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Effect of Different Laser Treatments on the Bond Strength of Intracanal Fiber Posts Cemented with a Self-Adhesive Resin Cement

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Abstract

Purpose: To evaluate the influence of laser-activated irrigation by Er:YAG and Er:YSGG (LAI) protocols and Nd:YAG laser irradiation on the bond strength of self-adhesively cemented fiber posts to root canal dentine.
Materials and Methods: The study sample consisted of 84 human single-rooted permanent teeth instrumented with ProTaper Next technique. After obturation, post space preparations were created for fiber-reinforced composite posts. The prepared specimens were divided according to the laser treatment of the post space preparations: group 1: LAI (Er:YAG) + saline solution (pulse energy: 20 mJ, repetition rate: 15 Hz); group 2: LAI (Er:YAG) + QMiX solution (pulse energy: 20 mJ, repetition rate: 15 Hz); group 3: LAI (Er,Cr:YSGG) + saline solution (pulse energy: 62.5 mJ, 20 Hz); group 4: LAI (Er,Cr:YSGG) + QMiX (pulse energy: 62.5 mJ, 20 Hz); Nd:YAG laser (pulse energy: 100 mJ, 10 Hz). Fiber-reinforced posts were cemented with a self-adhesive cement. The bond strength was evaluated by the push-out bond strength test, and the mode of failure was determined under a stereomicroscope. Kruskal-Wallis test was used for the intergroup comparative analysis with 5% level of significance.
Results: The highest bond strength was recorded in the Er:YAG + QMiX group (mean 3.401 MPa) ($p < 0.05$), followed by the Er,Cr:YSGG and the Er:YAG + saline solution (mean 1.111 MPa and 1.094 MPa, respectively), which did not differ significantly ($p = 0.232$). The irradiation with the Nd:YAG laser caused similar bond strength as the Er,Cr:YSGG + QMiX ($p = 0.942$).
Conclusion: All laser protocols enhanced the bond strength of the self-adhesive cement in root canals compared to only saline irrigation. The bond strength of the self-adhesive cement depended on the laser parameters and irrigant used for the LAI.

Endodontically treated teeth often have insufficient remaining coronal structure due to previous restorations, carious lesion, or fracture. Therefore, placement of a post is necessary for such teeth in order to provide sufficient restoration retention.[1] Fiber-reinforced composite posts (FRCP) have the advantage of good esthetics and a modulus of elasticity similar to that of dentin, thereby improving the equal distribution of functional loads to the root canal walls.[2]

FRCPs are adhesively bonded in the root canal with resinous cements, creating a structural and mechanically homogenous complex inside the root canal.[3,4] Different adhesive systems (etch-and-rinse and self-etch) and various luting cements are available for the cementation of fiber posts.[5] A group of self-adhesive resin cements introduced in 2002 simplify the cementation procedure and eliminate potential mistakes of intra-radicular bonding.[6] Self-adhesive resin cement's adhesion mechanism is based on micromechanical retention and chemical interaction between monomer acidic groups and hydroxyapatite.[7] SpeedCEM (Vivadent Ivoclar, Schaan, Lichtenstein) is a self-adhesive, dual-curing resin cement. According to the manufacturer, phosphoric acid groups in a long-chain methacrylate of the SpeedCEM react with the calcium ions of the dental hard tissues and, in the process, enable infiltration of the smear layer and tooth structure by the cement.

The interface between the cement and the dentin could be compromised by the smear layer and debris created along the canal walls during post space preparation.[8] Many studies have been conducted on the efficacy of different irrigation solutions (sodium hypochlorite [NaOCl], ethylenediaminotetraacetic acid [EDTA], chlorhexidine [CHX]) on the bonding to root canal dentine after post space preparation.[9-11] Sodium hypochlorite is an oxidizing agent that, according to some studies, may inhibit polymerization and affect the bond strength of various adhesive systems negatively.[9] Other studies did not find a difference in bond strength of cement to dentine when treated with NaOCl or other irrigants.[12,13] The new irrigant QMiX, which is a combination of EDTA, CHX, and detergent, was claimed to effectively remove smear layer and debris[14] and could improve the bond strength of self-adhesive cement to a root canal wall.[15] On the other hand, some authors claimed that the presence of a smear layer does not influence the bond strength of self-adhesive cement to the root canal wall.[6,7]

Lasers are a more recent suggestion for root canal disinfection and debridement.[16] The erbium, diode, and Nd:YAG lasers have been evaluated in the pretreatment of post space preparation.[17,18] However, the heat produced by the near-infrared lasers can change dentin morphology by melting, carbonization, or recrystallization and thus affect the bond strength of intracanal resin cements.[19,20] Erbium lasers can be used for the activation of irrigants in the canal (laser-activated irrigation, LAI) as a result of the formation of vapor bubbles and cavitations in liquid.[21] Er:YAG laser has been used at very low and short pulses (20 mJ, 50 μs) causing a pure photo-acoustic effect in the canal without thermal effect and vaporization, a protocol called photon-initiated photoacoustic streaming (PIPS).[22] LAI has been claimed to enhance the elimination of smear layer and dentine debris from root canal walls.[22] However, there is still no sufficient data on the interface of self-adhesive cements and dentine after laser root canal pretreatment.[19]

The aim of this study was to evaluate the effect of LAI performed by the Er:YAG laser and Er,Cr:YSGG laser and Nd:YAG laser irradiation on the bond strength of self-adhesive cement on intracanal dentine. The null hypothesis was that there were no differences in the bond strength of a self-adhesive cement to root canal dentin after different LAI protocols and Nd:YAG laser irradiation.

Materials and methods

Specimen preparation

The study was approved by the Ethics Committee of the School of Dental Medicine University of Zagreb (No 05-PA-26-6/2015). The study sample consisted of 84 anterior single-rooted permanent human teeth extracted for periodontal reasons. After extraction, the teeth were stored in 0.5% chloramine-T solution at 4°C and were there for about 3 months before being used in the study. The teeth were decoronated, and the working length was set at 16 mm long. The root canals were instrumented with ProTaper Next instruments (Dentsply/Maillefer, Tulsa, OK) to the final X3 (size 30, 0.07 taper). The canals were irrigated with 1 mL 2.5% NaOCl during instrumentation. A coronal reservoir for irrigant placement was created with a size 5 Gates Glidden drill (VDW, Munich, Germany) placed 5 mm into the canal. The smear layer was removed according to the following protocol: rinsing the canals with 1 ml 2.5% NaOCl for 30 seconds, 1 ml 15% EDTA left in canal for 1 minute, followed by final rinsing with 1 ml 2.5% NaOCl and 1 ml saline solution. The canals were dried with sterile paper points size X3 (ProTaper Next).

The root canals were filled with size X3 ProTaper Next gutta-percha points and epoxy resin based endodontic sealer (AH Plus; DeTrey Dentsply, Konstanz, Germany) using the lateral condensation technique. The orifices of the root canals were covered with a temporary cement (Caviton, GC Corporation; Tokyo, Japan) and stored in an incubator for 14 days at 37°C in 100% humidity for complete setting of the sealer.

After 14 days, the post space preparation was made with a low-speed drill, size #1 (diameter 0.8 mm at the tip), provided by the post system's manufacturer (FRC Postec Plus; Ivoclar Vivadent) to a depth of 7 mm into the canal. The preparations were rinsed with 1 ml distilled water and dried with sterile paper points (Dentsply Maillafer, Ballagues, Switzerland).

Laser treatments of the post space preparation

The 84 specimens were randomly divided into six groups (n = 14) according to the laser treatment of the post space preparations:

Group 1: PIPS (Er:YAG) + saline solution: The Er:YAG laser (LightWalker; Fotona, Ljubljana, Slovenia) (wavelength 2.94 μm) was used for the activation of the 5 ml saline solution, which was constantly injected in the canal by a 30-gauge needle for 25 seconds. During the irrigation, the 600 μm radial firing tip was positioned at the coronal entrance of the canal and activated. The PIPS protocol was repeated three times. The parameters of the Er:YAG laser were: pulse energy 20 mJ, pulse duration 50 μs, pulse repetition rate 15 Hz, energy density 2.06 J/cm^2.

Group 2: PIPS (Er:YAG) + QMiX solution: The protocol was the same as in group 1, except the irrigant was QMiX solution.

Group 3: LAI (Er,Cr:YSGG) + saline solution: The root canal was filled with saline solution, and then a 275 μm radial firing tip (Endolase Tip RFT2; Biolase, San Clemente, CA) of the the Er,Cr:YSGG laser (Waterlase iPlus; Biolase) (wavelength 2.78 μm) was moved in an apico-coronal direction at 2 mm/s for 5 seconds. The procedure was repeated five times,[23] and after each cycle of irradiation, a fresh amount of the irrigant was filled in the canal. The total amount of the irrigant was 5 ml. The laser parameters were: power 1.25 W, repetition rate 20 Hz, pulse duration 140 μs, pulse energy 62.5 mJ.

Group 4: LAI (Er,Cr:YSGG) + QMiX solution: The procedure was the same as in group 3, except the irrigant was QMiX solution.

Group 5. Nd:YAG laser: The 300 μm diameter fiberoptic delivery tip of the Nd:YAG laser (LightWalker) was placed 7 mm inside the post preparation and withdrawn to the cervical region using helical movements (five times for 5 seconds with 20-second breaks between). The parameters of the laser were: pulse energy 100 mJ, repetition rate 10 Hz, medium power 1.5 W, pulse duration: 100 μs, energy density 140.85 J/cm^2.

Table 1 Push-out bond strength values, mean, and standard deviation for each post space pretreatment (MPa)

Groups	N	Mean (MPa)	SD	Minimum (MPa)	Maximum (MPa)	Percentiles 25th	Percentiles 50th (Median)	Percentiles 75th
Needle+saline	14	0.737	0.128	0.500	0.810	0.610	0.810	0.810
Nd:YAG	14	0.868	0.074	0.800	1.010	0.830	0.840	0.913
PIPS+QMiX	14	3.401	1.506	0.840	5.510	2.110	3.090	5.020
Er: YSGG+QMiX	14	0.919	0.139	0.800	1.080	0.810	0.810	1.080
PIPS+saline	14	1.094	0.014	1.080	1.110	1.080	1.100	1.110
Er,Cr: YSGG+saline	14	1.111	0.033	1.080	1.170	1.080	1.110	1.128

Table 2 Comparison between the groups with exact *p* values

Groups	Needle +saline	PIPS +QMiX	Nd:YAG	Er,Cr:YSGG +QMiX	PIPS +saline	Er,Cr:YSGG +saline
Needle+saline		0.001	0.018	0.039	0.001	0.002
PIPS+QMiX	0.001		0.004	0.002	0.006	0.009
Nd:YAG	0.018	0.004		0.942	0.002	0.004
Er: YSGG+QMiX	0.039	0.002	0.942		0.005	0.006
PIPS+saline	0.001	0.006	0.002	0.005		0.232
Er,Cr:YSGG+saline	0.002	0.009	0.004	0.006	0.232	

In the control group (n = 14), the post space preparations were irrigated with saline solution delivered by 30G needle and syringe.

Cementation of fiber posts in root canal

An FRCP post size #1 (FRG Postec Plus; Vivadent Ivoclar) were silanized (Monobond Plus; Ivoclar Vivadent), left for 60 seconds, and air dried with a strong stream of air. The root canals were filled in with the self-adhesive resin cement (Speed CEM), and the posts were placed into each root canal and polymerized for 60 seconds each (Bluephase; Ivoclar Vivadent). Coronally, the posts were completely covered with the same resin cement (SpeedCEM).

After 1 week, the prepared specimens were mounted in methacrylate resin (Meliodent; Heraeus Kulzer, Wehrheim, Germany) and sectioned transversely with the water-cooled precision diamond saw (Isomet 1000; Buehler, Lake Bluff, IL) to get 1-mm thick discs. Three discs were cut from each specimen.

One specimen from each group was subjected to scanning electron microscopy (SEM) to visualize the bond between the cement and the dentine wall. The specimens were dehydrated in aqeous ethanol solutions (40%, 50%, 60%, 75%, 95%) for 20 minutes each. The specimens were sputter coated with a gold-palladium alloy, and the analysis was performed using SEM (Tescan Vega TS5136LS; Tescan, Brno, Czech Republic).

Push-out test

The push-out test was performed 1 month after the post cementation on the universal testing machine (AGS-10kND; Shimadzu Co., Kyoto, Japan). The push-out pin (ø1 mm) was loaded at the apical part of the root slice at 0.5 mm/min crosshead speed.[23] The bond strength (MPa) was calculated according to the formula: N (the recorded force at which the post broke out) / the area (A) of the cylinders ($A = 2\Pi rh$, where $\Pi = 3.14$, r = cylinder radius, h = cylinder thickness).

Modes of failure were determined under the stereomicroscope (Olympus SZX10; DF PL1.5, Hamburg, Germany) at 20x magnification. The failure modes were classified into three categories: type 1, adhesive failure between the luting material and root canal dentin; type 2, adhesive failures between the luting material and fiber post; type 3, mixed failure of failures 1 and 2.[19]

The average of three measurements obtained from three discs per specimen were statistically analyzed. Due to nonparametric data distribution, the Kruskal-Wallis test and Mann-Whitney U test were used for the intergroup comparative analysis of data. The significance level was set at 5%. Analyses were performed using IBM Statistics 19.0.0.1. (Statsoft, Tulsa, OK).

Results

Table 1 shows the bond strength values for each irrigation protocol. All laser protocols provided higher bond strength of the self-adhesive cement (SpeedCEM) in the post space preparation compared to the control group ($p < 0.05$). The levels of significance between the groups are presented in Table 2. The highest bond strength was recorded in the group PIPS + QMiX ($p < 0.05$), followed by the LAI (Er,Cr:YSGG) and the PIPS with saline solution, which did not differ significantly ($p = 0.232$). There were no statistically significant difference between the LAI (Er,Cr:YSGG) + QMiX and the Nd:YAG laser ($p = 0.942$).

Failure patterns are presented in Table 3. The mode of failures were mostly between the resin cement and the dentin (41.67%),

Table 3 Failure pattern distibution of different groups tested: Type 1, adhesive failure between the luting material and root canal dentin; Type 2, adhesive failure between the luting material and fiber post; Mixed failure of failures 1 and 2

Groups	N	Type 1 Adhesive failure (N)	Type 2 Adhesive failure (N)	Mixed failure (N)
Needle+saline	14	12	0	0
Nd:YAG	14	8	0	4
PIPS+QMiX	14	2	8	2
Er,Cr: YSGG+QMiX	14	3	5	4
PIPS+saline	14	3	7	2
Er,Cr:YSGG+saline	14	2	6	4

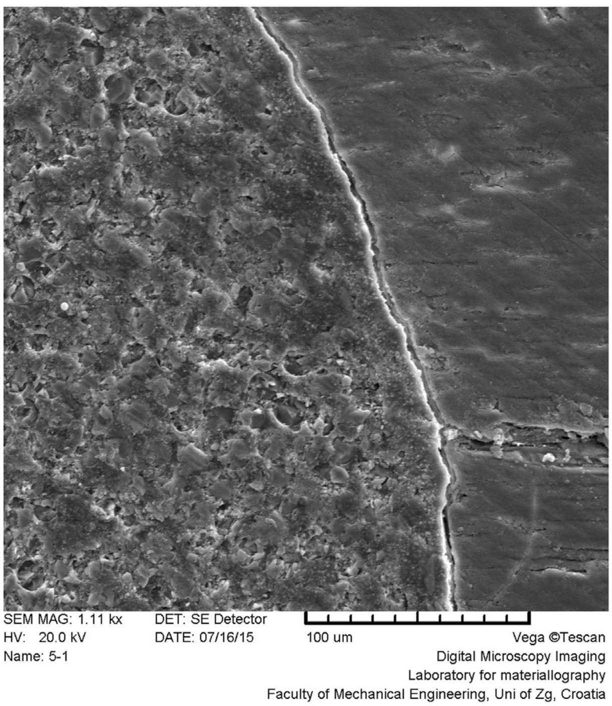

Figure 1 SEM image of the bond between dentine and cement after Nd:YAG irradiation.

followed by failures between the cement and the post (36.11%) and mixed failures (22.22%). In the control group, all failures were between the resin cement and the root canal dentin.

Figure 1 shows the SEM image of the bond between the cement and dentine after Nd:YAG irradiation. A large gap is visible between the resin cement and the post. Figure 2 shows the SEM image of the dentine border and resin cement after PIPS + QMiX treatment, which is without gaps. Similar results are seen after PIPS + saline solution (Fig 3). Figure 4 shows a small gap between the dentine and resin cement after Er,Cr:YSGG laser + QMiX treatment, and a large gap in dentin. Figure 5 shows the SEM of the bond between dentine and cement after Er,Cr:YSGG LAI + saline, and Figure 6 shows the SEM of the control group.

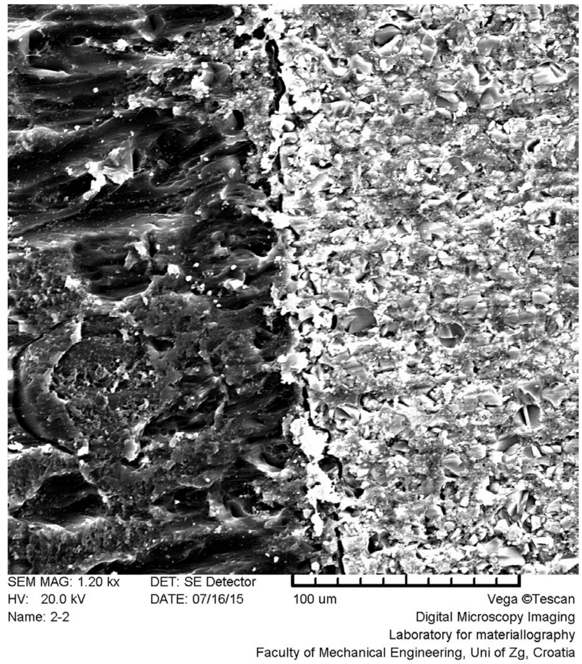

Figure 2 SEM image of the bond between dentine and cement after PIPS+QMiX.

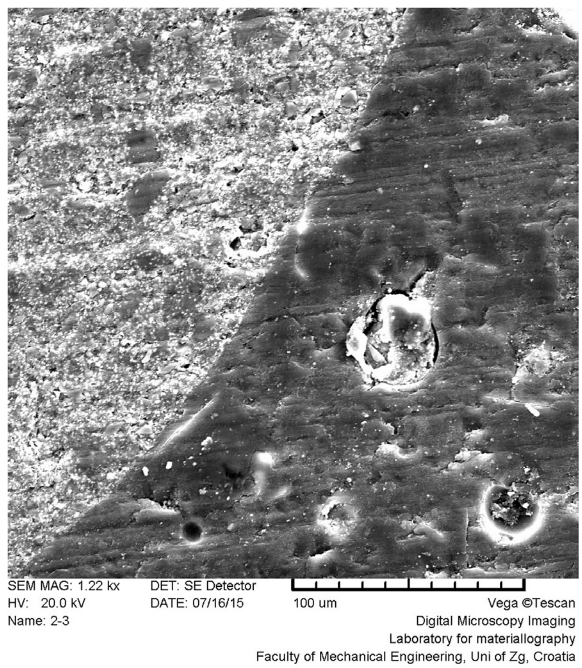

Figure 3 SEM image the bond between dentine and cement after PIPS+saline.

Discussion

The null hypothesis of this study was partially rejected, since the bond strength of the self- adhesive cement depended significantly on the laser parameters and irrigants used for the LAI. In the literature, there is still some contoversy regarding

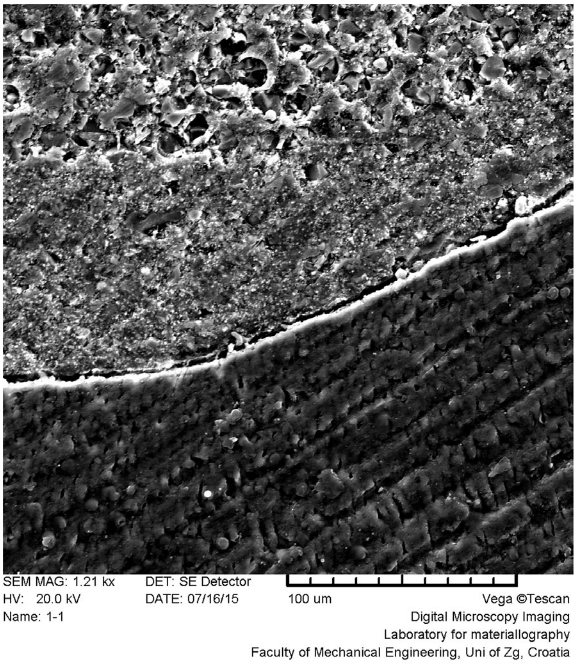

Figure 4 SEM image of the bond between dentine and cement after Er,Cr:YSGG LAI + QMiX.

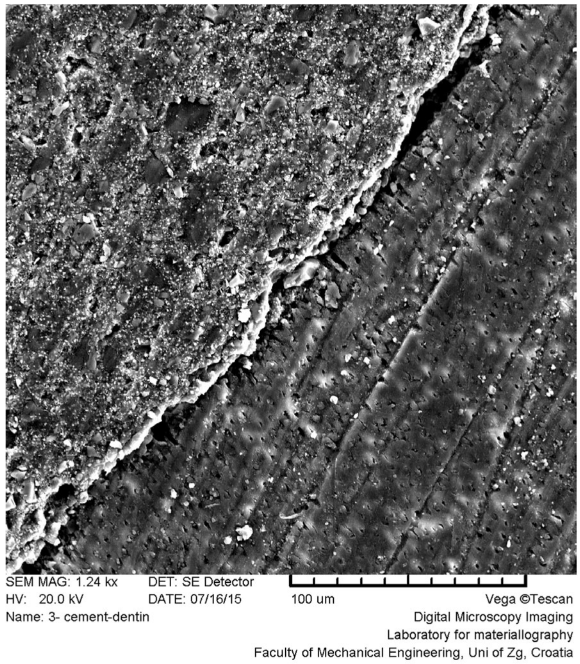

Figure 6 SEM of the bond between dentine and cement after in the control group (saline irrigation).

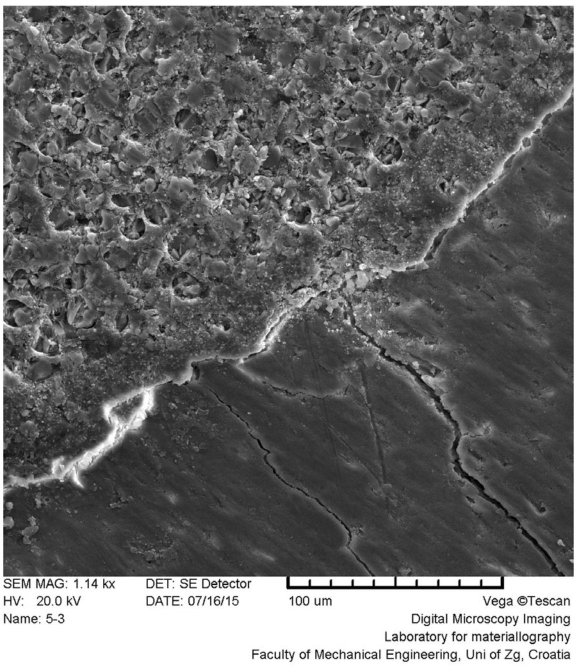

Figure 5 SEM image of the bond between dentine and cement after Er, Cr:YSGG LAI +saline.

the influence of smear layer on the adhesion mechanism of FRCPs cemented with a self-adhesive cement.[20,24] The penetration of self-adhesive cements into the thick smear layer produced during post space preparation can be difficult due to the limited etching ability of acidic methacrylates during adhesive procedures.[7] Thus, investigators have proposed different pretreatments to aid in partially or totally removing the smear layer. Elnaghy[15] reported higher bond strength of the self-adhesively cemented (iCEM) fiber posts after irrigation of the post preparation with QMiX or EDTA compared to rinsing with distilled water or NaOCl. He also reported significantly less smear layer and debris after the QMiX and the EDTA irrigation compared to other irrigants. In our study, the QMiX also improved the bond strength of the FRCPs cemented with the self-adhesive cement (SpeedCEM) compared to saline solution irrigation. This could be due to the detegrent in the composition of the QMiX, which lowers the surface tension of the solution, increases its wettability, and, consequently enhances its contact with the smear layer and the underlying dentine.[14] In addition, EDTA in QMiX demineralizes the smear layer, and CHX disinfects the post space preparation.[14,19] Although we did not measure the smear layer removal score, it may be supposed that higher bond strength after the laser-assisted QMiX irrigation was due to its smear layer and debris removal.[15] Other authors[25] did not find significant influence of irrigation protocols on the bond strength of fiber posts cemented with self-adhesive cements. Crivano et al[6] claimed that bond strength of a self-adhesive cement did not depend on the presence of resin tags, so smear layer did not have to be removed. In addition, few studies have shown that antimicrobial endodontic procedures performed after the post space preparation may interfere with bonding of cements to root canal walls.[11]

It has already been demonstrated that laser irradiation could influence the strength of the bond between post and root canal dentin by causing fusion, carbonization, or melting the smear layer and underlying dentine.[19,20] Nagase et al[20] showed that Nd:YAG laser (124 J/cm^2) and Er,Cr:YSGG (0.75 W, water/air flow of 24% and 34%, respectively) did not improve the tensile bond strength of posts cemented with total-etch adhesive system. Contrary results were reported by Katalinic et al,[9] who found that Nd:YAG laser irradiation (4 W, 20 Hz, 10 seconds) provided the highest bond strength of the self-etch adhesively bonded post and core system to root canal dentine. In this study, the Nd:YAG laser irradiation (140.85 J/cm^2) caused the lowest bond strength of the self-adhesive cement to root dentine compared to the LAI. This was also shown in SEM, which revealed a large gap between the dentine and resin cement, probably caused by the thermal effect of the Nd:YAG laser on the smear layer. In Anic et al's study,[26] the Nd:YAG laser irradiation of dentine surface caused morphological alterations, such as melting and resolidification, and the formation of small globules. We can assume that the lower bond strength after Nd:YAG irradiation in this study could be result of alteration of the collagen fibrils or increase of the acidic resistance of the irradiated substrate.[26,27] Few studies have been published on the influence of LAI on the push-out bond strength of posts and cements in root canals. Mohammadi et al[19] found that treatment of post preparation with Er,Cr:YSGG laser with 20% (0.5 W) and 50% (2.5 W) distilled water increased the bond strength of a self-adhesive cement. LAI has already been shown to be effective in smear layer and debris removal,[16,22,28] which could promote better adhesion of self-adhesive cements.[15] Arslan et al[29] showed that the Er:YAG laser irradiation (1.5 W, 10 Hz) with/without EDTA enhanced the bond strength of fiber-reinforced posts to root canal dentin.

In this study, we evaluated Er:YAG (PIPS) and Er,Cr:YSGG LAI with saline solution and the QMiX. The laser parameters used for the PIPS and Er,Cr:YSGG LAI in this study were according to the manufacurer's reccommendations and had already proven successful in intracanal debris removal.[30,31] The better results obtained with the PIPS could be attributed to the subablative settings of the laser (20 mJ pulse energy), which caused only photoacoustic effect in the QMiX and the saline solution. These results are also explained by SEM, which showed a homogeneous bond between the dentine and resin cement after PIPS. Lower bond strength after the Er,Cr:YSGG irradiation could be attributed to the higher pulse energy of 62.5 mJ, which might have caused a slight thermal effect on the dentine walls, and thus compromised the bonding of the cement.[20] Also, SEM revealed small gaps between the dentine and the cement after the Er,Cr:YSGG laser, probably due to partial vaporization of the smear layer. The fracture line found in the dentine tissue in group Er,Cr:YSGG laser + saline solution could be an artefact. On the other hand, Kirmali et al[32] evaluated the influence of different intensities of Er,Cr:YSGG laser (1W, 2W, 3W) on the push-out bond strength of glass fiber posts and did not find any influence of laser irradiation on bond strength. Similarly, Bitter et al[33] found no effects of the Er:YAG laser (140 mJ, 15 Hz, 3 × 10 second) irradiation of root canal filled with NaCl on the push-out bond strength of cemented posts to root canal dentin. Different study results are probably due to different laser parameters (wavelength, energy density), the type of irrigant used, mode of irrigation (continuous or intermittent), and type of cement and post.

The push-out test has generally been used to measure the bonding of posts in root canals cemented with different cements.[24,25,33,34] However, great variability in results and methodologies, with variations up to 4.73 MPa among studies, have raised concerns with this method.[34] Load speed, adhesive area, tooth type, and tooth portion could influence the results, and thus, the interpretation of different studies.[35] Another possible limitation of the push-out test could be irregular and deviated sectioning of the root due to the fact that natural roots are not perfectly straight, resulting in frictional resistance during the push-out test.[36] Collares et al[34] recommended standardization of all variables to obtain more comparable and reproducible results.

The results of this study provide new knowledge about the positive influence of LAI on the bond strength of self-adhesive cements. Since there are only a few studies published so far on this topic, further investigations are required to determine the effect of other laser parameters or irrigants on the bond strength of self-adhesive cements to root canal dentine surface.

Conclusions

The results of this study showed that bond strength of the self-adhesive cement depended significantly on the laser parameters and irrigant used for the LAI. The clinical significance of the study is new knowledge about the enhanced bond strength of self-adhesive resin cement to dentin after laser-activated irrigation of post space preparation with a solution composed of EDTA.

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