



Push-out bond strength of calcium-silicate cements following Er:YAG and diode laser irradiation of root dentin

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Abstract

This study aimed to compare the effects of diode and Er:YAG laser irradiation of root dentin on push-out bond strength of mineral trioxide aggregate (MTA) and calcium-enriched mixture (CEM) cements. An in vitro experimental study was conducted on 90 dentin discs, cut out of freshly extracted human teeth. The discs were instrumented to obtain 1.3-mm lumen diameter. Then, they were randomly divided into six groups ($n = 15$). Groups 1 and 4 subjected to diode laser (Wiser, Doctor Smile, Italy) (980 nm, 1 W, continuous mode) for 10 s and filled with MTA and CEM cements. Groups 2 and 5 subjected to Er:YAG laser (Deka, Italy) (2940 nm, 1 W, 10 Hz, 230 μ s) for 10 s and filled with MTA and CEM cements. Groups 3 and 6 (control groups) were filled with MTA and CEM cements without laser irradiation. After 7 days, push-out bond strength test was performed using a universal testing machine in order to evaluate the adhesion of the biomaterials to dentin. The samples were evaluated under a light microscope at $\times 40$ magnification to determine the mode of fracture. Data were analyzed using two-way ANOVA. The highest push-out bond strength (8.76 ± 3.62 MPa) was noted in group 1 (diode/MTA), which was significantly higher than the other groups ($P < 0.001$). The lowest bond strength (2.61 ± 0.81) was noted in group 6 (control/CEM). Diode laser significantly increased the bond strength of both cements ($P < 0.05$), but Er:YAG laser irradiation only increased the bond strength of CEM and had no significant effect on MTA ($P = 0.603$). The bond strength of MTA control group was higher than that of CEM control group ($P = 0.001$). Push-out bond strength of endodontic cements can be affected by dentin conditioning with diode 980 nm and Er:YAG laser. Nine hundred eighty-nanometer diode laser irradiation is recommended to increase the bond strength of endodontic cements particularly the CEM cement to dentin.

Keywords Mineral trioxide aggregate · Calcium-enriched mixture cement · Diode laser · Er:YAG laser · Push-out bond strength

Introduction

An ideal endodontic cement must have excellent biocompatibility, dimensional stability, sealing ability,

impermeability, and resistance to dislodging forces and provide a strong bond to dentin [1]. Mineral trioxide aggregate (MTA) is an endodontic cement with advantages such as excellent biocompatibility, optimal sealing ability,

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and polymerization in presence of blood and moisture [2, 3]. Due to these properties, MTA is not only used as a root end filling material, but is also applied in periapical surgery, pulpotomy, perforation repair, and as a pulp capping agent and apical plug in open apex, immature necrotic teeth [4, 5]. However, long setting time and difficult handling are among the drawbacks of MTA [6]. To overcome these shortcomings, some other endodontic cements were introduced to the market such as calcium-enriched mixture (CEM) cement. Evidence shows that CEM cement yields clinical results similar to those of MTA and has favorable properties such as easy handling and short setting time (less than 1 h) [7, 8]. Endodontic cements are used to provide a hermetic seal and an impermeable barrier between the oral environment and periradicular tissues and the root canal system. To maintain a hermetic seal, these cements must have adequate strength against the dislodging forces including occlusal forces applied during masticatory function or loads applied for condensation of dental materials over the cements [9, 10]. The bond strength of these cements depends on their mechanical and physical properties as well as the prepared dentin surface [11].

Laser application has gained increasing popularity in dentistry and particularly in endodontics in the recent years due to the antibacterial and antibiofilm activity [12, 13].

Evidence shows that diode and Er:YAG laser irradiation change the dentin structure through distinct mechanisms. Diode laser penetrates deeply into the soft tissue. It is well absorbed by melanin and hemoglobin especially in the areas of inflammation but it is transmitted through water due to the low water absorption coefficient, appropriate for soft tissue manipulation with minimum influence on healthy dental hard tissue. Er:YAG is categorized as a shallow penetrating laser [14]. It has a peak absorption in water and can interact with hydroxyapatite through water-mediated ablation mechanism [15] but diode laser does not interact with hard tissue and merely produce heat that can change crystal phase of dental structure [16]. On the other hand, diode laser has peak absorption in pigments and the main mechanism is photothermal effect [17]. It has been shown that both lasers remove the smear layer and debris, melt dentin, open or obstruct the dentinal tubules, and create an irregular surface. Such alterations in dentin structure change the mechanical properties and compromise the seal provided by endodontic cements and, thus, affect the bond strength of these cements to dentin [18–21].

Previous studies in this field suffer from a number of shortcomings. Moreover, a consensus has not been reached on the efficacy of lasers for this purpose. Considering the significance of bond strength of endodontic cements to dentin, this study aimed to assess the effect of diode and Er:YAG laser irradiation of root dentin on push-out bond strength of endodontic cements such as MTA and CEM cement.

Materials and methods

This in vitro, experimental study was performed on 50 extracted single-rooted human teeth stored in 0.5% chloramine T solution at 4 °C.

Specimens' preparation

Using a diamond saw microtome (SP1600; Leica, Nußloch, Germany), sections were made perpendicular to the longitudinal axis of the tooth at the middle third of the root; 90 slices with 1 ± 0.5 -mm thickness were made. The lumen of dentin discs was enlarged using no. 2–5 Gates Glidden drills (Dentsply Maillefer, Ballaigues, Switzerland) to standardize the lumen size (1.3 mm). The samples were irrigated using NaOCl 5.25% (Chloraxid, Cerkamed, Poland).

Experimental groups

Dentin discs were then randomly divided into six groups ($n = 15$) (Fig. 1).

In group one, the lumen of the discs was subjected to diode laser irradiation (Wiser, Doctor Smile, Italy) with wavelength of 980 nm and 1-W power in continuous wave mode with 1-mm distance from the surface for 10 s. The fiber tip diameter was 400 μm and power density was 795.77 W/cm^2 . Each laser tip was used for preparation of 10 samples. The canal lumen was then filled with white ProRoot MTA (Dentsply, Tulsa, OK, USA), prepared by mixing the powder and liquid in 3:1 ratio as recommended by the manufacturer.

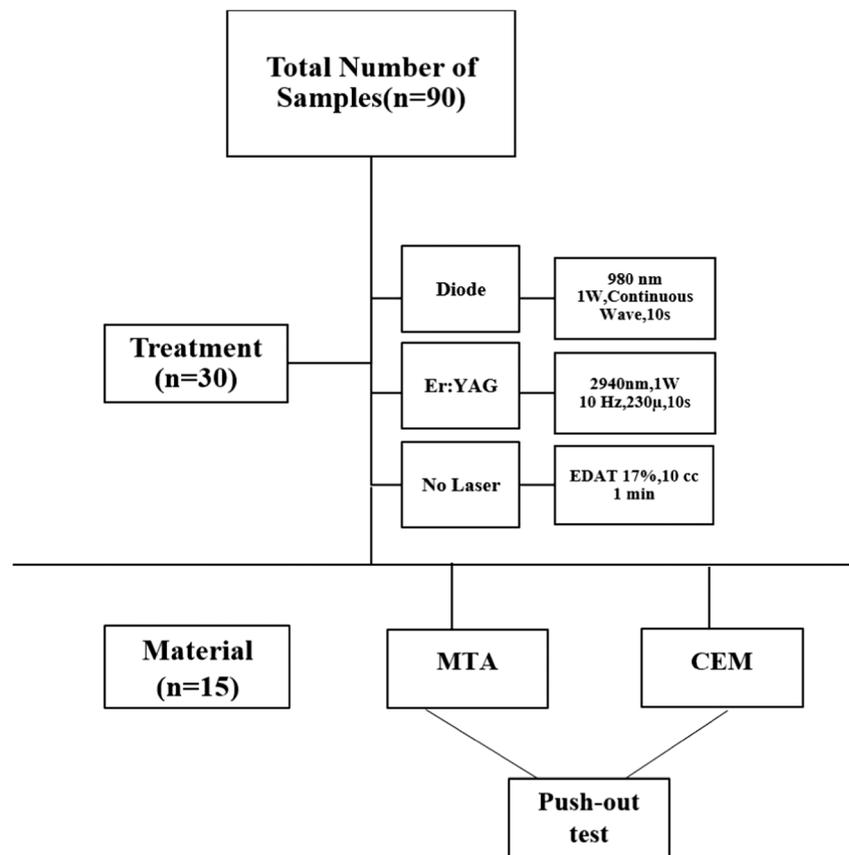
In group two, the lumen of the discs was subjected to Er:YAG (Deka, Italy) laser irradiation with 1-W power, 10-Hz frequency, 100-mJ energy, 230- μs pulse width and 4-mm distance from the surface with non-contact handpiece for 10 s. The beam diameter was 1 mm and power density was 127.34 W/cm^2 . The canal lumens were filled with white ProRoot MTA as in group one.

In group three, the smear layer was removed using EDTA 17% (MD-Cleaner, Meta, Korea), 10 cc for 1 min. Then, the lumen of the discs was filled with ProRoot MTA without laser irradiation (control).

In group four, lumen of the discs was subjected to diode laser irradiation with exposure parameters similar to those in group one. The lumen was filled with CEM cement (BioniqueDent, Tehran, Iran) with powder-to-liquid ratio of 3:1 as recommended by the manufacturer.

In group five, the lumen of the canals was subjected to Er:YAG laser irradiation with exposure parameters similar to those in group two. The lumens were then filled with CEM cement as explained for group four.

Fig. 1 Consort diagram showing study setup



In group six, the lumens were irrigated with EDTA 17% and then filled with CEM cement without laser irradiation (control).

To prevent extrusion of cements from the bottom of the dentin discs, Gelatamp (Coltene/Whaledent, Langenau, Germany) dipped in saline was used as a matrix. Slight pressure was applied to fill the lumen with cements. The discs in all groups were then covered with a moist gauze (dipped in distilled water) and incubated at 37 °C for 72 h at 100% relative humidity.

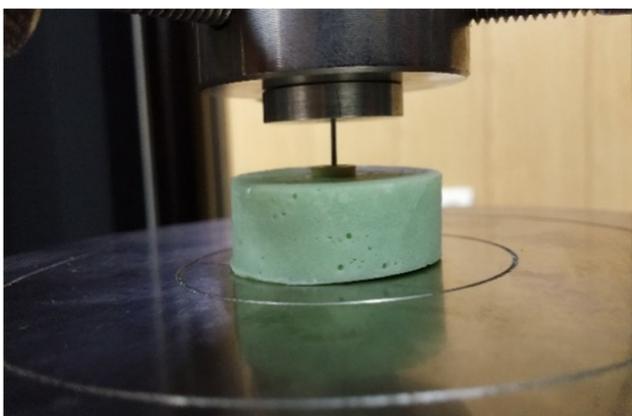


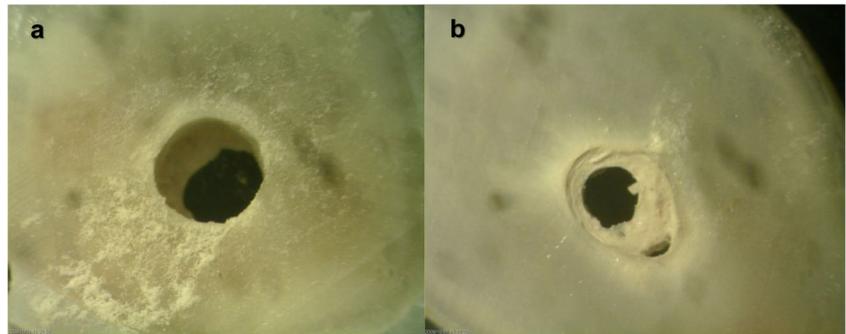
Fig. 2 Push-out bond test using universal testing machine

Push-out bond strength test

A universal testing machine (Z050; Zwick/Roell, Ulm, Germany) was used to measure the push-out bond strength (Fig. 2). For this purpose, the discs were placed on a metal slab with a hole at the center to allow free movement of plunger. Using a stainless steel cylindrical plunger with 1 mm diameter, compressive load was applied to the cement surface with a crosshead speed of 1 mm/min. The plunger had about 0.2-mm distance from the dentin margin to ensure that it would only contact the cement. Maximum load causing dislodgement of cement from the lumen was recorded in Newtons (N). To express the bond strength value in megapascals (MPa), load in Newtons was divided by the adhesion surface area in square millimeters (mm^2), which was calculated using the formula $2\pi rh$ where π is a constant value, r is the canal radius, and h is the root slice thickness in millimeters (mm).

To determine the mode of fracture, each slice was inspected under a light microscope (Nikon, Tokyo, Japan) at $\times 40$ magnification. The mode of fracture was categorized into three groups of adhesive (fracture at the dentin-cement interface) (Fig. 3a), cohesive (fracture within the cement), and mixed (fracture at the dentin-cement interface and within the cement) (Fig. 3b).

Fig. 3 Mode of bond failure. **a** Adhesive bond failure in MTA/diode group. **b** Mixed bond failure in CEM/Er:YAG



Statistical analysis

The sample size of each testing was calculated using two-level factorial tab of minitab10 considering $\alpha = 0.05$, $\beta = 0.2$, and pooled standard deviation = 1.32.

Data were analyzed using two-way ANOVA at 0.05 level of significance. Because the interaction effect was significant subgroup analysis applied using independent sample *t* test, one-way ANOVA, and Tukey's HSD post hoc.

Results

Table 1 shows the mean bond strength values in the groups. The results showed the highest push-out bond strength (8.76 ± 3.62 MPa) in group 1 (diode/MTA) and the lowest bond strength (2.61 ± 0.81 MPa) was noted in group 6 (CEM cement control group). The interaction effect of laser irradiation and type of material was significant ($P = 0.001$). In MTA and CEM groups, the bond strength values were statistically significant among three subgroups ($P = 0.004$ and 0.011 , respectively) (Table 2). Table 3 presents the results of multiple comparison between push-out bond strength of the study groups. Diode laser significantly increased the bond strength of both cements to dentin ($P < 0.05$), but Er:YAG laser only increased the bond strength of CEM cement to dentin and had no significant effect on MTA ($P = 0.603$). The bond strength of MTA control group was significantly higher than that of CEM cement control group ($P = 0.001$) (Fig. 4). Observation of the samples under a light microscope showed that the

fracture mode in MTA groups was mainly adhesive. The fracture mode in CEM cement and CEM cement/Er:YAG laser groups was mainly mixed, whereas in CEM cement/diode laser group, the dominant mode of fracture was adhesive.

Discussion

An ideal endodontic cement must be able to resist dislodging forces such as mechanical stresses and occlusal forces applied during function (as in pulp capping and pulpotomy treatments), loads applied during condensation of restorative materials (as in furcal perforation repair), and loads applied for condensation of root filling materials over the apical plug in open-apex teeth [22, 23]. It has been shown that the push-out bond strength test is highly efficient and reliable for assessment of bond strength [24]. Er:YAG and diode laser irradiation can cause structural changes in root dentin and condition the dentin surface. Thus, they have been the topic of many studies [25]. Considering the limited number of studies on the effects of diode and Er:YAG laser on push-out bond strength of endodontic cements, this study evaluated the effect of diode and Er:YAG laser irradiation of root dentin on push-out bond strength of MTA and CEM cements.

The results of this study showed that diode laser increased the bond strength of MTA and CEM cement. Increased push-out bond strength noted in 980-nm diode laser groups may be due to the elimination of smear layer and debris from the dentin surface, which was also mentioned by Wang et al. [26] and Marchesan et al. [27]. Laser parameters used in the present study (1 W/continuous wave mode) might result in open dentinal tubules, free of smear layer rather than melting dentin surface and occluding tubules. Lotfi et al., in their study, evaluated the effect of elimination of smear layer on push-out bond strength of MTA and CEM cements and showed that elimination of smear layer significantly increased the bond strength of these two cements, which was in agreement with our results [28].

Saghiri et al. showed that 810-nm diode laser irradiation and output power 2 W decreased the bond strength of MTA to dentin compared to the control group, while the present study using

Table 1 Descriptive values of push-out bond strength of the groups

Treatment	Material	Range	Mean \pm SD
MTA	No laser	1.88–10.69	5.94 ± 2.88
	Diode	3.20–14.11	8.76 ± 3.62
	Er:YAG	1.33–9.77	4.83 ± 2.86
CEM	No laser	1.17–4.01	2.61 ± 0.81
	Diode	1.61–6.44	3.90 ± 1.59
	Er:YAG	1.65–5.90	3.71 ± 1.09

Table 2 The result of one-way ANOVA test between lased and unlased groups in MTA and CEM

Material		Sum of squares	df	Mean square	F	Sig.
MTA	Between groups	2050/309	2	1025/154	6/219	/004
	Within groups	6923/347	42	164/842		
	Total	8973/656	44			
CEM	Between groups	245/581	2	122/790	5/032	/011
	Within groups	1024/893	42	24/402		
	Total	1270/473	44			

980-nm diode laser and 1-W power revealed higher bond strength in endodontic cements. The conflicting results might be attributed to different methodologies and diode laser parameters. They explained that irradiation of diode laser causes dentin surface melting, which interferes with the chemical bond of MTA to dentin [29]. It has been shown that the 980-nm diode laser energy is absorbed by mineral content of dentin, causing morphological changes in dentin and smear layer removal [30]. The structural changes in dentin may justify the enhancement of the bond strength of endodontic cements in this study. In the current study, Er:YAG laser irradiation only increased the bond strength of CEM cement to dentin and had no significant effect on bond strength of MTA. Evidence shows that Er:YAG and Er,Cr:YSGG laser irradiations create irregular and rough dentin surfaces [11, 19]. This can affect the bond strength of cements to dentin. Due to high viscosity, MTA cannot well penetrate into the irregularities and dentinal tubules of laser-irradiated surfaces. Furthermore, Er:YAG laser excessively eliminates the smear layer, a wet layer that serves as a coupling agent and increases the adaptation of hydrophilic materials such as MTA to root canal walls. Thus, excessive elimination of smear layer can have a negative effect on bond strength [31]. However, it seems that increased bond strength in CEM cement groups following Er:YAG laser irradiation is due to the increased micromechanical retention following changes in dentin surface

caused by laser irradiation and penetration of cement into open dentinal tubules as the result of smaller size of particles of this cement [32].

Based on the results of the current study, the push-out bond strength of MTA was higher than that of CEM cement, which may be explained by the fact that fluoride ions present in the composition of MTA delay its setting time, increase its expansion, and enhance its adhesion, which may confer extra resistance to MTA against the dislodging forces [33].

In our study, mode of fracture was adhesive in MTA groups irrespective of laser irradiation and mixed in CEM cement and CEM cement/Er:YAG laser groups. However, mode of fracture was adhesive in CEM cement/diode laser group.

In studies by Adl et al. [34] and Saghiri et al. [35], fracture mode was mainly adhesive following the application of MTA, which was in agreement with our results since the dominant mode of fracture in our study was adhesive in MTA groups irrespective of laser irradiation. The adhesive mode of fracture in MTA groups is probably due to the high compressive and cohesive strength of MTA; as the result, MTA is dislodged as a bulk [31]. Moreover, MTA is a bioactive material, which can form a hydroxyapatite or carbonate apatite layer when exposed to a phosphate-containing liquid for 2 months [36, 37]. Therefore, adhesive failure in our study may be related to the short storage time before the push-out test, which was

Table 3 The results of multiple comparison between push-out bond strength of the study groups based on the Tukey HSD test

Materials			Mean different (I-J)	Std. error	Sig.	95% confidence interval	
						Lower bound	Upper bound
MTA	No	Diode	- 11.51371*	4/68816	/047	- 22/9036	- /1238
		Er;YAG	4/51965	4/68816	/603	- 6/8702	15/9095
	Diode	No	11.51371*	4/68816	/047	/1238	22/9036
		Er;YAG	16.03337*	4/68816	/004	4/6435	27/4232
	Er;YAG	No	- 4/51965	4/68816	/603	- 15/9095	- 6/8702
		Diode	- 16.03337*	4/68816	/004	- 27/4232	- 4/6435
CEM	No	Diode	- 5.29855*	1/80378	/015	- 9/6808	- /9163
		Er;YAG	- 4.52066*	1/80378	/042	- 8/9029	- /1384
	Diode	No	5.29855*	1/80378	/015	/9163	9/6808
		Er;YAG	/77789	1/80378	/903	- 3/6044	5/1602
	Er;YAG	No	4.52066*	1/80378	/042	/1384	8/9029
		Diode	/77789	1/80378	/903	- 5/1602	3/6044

**p* value < 0.05

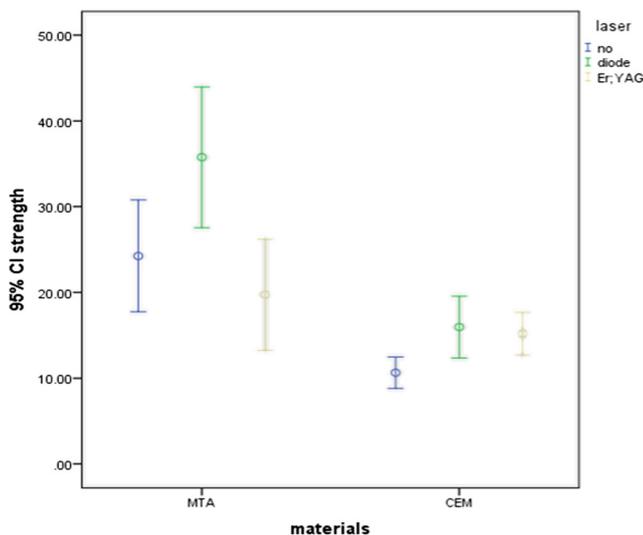


Fig. 4 The distribution of push-out bond strength values among the groups

not long enough to allow formation of hydroxyapatite or carbonate apatite layer [10]. Large size of cement particles can also prevent their penetration into dentinal tubules and consequently result in adhesive fracture [32].

The dominant mode of fracture was cohesive in CEM cement group in studies by Adl et al. [34] and Sobhnamyan et al. [38] and in CEM cement group with/without Er,Cr:YSGG laser irradiation in the study by Shokouhinejad et al. [31]. However, in the current study, similar to that of Lotfi et al. [28], the mode of fracture was mainly mixed in CEM cement group and CEM cement/Er:YAG laser group while the mode of fracture was dominantly adhesive in CEM cement/diode laser group. Controversy in the results of studies may be due to the difference in methodologies such as different incubation times. The incubation time was 2 months in the study by Shokouhinejad et al. [31].

Difference in the mode of fracture between the MTA and CEM cement groups may be due to the difference in chemical composition of cements. It has been demonstrated that phosphorus is the most important component of CEM cement while it is found in smaller amounts in MTA. Resultantly, deposition of hydroxyapatite occurs in greater amounts in use of CEM cement. This results in reduction of gap between the dentinal walls and cement. Therefore, a stronger chemical bond is formed, decreasing the frequency of adhesive mode of fracture [31]. Another possible explanation may be due to the changes in dentin structure as a result of pretreatment with either Er:YAG laser [39] or diode 980 laser [40] that may affect the chemical bond of endodontic cements in a different manner but needs to be confirmed in further studies.

In clinical conditions such as vital pulp therapy or perforation repair where MTA and CEM cements are in direct contact with blood, they may behave differently [41]. Therefore, additional studies such as scanning electron microscope (SEM)

analysis is required on the effects of laser irradiation on bond strength of endodontic cements to dentinal walls with special emphasis on their chemical composition.

Conclusion

Within the limitations of this study, it appears that push-out bond strength of endodontic cements can be affected by dentin conditioning with 980-nm diode and Er:YAG lasers. According to the findings of present study, 980-nm diode laser irradiation is recommended to increase the bond strength of endodontic cements particularly CEM cement to dentin. Further clinical trials is suggested to support the findings.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study is an ex vivo study and does not include animal or human participants.

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