Effect of Different Cleaning Methods on Bond Strength of Resin to Saliva-Contaminated Zirconia: A Systematic Review and Meta-analysis of in Vitro Studies

Alireza Sarraf Shirazi[1]
Sara Majidinia[2]
Tahereh Parhizkar[3]

[1] Professor, Department of Pediatric Dentistry, Mashhad University of Medical Sciences, Masshad, Iran ORCID: 0000-0001-6539-5478
[2] Assistant Professor, Dental Research Center, Department of Operative Dentistry, Mashhad Dental School, Mashhad University of Medical Sciences, Mashhad, IranORCID: 0000-0002-7601-114X
[3] Postgraduate student, Department of Operative Dentistry, Mashhad Dental School, Mashhad University of Medical Sciences, Mashhad, Iran

Corresponding author: Tahereh Parhizkar
E-mail: Tahereh_parhizkar@yahoo.com

ABSTRACT

Background

Saliva contamination during the try-in procedure is one of the leading causes of decreased bond strength of resin to zirconia. In this meta-analysis, we evaluated the effects of different cleaning methods on the bond strength of the zirconia restoration.

Methods

A systematic search was performed through MEDLINE via PubMed, EMBASE, Scopus, ISI web of knowledge, and Cochrane databases. In vitro articles in which the cleaning methods were compared with contaminated and non-contaminated surfaces were selected for this study. The duration of storage was separated into two subgroups of <1 and >1 week.

Results

Out of 909 results of database searches, 15 studies were included in the systematic review. In the storage period of <1 week, there were significant differences between the saliva-contaminated, decontamination with air abrasion (SDM: 2.478, P<0.01), and Ivoclean (SDM: 3.055, P<0.01) groups. Also, in the storage period of >1 week, significant differences were observed between air abrasion (SDM: 2.714, P<0.01), Ivoclean (SDM: 2.575, P<0.01), and argon plasma (SDM: 1.998, P<0.01) groups. There was a significant difference between non-contaminated and isopropanol (<1 week storage period: SDM: -3.252, P=0.05; >1 week storage period; SDM: -1.302, P<0.01) and phosphoric acid (<1 week storage period: SDM: -1.584, P<0.01; storage period >1 week; SDM: -2.021, P<0.01) decontaminated groups.

Conclusion

Sandblasting with airborne-particle abrasion (Al_2O_3), Ivoclean, and argon plasma has been effective in recovering the bond strength of resin to saliva-contaminated zirconia, while bond strength of decontaminated surface with alcohol and phosphoric acid is significantly weaker than in non-contaminated situations.

Key words: Bond strength, cleaning, saliva contamination, zirconia.

Authors
Alireza Sarraf Shirazi - Professor, Department of Pediatric Dentistry, Mashhad University of Medical Sciences, Masshad, Iran ORCID: 0000-0001-6539-5478

Sara Majidinia - Assistant Professor, Dental Research Center, Department of Operative Dentistry, Mashhad Dental School, Mashhad University of Medical Sciences, Mashhad, IranORCID: 0000-0002-7601-114X

Tahereh Parhizkar - Postgraduate student, Department of Operative Dentistry, Mashhad Dental School, Mashhad University of Medical Sciences, Mashhad, Iran

How to Cite
A Sarraf Shirazi, S Majidinia, T Parhizkar. Effect of Different Cleaning Methods on Bond Strength of Resin to Saliva-Contaminated Zirconia: A Systematic Review and Meta-analysis of in Vitro Studies
Annali Di Stomatologia, 15(1), 27-38. https://doi.org/10.59987/ads/2024.1.27-38

Introduction

Recently, the use of the high-strength ceramic material yttrium-oxide-partially-stabilized zirconia (YPSZ) ceramic, as a restorative dental material, has gained tremendous interest in dentistry. Considering the advantages of zirconia, such as esthetic, biocompatibility, mechanical characteristics, and excellent optical behavior, it is used in implants, implant abutments all-ceramic crowns and bridges, all-ceramic post and core systems, and for single and/or multi-unit fixed dental prostheses (1). In addition, the application of the cementation process between the tooth and restoration plays an important role in the clinical success of zirconia restorations.

Although recently there have been advances in adhesive promotors, the use of resin-bonded minimal invasive restorations in reconstructive dentistry has increased significantly. Adhesive resin cements have become popular because they increase retention and marginal adaptability (2). However, the bonding surface is prone to contamination and moisture, leading to decreased bond strength; it is difficult to avoid the contamination of the bonding interface (3).

Before adjusting the restoration, there is a need for a try-in procedure to achieve optimal fixation. During this procedure, the bonding surface might become contaminated by silicone indicators, blood, or saliva. Among them, saliva contamination is one of the main causes of decreased bond strength (4). Zirconium shows a strong affinity for the phosphate groups found in saliva, which react with the zirconia surface (5). Hence, several cleaning methods have been studied to clean these contaminations and prepare an appropriate bonding surface for clinically successful restoration. Cleaning with water, alcohol (70% to 96% isopropanol), phosphoric acid, a newly introduced product Ivoclean, plasma, and additional airborne particle abrasion (Al_2O_3) are some of the well-known methods used to remove zirconia surface contamination (6).

Both acid etching and alkaline-based agents can be used as chemical cleaning methods. Previous studies have reported that sandblasting with Al_2O_3 and chemical cleaning methods like Ivoclean are effective methods in recovering the bond strength (7). Studies have claimed that acid-based methods can recover the bond strength, but phosphoric acid leaves a phosphorous residue that can weaken the resin-cement bond (8). Also, airborne particle abrasion is recommended as an effective method in recovering the strength of resin bonds to zirconia ceramic, which was superior to isopropanol and phosphoric acid in a previous study by Yang et al (9).

This meta-analysis evaluated the effects of different cleaning methods on the shear bond strength of zirconia restorations contaminated with saliva.

METHODS

This study was conducted based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (10). The PICOS was identified as Table 1.

Search strategy

We electronically searched MEDLINE via PubMed, EMBASE, Scopus, ISI Web of Science, and Cochrane databases using the search strategy of (Zirconia OR zirconium OR Ceramic OR Ceramics OR 3Y-TZP OR CAD/CAM OR CAD-CAM) AND (Contamination OR Cleaning OR Decontamination OR Cleansing) AND ((Bond strength) OR Bonding OR Adhesion OR Adhesive OR Adhesives OR µTBS) on 7 February 2021 without time and language limitation.

Eligibility criteria

The inclusion criteria for this study were:

1. A comparison of bond strengths between a cleaning method and a control group
2. Zirconia-adjusted ceramics
3. Zirconia ceramics which were contaminated with saliva
4. The studies used appropriate statistical tests to analyze the bond strength data and the sample size. P-values, means, and standard deviations were reported in the results.

Study selection and data extraction

The results of the searches were imported into the EndNote application, and after removing duplicated studies, two authors (SM and TP) independently screened the articles based on titles and abstracts. Studies that did not meet the inclusion criteria in titles or abstracts were excluded from the study. In case of any disagreement, it was resolved after discussion or by an expert researcher's (AS) comment. Afterward, possible related studies were investigated in the full-text stage. For complete coverage of published studies, the reference list of each article was also checked. Finally, the data regarding the

Table 1. Search strategy using PICOs analysis

	Definition
Participants	Zirconia restorations
Innervation	Different cleaning methods
Comparison	Contaminated/non contaminated zirconia
Outcomes	Bond strength
Study design	Invitro studies

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type of intervention, duration of the storage period, the comparison, and the bond strengths from each study were extracted using a data extraction table.

The authors of articles with insufficient data were contacted via e-mail to receive the missing data and information. If no response was received within two weeks of the initial e-mail contact, a second e-mail was sent. One month after the first contact, the article was excluded if no reply or an incomplete reply was received from the authors.

All the eligible articles were compared with contaminated and non-contaminated surfaces according to the cleaning methods (including air abrasion, isopropanol, Ivoclean, phosphoric acid, argon plasma, and sodium hypochlorite). The duration of storage was categorized into two subgroups of <1 and >1 week. A summary of the included studies is presented in Table 2

Risk of bias assessments

The risk of bias was assessed in terms of randomization, use of the material according to instructions, sample size calculation, identical interventions other than the intervention of interest, same operator outcome measurements, and blinding of outcome assessors. Papers that reported one or two items were classified as high risk of bias, with three or four as medium risk and five to six as low risk.

Statistics

The statistical analyses were conducted using the comprehensive meta-analysis 2 (CMA2) software with 95 confidence intervals and an 0.05 level of significance for P-value. The outcomes were reported as standardized differences in means (SDM) between the interven-

Table 2. The summary of eligible studies in this meta analysis

First author, year	Country	Cleaning method	Cement type	Type of bond strength	Duration of storage
Farahnaz Nejatidanesh 2018	Iran	Air abrasion Isopropanol Ivoclean	3M ESPE	Shear	< 1 week >1 week
Da-Hye Kim, 2015	Korea	Air abrasion Ivoclean	Panavia F2	Shear	< 1 week >1 week
Christoph Piest, 2018	Germany	Isopropanol Argon plasma	Panavia 21	Tensile	< 1 week >1 week
Philip Guers, 2019	Germany	Isopropanol	Panavia 21	Tensile	< 1 week
Mayara Noronha, 2020	Brazil	Isopropanol Ivoclean Argon plasma	Variolink LC	Shear	< 1 week >1 week
Francisco Martinez, 2021	Spain	Ivoclean Argon plasma	Panavia SA	Shear	>1 week
Asuka Kawaguchi, 2017	Japan	Air abrasion Phosphoric acid	Panavia V5	µ Tensile	< 1 week >1 week
Ryo Ishi, 2014	Japan	Air abrasion Ivoclean Phosphoric acid	Not mentioned	Shear	< 1 week >1 week
Sa Feitosa 2014	USA	Isopropanol Ivoclean Phosphoric acid	Multilink	Shear	< 1 week >1 week
Akifumi Takahashi, 2018	Japan	Ivoclean	PanaviaSA/ Rely X unicem2/Speed Cem	Tensile	<1 week
Stephanie Krifka, 2017	Germany	Sodium hypochlorite	Rely X unicem2/ Multilink/ Rely X ultimate	Shear	<1 week
Akin Aldag, 2014	Turkey	Ivoclean Sodium hypochlorite	Variolink II	µ Shear	<1 week
Pattarika Angkasith, 2016	USA	Air abrasion Ivoclean Phosphoric acid	Not mentioned	Shear	>1 week
Zhang S, 2010	Slovenia	Phosphoric acid	Panavia 21	Tensile	< 1 week >1 week
Elisabetta Mangione, 2019	Switzerland	Air abrasion Phosphoric acid	Panavia 21/ Variolink II	µ Shear	< 1 week >1 week

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tion and control groups. The results were presented in forest plots, too. The control group could only be contaminated with saliva or non-contaminated, considered negative and positive control groups, respectively. The duration of storage was categorized into two groups of <1 and >1 week. Due to diversities in the cement types applied, duration of storage, different operators and conditions a random-effect model was used for the meta-analysis.

RESULTS

After two steps of assessing the eligibility of the studies, of 909 results of database searches, 15 studies were included in this systematic review (6, 12-25) (Figure 1). Table 3 summarizes the results of meta-analyses.

Air abrasion

Six included studies assessed the cleaning effects of the air abrasion method. According to the present meta-analysis, there was no significant difference between the non-contaminated and air abrasion cleaning groups in the storage period of >1 week (6 studies; 10 comparisons; SDM: -0.441, P=0.27); however, there was a significant difference between the non-contaminated and air abrasion cleaning groups in the storage period of <1 week (3 studies; 4 comparisons; SDM: -0.795, P<0.01). In addition, there was a significant difference between the air abrasion and surface-contaminated groups in both storage periods of <1 week (3 studies; 4 comparisons; SDM: 2.478, P<0.01) and >1 week (6 studies; 10 comparisons; SDM: 2.714, P<0.01) (Supplementary Figures 1-4).

Isopropanol

Five included studies assessed the cleaning effects of isopropanol. In terms of isopropanol, although there was a significant difference between the saliva-contaminated group and the group decontaminated with isopropanol with storage periods of >1 week (3 studies; 4 comparisons; SDM: 0.048, P=0.87), there was

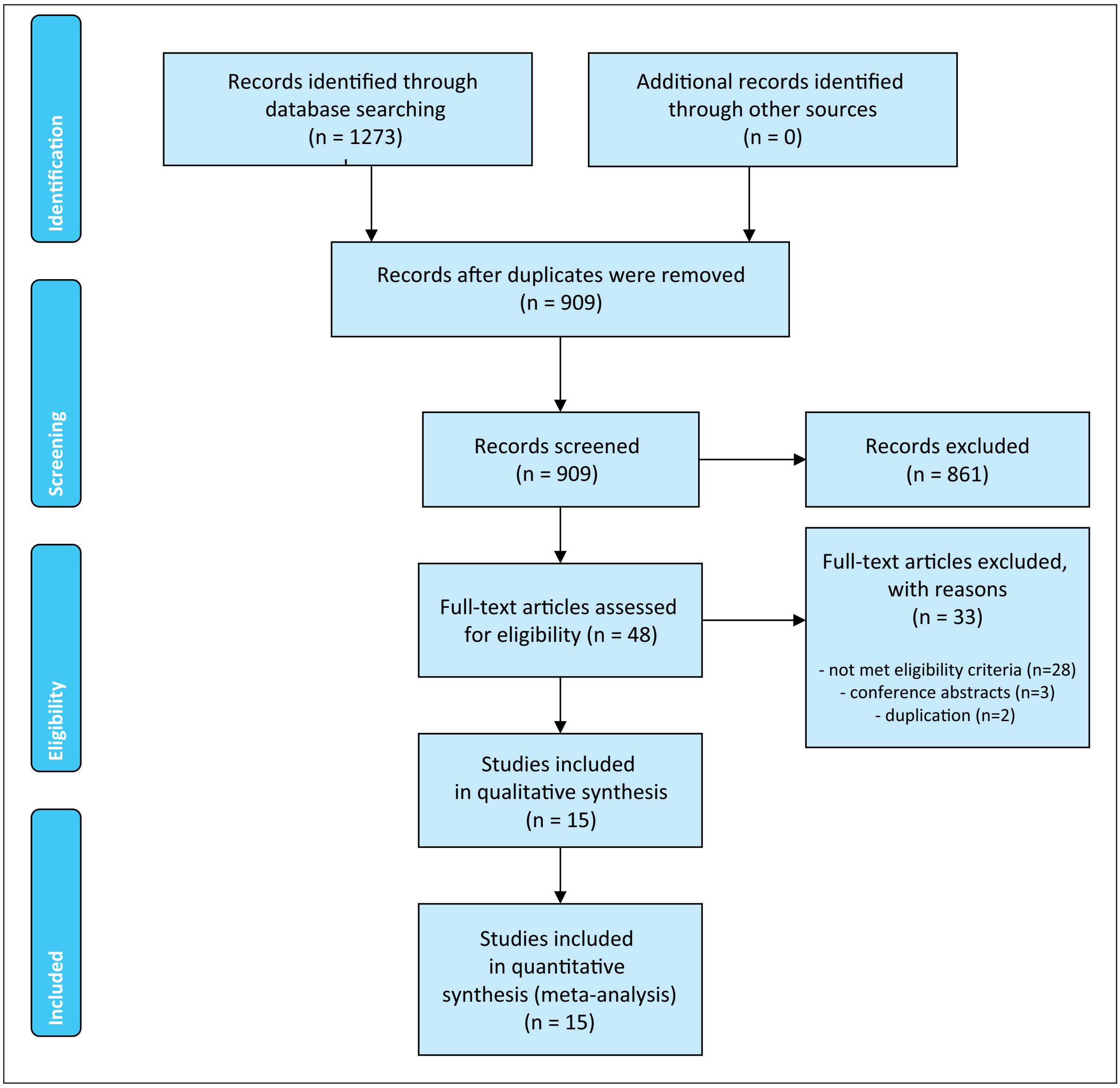

Figure 1. PRISMA Flow Diagram.

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Table 3. Summary of the results of meta-analyses

Intervention (Forest plot in supplementary material)	Comparison	Storage	Standard difference in means	95% confidence interval		P-value
				Lower limit	Upper limit	
Air abrasion (SF1)	Non-contaminated	<1 week	-0.795	-1.360	-0.230	**<0.01***
Air abrasion (SF2)	Non-contaminated	>1 week	-0.441	-1.235	0.353	0.27
Air abrasion (SF3)	Contaminated	<1 week	2.478	0.646	4.310	**<0.01***
Air abrasion (SF4)	Contaminated	>1 week	2.714	1.782	3.647	**<0.01***
Isopropanol (SF1)	Non-contaminated	<1 week	-3.252	-6.498	-0.005	**0.05***
Isopropanol (SF2)	Non-contaminated	>1 week	-1.302	-2.146	-0.458	**<0.01***
Isopropanol (SF4)	Contaminated	>1 week	0.048	-0.556	0.653	0.87
Ivoclean (SF1)	Non-contaminated	<1 week	-0.144	-0.494	0.205	0.41
Ivoclean (SF2)	Non-contaminated	>1 week	-0.317	-0.646	0.013	0.06
Ivoclean (SF3)	Contaminated	<1 week	3.055	1.318	4.791	**<0.01***
Ivoclean (SF4)	Contaminated	>1 week	2.575	1.455	3.695	**<0.01***
Phosphoric acid (SF1)	Non-contaminated	<1 week	-1.584	-2.129	-1.039	**<0.01***
Phosphoric acid (SF2)	Non-contaminated	>1 week	-2.021	-2.677	-1.365	**<0.01***
Phosphoric acid (SF3)	Contaminated	<1 week	0.980	-0.530	2.490	0.20
Phosphoric acid (SF4)	Contaminated	>1 week	0.789	-0.298	1.876	0.15
Argon plasma (SF2)	Non-contaminated	>1 week	-1.143	-3.352	1.067	0.31
Argon plasma (SF4)	Contaminated	>1 week	1.998	1.278	2.717	**0.00***
Sodium hypochlorite (SF3)	Contaminated	<1 week	0.217	-0.214	0.647	0.32

SF: Supplementary figure

a significant difference between the non-contaminated group and the group with isopropanol cleaning method in both storage periods of <1 week (3 studies; 3 comparisons; SDM: -3.252, P=0.05) and >1 week (4 studies; 5 comparisons; SDM: -1.302, P<0.01) (Supplementary Figures 1,2 and 4).

Ivoclean

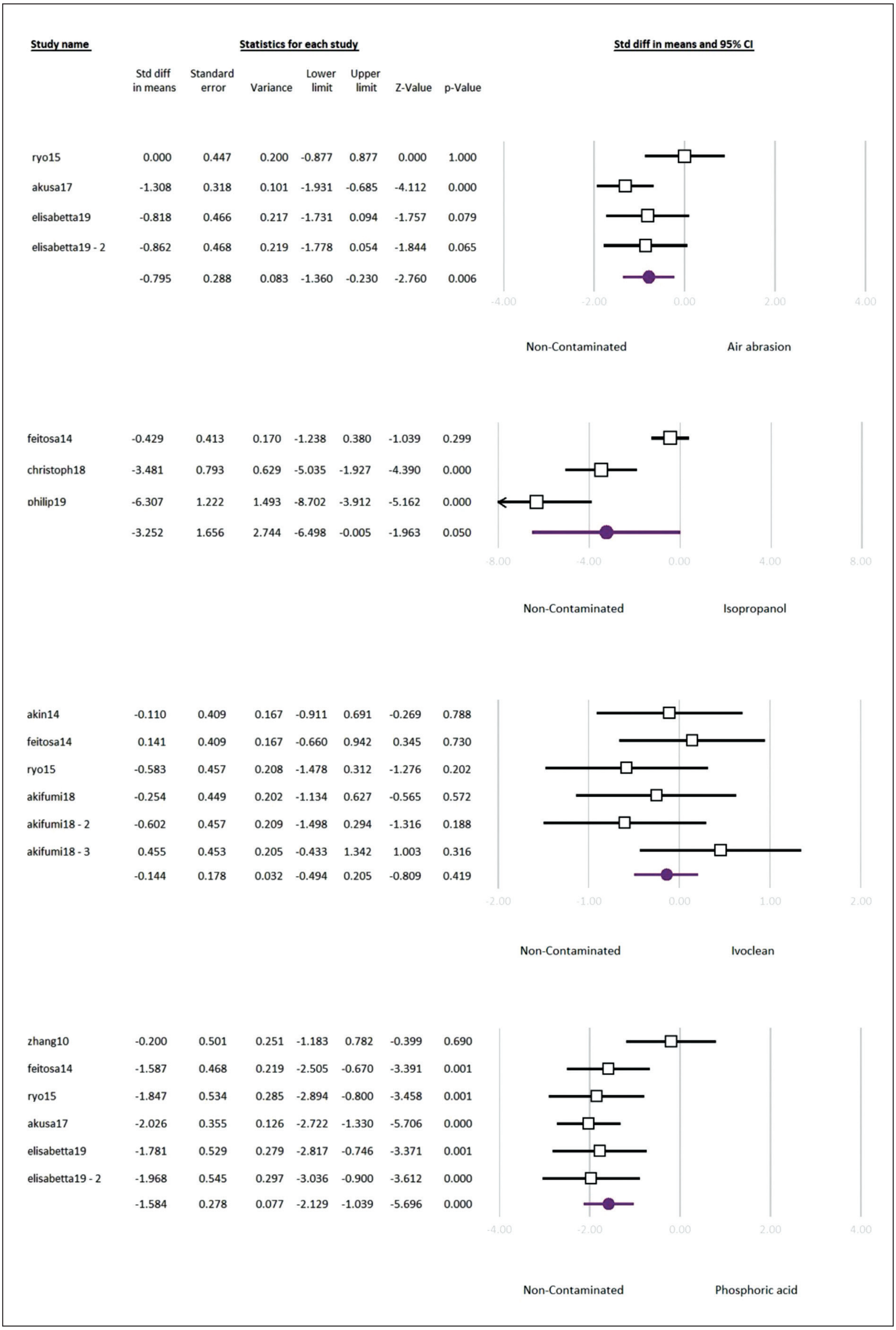
Nine included studies assessed the cleaning effects of Ivoclean. There was a significant difference between the Ivoclean-decontaminated group and the contaminated groups in both storage periods of <1 week (4 studies; 6 comparisons; SDM: 3.055, P<0.01) and >1 week (7 studies; 9 comparisons; SDM: 2.575, P<0.01). However, there was no significant difference between non-contaminated groups and the Ivoclean group in the storage durations of <1 week (4 studies; 6 comparisons; SDM: -0.144, P=0.41) and >1 week (7 studies; 9 comparisons; SDM: -0.317, P=0.06) (Supplementary Figures 1-4).

Phosphoric acid

Six included studies assessed the cleaning effects of phosphoric acid. In assessing the effects of phosphoric acid as a cleaning method, there was no significant difference between decontaminated and contaminated groups in <1-week storage (5 studies; 6 comparisons; SDM: 0.980, P=0.20) and >1-week storage (6 studies; 10 comparisons; SDM: 0.789, P=0.15). However, a significant difference was observed between the surfaces cleaned with phosphoric acid and non-contaminated surfaces in storage periods of <1 week (5 studies; 6 comparisons; SDM: -1.584, P<0.01) and >1 week (6 studies; 10 comparisons; SDM: -2.021, P<0.01) (Supplementary Figures 1-4).

Argon plasma

Three included studies assessed the cleaning effects of argon plasma. Although there was a significant difference between decontaminated and contaminated



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
ryo15	0.000	0.447	0.200	-0.877	0.877	0.000	1.000
akusa17	-1.308	0.318	0.101	-1.931	-0.685	-4.112	0.000
elisabetta19	-0.818	0.466	0.217	-1.731	0.094	-1.757	0.079
elisabetta19 - 2	-0.862	0.468	0.219	-1.778	0.054	-1.844	0.065
	-0.795	0.288	0.083	-1.360	-0.230	-2.760	0.006

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
feitosa14	-0.429	0.413	0.170	-1.238	0.380	-1.039	0.299
christoph18	-3.481	0.793	0.629	-5.035	-1.927	-4.390	0.000
philip19	-6.307	1.222	1.493	-8.702	-3.912	-5.162	0.000
	-3.252	1.656	2.744	-6.498	-0.005	-1.963	0.050

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
akin14	-0.110	0.409	0.167	-0.911	0.691	-0.269	0.788
feitosa14	0.141	0.409	0.167	-0.660	0.942	0.345	0.730
ryo15	-0.583	0.457	0.208	-1.478	0.312	-1.276	0.202
akifumi18	-0.254	0.449	0.202	-1.134	0.627	-0.565	0.572
akifumi18 - 2	-0.602	0.457	0.209	-1.498	0.294	-1.316	0.188
akifumi18 - 3	0.455	0.453	0.205	-0.433	1.342	1.003	0.316
	-0.144	0.178	0.032	-0.494	0.205	-0.809	0.419

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
zhang10	-0.200	0.501	0.251	-1.183	0.782	-0.399	0.690
feitosa14	-1.587	0.468	0.219	-2.505	-0.670	-3.391	0.001
ryo15	-1.847	0.534	0.285	-2.894	-0.800	-3.458	0.001
akusa17	-2.026	0.355	0.126	-2.722	-1.330	-5.706	0.000
elisabetta19	-1.781	0.529	0.279	-2.817	-0.746	-3.371	0.001
elisabetta19 - 2	-1.968	0.545	0.297	-3.036	-0.900	-3.612	0.000
	-1.584	0.278	0.077	-2.129	-1.039	-5.696	0.000

Supplementary figure 1. The meta-analysis of the comparison of bond strength between cleaned surface with different cleaning methods and non-contaminated surface. Duration of storage was <1 week in these studies.

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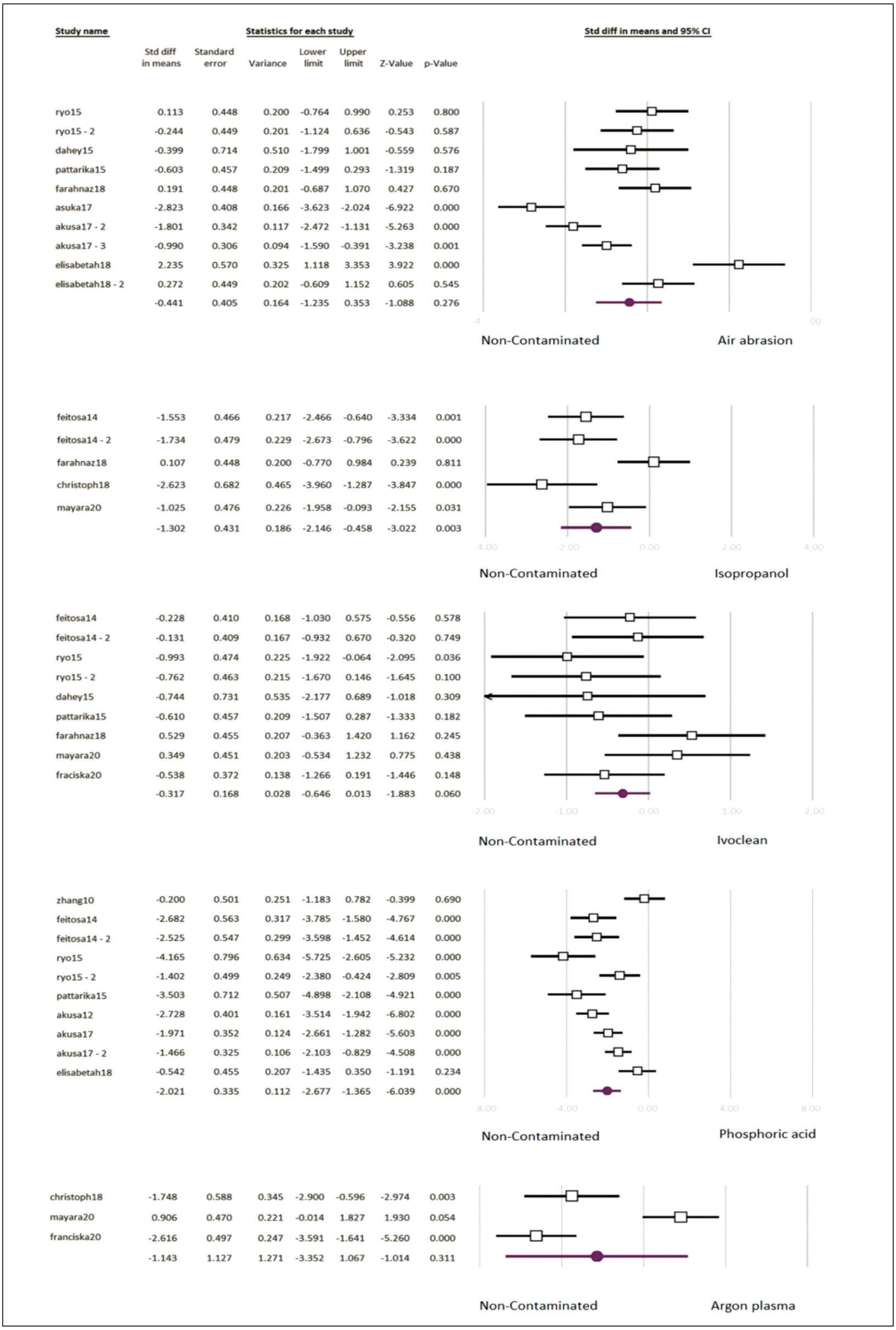
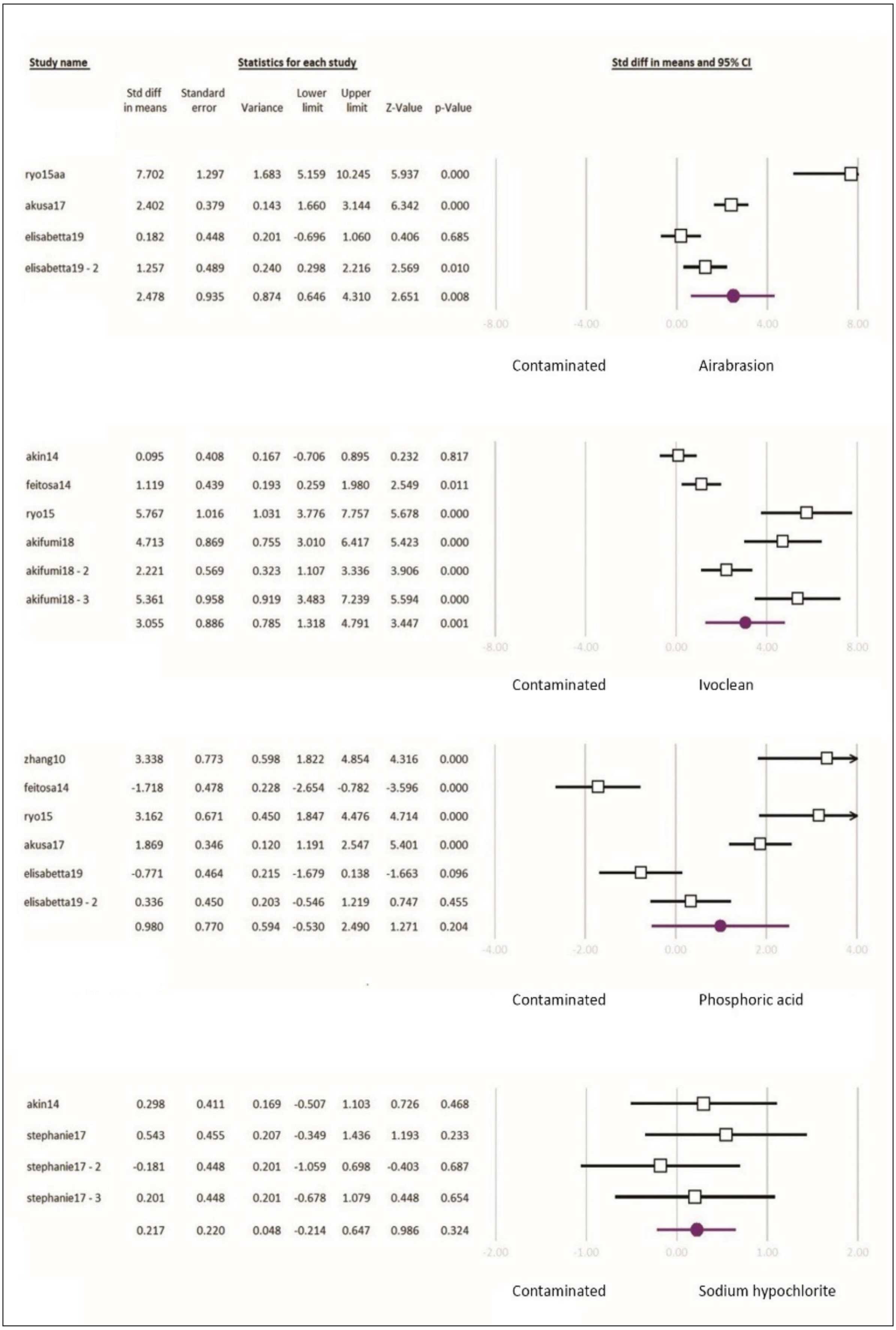


Supplementary figure 2. The meta-analysis of the comparison of bond strength between cleaned surface with different cleaning methods and non-contaminated surface. Duration of storage was >1 week in these studies.



Supplementary figure 3. The meta-analysis of the comparison of bond strength between cleaned surface with different cleaning methods and contaminated surface. Duration of storage was <1 week in these studies.

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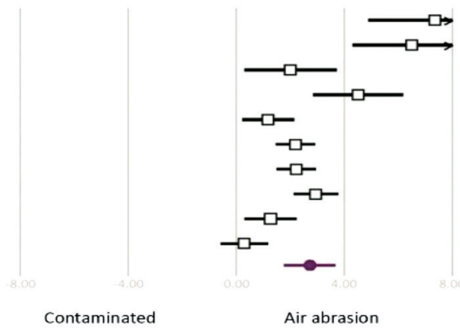
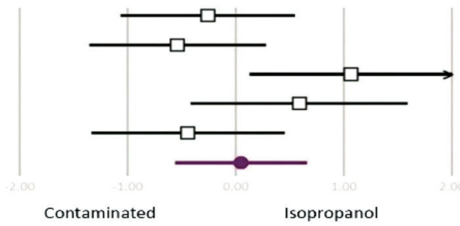
Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
ryo15	7.353	1.246	1.552	4.912	9.795	5.903	0.000
ryo15 - 2	6.513	1.123	1.260	4.312	8.713	5.801	0.000
dahey15	2.003	0.866	0.751	0.305	3.701	2.312	0.021
pattarika15	4.511	0.842	0.709	2.861	6.161	5.358	0.000
farahnazi18	1.183	0.485	0.235	0.233	2.134	2.441	0.015
akusa17	2.201	0.366	0.134	1.484	2.918	6.018	0.000
akusa17 - 2	2.216	0.367	0.134	1.497	2.934	6.042	0.000
akusa17 - 3	2.952	0.417	0.174	2.134	3.770	7.075	0.000
elisabeta19	1.270	0.490	0.240	0.309	2.231	2.591	0.010
elisabeta19 - 2	0.300	0.450	0.202	-0.581	1.181	0.667	0.505
	2.714	0.476	0.226	1.782	3.647	5.704	0.000

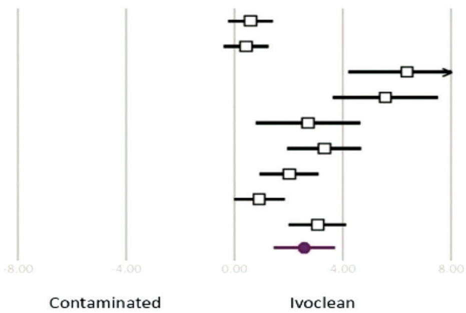
Std diff in means and 95% CI



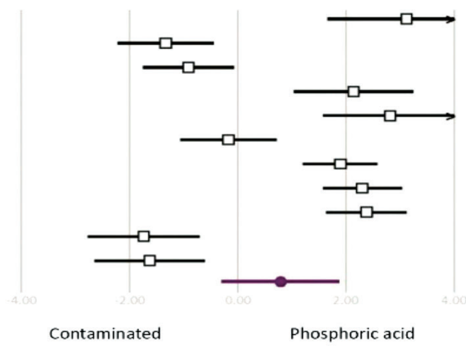
Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
feitosa14	-0.260	0.410	0.168	-1.064	0.543	-0.635	0.525
feitosa14 - 2	-0.538	0.416	0.173	-1.352	0.277	-1.295	0.195
farahnazi18	1.067	0.478	0.228	0.130	2.004	2.232	0.026
christoph18	0.589	0.511	0.261	-0.412	1.590	1.154	0.249
maya20	-0.442	0.453	0.205	-1.329	0.445	-0.976	0.329
	0.048	0.308	0.095	-0.556	0.653	0.157	0.875



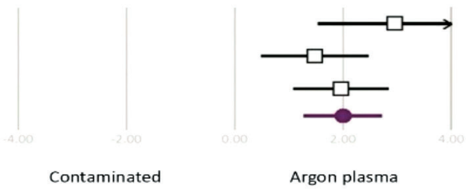
Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
feitosa14	0.596	0.417	0.174	-0.222	1.413	1.428	0.153
feitosa14 - 2	0.432	0.413	0.171	-0.377	1.242	1.047	0.295
ryo15	6.380	1.103	1.218	4.217	8.542	5.782	0.000
ryo15 - 2	5.571	0.988	0.976	3.635	7.507	5.639	0.000
dahey15	2.718	0.981	0.962	0.796	4.640	2.771	0.006
pattarika15	3.323	0.690	0.476	1.971	4.675	4.816	0.000
farahnazi18	2.026	0.550	0.303	0.948	3.104	3.683	0.000
maya20	0.918	0.470	0.221	-0.004	1.839	1.952	0.051
francisca20	3.071	0.539	0.290	2.014	4.127	5.697	0.000
	2.575	0.571	0.326	1.455	3.695	4.506	0.000



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
zhang10	3.120	0.744	0.554	1.661	4.579	4.191	0.000
feitosa14	-1.328	0.451	0.203	-2.212	-0.444	-2.944	0.003
feitosa14 - 2	-0.912	0.429	0.184	-1.753	-0.071	-2.126	0.033
ryo15	2.140	0.561	0.314	1.041	3.239	3.816	0.000
ryo15 - 2	2.819	0.631	0.399	1.581	4.056	4.464	0.000
pattarika15	-0.172	0.448	0.201	-1.050	0.706	-0.383	0.702
akusa17	1.895	0.347	0.121	1.214	2.576	5.453	0.000
akusa17 - 2	2.303	0.372	0.139	1.574	3.033	6.187	0.000
akusa17 - 3	2.378	0.377	0.142	1.639	3.117	6.306	0.000
elisabeta19	-1.738	0.525	0.276	-2.767	-0.709	-3.311	0.001
elisabeta19 - 2	-1.626	0.516	0.266	-2.637	-0.615	-3.153	0.002
	0.789	0.555	0.308	-0.298	1.876	1.422	0.155



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
christoph18	2.959	0.724	0.524	1.541	4.377	4.089	0.000
maya20	1.483	0.505	0.255	0.493	2.473	2.937	0.003
francisca20	1.961	0.444	0.197	1.090	2.832	4.413	0.000
	1.998	0.367	0.135	1.278	2.717	5.442	0.000



Supplementary figure 4. The meta-analysis of the comparison of bond strength between cleaned surface with different cleaning methods and contaminated surface. Duration of storage was >1 week in these studies.

Supplementary Table 1. Details of Risk of Bias assessments.

Study	Randomization	Use of material according to instructions	Sample size calculation	Identical interventions*	Same operator outcome measurements	Blinding of outcome assessors	Overall risk of bias
Nejatidanesh 2018	UC	Yes	Yes	Yes	UC	UC	Medium
Kim 2015	UC	Yes	No	Yes	UC	UC	High
Piest 2018	UC	Yes	No	Yes	UC	UC	High
Güers 2019	UC	Yes	No	Yes	UC	UC	High
Noronha 2020	UC	Yes	No	Yes	UC	UC	High
Martínez 2021	Yes	Yes	Yes	Yes	UC	UC	Medium
Kawaguchi 2017	UC	Yes	No	Yes	UC	UC	High
ISHII 2015	UC	Yes	No	Yes	UC	UC	High
Feitosa 2015	UC	Yes	No	Yes	Yes	UC	Medium
Takahashi 2017	UC	Yes	No	Yes	UC	UC	High
Krifka 2017	No	Yes	No	Yes	UC	UC	High
Aladağ 2015	No	Yes	No	Yes	UC	UC	High
Angkasith 2015	UC	Yes	No	Yes	UC	UC	High
Zhang 2010	No	Yes	No	Yes	UC	UC	High
Mangione 2019	UC	Yes	Yes	Yes	UC	UC	Medium

groups with a storage period of >1 week (3 studies; 3 comparisons; SDM: 1.998, P<0.01), there were no significant differences between the argon plasma group and non-contaminated group with storage of >1 week (3 studies; 3 comparisons; SDM: -1.143, P: 0.31) (Supplementary Figures 2 and 4).

Sodium hypochlorite

Two included studies assessed the cleaning effects of sodium hypochlorite. Finally, a meta-analysis of the effects of sodium hypochlorite did not show a significant difference between the decontaminated and contaminated groups with a storage period of <1 week (2 studies; 4 comparisons; SDM: 0.217, P=0.32) (Supplementary Figure 3).

Risk of bias

Supplementary Table 1 presents the results of risk of bias assessments. The randomization procedure was unclear in most of the studies. Appropriate sample size calculation was carried out only in three studies. The same operator for outcome measurements was mentioned only in one study, and blinding of outcome assessors was reported in none of the included studies. The overall risk of bias in four studies was medium and high in eleven studies.

Discussion

This study was performed to evaluate the effects of different decontamination methods on the bond strength of resin to zirconia ceramic after contamination with saliva. The meta-analysis results showed that air abrasion, Ivoclean, and argon plasma were effective cleaning methods compared with other methods, including isopropanol, phosphoric acid, and sodium hypochlorite. In addition, Ivoclean could completely recover the bond strength to the same level as the non-contaminated surface in both <1 and >1 week storage periods. In the <1 week storage period, there was a significant difference between air abrasion decontaminated and non-contaminated groups.

Over the past years, YTZP, as a core material for manufacturing dental restorations, has gained widespread popularity in dentistry. It is being used in various types of restorations, including full-coverage crowns, fixed partial prostheses, veneers, endodontic posts, and implant abutments, mainly due to high biocompatibility, excellent mechanical properties, aesthetics, and suitable optical behavior (15). Selecting an appropriate cementation pro-

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cess between the tooth and zirconia restoration plays a crucial role in the clinical success of the restoration. It is important to have an optimal bond strength at two different interfaces (dentin-resin cement and ceramic-resin cement interfaces) in bonding the ceramic to the tooth substrate. Although zirconia restorations can be luted with both traditional and resin adhesive cements, using resin can be beneficial in many cases due to its better retention and marginal seal (26).

The restorative surface is at risk of becoming contaminated during a try-in session. The ceramics might become contaminated by saliva, blood, or silicone disclosing agents in the try-in procedure, negatively affecting the composite-ceramic bond strength clinically (14). Unfortunately, it is impossible to avoid ceramic surface contamination; therefore, there are several cleaning methods to remove the contamination, obtain a clean bonding surface, and provide a strong bond. Rinsing with water, immersing in isopropanol, cleaning with ethanol, phosphoric acid, sodium hypochlorite, and airborne-particle abrasion with Al_2O_3 are some techniques that decontaminate the zirconia surface (17). The present meta-analysis showed that air abrasion, Ivoclean, and argon plasma are effective cleaning methods for the decontamination of saliva-contaminated surfaces.

Air abrasion is not a new technique, but it has recently regained attention in dentistry. This method removes the contaminated layers from the surface, allowing the resin cement to create a stronger micromechanical interlocking (27). Based on our assessment, air abrasion can significantly improve the strength of contaminated surfaces. Ivoclean is an alkaline surface cleansing agent whose main composition is sodium hydroxide (NaOH) solution, which can enhance the phosphate adsorption properties. By absorbing the phosphate contaminants found in the saliva, Ivoclean can recover the strength of bonds in 20 seconds based on the manufacturer's claims (27). Based on our meta-analysis, Ivoclean decontamination significantly enhances the bond strengths of saliva-contaminated surfaces to the same level as non-contaminated surfaces in all the investigated conditions.

Although the present study found the same level of bond strength between non-contaminated and decontaminated groups with argon plasma, the small number of included studies makes the conclusion unreliable. A direct comparison of argon plasma with Ivoclean showed that the cleaning paste was more effective in removing saliva contamination (17).

Quaas et al used four different cleaning methods, including air abrasion with 50-µm Al_2O_3, phosphoric acid for 60 s once or 30 s twice, and isopropanol on a contaminated resin surface to compare the effects. They concluded that air abrasion of the contaminated surface provided higher bonding stress than other methods after 3 and 150 days compared to alcohol cleaning, which did not result in durable bond strength after the same time (28). Kim et al used seven different conditions, including non-contaminated, water-spray rinsing, additional air abrasion, Ivoclean, sodium dodecyl sulfate, hydrogen peroxide, and sodium hypochlorite, to clean the saliva-contaminated zirconia. Air abrasion and solutions like Ivoclean or sodium hypochlorite seemed to be effective in removing the contamination and, at the same time, in enhancing the resin bond strength. In contrast, water spray decreased the bond strength (13). Also, a study in Japan showed that water rinsing, phosphoric acid, and Ivoclean cleaning methods, used to eliminate saliva, could not achieve a durable resin bonding to zirconia after application (29). Our meta-analysis showed that air abrasion, Ivoclean, and argon plasma effectively cleaned saliva-contaminated zirconia ceramic interfaces, with the least effects on the bond strength.

The present study had some limitations, including the limited number of clinical trials for our purpose. Also, the bond strength of resin cement to zirconia has been measured with different methods in the included articles, and the meta-analyses of the data were carried out by ignoring the differences in applied methods, types of cement, and duration of storage. Therefore, the mentioned limitations should be addressed in future studies.

Conclusion

In different decontamination methods, sandblasting with airborne-particle abrasion (Al_2O_3), an alkaline-based surface cleansing agent called Ivoclean, and argon plasma are effective in recovering the bond strength of resin to saliva-contaminated zirconia. Ivoclean can recover the bond strength to the same level as a non-contaminated surface. Alcohol (70% to 96% isopropanol) and phosphoric acid cannot significantly improve the bond strength of saliva-contaminated surfaces, which was significantly weaker than the non-contaminated surface. Future well-designed studies, especially clinical investigations, can make the available evidence in this regard more conclusive.

Acknowledgement

This study was supported by a grant from Mashhad Universiy Research Council, which is gratefully acknowledged.

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