted).

Groups	SB No Laser	SB+ Er:YAG 1.5W	SB+ Er:YAG 2.5W	SB+ Nd:YAG 1.5W	SB+ Nd:YAG 2.5W	SB+ Ho:YAG 4W	SB+ Ho:YAG 10W
ZrO_2	10	10	10	10	10	10	10
Ti	10	10	10	10	10	10	10

- Er:YAG (Deka Laser, Smart 2940D Plus, Florence, Italy)
- Nd:YAG (Deka Laser, Smarty A10, Florence, Italy)
- Ho:YAG (Holmium Laser StoneLight, AMS Inc., Minnetonka, MN)

140 samples were divided randomly into titanium and zirconium oxide groups (n=70) and both titanium and zirconium oxide samples were divided into 7 subgroups according to applied laser surface treatment (Table 2). In all the subgroups, low temperature porcelain (Ti-22 Kuraray-Noritake) was applied to sintered zirconium oxide and titanium metal substructures after the application of surface treatments. Metal substructures were soaked in 37±1°C distilled water for 24 hours after embedding in acrylic blocks.

Veneer porcelain was applied on the substructures of all groups as 5 mm in diameter and 3 mm in height in line with ISO/TR 11405 standards. After the porcelain application, the samples were placed in the porcelain furnace with a metal mould and the porcelains were fired in the furnace. The firing process was performed in a programmable vacuum porcelain furnace.

Porcelain applied zirconium oxide and titanium substructure samples prepared for the study were embedded in acrylic resin in aluminium moulds with a diameter of 14 mm and height of 12 mm. All samples were soaked in distilled water at 37±1°C for 24 hours before the test (Nüve BM 302, Nüve San. M. I TAS, Ankara, Turkey).

The samples taken out of the distilled water were exposed to shear bond test at 0.5 mm/min head speed in Universal test device (Lloyd instruments LF Plus Segensworth Fareham/England) in Cumhuriyet University Faculty of Dentistry Research Laboratory. The blade tip to perform the cutting was prepared at a thickness of 1 mm and bluntly as specified in ISO TR 11405 specification (Figure 1). The blade tip was positioned in a way that it is at an angle of 90° at the point where the samples met the substructure and substructure material. The forces were measured as Newton (N) and Newton (N) values were turned into Megapascal (MPa) value in order to be able to determine the amount of load per unit area.

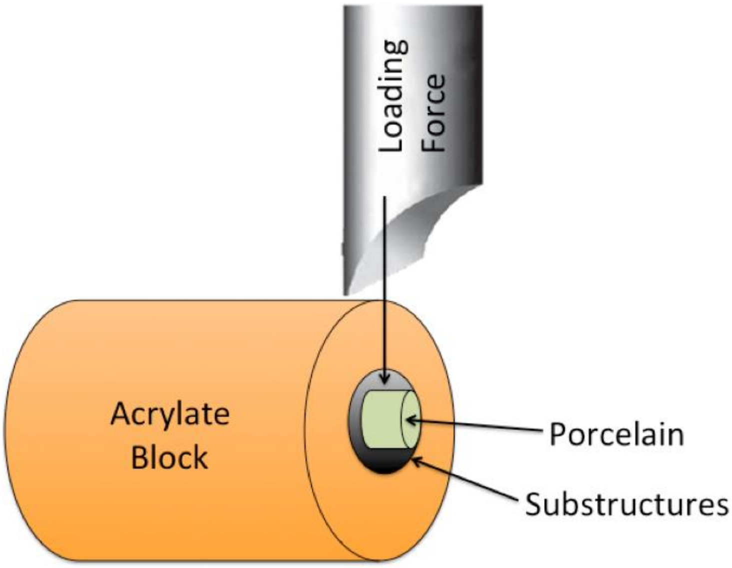


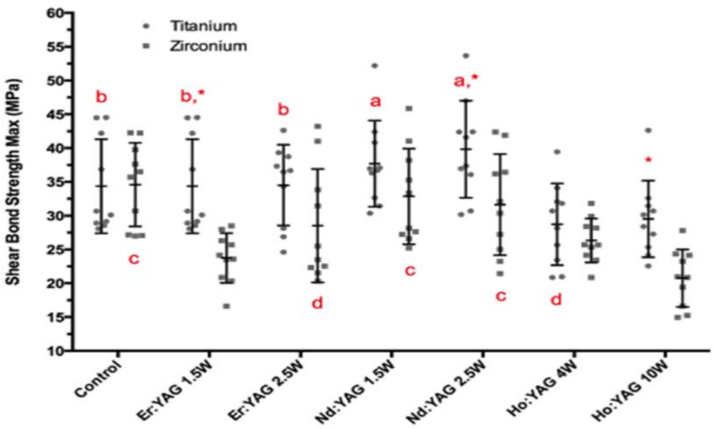
FIG.1

Figure 1. Representative drawing of study specimens, including titanium and zirconium oxide substructure and porcelain, used in the experiments.

Statistical analysis

Data were presented as the mean ± SD and analyzed with ANOVA followed by the Student-Newman-Keuls test for post hoc pairwise comparisons. The difference was considered significant when the P value was <0.05.

RESULTS



		Control	Er:YAG 1.5 W	Er:YAG 2.5 W	Nd:YAG 1.5 W	Nd:YAG 2.5 W	Ho:YAG 4 W	Ho:YAG 10 W
Mean (SD)	Ti	48.6 (9.8)	46.5 (9.1)	48.3 (8.3)	53.3 (9.0)	56.3 (10.1)	40.6 (8.5)	41.7 (7.9)
	ZrO	48.0 (10.1)	33.6 (5.2)	40.3 (11.8)	46.4 (9.9)	44.7 (10.5)	37.2 (4.6)	28.8 (5.7)
Median (min-max)	Ti	43.0 (39.7-63.1)	47.4 (33.1-61.4)	50.1 (34.6-60.3)	52.1 (42.9-73.8)	55.8 (42.6-75.9)	41.6 (29.5-55.8)	41.4 (31.9-60.3)
	ZrO	51.0 (30.9-59.8)	33.7 (23.5-40.3)	34.6 (28.7-61.1)	43.4 (39.7-64.8)	44.1 (30.3-59.9)	36.3 (29.6-45.0)	29.1 (21.1-39.3)
IQ Range (25-75%)	Ti	40.7-60.5	38.3-52.4	39.3-55.0	45.7-58.3	49.1-61.6	32.2-46.1	35.4-44.8
FIG.2	ZrO	37.9-57.1	29.3-57.8	31.2-50.3	38.3-55.0	34.7-53.4	33.9-40.7	23.0-33.2

Figure 2. presents the SBS values of titanium and zirconium oxide substructures to low fusion-dental porcelain in the sandblasting, and Er:YAG 1.5W, Er:YAG 2.5W, Nd:YAG 1.5W, Nd:YAG 2.5W, Ho:YAG 4W and Ho:YAG 10W laser groups. In the titanium specimens, the SBS values of the Nd:YAG laser 2.5W and 1.5W groups were significantly higher than those of the control and other laser groups, respectively ($p<0.05$); the SBS values of control, Er:YAG 2.5W and Er:YAG 1.5W groups were significantly higher than those of the Ho:YAG 4W and Ho:YAG 10W groups ($p<0.05$). Of the SBS values, we found no significant differences among the Nd:YAG laser 2.5W and 1.5W groups; among the control, Er:YAG 2.5W and Er:YAG 1.5W groups; and between the Ho:YAG 4W and Ho:YAG 10W groups ($p>0.05$).

In the zirconium oxide specimens, the SBS values of the control, Nd:YAG 1.5W and Nd:YAG 2.5W groups were significantly higher than those of the other laser groups, respectively ($p<0.05$); the SBS values of Er:YAG 2.5W, Ho:YAG 4W, and Er:YAG 1.5W groups were significantly higher than the Ho:YAG 10W laser group, respectively ($p<0.05$). Of the SBS values, we found no significant differences among the control, Nd:YAG laser 1.5W and 2.5W groups; among the control, Er:YAG 2.5W, Ho:YAG 4W, and Er:YAG 1.5W groups ($p>0.05$).

On the titanium specimens, Er:YAG 1.5W, Nd:YAG 2.5W, and Ho:YAG 10W laser applications provided significantly higher SBS values compared to those of zirconium oxide specimens ($p<0.05$). In the other laser applications, the titanium and zirconium oxide specimens had comparable SBS values ($p>0.05$).

SEM images revealed that the laser surface treatments showed in irregularities, abrasion, and many cavities on the outer surface of titanium and zirconium oxide substructures. Sandblasting caused more roughening on the surfaces of titanium samples compared to zirconium oxide ones. Er:YAG laser caused micro porosity on the surface of titanium samples but deep defects on the surface of zirconium oxide samples. Nd:YAG laser caused more homogeneous surface roughness on both titanium and zirconium oxide samples compared to the other laser modalities. Ho:YAG laser caused shallow and more heterogeneous surface roughness on both titanium and zirconium oxide samples compared to the other laser modalities, although on the surface of titanium samples, there were deep laser penetration areas (Figure 3).

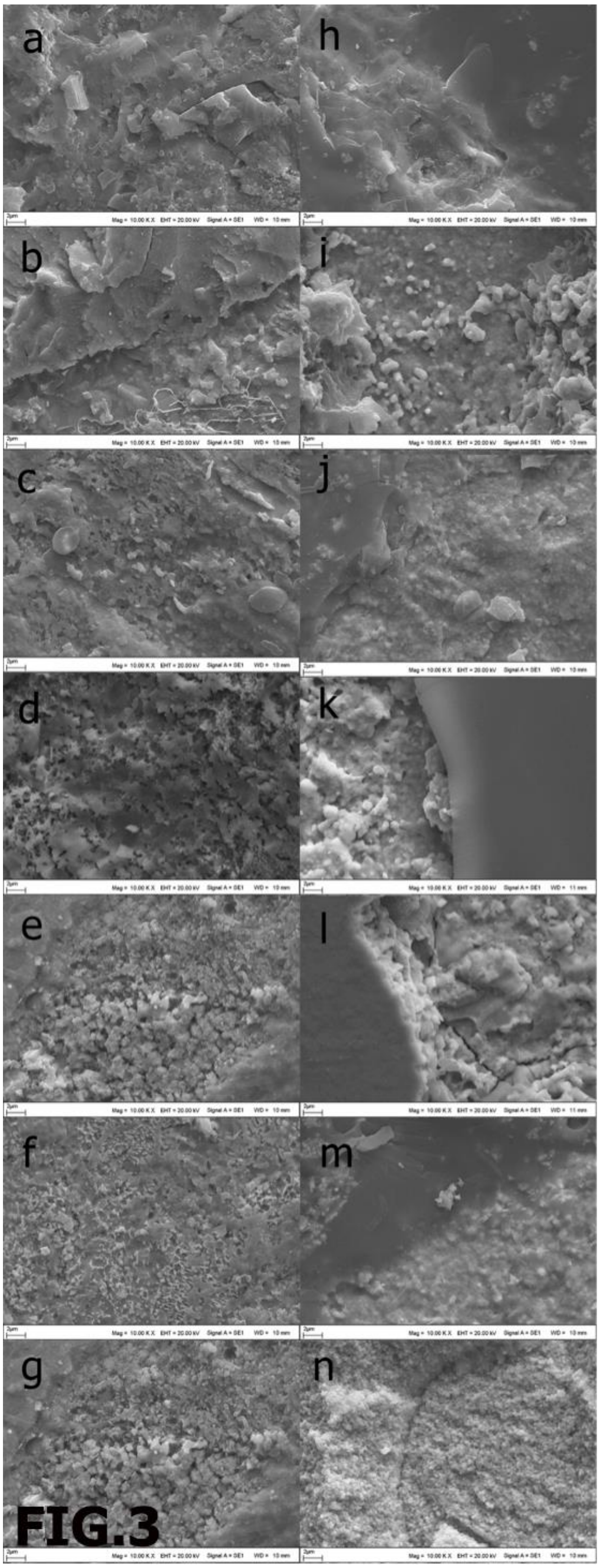


Figure 3. Representative scanning electron microscopic images of laser treated surfaces of titanium and zirconium oxide metal substructures. 10k magnification of titanium placemens; a. sandblasting, b. Er:YAG 1.5W, c. Er:YAG

2.5W, d. Nd:YAG 1.5W, e. Nd:YAG 2.5W, f. Ho:YAG 4W, g. Ho:YAG 10W; 10k magnification of zirconium oxide placemens: h. sandblasting, i. Er:YAG 1.5W, j. Er:YAG 2.5W, k. Nd:YAG 1.5W, l. Nd:YAG 2.5W, m. Ho:YAG 4W, n. Ho:YAG 10W. SEM images revealed that the surface treatment resulted in irregularities, many small pits, and scratches on the surface of the metal substructures; however, there was no meaningful differences among the surface changes of samples due to the applied laser type and power.

3. DISCUSSION

In the literature, there are studies investigated the effect of Er:YAG and Nd:YAG lasers for the surface treatment of titanium and zirconium oxide with the following ranges of power:1-5W [37-41]. In a recent study of our research group, Ho:YAG laser was used similarly with a power setting of 4W[39].

The SBS values of low fusion dental porcelain and sandblasting applied titanium and zirconium oxide substructures were found similar. Certain significant differences were detected between SBS values after the laser application to sandblasted titanium substructures. Nd:YAG laser applications increased the SBS values when compared to the sandblasting, Er:YAG and Ho:YAG laser applications. Er:YAG laser applications had a similar effect on SBS values with the sandblasting application. Ho:YAG laser applications reduced the SBS values when compared to the application of sandblasting. SBS values obtained after low and high power laser applications chosen for the research were found similar. In the light of these findings; Nd:YAG, Er:YAG and Ho:YAG laser applications had a similar effect on sandblasted titanium substructure's SBS values, while Nd:YAG had a laser increasing effect, Er:YAG provided a similar effect with laser sandblasting, and Ho:YAG laser showed a decreasing effect.

Certain significant differences were detected between SBS values after the laser applications on sandblasted zirconium oxide substructures. Nd:YAG laser sandblasting applications increased the SBS values when compared to Er:YAG and Ho:YAG laser applications. Nd:YAG laser applications had a similar effect on SBS values with sandblasting. Ho:YAG laser applications decreased the SBS values when compared to the sandblasting application. SBS values obtained after the laser applications of low and high power chosen for the research were found similar. In the light of these findings; Nd:YAG, Er:YAG and Ho:YAG laser applications of low and high power had a similar effect on the SBS values of sandblasted zirconium substructures. While Nd:YAG laser had an increasing effect, it provided a similar effect with sandblasting, and Er:YAG laser and Ho:YAG laser showed a decreasing effect.

Considering the titanium and zirconium oxide substructures, after applications of Er:YAG 1.5W, Nd:YAG 2.5W, and Ho:YAG 10W laser modalities, the SBS values were higher in the titanium substructures, and after applications of other laser modalities, the SBS values were found similar. Overall, while Nd:YAG laser increased the SBS value of titanium substructures and low fusion dental porcelain when compared to sandblasting, Er:YAG did not change it, but Ho:YAG decreased it. While Nd:YAG laser did not change the SBS value of zirconium oxide substructures and low fusion dental porcelain when compared to sandblasting, Er:YAG and Ho:YAG decreased it. Upon viewing the laser modalities applied for the research, it was seen that Nd:YAG laser was more successful when compared to other laser applications and Ho:YAG laser was unsuccessful.

SBS test is considerably applied in dental literature to assess the primary mechanical characterizations of dissimilar forms of dental metalloceramic applications [14]. This test provide a controlled environment offering controlled conditions to choose the specimen properties and the loading forces. The fracture form's mechanics enable enhance knowledge of the failure mechanism [15, 16]. The bonding strength of metalloceramic restorations is determined by several factors: especially the grade of compressive stress in the veneering ceramic and titanium or zirconium frameworks [17-20]. Between those factors, the mechanical bonding is primarily linked on the surface irregularity of titanium and zirconium oxide [21, 22]. In metalloceramic restorations, a bond strength greater than 25 MPa between the layering porcelain and metal is believed to be adequate according to the International Standards Organization (ISO) Bond strength tests evaluate resistance to exercised stress and similar residual stress [23].

Metaloceramic restorations already indicate the generality of most dependable dental restorations particularly if a good bonding among the two materials is accomplished [24]. Actually, the good bonding among materials is of perfect essential since, considering the long durability of metaloceramic restorations, failures yet arise primarily by reason interfacial fealure of the metaloceramic bond [25]. Computer aided design and computer aided manufacturing (CAD/CAM) technologies contributed considerably to the prosthodontics by improving the manufacturing methods and materials [26]. The success of CAD/CAM technologies was demonstrated by recent studies investigated the ceramic bonding to metal structures provided by these technologies compared to conventional techniques [27].

Titanium preferred for dental prostheses due to its considerable useful mechanical properties and excellent biocompatibility [28-30]. These type of prostheses were evaluated in several clinical studies with promising clinical results [31-33].

The fabrication of titanium prostheses was improved after the application of dental CAD/CAM system and this provided high precision and this improved clinical outcomes [34, 35]. As stated in a recent review, In vitro efficiency of ceramic-titanium restorations is considerably satisfactory to suggest as a treatment option [35], although there are limited data currently available on the clinical outcome of CAD/CAM-fabricated ceramic-titanium prostheses [39]. In a study by Walter et al. [32] the clinical outcome of titanium and high-gold porcelain-fused-to-metal fixed partial dentures fabricated from CAD/CAM-milled titanium.

Murray et al. [40] examined the effect of laser application on the surface of Ni-Cr alloy on the tensile bond strength of composite resin compared to the traditional sandblasting technique. It was point out that laser treatment might be a pertinent option to other surface pretreatments for increasing the bond strength of dental materials. In this study, metal substructures surfaces were irradiated with Er: YAG, Nd:YAG and Ho:YAG lasers as surface treatments. Additionally, the output power of the Er:YAG, Nd:YAG and Ho:YAG lasers affected the bond between the titanium and zirconium oxide substructure surfaces.

Li et al. [41] suggested that SBS would clearly decrease if laser energy was 0.6 W and lower parameters. Compatible, in our study, we used higher parameters than 0.6W.

Oskoee et al. [42] studied that was to compare the effect of surface treatment with Er; Cr:YSSG, Nd:YAG, and CO_2 lasers. They found effective that lasers on repair SBS of a Sloane-based composite resin. Er; Cr:YSSG was found more effective compared to other lasers. In our study, we found that Nd:YAG laser more effective on zirconium oxide and titanium metal substructure surfaces.

Long-term evaluation of the clinical performance of the metalloceramic restorations requires long-term follow-up periods. In the era of continuous addition of new materials for clinical use, it is difficult to interpret the results of previous materials for the prediction of performance of new materials. For this reason, there is inevitably a need to improve and use in vitro test for the metalloceramic restorations. In this study, CAD/CAM system and low-fusion dental porcelain were used. Therefore, clinical implications should not be drawn from results of this study.

4. CONCLUSIONS

Effective surface treatment is considered essential for successful metalloceramic restorations. Within the restriction of this study, the following conclusions can be drawn. Considering the power settings of Ho:YAG, Er:YAG, and Nd:YAG laser applications, this study demonstrated that not all titanium and zirconium oxide specimens display the expected quality of surface roughness after studied laser applications and the expected SBS to veneering porcelain. For increasing SBS between low fusion porcelain and titanium and zirconium oxide substructures, among the studied laser modalities, Nd:YAG laser is more successful compared to Er:YAG and Ho:YAG lasers. That the laser applications used in the research exhibited different experimental results although there are no obvious differences between the surface images of titanium and zirconium oxide substructures through SEM imaging requires further research in order to illuminate this subject. Particularly, assessing the substructure surfaces that are exposed to separation after SBS measurement may put forth whether there is a difference between separation mechanisms through assessment with SEM investigations. These findings may initiate the development of the laser applications of suitable properties in terms of developing successful laser surface treatments.

Author Disclosure Statement

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Conflict of interest

The authors declare that there is no conflict of interest.

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