Eur. J. Prosthodont. Rest. Dent., Vol.21, No. 1, pp 34-39
Printed in Great Britain

doi:10.1922/EJPRD_1047-AlOmari06

The Effect of Laser Irradiation on Retention of Full Cast Crowns

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Abstract - *The objective of this work was to determine the effect on the retention force of full cast crowns cemented on short tooth preparations after preparation of dentine with an erbium, chromium: yttrium scandium gallium garnet (Er,Cr:YSGG) laser at different sub-ablative power settings. Thirty teeth were prepared for full cast crowns using a milling machine. The surface area for all preparations was measured. The surfaces of the preparations were irradiated with 0 (control), 0.25 and 0.75 W laser. The crowns were cemented with self-cure resin cement and tested for retention on a Hounsfield Tensometer machine. The 0.75 W power setting produced the highest failure load value (346.2 ± 86.1 N) and was significantly higher than the other groups. There were no significant differences between the 0.25 W and 0 W control groups*

KEY WORDS: Er,Cr:YSGG, resin cement, short preparations, retention

INTRODUCTION

A close correlation has been found between features in the preparation of full coverage crowns such as taper, abutment height and crown retention [1, 2]. The advent of adhesive resin-based luting cements has compensated for the lack of geometric retention features. Adhesive cements were demonstrated to increase the retention of full coverage crowns cemented on preparations with greater taper compared to non-adhesive cements [3]. Acid etching as firstly proposed by Buonocore, remains the standard for increasing the bond between resin based composite and tooth structure [4].

Lasers have been used to prepare cavities for direct restorations as an alternative to conventional cutting. The use of lasers is appealing to clinicians because it is painless and does not produce uncomfortable vibrations [5], along with other suggested benefits which include reduced hypersensitivity [6], antibacterial effects [7] and formation of less soluble compounds [8]. It was also reported that laser irradiation produces uneven surface characteristics and exposes dentinal tubules which may appear to be conducive for bonding [9]. Recently, laser etching was suggested as a potential alternative to acid etching of enamel and dentin [9].

The Er:YAG laser has shown to be efficient in cutting dental tissues due to the high affinity of its wavelength to water and hydroxyapatite [9]. Hence, it was also suggested for etching of dental hard tissues for adhesion [9]. However, adhesion to dental hard tissues after Er:YAG laser etching was inferior to that obtained after conventional acid etching [10]. This may be attributed to the extensive fissured, cracked and slightly denatured subsurface probably produced by the thermal ablative effect and that does not appear favourable for adhesion [5,10-12].

On the other hand, The Er,Cr:YSGG laser has been reported to be effective for cutting enamel, dentin and bone [13-14] and produced similar morphological changes on dentin like the Er:YAG laser [15]. Compared to bur-cutting methods, it has produced a similar calcium-to-phosphorous ratio and hardness [16-18]. As an etching tool, a study on the microtensile bond strengths of porcelain veneers bonded to tooth surfaces was reported to have similar values when treated with Er,Cr:YSGG laser or acid etched [18]. The bond strength to enamel etched with Er,Cr:YSGG laser was similar although lower and less predictable than etching with 37% orthophosphoric acid [19]. In a recent study Er,Cr:YSGG laser used at power output of 3.5 W has adversely affected adhesion of resin to dentin unless followed by acid etching [20]. The contrary results in relation to the effect of laser irradiation on bonding quality may be attributed to the use of different exposure time, different power parameters and variations in sample preparation. Furthermore, class II composite cavities prepared with Er,Cr:YSGG laser irradiation and acid etching demonstrated similar microleakage as those prepared with conventional bur [21].

Relatively low subablative power settings of Er,Cr:YSGG laser were used for laser etching of enamel (1 W, 2 W) [18-19] which produced greater bonding strength of resin based materials to irradiated dentin compared with higher power settings [20]. For the above mentioned reasons, the current study employed low power setting to modify the dentin surfaces of tooth preparations (0.25 and 0.75 W) in an attempt to alter the surface characteristics in favourable way without producing thermal (heat) and ablative (cracks) side effects.

Although the potential use of Er,Cr:YSGG laser as an etching tool and the tensile bond strength of resin composite to laser treated dentin have been investigated, no effort has been made to assess wider clinical application such as the influence of Er,Cr:YSGG laser irradiation at low power settings on surface modification of dentin and its subsequent effect on the retention of full cast crowns cemented

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with resin-based cement. The aim of the current study was to determine the effect of surface modifications of short tooth preparations using Er,Cr:YSGG laser irradiation on the retention of full coverage crowns.

MATERIAL AND METHODS

An application to collect human teeth for research purposes was submitted to the University of Melbourne for ethics approval, and granted. Thirty sound human teeth (anteriors, premolars, and molars) were collected and soaked in 0.5% Chloramine T Hydrate (SIGMA) solution. Each tooth was mounted on a Whipmix base using pink acrylic resin under vacuum pressure. Each tooth was initially prepared with a flat incisal/occlusal surface for the purpose of simplifying height measurement. After that, preparation was carried out on a milling machine (Bredent) using standard tapered diamond burs and copious water irrigation resulting in a preparation total occlusal convergence of 10º and a 0.5 mm shoulder finish line. A new bur was used for every three preparations. Sharp preparation margins were rounded with the same diamond burs. The distance from the incisal/occlusal surface and the finish line was measured using an endodontic ruler (graduated to 0.1 mm). The preparation height was 2 mm for each tooth.

Two addition silicone impressions (Aquasil Ultra Fast Set) were taken of each preparation. One impression was poured in type IV improved die stone (GC Fuji Rock). Each die was trimmed and four coats of die spacer were applied with a reported thickness of 8-10 µm for each coat. A separator (Duceram) was applied on each die and a wax-up for a metal crown with a loop (to apply the tensile load) was fabricated. All wax-ups were cast in base metal alloy (Argeloy Non-Precious, Table 1). The average thickness of the crowns was 0.8 mm. Each crown was checked on its die, sandblasted with Al_2O_3 (50 µm particle size), rinsed with water and dried.

A Canon EOS, 350 D, camera with a 100 mm f2.8 macro lens was used from a set distance to photograph a grid containing square millimetres. Each other silicone impression was cut into five flattened surfaces. Cuts were made at the line angles to minimize the effect of the curved surfaces. Each cut surface was photographed with the same standards used for photographing the standardized grid. Utilizing the image tool software (UTHSCSA, version 3) enabled demarcation of the desired surface area of each photo and allowed counting of the total number of pixels for each tooth. The surface areas for each tooth were calculated at all heights by dividing the number of pixels for the demarcated areas of the five impression surface photos at each height by the calibrated number of pixels for one square millimetre of the grid.

The teeth were distributed into three experimental groups (n = 10), anterior, premolar and molar teeth in each. Teeth of approximately equal surface areas were selected to reduce variability between the samples. This was later confirmed statistically using one-way analysis of variance (ANOVA) test where the differences between the averaged surface area for all the samples in different groups were not significantly different and were approximately similar for the average surface area for each tooth type samples subsets between the groups ($p = 0.98$).

All teeth were cleaned, rinsed with water and dried. The teeth were irradiated with Er,Cr:YSGG laser (Biolase). This system emits irradiation at a wavelength of 2.78 µm with pulse duration of 140 µs. The repetition rate was 20 Hz and a power output range of 0 to 6 W. The pulse energy varies from 0 to 300 mJ. A G6 sapphire tip of 600 µm diameter was used. Each tooth was irradiated manually at an approximate distance of 1 mm from prepared surface to simulate clinical situation. Group one was not irradiated and served as control (3 anteriors, 4 premolars, 3 molars), group 2 (3 anteriors, 3 premolars, 4 molars) was irradiated with a power output of 0.25 W (30% water, 30% air equivalent to 19 ml/min), and group 3 (4 anteriors, 3 premolars, 3 molars) irradiated with 0.75 W (30% water, 30% air equivalent to 19 ml/min). Air and water setting were according to manufacturer's specifications for the selected powers. Based on calculation of energy per surface area, the anterior teeth were irradiated for 30 second, premolar teeth for 50 seconds and molar teeth for 70 seconds to compensate for differences in surface area and produce standardized energy density after exposure.

All teeth were then treated by Multilink Monobond primers A & B for 15 seconds and then dried by air (Table 2). The crowns were cleaned, sandblasted with Al_2O_3 (50-100 µm), rinsed with water, dried, and treated with Multilink metal primer for 60 seconds. Multilink Automix is a self-curing self-adhesive luting composite with light-curing option. The cement was automixed and then injected in each crown. The crowns were cemented. Sustained finger pressure was applied to the crown to seat the restoration on the prepared tooth, and the excess cement was removed with a Hollenback carver after light curing for two seconds and were then stored for 48 hours in temperature and humidity cabinet at 37º C and 95% humidity.

Each mounted tooth was attached to a Hounsfield Tensometer machine by screwing the machine screw into the Whipmix base plate. The tooth was centred in the middle of the base plate and the chain tensioned to allow the force to act parallel to the tooth axis and perpendicular to the base plate. A pull-off test was performed using this machine

Table 1. *Composition of the metal alloy and resin materials used in the study.*

Material	*Composition*
Argeloy Non-Precious	Ni 76%, Cr 14%, Mo 6%, Al 2%, Be 1.8%, and others < 1%
Multilink Monobond Primer A	Water, 85.7% Initiators 14.3%
Multilink Monobond Primer B	Phosphonic acid acrylate 48.1% Hydroxyethyl methacrylate 48.1% Methacrylate mod. polyacrylic acid 3.8% Stabilizers < 0.02%
Metal Primer	Solvent 87.9% Phosphonic acid acrylate 5.0% Ethoxylated Bis-EMA 5.0% Initiators and Stabilizers 2.0%
Multilink Automix	Dimethacrylate and HEMA 30.5% Barium glass filler and Silica filler 45.5% Ytterbiumtrifluoride 23.0% Catalysts and Stabilizers 1.0% Pigments < 0.01%

Table 2. *Bonding and Multilink application procedures*

Material	*Composition*
Multilink Monobond Primer A & B	Mix the two Multilink Primer liquids A and B in a 1:1 mixing ratio Apply on prepared dentine for 15 seconds with a microbrush. Disperse excess with a strong stream of air.
Metal Primer	Crowns were cleaned, sandblasted with Al2O3 (50-100 µm), rinsed with water and dried. Apply with a brush to the pre-treated metal crown intaglio surface. Allow the material to react for 60 seconds. Air dry to remove excess.
Multilink Automix	Dispense from the automix syringe Apply onto the restoration and fix/hold Light cure the margins for 2 seconds and remove the excess (Optional)

Table 3. *Means and standard deviations of surface area in mm² of tested teeth in each group.*

Tooth / *Group*	*Control*	*0.25 W*	*0.75 W*
Anterior	33.67 (8.38)	32.00 (17.43)	37.75 (13.02)
Premolar	57.50 (6.25)	53.33 (10.5)	59.00 (15.81)
Molar	82.33 (8.38)	90.75 (9.2)	84.00 (12.8)
Average Surface Area (mm^2)	*57.9 (20.9	*61.4 (28.3)	*58.1 (24.3)

**No significant differences between groups.*

Table 4. *Means and standard deviations of failure loads in Newton.*

Group	*Average Failure load (N)*	*SD*
Control	240.5 [a]	74.7
Laser of 0.25 W	220.2 [a]	82.6
Laser of 0.75 W	341.4 [b]	82.4

** Values with the different superscripts are significantly different*

Table 5. *Types of crown failure.*

Group	*Cement on crown*	*Cement on dentin*	*Cement on crown and dentin*	*Tooth fracture*
Control	2	-	7	-
0.25 W	3	-	6	-
0.75 W	1	-	5	3

which allowed a manual increase of the tensile force until failure. The load was a function of the displacement control which was done at a constant rate of two rotations of the handle per second. Maximum peak tensile force (N) was electronically recorded before decementation.

Following the testing, the samples were examined and failure types of crowns were categorized as one of the following:

- Cement on metal
- Cement on dentine
- Cement on metal and dentine
- Tooth fracture

Representative debonded specimens from each group were dried; gold-sputter coated and examined using a field-emission scanning electron microscope, (Philips XL30 FE-SEM)

RESULTS

The averaged surface area values of specimens in each group are presented in Table 3. One-Way ANOVA revealed non-significant differences between the groups ($p = 0.98$). The same result was reported for the surface area of the each tooth type subgroup compared with its counterpart on the other groups which indicated homogeneity within the groups (Table 3).

The greatest failure load values were reported for the samples irradiated with laser output of 0.75 W (Table 4). One-Way ANOVA test indicated that there was significant difference in failure load between the experimental groups. Tukey's studentized post-hoc test revealed that the significant differences were between the control group and the group irradiated with laser 0.75 W ($p = 0.023$), and between the group irradiated with laser output of 0.25 W and that irradiated with laser output of 0.75 W ($p = 0.005$). When subgroups based on tooth types were compared between the 3 groups, the same trends were found (Figure 1).

Crown failure types are presented in Table 5. The highest rate was of adhesive failure on dentin, where cement was retained on the crown, was observed in the 0.25 W group followed by the control group. However, no tooth fracture was observed for these groups. The most frequent failure mode observed for all groups was cement on dentin and crown. However, three specimens in the 0.75 W group showed tooth fracture.

The scanning electron micrographs showed that the fracture pattern was predominantly a mixed fracture exhibiting dentin surface and remnants of adhesive resin cement. Figure 2 shows an adhesive failure pattern between crown and dentin of a control specimen where dentin is covered with remnants of resin luting cement. Although, Fig 3 shows a mixed failure pattern for a specimen irradiated with 0.25 W, but the surface was not corrugated and exhibited remnants of adhesive cement and open dentinal tubules. However, the later pattern of fracture was more predominant in the specimens irradiated with 0.75 W. Fig 4 shows cohesive failure within dentin, open dentinal tubules and corrugated surface in addition to remnants of resin cement.

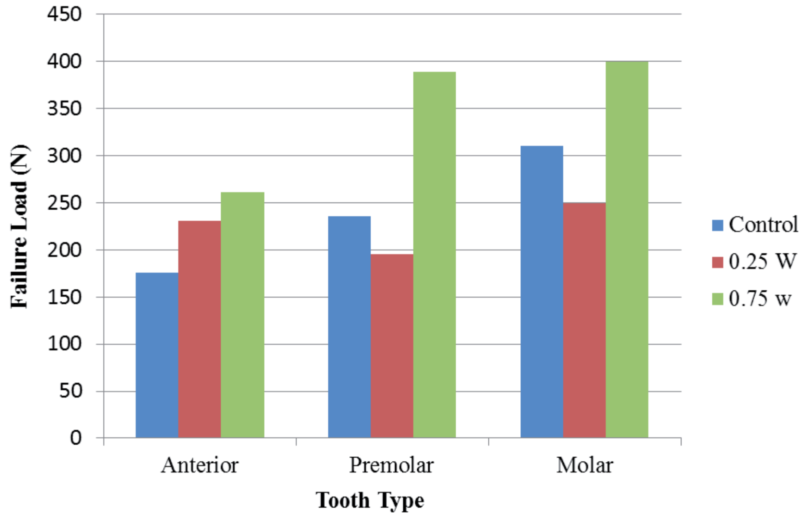

Figure 1. *The average failure load (N) according to tooth type in all the experimental groups.*

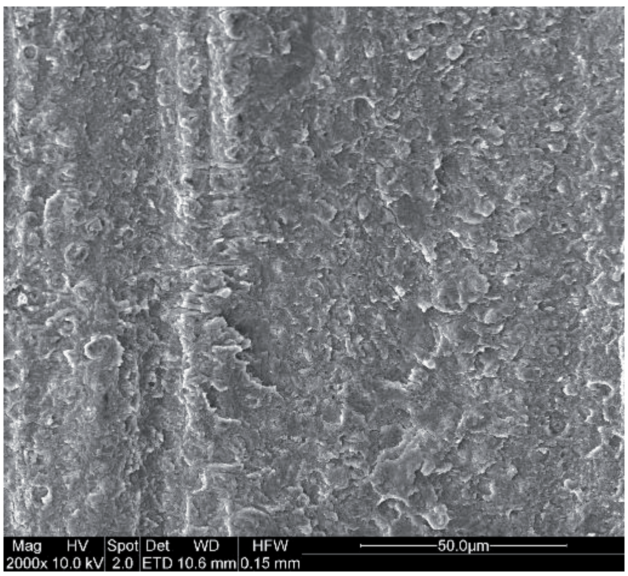

Figure 2. *Scanning electron photomicrograph (SEM) of debonded control specimen. It demonstrated remnants of luting resin cement on dentin surface (original magnification x 2000).*

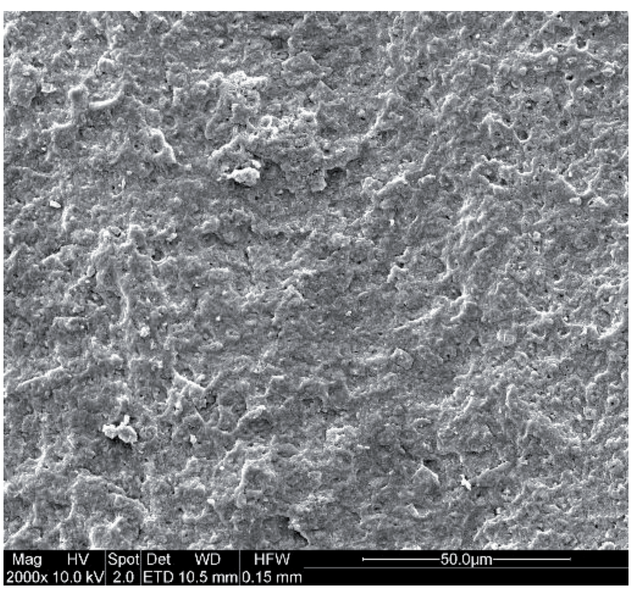

Figure 3. *Scanning electron photomicrograph (SEM) of debonded specimen irradiated with 0.25 W. Open dentinal tubules and remnants of resin cement showing a mixed failure mode (original magnification x 2000).*

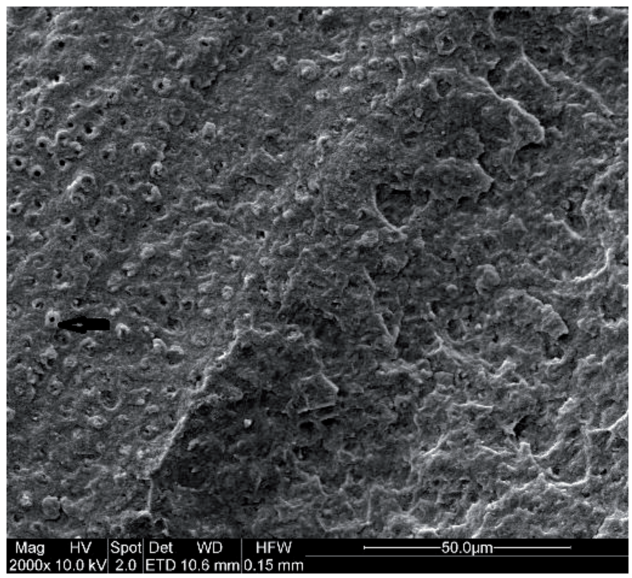

Figure 4. *Scanning electron photomicrograph (SEM) of debonded specimen irradiated with 0.75 W. Corrugated dentinal surface with open dentinal tubules with protruded peritubular dentin and remnants of resin cement are apparent showing a mixed failure mode (original magnification x 2000).*

DISCUSSION

Preparations produced by erbium lasers have a characteristic chalky appearance when used on enamel, and for dentin a rough crater like surface or scaly roughened features accompanied by the exposed openings of dentinal tubules is typical. Most tubules are generally clean and there is very little or no smear layer [22]. The surface irregularities produced by Er,Cr:YSGG laser are caused by the microexplosions during tissue ablation [14]. The micromorphology of laser treated enamel and dentin with the preferential vaporization of intertubular dentin is theoretically favorable for adhesion [18, 20]. The presence of greater highly mineralised peritubular dentin compared to intertubular dentin may result in better bonding to the dentin [9]. This was also demonstrated in the current study (Fig 4) where subablative power levels were used.

The mixed mode of failure was demonstrated in the majority of specimens in addition to dentin adhesive failure of some specimens in group 1 and 2. That indicated that the bond strength between the cement and metal was probably stronger than the bond between cement and dentin or cohesive failure within the cement. However, irradiation with 0.75 W has significantly increased the debonding force of the luted crowns. Moreover, in the 0.75W group, three specimens demonstrated tooth fracture and cohesive failure within dentin which indicated stronger bond to dentin in group 3.

As we now have a better understanding of the adhesion mechanism and the structural alterations produced by laser on the target dental hard tissue, lower power settings are currently favoured to avoid thermal effects such as vitrification, carbonization, charring recrystalization and crack formation [23]. In a previous investigation dentin irradiated with Er,Cr:YSGG laser at 3.5 W and 4.5 W showed glassy molten substance composed of the same elements as hydroxyapatite [24]. The crystalline molten glassy deposits may contribute to weak bonding quality due to redisposition of ablated debris and subsurface cracking [18].

In the current investigation the laser irradiation at subablative power settings was used to modify preparations with axial walls height of only 2 mm in conjunction with a self-priming resin based luting cements. Short preparations present a clinical problem for lack of adequate retention and resistance form. Teeth with varying occlusocervical to faciolingual dimension ratios were used namely anterior, premolar and molar teeth. The surface areas of the preparation were also different (Table 3). Preparations which are short are vulnerable to crown decementation. It is clinically possible to extend the finish line at the base of the preparation but this can result in deep finishing line that might invade the biologic width, cause excessive unnecessary destruction of tooth tissue, and may compromise the integrity of the pulp [25]. Resin cements provide a relatively simple option to overcome the lack of adequate retention form, the low tensile strength and poor adhesive properties of conventional cements [3, 25]. However, it is always recommended to combine the advantages of retentive geometrical features with resin cementation [25].

Er,Cr:YSGG laser at sub-ablative power parameters was used to assess its potential application in clinical dentistry in substantiating the effect of self-etched luting cement to increase the retention of short preparations without the need for further extensive tooth structure mechanical design modification. In the current study, laser irradiation was not used as an alternative to acid etching. Previous report found that bonding to Er,Cr:YSGG laser irradiated dentin was inferior to acid etched dentin, and that acid etching after irradiation was necessary to achieve optimal bonding [20]. That was explained by the fact that Er,Cr:YSGG laser use at ablative power setting could not selectively remove hydroxyapatite without inflicting a damaging effect to the collagen fibre network, and without acid etching, the collagen fibres were not completely exposed thus hybrid layer quality was poor in addition to the thermal side effects that might have impeded bonding.

Ceballo *et al* reported that Er:YAG laser irradiation has denatured collagen fibrils and those fibrils were subsequently poorly attached to underlying dentin substrate due to loss of cross banding [26]. The thermal effect affecting the subsurface and reduced interfibrillar spaces have impaired the infiltration of primer. Provided that the Er,Cr:YSGG laser has similar absorption peak as that of Er:YAG laser, and is also highly absorbed by the protein and lipids in collagen fibres, similar effect could be anticipated [24]. Lack of a good hybrid layer in Er,Cr:YSGG laser irradiated dentin was recently reported [20].

The sub-ablative power settings were used in an attempt to encourage selective surface modification without inducing severe harmful effect on the collagen fibres and to avoid the possible localized thermal (heat) and ablative (crack) side effects. Additionally, surface modifications by roughening tend to increase the surface area available for bonding. The use of a power output of 0.25 W did not have any significant effect on the retention of the cast crowns and was comparable to control group. However, the 0.75 W has significantly increased the retention of the crowns. Apparently the 0.25 W was too low to induce any significant surface alterations on the preparations, and thus 0.75 W was more efficient sub-ablative power parameter for this purpose. A possible explanation of the results is that an optimal energy density and power output is required to alter, corrugate and roughen the irradiated dentin surfaces to significantly increase the surface area available for bonding without undermining the collagen fibres or producing any potential thermal or ablative side effects that may jeopardise the bonding quality. Based on the results of the current study, it seems that the 0.25 W was too low a power setting to produce significant changes on the dentin surface to improve retention, while 0.75 W was sufficient to modify the surface to an extent that had a positive impact on the retention of the crowns.

The findings of the current investigations could not be directly compared to any previous investigation due to wide differences in methodology and power settings used. To avoid extreme surface modifications, the use of lower energy output than that used for hard tissue ablation should be recommended [23].

CONCLUSION

Within the limitation of the current investigation it was concluded that the surface modification with 0.75 W Er,Cr:YSGG laser has significantly increased retention of full cast crowns cemented over short preparations of various surface areas using self-etching dual cure resin cement when compared to preparations irradiated with 0.25 W Er,Cr:YSGG laser or the non-irradiated control groups.

ACKNOWLEDGEMENTS

The current study was generously funded by Jordan University of Science and Technology and Melbourne University.

MANUFACTURER DETAILS

- Whipmix Base Plate, Ivoclar Vivadent, Kentucky, USA.
- Pink Acrylic Resin, Vertex-Dental, Zeist, Netherlands.
- Milling Machine Bredent BF1, Senden, Germany.
- Addition Silicone Impressions, Aquasil Ultra Fast Set, light and heavy viscosities, Dentsply, Konstanz Germany.
- Die Spacer, Bredent, XPdent Corporation, Germany.
- Separator, Duceram, Dentsply, Hilzingen, Germany.
- Base Metal Alloy, Argeloy Non-Precious, Argibond, USA.
- Er,Cr:YSGG laser, Biolase, Waterlase Millennium, San Clement, CA, USA.
- Multilink Automix, Ivoclar Vivadent, Schaen, Liechtenstein.
- Humidity Cabinet, Thermoline Scientific Manufacturers and Distributors of Laboratory Equipment, Australia.
- Hounsfield Tensometer Machine, Tensometer Limited, England: Australian Calibrating Services "Asia" PTY. LTD.
- Electron Microscope, Philips XL30 FE-SEM; Philips, Eindhoven, the Netherlands.

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