Original Article

Evaluation of the effect of dentin surface treatment by air abrasion and Er:YAG laser on the retention of metal crowns luted with glass ionomer cement in teeth with reduced crown height: An *in vitro* study

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Abstract

Aim and Objectives: The purpose of this study was to investigate the effect of dentin surface treatment with aluminum oxide air abrasion and Er:YAG laser on tensile bond strength of metal crowns. Metal crowns were luted with conventional glass ionomer cement (GIC) in the teeth with reduced crown height, where preparation geometry did not provide optimal retention form.

Materials and Methods: Forty-eight human premolars were prepared to receive metal crowns and were randomly divided into four groups for tensile bond strength testing. Group A: Untreated dentin luted with self-adhesive composite resin cement as positive control; Group B: Untreated dentin luted with GIC as negative control; Group C: Surface treatment with 50 μm aluminum oxide air abrasion and luted with GIC; Group D: Surface treatment with Er:YAG laser (λ =2.94 mm) with a total energy 84.88 J/cm^2 of (60 mJ/pulse, 10 Hz, 60 pulses, and 100 μs pulse width) and luted with GIC. The cemented specimens were thermocycled and later subjected to axial load in a universal testing machine at 0.5 mm/min cross-head speed for tensile testing. Scanning electron microscopic evaluation of dentin surface treatment and cement–dentin interface was also done in representative specimens.

Results: One-way analysis of variance showed statistically significant difference among/within the groups ($P < 0.001$). Tukey's *post hoc* test presented significant increased tensile bond strength of Er:YAG laser group. Air abrasion group showed no significant increase in tensile bond strength values ($P = 0.033$).

Conclusion: Dentin surface treatment with Er:YAG laser significantly improved the tensile bond strength of luting GIC compared to air-abraded and untreated dentin.

Keywords: Air abrasion, complete metal crown, Er:YAG laser, glass ionomer cement, reduced crown height, tensile bond strength

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INTRODUCTION

Replacement of missing teeth with a fixed dental prosthesis (FDP) has remained a viable alternative over centuries. Success of any FDP depends primarily on the tooth preparation with optimum retention and resistance form.[1] Teeth with reduced crown height due to attrition, tooth malformation, or genetic factors often have compromised retention and resistance form after tooth preparation. Cementation of the crown is an important step for the longevity of any restoration and becomes even more important when prepared tooth geometry does not favor the optimum retention and resistance form. The clinical success of FDP is heavily dependent on the selection of cement and cementation procedure. The attachment of a dental cement may be mechanical, chemical, or combined action of both methods.[2] Ayad *et al*. reported a significant correlation between the area of dentin available for bonding and retention of the prosthetic crown and concluded that the surface roughness of prepared teeth encouraged mechanical interlocking of cement to the tooth surface, which enhanced the retention and reduced the need for additional retentive measures.[3]

Glass ionomer cement[4] (GIC) is a commonly used luting cement with physicochemical bonding and still remains a feasible choice for vital teeth because of its ability to resist caries due to fluoride release, minimal effect on the pulp, and low coefficient of thermal expansion. Tuntiprawon reported that increased tooth surface roughness positively influenced the bond strength of metal crowns luted with GIC. According to him, chemical and mechanical bonding of GIC was heavily dependent on the condition of prepared tooth surface.[5]

The role of aluminum oxide particle air abrasion and Er:YAG laser has been highlighted in many studies. These methods modify the surface topography and remove smear layer from the prepared tooth surface.[6,7] Composite resin and resin-modified GIC luting agents have already shown favorable results after undergoing these dentin surface treatments.[8,9] Altunsoy *et al*. concluded that Er:YAG laser was effective in improving the shear and microtensile bond strength of resin-modified GIC.[10] Another recent study done by Aljdaimi *et al*. also proved that laser etching of dentin leads to better restorative shear bond strength.[11]

The comprehensive review of literature reveals very limited research on metal crowns luted with conventional GIC after the surface treatment of prepared dentin. The setting and bonding mechanism of GIC is also different than resin-based cement. Therefore, this study was planned to assess the effect of aluminum oxide particle air abrasion and Er:YAG laser irradiation treatment on the dentin surface. The aim of this study was to evaluate the effect of dentin surface treatment with aluminum oxide air abrasion and Er:YAG laser irradiation on the tensile bond strength of metal crowns luted with GIC in teeth with reduced crown height. Morphological evaluations of untreated dentin, surface-treated dentin, and cement–dentin interface of the representative specimens were also carried out by scanning electron microscope (SEM).

The null hypothesis stated that there exists no difference in tensile bond strength of complete coverage metal crowns luted with GIC on untreated dentin surface, aluminum oxide particle air abrasion-treated dentin surface, and Er:YAG laser-treated dentin surface.

MATERIALS AND METHODS

An approval to conduct the study was obtained from the institutional ethical committee with approval no. SVIEC/ON/DENT/BNPG-14/D15009. From a previous study done by Kobayashi *et al*. in 2003[12] and assuming the bond strength of metal crowns among planned groups with the mean difference of 5.107 with standard deviation (SD) of 3, a power of 90%, and confidence interval of 99% and by applying the following formula: $N = Z^2/(\text{effect size})^2$ (where effect size = 1.703), a sample size per group of 10 samples was derived. By considering a 20% chance of error in processing of specimens, a sample size of 40 + 8 = 48 (12 per group) was kept. Another six specimens were prepared separately for SEM evaluation of untreated prepared dentin, air-abraded dentin, and Er:YAG laser-irradiated dentin.

A total of 54 (48 + 6) noncarious, nonrestored premolars of similar crown size, extracted for periodontal and orthodontic causes, were collected and stored in normal saline at room temperature in a sterile-sealed bottle. Calculus and debris were removed from the teeth by ultrasonic cleaning, and then, they were sterilized in autoclave in compliance with the recommendations of the Centers for Disease Control to avoid cross-contamination.[13]

Preparation of standard specimens for tensile bond strength testing

Occlusal surface of the extracted teeth was ground flat and roots were notched with rotating disc on a slow-speed handpiece. Teeth were embedded with the help of dental surveyor (Marathon–103, Saeyang Company) in the stainless steel molds in such a way that coronal portion of each tooth remained 2 mm above the cementoenamel junction and care was taken to keep the occlusal surface parallel to the horizontal plane. A high-speed dental handpiece was positioned in a custom-made attachment in such a way that the bur was oriented at an angle of 10° to create convergence angle of 20°. A flat end diamond bur with parallel sides was used to prepare axial walls under 25 ml/min water flow. The axial height of each specimen was kept 2.5 mm to simulate reduced crown height condition and 0.5-mm thick shoulder margin was prepared all around the surface[14] [Figure 1]. Impression of each prepared specimen was made in a custom tray made from autopolymerized resin. Impressions were made by two-step impression technique using soft putty and light body consistencies of addition silicon vinyl polysiloxane impression material (Lot No: ZP0011032, 624739, Express™ XT, 3M ESPE, Germany) for all specimens and poured into type IV gypsum die stone (Uni-base 300, Dentona) to prepare dies. Measurement of total prepared surface area for cementation was essential to measure tensile strength in standardized Mega Pascal (MPa) unit. Therefore, all prepared dies were scanned in a laboratory CAD/CAM scanner (AutoScan DS 100+) and three-dimensional (3D) scanned images were obtained in.STL file format. Image of each die was processed in the Geomagic Studio software with Geomagic Control tools: Version 2014 (Geomagic, Morrisville, NC, USA) and the prepared surface area was calculated on the 3D model with ±10 μm accuracy.[15]

Wax patterns were fabricated on dies with type II inlay pattern wax using dip-in method to achieve even thickness on all specimens. A wax loop was attached in the center on the occlusal surface of wax pattern exactly perpendicular to the base to allow tensile bond strength testing. Parallel positioning of wax loop was verified by analyzing rod attached to the vertical arm of the dental surveyor. The conventional casting technique was used to cast Ni-Cr alloy crowns (Dentsply International, USA).

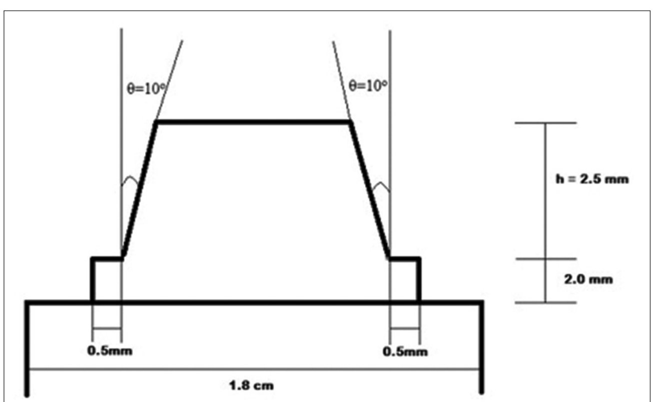


Figure 1: Longitudinal cross-section of master tooth preparation for complete crowns

Internal surface of all prepared crowns were sandblasted with 50 μ aluminum oxide sand. All the crowns were later checked for marginal accuracy on the prepared teeth by impression replica technique using light bodied vinyl polysiloxane impression material.[16] The marginal gap for all crowns was assessed in stereomicroscope (Motic, Hong Kong) under ×10 magnification. The captured images of margins of each crown were analyzed in Motic Image plus, Version 2.0 (Motic®, Hong Kong) image analyzing software. Crowns with marginal gap of <100 μm (clinically acceptable marginal gap) were considered acceptable for further procedure.[17] Crowns with marginal gap beyond 100 μm were rejected for the study and fabricated again by the same process. The specimens were randomly divided into four test groups according to computer-generated random sequence from https://www.random.org/sequences/[Table 1].

A total of four groups were made, of which two groups were kept as control groups for the study. Group A (positive control) and Group B (negative control) specimens were cemented without any dentin surface treatment. Group C and Group D (test groups) specimens were surface treated as follows:

Dentin surface treatment for Group C specimens (aluminum oxide particle air abrasion

Dentin surface was air abraded using a MicroJato intraoral microblaster (Bio-art Equipamentos Odontologicos Ltd., Brazil), with aluminum oxide particles of 50 μm under 60 psi pressure and delivered by a 0.46 mm diameter and 60° angulated tip [Figure 2]. Jet intensity was kept 5 g/min, applied at a focal distance of 5 mm with a 45° angle to the tooth surface to avoid particle reflection. Air abrasion was followed by rinsing with water for 40 s.[18]

Dentin surface treatment for Group D specimens (Er:YAG laser irradiation)

Dentin surface was treated with Er:YAG laser from Fotona Fidelis III (Fotona d.o.o., Slovenia, EU) of 0.3 mm focus beam at 60 mJ energy, 84.88 J/cm^2 energy density, and

Table 1: Four test groups of the study

Groups	Description
Group A (positive control group)	Untreated dentin and luting with self-cured composite resin luted cement-Rely X™ U200 (3M ESPE)
Group B (negative control group)	Untreated dentin and luting with glass ionomer luted cement-Ketac™ Cem radiopaque (3M ESPE)
Group C (test group)	Dentin surface treatment with 50 μm aluminum oxide particle air abrasion and luted with glass ionomer luting cement-Ketac™ Cem radiopaque (3M ESPE)
Group D (test group)	Dentin surface treatment with Er:YAG laser and luting with glass ionomer luted cement-Ketac™ Cem radiopaque (3M ESPE)

repetition rate of 10 Hz at very short pulse duration of 100 μs. R14-C handpiece in noncontact mode at a working distance of 2 mm from the dentin surface was used. A cylindrical fiber optic tip with 0.3 mm diameter and 20 mm length of R14-C handpiece: PRECISO 300/20: Cylindrical (Code: 83890) (Fotona d.o.o., Slovenia, EU) was used to irradiate the tooth surface [Figure 3]. The standard distance was maintained by attaching laser handpiece in a customized attachment of dental surveyor. The laser beam was directed perpendicular to the tooth surface. The surface was irrigated under constant air and water mist of 10 ml/min during irradiation.[6]

Cementation procedure

Specimens from Group A were cemented with self-cured composite resin luting cement RelyX™ U200 (Lot No.: 626726, 3M ESPE, Germany) and specimens from Groups B, C, and D were cemented with luting GIC Ketac™ Cem radiopaque (Lot No: 631789, 3M ESPE, Germany) using standard protocols and manufacturer's recommendations. Initially, crowns were seated with firm digital pressure and then subjected to an axial force of 5 kg for 10 min in a loading device.

After complete setting, all cemented specimens were kept in distilled water at room temperature for about 24 h. Specimens were later subjected to thermocycling at 5°C–55°C for 5000 cycles, with a dwell time of 30 s to simulate temperature changes of oral environment.[19]

Evaluation of tensile bond strength testing

After thermocycling process, crowns were subjected to an axial dislodgement force until failure occurs on a universal testing machine (Instron, Model No: 3300). The cross-head speed was set at 0.5 mm/min. The maximum force required for dislodgement was recorded in Newton (N). Measured force for dislodgement in Newton (N) was divided by previously measured total bonding surface area for cementation in mm^2 to obtain tensile bond strength values in Mega Pascal (MPa) for each specimen. The internal surfaces of the separated crowns and tooth surface were later examined under magnifying glass to determine the mode of cement failure. The mode of failures were categorized into the following four categories[20] [Table 2].

Scanning electron microscopy in representative specimens

Morphological analysis of untreated dentin, aluminum oxide particle air-abraded dentin, and Er:YAG laser-irradiated dentin was done under SEM in separately prepared six specimens. After tensile bond strength testing, two random specimens from all four groups were also subjected to SEM evaluation to assess morphological evaluation of cement–dentin interface. Scanning of the surfaces was done under ×2500 in SEM: Hitachi S-4700 FE-SEM Field Emission SEM (Hitachi High Technologies, Japan).

Statistical analysis

Mean and SD were calculated for each group. The data were analyzed with Statistical Package for the Social Sciences Version 20.1 (IBM Corp. Chicago, USA) software for descriptive and analytical statistics. The parametric one-way analysis of variance (ANOVA) test was used to check differences in mean scores between groups, and pairwise comparison was done using Tukey's honestly significant

Table 2: Modes of failure

Category	Description
Category 1	Cement mainly on prepared tooth (over 75%)
Category 2	Cement on both crown and tooth (between 25 and 75%)
Category 3	Cement mainly on crown (over 75%)
Category 4	Fracture of tooth during dislodgement

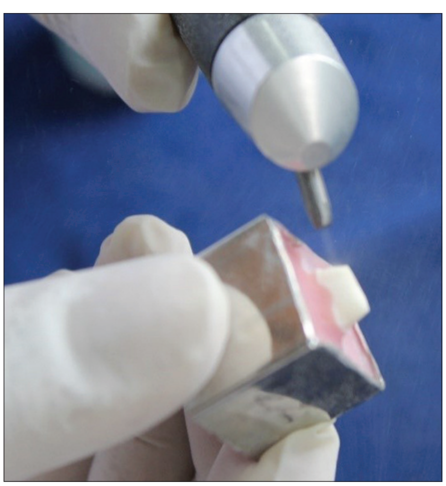


Figure 2: Dentin surface treatment by aluminum oxide air abrasion

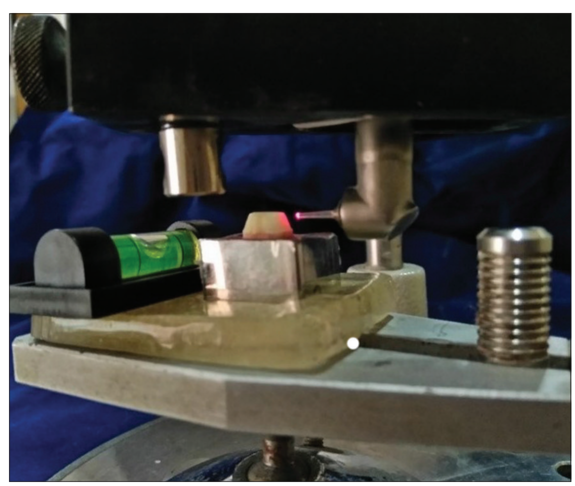


Figure 3: Dentin surface treatment by Er:YAG laser

difference (HSD) *post hoc* test. Level of significance was set at $P < 0.001$.

RESULTS

Results of tensile bond strength testing

The mean and SD tensile bond strength values of the four groups are presented in Table 3. According to the results of one-way ANOVA, a significant difference was found in the mean tensile bond strength values ($P < 0.0001$) for all the four groups [Table 4]. Self-cured composite resin cement group (Group A: positive control) showed maximum tensile bond strength while GIC group without any dentin surface treatment (Group B: negative control) showed minimum tensile bond strength. Tukey's HSD *post hoc* test [Table 5] showed statistically significant improvement in tensile bond strength of GIC after dentin surface treatment with Er:YAG laser irradiation (Group D) ($P < 0.001$) while aluminum oxide air abrasion showed no statistically significant improvement in tensile bond strength of GIC (Group C) ($P = 0.033$). Graphical representation of mean tensile bond strength of four groups is shown in Graph 1. After tensile bond strength testing, all the specimens were evaluated for the modes of failure which are presented in Table 6.

Table 3: Mean tensile bond strength testing values

Group	Mean tensile bond strength (MPa)
Group A	5.14±0.33
Group B	3.97±0.37
Group C	4.31±0.24
Group D	4.88±0.24

MPa: Mega Pascal

Table 4: One-way analysis of variance

Source	SS	df	MS	*F*	*P*
Factor (between groups)	10.2784	3	3.4261	38.17	0.000016
Error	3.949	44	0.0898		
Total	14.2274	47			

SS: Sum of squares, df: Degree of freedom, MS: Mean of square

Table 5: Tukey's honestly significant difference *post hoc* test results among groups

Group	MD	*F*	Significance *P*<0.005
Group A versus Group B	1.17	<0.001	Significant
Group A versus Group C	0.83	<0.001	Significant
Group A versus Group D	0.26	0.147	Non-significant
Group B versus Group C	−0.34	0.033	Non-significant
Group B versus Group D	−0.91	<0.001	Significant
Group C versus Group D	−0.56	<0.001	Significant

HSD: Honestly significant difference, MD: Mean difference

Results of scanning electron microscopic evaluation of dentin surface before cementation in representative specimens

The SEM image of dentin surface without any surface treatment showed a relatively flat topography. Dentin surface showed track lines formation due to the use of rotary burs and the presence of large amount of loosely attached smear layer on dentin. Dentinal tubules were completely occluded by smear layer [Figure 4].

The SEM image after the application of 50 μm aluminum oxide air abrasion showed microscopically visible irregularities with cracks, surface roughness, partial removal of smear layer, and some amount of opened dentinal tubules [Figure 5].

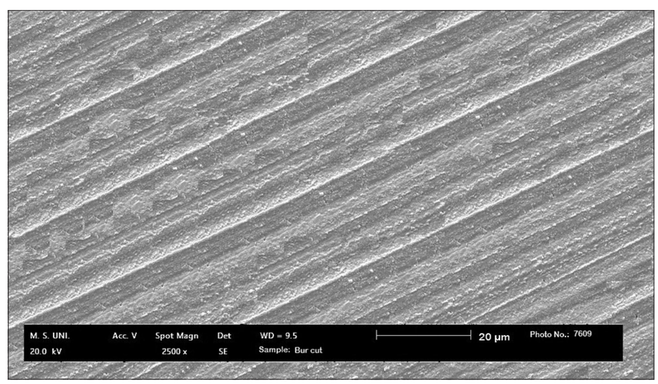


Figure 4: Scanning electron microscopic image of bur prepared dentin surface

Table 6: Summary of modes of failure among groups

Groups	Mode of failure (%)			
	Category 1	Category 2	Category 3	Category 4
Group A				
Number of specimens (*n*=12)	4	6	-	2
Percentage	33.33	50	0	16.67
Group B				
Number of specimens (*n*=12)	1	7	4	-
Percentage	8.33	58.33	33.33	0
Group C				
Number of specimens (*n*=12)	2	9	1	-
Percentage	16.67	75	8.33	0
Group D				
Number of specimens (*n*=12)	7	4	1	-
Percentage	58.33	33.33	8.33	0

Er:YAG laser-irradiated dentin showed extensive surface roughening, absence of a smear layer along with opened dentinal tubules. It also showed more ablation of intertubular dentin than peritubular dentin [Figure 6].

Results of scanning electron microscopic evaluation after tensile bond strength testing in representative specimens

SEM evaluation of cement–dentin interface of representative specimens of Group A showed resin tags had well penetrated the dentinal tubules. The resin tags were significantly similar in size all over the surface and exhibited cylindrical shape [Figure 7]. Group B showed no penetration of cement into the dentinal tubules and presence of a smear layer [Figure 8]. Group C showed less penetration of cement tags into dentinal tubules which were not uniform in nature, size, and shape. A few dentinal tubules were also seen without cement penetration [Figure 9]. Group D cement–dentin interface showed acceptable penetration of cement into dentinal tubules all over the surface [Figure 10].

DISCUSSION

The results of this study rejected the null hypothesis as dentin surface treatment with Er:YAG laser significantly increased the tensile bond strength of GIC. However, the dentin surface treatment by aluminum oxide air abrasion did not improve the tensile bond strength of GIC.

In this study, dentin surface treatment with Er:YAG laser irradiation showed a statistically significant improvement in tensile bond strength of GIC, which was comparable to the bond strength of positive control group of self-cured composite resin cement (RelyX U200). The reason of increase in tensile bond strength values in Er:YAG laser group may be because of effective removal of smear layer from the prepared tooth surface and opening of dentinal tubules orifices after laser irradiation. Previously done studies have proved that the treatment with laser results in an anfractuous surface (fractured and uneven) which leads to better bonding of cement.[21-23] SEM evaluation of representative specimens of Er:YAG laser-irradiated dentin in this study also demonstrated the complete removal of smear layer and opened dentinal tubules orifices. Similar findings were also observed in the study carried out by Hossain *et al*.[24]

Dentin surface treatment with aluminum oxide air abrasion assessed in this study did not show a statistically significant improvement in tensile bond strength of GIC.

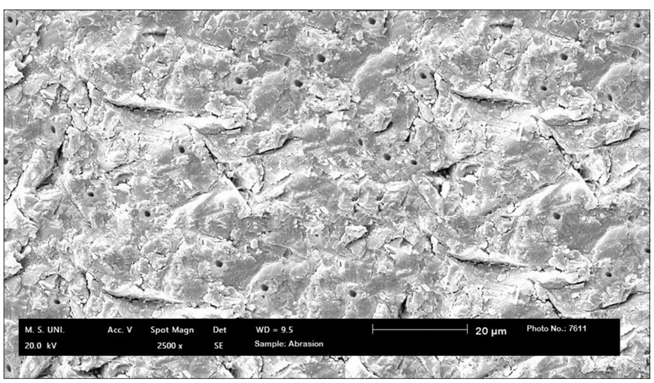


Figure 5: Scanning electron microscopic image of air-abraded dentin

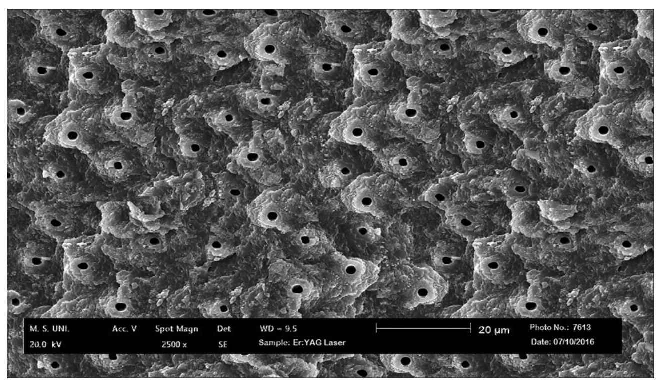


Figure 6: Scanning electron microscopic image of Er:YAG laser-irradiated dentin

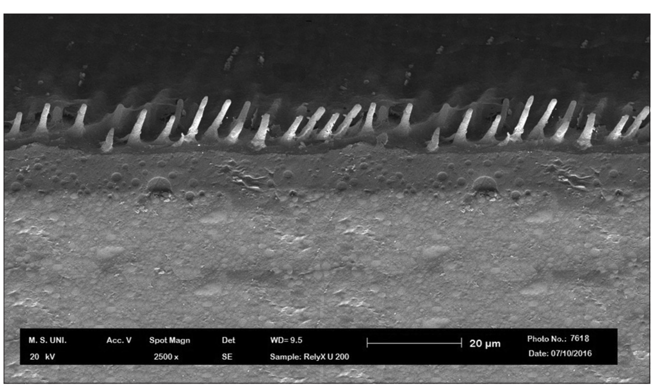


Figure 7: Scanning electron microscopic image of cement–dentin interface (Untreated, resin cement group)

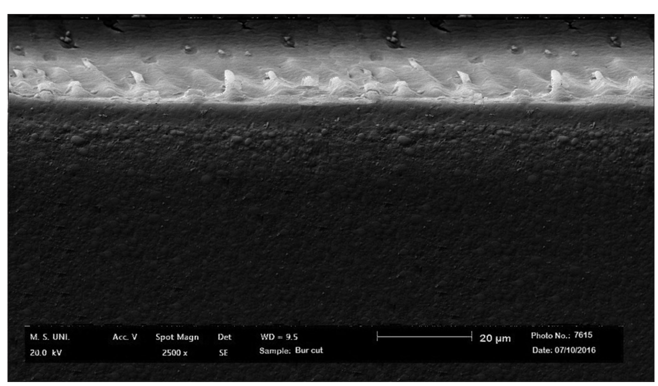


Figure 8: Scanning electron microscopic image of cement–dentin interface (Untreated, glass ionomer cement group)

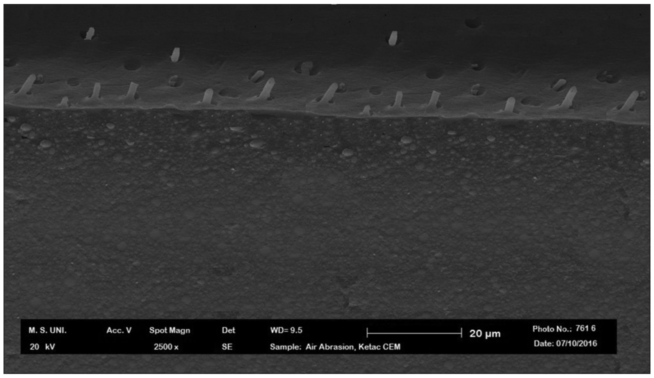


Figure 9: Scanning electron microscopic image of cement–dentin interface (air abrasion, glass ionomer cement group)

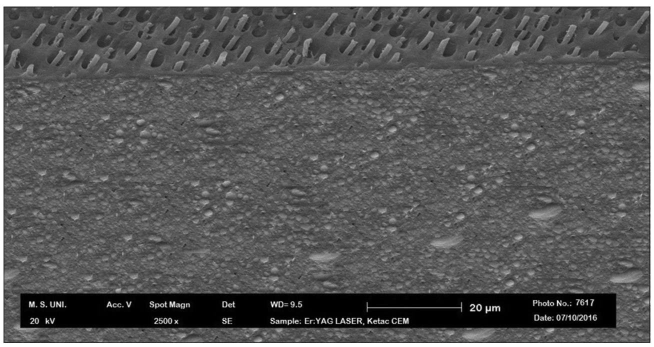
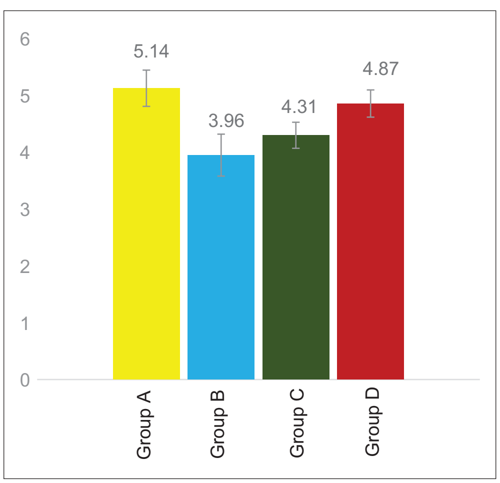


Figure 10: Scanning electron microscopic image of cement–dentin interface (Er:YAG laser, glass ionomer cement group)



Graph 1: Graphical representation of mean tensile bond strength (MPa) of four groups

SEM evaluation of representative specimens also showed partial removal of smear layer and few open dentinal tubules with surface roughness. According to Parab and Ram, aluminum oxide air abrasion acts on the surface of hard dental tissues by emission of particles under high pressure, not selectively removing the organic and inorganic portions of the substrate. This leads to the formation of a characteristic layer on the tooth surface which consists of dental hard tissue and aluminum oxide particles.[6] This may be the possible reason for no improvement seen in tensile bond strength of GIC after dentin surface treatment with air abrasion in this study.

In this study, types of failures were also assessed after tensile bond strength testing. Specimens of Er:YAG laser-treated group showed mostly the cohesive type of failure (58.33%) which also suggests that bonding of cement to the laser treated dentin may be satisfactory, because of which the cement remained attached to the tooth. According to Jiang *et al*., cohesive failure mostly suggests that the bond to the tooth is stronger than the cohesive strength of the cement.[25]

A systematic review by Ng *et al*. in 2007 showed 68%–85% success rate of primary root canal treatments.[26] Thus, necessity of re-root canal treatment cannot be ruled out during the life span of the patient, which may require retrieval of the cemented crown. However, in clinical scenario, if crown requires removal, high retentive strength of resin-based luting cements may be sometimes detrimental to healthy tooth structure. Thus, if favorable retention is achieved even with conventional GIC after laser surface treatment, it may be quite advantageous.

This study was conducted on crowns with reduced clinical height to simulate a clinical scenario which clinicians encounter most often in day-to-day practice. It also compared the conventional GIC after laser surface treatment with gold standard resin-based cement. The difference between two groups came nonsignificant; thus, the results may be applied by further testing other parameters in *in vitro* and *in vivo* setups. Various authors have also suggested the potential of Er:YAG laser in reduction of postoperative sensitivity.[27,28] Thus, laser surface treatment with various luting cements in clinical situations of vital abutments can be applied after further research on teeth sensitivity aspects. Future studies on a larger number of SEM specimens can also be conducted to comprehensively investigate the cement–dentin interface. Research may also be undertaken using a combination of various dentin surface treatments.

There are a few limitations of this *in vitro* study. The SEM evaluation done in this study to confirm the results of tensile bond strength testing was on limited specimens only. Intrapulpal temperature changes due to Er:YAG laser irradiation was also not assessed in this study. The results obtained from this study are from standardized tooth preparation and in ideal experimental conditions. Variations in results might be possible in clinical setups, where the tooth preparation cannot be controlled precisely by clinicians due to clinical restraints.

CONCLUSION

Within the limitations of this *in vitro* study, the dentin surface treatment with Er:YAG laser significantly improved the tensile bond strength of luting GIC as compared to untreated dentin and air-abraded dentin.

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Conflicts of interest

There are no conflicts of interest.

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