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The Effect of Mechanical and Chemical Surface Preparation Methods on the Bond Strength in Repairing the Surface of Metal-Ceramic Crowns with Composite Resin: a Systematic Review and Meta-Analysis

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ABSTRACT

The aim of this study was to find the most effective surface preparation methods to enhance the bond strength between the composite resin and surface remaining from ceramic fracture. In this systematic review and meta-analysis, 39 studies were examined. The information related to the studies was extracted and categorized based on the type of the substrate material and applying or not applying thermal cycles ($p<0.05$). In the meta-analysis of substrate metal-ceramic samples without aging, application of air abrasion resulted in a significant increase of the bond strength to composite resin when using chemical compounds of the group without the mentioned functional monomers. Application of mechanical and chemical surface preparation methods can result in enhanced bond strength of the composite to the substrate material, which depends on the type of substrate material.

Keywords: dental alloy, metal-ceramic restoration, bond strength, composite resin.

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INTRODUCTION

Ceramic-metal restorations are common in dentistry because of their aesthetics and desirable mechanical properties (1-3). In spite of their suitable durability and clinical function, the ceramic of crowns have the potential for fracture, with a reported rate of 2.3-8% (4-6). Although the fracture of ceramic does not necessarily mean failure of restoration, it is challenging for both the patient and dentist in terms of beauty and function. In addition, the lines of cracks and fractures are a suitable site for aggregation of microorganisms, formation of dental plaques, and discoloration of the restoration (7).

Ceramic-metal restorations are made of a casted metal substrate on which the ceramic is cured. In these systems, there are several requirements for both the alloy and ceramic, including a higher melting range of the alloy compared to the ceramic curing temperature, desirable rigidity and strength of metal substrate, proper bond of ceramic to metal surface oxides, and compatibility of the thermal expansion coefficient between metal and ceramic (8). Blum et al categorized ceramic fracture in ceramic-metal crowns into simple and complex types (9). Simple cracks occur only in the ceramic and are a result of its structural defects, impact, and parafunctional habits (3, 7, 9). Complex cracks result in appearance of the substrate metal, which is a result of metal-ceramic interface defects, improper design, lack of adequate support of the ceramic by the metal, metal fatigue, or mismatch of linear thermal expansion coefficient between the metal and ceramic (9). Generally, it can be stated that fracture factors in these crowns are related to the technician, dentist, patient, environment, restoration design, and intrinsic defects of the ceramic (10). An ideal treatment in case of ceramic fracture is replacement of the crown; however, intraoral repair is sometimes a less expensive and time-consuming option (11).

Various methods have been proposed for repairing ceramic-metal crowns. In the direct method, composite resins are used, while indirect methods are performed through dentistry laboratories (12-15). Among the advantages of direct method are less cost and time as well as easier usage. Disadvantages include less abrasive and aesthetic properties compared to ceramics (16-18). Meanwhile, the downsides of the indirect method include requiring various clinical and laboratory stages (4).

The clinical success of ceramic repair and direct method is dependent on the bond between the fractured surface and composite resin (7, 19). To develop the maximum bond between these two surfaces, various methods of providing mechanical and chemical fixation can be used. Mechanical methods such as air abrasion with aluminum oxide particles result in clearing superficial contaminations, increasing the wettability potential of the surface by resins, enhancing the surface roughness, and strengthening the bond between the composite and surface (7, 20, 21). Etching the surface with acids such as hydrofluoric acid causes dissolution of glass matrix of ceramics and development of a porous surface for better bond of the composite resin in them (7, 22). Nevertheless, acid etching of the surface of alloys, based on different studies, cannot develop a sufficiently fixed surface alone for bond of the composite resin (23-25). Diamond burs can cause increased abrasion of the alloy surface and development of fixed points for increasing the surface roughness (26, 27) and use of laser either alone or in combination with other methods (28, 30). In air abrasion by aluminum oxide particles coated with silica, pressure is exerted to the surface. In this method, in addition to surface roughness, the remaining silica on that metal surface results in improved silane function in the composite resin bonding (31, 32). Tin plating noble Silane is able to establish a chemical bond between organic and inorganic components, and its usage in combination with other methods such as Cojet method causes augmented strength of the bond of composite resin especially to the ceramic surface (7, 32, 33). Tin plating noble metals allow an enhanced mechanical fixation and development of an oxide layer for facilitating establishment of chemical bonds (34). The functional monomers present in connector systems affecting bond of composite resins to metals (35-38), include: 1) 4-MET molecule (powder form without water: 4-meta) containing two carboxylic groups attached to aromatic group, causing development of acidic properties and improved wettability and better bond to metals such as amalgam and gold (39, 40); 2) 10-MDP monomer essentially considered an etching molecule due to its dihydrogen phos-

phate group and ability of forming ionic bonds (41, 42); 3) other monomers containing a phosphate group; 4) monomers containing sulfur groups such as thiophenol, thiouracil, and disulfide absorbed by noble metals whereby chemical reactions occur (43, 44).

For better bond of composite resins to metal alloys used in ceramic-metal crowns, various mechanical and chemical surface preparation methods are used. Therefore, different compounds of various connector systems, composite resins, and methods for preparing surfaces have been proposed for repairing the surface of the fractured ceramics using composite resins.

Due to the absence of a specific protocol for repairing metal-ceramic crowns as well as the diversity of the proposed materials and systems, we intended to evaluate the benefit of surface preparation methods used in the method of direct repairing the surface of ceramic-metal restorations using a systematic investigation by examining the strength of bond between the composite and the prepared fractured surface. This allows for increasing the time of clinical servicing of restoration inside the patient's mouth through a conservative method, while saving time and costs. ❑

MATERIALS AND METHODS

Selection of studies and search strategy

In order to find the papers required for performing this systematic review and meta-analysis study, using keywords chosen based on PICO model, experimental studies until December 2017 were searched from databases including EBSCO and PubMed along with English and Persian papers from the databases of magiran, irandoc, and SID (Table 1). The keywords were searched using OR in each part, after which the results were combined by AND, whereby the final results were extracted (Table 2). Once the papers obtained, similar papers were removed and the remaining ones were investigated based on inclusion and exclusion criteria by two researcher of this study. These two individuals started examining the title and abstract as well as text of papers separately. Once the papers were chosen based on the title and abstract, they were studied in detail, whereby the final usable studies to be incorporated into research were identified. After searching in databases, manual

TABLE 1. Selected keywords based on PICO pattern

	Keywords
P	Metal ceramic alloys (MeSH), dental porcelain (MeSH), ceramics (MeSH), metal, fixed dental prosthesis, porcelain fused to metal
I	Dental restoration repair (MeSH), composite resins (MeSH), surface treatment, surface condition
C	–
O	Shear strength (MeSH), tensile strength (MeSH), bond strength

TABLE 2. Search strategy used in PubMed (MEDLINE) and EBSCO

	Search terms
No. 11	Search No.4 AND No.7 AND No.10
No. 10	Search No.8 OR No.9
No. 9	Search (Strength, Tensile) OR (Strengths, Tensile) OR (Tensile Strengths)
No. 8	Search (Strength, shear)
No. 7	Search No.5 OR No.6
No. 6	Search (Dental Restoration Repairs) OR (Repair, Dental Restoration) OR (Repairs, Dental Restoration) OR (Restoration Repair, Dental) OR (Restoration Repairs, Dental)
No. 5	Search (Resins, Composite)
No. 4	Search No.1 OR No.2 OR No.3
No. 3	Search ceramics
No. 2	Search (Porcelain) OR (Porcelains) OR (Porcelain, Dental) OR (Dental Porcelains) OR (Porcelains, Dental)
No. 1	Search (alloys, metal ceramic) OR (porcelain-metal alloys) OR (alloys, porcelain metal) OR (porcelain metal alloys) OR (metalloceramic alloys) OR (alloys, metalloceramic) OR (metallo-ceramic alloys) OR (alloys,metallo-ceramic) OR (metallo ceramic alloys) OR (metalloceramic alloy) OR (alloy, metalloceramic) OR (metal ceramic alloy) OR (alloy, metal ceramic) OR (metallo ceramic alloy) OR (metal ceramic restorations) OR (restorations, metal ceramic)

search process was performed by examining the list of references of studies as well as the referenced textbooks of restorative dentistry by choosing proper papers and extracting their data. Further, relevant theses and gray references in ProQuest have been also investigated.

Eligibility criteria

Inclusion criteria: Experimental studies, bond of composite resins to the metal surface of the sample should have been investigated, the effect of mechanical and chemical preparation methods for remaining surfaces of the crown before using the composite resins should have been examined, the test for measuring the experimental bond strength should have been of shear or tensile type.

Exclusion criteria: Non-experimental studies such as clinical studies and review studies, in which the use of composite resins was not the same as the conditions of their clinical usage in direct method for repairing the metal-ceramic crowns, for examples include studies in which bond of braces has been investigated.

Data collection

In order to enter data obtained from the selected papers, Microsoft Office Excel 2010 (Microsoft, Redmond Corporation, WA, USA) was used. Data included title of the study, authors' name, year of publication, name of substrate material and number of samples, the mechanical and chemical preparation performed on the substrate, the utilized bonding and composite resin, the conditions and time of maintaining the samples before doing the bond strength test, the manner of applying thermal cycle to the samples if it was performed, the type of bond strength test, the rate of force exertion (min/mm), the mean reported bond strength number (MPa), and standard deviation.

Mechanical etchings (ME) of surfaces were introduced into the data collection software with the following abbreviations: B: roughening with bur, E: acid etching (E1: etching with phosphoric acid, E2: etching with hydrofluoric acid), SB: air abrasion with aluminum oxide particles, L: laser, no treatment (polishing but not performing mechanical etching).

Chemical preparation (CHE) was performed in primer/connector systems based on the type of the effective operating molecule: P (systems containing phosphate monomers such as the systems including MDP, PENTA, and acrylate/phosphate metacrylate), MET (systems containing 4-META and 4-MET), Q (compounds containing sulfur group such as thio-octanes and typical compounds), and R (systems lacking the above-mentioned functional groups). Further, usage of silane, tin plating, and Cojet was represented by Si, T, and C, respectively.

In case of maintaining the samples for three months or more in water or applying more than 1000 thermal cycles, they were placed in the aged group; otherwise, the samples were categorized in the non-aged group. Analysis of the statistical results was performed by free comprehensive software for meta-analysis. $P<0.05$ was considered significant. ❑

RESULTS

Study selection

Generally, in searching the keywords in the databases in Table 1, 312 studies were obtained from EBSCO database and 1 834 from PubMed. By removing 1 126 repeated papers using EndNote X7 (Thompson Reuters Philadelphia, PA, USA), 1 120 papers remained for the preliminary study. By searching Persian and English keywords in databases including Magiran, Irandoc, and SID, 136 studies were obtained, where 20 were repeated, and hence, 116 studies remained. In searching the database at this stage, studies were first separated by title and then abstract. The full text of the remaining 114 studies from EBSCO and PubMed databases and 10 remaining studies from the three Iranian databases were examined for final selection. Eventually, 31 studies eligible for inclusion criteria and devoid of exclusion criteria were identified. After selecting the relevant papers, the manual search process was performed by investigating the list of references. Then, after removing repeated references and investigating the title, abstract, and full text, seven other studies were added to the final results. In searching for the gray references, 30 studies were obtained, and after investigating the title and abstract, six studies remained for full text investigation.

TABLE 3. Demographic data of included studies in non-aged base metal group

First author / Year	Mechanical/ chemical surface treatment*	Number of samples	Storage conditions	Bond strength test	Mean bond strength (MPa)	Standard deviation
Bertolotti / 1989	ME-SB+CHE-P (ME-SB+CHE-E)+ CHE-P	10 10	25°C water/1 day	Shear	7.73 4.51	1.56 1.21
Chang /1993	ME-SB+CHE-P ME-SB+CHE-R ME-SB+CHE-MET	10 10 5	23°C water/1 day	Tensile	17.43 13 14.2	4.46 2.26 2.4
White /1994	ME-no treatment+ CHE-R ME-SB+CHE-R	5 30	37°C water/1 day	Shear	3.9 23.7	0.5 3.59
Czrew /1995	ME-SB+CHE-P ME-SB+CHE-MET ME-SB+CHE-R	20 20 10	37°C water/ 5 days + 500 cycles 6-60℃	Shear	13.25 14.55 14.3	1.06 6.01 3.4
Chung /1997	ME-no treatment+ CHE-R ME-no treatment+ CHE-P ME-no treatment+ CHE-MET ME-SB+CHE-R ME-SB+CHE-P ME-SB+CHE-MET	30 20 10 30 20 10	37°C water /1 day	Shear	1.76 4.55 15.9 6.83 10.58 17	0.86 3.04 2.3 1.25 0.91 1.7
Proano /1998	ME-no treatment+ (CHE-C+CHE-Si) ME-SB+CHE-Si	14 7	30°C water/30 days	Shear	12.45 8.1	0.49 1.2
Tulunoglu /2000	ME-SB+CHE-MET ME-SB CHE-P ME-SB+CHE-R	8 8 16	37°C water/1 day + 500 cycles 5-50°C	Shear	34.55 20.57 9.32	5.74 2.33 0.86
Yesil /2007	ME-SB+CHE-P ME-B+CHE-P	7 7	37°C water/7 days + 300 cycles 5-55℃	Shear	11.9 9.35	2.09 2.89
Nima /2016	ME-SB+CHE-R ME-SB+ (CHE-P+CHE-Q) ME-SB+CHE-P ME-SB+CHE-MET ME-SB+ (CHE-P+CHE-MET)	5 15 15 5 5	37°C water /1 day	Shear	11.4 24.9 21.03 12.6 12.3	1.5 6.53 4.92 1.3 1.7
Nima /2017	ME-SB+CHE-R ME-SB+(CHE-P+CHE-Q) ME-SB CHE-MET ME-SB+(CHE-MET+CHE-P) ME-SB+CHE-P	6 9 3 3 6	37°C water/1 day	Shear	16.7 24.16 12.6 12.3 20.55	7.49 5.21 1.3 1.7 6.85
Khoroushi /2008	ME-E CHE-MET ME-SB+CHE-MET (ME-SB+ME-E)+ CHE-ME	10 10 10	37°C water /until doing the test	Shear	1.84 4.77 17.97	0.49 0.77 3.5
Tjan /1987	ME-no treatment+ CHE-R ME-no treatment+ CHE-P	10 20	Half: 30% moisture /23°C/ 7 days Half: 100% moisture /37°C/7 days	Shear	2.66 3.69	0.05 1.45
Capa /2009	ME-SB+CHE-P ME-SB+CHE-G	30 30	37°C water /1 day	Shear	7.19 6.09	0.89 0.97

Eventually, one study was chosen. Across all mentioned stages, disagreements between the two researchers for choosing studies were resolved through discussion and opinion exchange.

The preparation methods used in the studies were categorized based on their abbreviated name and classified into four groups based on the type of substrate material as well as the conditions of maintaining the samples: base metal alloys which had undergone aging, base metal alloys on which aging had not been applied, ceramic-base metal alloys which had undergone aging, ceramic-base metal alloys on which aging had not been performed.

Descriptive and analytical statistics related to the group of base metal alloy without aging

Out of the 39 studies obtained, the data extracted from 13 studies were placed in the base metal alloy group which had not undergone aging (23, 32, 45-55). The mean and standard deviation of the strength of composite bond to the samples present in each study which had the same mechanical and chemical preparation methods were calculated and assumed as one single group (Table 3). The major surface preparation method used in the studies of this group was usage of air abrasion with aluminum oxide particles and compounds based on phosphate monomers, utilized in nine studies (23, 45, 47, 49-53, 55), indicating bond strength range of 7.73-20.57 MPa. The other highly utilized methods included use of air abrasion and chemical compounds of group R in eight studies with the bond strength of 1.76-3.9 MPa, as well as concurrent use of air abrasion mechanical methods and the compounds containing MET-4 group in seven studies with the bond strength of 4.77-34.55 MPa (23, 45, 46, 49, 50, 52, 53).

The maximum extent of bond strength among the 13 studies in the base metal group without applying aging, given the difference in the conditions of studies, had been achieved by applying the air abrasion method with aluminum oxide particles and use of the compounds of MET group (34.55 MPa) (50). On the other hand, the minimum strength had been obtained by applying hydrofluoric acid etcher and use of compounds of MET group (1.84 MPa) (46).

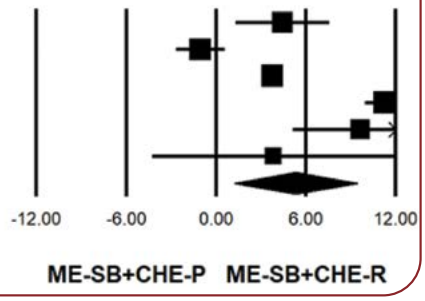
As at least two surface preparation methods had been repeated in eight studies (25, 52, 56-61), performing meta-analysis is feasible. A total of 11 dual combinations were obtained from the repeated preparation methods.

The comparisons performed between the repeated dual combinations in the studies are as follows:

1. Comparing the two preparation methods of ME-SB+CHE-R and ME-SE+CHE-P (Figure 1-A), the mean bond strength of the composite resin using the air abrasion and phosphate monomers was 5.31±2.08 MPa higher than that of the other method, where this difference was significant ($P<0.05$).
2. Comparing the two preparation methods of ME-SB+CHE-P and ME-SB+CHE-MET (Figure 1-B), application of air abrasion method and phosphate monomers developed 2.7±0.7 less bond strength compared to the other method, but this difference was not significant ($P>0.05$).
3. Comparing the two preparation methods of ME-SB+CHE-P and ME-SB+(CHE-P+CHE-Q) (Figure 1-C), the air abrasion method and use of phosphate and sulfur monomers developed 0.6±0.21 MPa greater bond strength, but this difference was not significant ($P>0.05$).
4. Comparing the two preparation methods ME-SB+CHE-P and ME-SB+(CHE-P+CHE-MET) (Figure 1-D), the air abrasion method and phosphate monomers developed 8.61 MPa greater bond strength on average, and the difference was significant ($P<0.05$).
5. Comparing the two preparation methods of ME-SB+CHE-MET and ME-SB+CHE-R (Figure 1-E), concurrent use of air abrasion mechanical methods and the compounds containing 4-META monomers developed 6.03±3.4 MPa greater bond strength, where the difference was significant ($p<0.05$).
6. Comparing the two preparation methods of ME-no treatment + CHE-R and ME-SB+CHE-R (Figure 1-F), usage of air abrasion method and the compounds containing R monomers developed greater bond strength by 12.3 MPa on average, but this difference was not significant ($P>0.05$).
7. Comparing the two preparation methods of ME-SB+CHE-R and ME-SB +(CHE-P+CHE-Q) (Figure 1-G), the combination of air abrasion method as well as phosphate and sulfur monomers compared to the

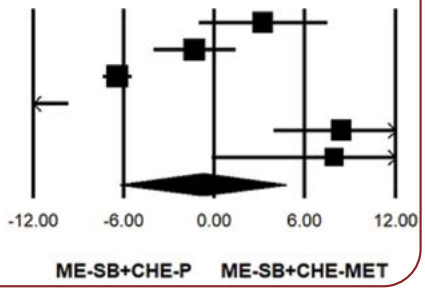
A.

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Chang(1993)	4.430	1.581	2.500	1.331	7.529	2.802	0.005
Czrew(1995)	-1.050	0.820	0.672	-2.656	0.556	-1.281	0.200
Chung(1997)	3.750	0.326	0.106	3.112	4.388	11.519	0.000
Tulunoglu(2000)	11.250	0.647	0.418	9.982	12.518	17.392	0.000
Nima(2016)	9.630	2.270	5.154	5.180	14.080	4.242	0.000
Nima(2017)	3.850	4.144	17.170	-4.272	11.972	0.929	0.353
	5.310	2.088	4.358	1.218	9.402	2.544	0.011



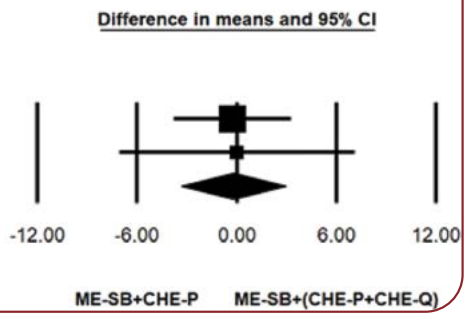
B.

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Chang(1993)	3.230	2.159	4.663	-1.002	7.462	1.496	0.135
Czrew(1995)	-1.300	1.365	1.862	-3.975	1.375	-0.953	0.341
Chung(1997)	-6.420	0.473	0.224	-7.347	-5.493	-13.576	0.000
Tulunoglu(2000)	-13.980	2.190	4.797	-18.273	-9.687	-6.383	0.000
Nima(2016)	8.430	2.263	5.121	3.995	12.865	3.725	0.000
Nima(2017)	7.950	4.123	16.999	-0.131	16.031	1.928	0.054
	-0.767	2.795	7.813	-6.245	4.712	-0.274	0.784



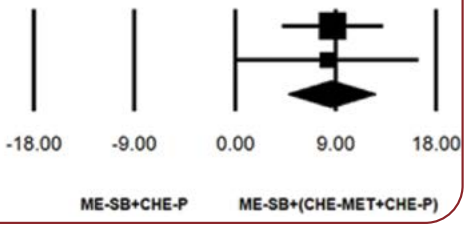
C.

	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Nima(2016)	-0.270	1.797	3.228	-3.791	3.251	-0.150	0.881
Nima(2017)	0.000	3.610	13.034	-7.076	7.076	0.000	1.000
	-0.216	1.608	2.587	-3.369	2.936	-0.135	0.893



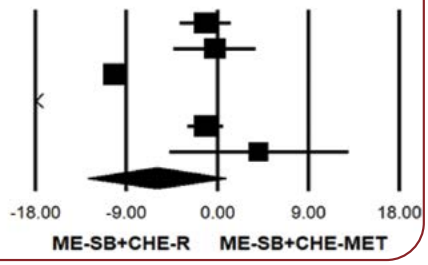
D.

	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Nima(2016)	8.730	2.279	5.192	4.264	13.196	3.831	0.000
Nima(2017)	8.250	4.144	17.171	0.128	16.372	1.991	0.046
	8.619	1.997	3.986	4.705	12.532	4.317	0.000



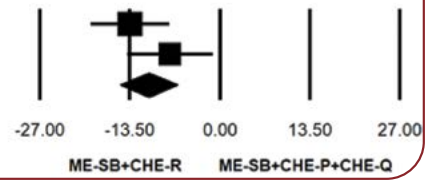
E.

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Chang(1993)	-1.200	1.262	1.593	-3.673	1.273	-0.951	0.342
Czrew(1995)	-0.250	2.058	4.234	-4.283	3.783	-0.121	0.903
Chung(1997)	-10.170	0.500	0.250	-11.150	-9.190	-20.330	0.000
Tulunoglu(2000)	-25.230	1.435	2.060	-28.043	-22.417	-17.578	0.000
Nima(2016)	-1.200	0.888	0.788	-2.940	0.540	-1.352	0.176
Nima(2017)	4.100	4.503	20.277	-4.726	12.926	0.911	0.363
	-6.034	3.470	12.041	-12.835	0.767	-1.739	0.082



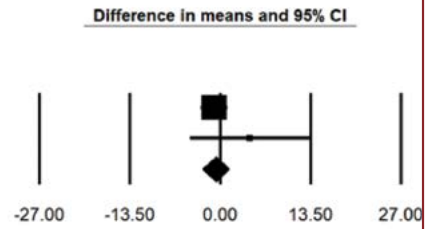
F.

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Nima et al (2016)	-13.500	2.996	8.977	-19.372	-7.628	-4.506	0.000
Nima et al (2017)	-7.460	3.261	10.634	-13.851	-1.069	-2.288	0.022
	-10.735	2.206	4.868	-15.059	-6.411	-4.866	0.000



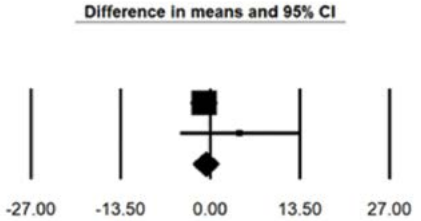
G.

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Nima et al (2016)	-0.900	1.014	1.028	-2.887	1.087	-0.888	0.375
Nima et al (2017)	4.400	4.522	20.449	-4.463	13.263	0.973	0.331
	-0.646	0.989	0.979	-2.585	1.293	-0.653	0.514



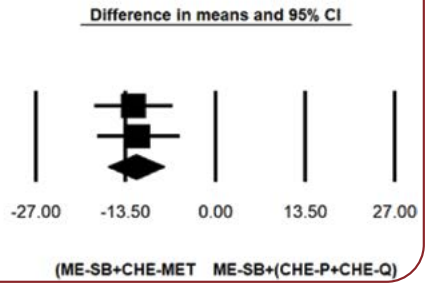
H.

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Nima et al (2016)	-0.900	1.014	1.028	-2.887	1.087	-0.888	0.375
Nima et al (2017)	4.400	4.522	20.449	-4.463	13.263	0.973	0.331
	-0.646	0.989	0.979	-2.585	1.293	-0.653	0.514



I.

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Nima et al (2016)	-12.300	2.991	8.944	-18.162	-6.438	-4.113	0.000
Nima et al (2017)	-11.560	3.131	9.801	-17.696	-5.424	-3.692	0.000
	-11.947	2.163	4.677	-16.185	-7.708	-5.524	0.000



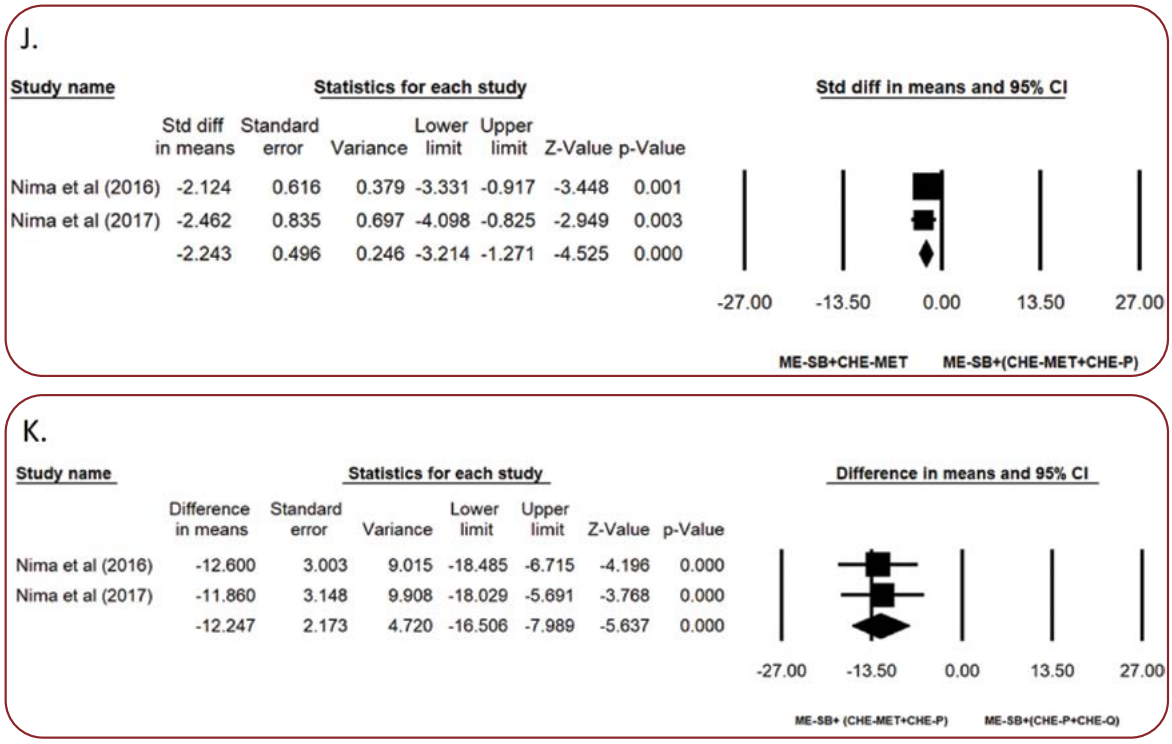


FIGURE 1. Results for the analysis of the mean bond strength of composite resins to base metal alloys without aging. **A.** Surface treatment by using air abrasion + phosphate monomers (ME-SB+CHE-P) *versus* air abrasion + R- monomers (ME-SB+CHE-R). **B.** Surface treatment by using air abrasion + phosphate monomers (ME-SB+CHE-P) *versus* air abrasion + 4-MET monomers (ME-SB+CHE-MET). **C.** Surface treatment by using air abrasion + phosphate monomers (ME-SB+CHE-P) *versus* air abrasion+ phosphate and sulfur monomers (ME-SB+CHE-P+ CHE-Q). **D.** Surface treatment by using air abrasion + phosphate monomers (ME-SB+CHE-P) *versus* air abrasion + phosphate and 4-MET monomers (ME-SB+CHE-P+CHE-MET). **E.** Surface treatment by using air abrasion + R - monomers (ME-SB+CHE-R) *versus* air abrasion + 4- MET monomers (ME-SB+CHE-MET). **F.** Surface treatment by using air abrasion+ R- monomers (ME-SB+CHE-R) *versus* using R- monomers (ME-no treatment + CHE-R). **G.** Surface treatment by using air abrasion+ R- monomers (ME-SB+CHE-R) *versus* air abrasion + phosphate and sulfur- monomers (ME-SB+ CHE-P+ CHE-Q). **H.** Surface treatment by using air abrasion + R - monomers (ME-SB+CHE-R) *versus* air abrasion + phosphate and 4-MET monomers (ME-SB+CHE-P+CHE-MET). **I.** Surface treatment by using air abrasion + 4-MET monomers (ME-SB+CHE-MET) *versus* air abrasion + phosphate and sulfur monomers (ME-SB+CHE-P+CHE-Q) **J.** Surface treatment by using air abrasion + 4-MET monomers (ME-SB+CHE-MET) *versus* air abrasion + phosphate and 4-MET monomers (ME-SB+CHE-P+CHE-MET). **K.** Surface treatment by using air abrasion + phosphate and 4-MET monomers (ME-SB+CHE-P+CHE-MET) *versus* air abrasion+ phosphate and sulfur monomers (ME-SB+ CHE-P+CHE-Q).

other method developed greater bond strength of 7.10±2.2 MPa, and this difference was significant (P<0.05).

8. Comparing the two preparation methods of ME-SB+CHE-R and ME-SB+(CHE-P+CHE-MET) (Figure 1-H), the air abrasion method and the chemical compounds containing phosphate monomers and 4-MET developed greater bond strength, but this difference was not significant (P>0.05).

9. Comparing the two preparation methods of ME-SB+CHE-MET and ME-SB+(CHE-P+CHE-Q) (Figure 1-I), usage of air abrasion alongside compounds containing phosphate and sulfur monomers created greater bond strength of 11.4 MPa compared to the other method, and this difference was significant (P<0.05).

10. Comparing the two preparation methods of ME-SB+CHE-MET and ME-SB+(CHE-P+CHE-MET) (Figure 1-J), utilization of air abrasion method as well as 4-META and phosphate monomers yielded greater bond strength compared to the other method, and the difference was significant (P<0.05).

11. Comparing the two preparation methods of ME-SB+(CHE-MET+CHE-P) and ME-SB+(CHE-P+CHE-Q) (Figure 1-K), ap-

First author / Year	Mechanical/ chemical surface treatment*	Number of samples	Storage conditions	Bond strength test	Mean bond strength (MPa)	Standard deviation
Chung /1993	ME-SB+CHE-P ME-SB+CHE-MET ME-SB+CHE-R	30 10 20	Half: 1000 cycles 5-55℃ Half: 23℃/6 months	Tensile	15.4 15.4 12.25	3.14 3.14 4
Proano /1998	ME- no treatment+ CHE-C+CHE-Si ME-SB+CHE-Si	14 7	30℃ water/28 days 2000 cycles 5-55℃	Shear	12.95 5.8	0.07 0.9
Dos santos /2006	ME-SB+ CHE-P ME-SB+ (CHE-C+CHE-Si) (ME-SB+ME-E) + CHE-R	20 10 20	30℃ water/1 day 1000 cycles 5-55℃	Shear	13.48 25.24 14.68	6.95 3.46 2.22
Ikemura /2011	ME-S+CHE-P+ CHE-Si ME-SB+(CHE-P+ CHE-Si+CHE-MET) ME-SB+CHE-P	6 6 6	37℃ water/1 day 2000 cycles 4-60℃	Shear	26.9 29.7 14	6.8 7.1 3.8
Koccagoalu /2015	ME-SB+ME-E+ CHE-P (ME-SB+ME-B)+ CHE-Si	10 10	37℃ water/1 day 1200 cycles 5-55℃	Shear	19.75 4.55	1.1 0.25
Madani /2015	ME-SB+CHE-R (ME-SB+ME-L)+ CHE-R ME-SB+(CHE-C+ CHE-Si) (ME-SB+ME-) +(CHE-C+CHE-Si)	8 8 8 8	37℃ water/1 day 1000 cycles 5-55℃	Shear	5 10.6 18.5 9.2	0.7 2.8 4.1 3.7
Yoo/ 2015	ME-B+CHE-R ME-SB+CHE-R ME-no treatment+ (CHE-C+CHE-Si)	5 5 5	37℃ water/8 days 1000 cycles 5-55℃	Shear	3.12 6.56 13.81	1.16 2.88 4.1
Nima/ 2016	ME-SB+CHE-R ME-SB+ (CHE-P+CHE-Q) ME-SB CHE-P ME-SB CHE-MET ME-SB+ (CHE-MET+CHE-P)	5 15 15 5 5	37℃ water/1 day 5000 cycles 5-55℃	Shear	6.9 16.76 17.4 7.8 6.7	2.2 4.69 9.62 1.2 1.4
Nima/ 2017	ME-SB+CHE-R ME-SB+ (CHE-P+CHE-Q) ME-SB+CHE-P ME-SB+CHE-MET ME-SB+ (CHE-MET+CHE-P)	14 21 14 7 7	37℃ water/1 day 5000 cycles 5-55℃	Shear	13.05 16.76 13.35 7.8 6.7	8.69 4.69 17.88 1.2 1.4
Khoroushi /2008	ME-E+CHE-MET ME-SB+CHE-MET (ME-SB+ME-E) +CHE-MET	10 10 10	1000 cycles 5-55℃	Shear	1.08 1.98 12.77	0.62 0.81 2.38
Nakhaei /2016	ME-SB+CHE-R ME-SB (CHE-C+CHE-Si) (ME-SB+ME-L) +CHE-Si	8 8 16	37℃ water/1 day 5000 cycles 5-55℃	Shear	5 18.5 7.9	0.7 4.1 1.8
Yasini/ 2007	ME-SB+CHE-R ME-SB+CHE-Si ME-SB+CHE-Q ME-SB+CHE-P	10 10 10 10	37℃ water/2 days 5000 cycles 5-55℃	Shear	17.6 14.72 19.04 21.37	2.85 1.2 2.2 2.1

Continued on next page

Continued from previous page

Yasini/ 2016	ME-SB+CHE-R ME-SB+ (CHE-P+CHE-Q) ME-SB+CHE-P	40 40 40	1000 cycles 5-55℃	Shear	8.32 7.52 9.43	4.77 0.84 4.65
Painiya/ 2012	ME-SB+CHE-R ME-SB+ (CHE-P+CHE-Q)	10 20	37℃ water/1 day 5000 cycles 5-55℃	Shear	14.32 18.99	3.15 8.01
Pilo/ 2016	ME-no treatment ME-SB+ CHE-Si (CHE-C+CHE-Si) ME-SB+CHE-Si	10 10 20	37℃ water/5 days 3000 cycles 5-55℃	Shear	5.6 20.9 26.25	2.3 2.5 0.21
Raeisosadat /2014	ME-SB+CHE-P	20	37℃ water/1 day 2000 cycles 5-55℃	Shear	15.86	3.95
An/ 2011	(ME-SB+ME-E) +CHE-P	20	1000 cycles 5-55℃	Shear	8.38	0.56

TABLE 4. Demographic data of included studies in aged base metal group

plying air abrasion method and the compounds containing phosphate and sulfur monomers developed greater bond strength on average by 12.24 MPa compared to the other method, and this difference was significant ($P<0.05$).

Descriptive and analytical statistics related to the base metal alloy group with aging

Out of the 39 obtained studies, data extracted from 17 studies were placed in the base metal group undergoing aging (6, 32, 46, 52, 53, 57-59, 62-69) (Table 4). The major surface preparation method used in this group was usage of air abrasion with aluminum oxide particles and application of chemical compounds of R group, which had been used by eight studies, and showed a strength range of 5-14.32 MPa. It was followed by usage of air abrasion with aluminum oxide particles and compounds with phosphate monomers in seven studies with bond strengths of 15.43-21.37 MPa. The third rank belonged to combination of air abrasion method with aluminum oxide particles and the particles coated with silica and usage of silane with an bond strength range of 18.5-25.24 MPa in four studies, followed by application of air abrasion method with aluminum oxide particles and chemical compounds containing 4-MET in three studies with the bond strengths of 1.98-15.4 MPa, air abrasion method with aluminum oxide particles and use of silane in three studies with bond strengths of 5.8-26.25 MPa, and use of air abrasion method and concurrent use of compounds containing sulfate and phosphate monomers with the bond strengths of 7.52-18.99 MPa. Other methods presented in the table were used less than three times.

The maximum composite bond strength across the 17 studies had been obtained by applying the air abrasion method with aluminum oxide particles and use of compounds containing phosphate monomers, monomers containing 4-MET, and silane (29.7 MPa) (65). On the other hand, the minimum bond strength had been achieved by applying air abrasion method with aluminum oxide particles and usage of compounds containing 4-MET monomer (46).

As at least two surface preparation methods were repeated in eight studies, meta-analysis could be performed. Six dual combinations were obtained from repeated preparation methods. Comparisons made between the repeated dual compounds are as follows:

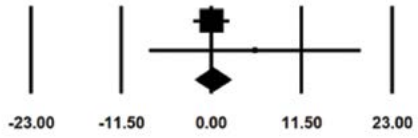
1. Comparing the two preparation methods of ME-SB+CHE-P and ME-SB+CHE-MET (Figure 2-A), usage of air abrasion method and phosphate monomers developed greater bond strength by 0.1 MPa on average compared to the other method, but this difference was not significant ($P>0.05$).
2. Comparing the two preparation methods of ME-SB+CHE-P and ME-SB+CHE-R (Figure 2-B), usage of air abrasion method and phosphate monomers created greater bond strength with the difference being significant ($P<0.05$).
3. Comparing the two preparation methods of ME-SB+CHE-P and ME-SB+

(CHE-MET+CHE-P) (Figure 2-C), usage of air abrasion method and phosphate monomers yielded greater bond strength and this difference was significant ($P<0.05$).

4. Comparing the two preparation methods of ME-SB+CHE-MET and ME-SB+CHE-R (Figure 2-D), usage of 4-META compound created less bond strength, but this difference was not significant ($P>0.05$).

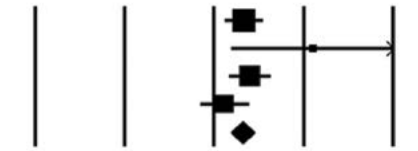
A.

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Chung et al(1993)	0.000	1.147	1.315	-2.247	2.247	0.000	1.000
Nima et al(2017)	5.550	6.853	46.970	-7.883	18.983	0.810	0.418
	0.151	1.131	1.279	-2.065	2.368	0.134	0.894



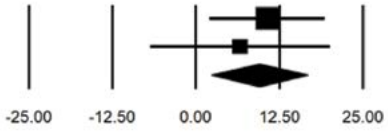
B.

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Chang et al(1993)	3.150	1.012	1.024	1.166	5.134	3.113	0.002
Nima et al(2016)	10.500	4.414	19.481	1.849	19.151	2.379	0.017
Yasini et al(2007)	3.770	1.119	1.253	1.576	5.964	3.368	0.001
Yasini et al(2016)	1.110	1.296	1.679	-1.429	3.649	0.857	0.392
	3.008	0.643	0.413	1.749	4.268	4.681	0.000



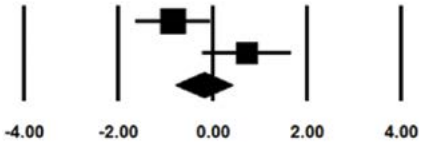
C.

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Nima et al(2016)	10.700	4.394	19.311	2.087	19.313	2.435	0.015
Nima et al(2017)	6.650	6.818	46.482	-6.713	20.013	0.975	0.329
	9.511	3.694	13.643	2.272	16.751	2.575	0.010



D.

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Chung et al(1993)	-0.841	0.402	0.162	-1.629	-0.053	-2.091	0.037
Nima et al(2017)	0.727	0.476	0.227	-0.206	1.661	1.527	0.127
	-0.188	0.307	0.094	-0.791	0.414	-0.613	0.540



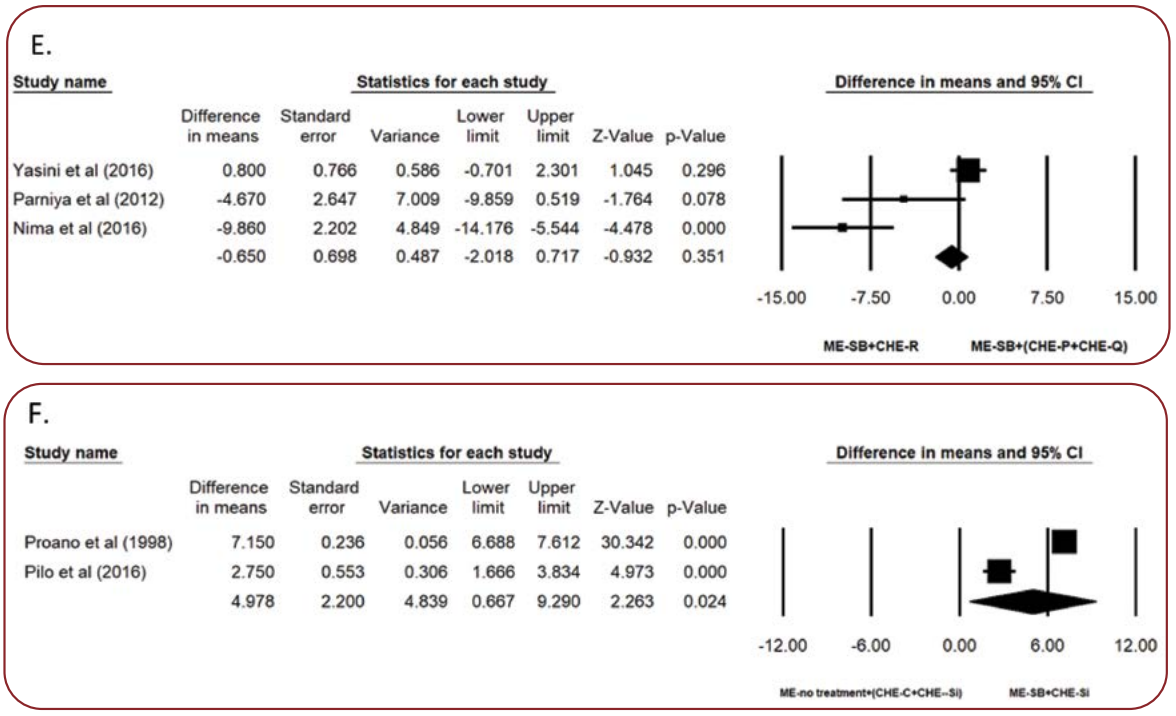


FIGURE 2. Results for the analysis of the mean bond strength of composite resins to base metal alloys with aging. **A.** Surface treatment by using air abrasion+ phosphate monomers (ME-SB+CHE-P) *versus* air abrasion + 4-MET monomers (ME-SB+ CHE-MET). **B.** Surface treatment by using air abrasion+ phosphate monomers (ME-SB+CHE-P) *versus* air abrasion + R - monomers (ME-SB+CHE-R). **C.** Surface treatment by using air abrasion + phosphate monomers (ME-SB+CHE-P) *versus* air abrasion+ Phosphate and 4-MET monomers (ME-SB+CHE-P+CHE-MET). **D.** Surface treatment by using air abrasion + 4-MET monomers (ME-SB+CHE-MET) *versus* air abrasion + R- monomers (ME-SB+CHE-R). **E.** Surface treatment by using air abrasion + R - monomers (ME-SB+CHE-P) *versus* air abrasion + phosphate and sulfur monomers (ME-SB+CHE-P+CHE-Q). **F.** Surface treatment by using air abrasion + silane application (ME-SB+CHE-Si) *versus* using cojet technique and silane application (ME-SB+CHE-C+CHE-Si).

5. Comparing the two preparation methods of ME-SB+CHE-R and ME-SB+(CHE-P+CHE-Q) (Figure 2-E), usage of chemical compounds containing phosphate in sulfur monomers a created greater bond strength on average compared to the other method, but this difference was not significant (P>0.05).

6. Comparing the two preparation methods of ME-no treatment + (CHE-C+CHE-Si) and ME-SB+CHE-SI (Figure 2-F), usage of Cojet method and silane created greater bond

First author / Year	Mechanical/ chemical surface treatment*	Number of samples	Storage conditions	Bond strength test	Mean bond strength (MPa)	Standard deviation
Jain /2013	(ME-E_2+ME-B)+ (CHE-P CHE-Si)	10	5000 cycles 5-55℃ 37℃ water/7 days	Shear	9.42	1.44
	(ME-E_2+ME-B)+CHE-P	10			14.44	3.23
	(ME-E2+ME-B)+ CHE-MET	10			11.86	2.24
	(ME-E2+ME-B)+ (CHE-P+CHE-Si)	10			18.61	2.6
	(ME-E2+ME-SB)+ CHE-P	10			14.98	2.73
	(ME-E2+ME-SB)+ CHE-MET	10			13.24	2.72

TABLE 5. Demographic data of included studies in aged porcelain + base metal group

strength in comparison to air abrasion with aluminum oxide particles and use of silane on average, and this difference was significant ($P<0.05$).

Descriptive statistics related to the ceramic-base metal alloy group plus aging

In a study (27) which had examined the strength of the shear bond of the composite to ceramic-base metal alloy samples prepared under aging conditions (Table 5), application of air abrasion and surface etching with hydrofluoric acid plus usage of phosphate monomer compounds and silane yielded the maximum average magnitude of the composite bond strength to the surface (18.16 MPa).

Descriptive and analytical statistics related to the ceramic-base metal alloy group without aging

Among four other studies (18, 76, 49, 50) the strength of the shear bond of the composite resin to the ceramic-base metal alloy samples without applying thermal cycles (Table 6) was maximum in the group in which air abrasion, surface etching with hydrofluoric acid, and phosphate compounds had been used. Further, in the group where only R chemical compound had been employed, the minimum bond strength (4.43 MPa) was obtained (49). As at least two surface preparation methods had been repeated in two studies, meta-analysis could be performed. A dual combination was obtained from the repeated preparation methods. The compa-

First author / Year	Mechanical/ chemical surface treatment*	Number of samples	Storage conditions	Bond strength test	Mean bond strength (MPa)	Standard deviation
Chung /1997	B+P: ME-no treatment+ CHE-R B+P: ME-no treatment+ CHE-MET B+P: ME-no treatment+ CHE-P B: ME-SB+CHE-R/ P:ME-E_1+CHE-R B: ME-SB+CHE-MET/ P:ME-E_1+ CHE-MET B: ME-SB+CHE-P/ P:ME-E1+ CHE-P B+P: ME-SB+CHE-R B+P: ME-SB+CHE-MET B+P: ME-SB+CHE-P	30 10 20 30 10 20 30 10 20	37℃ water/ 1day	Shear	4.43 10.4 7.7 8.66 14.7 14.8 7.96 13.4 8.15	0.11 1.2 2.54 0.49 2.8 0.7 0.4 1.7 0.35
Yesil /2007	B+P: ME-SB+CHE-P B+P: ME-B+CHE-P	7 7	300 cycles 5-55℃ 37℃ water/ 7days	Shear	11.3 11.25	2.67 1.83
Yesil /2007	B+P: ME-SB+CHE-R	12	200 cycles 5-55° C 37℃ water/ 7days	Shear	6.0	1.79
Gourav /2013	B+P: ME-SB+CHE-R B: ME-SB+CHE-R/ P: (ME-SB+ME-E_1)+ CHE-R B+P: (ME-E_2+ME-B)+ CHE-R B+P: ME-no treatment+ CHE-R	30 30 30 30	37℃/7 days	Shear	9.04 8.33 6.13 4.58	1.2 1.42 1.44 1.07

TABLE 6. Demographic data of included studies in non-aged porcelain + base metal group

rison made between the dual repeated compounds in the studies is as follows:

Comparing the two preparation methods of ME-SB+CHE-R and ME-no treatment +CHE-R (Figure 3), usage of air abrasion method developed greater bond strength compared to the other group, and this difference was significant ($P<0.05$). ❑

DISCUSSION

The aim of this systematic review and meta-analysis was to organize information about the effect of different chemical and physical surface preparation methods for ceramic-metal crowns on the bond strength in repairing fractured ceramic with composite resins. A systematic review should be performed based on a clear research question as well as specific inclusion and exclusion criteria.

This systematic review and meta-analysis included 39 studies. The data extracted from them indicated a great diversity in their approach to applying mechanical and chemical methods for preparing the surface of substrates, which made it difficult to directly compare the results.

Various physical and mechanical surface methods have been proposed for this purpose, including air abrasion with aluminum oxide particles (7, 22, 23), etching surface with acids (25-27), roughening the surface with burs (28, 29), use of laser (30-32), air abrasion with silica-coated aluminum oxide particles (7, 34, 35), tin plating noble metals (36), and use of chemical compounds containing functional monomers (37-40). In addition, alloys used for ceramic--metal restorations are composed of different elements which influence their surface preparation (70).

The bond strength of the composite resin to substrates was examined in two groups of aging and without aging. Most studies have suggested that applying thermal cycling leads to diminished bond strength of the composite resin (32, 46, 71, 72). However, some other studies did not confirm this (45, 52). For this reason, in this study, applying and not applying aging has been considered. There are also controversies over the proper number and manner of applying thermal cycling (7, 73, 74). Since teeth in the mouth environment are subjected to extreme limits of thermal stresses 10 times *per* day on average (46, 64) at least 1 000 thermal cycles were considered as aging. This number of cycles is equivalent to three months of exposure to the mouth environment. Therefore, studies in which the samples had been kept at least three months in water or at least 1 000 thermal cycles had been applied before performing the test of bond strength on them were placed in the aging group.

In the base metal alloy group which had not undergone aging, usage of compounds containing phosphate and 4-META monomers as well as concurrent use of compounds containing sulfur and phosphate monomers resulted in a significant increase in the bond of the composite resin compared to usage of monomers without the above-mentioned functional groups on the air abraded surface. Increased composite resin strength to the air abraded surface following use of compounds containing 4-METAmonomers and concurrent usage of compounds containing sulfur and phosphate monomers was observed in comparison to applying phosphate monomer compounds (25, 52, 56-61). Usage of compounds containing phosphate monomers or 4-META monomer alone as well as concurrent use of compounds containing sulfur and phos-

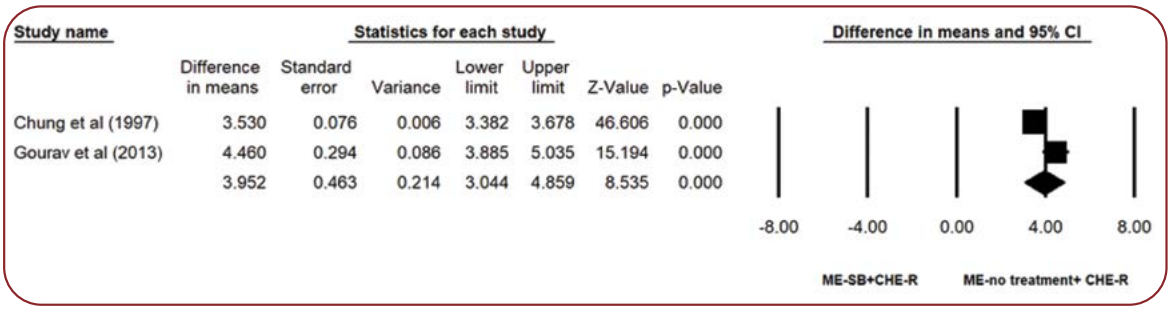


FIGURE 2. Results for the analysis of the mean bond strength of composite resins to porcelain fused to base metal alloys without aging when surfaces were treated by using air abrasion + R-monomers *versus* using R-monomers

phate monomers resulted in a significant increase in the bond strength of the composite resin to the air abraded surface as compared to simultaneous usage of phosphate and 4-META monomers. Air abrasion with aluminum oxide particles leads to clearance of superficial contaminations, increased wettability of the surface by resins, enhanced surface roughness, and stronger bond of the composite resin to the surface (7, 20, 21). 4-MET molecule is essentially known as an bond promoting and demineralizing molecule (35, 76). The two carboxylic groups attached to the aromatic group in it cause improved wettability (39). The thiol group present in sulfate compounds chemically reacts with metals and bonds with metacrylate-based resins (52). The minimum bond strength among the studies, given the differences across the studies, was related to the group of etching with hydrofluoric acid and 4-MET group (46). This can be attributed to inadequate fixation resulting from dissolution of inter-dendrite structures in nickel-chromium-beryllium alloys (24, 25, 76, 77).

In the base metal alloys group not subjected to aging, shear test had been used across all studies, except for Cheng *et al.'s* study who had employed tensile bond strength test (45). Among the advantages of the shear bond strength test are easy usage and the force being perpendicular to the attached region. The disadvantages, however, include unbalanced distribution of stresses and the chance of incidence of failure in the composite structure and development of error in interpreting the results. In the tensile strength test, the forces are exerted to the sample vertically and there is little chance of developing internal defects in the composite resin. However, preparation of samples in this test requires high accuracy to prevent development of internal defects. Indeed, drawing a conclusion is difficult given the differences in the methodologies of the above studies.

In the group of base metal alloys undergoing aging, the maximum composite bond strength, given the differences between study methodologies, was obtained by applying the air abrasion method with aluminum oxide particles and usage of compounds containing phosphate monomers, 4-MET monomers, and silane (65). Air abrasion with silica-coated aluminum oxide particles developed greater bond strength compared to usage of air abrasion with aluminum oxide particles before using silane ($P>0.05$). Application of compounds containing phosphate monomers resulted in enhanced bond strength of the composite resin to the air abraded surface compared to application of 4-META monomers ($P>0.05$). In another group of the same study, combination of air abrasion with aluminum oxide particles plus phosphate monomers and silane yielded a relatively similar bond strength. Phosphate monomers such as 10-MDP bond with the cations of the oxide layer of base metals. Further, the attaching groups of silane molecule are degraded in acidic environments and can cause development of active silanol groups. With establishment of hydrogen bonds between these active components, oligomers are formed, while with loss of water when applying thermal cycling, covalent bonds are developed (65). Except for one study (45), tensile bond strength test had been used in other studies of this group.

Silane is able to establish a chemical bond between organic and inorganic components, and its application alongside the silica layer remaining on the surface in response to the Cojet method in the studies by Ozcan et al (7), Guggenberger *et al.* (31), and Proano *et al.* (32) resulted in increased bond strength of the composite especially to the ceramic surface. The results of tests measuring bond strength are dependent on many variables, and thus there is a need for a single standard for performing experimental tests that examine the bond strength. ❑

CONCLUSION

Application of mechanical and chemical surface preparation methods can result in enhanced composite bond strength to the substrate, which varies given the type of substrate. Considering the findings and limitations of the investigated studies, the following are recommended when preparing the surface of ceramic-metal crowns: concurrent use of mechanical and chemical methods for preparing the surface of ceramic-metal samples and usage of chemical methods containing functional monomers. ❑

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References

1. **Furuchi M, Oshima A, Ishikawa Y, et al.** Effect of metal priming agents on bond strength of resin-modified glass ionomers joined to gold alloy. *Dent Mater J* 2007;5:728-732.
2. **Anusavice K, Kakar K, Ferree N.** Which mechanical and physical testing methods are relevant for predicting the clinical performance of ceramic-based dental prostheses? *Clin Oral Implants Res* 2007;Suppl 3:218-231.
3. **dos Santos JG, Fonseca RG, Adabo GL, dos Santos Cruz CA.** Shear bond strength of metal-ceramic repair systems. *J Prosthet Dent* 2006;3:165-173.
4. **Galiatsatos AA.** An indirect repair technique for fractured metal-ceramic restorations: a clinical report. *J Prosthet Dent* 2005;4:321-323.
5. **Haselton DR, Diaz-Arnold AM, Dunne JT.** Shear bond strengths of 2 intraoral porcelain repair systems to porcelain or metal substrates. *J Prosthet Dent* 2001;5:526-531.
6. **Madani AS, Astaneh PA, Nakhaei M, et al.** Effectiveness of Silica-Lasing Method on the Bond Strength of Composite Resin Repair to Ni-Cr Alloy. *J Prosthodont* 2015;3:225-232.
7. **Özcan M.** Evaluation of alternative intra-oral repair techniques for fractured ceramic-fused-to-metal restorations. *J Oral Rehabil* 2003;2:194-203.
8. **Powers JM.** *Craig's Restorative Dental Materials.* Elsevier, 2012, pp 222-230.
9. **Blum IR, Jagger DC, Wilson NH.** Defective dental restorations: to repair or not to repair? part 2: all–ceramics and porcelain fused to metal systems. *Dent Update* 2011;3:150-158.
10. **Shadid RM, Sadaqah NR, Abu-Naba'a L, Al-Omari WM.** Porcelain fracture of metal-ceramic tooth-supported and implant-supported restorations: A review. *Open Journal of Stomatology* 2013;8:411-418.
11. **Wahab MHKA, Bakar WZW, Husein A.** Different surface preparation techniques of porcelain repaired with composite resin and fracture resistance. *JCD* 2011;56:387.
12. **Lacy A.** Clinical techniques for intraoral repair of fractured porcelain when metal is exposed. *Quintessence Int* (Berlin, Germany: 1985) 1989;160:595.
13. **Raposo LHA, Neiva NA, Silva GRd, et al.** Ceramic restoration repair: report of two cases. *J Appl Oral Sci* 2009;2:140-144.
14. **Mancuso A.** Salvaging a porcelain/metal bridge with a bonded porcelain-fused-to-metal overcasting. *General Dentistry* 2003;255:456-457.
15. **Hirschfeld Z, Rehany A.** Esthetic repair of porcelain in a complete-mouth reconstruction: a case report. *Quintessence Int* 1991;12:945-947.
16. **Barreto M, Bottaro B.** A practical approach to porcelain repair. *J Prosthet Dent* 1982;144:51-349.
17. **Burke F.** Repair of metal-ceramic restorations using an abrasive silica-impregnating technique: two case reports. *Dent Update* 2002;232:398-402.
18. **Yesil ZD, Karaoglanoglu S, Akyil MS, Seven N.** Evaluation of the bond strength of different composite resins to porcelain and metal alloy. *Int J Adhes Adhes* 2007;3:258-262.
19. **Nesse W, Spijkervet F, Abbas F, et al.** Materials in Medicine 2006;1:7-13. UMCG Disciplinegroep: ACM Ref. ID: 1143 Ozcan, M., Van Der Sleen, JM, Kurunmaki, H., Vallittu, PK Comparison of repair methods for ceramic-fused-to-metal crowns. *J Prosthodont* 5:283-288, 2006 UMCG Disciplinegroep: ACM Ref. ID: 7158. *Dent Mater* 2006;66:283-290.
20. **Schneider W, Powers J, Pierpont H.** Bond strength of composites to etched and silica-coated porcelain fusing alloys. *Dent Mater* 1992;3:211-215.
21. **Lacy AM, LaLuz J, Watanabe LG, Dellinges M.** Effect of porcelain surface treatment on the bond to composite. *J Prosthet Dent* 1988;3:288-291.
22. **Stangel I, Nathanson D, Hsu C.** Shear strength of the composite bond to etched porcelain. *J Dent Res* 1987;9:1460-1465.
23. **Czerw R, Wakefield C, Robbins J, Fulkerson M.** Shear bond strength of composite resin to microetched metal with five newer-generation bonding agents. *Oper Dent* 1995;2:58-62.
24. **Ishijima T, Caputo A, Mito R.** Adhesion of resin to casting alloys. *J Prosthet Dent* 1992;4:445-449.
25. **Frankenberger R, Kramer N, Sindel J.** Repair strength of etched vs silica-coated metal-ceramic and all-ceramic restorations. *Oper Dent* 2000;3:209-215.
26. **Castellani D, Baccetti T, Clauser C, Bernardini UD.** Thermal distortion of different materials in crown construction. *J Prosthet Dent* 1994;4:360-366.
27. **Jain S, Parkash H, Gupta S, Bhargava A.** To evaluate the effect of various surface treatments on the shear bond strength of three different intraoral ceramic repair systems: an in vitro study. *J Indian Prosthodont Soc* 2013;3:315-320.
28. **Kunt GE, Güler AU, Ceylan G, et al.** Effects of Er: YAG laser treatments on surface roughness of base metal alloys. *Lasers in Medical Science* 2012;27:47-51.
29. **Murray AK, Attrill DC, Dickinson MR.** The effects of XeCl laser etching of Ni–Cr alloy on bond strengths to composite resin: a comparison with sandblasting procedures. *Dent Mater* 2005;6:538-544.
30. **Madani A, Astaneh P, Shahabi S, et al.** Influence of different power outputs of intraoral Nd: YAG laser on shear bond strength of a resin cement to nickel-chromium dental alloy. *Lasers Med Sci* 2013;1:229-234.
31. **Guggenberger R.** Das Rocatec System-Haftung durch tribochemische Beschichtung. *Dtsch Zahnarztl Z* 1989;44:874-876.
32. **Proano P, Pfeiffer P, Nergiz I, Niedermeier W.** Shear bond strength of repair resin using an intraoral tribochemical coating on ceramometal, ceramic, and resin surfaces. *J Adhes Sci Technol* 1998;10:1121-1135.
33. **Plueddemann EP.** *Nature of adhesion through silane coupling agents.* Silane Coupling Agents: Springer, 1982, pp 111-139.
34. **Kiatsirirote K, Northeast SE, van Noort R.** Bonding procedures for intraoral repair of exposed metal with resin composite. *J Adhes Dent* 1999;4:315-321.
35. **Chang JC, Hurst TL, Hart DA, Estey AW.** 4-META use in dentistry: a literature review. *J Prosthet Dent* 2002;2:216-224.
36. **Van Landuyt KL, Snauwaert J, De Munck J, et al.** Systematic review of the chemical composition of contemporary dental adhesives. *Biomaterials* 2007;28:3757-3785.
37. **Kadoma Y, Kojima K, Tamaki Y, Nomura Y.** Water durability of resin bond to pure gold treated with various adhesion promoting thiirane monomers. *Dent Mater J* 2007;26:29-37.
38. **Minami H, Murahara S, Suzuki S, Tanaka T.** Effects of metal primers on the bonding of an adhesive resin cement to noble metal ceramic alloys after thermal cycling. *J Prosthet Dent* 2011;6:378-385.
39. **Chang JC.** Amalgam repair with a 4-META resin. *J Prosthet Dent* 2004;460:7-506.
40. **Ohno H, Endo K, Hashimoto M.** New mechanical retention method for resin and gold alloy bonding. *Dent Mater* 2004;4:330-337.
41. **Yoshida Y, Nagakane K, Fukuda R, et al.** Comparative study on adhesive performance of functional monomers. *J Dent Res* 2004;6:454-458.
42. **Peumans M, Kanumilli P, De Munck J, et al.** Clinical effectiveness of contemporary adhesives: a systematic review of current clinical trials. *Dent Mater* 2005;9:864-881.

43. **Suzuki M, Miyazaki T, Hisamitsu H, et al.** Study on chemical reaction of methylthiirane on gold colloid by surface-enhanced Raman scattering. *Langmuir* 1999;15:7409-7410.
44. **Suzuki M, Yamamoto M, Fujishima A, et al.** Raman and IR studies on adsorption behavior of adhesive monomers in a metal primer for Au, Ag, Cu, and Cr surfaces. *Journal of Biomedical Materials Research: An Official Journal of The Society for Biomaterials, The Japanese Society for Biomaterials, and The Australian Society for Biomaterials and the Korean Society for Biomaterials* 2002;62:37-45.
45. **Chang JC, Powers JM, Hart D.** Bond strength of composite to alloy treated with bonding systems. *J Prosthodont* **1993;2:110-114.**
46. **Khoroushi M, Bazzazzadeh M.** Effect of thermocycling on the shear bond strength of composite-resin to Supercast alloy. *Shahid Beheshti University Dental Journal* 2008;26:32-39.
47. **Bertolotti RL, Lacy AM, Watanabe LC.** Adhesive monomers for porcelain repair. *Int J Prosthodont* 1989;5:483-489.
48. **White SN, Yu Z, Zhao XY.** High-energy abrasion: an innovative esthetic modality to enhance adhesion. *J Esthet Restor Dent* 1994;6:267-273.
49. **Chung K-h, Hwang Y-C.** Bonding strengths of porcelain repair systems with various surface treatments. *J Prosthet Dent* 1997;3:267-274.
50. **Tulunoglu IF, Beydemir B.** Resin shear bond strength to porcelain and a base metal alloy using two polymerization schemes. *J Prosthet Dent* 2000;2:181-186.
51. **Yesil ZD, Karaoglanoglu S, Akgül N, Ozdabak N, Ilday NO.** Effect of different surfaces and surface applications on bonding strength of porcelain repair material. *NY State Dent J* 2007;3:28-32.
52. **Nima G, Ferreira P, Giannini M.** Bond strength of composite resin to nickel-chrome alloy using primers. *Dental Mater* 2016;32:e46.
53. **Nima G, Ferreira PVC, Paula ABd, Consani S, Giannini M.** Effect of metal primers on bond strength of a composite resin to nickel-chrome metal alloy. *Brazilian Dental Journal* 2017;2:210-215.
54. **Tjan AH, Nemetz H, Tjan AH.** Bond strength of composite to metal mediated by metal adhesive promoters. *J Prosthet Dent* 1987;5:550-554.
55. **Capa N, Özkurt Z, Canpolat C, Kazazoglu E.** Shear bond strength of luting agents to fixed prosthodontic restorative core materials. *Australian Dental Journal* 2009;4:334-340.
56. **Ikemura K, Kojima K, Endo T, Kadoma Y.** Effect of novel dithiooctanoate monomers, in comparison with various sulfur-containing adhesive monomers, on adhesion to precious metals and alloys. *Dental Mater J* 2011;1:72-78.
57. **Nakhaei M, Madani AS, Ansari Astaneh P, et al.** Influence of Silica-Lasing Method on the Bond Strength of Composite Resin to Ni-Cr Alloy: Comparison of CO_2 and Nd: YAG Lasers. *Journal of Mashhad Dental School* 2016;40:83-92.
58. **Yasini E, Mirzaie M, Kermanshah H, et al.** Effect of Type of Surface Treatment and Adhesive System on Shear Bond Strength of Composite Resin to a Non-Precious Metal Alloy. *Journal of Islamic Dental Association of Iran* 2016;56:64-71.
59. **Raeisosadat F, Ghavam M, Tabatabaei MH, et al.** Bond strength of resin cements to noble and base metal alloys with different surface treatments. *Journal of Dentistry* (Tehran, Iran) 2014;55:596.
60. **Yamashita M, Koizumi H, Ishii T, et al.** Evaluation of thiouracil-based adhesive systems for bonding cast silver-palladium-copper-gold alloy. *J Oral Sci* 2010;3:405-410.
61. **Haselton DR, Diaz-Arnold AM, Dunne Jr JT.** Shear bond strengths of 2 intraoral porcelain repair systems to porcelain or metal substrates. *J Prosthet Dent* 2001;5:526-531.
62. **Kocaağaoğlu HH, Gürbulak A.** An assessment of shear bond strength between ceramic repair systems and different ceramic infrastructures. *Scanning* 2015;148:300-305.
63. **Yoo J-Y, Yoon H-I, Park J-M, Park E-J.** Porcelain repair-Influence of different systems and surface treatments on resin bond strength. *J Adv Prosthodont* 2015;5:343-348.
64. **dos Santos JG, Fonseca RG, Adabo GL, dos Santos Cruz CA.** Shear bond strength of metal-ceramic repair systems. *J Prosthet Dent* 2006;3:165-173.
65. **Ikemura K, Tanaka H, Fujii T, et al.** Design of a new, multi-purpose, light-curing adhesive comprising a silane coupling agent, acidic adhesive monomers and dithiooctanoate monomers for bonding to varied metal and dental ceramic materials. *Dent Mater J* 2011;120:493-500.
66. **Yasni E, Almasi S.** Evaluation of shear bond strength of composite resin to nonprecious metal alloys with different surface treatments. *Journal of Dental Medicine* 2007;3:193-200.
67. **Parniya F, Hafez Qoran A, Safaeian S.** Shear Bond Strength of Three Intra-oral Metal-ceramic Repair Systems. *Shahid Beheshti University Dental Journal* 2012;145:413-421.
68. **Pilo R, Dimitriadi M, Silikas N, Eliades G.** Novel silane encapsulation system for tribochemical resin bonding to a Co-Cr alloy. *J Dent* 2016;50:60-68.
69. **An H-S, Park J-M, Park E-J.** Evaluation of shear bond strengths of gingiva-colored composite resin to porcelain, metal and zirconia substrates. *J Advanced Prosthodont* 2011;3:166-171.
70. **Goto S-i, Churnjitapirom P, Miyagawa Y, Ogura H.** Effect of additive metals, Sn, Ga, and In in Ag-Pd-Au-Cu alloys on initial bond strength of 4-META adhesive cement to these alloys. *Dent Mater J* 2008;5:678-686.
71. **Azimian F, Klosa K, Kern M.** Evaluation of a new universal primer for ceramics and alloys. *J Adhes Dent* 2012;3:275-282.
72. **Kern M, Thompson VP.** Influence of prolonged thermal cycling and water storage on the tensile bond strength of composite to NiCr alloy. *Dental Materials* 1994;10:19-25.
73. **Thompson VP, Del Castillo E, Livaditis GJ.** Resin-bonded retainers. Part I: Resin bond to electrolytically etched nonprecious alloys. *J Prosthet Dent* 1983;6:771-779.
74. **Özcan M, Van Der Sleen JM, Kurunmäki H, Vallittu PK.** Comparison of repair methods for ceramic-fused-to-metal crowns. *Journal of Prosthodontics* 2006;5:283-288.
75. **Nakabayashi N, Hiranuma K.** Effect of etchant variation on wet and dry dentin bonding primed with 4-META/acetone. *Dental Materials* 2000;4:274-279.
76. **Cobb D, Vargas M, Fridrich T, Bouschlicher M.** Metal surface treatment: characterization and effect on composite-to-metal bond strength. *Operative Dentistry* 2000;5:427-433.
77. **Barzilay I, Myers ML, Cooper LB, Graser GN.** Mechanical and chemical retention of laboratory cured composite to metal surfaces. *J Prosthet Dent* 1988;2:131-137.