# Effect of laser irradiation on bond strength between zirconia and resin cement or veneer ceramic: A systematic review and meta-analysis

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## Abstract

**Aim:** This systematic review with meta-analysis aimed to evaluate the effect of the laser treatment on bond strength between Y-TZP and the resin cement or with the veneering ceramic, and the effect on the alteration of the Y-TZP surface roughness.

**Settings and Design:** Systematic review and meta analysis following PROSPERO guidelines.

**Materials and Methods:** A comprehensive review was performed up to September 2020 on four databases (PubMed/MEDLINE, Embase, Scopus, and Cochrane Library), using the combination of keywords: "laser AND zirconia AND surface treatment AND bond strength".

**Statistical Analysis Used:** The meta-analysis was based on the Mantel–Haenszel and inverse variance methods. The continuous outcome was evaluated by mean difference and the corresponding 95% confidence intervals.

**Results:** A total of 37 studies were identified for the inclusion of data, with only *in vitro* studies. The types of laser reported in the studies were: Er:YAG, Nd:YAG, Er,Cr:YSGG, CO2, Femtosecond, and Yb lasers. A random-effect model found statistically significant differences between lasers and control groups of Y-TZP ($P < 0.00001$; MD: 3.08; 95% CI: 2.58 to 3.58). Only the bond strength with the Er:YAG laser did not present statistical difference ($P = 0.51$; MD: 0.22; 95% CI: −0.44–0.88). In another analysis, a random-effect model found a statistically significant difference between the laser and control groups on surface roughness ($P < 0.00001$; MD: 0.96; 95% CI: 0.86 to 1.06).

**Conclusions:** Laser irradiation is capable to improve the Y-TZP surface roughness and the bond strength of zirconia with resin cement and veneering ceramics. However, there is a lack of laser protocol for the zirconia surface, a fact that makes a simple and direct comparison difficult.

**Keywords:** Lasers, resin cement, shear strength, veneering ceramic, zirconium oxide

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## INTRODUCTION

The zirconia has been outstanding among other dental ceramics due to its mechanical properties, such as shear strength, hardness, good esthetics, and biocompatibility with periodontal tissues.[1-4] Zirconia, especially yttria-stabilized tetragonal zirconia (Y-TZP), is considered the ceramic with the best mechanical properties among all dental ceramics.[2,3,5] In this way, the computer-aided design (CAD)/computer-aided manufacturing technology promoted the popularity of the use of these ceramics, mainly as a fixed partial denture infrastructure, implant abutment, all-ceramics crowns, inlays, and onlays.[1,3,4,6,7]

Due to the absence of vitreous components, Y-TZP is not altered by hydrofluoric or phosphoric acid, nor the application of silane is sufficient to increase the bond strength with resin cement or veneering ceramic.[1,8-10] Methods to improve this bond strength are highly researched today, to promote the long-term success of restorations with zirconia infrastructure.[3,4,9,11] However, good bond strength to Y-TZP is only obtained through pretreatment on its surface.[8,12] This pretreatment aims to alter the zirconia surface, either by increasing the surface roughness, by promoting micromechanical retention with the resin cement and/or veneering ceramic, or by improving the chemical affinity between the materials.[1,8,12] Thus, several protocols are proposed as a treatment of Y-TZP; however, there is still no standard treatment established in the literature.[1,3,4,13,14] Moreover, sandblasting is the pretreatment most suggested by manufacturers, either with aluminum oxide particles ($Al_2O_3$) or with silica-coated aluminum particles (tribochemical silica coating).[11,15,16] This treatment is capable to promote a physical alteration of the Y-TZP surface, increasing its surface energy, wettability, and surface roughness, promoting a micromechanical retention to its surface.[3,8,10] Nevertheless, it was reported that sandblasting is capable to induce the phase transformation (tetragonal to monoclinic) of Y-TZP, creating zones of high compressive stress, and may weaken the long term of Y-TZP.[14,17,18]

There is no established protocol indicated the ideal pretreatment for Y-TZP. Thus, the use of laser as a surface treatment of dental ceramics has increased, aiming to promote a superficial alteration employing laser energy discharges, generating microexplosions, vaporization, or melting of the superficial layer of the ceramic,[3,19,20] being used in diverse clinical applications. The neodymium: yttrium–aluminum–garnet (Nd:YAG) is used in the control of tooth sensitivity, removal of caries lesions, tooth whitening, and to promote alteration in the surface roughness of dental ceramics.[18,21] Erbium: yttrium–aluminum–garnet (Er:YAG) has similar dental applications, including preparation of dental cavities and modification of ceramic surfaces.[1,22] The erbium, chromium: yttrium–scandium gallium–garnet (Er, Cr:YSGG) laser, as well as Er:YAG, can remove particles by a process called "ablation," including microexplosions and vaporization.[1,3,20] Another laser used in dentistry is the carbon dioxide ($CO_2$) laser, frequently used on the improvement of the osseointegration of zirconia implants and the surface alteration of feldspathic ceramics.[6,23,24]

Although different compositions and parameters are described in the literature, there is no gold standard protocol for laser irradiation on Y-TZP. Thus, this systematic review and meta-analysis aimed to evaluate the effect of the laser treatment on the bond strength between Y-TZP and the resin cement or with veneering ceramic and the effect on the surface roughness of the Y-TZP surface. The null hypothesis was that the laser treatment would present similar results to the control group, with no increase in the bond strength with the materials used, nor any change in surface roughness of Y-TZP.

## MATERIALS AND METHODS

### Research strategy and information sources

This systematic review and meta-analysis was structured according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) criteria, described by Moher *et al.*,[25] and the methods used to perform the present study were registered in the PROSPERO platform (CRD42017078229).

### Criteria for selection of studies

The authors selected the studies according to previously defined inclusion and exclusion criteria, to identify all the studies that approached the subject in question, followed by the reading of the abstracts and full texts. Due to the absence of retrospective and prospective studies, and controlled and randomized clinical trials, *in vitro* studies were also considered eligible. When there were disagreements, they were solved among the examiners through a consensus meeting.

### Search strategy

The searches were performed by two independent examiners, on the principal international databases (PubMed/MEDLINE, Embase, Scopus, and Cochrane Library) from the earliest available dates through September 2020. Manual searches were conducted in the main Journals related to the Prosthodontics field. The following keyword combination was used in all databases: "laser AND zirconia AND surface treatment AND bond strength." An interexaminer test (kappa) was performed through analysis of the selected titles and abstracts, obtaining a concordance test value of the study (kappa = 0.90).

### Inclusion/exclusion criteria

Predetermined inclusion and exclusion criteria were established and used in all steps of searches. The inclusion criteria were studies that performed laser treatment as a surface treatment before the application of veneering ceramic and/or cementation with resin cement and performed bond strength tests to verify the bond between zirconia and veneering ceramic or resin cement. Furthermore, *in vivo* and *in vitro* studies, controlled and randomized clinical, prospective, and retrospective studies, studies where no type of surface treatment was performed in the control group, and studies published in English were included, with no year limit of publication. The exclusion criteria were studies that did not relate to the subject aim, theoretical studies, clinical cases, studies with duplicate and/or previously published data, and systematic literature reviews.

### Study selection

The studies were selected according to the titles and abstracts, being used for final analysis only *in vitro* studies. After the selection through the search, the full readings of the selected articles were done, according to the inclusion and exclusion criteria.

This review was based on the PICO criteria, as recommended by the PRISMA topic, where we sought to find to answer to the following question: "What is the effect of laser treatment on surface modification and bond strength between zirconia and veneering ceramic or resin cement?". The Participants (P) were Y-TZP samples covered with veneering ceramic or cemented with resin cement. The Intervention (I) was the evaluation of Y-TZP samples that received treatment with a laser before the bonding process with the veneering ceramics or resin cement. The Comparison (C) was perfomed with samples that did not receive surface treatments. The Outcomes (O) were to evaluate the bond strength between materials as a primary outcome and the roughness as a secondary outcome.

### Data analysis

The following data were collected in the included studies: first author and year of publication of the study, the number of samples made in each study, material (manufacturer) used to manufacture the samples, type of material used for bond strength test, surface treatments that were performed, laser parameters, control group characteristics, bond strength results of the tested groups, as well as the results of surface roughness analysis, when described in the studies.

### Meta-analysis

The meta-analysis was based on the Mantel–Haenszel and inverse variance methods. The continuous outcome (comparison of laser treatment and control on bond strength and surface roughness) was evaluated by mean difference (MD) and the corresponding 95% confidence intervals (CIs). The MD values were evaluated with 95% of significance. The software Review Manager 5 (RevMan) (Cochrane Group) was used to perform the meta-analysis.

## RESULTS

### General outcomes

The searches on databases found a total of 192 studies: PubMed/Medline (60 studies), Embase (52 studies), Scopus (76 studies), and Cochrane Library (4 studies). After duplicate removal, 84 studies were selected for an initial reading of the title and abstracts. Manual searches were realized in the journals of relevance, although no new article was included. A total of 45 studies were selected for readings of full text, applying the predetermined inclusion and exclusion criteria. After this step, 8 studies were excluded: for performing sandblasting in all groups, including the control group;[11,26,27] for been used another type of zirconia;[28] for not shown sufficient data to compare the groups;[29] for the absence of a group with laser irradiation isolated;[9,30] and to had applied liner in all groups.[31] After the consensus meeting, 37 studies were selected for inclusion in this systematic review. The search strategy is illustrated in a flowchart [Figure 1].

### Demographic data

Of the 37 included studies, 4.010 samples were produced, with a mean of 108.38 samples/study. The "n" minimum for group was 5[14,32] and maximum was 60.[33] Different brands of zirconia Y-TZP were used, such as ICE Zirkon,[23,34-38] Cercon,[1,15,33,39-41] IPS e.max ZirCAD,[16,22,42-44] Zirkonzahn,[7,19,20,45,46] Ceramil,[47,48] Kavo Everest,[6,21] Noritake,[3,4] Vita In-Ceram YZ,[13,49] Copran Zircon Blank,[10] Cortis YZ,[14] CosmoPost,[32] Dental Durekt,[24] Lava,[18] Procera,[50] and Vita.[12] According to the material used to analyze the bond strength, there was a prevalence for resin cement,[1,6,7,10,12-16,18-21,23,24,32-35,37-40,42,44-50] followed by veneering ceramic.[3,4,22,36,41,43] The sample's shapes were varied, being disc[7,10,12,19,20,22,23,36,37,41,45,46,48] more prevalent, followed by block,[3,6,18,21,24,34,42,44,49,50] plate,[1,14,38,39,43] cube,[35,47] square,[15,33,40] cylinder,[4,16] and post.[32]

Among the lasers used, the Er:YAG was more prevalent, used in 15 studies.[1,6,7,10,20,22,32-35,39,43,47,49,50] The

$CO_2$[10,12,14,18,20,23,24,37,41,44,47,48] and Nd:YAG lasers[10,16,18-22,32,34,38,46] were also frequently utilized in the included studies. Er, Cr:YSGG,[3,4,42,45] femtosecond,[13,15,40,43] and Ytterbium (Yb)[36] were used less frequently. Regarding the other surface treatments, sandblasting was more used, being described in 31 studies.[1,3,4,6,10,12,14-16,18-24,32-36,38-44,46,49,50] Silica coating was described in 11 studies,[10,15,16,18,19,32,33,35,40,42,49] primers in 5 studies,[1,24,42,44,50] hydrofluoric acid in 4 studies,[12,14,23,38] and liner[22] and hand grinding[39] were described in one study each.

There was a large variation in the laser protocols described in the studies included, even with the same kind of laser. In the $CO_2$ laser groups, the output ranged of 2[10,37,47] to 20 W,[24] the exposure time was between 10[24,47,48] to 300 s,[41] the pulse range from 2 μs[10] to 1.75 ms,[24] and the distance was from 1[14,18,48] to 5 mm.[44] In the Er:YAG laser groups, the output varied from 1[6,7,10] to 6 W,[43,47] the exposure time from 5[1,6,39,47,50] to 20 s,[20,22,32] pulse between 75 μs[10,43] and 20 s,[7] and the distance from 1[10,43,49] to 10 mm.[22,32,35,47] The Nd:YAG laser groups described output from 0.8[20] to 4 W,[10] exposure time between 20 s[22,32] and 2 min,[10] pulse ranging 10 ns[46] and 2 min,[19] and the distance was 1 mm in all studies[10,16,19,21,22,34] that reported this information. In Er, Cr:YSGG laser groups, outputs were used between 1[3,4] to 6 W,[3,4] exposure time ranging from 20[3,4] and 50 s,[45] pulse from 140[3,4,45] to 200 μs,[3,4] and distance from 1[42,45] to 10 mm.[3,4] Studies that used femtosecond presented output of 700 mW[13] and 730 mW,[43] exposure time of 496 s,[43] and pulse of 40 fs.[15,40] The only study that used Yb laser described output of 85 W and distance of 17.8 mm.[36]

Several treatment associations using laser were described, such as sandblasting and laser,[10,18,22,44,49] laser and silica coating,[18,33] laser and primer,[42] and laser and liner.[22] Other associations were also described in the studies included, sandblasting and silica coating,[35] sandblasting and primer,[42] silica coating and primer,[42] and sandblasting and liner.[22]

The bond strength results were analyzed in all 37 studies included and the groups with some surface treatment showed higher bond strength values compared to the control groups. Regarding these results, the laser groups showed higher values in the majority of studies,[3,7,13-16,20,23,37-41,43,44,47,48] followed by sandblasting.[1,4,6,10,12,21,34,36,45,46,50] The other treatments with good bond strength results were silica coating,[14,19,32] primer,[24] and the associations with sandblasting and Er:YAG laser,[22,49] sandblasting and Nd:YAG laser,[18] silica coating and primer,[42] and sandblasting and silica coating.[35]

The surface roughness was analyzed in 14 studies,[4,6,12,13,16,18,32,34,36,38,39,41,46,49] and the sandblasting groups[4,6,12,15,21,41] showed higher roughness values compared to the other groups. Regarding laser groups, in all studies that presented the highest roughness values, the Nd:YAG laser was used.[16,18,32,34,38,46] Yb laser[36] and the association between sandblasting and Nd:YAG laser[49] showed higher roughness results in one study each.

### Meta-analysis

A general analysis of all surface treatments was realized in 35 eligible studies, and a random-effects model found statistically significant difference between laser and control groups on bond strength ($P < 0.00001$; MD: 3.10; 95% CI: 2.60–3.60) [Figure 2]. The bond strength was, also, analyzed according to the type of laser treatment, divided in $CO_2$ ($P < 0.00001$; MD: 5.56; 95% CI: 4.11–7.02) [Figure 3], Er:YAG ($P = 0.51$; MD: 0.22; 95% CI: −0.44–0.88) [Figure 4], Nd:YAG ($P < 0.00001$; MD: 2.00; 95% CI: 1.47–2.52) [Figure 5], Er, Cr:YSGG ($P = 0.002$; MD: 3.20; 95% CI: 1.16–5.24) [Figure 6], and femtosecond laser ($P < 0.00001$; MD: 7.69; 95% CI: 5.87–9.51) [Figure 7]. In another analysis, only 12 studies were eligible to analysis, and a random-effects model found statistically significant difference between the laser and control groups on surface roughness ($P < 0.00001$; MD: 0.96; 95% CI: 0.86–1.06) [Figure 8].

## DISCUSSION

With the popularity of metal-free restorations, the use of Y-TZP as infrastructure raised significantly. However, the probability of decementation or debonding of veneering ceramic also increased.[10,34,49] Since Y-TZP presents an inert surface, the bond with the surface is an aim of several studies, the surface treatment of Y-TZP being the best way to avoid these issues. Among these treatments, laser therapy is widely used and described as a good method to promote a surface alteration of Y-TZP, showing great results on bond strength between both resin cement[16,23,35] and veneering ceramic.[3,36,43] Different laser wavelengths have been described, aiming to modify the zirconia surface and, consequently, to increase the bond strength to its surface, including Nd:YAG laser (1064 nm), Er:YAG laser (2940 nm), $CO_2$ laser (10,600 nm), and Er, Cr:YSGG laser (2780 nm).[10,18,35,42]

Y-TZP is widely treated with laser and is recommended due to its less thermal conductivity and higher resistance.[9,51] It was reported that zirconia surface texture changes according to the type of laser and wavelength that was used.[42] Therefore, several studies[10,13,23,24,45] have been

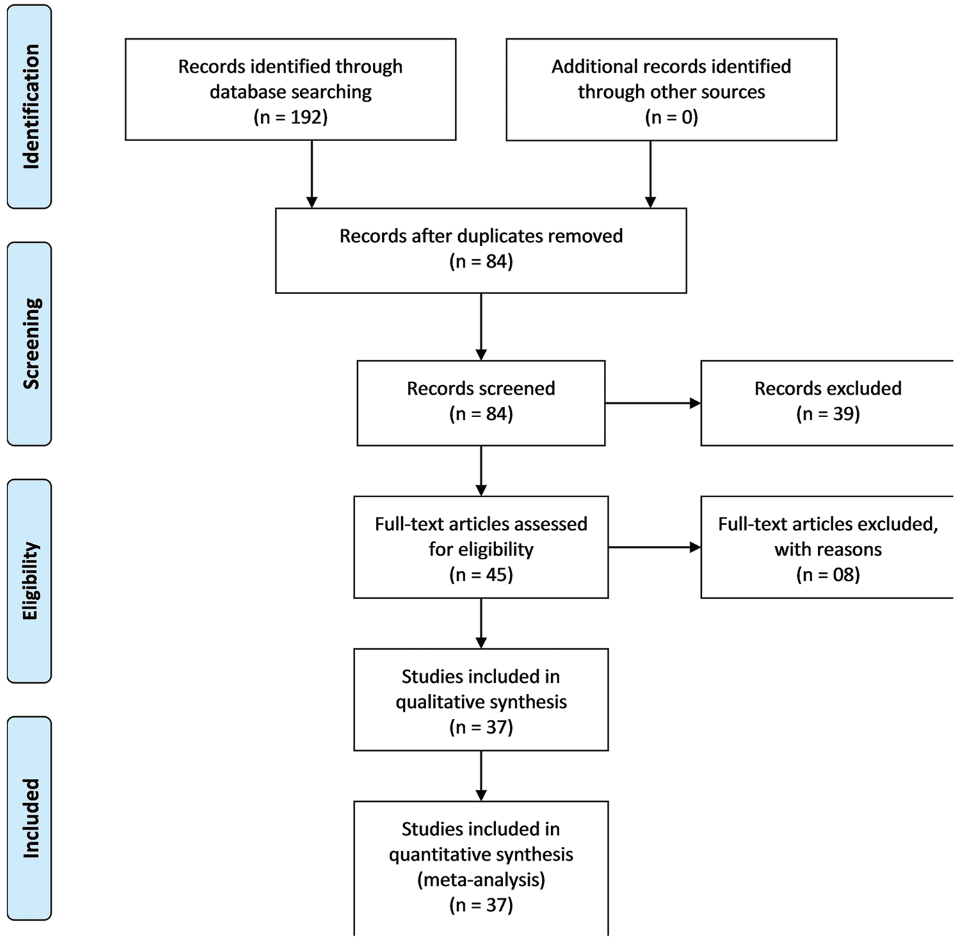


**Figure 1:** Flowchart of search strategy according to the Preferred Reporting Items for Systematic reviews and Meta-Analysis statement

aiming to show the laser effect on Y-TZP surfaces. Different compositions were found in the present systematic review. In this systematic review and meta-analysis, studies that performed the application of the laser on the zirconia surface as a pretreatment, before the application of the veneering ceramics or the bond with the resin cement, were included. As the main purpose was to evaluate the effect of the laser on the zirconia, regardless of the material to which it was bonded, studies that evaluated the bond strength with both the veneering ceramic and resin cement were included. Allied to that, the roughness was also evaluated, aiming to compare the effect of the laser with the different surface treatments of zirconia. Based on the results obtained, the null hypothesis that the laser treatment would not improve the bond strength of Y-TZP and change the surface roughness was rejected.

Different types of laser were accessed after an extensive search, the Er:YAG laser being the most used and frequently reported in the included studies. This laser shows several applications in dentistry, as reducing dental sensitivity, bleaching, and removing caries lesions.[20] Furthermore, this laser is used to promote a superficial alteration of ceramics due to the wavelength match with the water peak absorption, being well absorbed by the $OH^-$group of hydroxyapatites,[10,52] and capable to remove particles by ablation process, microexplosions, and vaporizing.[1,20] In the included studies, there was an output variation from 1 to 6 W. Akyil *et al*.[10] used Er:YAG laser irradiation at a power output of 2 W (200 mJ/pulse, 10 Hz) for 10 seconds, and in the SEM images, they found a rough surface similar to that of air abrasion. However, the authors concluded that this laser promoted lower bond strength values compared to the sandblasting group, while higher values were found when compared to the control group.[10] The same information was described by Cavalcanti *et al*.[1] A power setting of 200 mJ/pulse, 10 Hz, for 5 seconds was used and this group presented the lowest values, even when compared to the control group. This data corroborates with the results of the meta-analysis of Er:YAG laser groups performed in the present study [Figure 4] that there was no statistical difference between Er:YAG laser and control groups. Several studies[1,6,52] have been reported that a stronger laser output setting (400 or 500 mJ) is capable to damage

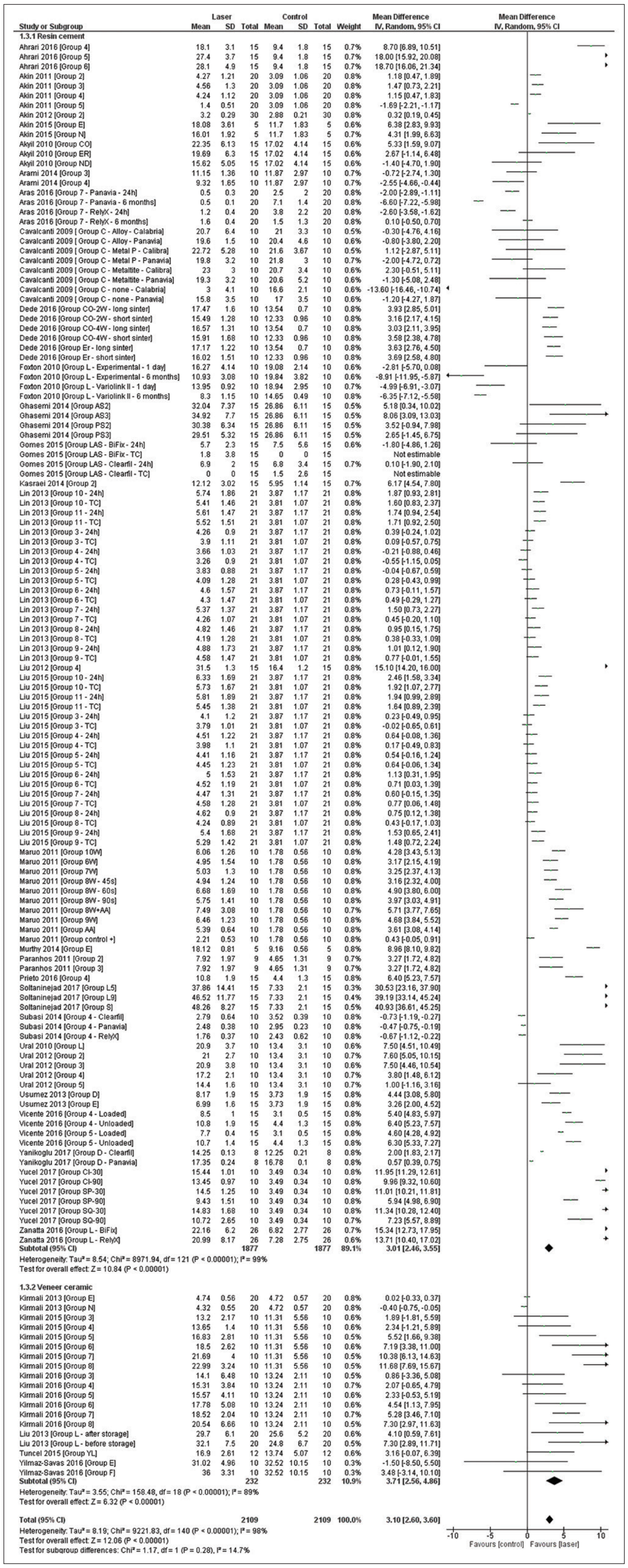

**Figure 2:** Meta-analysis between untreated and laser groups of Y-TZP (*P* < 0.00001; mean difference: 3.08; 95% confidence interval: 2.58 to 3.58)

the surface ceramic materials. However, the lower output power may not be able to enhance the bond strength between Y-TZP and resin cement, as reported by Lin *et al*.[6] and Foxton *et al*.[50] These authors reported a significant enlargement of the Y-TZP particles with irradiation at 200 mJ, while some cracks and loss of surface material was found with irradiation at 300 mJ. Another study[49] reported that cement selection is more important than the surface treatment of zirconia. On the other hand, Dede *et al*.[47] used output power at 400 mJ and reported that this treatment reached sufficient bond strength between Y-TZP and resin cement. Based on the studies that used this laser treatment, and on the results of the meta-analysis performed, this treatment appears not to be the best treatment for the improvement of zirconia bond strength.

The $CO_2$ laser was, initially, used to enhance the osseointegration of zirconia implants.[20,53] This laser was effectively used for surface treatment of dental ceramics due to the well absorption of the laser wavelength by the ceramics surface.[20,24,44,53,54] The process occurs due to thermomechanical ablation, enhancing micromechanical retention and, consequently, the bond strength with zirconia.[24] Furthermore, the possibility of surface chemical alteration may occur, resulting in better bond strength with zirconia. There was the highest variation on output power (2–20 W) in the studies that used $CO_2$ laser when compared to the other lasers found. In the study of Akyil *et al*.,[10] the authors analyzed several output configurations (from 2 to 5 W), selecting the parameter with 4 W for 50 s as the better option for bonding with resin cement. The authors reported that this configuration promoted better surface alteration, originating a rough surface with a plaque-like scaly appearance.[10] A micromechanical retention between zirconia and resin cement after CO2 irradiation was previous reported, due to the heat induction and rapid expansion of the Y-TZP surface.[20,27,47] However, Akin *et al*.[20] utilized the same parameters (4 W, 50 s) and found that $CO_2$ laser irradiation did not increase the bond strength with resin cement. The main difference between the studies, that could explain this discrepancy, is that in the Akin *et al*.'s study,[20] the specimens had two adhesive interfaces simulating clinical situations (between zirconia and resin and between resin and dentin), which may interfere with the bond strength test. Another disagreement was found between Dede *et al*.[47] and Paranhos *et al*.;[18] even using similar parameters, the first study reported an increase in bond strength with resin cement, but the second study contraindicates the use due to significant microcracks found.

On the other hand, Ahrari *et al*.[24] used the $CO_2$ fractional laser with an output of 10 W/14 mJ and 20 W/10 mJ for 10 s. This technique is widely used in the medical and

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Ahrari 2016 [Group 4] | 18.1 | 3.1 | 15 | 9.4 | 1.8 | 15 | 3.9% | 8.70 [6.89, 10.51] |
| Ahrari 2016 [Group 5] | 27.4 | 3.7 | 15 | 9.4 | 1.8 | 15 | 3.8% | 18.00 [15.92, 20.08] |
| Ahrari 2016 [Group 6] | 28.1 | 4.9 | 15 | 9.4 | 1.8 | 15 | 3.6% | 18.70 [16.06, 21.34] |
| Akin 2011 [Group 5] | 1.4 | 0.51 | 20 | 3.09 | 1.06 | 20 | 4.1% | -1.69 [-2.21, -1.17] |
| Akyil 2010 [Group CO] | 22.35 | 6.13 | 15 | 17.02 | 4.14 | 15 | 3.2% | 5.33 [1.59, 9.07] |
| Dede 2016 [Group CO-2W - long sinter] | 17.47 | 1.6 | 10 | 13.54 | 0.7 | 10 | 4.0% | 3.93 [2.85, 5.01] |
| Dede 2016 [Group CO-2W - short sinter] | 15.49 | 1.28 | 10 | 12.33 | 0.96 | 10 | 4.1% | 3.16 [2.17, 4.15] |
| Dede 2016 [Group CO-4W - long sinter] | 16.57 | 1.31 | 10 | 13.54 | 0.7 | 10 | 4.1% | 3.03 [2.11, 3.95] |
| Dede 2016 [Group CO-4W - short sinter] | 15.91 | 1.68 | 10 | 12.33 | 0.96 | 10 | 4.0% | 3.58 [2.38, 4.78] |
| Kasraei 2014 [Group 2] | 12.12 | 3.02 | 15 | 5.95 | 1.14 | 15 | 3.9% | 6.17 [4.54, 7.80] |
| Liu 2013 [Group L - after storage] | 29.7 | 6.1 | 20 | 25.6 | 5.2 | 20 | 3.3% | 4.10 [0.59, 7.61] |
| Liu 2013 [Group L - before storage] | 32.1 | 7.5 | 20 | 24.8 | 6.7 | 20 | 3.0% | 7.30 [2.89, 11.71] |
| Maruo 2011 [Group 10W] | 6.06 | 1.26 | 10 | 1.78 | 0.56 | 10 | 4.1% | 4.28 [3.43, 5.13] |
| Maruo 2011 [Group 6W] | 4.95 | 1.54 | 10 | 1.78 | 0.56 | 10 | 4.1% | 3.17 [2.15, 4.19] |
| Maruo 2011 [Group 7W] | 5.03 | 1.3 | 10 | 1.78 | 0.56 | 10 | 4.1% | 3.25 [2.37, 4.13] |
| Maruo 2011 [Group 8W - 45s] | 4.94 | 1.24 | 10 | 1.78 | 0.56 | 10 | 4.1% | 3.16 [2.32, 4.00] |
| Maruo 2011 [Group 8W - 60s] | 6.68 | 1.69 | 10 | 1.78 | 0.56 | 10 | 4.0% | 4.90 [3.80, 6.00] |
| Maruo 2011 [Group 8W - 90s] | 5.75 | 1.41 | 10 | 1.78 | 0.56 | 10 | 4.1% | 3.97 [3.03, 4.91] |
| Maruo 2011 [Group 9W] | 6.46 | 1.23 | 10 | 1.78 | 0.56 | 10 | 4.1% | 4.68 [3.84, 5.52] |
| Murthy 2014 [Group E] | 18.12 | 0.81 | 5 | 9.16 | 0.56 | 5 | 4.1% | 8.96 [8.10, 9.82] |
| Paranhos 2011 [Group 2] | 7.92 | 1.97 | 9 | 4.65 | 1.31 | 9 | 4.0% | 3.27 [1.72, 4.82] |
| Ural 2010 [Group L] | 20.9 | 3.7 | 10 | 13.4 | 3.1 | 10 | 3.5% | 7.50 [4.51, 10.49] |
| Ural 2012 [Group 2] | 21 | 2.7 | 10 | 13.4 | 3.1 | 10 | 3.7% | 7.60 [5.05, 10.15] |
| Ural 2012 [Group 3] | 20.9 | 3.8 | 10 | 13.4 | 3.1 | 10 | 3.5% | 7.50 [4.46, 10.54] |
| Ural 2012 [Group 4] | 17.2 | 2.1 | 10 | 13.4 | 3.1 | 10 | 3.7% | 3.80 [1.48, 6.12] |
| Ural 2012 [Group 5] | 14.4 | 1.6 | 10 | 13.4 | 3.1 | 10 | 3.8% | 1.00 [-1.16, 3.16] |
| **Total (95% CI)** | | | **309** | | | **309** | **100.0%** | **5.56 [4.11, 7.02]** |

Heterogeneity: $Tau^2 = 13.29$; $Chi^2 = 952.36$, df = 25 ($P < 0.00001$); $I^2 = 97\%$
Test for overall effect: Z = 7.50 ($P < 0.00001$)

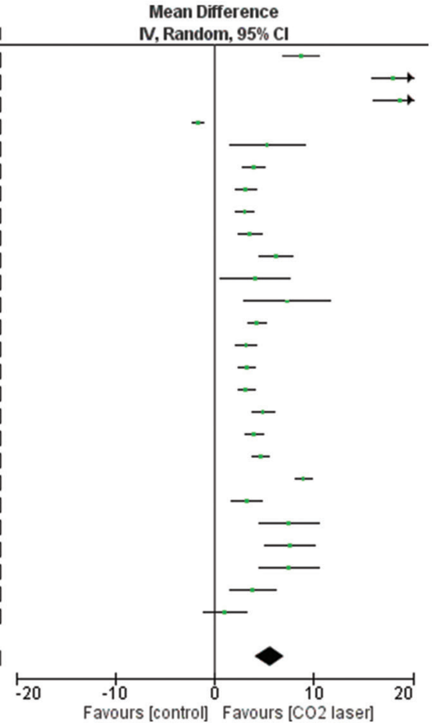


**Figure 3:** Meta-analysis between untreated and $CO_2$ laser groups of Y-TZP ($P < 0.00001$; mean difference: 5.56; 95% confidence interval: 4.11–7.02)

dermatological areas, due to the noninvasive effect.[24,55,56] This fractional laser therapy uses equipment capable to irradiate a wide area, promoting thousands of treated microscopy zones, maintaining the surrounding tissue healthy and untreated.[24,55] Through this technique, it is possible to irradiate multiple zones with a predetermined space between them, eliminating the necessity of manual movements by an operator, promoting a superficial alteration more homogeneous.[24] Thus, even with high output values (20 W), the authors[24,56] reported this strategy as more effective to enhance the bond strength with the resin cement, probably due to its factional effect. Therefore, it was recommended to use a $CO_2$ laser beam with low energy settings such as 80, 150, or 200 J/cm$^2$ for zirconia ceramics.[20,47]

The Nd:YAG laser is efficiently used on dental sensitivity reduction, whitening, caries removal, and to promote a superficial rough of dental ceramics before cementation.[16,20,46] Like the Er:YAG, this laser is capable to remove content from the zirconia surface due to the punctate action of the laser, inducing microexplosions and generating voids.[16] In addition, it also promotes fusing and melting of the most superficial ceramic layer due to thermal changes, followed by freezing of melted material, promoting a blister-like surface.[16,46] It is important to mention that when higher laser energy was used, bigger and deeper cracks can be formed on zirconia surfaces.[46] Akyil *et al*.[10] reported that Nd:YAG laser irradiation decreased the bond strength with resin cement when compared to the control group. The authors also mentioned that the SEM micrographs showed a surface with a bubbled blister-like appearance and unusual microcracks when irradiated at a power output of 2 W. This fact may be due to the development of a heat-damaged layer of Nd:YAG laser that may be poorly attached to the infra layer of the substrate.[10] This decrease on the bond strength after Nd:YAG laser irradiation has been described by few authors,[21,34] due to the surface heat generated on Y-TZP surface, being the main factor that interferes on the bond strength between zirconia and resin cement. The increase of irradiation power and time may cause a material defect.[21] Kirmali *et al*.[22] reported that only Nd:YAG treatment was not effective to alter the Y-TZP surface for the bond strength between zirconia and veneering ceramic.

On the other hand, several authors[7,16,18,20,38,46,57] reported an increase in bond strength values using this laser composition. Akin *et al*.[32] evaluated different surface treatments (sandblasting, silica coating, Er:YAG, and Nd:YAG) and reported that the roughness was similar to the control group, except for Nd:YAG laser treatment. The authors[32] found scratch-like traces and shallow pits after this treatment. In another study,[16] it was reported some kind of melting pattern after irradiation, enhancing the bond strength results with resin cement. The effect of

| Study or Subgroup | Laser therapy Mean | Laser therapy SD | Laser therapy Total | Control Mean | Control SD | Control Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Akin 2011 [Group 2] | 4.27 | 1.21 | 20 | 3.09 | 1.06 | 20 | 2.6% | 1.18 [0.47, 1.89] |
| Akin 2012 [Group 2] | 3.2 | 0.29 | 30 | 2.88 | 0.21 | 30 | 2.7% | 0.32 [0.19, 0.45] |
| Akin 2015 [Group E] | 18.08 | 3.61 | 5 | 11.7 | 1.83 | 5 | 1.5% | 6.38 [2.83, 9.93] |
| Akyil 2010 [Group ER] | 19.69 | 6.3 | 15 | 17.02 | 4.14 | 15 | 1.4% | 2.67 [-1.14, 6.48] |
| Arami 2014 [Group 3] | 11.15 | 1.36 | 10 | 11.87 | 2.97 | 10 | 2.1% | -0.72 [-2.74, 1.30] |
| Cavalcanti 2009 [ Group C - Alloy - Calabria] | 20.7 | 6.4 | 10 | 21 | 3.3 | 10 | 1.2% | -0.30 [-4.76, 4.16] |
| Cavalcanti 2009 [ Group C - Alloy - Panavia] | 19.6 | 1.5 | 10 | 20.4 | 4.6 | 10 | 1.7% | -0.80 [-3.80, 2.20] |
| Cavalcanti 2009 [ Group C - Metal P - Calibra] | 22.72 | 5.28 | 10 | 21.6 | 3.67 | 10 | 1.3% | 1.12 [-2.87, 5.11] |
| Cavalcanti 2009 [ Group C - Metal P - Panavia] | 19.8 | 3.2 | 10 | 21.8 | 3 | 10 | 1.8% | -2.00 [-4.72, 0.72] |
| Cavalcanti 2009 [ Group C - Metaltite - Calibra] | 23 | 3 | 10 | 20.7 | 3.4 | 10 | 1.8% | 2.30 [-0.51, 5.11] |
| Cavalcanti 2009 [ Group C - Metaltite - Panavia] | 19.3 | 3.2 | 10 | 20.6 | 5.2 | 10 | 1.4% | -1.30 [-5.08, 2.48] |
| Cavalcanti 2009 [ Group C - none - Calabria] | 3 | 4.1 | 10 | 16.6 | 2.1 | 10 | 1.8% | -13.60 [-16.46, -10.74] |
| Cavalcanti 2009 [ Group C - none - Panavia] | 15.8 | 3.5 | 10 | 17 | 3.5 | 10 | 1.7% | -1.20 [-4.27, 1.87] |
| Dede 2016 [Group Er - long sinter] | 17.17 | 1.22 | 10 | 13.54 | 0.7 | 10 | 2.5% | 3.63 [2.76, 4.50] |
| Dede 2016 [Group Er - short sinter] | 16.02 | 1.51 | 10 | 12.33 | 0.96 | 10 | 2.5% | 3.69 [2.58, 4.80] |
| Foxton 2010 [Group L - Experimental - 1 day] | 16.27 | 4.14 | 10 | 19.08 | 2.14 | 10 | 1.8% | -2.81 [-5.70, 0.08] |
| Foxton 2010 [Group L - Experimental - 6 months] | 10.93 | 3.08 | 10 | 19.84 | 3.82 | 10 | 1.7% | -8.91 [-11.95, -5.87] |
| Foxton 2010 [Group L - Variolink II - 1 day] | 13.95 | 0.92 | 10 | 18.94 | 2.95 | 10 | 2.2% | -4.99 [-6.91, -3.07] |
| Foxton 2010 [Group L - Variolink II - 6 months] | 8.3 | 1.15 | 10 | 14.65 | 0.49 | 10 | 2.6% | -6.35 [-7.12, -5.58] |
| Gomes 2015 [Group LAS - BiFix - 24h] | 5.7 | 2.3 | 15 | 7.5 | 5.6 | 15 | 1.7% | -1.80 [-4.86, 1.26] |
| Gomes 2015 [Group LAS - BiFix - TC] | 1.8 | 3.8 | 15 | 0 | 0 | 15 | | Not estimable |
| Gomes 2015 [Group LAS - Clearfil - 24h] | 6.9 | 2 | 15 | 6.8 | 3.4 | 15 | 2.1% | 0.10 [-1.90, 2.10] |
| Gomes 2015 [Group LAS - Clearfil - TC] | 0 | 0 | 15 | 1.5 | 2.6 | 15 | | Not estimable |
| Kirmali 2013 [Group E] | 4.74 | 0.56 | 20 | 4.72 | 0.57 | 20 | 2.6% | 0.02 [-0.33, 0.37] |
| Lin 2013 [Group 10 - 24h] | 5.74 | 1.86 | 21 | 3.87 | 1.17 | 21 | 2.5% | 1.87 [0.93, 2.81] |
| Lin 2013 [Group 10 - TC] | 5.41 | 1.46 | 21 | 3.81 | 1.07 | 21 | 2.6% | 1.60 [0.83, 2.37] |
| Lin 2013 [Group 11 - 24h] | 5.61 | 1.47 | 21 | 3.87 | 1.17 | 21 | 2.6% | 1.74 [0.94, 2.54] |
| Lin 2013 [Group 11 - TC] | 5.52 | 1.51 | 21 | 3.81 | 1.07 | 21 | 2.6% | 1.71 [0.92, 2.50] |
| Lin 2013 [Group 3 - 24h] | 4.26 | 0.9 | 21 | 3.87 | 1.17 | 21 | 2.6% | 0.39 [-0.24, 1.02] |
| Lin 2013 [Group 3 - TC] | 3.9 | 1.11 | 21 | 3.81 | 1.07 | 21 | 2.6% | 0.09 [-0.57, 0.75] |
| Lin 2013 [Group 4 - 24h] | 3.66 | 1.03 | 21 | 3.87 | 1.17 | 21 | 2.6% | -0.21 [-0.88, 0.46] |
| Lin 2013 [Group 4 - TC] | 3.26 | 0.9 | 21 | 3.81 | 1.07 | 21 | 2.6% | -0.55 [-1.15, 0.05] |
| Lin 2013 [Group 5 - 24h] | 3.83 | 0.88 | 21 | 3.87 | 1.17 | 21 | 2.6% | -0.04 [-0.67, 0.59] |
| Lin 2013 [Group 5 - TC] | 4.09 | 1.28 | 21 | 3.81 | 1.07 | 21 | 2.6% | 0.28 [-0.43, 0.99] |
| Lin 2013 [Group 6 - 24h] | 4.6 | 1.57 | 21 | 3.87 | 1.17 | 21 | 2.5% | 0.73 [-0.11, 1.57] |
| Lin 2013 [Group 6 - TC] | 4.3 | 1.47 | 21 | 3.81 | 1.07 | 21 | 2.6% | 0.49 [-0.29, 1.27] |
| Lin 2013 [Group 7 - 24h] | 5.37 | 1.37 | 21 | 3.87 | 1.17 | 21 | 2.6% | 1.50 [0.73, 2.27] |
| Lin 2013 [Group 7 - TC] | 4.26 | 1.07 | 21 | 3.81 | 1.07 | 21 | 2.6% | 0.45 [-0.20, 1.10] |
| Lin 2013 [Group 8 - 24h] | 4.82 | 1.46 | 21 | 3.87 | 1.17 | 21 | 2.6% | 0.95 [0.15, 1.75] |
| Lin 2013 [Group 8 - TC] | 4.19 | 1.28 | 21 | 3.81 | 1.07 | 21 | 2.6% | 0.38 [-0.33, 1.09] |
| Lin 2013 [Group 9 - 24h] | 4.88 | 1.73 | 21 | 3.87 | 1.17 | 21 | 2.5% | 1.01 [0.12, 1.90] |
| Lin 2013 [Group 9 - TC] | 4.58 | 1.47 | 21 | 3.81 | 1.07 | 21 | 2.6% | 0.77 [-0.01, 1.55] |
| Liu 2012 [Group 4] | 31.5 | 1.3 | 15 | 16.4 | 1.2 | 15 | 2.5% | 15.10 [14.20, 16.00] |
| Subasi 2014 [Group 4 - Clearfil] | 2.79 | 0.64 | 10 | 3.52 | 0.39 | 10 | 2.6% | -0.73 [-1.19, -0.27] |
| Subasi 2014 [Group 4 - Panavia] | 2.48 | 0.38 | 10 | 2.95 | 0.23 | 10 | 2.6% | -0.47 [-0.75, -0.19] |
| Subasi 2014 [Group 4 - RelyX] | 1.76 | 0.37 | 10 | 2.43 | 0.62 | 10 | 2.6% | -0.67 [-1.12, -0.22] |
| Yilmaz-Savas 2016 [Group E] | 31.02 | 4.96 | 10 | 32.52 | 10.15 | 10 | 0.7% | -1.50 [-8.50, 5.50] |
| **Total (95% CI)** | | | **733** | | | **733** | **100.0%** | **0.22 [-0.44, 0.88]** |

Heterogeneity: Tau² = 4.26; Chi² = 1757.97, df = 44 (P < 0.00001); I² = 97%
Test for overall effect: Z = 0.66 (P = 0.51)

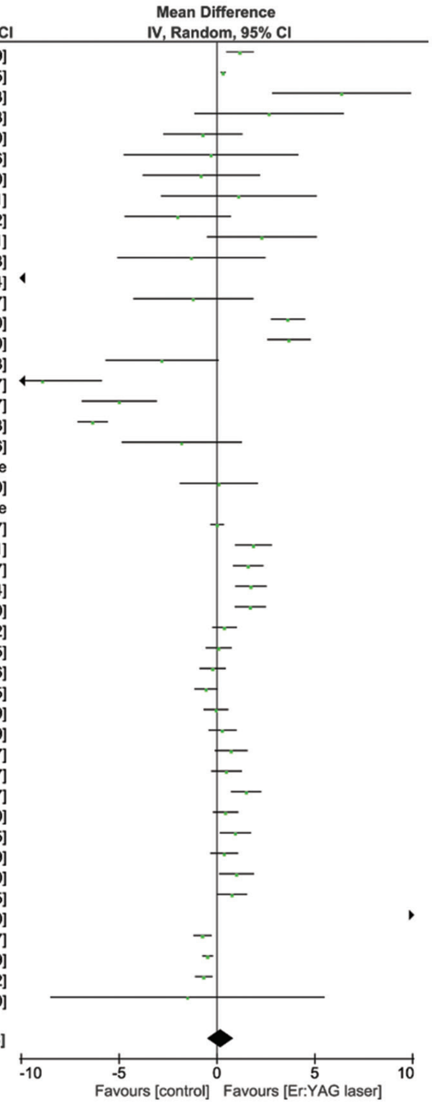


**Figure 4:** Meta-analysis between untreated and erbium:yttrium–aluminum–garnet laser groups of Y-TZP (P = 0.51; mean difference: 0.22; 95% confidence interval: −0.44–0.88)

Nd:YAG laser irradiation was studied with short and long pulse durations, and the results of roughness and bond strength with resin cement of short pulse laser irradiation were better, even causing microcracks and remarkably high monoclinic content of zirconia.[38] On the other hand, Soltaninejad *et al*.[46] did not found any phase transformation after irradiation with Nd:YAG with, consequently, an increase of bond strength between Y-TZP and resin cement. Thus, even with these controversial aspects, the meta-analysis of studies that used Nd:YAG presented a tendency for laser treatment when compared to the control group in bond strength, showing a low influence of the heat generated on bond strength.

The Er, Cr:YSGG laser has been also used to remove carious dental hard tissues.[3,4] This laser is also used to evaluate the morphological changes in human enamel and dentin that have been irradiated by it.[4] The literature about this laser is scarce, but it was reported that this laser uses the same methods of action of Nd:YAG and Er:YAG, causing a surface alteration by ablation, microexplosions, and vaporization.[3,4] Kirmali *et al*.[3] reported that 6 W laser irradiation of the Y-TZP surface before sintering was the most effective surface treatment. In another study[4] conducted by the same authors, they concluded that sandblasting and Er, Cr:YSGG laser irradiation with high intensities (3–6 W) provided a significant increase in bond strength, while 1 and 2 W laser irradiations were not effective as surface treatments to improve bond strength. Both studies were conducted in the same way of parameters; however, the laser irradiation was conducted before[3] and after[4] final sintering of zirconia. Thus, the

| Study or Subgroup | Laser therapy Mean | SD | Total | Control Mean | SD | Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Akin 2011 [Group 3] | 4.56 | 1.3 | 20 | 3.09 | 1.06 | 20 | 3.5% | 1.47 [0.73, 2.21] |
| Akin 2011 [Group 4] | 4.24 | 1.12 | 20 | 3.09 | 1.06 | 20 | 3.5% | 1.15 [0.47, 1.83] |
| Akin 2015 [Group N] | 16.01 | 1.92 | 5 | 11.7 | 1.83 | 5 | 2.2% | 4.31 [1.99, 6.63] |
| Akyil 2010 [Group ND] | 15.62 | 5.05 | 15 | 17.02 | 4.14 | 15 | 1.5% | -1.40 [-4.70, 1.90] |
| Arami 2014 [Group 4] | 9.32 | 1.65 | 10 | 11.87 | 2.97 | 10 | 2.3% | -2.55 [-4.66, -0.44] |
| Kirmali 2013 [Group N] | 4.32 | 0.55 | 20 | 4.72 | 0.57 | 20 | 3.7% | -0.40 [-0.75, -0.05] |
| Liu 2015 [Group 10 - 24h] | 6.33 | 1.69 | 21 | 3.87 | 1.17 | 21 | 3.4% | 2.46 [1.58, 3.34] |
| Liu 2015 [Group 10 - TC] | 5.73 | 1.67 | 21 | 3.81 | 1.07 | 21 | 3.4% | 1.92 [1.07, 2.77] |
| Liu 2015 [Group 11 - 24h] | 5.81 | 1.89 | 21 | 3.87 | 1.17 | 21 | 3.3% | 1.94 [0.99, 2.89] |
| Liu 2015 [Group 11 - TC] | 5.45 | 1.38 | 21 | 3.81 | 1.07 | 21 | 3.5% | 1.64 [0.89, 2.39] |
| Liu 2015 [Group 3 - 24h] | 4.1 | 1.2 | 21 | 3.87 | 1.17 | 21 | 3.5% | 0.23 [-0.49, 0.95] |
| Liu 2015 [Group 3 - TC] | 3.79 | 1.01 | 21 | 3.81 | 1.07 | 21 | 3.5% | -0.02 [-0.65, 0.61] |
| Liu 2015 [Group 4 - 24h] | 4.51 | 1.22 | 21 | 3.87 | 1.17 | 21 | 3.5% | 0.64 [-0.08, 1.36] |
| Liu 2015 [Group 4 - TC] | 3.98 | 1.1 | 21 | 3.81 | 1.07 | 21 | 3.5% | 0.17 [-0.49, 0.83] |
| Liu 2015 [Group 5 - 24h] | 4.41 | 1.16 | 21 | 3.87 | 1.17 | 21 | 3.5% | 0.54 [-0.16, 1.24] |
| Liu 2015 [Group 5 - TC] | 4.45 | 1.23 | 21 | 3.81 | 1.07 | 21 | 3.5% | 0.64 [-0.06, 1.34] |
| Liu 2015 [Group 6 - 24h] | 5 | 1.53 | 21 | 3.87 | 1.17 | 21 | 3.4% | 1.13 [0.31, 1.95] |
| Liu 2015 [Group 6 - TC] | 4.52 | 1.19 | 21 | 3.81 | 1.07 | 21 | 3.5% | 0.71 [0.03, 1.39] |
| Liu 2015 [Group 7 - 24h] | 4.47 | 1.31 | 21 | 3.87 | 1.17 | 21 | 3.5% | 0.60 [-0.15, 1.35] |
| Liu 2015 [Group 7 - TC] | 4.58 | 1.28 | 21 | 3.81 | 1.07 | 21 | 3.5% | 0.77 [0.06, 1.48] |
| Liu 2015 [Group 8 - 24h] | 4.62 | 0.9 | 21 | 3.87 | 1.17 | 21 | 3.5% | 0.75 [0.12, 1.38] |
| Liu 2015 [Group 8 - TC] | 4.24 | 0.89 | 21 | 3.81 | 1.07 | 21 | 3.6% | 0.43 [-0.17, 1.03] |
| Liu 2015 [Group 9 - 24h] | 5.4 | 1.68 | 21 | 3.87 | 1.17 | 21 | 3.4% | 1.53 [0.65, 2.41] |
| Liu 2015 [Group 9 - TC] | 5.29 | 1.42 | 21 | 3.81 | 1.07 | 21 | 3.5% | 1.48 [0.72, 2.24] |
| Paranhos 2011 [Group 3] | 7.92 | 1.97 | 9 | 4.65 | 1.31 | 9 | 2.8% | 3.27 [1.72, 4.82] |
| Soltaninejad 2017 [Group L5] | 37.86 | 14.41 | 15 | 7.33 | 2.1 | 15 | 0.4% | 30.53 [23.16, 37.90] |
| Soltaninejad 2017 [Group L9] | 46.52 | 11.77 | 15 | 7.33 | 2.1 | 15 | 0.6% | 39.19 [33.14, 45.24] |
| Usumez 2013 [Group D] | 8.17 | 1.9 | 15 | 3.73 | 1.9 | 15 | 3.0% | 4.44 [3.08, 5.80] |
| Usumez 2013 [Group E] | 6.99 | 1.6 | 15 | 3.73 | 1.9 | 15 | 3.1% | 3.26 [2.00, 4.52] |
| Yanikoglu 2017 [Group D - Clearfil] | 14.25 | 0.13 | 8 | 12.25 | 0.21 | 8 | 3.7% | 2.00 [1.83, 2.17] |
| Yanikoglu 2017 [Group D - Panavia] | 17.35 | 0.24 | 8 | 16.78 | 0.1 | 8 | 3.7% | 0.57 [0.39, 0.75] |
| Zanatta 2016 [Group L - BiFix] | 22.16 | 6.2 | 26 | 6.82 | 2.77 | 26 | 1.9% | 15.34 [12.73, 17.95] |
| Zanatta 2016 [Group L - RelyX] | 20.99 | 8.17 | 26 | 7.28 | 2.75 | 26 | 1.5% | 13.71 [10.40, 17.02] |
| **Total (95% CI)** | | | **605** | | | **605** | **100.0%** | **2.00 [1.47, 2.52]** |

Heterogeneity: Tau² = 1.91; Chi² = 719.31, df = 32 (P < 0.00001); I² = 96%
Test for overall effect: Z = 7.47 (P < 0.00001)

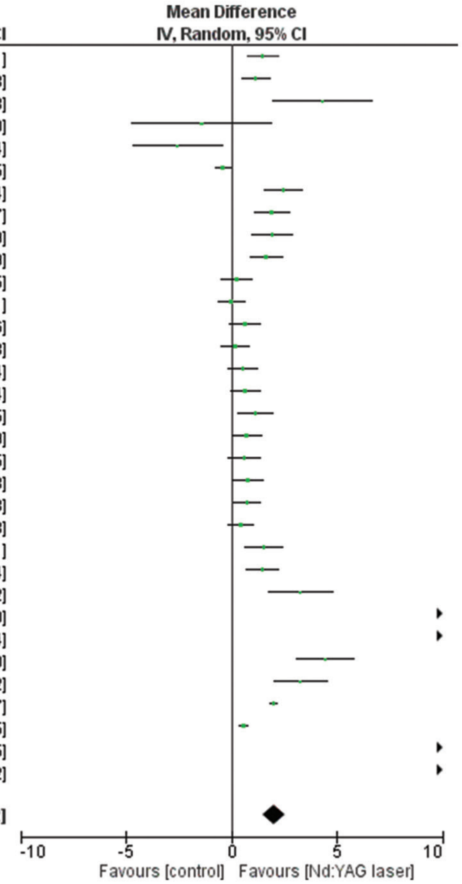


**Figure 5:** Meta-analysis between untreated and neodymium:yttrium–aluminum–garnet laser groups of Y-TZP (P < 0.00001; mean difference: 2.00; 95% confidence interval: 1.47–2.52)

irradiation process can be performed before or after the zirconia sintering, presenting high bond strength values between zirconia and veneering ceramic. Likewise, Ghasemi *et al*.[45] tested the Er, Cr:YSGG laser irradiation with different output power before and after zirconia sintering. The authors[45] reported that the 3W power setting was not recommended for treatment of presintered Y-TZP, while enhanced the bond strength of resin cement to a sintered Y-TZP. Corroborating with this, Aras *et al*.[42] treated presintered Y-TZP with Er, Cr:YSGG laser and concluded that was not sufficient to increase the bond strength between Y-TZP and resin cement. Based on these findings, the laser treatment before zirconia sintering may not be recommended as a surface treatment for the bond to resin cement.

Femtosecond technology is an innovative laser technology that uses a laser based on titanium/sapphire crystals, producing wavelengths near the infrared (795 nm).[15,43] This laser produces ultrashort light pulses, below the picosecond scale, in the femtosecond domain (1 fs = $10^{-15}$ s).[40,43] This laser has been used in the medical and dental areas, due to cell ablation.[40,43] This laser can be used as an alternative in the field of adhesion in dentistry, being a tool for orthodontics, dental surgery, conditioning agent, and for the ablation of different types of surfaces, due to the minimum amount of thermal and mechanical damage to the surfaces.[15,40,43] Even though lasers with long pulses are generally used in dentistry, lasers with ultrashort pulses have superior parameters, with a very restricted heat-affected area and minimal injury in comparison with other laser types.[13] However, there is a lack of information about the effect of the femtosecond laser as a surface treatment of zirconia ceramics and its effect on bonding strength with veneering ceramic.[43] Among the studies that used this laser, Yucel *et al*.[13] tested different shapes and angles of the femtosecond laser, and the authors reported that the angle between the zirconia surface and the laser beam decreased as the bond strength between zirconia and resin cement increased. They concluded that the highest bond strength values were achieved with the spiral and square surfaces using a 30° angle laser beam.[13] In another study, Vicente *et al*.[40] tested different protocols of the femtosecond laser to improve the bond strength with resin cement, reporting that irradiation at step 40 is desirable since it is more efficient and faster, being considered a reliable way

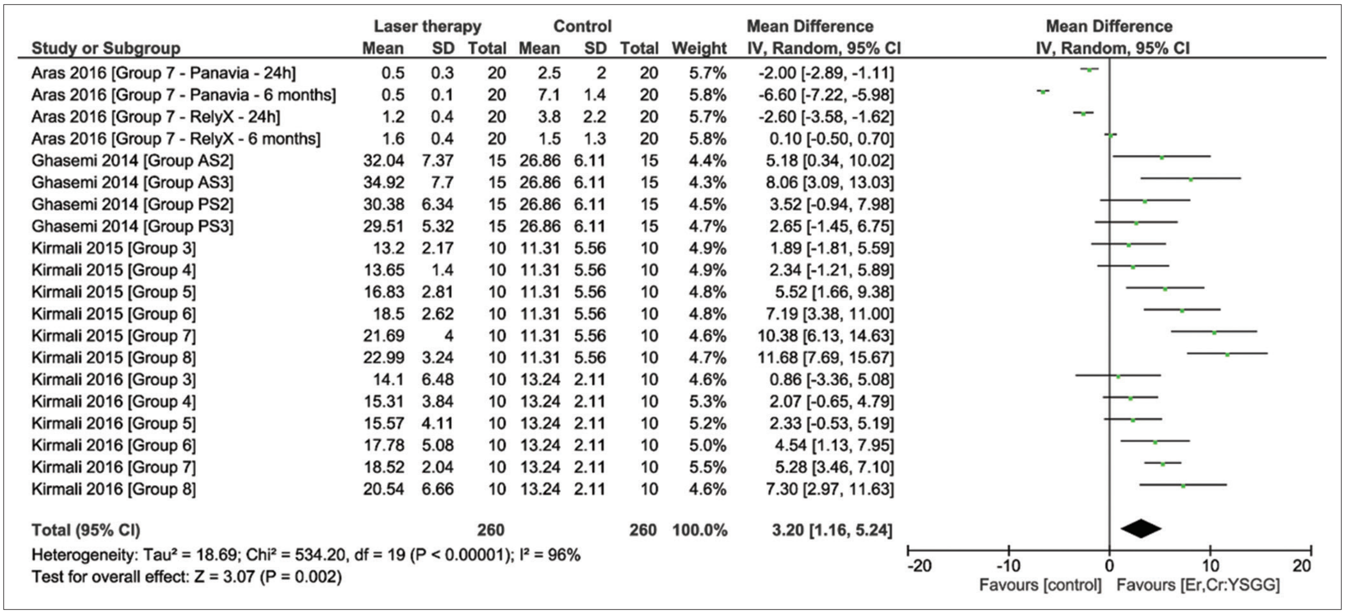


**Figure 6:** Meta-analysis between untreated and erbium, chromium:yttrium–scandium gallium–garnet laser groups of Y-TZP (P = 0.002; mean difference: 3.20; 95% confidence interval: 1.16–5.24)

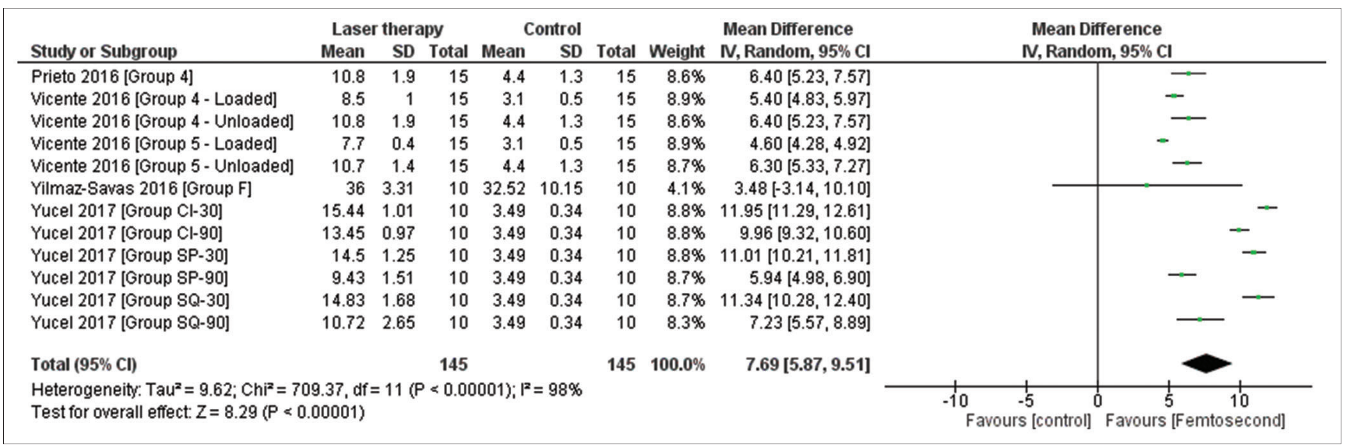


**Figure 7:** Meta-analysis between untreated and femtosecond laser groups of Y-TZP (P < 0.00001; mean difference: 7.69; 95% confidence interval: 5.87–9.51)

to achieve a suitable adhesion between zirconia and resin cement. Vicente Prieto *et al*.[15] compared the effect of this laser with sandblasting with 25-μm $Al_2O_3$ particles, concluding that the laser treatment improved the bond strength with resin cement, even more, when associated with tribochemical silica coating. When compared this laser with Er:YAG laser irradiation, it was reported that the femtosecond laser irradiation formed more regular pits on the zirconia surface, providing better micromechanical adhesion with the veneering ceramic.[43] All the studies[13,15,40] reported better results for the femtosecond laser treatment for bonding to resin cement. On the other hand, Yilmaz-Savas *et al*.[43] reported no statistical difference in bond strength between the femtosecond laser and the control group. However, they evaluated the bond strength with lithium disilicate ceramic, using a glass fusion ceramic and crystallized it according to the CAD-on technique, which may have improved the process of bonding between the ceramics.

It is important to mention that the difference between the results found in the included studies may be assigned to the difference in equipment used and in the laser parameters (energy, output power, pulse duration, and distance of application).[24,32] Associated with these factors, the manual handling of a laser point may promote a nonhomogeneous pattern of roughness.[24] Several studies reported that during the irradiation process, a local thermal alteration can generate harming the mechanical properties of zirconia, due to phase transformation that could occur during

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Akin 2015 [Group E] | 0.62 | 0.03 | 5 | 0.62 | 0.06 | 5 | 2.5% | 0.00 [-0.06, 0.06] |
| Akin 2015 [Group N] | 0.72 | 0.07 | 5 | 0.62 | 0.06 | 5 | 2.5% | 0.10 [0.02, 0.18] |
| Arami 2014 [Group 3] | 0.53 | 0.04 | 10 | 0.23 | 0.07 | 10 | 2.5% | 0.30 [0.25, 0.35] |
| Arami 2014 [Group 4] | 2.7 | 0.16 | 10 | 0.23 | 0.07 | 10 | 2.5% | 2.47 [2.36, 2.58] |
| Kirmali 2015 [Group 3] | 0.79 | 0.07 | 10 | 0.75 | 0.08 | 10 | 2.5% | 0.04 [-0.03, 0.11] |
| Kirmali 2015 [Group 4] | 0.82 | 0.05 | 10 | 0.75 | 0.08 | 10 | 2.5% | 0.07 [0.01, 0.13] |
| Kirmali 2015 [Group 5] | 0.83 | 0.03 | 10 | 0.75 | 0.08 | 10 | 2.5% | 0.08 [0.03, 0.13] |
| Kirmali 2015 [Group 6] | 0.84 | 0.08 | 10 | 0.75 | 0.08 | 10 | 2.5% | 0.09 [0.02, 0.16] |
| Kirmali 2015 [Group 7] | 0.84 | 0.06 | 10 | 0.75 | 0.08 | 10 | 2.5% | 0.09 [0.03, 0.15] |
| Kirmali 2015 [Group 8] | 0.83 | 0.08 | 10 | 0.75 | 0.08 | 10 | 2.5% | 0.08 [0.01, 0.15] |
| Lin 2013 [Group 10 - 24h] | 0.64 | 0.12 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.26 [0.20, 0.32] |
| Lin 2013 [Group 11 - 24h] | 0.66 | 0.16 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.28 [0.21, 0.35] |
| Lin 2013 [Group 3 - 24h] | 0.43 | 0.08 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.05 [0.01, 0.09] |
| Lin 2013 [Group 4 - 24h] | 0.43 | 0.09 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.05 [0.00, 0.10] |
| Lin 2013 [Group 5 - 24h] | 0.47 | 0.1 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.09 [0.04, 0.14] |
| Lin 2013 [Group 6 - 24h] | 0.55 | 0.12 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.17 [0.11, 0.23] |
| Lin 2013 [Group 7 - 24h] | 0.56 | 0.13 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.18 [0.12, 0.24] |
| Lin 2013 [Group 8 - 24h] | 0.59 | 0.11 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.21 [0.16, 0.26] |
| Lin 2013 [Group 9 - 24h] | 0.59 | 0.12 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.21 [0.15, 0.27] |
| Liu 2013 [Group L - before storage] | 0.98 | 0.17 | 20 | 0.196 | 0.026 | 21 | 2.5% | 0.78 [0.71, 0.86] |
| Liu 2015 [Group 10 - 24h] | 0.62 | 0.13 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.24 [0.18, 0.30] |
| Liu 2015 [Group 11 - 24h] | 0.65 | 0.13 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.27 [0.21, 0.33] |
| Liu 2015 [Group 3 - 24h] | 0.34 | 0.08 | 21 | 0.38 | 0.06 | 21 | 2.5% | -0.04 [-0.08, 0.00] |
| Liu 2015 [Group 4 - 24h] | 0.36 | 0.09 | 21 | 0.38 | 0.06 | 21 | 2.5% | -0.02 [-0.07, 0.03] |
| Liu 2015 [Group 5 - 24h] | 0.42 | 0.12 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.04 [-0.02, 0.10] |
| Liu 2015 [Group 6 - 24h] | 0.41 | 0.04 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.03 [-0.00, 0.06] |
| Liu 2015 [Group 7 - 24h] | 0.45 | 0.09 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.07 [0.02, 0.12] |
| Liu 2015 [Group 8 - 24h] | 0.54 | 0.07 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.16 [0.12, 0.20] |
| Liu 2015 [Group 9 - 24h] | 0.53 | 0.1 | 21 | 0.38 | 0.06 | 21 | 2.5% | 0.15 [0.10, 0.20] |
| Soltaninejad 2017 [Group L5] | 0.04 | 0.01 | 10 | 0.04 | 0.01 | 10 | 2.5% | 0.00 [-0.01, 0.01] |
| Soltaninejad 2017 [Group L9] | 0.17 | 0.03 | 10 | 0.04 | 0.01 | 10 | 2.5% | 0.13 [0.11, 0.15] |
| Soltaninejad 2017 [Group S] | 0.16 | 0.03 | 10 | 0.04 | 0.01 | 10 | 2.5% | 0.12 [0.10, 0.14] |
| Subasi 2014 [Group 4] | 0.34 | 0.14 | 10 | 0.22 | 0.04 | 10 | 2.5% | 0.12 [0.03, 0.21] |
| Tuncel 2015 [Group YL] | 2.9 | 0.69 | 12 | 0.41 | 0.1 | 12 | 1.8% | 2.49 [2.10, 2.88] |
| Usumez 2013 [Group D] | 6.39 | 1.08 | 15 | 0.16 | 0.09 | 15 | 1.5% | 6.23 [5.68, 6.78] |
| Usumez 2013 [Group E] | 3.41 | 0.8 | 15 | 0.16 | 0.09 | 15 | 1.8% | 3.25 [2.84, 3.66] |
| Yucel 2017 [Group CI-30] | 8.24 | 0.66 | 15 | 0.47 | 0.1 | 15 | 2.0% | 7.77 [7.43, 8.11] |
| Yucel 2017 [Group CI-90] | 5.63 | 0.75 | 15 | 0.47 | 0.1 | 15 | 1.9% | 5.16 [4.78, 5.54] |
| Yucel 2017 [Group SP-30] | 7.21 | 0.73 | 15 | 0.47 | 0.1 | 15 | 1.9% | 6.74 [6.37, 7.11] |
| Yucel 2017 [Group SP-90] | 2.98 | 0.93 | 15 | 0.47 | 0.1 | 15 | 1.6% | 2.51 [2.04, 2.98] |
| Yucel 2017 [Group SQ-30] | 7.54 | 1.23 | 15 | 0.47 | 0.1 | 15 | 1.3% | 7.07 [6.45, 7.69] |
| Yucel 2017 [Group SQ-90] | 3.37 | 1.11 | 15 | 0.47 | 0.1 | 15 | 1.4% | 2.90 [2.34, 3.46] |
| Zanatta 2016 [Group L] | 1.98 | 0.35 | 26 | 0.06 | 0.04 | 26 | 2.4% | 1.92 [1.78, 2.06] |
| **Total (95% CI)** | | | **686** | | | **687** | **100.0%** | **0.96 [0.86, 1.06]** |

Heterogeneity: $Tau^2 = 0.11$; $Chi^2 = 9069.84$, df = 42 ($P < 0.00001$); $I^2 = 100\%$
Test for overall effect: Z = 18.53 ($P < 0.00001$)

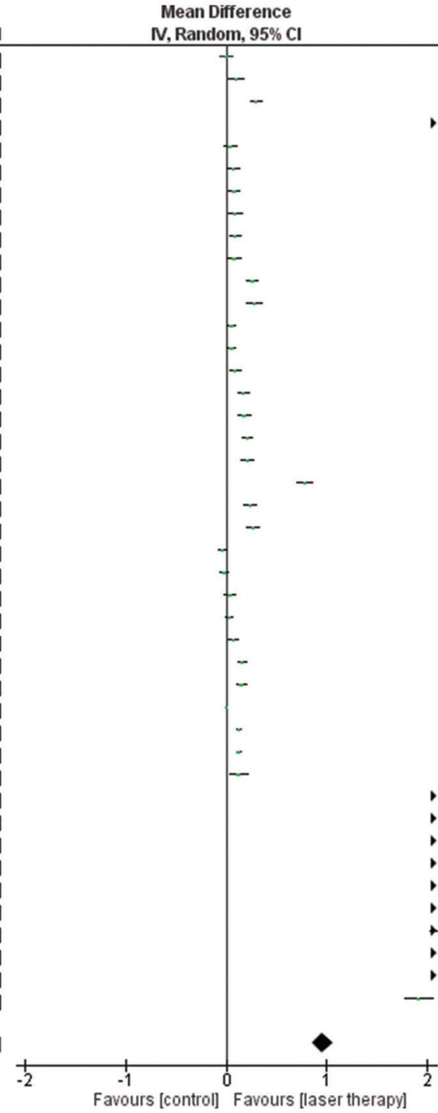


**Figure 8:** Meta-analysis of Y-TZP surface roughness between untreated and laser groups (P < 0.00001; mean difference: 0.96; 95% confidence interval: 0.86–1.06)

the laser treatment.[20,58] However, most of the included studies reported that laser irradiation as a surface treatment is a viable way to promote a rough surface, increasing the bond strength with both resin cement and veneering ceramic. Based on the findings on meta-analysis, it is important to highlight that, except Er:YAG laser, all types of laser showed a favorable result in improving the bond strength to zirconia.

The present study found different lasers protocols of the Y-TZP surface. This lack of a protocol difficult a specific comparison between the studies included, due to the larger approach used in the meta-analysis, e.g., using random effects on meta-analysis to compare the effect of treated and untreated samples. This systematic review and meta-analysis presents some limitations, such as the absence of a protocol of laser treatment, the variety of methods for analyzing the bond strength, and the inclusion of only in vitro studies. Although the limitations, this study presented an overview of all types, settings, and methods of Y-TZP surface treatment with laser described in the literature.

## CONCLUSION

Based on the findings of a large number of included studies, some points can be concluded:

1. In general, laser treatment is capable to improve the rough of zirconia surface and, consequently, the bond strength with resin cement and veneering ceramics; only Er:YAG laser did not present a favorable tendency on bond strength
2. There is a lack of laser protocol for zirconia surface treatment. This fact difficults the comparison between

the lasers, and more studies to try to establish a protocol of laser irradiation on zirconia surfaces is encouraged.

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### Conflicts of interest

There are no conflicts of interest.

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