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ORIGINAL ARTICLE

Influence of different laser-assisted retrograde cavity preparation techniques on bond strength of bioceramic-based material to root dentine

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Abstract

The purposes of the study were to evaluate the bond strength of bioceramic TotalFill root repair material (RRM) in retrograde cavities prepared using Er:YAG and Er,Cr:YSGG laser and steel bur, and to analyze failure modes. The root canals of 30 single-rooted teeth were endodontically treated, their root-ends were resected using a diamond bur, and the teeth were randomly divided into three groups ($N = 10$) according to the retrograde cavity preparation technique: (1) Er:YAG laser, (2) Er,Cr:YSGG laser, and (3) steel bur. All retrograde cavities were filled with the TotalFill RRM which was prepared according to the manufacturers' instructions. Push-out test was performed using universal testing machine, and failure mode was analyzed using a scanning electron microscope. The data were analyzed using one-way ANOVA, post hoc analysis with Bonferroni correction, and Fisher-Freeman-Halton exact test ($p < 0.05$). In the Er:YAG-, Er,Cr:YSGG-, and steel bur–prepared cavities, mean bond strengths (MPa) were 12.76, 8.44, and 6.01, respectively. The bond strength of the TotalFill RRM to dentin was significantly higher in the Er:YAG laser compared with the steel bur–prepared cavities ($p = 0.004$). The bond strength was not significantly different between the Er:YAG and Er,Cr:YSGG cavities ($p = 0.074$) and between the Er,Cr:YSGG and bur cavities ($p = 0.648$). In the cavities prepared by the Er,Cr:YSGG laser and bur, the failure mode of the TotalFill RRM was predominantly mixed, then adhesive and cohesive. In the Er:YAG laser–prepared cavities, the most common failure mode was adhesive, followed by mixed type and no cohesive failure. The bond strength of the TotalFill RRM to dentin was highest in the group of retrograde cavities prepared by the Er:YAG laser.

Keywords Bond strength · Er,Cr:YSGG laser · Er:YAG laser · Push-out test · TotalFill RRM

Introduction

Periapical surgery is indicated in the cases of persistent apical periodontitis where orthograde retreatment is difficult to perform or unlikely to enable healing [1]. This procedure includes surgical debridement of pathological periradicular tissue, the resection of the apical 3 mm of the root followed by retrograde cavity preparation and root-end filling placement [2].

There are several advantages of using lasers in periapical surgery compared with burs and ultrasonic devices such as cutting the root perpendicular to its long axis, thus exposing less dentinal tubules and less micro-crack formation [3, 4]. Further advantages include easier achievement of bloodless surgical field, reduction of the bacteria load, and sealing of

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the irradiated surface which enables better adaptation of the root-end filling material [5, 6].

The wavelengths of middle infrared lasers such as Er:YAG and Er,Cr:YSGG (2940 and 2790 nm, respectively) are very well absorbed by water and hydroxyapatite which makes them suitable for cutting hard dental tissues without significant thermal damage [7]. In vitro studies using the Er:YAG laser for root-end resection and retrograde cavity preparation showed satisfying results regarding surface appearance, working time, and leakage [5, 8]. Clinically, the absence of discomfort and vibration, less probable contamination of the surgical site, and reduced risk of trauma to adjacent tissue was reported with the use of the Er:YAG in periapical surgery [6]. The use of the Er,Cr:YSGG in the preparation of retrograde cavities caused less chipping than ultrasonic devices [9]. It was also found that the Er,Cr:YSGG laser produces a micro-retentive surface which may increase the micro-mechanical bond strength between root-end filling material and dentinal walls [7]. Clinical outcome of the Er:YAG and Er,Cr:YSGG laser–assisted root-end resection resulted in a high success rate [10].

Good adherence of root-end filling material to radicular dentin and its resistance to dislodgement provide a persistent apical seal during function and operative procedures. In addition to resisting dislodgement once set, an ideal root-end filling material should be dimensionally stable, have radiopacity, have proper setting time, have antimicrobial activity, have biocompatibility, have biomimetic properties, and have low solubility [11, 12]. Mineral trioxide aggregate (MTA) was accepted as the gold-standard root-end filling material because it is a biocompatible and bioactive material possessing good sealing abilities, but it has some disadvantages including poor handling properties and long setting time [13].

There are more than a few formulations of calcium-silicate-based materials introduced to the market claiming easier manipulation and shorter setting time than the MTA. Among these is a bioceramic TotalFill root repair material (RRM) (FKG Dentaire, La Chaux-de-Fonds, Switzerland), presented in ready-to-use form. In the previous research of the same authors, the TotalFill RRM exhibited superior resistance to dislodgement than the MTA and Biodentine in retrograde cavities prepared using an ultrasound device [14]. Therefore, the aim was to investigate the influence of retrograde cavity preparation technique on the bond strength of the same bioceramic material to radicular dentine. According to the available literature, there has not been any study evaluating bond strength of bioceramic root-end filling materials to radicular dentin after preparation with erbium lasers.

The purposes of this study were to evaluate the bond strength of the TotalFill RRM root-end filling material to root dentin after root-end cavity preparation using the Er:YAG laser, the Er,Cr:YSGG laser, and the round steel bur, and to analyze the failure mode using stereomicroscope.

Material and methods

Preparation of specimens

The study was approved by the Ethical Committee of the School of Dental Medicine, University of Zagreb. In this study, 30 single-rooted human maxillary incisors extracted due to periodontal disease were used. Inclusion criteria were fully formed roots, single straight canal, and no previous endodontic treatment. In order to remove any remaining soft tissue and calculus, root surfaces were scaled with periodontal curettes. The teeth were stored in phosphate-buffered solution (PBS). The crowns were sectioned below the cementoenamel junction using a water-cooled diamond drill. The root canals were then instrumented using rotating ProTaper instruments (Dentsply Maillefer, Ballaigues, Switzerland) using the sequence as follows: SX, S1, S2, F1, F2, and F3, enlarging the apical area to a size no. 30. During instrumentation, Glyde root canal lubricant (Dentsply Maillefer, Ballaigues, Switzerland) was used. After the use of each file, every canal was irrigated with 2 ml of 2.5% sodium hypochlorite. At the end, canals were rinsed with 2 ml of 17% EDTA (pH 7.7) for 3 min to remove the smear layer. Final irrigation was carried out with saline. Afterwards, root canals were dried with paper points and obturated with gutta-percha size 30 (Dentsply Maillefer, Ballaigues, Switzerland) and endodontic sealer AH Plus (Dentsply, DeTrey, Konstanz, Germany) using a single-cone technique. The roots were then stored at 37 °C in a 100% moist environment to allow sufficient time for the sealer to set.

One week later, roots were sectioned perpendicularly to their long axis with a diamond bur under constant water cooling, 3 mm short of the apex. The roots were randomly divided into three groups, 1, 2, and 3, each containing 10 roots. In every group, 3-mm-deep retrograde cavities were prepared using different techniques. In group 1 ($n = 10$), the Er:YAG laser (LightWalker, Fotona, Ljubljana, Slovenia); in group 2 ($n = 10$), the Er,Cr:YSGG laser (Waterlase, Biolase, Irvine, CA, USA); and in group 3 ($n = 10$), the round steel bur (0.9 mm in diameter) in a surgical micro-head handpiece (KaVo, Biberach, Germany) were used. The Er:YAG laser was used via 0.9-mm-wide cylindrical quartz fiber tip with the following parameters: quantum square pulse (QSP) mode, 15 Hz, 4.5 W, water spray water on 3 (around 32 ml/min), air on 5. In the QSP mode, a standard laser pulse of 600 μs was chopped into a series of five short pulses of 50 μs separated by 85 μs [15]. Taking into account these parameters, the peak power of one short pulse of 50 μs was calculated to be 1.2 kW. The Er,Cr:YSGG laser was used in H mode via 0.9-mm-wide quartz fiber tip with the following parameters: 15 Hz, 4.75 W, water/air spray with 70% water corresponding to 12–13 ml/min, and pulse duration of 60 μs. Calculated pulse peak power was 5.2 kW. The irradiation was not performed free-handed. The headpieces were fixed on stands, and the apexes were irradiated following the long axis of the tooth. In clinical settings, this position might be hard to achieve, but in this in vitro study, the repeatable position enabled uniform samples in each group. Both lasers were continuously activated for 3 s, and then the depth of the preparation was measured using graduated probe. Additional ablations, each lasting 3 s, were performed until wanted cavity depth. The mean number of ablations was six, the mean irradiation time for each tooth was therefore 18 s. Energy per one ablation cycle lasting 3 s for the Er:YAG laser was 13.5 J, and the total energy received by a tooth during six ablations was 81 J. For the Er,Cr:YSGG laser, energy per one ablation cycle was 14.25 J and the total energy received by a tooth is 85.5 J. The distance between the tip and the target was 0.2 mm. Considering laser beam divergence declared by manufacturers (8° or more for the Er,Cr:YSGG and 11.5° for the Er:YAG) and tip area of a 900-μm tip (0.0064 cm^2), the spot diameter at tissue level was calculated to be 0.0956 cm and spot area 0.0072 cm^2. For the Er:YAG laser, the peak power was 6000 W and the average energy density was 1785 J/cm^2, and for the Er,Cr:YSGG laser, peak power was 5283 W and average energy density was 1986 J/cm^2.

The prepared retrograde cavities were then filled with the TotalFill RRM (FKG Dentaire, La Chaux-de-Fonds, Switzerland). The material was prepared and used according to the manufacturers' instructions. After placement, each root-end filling was compacted with a small plugger and the specimens were stored in PBS (0.9%) for 3 months.

Push-out test

Three months later, the roots were embedded in acrylic resin (Orthocryl, Dentaurum, Ispringen, Germany). The apical part of each root was cut perpendicularly to the long axis into 1-mm-thick slices with a diamond blade using Isomet 1000 precision saw (Buehler, Düsseldorf, Germany), at a speed of 150–200 rpm. Digital caliper (Roc International Industry Co., Ltd., Guangdong, China) with precision level ± 0.001 mm was used to measure the thickness of each slice, and the value was recorded. The bonding surface was calculated using the conical frustum formula:

$$\text{Area} = \pi(R1 + R2)\sqrt{}(R1\text{–}R2)^2 + h^2$$

with $R1$ as the larger radius, $R2$ as the smaller radius, and h as the thickness of a slice.

A universal testing machine (double-column 3300 series, Instron, IL, USA) was used for push-out test. The slices were centered over a hole in the device, and a compressive load was applied with a 1.0-mm-diameter blunt-shaped probe at a speed of 0.5 mm/min until failure. At the moment of failure, the maximum load was recorded in Newtons (N). The push-out bond strength expressed in megapascals (MPa) was calculated by dividing the load at failure by the bonding surface. The slices were observed under a stereomicroscope (× 10–× 50) to verify the failure mode (adhesive, cohesive, or mixed). Following that, specimens were processed for SEM observation, including mounting on stubs with conductive glue, sputter coating (JEOL FFC-1100, Japan), and analysis with a scanning electron microscope (JEOL JSM-840A, Japan) at a magnification of × 50–× 2000 to further assess fractures and failure mode.

Statistical analysis

The data were analyzed using one-way analysis of variance (ANOVA). Post hoc analysis with Bonferroni correction has been done to test the differences in bond strength between the preparation techniques. Fisher-Freeman-Halton exact test was used to analyze the types of fracture. The level of significance was set at $\alpha = 0.05$. IBM SPSS Statistics version 25 was used in all statistical procedures.

Results

Mean bond strengths (MPa) of the TotalFill RRM in retrograde cavities prepared with the Er:YAG laser, Er,Cr:YSGG laser, and steel bur were 12.76, 8.44, and 6.01, respectively (Table 1). The results are shown in Fig. 1. The bond strength of the TotalFill RRM to radicular dentin was significantly higher in the cavities prepared with the Er:YAG laser when compared with the cavities prepared with the bur ($p = 0.004$). The difference between the Er:YAG and Er,Cr:YSGG cavities was not significant in terms of bond strength of the TotalFill RRM to dentin surface ($p = 0.074$) (Table 2). Also, there was no statistically significant difference between the Er,Cr:YSGG cavities and the bur cavities ($p = 0.648$) (Table 2). The TotalFill RRM had predominantly mixed types of bond fracture in the cavities prepared by the bur and Er,Cr:YSGG laser. In the Er:YAG laser–prepared cavities, the most common type of bond fracture was adhesive, followed by mixed type and no cohesive bond fracture at all (Figs. 2 and 3).

Discussion

The TotalFill RRM, also known as EndoSequence® RRM in the USA and Canada (ERRM; Brasseler USA, Savannah, GA, USA), is a bioceramic material that has been developed recently [14]. It has been demonstrated to be bioactive [16] and able to seal root-end cavities [17]. The TotalFill RRM was chosen for this study because it adhered significantly

Table 1 The results of bond strength in MPa of TotalFill material to the radicular dentin for the three groups of samples prepared using bur, Er:YAG laser, and Er,Cr:YSGG laser

	No. of samples	Mean bond strength (MPa)	SD	95% confidence		Minimum	Maximum
				Lower bound	Upper bound		
Bur	12	6.01	2.70	4.29	7.73	3.11	12.20
Er:YAG	14	12.76	7.65	8.34	17.18	3.41	30.64
Er,Cr:YSGG	15	8.44	2.67	6.96	9.91	3.84	12.91

better to radicular dentin than the MTA and Biodentine in ultrasound-prepared cavities in the previous study, so the authors wanted to investigate whether the retrograde cavity preparation technique would influence its bond strength to dentine [18]. The present in vitro study further evaluated the bond strengths of the TotalFill RRM, using push-out test, in root-end cavities prepared using different techniques: Er:YAG and Er,Cr:YSGG lasers and steel bur.

Prior to the measurements, the specimens were stored in PBS for 3 months since it was shown that the bond strength of the TotalFill BC™ (FKG Dentaire, La Chaux-de-Fonds, Switzerland) to dentine was higher at 3 months compared with 2 weeks after obturation [19]. The authors attributed this to the increased hardening of the material over time [19].

The bond strength of the TotalFill RRM to radicular dentin in our study was significantly higher when retrograde cavities were prepared with the Er:YAG laser compared with the bur-prepared cavities. In the context of marginal adaptation and bond strength of a bioceramic material to radicular dentin, it is important what dentin surface looks like before its placement in the retrograde cavity. It was reported that dentin surface prepared using a rotating bur was covered with a thick smear layer occluding the entrances of dentinal tubules, while the dentin surfaces irradiated with lasers appeared irregular and rough, had no smear layer, the dentin tubules were open, and peritubular dentin was prominent, which provided micro-retentive patterns [20, 21]. Besides dentin surface appearance, the properties of the material, such as particles' size and the setting chemistry, also define its anchorage to the cavity walls. The setting chemistry of the TotalFill RRM is similar to the calcium-silicate-based materials, while tag-like structures and a hybrid layer at the material-dentin interface constitute micro-mechanical bond [22, 23]. The bioceramic material used in this study contains the particles of the nanospheric size up to 1×10^{-3} μm, which probably contributes to its penetration into open dentinal tubules of the lased dentin surfaces. Indeed, it was previously visualized using the scanning electron microscope (SEM) that the calcium-silicate-based material with smaller particle size penetrated deeper into the dentinal tubules and formed dentinal bridges as a result of crystal growth within the dentinal tubules [24, 25]. This could explain why the bond between dentine and the TotalFill RRM material in our study was significantly higher after preparation with the Er:YAG laser compared with the bur where the smear layer occluded dentinal

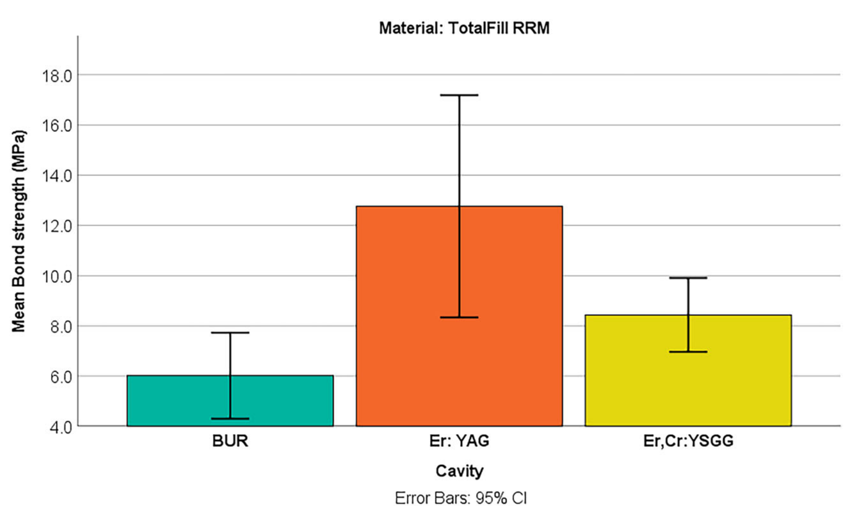

Fig. 1 Mean bond strengths (MPa) of TotalFill RRM in retrograde cavities prepared with bur, Er:YAG laser, and Er,Cr:YSGG laser

Table 2 Post hoc analysis (Bonferroni) of differences between bond strengths among retrograde cavity preparation techniques for material TotalFill RRM

(I) Cavity		Mean difference (I-J)	Std. error	*P*	95% confidence interval	
					Lower bound	Upper bound
BUR	Er:YAG	− 6.75	1.96	0.004	− 11.65	− 1.84
	Er,Cr:YSGG	− 2.43	1.93	0.648	− 7.25	2.40
Er:YAG	BUR	6.75	1.96	0.004	1.84	11.65
	Er,Cr:YSGG	4.32	1.85	0.074	− 0.31	8.96
Er,Cr:YSGG	BUR	2.43	1.93	0.648	− 2.40	7.25
	Er:YAG	− 4.32	1.85	0.074	− 8.96	0.31

The mean difference is significant at the 0.05 level

tubules. Furthermore, the higher bond strength of the TotalFill RRM to dentin after the Er:YAG laser could be attributed to the changed in mineral and organic content of the irradiated dentine surface especially in the context of the reported dentin-mineral infiltration zone with calcium-silicate material [26]. The increased mineral content, and relatively higher micro-hardness when compared with the bur-prepared cavities [27, 28], may be related to the vaporization of water and oxidation of organic components of dentin [28, 29]. Due to this relative reduction of organic components in the lased samples, it could be that the caustic effect of high pH during the setting of the TotalFill RRM is less pronounced, which might increase the bond strength between the TotalFill RRM and dentin when retrograde cavities were prepared with the Er:YAG laser.

The bond strength of the TotalFill RRM to dentin was not significantly different when the Er:YAG and Er,Cr:YSGG lasers were compared, but was weaker in the case of the samples prepared using the Er,Cr:YSGG laser. Besides the micro-retentive potential of the lased dentin surface defined by the percentage of open dentinal tubules and surface irregularities, the adhesion could be influenced by sub-superficial undesired changes of the irradiated dentin. The mechanical shock arising from the evaporation of water during ablation could cause sub-superficial cracking of dentin, reducing mechanical properties of dentin and possibly compromising adhesion of dental materials to the irradiated surfaces [30]. Dentin absorption coefficients for the Er:YAG and Er,Cr:YSGG were reported to be 2000 cm^{-1} and 700 cm^{-1}, respectively, resulting in the penetration depth of approximately 5 μm for the Er:YAG and 15 μm for the Er,Cr:YSGG [31, 32]. The deeper penetration might have an effect on mechanical properties of sub-superficial dentin and could possibly be correlated to the weaker bond strength of the TotalFill after preparation of dentin with the Er,Cr:YSGG. However, since in our study the differences between the two lasers' average power density and fluence were very small, and ablation thresholds in dentin were similar (2.97–3.56 J/cm^2 and 2.69–3.66 J/cm^2 for the Er:YAG and Er,Cr:YSGG lasers, respectively) [33], the

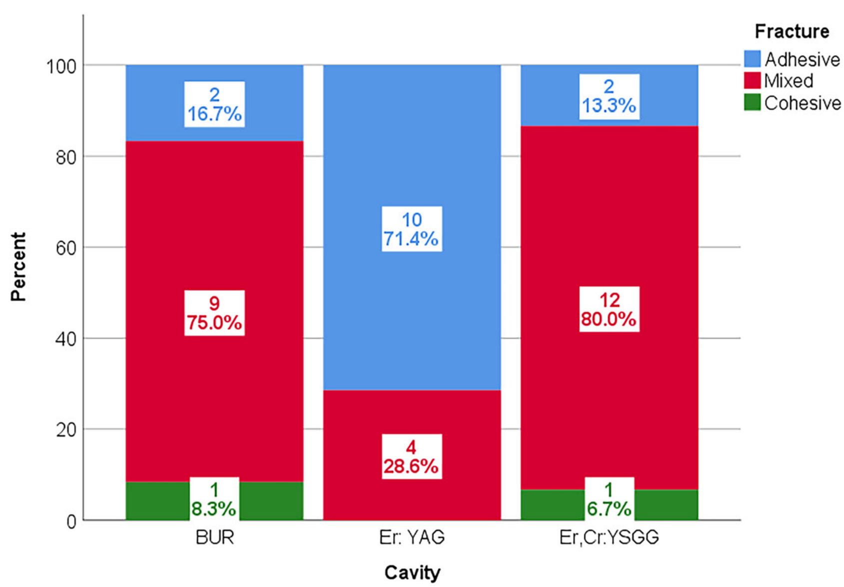

Fig. 2 Types of bond fracture of TotalFill RRM in retrograde cavities prepared with bur, Er:YAG, and Er,Cr:YSGG

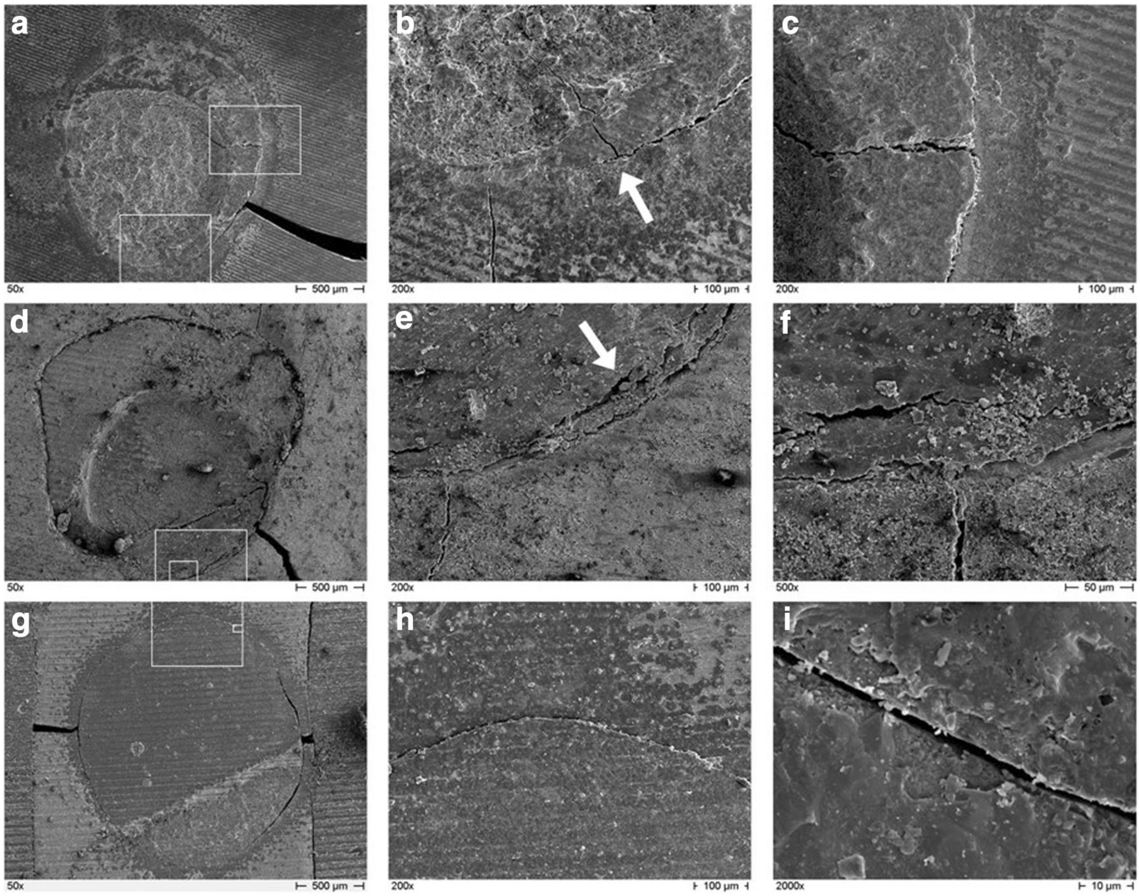

Fig. 3 SEM micrographs depicting test specimens after push-out. Panel **a** shows a specimen which cavity was prepared with bur, demonstrating a mixed fracture. Magnifications at × 200 of the same specimen (**b** and **c**) show, apart from the adhesive failure at the interface, the origin of cohesive fractures as well (arrow in **b**). An Er,Cr:YSGG-prepared specimen is shown at progressively higher magnifications in **d**, **e**, and **f**, demonstrating a mixed failure mode. Indeed, a fragment of retrograde obturation material TotalFill RRM is detaching parallelly to the adhesive fracture (arrow in **e**), thus displaying a cohesive fracture as well. An Er:YAG-prepared specimen is shown in **g**, **h**, and **i** at progressively higher magnifications. A pure adhesive fracture can be seen, and even at high magnification (**i**), a very clean detachment occurred between the filling material and the cavity wall, almost without the presence of debris. Dentin cracks are present in all specimens because of the void exposure in the SEM chamber

sub-superficial effect on dentin with either laser should probably be similar, as well. This could explain our finding of no statistically significant difference in bond strength between the TotalFill RRM and retrograde cavities prepared with the two erbium lasers.

In the Er:YAG laser–prepared cavities, adhesive failures were most observed, and there were not any cohesive fractures. This finding was not expected, considering the recorded bond strength was highest in the Er:YAG samples. Furthermore, the TotalFill RRM had predominantly mixed types of bond failures in the cavities prepared by the bur and Er,Cr:YSGG laser. Mixed type of failures suggests the adhesive interface between dentin and the TotalFill RRM retrograde fillings was at least partly preserved, even in the Er:YAG-prepared retrograde cavities. Irrespective of the preparation technique applied, rare finding of cohesive failure would indicate relatively good quality and flexural strength of the bioceramic retrograde filling material, TotalFill RRM.

Conclusions

Within the limits of this study, we can conclude that the preparation of retrograde cavities with the Er:YAG laser results in significantly higher bond strength of the bioceramic root-end filling material TotalFill RRM to dentin surface in comparison with the steel bur. However, there was no statistically significant difference in bond strength between the Er,Cr:YSGG laser and Er;YAG laser or the Er,Cr;YSGG laser and steel bur.

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