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Fiber Laser Effect on Bond Strength of Titanium implant abutment to Resin Cement

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Abstract: Aim: surface modification of titanium using fiber laser 1064 nm to enhance the bond strength to resin cement. **Material and Methods:** thirty titanium discs of 0.6 cm x 0.3 cm (diameter and thickness respectively) were categorized after preparation into three groups (n=10) as follows: control group with no surface treatment and two test groups were treated with fiber laser after estimation the appropriate parameters in the pilot study which are 81 ns pulse duration, 30,000 Hz frequency, 50 µm spot size and 10,000 mm/s scanning speed and different average power values (10 W and 20 W) depending on the tested group. Titanium discs surface characterization was performed by scanning electron microscope (SEM), and surface roughness tester. Following these tests, resin cement application to titanium discs was performed. Shear bond strength (SBS) values were determined by universal testing machine. ANOVA and Tukey HSD tests were used for analyzing of data (α = 0.05).**Results:** Higher average surface roughness (Ra) value was observed in (10 W) group followed by (20 W) group and the lowest surface roughness value was in the control group, additionally lowest SBS value was obtained from the control group and the highest SBS value was obtained from (20 W) group followed by (10 W) group. **Conclusion:** bond strength between titanium and resin cement can be significantly enhanced by using fiber laser as a surface treatment. Average power of fiber laser is essential parameter in enhancing the roughness of titanium surface and bonding to resin cement.

Keywords: fiber laser, shear bond strength, titanium, surface roughness.

1. Introduction:

The most important part of the dental implant system is implant abutment which could be made of titanium or its alloys or recently zirconia and PEEK were also suggested (Shafie, 2014).

Implant abutment represents the connection between the intra boney part (fixture) with the oral substitute structure (crown, bridge, and denture) therefore; this part may play a great role in the restoration longevity (Iocca, 2016). This obligates to establish well-tolerated connection between the restoration and abutment. Two main connection methods were suggested with the introduction of dental implant in service either screws or cement-retained prosthesis (Chaar et al., 2011). The most popular and easier type is cement retained prosthesis because it does not require complicated steps or preparation with very good results and withstand load (Akin & Guney, 2012).

The connection between implant abutment and restoration can be improved depending on many factors including surface area, height of abutment, abutment taper, type of luting cement and finish or roughness of surface (Sahu et al., 2014). When the surface area of abutment increased, the resistance to dislodgement can be physically increased. Wide surface area could be inherent especially in long or wide diameter abutments, but since dental implant cover a wide range of cases some of these could be with short, small in diameter or angled abutment. All these situations require some modification in implant abutment to improve surface area, which in turn enhances restoration resistance to dislodging functional loads (Oshida et al., 2010). Various techniques were used to enhance the bonding characteristics by surface modification of titanium abutment such as sandblasting, acid etching, electro discharge machining, grinding with bur, or a combination of these methods. Studies have shown that these techniques affect the bond strength at various amount (Ates et al., 2017; Cao et al., 2019; Kim & Cho, 2009). Lasers currently used in medical applications because it performs without residue and can be used safely with minimal precautions or preparations. ((Kim et al., 2020; Safi et al., 2019)

Titanium laser treatment were applied for fixture or restoration, it gave interesting results when proper laser was selected. Fiber laser 1064 nm is among the lasers which well absorbed and interact with titanium. Studies using different lasers as Nd:YAG 1064 nm, CO_2 10600 nm or Er:YAG 2940 nm gave promising results considering surface modification of titanium (Marticorena et al 2007; Yeo, 2020) Fiber laser 1064 nm is among the lasers which is well absorbed by titanium, it used currently in surface texturing and in some biological studies to create favorable modification by cells or proteins (Oktem et al., 2010; Riveiro et al. ,2018). Abutment-laser interaction may result in ablation and surface roughness enhancement, which could increase surface area and creates mechanical interlocking which probably improve retention. This roughness can be also obtained by sandblasting, grinding or etching but with wide range of variations, which may affect on standardization and homogeneity (Ajay et al., 2017).The present study aimed to investigate the effect of fiber laser 1064 nm on surface roughness and shear bond strength of titanium being used as abutment to resin cement for enhancing crown retention.

2. Material and methods:

Thirty titanium discs of 0.6 cm x 0.3 cm (diameter and thickness respectively) were cut by wire cut lathe machine (Bantam/ Italy) from commercially pure titanium rod grade Ⅱ (Baoji Jinsheng Metal Material/China) (Śmielak et al., 2015).Titanium discs were grinded and polished using silicon carbide papers in sequence of 120, 320, 500, 800, 1200, 2000 and 2400 grit size to obtain a uniform surface as shown in figure (1), after that the discs were cleaned ultrasonically with ethanol for 15 min then with distilled water for 10 min and left to dry.

Figure (1): Titanium discs were grinded and polished using silicon carbide papers in sequence of 120, 320, 500, 800, 1200, 2000 and 2400 grit size to obtain a uniform surface)

Ytterbium (Yb) Q-switched fiber laser 1064 nm (Wuxi Raycus fiber laser Technologies /RFL-P 100Q, China) was used for surface modification of titanium discs with 81 ns pulse duration, 30,000 Hz repetition rate, 50 µm spot size and 10,000 mm/s scanning speed. The average power was 10 W or 20 W depending on the tested group. Surface modification pattern was in the form of lines with 100 µm hatch distance.

Titanium discs were arranged into three groups in accordance with the variation in average power of fiber laser (n=10) as follows:

1. Control group: with no surface modification.
2. 10 W group: modification with fiber laser (average power 10 W and peak power 4115.2 W).
3. 20 W group: modification with fiber laser (average power 20 W and peak power 8230.4 W).

Following laser irradiation of titanium discs, from each group one disc surface was examined by (SEM) (TESCAN / VEGA 2, Czech) with magnification of 2000x to examine the surface morphology and to determine that if any cracks or defects are formed following laser treatment.

Average surface roughness (Ra) of titanium discs were examined by surface roughness tester (SRT 6210, China) that illustrated in figure (2) which contained 5 µm radius diamond probe pin oriented vertically to the surface of titanium disc with 0.25 mm cut off distance. The average value in micrometer was determined from three measurements on each surface.

Figure (2): Surface roughness tester.

After that, titanium discs embedded in mold of cold-cure acrylic to depth of 2 mm and about 1 mm from disc height was remained uncovered to guarantee that Ti disc remain intact throughout cementation as shown in figure (3).

For application of resin cement, a customized made silicon mold that shown in figure (4) was constructed with a central circular opening of 5 mm x 3 mm (diameter and depth respectively) to mold the cement over the disc, and this opening surrounded by another wider border of 6 mm x 1 mm (diameter and depth respectively) for encountering the disc to fit the mold over it.

Figure (3): Acrylic molds of titanium discs which embedded to depth of 2 mm and about 1 mm from disc height was remained uncovered to guarantee that Ti disc remain intact throughout cementation.

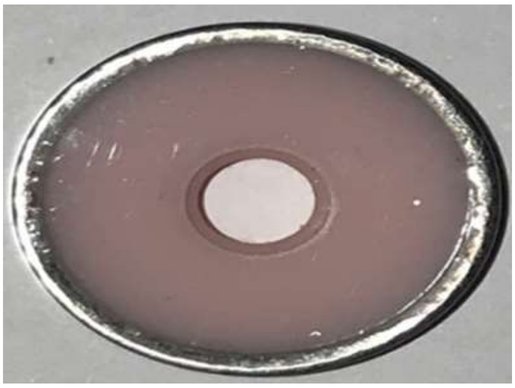

Figure (4): A customized made silicone mold for application of resin cement over the titanium discs.

Cementation procedure that shown in figure (5) was done using resin cement (Breeze self-adhesive resin cement, Pentron/ USA) following manufactures instructions.

Figure (5): Cementation procedure performed by dispensing an equal volume of resin cement through mixing tip and distributed through the mold opening then photopolymerized by light curing device.

An equal volume of resin cement mixed by mixing tip and distributed through the silicon mold opening, then photopolymerization of resin cement done via light curing device for 40 seconds. After silicone mold removing, the discs were kept in a water bath contained distilled water for 24 hours at 37 °C (Ates et al., 2017).

Shear bond strength (SBS) test was performed using universal testing machine (LARYEE/WDW 50, China), the blade-end rod position was perpendicularly to titanium–resin cement interface, and load application performed with 0.5 mm/ min crosshead speed until the occurrence of failure (Cao et al., 2019). Values of SBS (MPa) were estimated according to this formulation (Murthy, Manoharan, & Livingstone, 2014) :

$$S = \frac{F}{A}$$

Where;

S = Shear bond strength [MPa]

F = Applied force [N]

A = bond area [mm²]

3. Statistical analysis:

Analyzing of data was achieved using SPSS version 24 to analyze the data including descriptive and inferential statistics. ANOVA test was done for detection the significant differences of Ra and SBS between the groups, while Tukey HSD-test performed for detection the significant differences of SBS between every two groups at ($P < 0.05$).

4. Results:

4.1 Scanning electron microscope:

Photographs of SEM of the control and irradiated discs were illustrated in Figure (6). Control specimen appears to be smooth in comparison with test group specimens. The texture of the test group specimens consist of micro retentive grooves and display uniform roughness pattern, deep penetration areas by fiber laser beam without the presence of defects or cracks.

4.2 Surface roughness:

Higher Ra value was observed in (10 W) group followed by (20 W). The control group displayed the lowest Ra value as compared with the other groups Table (1). ANOVA test in table (2) shows a high significant difference for Ra than the control group ($P < 0.05$).

4.3 Shear bond strength:

Results considering SBS test showed that the highest value of SBS mean was obtained at average power of 20 W followed by 10 W while the lowest value SBS mean observed in control group as shown in Table (1). ANOVA test in table (3) shows a high significant difference for SBS than the control group ($P < 0.05$).

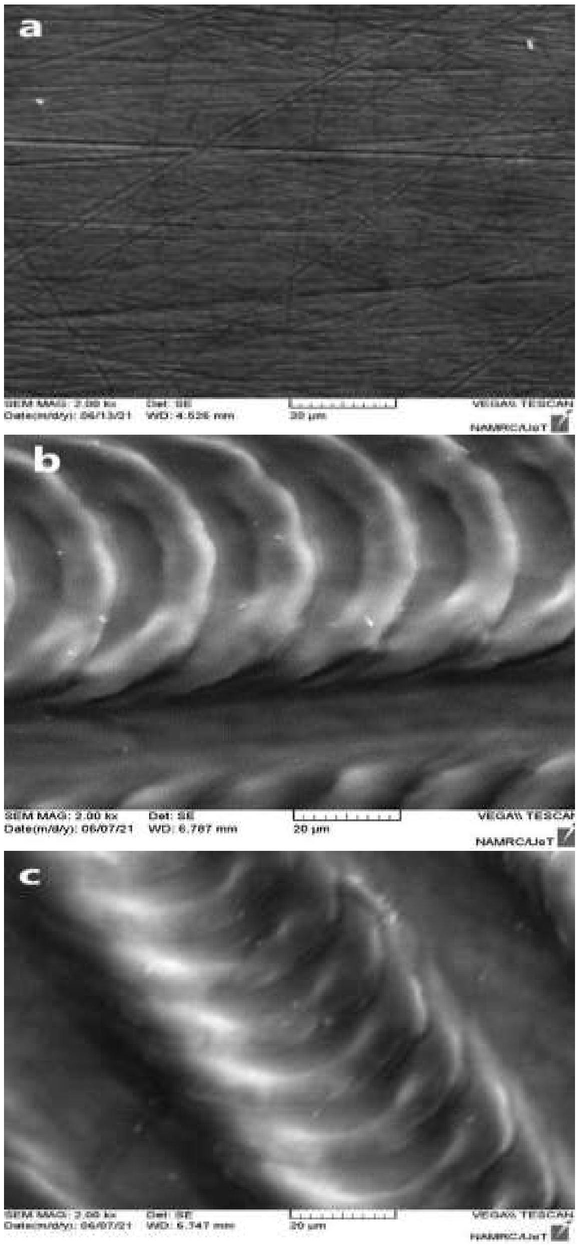

Figure (6): SEM photographs of titanium discs at magnification of 2000x (a) control, (b) 10 W and (c) 20 W.

Tukey HSD test in Table (4) shows that there is a high significant difference between the control group and each of the experimental groups and there is a high significant difference among the laser-irradiated groups.

Table 1: Descriptive statistics of Ra (mean ± SD) and SBS (mean ± SD).

Groups	Ra (µm)	SBS (MPa)
control	0.421±0.030	1.585±0.089
10 W	2.357±0.002	3.896±0.050
20 W	2.292±0.005	5.981±0.058

Table (2): ANOVA Test of Ra Data

	Sum of Squares	Df	Mean square	F	Significance
Between groups	24.162	2	12.081	38057.665	0.000
Within groups	.009	27	.000		
Total	24.171	29			

Table (3): ANOVA Test of SBS Data

	Sum of Squares	Df	Mean square	F	Significance
Between groups	96.727	2	48.363	10466.757	0.000
Within groups	.125	27	.005		
Total	96.852	29			

Table (4): Tukey HSD Test between groups for SBS.

SBS			
Groups		**Mean Difference**	**Significance**
Control	10 W	-2.311	0.000
	20 W	-4.396	0.000
10 W	20 W	-2.085	0.000

5. Discussion:

Retention loss is a common issue with cement-retained implant supported prostheses about 16.8% Chaar et al., 2011), therefore to ensure optimal prosthesis performance, a strong bond between the titanium abutment and cement is required. This study was performed for investigation the effect of different average power values of fiber laser on the surface roughness and SBS of resin cement to titanium. SEM analysis revealed a different in morphology of the surface between control specimen and fiber laser treated specimens that occurred because titanium absorbing laser energy and converting it into thermal energy, resulting in melting and vaporization. Modification of titanium surface with fiber laser enhance Ra that result in increasing the surface area with no defects or cracks, the surface area is directly proportional with retention which is important to improve bonding of cement to abutment, the findings of this study are in agreement with those of Korkmaz and Aycan 2019, who found that using a fiber laser to treat titanium alloy resulted in an increase in surface roughness without defects or cracks. When compared to the control group, all experimental groups showed greater Ra values, Surface roughness differed between the experimental groups due to differences in the average power of the fiber laser resulting in varying degrees of melting and vaporization. Furthermore, at higher value of average power (20 W) reduction in Ra was noticed because the temperature received by the specimen increased, leading to increase melting and further melt deposition on the surface and this lead to reduction in roughness to particular extent (Xi et al., 2019).

In comparison to the control group, the two laser treated groups had high significant SBS values because the surface area of titanium increases as the Ra increases, and surface roughness produce areas of mechanical interlocking that are advantageous to the cement material, improving bond strength (Elsaka, 2013), This is in conformity with the results of Ates et al. , 2017 study who found that treatment of titanium with fiber laser enhance the roughness of the surface and raised the SBS significantly.

Moreover, in this study it was found that excessive roughness of the surface that obtained from (10 W) group lead to reduction in SBS value as compared with (20 W) group, this leading to actuality that excessive roughness does not increase SBS value because excessive roughness of the surface create intense-stress areas at the interface of cement and titanium wherein severe angled edges contribute to insufficient resin cement flow into the surface's minute roughness, preventing the adhesive from fully bonding to the surface (Fawzy & El-Askary, 2009).This finding is consistent with prior studies that found that increasing roughness of the surface did not increase the bond strength (Elsaka, 2013; Elsaka & Swain, 2013; Seker, et al.,2015).

6. Conclusions:

Irradiation the surface of titanium with Fiber laser lead to increase the surface roughness with no cracks or defects and it has a significant improvement on the SBS between titanium and resin cement.

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تأثير الليزر الليفي على قوة ارتباط دعامة زرعة التيتانيوم بإسمنت الراتنج

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الخلاصة :الهدف: تعديل سطح التيتانيوم باستخدام الليزر الليفي ذو الطول الموجي 1064 نانومتر لتعزيز قوة الترابط مع اسمنت الراتنج. **المواد والطرق:** تم تصنيف ثلاثين قرصًا من التيتانيوم بحجم 0.6 سم × 0.3 سم (قطر وسمك على التوالي) بعد التحضير إلى ثلاث مجموعات (ن = 10) على النحو التالي: مجموعة التحكم دون أي معالجة سطحية ومجموعتين تمت معالجتهما بألياف الليزر مدة النبضة 81 نانوثانية، التردد 30000 هرتز ، حجم البقعة 50 ميكرومتر وسرعة المسح 10000 مم / ثانية ومتوسط قيم الطاقة مختلفة (10 واط و 20 واط) حسب المجموعة المختبرة. تم إجراء توصيف أقراص التيتانيوم عن طريق مسح المجهر الإلكتروني (SEM) واختبار خشونة السطح. بعد هذه الاختبارات ، تم تطبيق مادة الإسمنت الراتينجية على أقراص التيتانيوم. تم تحديد قيم قوة رابطة القص (SBS) بواسطة آلة اختبار عالمية. تم استخدام اختبارات ANOVA و Tukey HSD لتحليل البيانات ($\alpha = 0.05$). **النتائج:** لوحظ ارتفاع قيمة خشونة السطح في مجموعة (10 واط) تليها مجموعة (20 واط) وأدنى درجة خشونة للسطح كانت في مجموعة التحكم، بالإضافة إلى ذلك تم الحصول على أدنى قيمة SBS من مجموعة التحكم وأعلى قيمة SBS من مجموعة (20 واط) تليها مجموعة (10 واط).**الاستنتاج:** يمكن تعزيز قوة الترابط بين التيتانيوم واسمنت الراتنج بشكل كبير باستخدام الليزر الليفي كعلاج للسطح. يعد متوسط طاقة ألياف الليزر معلمة أساسية في تعزيز خشونة سطح التيتانيوم والالتصاق بإسمنت الراتنج ؛ بالإضافة إلى ذلك ، لوحظ وجود ارتباط سلبي بين خشونة السطح و قوة رابطة القص في المجموعات التجريبية.