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SYSTEMATIC REVIEW

Evaluation of zirconia surface roughness after aluminum oxide airborne-particle abrasion and the erbium-YAG, neodymium-doped YAG, or CO_2 lasers: A systematic review and meta-analysis

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ABSTRACT

Statement of problem. Veneer chipping and crown decementation are the most frequent failures in restorations using zirconia as an infrastructure. Increasing the roughness of the zirconia surface has been suggested to address this problem.

Purpose. The purpose of this systematic review and meta-analysis was to evaluate yttria-stabilized tetragonal zirconia polycrystal surface roughness, produced with aluminum oxide airborne-particle abrasion and the erbium yttrium aluminum garnet (YAG), neodymium-doped YAG, or CO_2 lasers.

Material and methods. This study was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist. The review identified relevant studies through December 2017 with no limit on the publication year in the search databases: Web of Science, Scopus, and MEDLINE via PubMed. The selected studies were submitted to a risk of bias assessment. The means and standard deviations of roughness were evaluated for the meta-analysis using Review Manager software.

Results. The 17 studies that met all inclusion criteria presented a medium risk of bias. All the treatment methods tested were able to create a roughness on the yttria-stabilized tetragonal zirconia polycrystal surface. The I^2 test values presented a high heterogeneity among the studies.

Conclusions. The presintered specimens submitted to airborne-particle abrasion had higher surface roughness compared with abrasion after the sintering process. Irradiation with the neodymium-doped YAG and CO_2 lasers was destructive to the zirconia surfaces. The erbium laser used with lower energy intensity appears to be a promising method for surface treatment. (J Prosthet Dent 2019;121:895-903)

When yttria-stabilized tetragonal zirconia polycrystal (YTZP) is subject to thermomechanical factors, transformation of its tetragonal to monoclinic phase occurs.[1-3] This transformation-toughening property is responsible for its high fracture resistance,[3,4] making zirconia suitable for use as a framework for fixed dental prostheses, resin-bonded fixed dental prostheses, and dental implant abutments.[3-6]

The clinical success and reliability of a ceramic system are related to the mechanical integrity and bond strength of the materials.[7-11] Chipping of the veneer ceramic and decementation of the prosthetic crown are the most frequent failures in restorations using zirconia as a framework.[12-22] For this reason, new strategies are needed to increase the bond strength at the interface, including increasing the surface roughness of zirconia.[3,23]

Different types of lasers and airborne-particle abrasion with aluminum oxide have been tested in laboratory studies to enhance zirconia roughness, with variable and divergent results.[23-40] For instance, some treatments triggered the transformation of the tetragonal to monoclinic phase (t→m), resulting in surface microcracks and creating a layer of residual compressive stresses due to the increased volume of the zirconia, thus, emphasizing

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Clinical Implications

Surface roughness is essential for the retention of dental restorations. These results provide a reference for the most researched and effective surface treatments. Also, they indicate which treatment might compromise the mechanical properties of zirconia and lead to premature failure.

the need to better understand the effects of different zirconia treatments.[26-33,41-58]

The purpose of this systematic review with meta-analysis was to evaluate the available scientific literature and answer the research question: in surface treatment, what are the differences resulting from the use of erbium yttrium aluminum garnet (YAG), neodymium-doped (Nd) YAG, or CO_2 lasers and the aluminum oxide airborne-particle abrasion in the creation of rough surfaces in zirconia ceramics?

MATERIAL AND METHODS

The systematic review and meta-analysis were based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist. The patient, problem, or population; intervention; comparison, control, or comparator; outcome (PICO) tool was used to develop the research strategies. The studied population (P) comprised specimens made of YTZP material, according to the ISO 6872.[3] Intervention (I) was characterized by treatment methodologies to create surface roughness based on airborne-particle abrasion protocols with aluminum oxide particles and with the use of erbium-YAG, Nd:YAG, or CO_2 laser. Only those studies that had a control group (C) without surface treatment were selected. The outcome (O) of interest was the surface roughness evaluated by a profilometer.

The bibliographic research was carried out in the following search databases: Web of Science Core Collection, Scopus, and MEDLINE via PubMed, to identify relevant studies through December 2017 with no limit on the publication year. The specific medical subject headings (MeSH) and the key words (free text word) were also used: (((((((zirconium[MeSH Terms]) OR zirconium[Title/Abstract]) OR zirconia[Title/Abstract]) OR yttria*[Title/Abstract]) OR y-tzp[Title/Abstract]) OR y tzp [Title/Abstract])) AND ((((((((((((Air abrasion, dental [MeSH Terms]) OR lasers[MeSH Terms]) OR Air abrasion, dental[Title/Abstract]) OR lasers[Title/Abstract]) OR laser[Title/Abstract]) OR air abrasion*[Title/Abstract]) OR sand blasting[Title/Abstract]) OR sandblast*[Title/Abstract]) OR al2o3[Title/Abstract]) OR Er:yag[Title/Abstract]) OR Nd:yag[Title/Abstract]) OR co2[Title/Abstract]) OR Surface treatment[Title/Abstract]).

First, the titles and abstracts were analyzed independently by 2 authors (F.V.M. and E.M.F.) and selected for full reading if they met the following inclusion criteria: relation with dentistry, relation with zirconia, and evaluation of surface roughness with a profilometer. In the second step, the final inclusion was done based on the complete text and with the consensus of the authors. Studies that met the following criteria were included: control groups without surface treatment, zirconia specimens submitted to the sintering process, and data presented as the mean and standard deviation. Studies that did not allow the isolated evaluation of the treatment effect, such as those submitted to thermal procedures or force tests, resin cementation, or the application of ceramic veneering, were excluded. For each step, the interrater agreement (kappa) between evaluators in study inclusions was calculated.

The risk of bias assessment was adapted based on the study by Aurélio et al[3] The analysis was performed according to the following parameters: division of the specimens into groups in a random manner, standardization of the specimen preparation, description of the surface treatment methodology with aluminum oxide particles or lasers, implementation of the single operator protocol, demonstration of the sample size calculation, blinding of the testing machine operator, and the test design, and the surface roughness calculation according to the ISO standards. The score was thus defined: zero if the study reported the roughness test performed and presented the parameters clearly, score 01 if the study reported the roughness test performed and presented the parameters incompletely, and score 02 if the study reported the roughness test performed but did not present the parameters. The studies scored from zero to 04 were classified as low risk, from 05 to 09 as medium risk, and from 10 to 14 as high risk of bias.

A protocol for data collection was defined and then extracted by the author (F.V.M) and checked by the second author (C.T.M.). Any disagreement was discussed between the authors. For the systematic review, the following data were extracted: author and year, YTZP brand manufacturer, YTZP grain size, comparison groups, and profilometer equipment.

In the meta-analysis, the data of the experimental and control groups were compared. All analyses were performed using the Review Manager Software v5.3 using the random effect model at a 5% significance level. For studies that presented multiple groups, the Review Manager calculator was used to create a comparison of simple pairs. A value of $P \leq .05$ was considered statistically significant (Z test). Heterogeneity among studies was assessed using the I^2 inconsistency test. Values above 50% were considered an indication of substantial heterogeneity. The "one-study remove" sensitivity analyses were performed when there was high heterogeneity. The

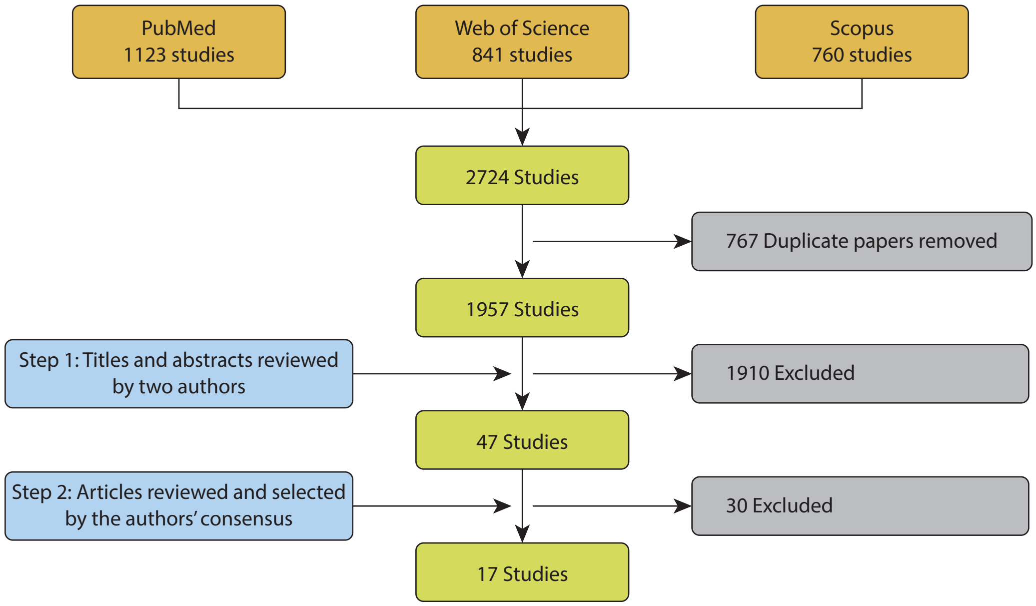


Figure 1. Study selection according to PRISMA checklist. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

analyses were performed multiple times, each with a different and single study removed, to detect whether any one study unduly influenced the heterogeneity. The authors interpreted the results.

The studies were assessed as 3 groups. In a global group, the data of all articles were included, one for airborne-particle abrasion with aluminum oxide and one for all types of lasers. In the airborne-particle abrasion subgroups, different methodologies applied before or after the sintering process were evaluated both for the use of silicon carbide paper during the process of making the specimen and for the airborne-particle abrasion with aluminum oxide. For the analysis of the laser, subgroups were created for the different types of lasers. The mean and standard deviation data for each subgroup were organized by the author (F.V.M.) and checked by the second author (C.T.M.).

RESULTS

Figure 1 summarizes the selection of studies. Of the 1957 studies, 1910 were excluded because they did not meet the eligibility criteria. The remaining 47 studies were selected for full-text analysis, of which 30 articles were excluded. Thus, 17 studies (Supplementary Table 1, available online) fulfilled all inclusion criteria and were included in this meta-analysis. The kappa values for the interrater agreement between the reviewers were 0.92 for the first step and 0.82 for the second step.

The 17 studies presented a medium risk of bias. The most common risks of bias were the absence of a single-operator protocol, absence of a description of the sample size calculation, and lack of blind operation of the test machine.

In the global analysis, all 17 studies were evaluated (Fig. 2A). The meta-analysis presented a statistical difference among the groups, showing evidence that roughness was higher in the experimental groups submitted to surface treatment ($P \leq .05$). A high heterogeneity among the studies was observed (I^2=98%).

The first analysis of the subgroups was performed using the aluminum oxide airborne-particle abrasion and lasers. In this analysis, 26 data sets were used from the 17 studies included (Fig. 2B). In both strata, the meta-analysis detected a statistical difference between the groups, showing evidence that the roughness was higher in the experimental groups submitted to surface treatment ($P \leq .05$). The most significant difference was observed in the laser subgroup, 1.37, when compared with aluminum oxide airborne-particle abrasion, 0.49. High heterogeneity among the studies was observed (I^2=97% and 98%).

In the selected studies, different methodologies were reported for the preparation of the test specimens and the airborne-particle abrasion with aluminum oxide. In the second analysis, methodologies were subgrouped into 4 modalities: polished with silicon carbide abrasive papers in the presintered stage and airborne-particle abrasion with aluminum oxide after the sintering process; polished with silicon carbide abrasive papers in the presintered stage and airborne-particle abrasion with aluminum oxide after the sintering process; polished with silicon carbide abrasive papers in the postsintered stage and airborne-particle abrasion with aluminum oxide after the sintering process; and no polish and airborne-particle abrasion with aluminum oxide after the sintering process. For the analysis of these subgroups, 16 data sets were

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random (95% CI)
1.1.1 Global								
Abi-Rached et al. 2014	0.8167	0.2652	60	0.35	0.05	20	7.5%	0.47 (0.40, 0.54)
Arami et al. 2014	2.181	2.5404	70	0.23	0.07	7	3.5%	1.95 (1.35, 2.55)
Arami S. et al. 2014	1.27	1.0331	30	0.23	0.07	10	5.2%	1.04 (0.67, 1.41)
Cavalcanti et al. 2009	5.2088	4.994	48	0.545	0.2943	12	1.0%	4.66 (3.24, 6.09)
Demir et al. 2012	0.435	0.2653	40	0.22	0.03	10	7.5%	0.21 (0.13, 0.30)
El-Korashy et al. 2014	0.778	0.0164	5	0.472	0.0335	5	7.6%	0.31 (0.27, 0.34)
Elsaka 2016	2.47	0.2248	20	1.245	0.0815	20	7.4%	1.23 (1.12, 1.33)
He et al. 2014	2.3567	1.7845	33	0.63	0.42	11	3.1%	1.73 (1.07, 2.38)
Karoca et al. 2009	1.5567	0.0679	30	1.1497	0.5861	30	6.7%	0.41 (0.20, 0.62)
Kirmali et al. 2015	0.8357	0.0671	70	0.75	0.08	10	7.6%	0.09 (0.03, 0.14)
Kirmali et al. 2015	5.2314	2.8052	70	0.77	0.03	10	3.1%	4.46 (3.80, 5.12)
Queiroz et al. 2012	0.455	0.184	40	0.11	0.01	4	7.6%	0.35 (0.29, 0.40)
Sarmento et al. 2014	0.625	0.1922	6	0.16	0.01	3	7.1%	0.46 (0.31, 0.62)
Subaşı et al. 2012	0.544	0.3022	40	0.221	0.04	20	7.4%	0.32 (0.23, 0.42)
Subaşı et al. 2014	0.61	0.2369	93	0.22	0.04	31	7.6%	0.39 (0.34, 0.44)
Subaşı M. et al. 2014	0.77	0.11	21	0.47	0.15	21	7.5%	0.30 (0.22, 0.38)
Usumez et al. 2012	3.33	2.6709	45	0.16	0.09	15	2.5%	3.17 (2.39, 3.95)
Subtotal (95% CI)			**721**			**239**	**100.0%**	**0.77 (0.62, 0.92)**
Heterogeneity: τ^2=0.08; χ^2=693.85, *df*=16 (*P*<.001); I^2=98%								
Test for overall effect: Z=10.08 (*P*<.001)								
Total (95% CI)			**721**			**239**	**100.0%**	**0.77 (0.62, 0.92)**
Heterogeneity: τ^2=0.08; χ^2=693.85, *df*=16 (*P*<.001); I^2=98%								
Test for overall effect: Z=10.08 (*P*<.001)								
Test for subgroup differences: Not applicable								

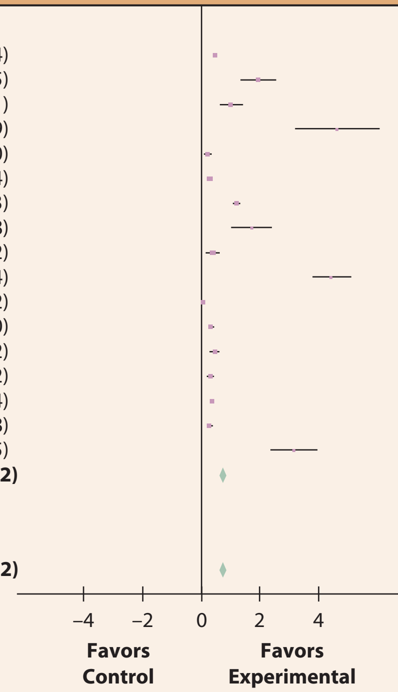


Figure 2. Forest plots analysis. A, global analysis.

included (Fig. 2C). In the first 3 strata, the meta-analysis detected a statistical difference between the groups, showing evidence that the roughness was higher in the experimental groups submitted to surface treatment ($P\leq.05$). In the last strata, the meta-analysis did not detect statistical difference (P=.06) between the control and experimental groups. High heterogeneity was observed between the studies (I^2=98%) and low heterogeneity among the subgroups (I^2=23.1%). The group that used airborne-particle abrasion in the presintered stage presented an effect size of 2.71 as the value of greater surface roughness.

In the third analysis, the subgroups were examined according to the type of laser, and 11 data sets were included (Fig. 2D). It was not possible to create a subgroup for the CO_2 laser because only 1 study met the inclusion criteria. The meta-analysis detected statistically significant difference among the groups, showing evidence that roughness was higher in the experimental groups submitted to surface treatment ($P\leq.05$). The effect size favored the Nd:YAG laser as the highest surface roughness value, 4.15, when compared with the Er:YAG laser, 0.60. Once again, high heterogeneity was observed between the studies (I^2=97% and 98%).

Sensitivity analyses were performed to identify the studies responsible for the high heterogeneity. However, none of the combinations led to a decrease in heterogeneity.

DISCUSSION

The most frequent failure in restorations using zirconia as infrastructure is veneer ceramic chipping.[12-22] Cohesive fractures of the veneering ceramic (chipping) occur more frequently in the short term.[18,19] In posterior restorations, fractographic analyses identified the fracture origins as often being on the occlusal surfaces, presumably from repetitive occlusal contact.[19]

Debonding of the prosthetic restoration has been presented as the second most frequent failure.[18,19] In oxide ceramic restorations, cementation bond strength occurs by micromechanical and chemical retention between the adhesive cement and the ceramic surface.[20] The absence of a silica component makes the zirconia resistant to hydrofluoric acid and not susceptible to silanization.[10,11,16,17] Therefore, retention of a single crown depends primarily on the geometry of the tooth preparation.[21] However, resin-bonded fixed dental prostheses and crowns on short or excessively tapered preparations are highly dependent on adhesive cementation.[20-22] The roughness of the restoration surface influences micromechanical retention by increasing the surface energy and wettability, thus allowing the cement

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random (95% CI)
1.2.1 Airborne-particle abrasion								
Abi-Rached et al. 2014	0.8167	0.2652	60	0.35	0.05	20	4.8%	0.47 (0.40, 0.54)
Arami et al. 2014	0.58	0.05	7	0.23	0.07	7	4.8%	0.35 (0.29, 0.41)
Arami S. et al. 2014	0.58	0.05	10	0.23	0.07	10	4.8%	0.35 (0.30, 0.40)
Cavalcanti et al. 2009	1.635	0.8716	12	0.545	0.2943	12	2.5%	1.09 (0.57, 1.61)
Demir et al. 2012	0.8	0.25	10	0.22	0.03	10	4.5%	0.58 (0.42, 0.74)
El-Korashy et al. 2014	0.778	0.0164	5	0.472	0.0335	5	4.8%	0.31 (0.27, 0.34)
Elsaka 2016	2.47	0.2248	20	1.245	0.0815	20	4.7%	1.23 (1.12, 1.33)
He et al. 2014	2.3567	1.7845	33	0.63	0.42	11	1.9%	1.73 (1.07, 2.38)
Karoca et al. 2009	1.5567	0.3934	30	1.1497	0.5861	30	4.0%	0.41 (0.15, 0.66)
Kirmali et al. 2015	0.9	0.08	10	0.75	0.08	10	4.8%	0.15 (0.08, 0.22)
Kirmali et al. 2015	2.18	0.92	10	0.77	0.03	10	2.2%	1.41 (0.84, 1.98)
Queiroz et al. 2012	0.455	0.184	40	0.11	0.01	4	4.8%	0.35 (0.29, 0.40)
Sarmento et al. 2014	0.625	0.1922	6	0.16	0.01	3	4.5%	0.46 (0.31, 0.62)
Subaşı et al. 2012	0.753	0.107	20	0.221	0.04	20	4.8%	0.53 (0.48, 0.58)
Subaşı et al. 2014	0.74	0.13	31	0.22	0.04	31	4.8%	0.52 (0.47, 0.57)
Subaşı M. et al. 2014	0.77	0.11	21	0.47	0.15	21	4.8%	0.30 (0.22, 0.38)
Usumez et al. 2012	0.19	0.1	15	0.16	0.09	15	4.8%	0.03 (−0.04, 0.10)
Subtotal (95% CI)			**340**			**239**	**72.2%**	**0.49 (0.39, 0.60)**
Heterogeneity: τ^2=0.04; χ^2=536.98, *df*=16 (*P*<.001); I^2=97%								
Test for overall effect: Z=9.00 (*P*<.001)								
1.2.2 Lasers								
Arami et al. 2014	2.3589	2.6193	63	0.23	0.07	7	1.9%	2.13 (1.48, 2.78)
Arami S. et al. 2014	1.615	1.119	20	0.23	0.07	10	2.6%	1.39 (0.89, 1.88)
Cavalcanti et al. 2009	6.4	5.2358	36	0.545	0.2943	12	0.4%	5.86 (4.14, 7.57)
Demir et al. 2012	0.3133	0.1183	30	0.22	0.03	10	4.8%	0.09 (0.05, 0.14)
Kirmali et al. 2015	0.825	0.0638	60	0.75	0.08	10	4.8%	0.07 (0.02, 0.13)
Kirmali et al. 2015	5.74	2.6894	60	0.77	0.03	10	1.8%	4.97 (4.29, 5.65)
Subaşı et al. 2012	0.335	0.29	20	0.221	0.04	20	4.6%	0.11 (−0.01, 0.24)
Subaşı et al. 2014	0.34	0.14	31	0.22	0.04	31	4.8%	0.12 (0.07, 0.17)
Usumez et al. 2012	4.9	1.7801	30	0.16	0.09	15	2.0%	4.74 (4.10, 5.38)
Subtotal (95% CI)			**350**			**125**	**27.8%**	**1.37 (1.08, 1.67)**
Heterogeneity: τ^2=0.14; χ^2=505.10, *df*=8 (*P*<.001); I^2=98%								
Test for overall effect: Z=9.23 (*P*<.001)								
Total (95% CI)			**690**			**364**	**100.0%**	**0.68 (0.56, 0.80)**
Heterogeneity: τ^2=0.07; χ^2=1285.30, *df*=25 (*P*<.001); I^2=98%								
Test for overall effect: Z=11.40 (*P*<.001)								
Test for subgroup differences: χ^2=30.80. *df*=1 (*P*<.001), I^2=96.8%								

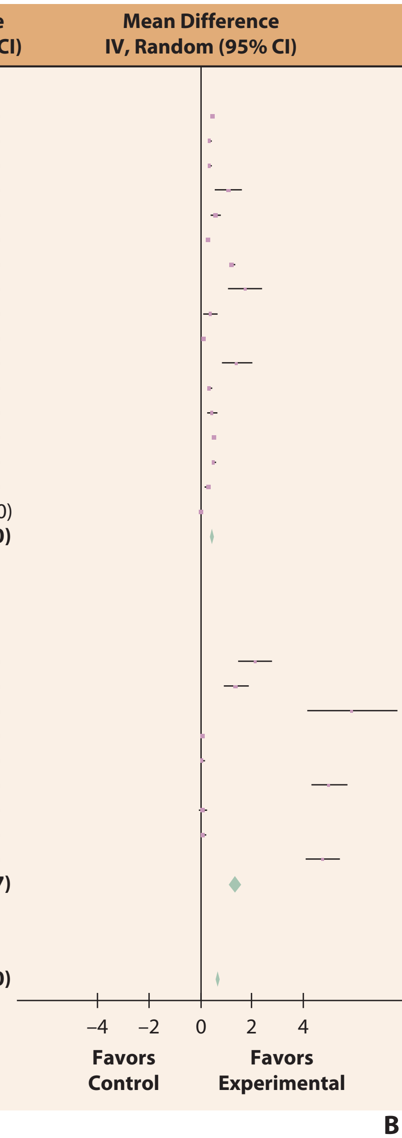


Figure 2. (*continued*). B, Airborne-particle abraded versus control and laser versus control.

or ceramic to flow into the microretentions and create a stronger interlock.[19,23]

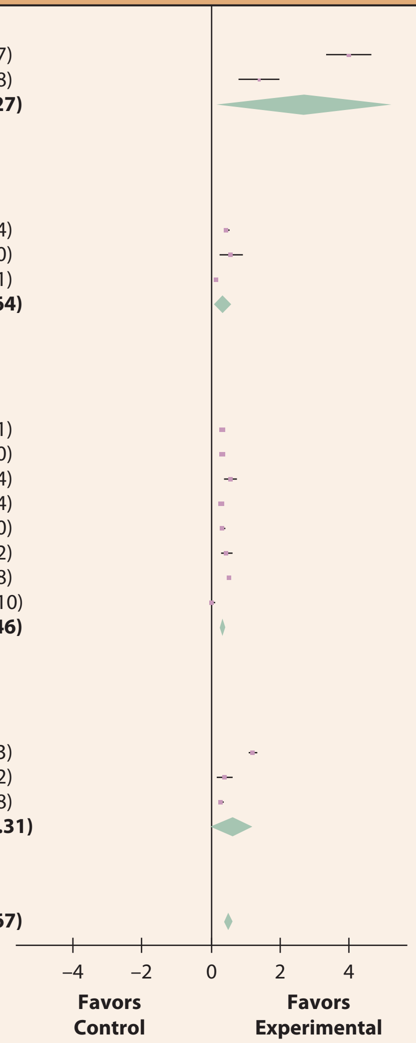
The present systematic review and meta-analysis revealed that all treatment protocols were capable of altering surface roughness. The meta-analysis showed high data heterogeneity as well as a high standard deviation, as has been previously reported, possibly due to the influence of the variables observed in the preparation of the specimens and the surface treatment methodologies on the results.[3]

The preparation of the specimens consists of cutting the zirconia and polishing with silicon carbide abrasive papers to obtain a smooth surface. Of the 17 selected studies, 13 different methodologies were used to prepare the test specimens. The use of silicon carbide abrasive papers played a key role in the results obtained in the control groups.[27,44,46,47] However, the protocols used for the polishing machine were not reported. The soft presintered specimens presented higher surface roughness and absence of grooves when compared with those polished after the sintering process.[27,47]

Techniques such as airborne-particle abrasion with aluminum oxide particles (Al_2O_3) were the most investigated surface treatment. In this systematic review, 94.7% of the airborne-particle abrasion was performed after the sintering process and only 5.3% before the sintering process.[46,47]

Airborne-particle abrasion with aluminum oxide before the sintering process was the most effective method because the presintered zirconia surface is softer and, thus, may be more affected by abrasion protocols.[46,47] Transformation of the tetragonal phase into

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random (95% CI)
1.3.1 Presintered polish and airborne-particle abrasion in presintered stage								
He et al. 2014	4.65	1.01	11	0.63	0.42	11	2.4%	4.02 (3.37, 4.67)
Kirmali et al. 2015	2.18	0.92	10	0.77	0.03	10	2.8%	1.41 (0.84, 1.98)
Subtotal (95% CI)			**21**			**21**	**5.3%**	**2.71 (0.15, 5.27)**
Heterogeneity: τ^2=3.31; χ^2=35.20, *df*=1 (*P*<.001); I^2=97%								
Test for overall effect: Z=2.08 (*P*<.04)								
1.3.2 Presintered polish and airborne-particle abrasion after sintering process								
Abi-Rached et al. 2014	0.8167	0.2652	60	0.35	0.05	20	7.1%	0.47 (0.40, 0.54)
He et al. 2014	1.21	0.4841	22	0.63	0.42	11	4.9%	0.58 (0.26, 0.90)
Kirmali et al. 2015	0.9	0.05	10	0.75	0.08	10	7.1%	0.15 (0.09, 0.21)
Subtotal (95% CI)			**92**			**41**	**19.1%**	**0.38 (0.11, 0.64)**
Heterogeneity: τ^2=0.05; χ^2=49.19, *df*=2 (*P*<.001); I^2=96%								
Test for overall effect: Z=2.74 (*P*=.006)								
1.3.3 Polish after sintered and airborne-particle abrasion after sintering process								
Arami et al. 2014	0.58	0.05	7	0.23	0.07	7	7.1%	0.35 (0.29, 0.41)
Arami S. et al. 2014	0.58	0.05	10	0.23	0.07	10	7.1%	0.35 (0.30, 0.40)
Demir et al. 2012	0.8	0.25	10	0.22	0.03	10	6.5%	0.58 (0.42, 0.74)
El-Korashy et al. 2014	0.778	0.0164	5	0.472	0.0335	5	7.2%	0.31 (0.27, 0.34)
Queiroz et al. 2012	0.455	0.184	40	0.11	0.01	4	7.1%	0.35 (0.29, 0.40)
Sarmento et al. 2014	0.625	0.1922	6	0.16	0.01	3	6.5%	0.46 (0.31, 0.62)
Subaşı et al. 2012	0.753	0.107	20	0.221	0.04	20	7.2%	0.53 (0.48, 0.58)
Usumez et al. 2012	0.19	0.1	15	0.16	0.09	15	7.1%	0.03 (−0.04, 0.10)
Subtotal (95% CI)			**113**			**74**	**55.8%**	**0.36 (0.26, 0.46)**
Heterogeneity: τ^2=0.02; χ^2=152.16, *df*=7 (*P*<.001); I^2=95%								
Test for overall effect: Z=7.08 (*P*<.001)								
1.3.4 No polish and airborne-particle abrasion after sintering process								
Elsaka 2016	2.47	0.2248	20	1.245	0.0815	20	6.9%	1.23 (1.12, 1.33)
Karoca et al. 2009	1.5567	0.0679	30	1.1497	0.5861	30	6.0%	0.41 (0.20, 0.62)
Subaşı et al. 2014	0.77	0.11	21	0.47	0.15	21	7.0%	0.30 (0.22, 1.38)
Subtotal (95% CI)			**71**			**71**	**19.9%**	**0.65 (−0.02, 1.31)**
Heterogeneity: τ^2=0.34; χ^2=194.09, *df*=2 (*P*<.001); I^2=99%								
Test for overall effect: Z=1.90 (*P*=.06)								
Total (95% CI)			**297**			**207**	**100.0%**	**0.54 (0.42, 0.67)**
Heterogeneity: τ^2=0.05; χ^2=616.34, *df*=15 (*P*<.001); I^2=98%								
Test for overall effect: Z=8.63 (*P*<.001)								
Test for subgroup differences: χ^2=3.90, *df*=3 (*P*=.27); I^2=23.1%								



C

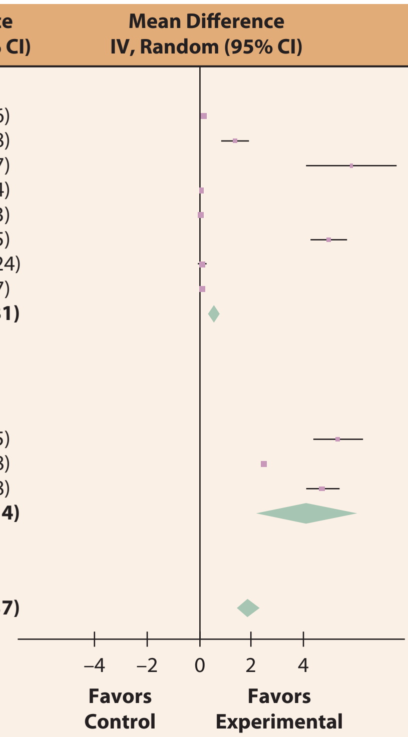
Figure 2. (*continued*). C, Silicon carbide abrasive papers during presintered phase and airborne-particle abrasion during presintered phase, silicon carbide abrasive papers during presintered phase and airborne-particle abrasion after sintering, silicon carbide abrasive papers after sintered process and airborne-particle abrasion after sintered, and no polishing and airborne-particle abrasion after sintered.

the monoclinic phase (t→m), the formation of microcracks, and the removal of the zirconia grains may also be avoided.[46,47] Other authors who performed surface treatment before the sintering process but who did not meet the inclusion criteria for this systematic review reported a rougher surface from scanning electron microscope images.[28-33]

Sintered zirconia has a high stiffness, which makes it difficult to change its surface morphology.[3] Recommendations to improve the effectiveness of airborne-particle abrasion with aluminum oxide have included increasing air pressure,[41,43,46,50] including particles of larger diameter,[27,44,46,47,50] increasing the abrasion time, or a combination of these.[44,53] However, many of these methods may result in excessive abrasion, which is believed to stress the zirconia surface and to accelerate the t→m transformation.[3] Thus, the higher energy impact can cause loss of ceramic grains or the formation of microcracks, compromise its mechanical properties, and cause premature failure.[4,26,45]

The use of the CO_2 (wavelength of 10 600 nm), Nd:YAG (wavelength of 1064 nm), Er:YAG, and Er,Cr:YSGG (wavelength of 2780 nm and 2940 nm) lasers in dental therapy expanded as a consequence of favorable in vitro and clinical studies.[34,35] Lasers have been used to clean implant surfaces, to treat peri-implantitis, to remove carious lesions, to prepare cavities, and to modify dentin to minimize marginal microleakage.[34-36]

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random (95% CI)
1.4.1 Er:YAG								
Arami et al. 2014	0.4	0.1764	21	0.23	0.07	7	10.3%	0.17 (0.08, 0.26)
Arami S. et al. 2014	1.615	1.119	20	0.23	0.07	10	9.3%	1.39 (0.89, 1.88)
Cavalcanti et al. 2009	6.4	5.2358	36	0.545	0.2943	12	4.2%	5.86 (4.14, 7.57)
Demir et al. 2012	0.3133	0.1183	30	0.22	0.03	10	10.4%	0.09 (0.05, 0.14)
Kirmali et al. 2015	0.825	0.0638	60	0.75	0.08	10	10.4%	0.07 (0.02, 0.13)
Kirmali et al. 2015	5.74	2.6894	60	0.77	0.03	10	8.4%	4.97 (4.29, 5.65)
Subaşı et al. 2012	0.335	0.29	20	0.221	0.04	20	10.3%	0.11 (−0.01, 0.24)
Subaşı et al. 2014	0.34	0.14	31	0.22	0.04	31	10.4%	0.12 (0.07, 0.17)
Subtotal (95% CI)			**278**			**110**	**73.7%**	**0.60 (0.39, 0.81)**
Heterogeneity: τ^2=0.07; χ^2=268.34, *df*=7 (*P*<.001); I^2=97%								
Test for overall effect: Z=5.62 (*P*<.001)								
1.4.2 Nd:YAG								
Arami et al. 2014	5.57	2.1236	21	0.23	0.07	7	7.3%	5.34 (4.43, 6.25)
Arami S. et al. 2014	2.7	0.16	10	0.23	0.07	10	10.3%	2.47 (2.36, 2.58)
Usumez et al. 2012	4.9	1.7801	30	0.16	0.09	15	8.6%	4.74 (4.10, 5.38)
Subtotal (95% CI)			**61**			**32**	**26.3%**	**4.15 (2.16, 6.14)**
Heterogeneity: τ^2=2.98; χ^2=83.25, *df*=2 (*P*<.001); I^2=98%								
Test for overall effect: Z=4.09 (*P*<.001)								
Total (95% CI)			**339**			**142**	**100.0%**	**1.91 (1.45, 2.37)**
Heterogeneity: τ^2=0.52; χ^2=2290.45, *df*=10 (*P*<.001); I^2=100%								
Test for overall effect: Z=8.21 (*P*<.001)								
Test for subgroup differences: χ^2=12.12, *df*=1 (*P*<.001); I^2=91.7%								



D

Figure 2. (*continued*). D, Analyses of Er:YAG and Nd:YAG lasers. Nd, neodymium-doped; YAG, yttrium aluminum garnet.

Studies of the Nd:YAG laser have indicated that treatment with a power of 1.5 W creates surface microcracks.[26,49] With increasing irradiation intensity, microcracks forming substantial flaws and loss of ceramic material became evident.[26] Arami et al[26] reported that 2- and 2.5-W irradiation caused areas of surface melting, cracks, and a carbonized layer with silver pigments. Usumez et al[52] confirmed that the treatment with the Nd:YAG laser led to the transformation of the tetragonal phase into the monoclinic phase.

Arami et al[26] also reported that the high temperature of the CO_2 laser facilitates melting of the zirconia surface and creates surface microcracks. The laser works by transforming the energy irradiated into heat.[37-40] Light absorption is influenced by pigmentation, amount of water, and surface roughness.[37,38,48] Studies indicate that the cited defects are formed on the zirconia surface during a local temperature change.[40] The melting and solidification process generates a volume change in the material, creating internal stress and cracking.[39,40] Other authors who used the CO_2 laser but did not meet the inclusion criteria for this systematic review observed the formation of surface microcracks from scanning electron microscope images.[26,54-56]

The Er:YAG and Er,Cr:YSGG lasers can remove surface particles by microexplosions (ablation) and vaporization.[24,27,40] Fusion of the ceramic material, formation of microcracks, and color change have been reported in some situations.[25,27,48,49] Subaşı and İnan[25] stated that the microexplosions create debris that can adhere to the melted ceramic surface, bind to the resin cement, and compromise the bond strength.

Cavalcanti et al[51] reported that the use of erbium laser with lower energy intensity may be a viable method for surface treatment of zirconia. Arami et al[26] reported that surfaces treated by the Er:YAG laser, at its lowest power, showed a surface roughness similar to abrasion with aluminum oxide.

One common aspect among the studies is the absence of a methodology for the laser application. In all 17 studies, the laser equipment produced beams with diameters of 0.3 mm to 1.3 mm and was applied manually. This application model can result in untreated areas or over irradiated areas.

CONCLUSIONS

Based on the results of this systematic review, the following conclusions were drawn:

1. Airborne-particle abrasion with aluminum oxide on presintered zirconia is currently the most efficient methodology.
2. Sintered zirconia is a high stiffness material, which makes it difficult to change its surface morphology.

3. Irradiation with the Er:YAG, Nd:YAG, and CO_2 lasers was destructive due to the formation of a melted surface, large cracks, and a carbonized layer with silver pigments.
4. An erbium laser used with lower energy intensity was the only nondetrimental laser methodology for the zirconia surface, providing roughness similar to that of airborne-particle abrasion with aluminum oxide.

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Noteworthy Abstracts of the Current Literature

A 30-year follow-up of a patient with mandibular complete-arch fixed implant-supported prosthesis on 4 implants: A clinical report

Balshi TJ, Wolfinger GJ, Balshi SF, Bidra AS

J Prosthodont 2019 Feb;28:97-102

Mandibular complete-arch fixed implant-supported prostheses are recognized as one of the earliest and most popular prostheses in implant dentistry. This prosthesis was the main focus in the early era of osseointegration. Despite its widespread popularity, few clinical reports have described long-term follow-up greater than 10 years for this type of prosthesis. This report describes a 30-year follow-up of a patient who underwent treatment for a mandibular complete-arch fixed implant-supported prosthesis with 4 machined surfaced implants, opposing a maxillary complete denture. This report documents a variety of photographs and radiographs taken over a period of 30 years to compare bone levels at various stages of care and maintenance, including de novo bone formation underneath the distal cantilevers due to functional loading. The biologic and biomechanical response to this treatment protocol and long-term clinical observations and prosthodontic outcome and maintenance needs are also addressed.

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Supplementary Table 1. Studies included

No.	Author and Year	YTZP Brand	YTZP Grain Size	Comparison Groups	Profilometer Equipment
1	Abi-Rached et al[44] 2014	Lava Frames; 3M ESPE	0.537 µm	50 µm Al_2O_3, 15 s, 0.28 MPa, 10 mm	Surftest SJ-400; Mitutoyo Corp
				120 µm Al_2O_3, 15 s, 0.28 MPa, 10 mm	
				250 µm Al_2O_3, 15 s, 0.28 MPa, 10 mm	
2	Subaşı et al[43] 2012	VITA In-Ceram; 2000 YZ for inLab	0.6 µm	110 µm Al_2O_3, 15 s, 0.3 MPa, 10 mm	Mitutoyo Surftest 402 Series 178
				Er:YAG, 15 s, 400 mJ, 10 Hz, 4 W	
3	Sarmento et al[45] 2014	Lava; 3M ESPE	0.537 µm	110 µm Al_2O_3, 20 s, 0.25 MPa, 10 mm	Wyko NT 1100 Optical Profiling System; Veeco
				110 µm Al_2O_3, 20 s, 0.35 MPa, 10 mm	
4	Subaşı MG et al[25] 2014	VITA In-Ceram; YZ for inLab	0.6 µm	110 µm Al_2O_3, 15 s, 0.3 MPa, 10 mm	Mitutoyo Surftest 402
				Er:YAG, 15 s, 400 mJ, 10 Hz, 4 W	
5	He et al[46] 2014	Nissin-Metec	N/A	110 mesh Al_2O_3, 10 s, 0.2 MPa, 10 mm	JB-4C; Taiming Optical Instrument
				100 mesh Al_2O_3, 10 s, 0.4 MPa, 10 mm	
6	Arami et al[26] 2014	ICE Zirkon; Zirkonzahn GmbH	N/A	50 µm Al_2O_3, 10 s, 0.28 MPa, 10 mm	T-8000 Hommel Werke; Jenoptik
				Er:YAG, 10 s, 4.39 J/cm^2, 10 Hz, 1.5 W, 4 mm	
				Er:YAG, 10 s, 5.85 J/cm^2, 10 Hz, 2 W, 4 mm	
				Er:YAG, 10 s, 7.32 J/cm^2, 10 Hz, 2.5 W, 4 mm	
				Nd:YAG, 60 s, 111.96 J/cm^2, 10 Hz, 1.5 W, 1 mm	
				Nd:YAG, 60 s, 149.28 J/cm^2, 10 Hz, 2 W, 1 mm	
				Nd:YAG, 60 s, 186.6 J/cm^2, 10 Hz, 2.5 W, 1 mm	
				CO_2, 60 s, 2.29 J/cm^2, 10 Hz, 3 W, 1 mm	
				CO_2, 60 s, 3.05 J/cm^2, 10 Hz, 4 W, 1 mm	
				CO_2, 60 s, 3.82 J/cm^2, 10 Hz, 3 W, 1 mm	
7	Kirmali et al[47] 2015	Noritake Co	0.78 µm	120 µm Al_2O_3, 15 s, 0.2 MPa, 10 mm	Mitutoyo Surftest SJ-301
				Er:YAG, 20 s, 10 Hz, 1 W, 10 mm	
				Er:YAG, 20 s, 10 Hz, 2 W, 10 mm	
				Er:YAG, 20 s, 10 Hz, 3 W, 10 mm	
				Er:YAG, 20 s, 10 Hz, 4 W, 10 mm	
				Er:YAG, 20 s, 10 Hz, 5 W, 10 mm	
				Er:YAG, 20 s, 10 Hz, 6 W, 10 mm	
8	Karakoca and Yilmaz[41] 2009	Cercon; Degudent GmbH, DentaCAD; Hint-Els GmbH, Zirkonzahn; Zirkonzahn GmbH	0.25-1.4 µm; N/A	110 µm Al_2O_3, 15 s, 0.4 MPa, 30 mm	Surtronic 10; Taylor Hobson
9	El-Korashy and El-Refai[42] 2014	inCoris ZI; Dentsply Sirona	0.4 µm	110 µm Al_2O_3, 10 s, 0.2067 MPa, 30 mm	TR220; Time Group
10	Subaşı and Inan[58] 2014	VITA In-Ceram; YZ for inLab	0.6 µm	110 µm Al_2O_3, 10 s, 0.3 MPa, 10 mm	Mitutoyo Surftest 402
11	Demir et al[48] 2012	VITA In-Ceram; YZ for inLab	0.6 µm	110 µm Al_2O_3, 50 s, 0.3 MPa, 10 mm	Mitutoyo Surftest 402
				Er:YAG, 15 s, 10 Hz, 200 mJ, 15.08 J/cm^2, 10 mm	
				Er:YAG, 15 s, 10 Hz, 300 mJ, 22.61 J/cm^2, 10 mm	
				Er:YAG, 15 s, 10 Hz, 400 mJ, 30.15 J/cm^2, 10 mm	
12	Arami et al[49] 2014	ICE Zirkon; Zirkonzahn GmbH	N/A	50 µm Al_2O_3, 10 s, 0.28 MPa, 10 mm	T-8000 Hommel Werke; Jenoptik
				Er:YAG, 10 s, 10 Hz, 2 W, 5.85 J/cm^2, 4 mm	
				Nd:YAG, 60 s, 10 Hz, 1.5 W, 230 µs, 4 mm	
13	Kirmali et al[27] 2015	Noritake Co	0.78 µm	120 µm Al_2O_3, 15 s, 0.2 MPa, 10 mm	Mitutoyo Surftest SJ-301
				Er, Cr:YSGG, 20 s, 20 Hz, 1 W, 10 mm	
				Er, Cr:YSGG, 20 s, 20 Hz, 2 W, 10 mm	
				Er, Cr:YSGG, 20 s, 20 Hz, 3 W, 10 mm	
				Er, Cr:YSGG, 20 s, 20 Hz, 4 W, 10 mm	
				Er, Cr:YSGG, 20 s, 20 Hz, 5 W, 10 mm	
				Er, Cr:YSGG, 20 s, 20 Hz, 6 W, 10 mm	

(*continued on next page*)

Supplementary Table 1. (*Continued*) Studies included

No.	Author and Year	YTZP Brand	YTZP Grain Size	Comparison Groups	Profilometer Equipment
14	Queiroz et al[50] 2012	Cercon Zirconia; Dentsply Sirona	0.25-1.4 µm	45 µm Al_2O_3, 2 s, 0.15 MPa, 10 mm	NT 1100; Veeco
				45 µm Al_2O_3, 2 s, 0.25 MPa, 10 mm	
				45 µm Al_2O_3, 2 s, 0.45 MPa, 10 mm	
				145 µm Al_2O_3, 2 s, 0.25 MPa, 10 mm	
				145 µm Al_2O_3, 2 s, 0.45 MPa, 10 mm	
				45 µm Al2O3, 4 s, 0.15 MPa, 10 mm	
				45 µm Al_2O_3, 4 s, 0.25 MPa, 10 mm	
				45 µm Al_2O_3, 4 s, 0.45 MPa, 10 mm	
				145 µm Al_2O_3, 4 s, 0.25 MPa, 10 mm	
				145 µm Al_2O_3, 4 s, 0.45 MPa, 10 mm	
15	Cavalcanti et al[51] 2009	Cercon Smart Ceramics; Degudent, Procera Zirconia; Nobel Biocare	0.25-1.4 µm; 0.3-1.6 µm	53 µm Al_2O_3, 15 s, 0.15 MPa, 10 mm	Tandem scanning confocal microscope; Noran Instruments
				Er:YAG, 5 s, 10 Hz, 200 mJ	
				Er:YAG, 5 s, 10 Hz, 400 mJ	
				Er:YAG, 5 s, 10 Hz, 600 mJ	
16	Usumez et al[52] 2013	ICE Zirkon Translucent; Zirkonzahn	N/A	110 µm Al_2O_3, 15 s, 0.28 MPa, 10 mm	Perthometer; Mahr
				Nd:YAG, 60 s, 10 Hz, 200 mJ, 180 µs	
				Nd:YAG, 60 s, 10 Hz, 200 mJ, 320 µs	
17	Elsaka[53] 2016	Zenostar T PSZ ZT; Wieland Dental, Prettau Anterior FSZ PA; Zirkonzahn	–	50 µm Al_2O_3, 20 s, 0.2 MPa, 15 mm	Surftest SJ-201P; Mitutoyo

Nd, neodymium-doped; YAG, yttrium aluminum garnet; YTZP, yttria-stabilized tetragonal zirconia polycrystal.