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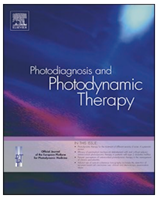

Review

Effect of laser irradiation on push-out bond strength of dental fiber posts to composite resin core buildups: A systematic review and meta-analysis

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ABSTRACT

Background: The bonding of fiber posts (FPs) to composite resin core buildups is a challenge due to limited penetration of resin to the polymeric matrix of FPs. This review article tries to answer this question: “What are the effects of laser surface treatment of FPs, compared to other surface roughening methods, on push-out bond strength (PBS) of FPs bonded to composite resin core buildups?”
Methods: Searches were run in seven electronic databases with a focus on proper key words. Related titles and abstracts, up to February 2019, were screened, selected, read and subjected to quality assessments.
Results: After the initial search, a total of 2635 articles were included in the study. Finally, 6 studies were reliable enough in methodology to be included. All the studies were in vitro with a total of 359 samples. Er:YAG (-0.05, 95% CI: -2.96 to 2.86; P = 0.97) and Er,Cr:YSGG (0.84, 95% CI: -0.12 to 1.81; P = 0.08) treated samples showed no significant overall mean differences in final PBS compared to the control groups. Moreover, pre-treatment with Er,Cr:YSGG laser and sandblasting with 50 µm alumina showed an overall mean difference of -0.42 for PBS (95% CI: -1.23 to 0.39) with no significant differences.
Conclusions: Laser irradiation of FPs seems to provide no significant increase in PBS values of FPs bonded to composite resin core buildups. Effects of surface treatment of FPs with laser irradiation and sandblasting with 50 µm alumina might be similar in increasing the final PBS, either.

1. Introduction

Extensively damaged or endodontically treated teeth might be a challenge for clinicians due to insufficient coronal structure [1]. Therefore, placing a post into the root canal space is required to retain the core superstructure [2]. Prefabricated fiber post (FP) is an alternative material for cast post and cores to restore these teeth by providing an acceptable bonding [3] FPs are mostly composed of a polymeric epoxy resin reinforced with carbon, quartz, zirconia, glass or silica fibers with a high degree of conversion and cross-linked structures [4]. These fibers are oriented parallel to the longitudinal axis and might comprise 30–50% of the FP structure [5]. Lower possibility of root fracture, a higher degree of polymerization with bonding materials because of translucent structure, biocompatibility and resistance to corrosion, and higher esthetic properties are some of the outstanding characteristics of FPs [6,7].

Despite the advantages mentioned above, debonding of FPs is one of their important drawbacks that may lead to restoration failure [5]. Apparently, the organic matrix of FPs and polymeric phase of composite resin core buildup (CRCB) materials may not provide a chemical reaction with each other [8]. In addition, untreated FPs have a smooth surface with the eliminated surface area for mechanical interlocking with resin materials [9]. Surface pretreatment of FP surface is recommended by clinicians to make changes in the FP matrix to improve the potential surface energy of FP [10–13]. Several pretreatment techniques have been suggested but they can be generally divided into three main categories of chemical (like priming and silica coating), micromechanical roughening (like etching or sandblasting), and

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combination of micromechanical and chemical methods (like Co-Jet) [14,15].

Recent innovations in laser technology have provided many advantages for many branches of dental sciences. Removing caries, treating tooth sensitivities, bleaching, and endodontic and peri-implantitis treatments are some examples of laser application [16,17]. Moreover, they can make positive surface alterations in several dental materials, especially FPs [18–20]. Therefore, some studies have evaluated the effect of laser irradiation on FP's surface to enhance the push-out bond strength (PBS) during bonding to CRCB [21–24]. Nevertheless, controversial results have been reported to date, with some of them reporting enhanced PBS of bonded FPs to CRCB after laser irradiation [21,23]; however, some of them have claimed that laser irradiation might not improve the PBS of FPs [22].

As the data on the effects of laser irradiation of FP's surface on final PBS seems to be sparse, and there is no systematic review on this subject, the aim of the present review study was to answer the following question: "What are the effects of laser surface treatment of FP, compared to other surface roughening methods, on PBS of FP bonded to CRCB?" Furthermore, the null hypothesis of this study was that laser treatment does not improve the final PBS of FP.

2. Materials and methods

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed during the preparation of this study [25]. PICO question was defined for screening the qualified studies: What are the effects of pretreatment of dental FPs (P, population) with laser irradiation (I, intervention), compared to other surface pretreatment methods (C, comparison), in final PBS of FPs bonded to CRCB (O, outcome)? A data search was performed using Cochrane library, PubMed, Scopus, Web of Science, Ovid, ProQuest, and Google Scholar electronic databases of articles, based on MeSH and non-MeSH terms, up to February 2019 (Table 1). The base of the search strategy, article selection, and critical appraisal of articles were according to a previously published study [26]. The full texts of the identified abstracts were obtained and selected based on inclusion and exclusion criteria (Table 2). Reviewers' (A.D. and R.M.) inter-agreement was calculated by Cohen κ test (MedCalc Software) (kappa score = 1.00).

The initial literature search yielded 3078 articles (Cochrane library = 4, PubMed = 35, Scopus = 787, Web of Science = 31, Ovid = 253, ProQuest = 745, and Google Scholar = 1223), of which 1189 articles remained after removing duplicates. After the first screening based on the title and abstract, 7 studies [21–23,27–30] were found eligible to be included in the study; however, one study was excluded because of inadequate sample size per group [30] (Fig. 1).

The following data were collected for each study: author, year, study design, sample size, the tests used, and significant outcomes. Studies with homogenate collected data (like similar laser irradiating device, FP, and cementing agent) were integrated for generating meta-analysis data. Two subgroup meta-analyses were carried out to compare the effect of Er:YAG and Er,Cr:YSGG lasers on final PBS values compared to untreated samples by using STATA software (STATA Corp, TX, USA). For statistical analysis, random-effects models were employed with a confidence interval of 95%. This variability model is directly related to the sample size. The larger the sample size is, the lower the variability is; therefore, the greater the weight of a given study in the meta-analysis measure estimate. The Forest plots and the weight of each study are shown in each graph. There is no statistical difference in the outcome of each study (i.e., no effect) when its horizontal line, representing the 95% confidence interval, touches the zero (vertical) line. There is also no statistical difference when a horizontal vertex of the diamond, which represents the 95% confidence interval of the overall mean of difference, touches the zero line.

3. Results

A total of 2635 articles were found after the initial search. A total of 1189 articles remained after removing the duplicate ones, of which 6 studies [21–23,27–29] were eligible to be included. The full texts of these articles were collected and those fulfilling the inclusion criteria were evaluated. Based on the MINORS scale (Table 3), one study had a score of 22 [22] and the rest scored 20 [21,23,27–29] (Fig. 2). Five articles were included in this review and all were subjected to subgroup meta-analysis.

All of the reviewed articles were in vitro studies with 359 samples and all investigated the effect of laser irradiation on PBS of FPs bonded to CRCB (Table 4). Quartz [21,22] and glass FPs [21–23,27–29] were tested in all of the studies. The crosshead speed of the universal testing machine was 0.5 [23] or 1 mm/min [21,22,27–29] for evaluating PBS (Table 4).

Table 5 demonstrates the study design of the articles in more detail. The lasers used were as follow: one study applied Diode [29], two studies used only Er:YAG [22,23], the rest of the studies used only Er,Cr:YSGG laser [21,27,28]. Sandblasting with alumina [21,23,28,29], silica coating [23], and etching with HF [21,29], H_2O_2 [29], and CH_2Cl_2 [21] were compared with laser irradiation in some of the studies. The applied wavelength, power, and energy varied as follows, respectively: 2780–2940 nm, 1 W–400W, 150–450 mJ. The repetition rate, pulse duration, and exposure time were also as follows: 10 or 20 Hz, 60–300 µs, 10–80 s.

Contradictory results were reported by studies in relation to the significant effect of laser irradiation on final PBS. One study claimed that the type of FP pretreatment plays a significant role in the final PBS as laser treatment reduced the final PBS of FPs, especially glass FPs samples [22]. However, another study reported that laser irradiation

Table 1
Applied MeSH and non-MeSH key words.

PICO	Key Words
Population	(Post and Core [MeSH Term]) OR (Dental Dowel [MeSH Term]) OR (Fiber Reinforced [MeSH Term]) OR (Fiber Post) OR (Dental Post) OR (Dental Post and Core) OR (Composite Resin Build Up) OR (Composite Resin Core) OR (Dental Composite Resins [MeSH Term])
Intervention	(Laser [MeSH Terms]) OR (Laser Therapy [MeSH Term]) OR (Erbium [MeSH Term]) OR (Lasers, Solid-State [MeSH Term]) OR (Laser Irradiation)
Comparison	(Air Abrasion, Dental [MeSH Term]) OR (Etch [MeSH Term]) OR (Abrasive Blasting [MeSH Term]) OR (Sandblast) OR (Airborne abrasion) OR (Pretreatment) OR (Surface Treatment) OR (Surface Roughness) OR (Roughening) OR (Grit Blasting)
Outcome	(Bond Strength [MeSH Term]) OR (Dental Prosthesis Retention [MeSH Term]) OR (Prosthesis Failure [MeSH Terms]) OR (Dental Restoration Failure [MeSH Terms]) OR (Push Out Bond Strength) OR (Loss of Retention)

Table 2
Defined inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
● English language studies that investigated the effect of laser irradiation of FP bodies on PBS values ● Maintaining the standard guidelines of calculating PBS and bonding FPs to composite resins ● Following manufacturer's instruction in all steps of observation like mounting the samples, polymerization of composite resin, light cure unit, universal testing machine.	● Technical reports and studies with missing data ● Researches on less than 5 samples in each groups ● Studies in languages other than English ● Repeatedly published studies; the last version was included ● Studies qualified as "very low" or "low" (MINORS score of < 13; for eliminating the risk of biases)

FP, fiber post; MINORS, Methodological Index for Non-Randomized Studies; PBS, push-out bond strength.

was significantly effective in increasing the PBS of FPs [28]. Most of the studies compared different laser irradiation parameters (like wavelength, power, energy) in their study groups [21,23,27,28]. Based on their results, the PBS values highly depended on irradiation parameters. One study claimed Er:YAG irradiation with 4.5 W and 450 mJ gave rise to significantly higher PBS values [23]; however, two studies believed that Er,Cr:YSGG irradiation with 1-W power resulted in higher PBS values [27,28].

Our meta-anaalysis on laser-treated samples showed significant heterogeneity for both Er,Cr:YSGG ($P = 0.000$, $I^2 = 85.3\%$) and Er:YAG ($P = 0.000$, $I^2 = 92.5\%$) groups; therefore, random-model effect was applied for analysis. The overall mean difference of PBS was 0.84 for Er,Cr:YSGG (95% CI: -0.12 to 1.81) and -0.05 for Er:YAG (95% CI: -2.96 to 2.86), demonstrating negative effects for Er:YAG laser and less positive effects for Er:YAG on final PBS, but with no statistical differences from the untreated samples ($P = 0.08$, $P = 0.97$, respectively) (Fig. 3). Meta-data analysis of studies in which compared Er,Cr:YSGG laser with sandblasting with 50 µm alumina ($P = 0.003$, $I^2 = 72.3\%$) showed overall mean difference of -0.42 for PBS of Er,Cr:YSGG groups (95% CI: -1.23 to 0.39). Although, Er,Cr:YSGG laser pretreatment resulted in lower PBS values than sandblasting, the difference was not significant (Fig. 4).

SEM surface analysis was carried out by several included studies to observe surface changes of FP bodies with more precision. Ablation and surface dissolution of laser-treated FPs were reported by most of the studies [22,23,27]. One study reported that Er:YAG laser-irradiated

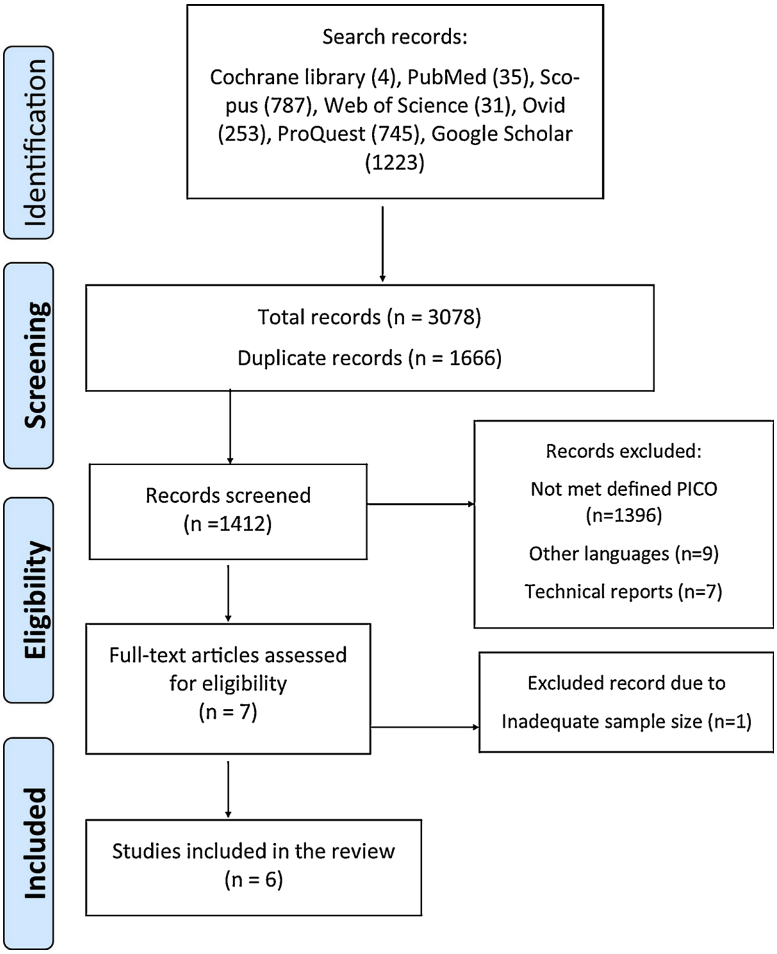

Fig. 1. Flowchart of search strategy.

Table 3
MINORS score calculation of selected studies.

MINORS criteria	Križnar et al	Arslan et al	Ghavami-Lahiji et al	Hashemikamangar et al	Kurtulmus-Yilmaz et al	Al-Qahtani et al
A clearly stated aim	2	2	2	2	2	2
Inclusion of consecutive samples	2	2	2	2	2	2
Prospective collection of data	2	2	2	2	2	2
Endpoints appropriate to the aim of the study	2	2	2	2	2	2
Unbiased assessment of the study endpoint	2	0	0	0	0	0
Assessment tests appropriate with the aim	2	2	2	2	2	2
Loss of samples less than 5%	2	2	2	2	2	2
Prospective calculation of the study size	0	0	0	0	0	0
An adequate control group	2	2	2	2	2	2
Contemporary groups	2	2	2	2	2	2
Baseline equivalence of groups	2	2	2	2	2	2
Adequate statistical analyses	2	2	2	2	2	2
Results	22	20	20	20	20	20

Items are scored as follows: 0 (not reported), 1 (reported but inadequate) or 2 (reported and adequate). Global ideal score is 16 for non-comparative studies, with 24 for comparative studies.
MINORS, Methodological Index for Non-Randomized Studies.

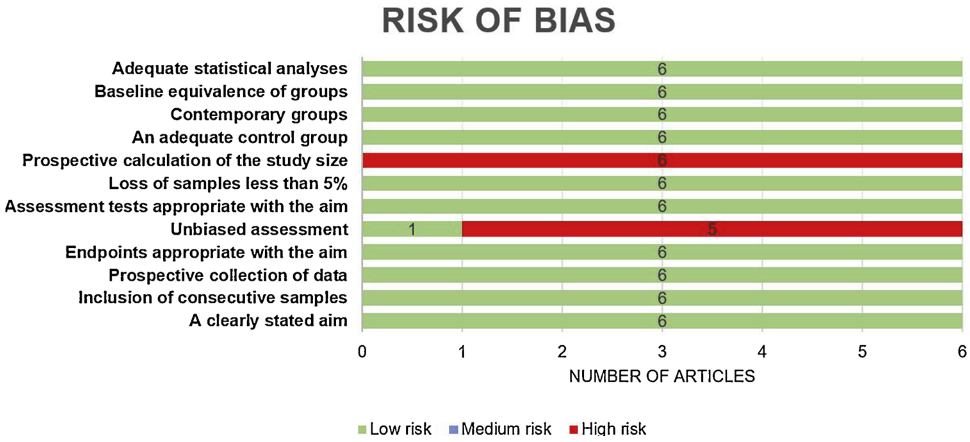

Fig. 2. Bias risk of included articles.

glass FPs exhibited more areas with surface ablation and cracking than that of quartz FPs [22]. According to one study, this surface ablation might be produced to more extent by increasing the energy power settings [23].

4. Discussion

Severely damaged endodontically treated teeth are more susceptible to structure loss. Use of FPs is one of the solutions to provide retention for restoration core and long-term clinical success [11]. The present systematic study tried to comprehensively review the effect of laser irradiation of FPs on their PBS when bonded to CRCB. According to the data the presumed null hypothesis was ruled out.

Uniform and smooth surfaces of FPs limit adequate mechanical interlocking with composite resins. Therefore, surface treatment of FPs is a possible solution to change the surface energy of FPs and increase the surface area available for chemical bonding between the composite resin and resin matrix of FPs [12]. Laser irradiation, sandblasting with alumina particles, and HF etching were tried in the studies included in this review. It is proposed that the energy delivered by laser is absorbed by hydroxyl groups in composite materials, like FPs, causing ablation of the organic matrix, which results in increased surface roughness by removing the outer layers of the organic matrix [22]. Al-Qahtani et al applied 2 W Diode laser irradiation on glass FPs and compared the final PBS with those treated with 50-μm alumina sandblasting method and found latter was more effective than laser irradiation [29]. In another study, Hashmikamangar et al [28] compared the effects of Er,Cr:YSGG laser irradiation (with different powers of 1, 1.5 and 2 W) and sandblasting with 50-μm alumina particles on final PBS of FPs bonded to CRCB. They reported that laser irradiation with 1-W power caused significantly higher PBS values than sandblasting technique or laser irradiation with other power settings [28]. They believed laser irradiation in a higher power (2 W) might destroy fibers and jeopardize the homogeneity and integrity of FPs, resulting in decreased ability to bond with composite resin [28]. Moreover, the produced heat by higher laser powers can cause surface ablation and physical damage to FP, with possible adverse effects on its chemical composition. Nevertheless, our meta-analysis revealed there was no significant differences in produced final PBS between Er,Cr:YSGG laser irradiation and sandblasting technique (Fig. 4). Further SEM analysis also showed that 1.5- and 2-W laser-treated groups exhibited areas of the resin matrix and fiber dugout. In another study, Arslan et al [23] used Er:YAG laser with different power energies (1.5, 3 and 4.5 W) and evaluated the final PBS compared to 30-μm alumina sandblasting technique. Their results were quite different from the previous study. They concluded that the final PBS is entirely dependent upon laser power and 4.5-W laser irradiation caused the highest PBS values with significant differences from other test groups [23]. Their SEM analysis showed that 4.5-W irradiation

Table 4
General information of reviewed article.

Author	Year	Objectives	Sample size	Post's detail	Composite resin	Push out bond strength test
Križnar et al	2015	Micro PBS of resin material to two types of FP using Er:YAG laser pretreatment.	40	1.Glass FP (Postec posts, Ivoclar-Vivadent) 2.Quartz FP (Radix Fiber posts, Dentsply International)	MultiCore Flow (Ivoclar-Vivadent, Schaan)	UTM (Instron Corp.) with crosshead speed of 1 mm/min
Arslan et al	2013	Effects of different surface treatments on the PBS of FPs to composite resin cores.	25	Glass FP (Cytec Blanco Glasfiber)	(Clearfil DC Core Automix)	UTM (Instron) with crosshead speed of 0.5 mm/min
Ghavami-Lahiji et al	2018	Effect of Er,Cr:YSGG on micro PBS of glass FPs to resin core material.	72	1.Conical glass FP (Angelus, Londrina) 2.Double tapered glass FP (White Post DC n. 2, FGM)	Nanofill composite core buildup (Dentocore Body)	UTM (Bongshin) with crosshead speed of 1 mm/min
Hashemikamangar et al	2017	Bond strength of FP to composite core following surface treatment with Er,Cr:YSGG laser at different powers and sandblasting with and without thermocycling	30	Glass FP (Glassix)	3M ESPE	UTM (Zwick Roell) with crosshead speed of 1 mm/min
Kurtulmus-Yilmaz et al	2014	Effects of laser application on the micro PBS between glass and quartz FPs and composite resin core material	192	1.Glass FP (Bisco) 2.Quartz FP (Hahnenkratt)	DMG	UTM (Shimadzu) with crosshead speed of 1 mm/min
Al-Qahtani et al	2018	Eff ;ect of diode laser on surface treatment of FP and its bond strength to resin core build-up material	50	Glass FP (Ivoclar Vivadent, Liechtenstein)	Multi-core Flow, Ivoclar Vivadent, Liechtenstein	UTM (walter + bai, AG, Switzerland) with crosshead speed of 1 mm/min

FP, fiber post; PBS, push-out bond strength; Er,Cr:YSGG, Erbium, Chromium-doped Yttrium, Scandium, Gallium and Garnet; Er:YAG, Erbium-doped Yttrium Aluminium Garnet; UTM, universal testing machine.

caused surface dissolution and more retentive surface (with no remarkable surface damage) compared to 1.5- and 3-W laser-irradiated samples [23]. Although their study design and the materials used were different from those in the study by Hashmikamangar et al, the exact reason for differences remained unclear. Both these studies used glass FPs but from different manufacturers. Also, Er,Cr:YSGG laser exerted effects similar to Er:YAG laser as its wavelength (2780 nm) is close to that of Er:YAG laser (2940 nm) [19]. Nevertheless, both studies agreed that laser irradiation in specific power energy improved the PBS values of FP bonded to composite resins compared to the control groups [23,28]. Having previous studies in mind, Kurtulmus-Yilmaz et al [21] conducted a comprehensive research to compare effects of different pretreatment methods (sandblasting with 50-μm alumina particles, HF etching, H_2O_2 immersion, and CH_2Cl_2 treating) with Er,Cr:YSGG laser irradiation (with 1-, 1.5- and 2-W power) on PBS of two different FPs (quartz and glass) bonded to CRCB [5]. Their results are more consistent with those of Hashmikamangar et al. They reported that all the tested pretreatment methods improved the PBS of quartz FPs except for the samples treated with laser irradiation with 2-W power [21]. Furthermore, they reported that all the mentioned pretreatments were effective on glass FPs except for HF etching and laser irradiation with 2-W power [21]. Their explanation for the results was similar to Hashmikamangar et al.

Our meta-analysis supported insignificant results for both Er,Cr:YSGG and Er:YAG lasers in improving the final PBS compared to the untreated samples. Some irradiation settings like emission mode, pulse energy, frequency, pulse duration, and air/water spray cooling are important during surface treating of FPs [20]. Both Kurtulmus-Yilmaz et al and Hashmikamangar et al adjusted laser repetition rate at 20 Hz which was much higher than Arslan et al study design with 10 Hz [23]. The higher repetition results in an increase in the surface roughness with less heat formation [21]. That might be one of the main reasons for differences in the results of previous studies.

In addition, the surface roughness of FPs, some other factors like the size, shape, chemical composition of FPs, and distribution and percentage of embedded fibers might influence the PBS of bonded FPs to CRCB [13,24]. Hence, Križnar et al [22] surveyed the role of Er:YAG laser irradiation on final PBS of glass and quartz FPs after bonding to CRCB [1]. Their results were similar to those reported by Kurtulmus-Yilmaz et al. They reported that the PBS of FP was not influenced by the composition, and laser irradiation decreased the PBS values of both type of PFs, especially glass FPs with significant differences [22]. The adjusted power energy and repetition time (500 W and 20 Hz) were so much higher than other studies, and they reported that laser treatment caused ablation of epoxy or resin polymers of the glass fiber matrix during SEM analysis [22].

Ghavami-Lahiji et al [27] focused on the effect of FP's shape in association with Er,Cr:YSGG laser irradiation with different powers (1 and 1.5 W) on final PBS of glass FP bonded to composite resins. They used two different shapes of FPs, conical and taper, and found out conical FPs showed significantly higher PBS values than double-tapered FPs. In addition, they claimed that the application of 1.5-W power for laser irradiation might reduce the PBS of both types of FPs, especially conical FPs. They believed lower PBS of tapered FPs is because of higher inter-distance space between fibers than that of conical fibers, and direction of applied force during the experiment, which was parallel to the embedded fibers [27]. Their results regarding the effects of laser power settings were similar to previous studies [21,22,28], which assumed higher power energy might cause surface damage of FPs due to overheating.

Type of bonding failure was another subject evaluated by all the included studies [21–23,27,28]. Based on the data collected, both cohesive and adhesive failures were seen in most of the reviewed studies. Three studies found that adhesive failure was more frequent in laser-irradiated samples [21,23,28]; howevr, Ghavami-Lahiji et al [27] reported that mixed failure was more prevalent in laser-treated samples.

Table 5
Detailed information about study design, grouping, and outcomes.

Author	Grouping	Irradiant	Wavelength	Power	Energy / energy density	Repetition rate	Pulse duration	Time of exposure /application	Fiber optic size	Outcomes
Križnar et al	Groups 1 (FRC-C) and 2 (RF-C): untreated quartz and glass FPs	–	–	–	–	–	–	–	–	-Type of FP did not have a sig effect on PBS while type of pretreatment did ($p < 0.001$). -Laser pretreatment decreased the PBS of the glass FP sig. However, no sig effect in the quartz FP. -The highest PBS was determined for the group FRC-C, followed by RF-C, and RF-L respectively, while the lowest PBS was recorded for FRC-L, with sig differences ($p < 0.05$) -Surface roughness of the laser pretreatment groups was sig higher ($p < 0.001$) -Laser pretreatment caused ablation of the epoxy or resin polymer matrix, exposing the glass fibers. Cracking and loosening of glass fibers were seen, especially in the FRC-L group. -In the RF-L group, an adhesive failure can be seen where cohesive failure was observed in the FRC-L group.
	Groups 3 (FRC-L) and 4 (RF-L): laser-treated quartz and glass FPs	Er:YAG	2940 nm	500 W	150 mJ	20 Hz	300 µs	20 s	1.9 mm^2	
Arslan et al	Groups 1, 2: untreated, co-jet sandblasting with 30-um alumina particles	–	–	–	–	–	–	–	–	-No sig differences among the groups, except for the 450 mJ group ($p < 0.05$). Laser irradiation affected PBS, depending upon the power setting. -The highest PBS was observed for the 450 mJ. -All of the specimens failed adhesively at the post-cement interface. -Surface dissolution of the epoxy resin matrix was seen in the laser treated 450 mJ. 150 mJ and 300 mJ laser irradiation did not produce sig changes.
	Group 3: laser-treated	Er;YAG	2940 nm	1.5 W	150 mJ	10 Hz	100 µs	60 s	400 um	
	Group 4: laser-treated	Er;YAG	2940 nm	3 W	300 mJ	10 Hz	100 µs	60 s	400 um	
	Group 5: laser-treated	Er;YAG	2940 nm	4.5 W	450 mJ	10 Hz	100 µs	60 s	400 um	
Ghavami-Lahiji et al	Group 1: untreated conical FP	–	–	–	–	–	–	–	–	The lowest and highest PBS were observed in groups 5 and 2. -1.5 W laser irradiation reduced the PBS in the conical FP groups. However, the difference between the control and 1 W groups was not sig. -No sig difference among double taper FPs. -Conical FPs revealed sig higher PBS compared to double taper FPs when using the 1 W laser and/or no treatment. -Laser caused partial dissolution of the epoxy resin matrix. There were no damaged or cracked fibers in double taper groups. However, several micro-cracks were found in conical FP irradiated with 1.5 W -Mixed failure mode was detected in all groups.
	Groups 2, 3: laser-treated conical PF	Er;Cr:YSGG	2780 nm	1 W 1.5 W	Not mentioned	20 Hz	140 µs	10s	8 um	
	Group 4: untreated double taper FP	–	–	–	–	–	–	–	–	
	Groups 5, 6: laser-treated double taper FP	Er;Cr:YSGG	2780 nm	1 W 1.5 W	Not mentioned	20 Hz	140 µs	10s	8 um	

(*continued on next page*)

Table 5 (*continued*)

Author	Grouping	Irradiant	Wavelength	Power	Energy / energy density	Repetition rate	Pulse duration	Time of exposure /application	Fiber optic size	Outcomes
Hashemikamangar et al	Groups 1, 2, 3: laser-treated	Er;Cr:YSGG	Not mentioned	1 W 1.5 W 2 W	Not mentioned	20 Hz	60 µs	80 s	Not mentioned	-Treatment method had sig effect on PBS (P = 0.017) but thermocycling had not. Sig difference was only found between the control and 1 W laser groups (P = 0.01). -The frequency percentage of adhesive, cohesive within the core, cohesive within the post and mixed failures were found to be 87%, 5.33%, 2.67% and 5.33%, respectively
	Groups 4, 5: sandblasted with 50-µm alumina particles, untreated	–	–	–	–	–	–	–	–	
	Group 3: No treatment	–	–	–	–	–	–	–	–	
Al-Qahtani et al	Group 1: Control	–	–	–	–	–	–	–	–	-The highest and lowest PBS was shown in groups 4 (139.86) and 1 (75.73). - The PBS of groups 5 and 3 were comparable. - The PBS of group 4 was sig higher than other groups.
	Group 2: 37% Phosphoric Acid + saline + resin primer	–	–	–	–	–	–	–	–	
	Group 3: 40% H2O2 for 10 min + saline + resin primer	–	–	–	–	–	–	–	–	
	Group 4: sandblasted with 50 µm alumina	–	–	–	–	–	–	–	–	
	Group 5: laser treated	Diode	Not mentioned	2W	Not mentioned	10 Hz	10 µs	40 s	200 µm	
Kurtulmus-Yilmaz et al	Groups 1 and 9: control, untreated quartz and glass FPs	–	–	–	–	–	–	–	–	-In the quartz FP groups, all surface treatments showed sig higher PBS than the control group, except for the laser 2 W group (p > 0.05). -For the glass FP groups; HF acid group showed the lowest PBS. The control and 2 W laser groups demonstrated sig lower PBS, whereas no sig difference was detected among the Al2O3, H2O2, CH2Cl2, 1 W, and 1.5 W laser groups. -No sig differences between quartz and glass FPs for the Al2O3, H2O2, laser, and control groups (p > 0.05). The most observed fracture pattern was adhesive failure for all the groups.
	Groups 2 and 10 (SB): sandblasted quartz and glass FPs with 50-µm alumina particles	–	–	–	–	–	–	–	–	
	Groups 3 and 11 (HF): etched quartz and glass FPs with 9.5% hydrofluoric acid	–	–	–	–	–	–	–	–	
	Groups 4 and 12: immersed quartz and glass FPs in H_2O_2	–	–	–	–	–	–	–	–	
	Groups 5 and 13: etched quartz and glass FPs with CH_2Cl_2	–	–	–	–	–	–	–	–	
	Groups 6 and 14; 7 and 15; 8 and 16: laser-treated quartz and glass FPs	Er,Cr:YSGG	Not mentioned	1 W 1.5 W 2 W	Not mentioned	20 Hz	140 µs	30 s	Not mentioned	

Er,Cr:YSGG, Erbium, Chromium-doped Yttrium, Scandium, Gallium and Garnet; Er:YAG, Erbium-doped Yttrium Aluminium Garnet; FP, fiber post; HF, hydrofluoric acid; PBS, push-out bond strength; Sig, significant; SEM, scanning electron microscope.

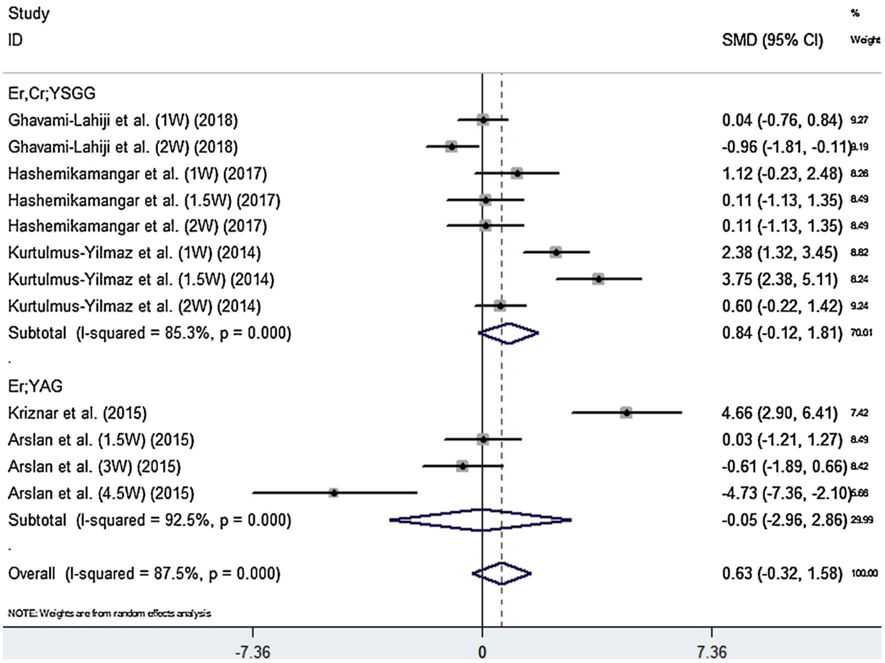

Fig. 3. Forest plot of studies used Er;YAG or Er,Cr;YAG lasers for FP pretreatment compared to untreated samples.

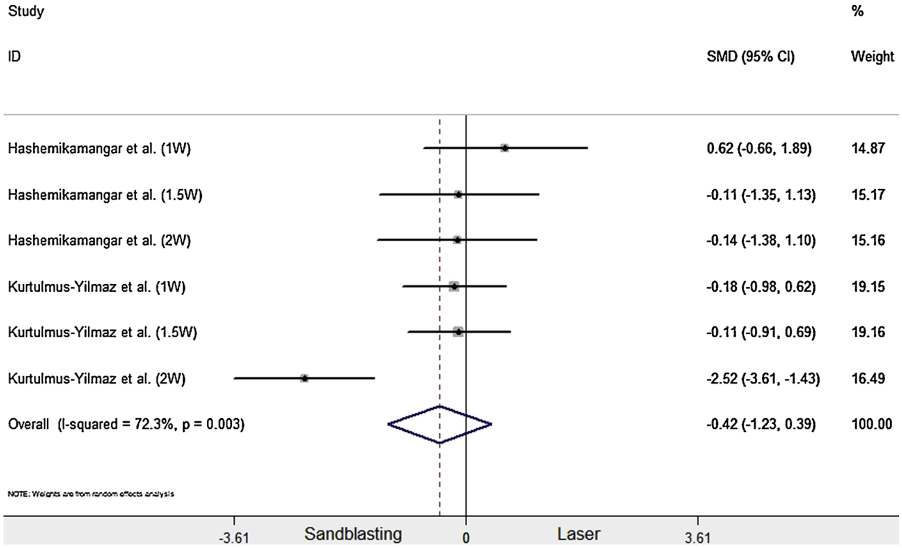

Fig. 4. Forest plot of studies used Er,Cr;YAG lasers compared to sandblasting with 50 μm alumina for FP pretreatment.

5. Conclusion

One of the major limitations of this study was the heterogeneity of collected data from laser studies that makes data integration difficult. However, like other meta-analyses on laser [31,32], to decrease the heterogeneity of collected data as much as possible, only studies that had integrative parameters were included to meta data analysis

By relying on gathered information from included studies it can be concluded that:

Laser irradiation of FPs body does not increase the final PBS of bonded FPs to CRCBs significantly. Nevertheless, Er,Cr:YSGG laser irradiation (if the irradiation settings were not adjusted in high power energy) may be more effective than Er:YAG laser irradiation. Er,Cr:YSGG laser irradiation and sandblasting with 50 μm alumina seems to provide similar PBS values of bonded FPs.

High energy power of laser irradiation device may damage the FP surface and decrease final PBS.

Glass FPs are more susceptible to surface damage when laser irradiation is administered.

Despite mentioned information, researchers are encouraged to compare the effect of both Er:YAG and Er,Cr:YSGG lasers on PBS of different FPs during their experiment and prepare a comparison with sandblasting technique to provide more decisive results with more precision.

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