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SYSTEMATIC REVIEW ARTICLE

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Zirconia Cementation: A Systematic Review of the Most Currently Used Protocols

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Abstract:

Objective: A systematic review of the existing literature was conducted and *in vitro* studies from 2019 to 2023 were analyzed on Zirconia's most resistant cementation protocol.

Methods: A systematic review of studies on the bond strength between zirconia and resin cement was carried out using different surface treatment protocols. The search was performed in two electronic databases, PubMed and Cochrane.

Results: Electronic searches yielded 1225 non-duplicated articles of which 388 were chosen after screening the titles and abstracts. After examining the full texts of these articles, a further 340 were excluded. There remained 48 studies to which the selection by inclusion and exclusion criteria was applied, eliminating 31 articles, of which 17 were finally included for the qualitative study.

Conclusion: Under the limitations of the present systematic review, it can be concluded that treating Zirconia with a combination of surface modifying agents, both mechanical and chemical, substantially improves its adhesive ability with resin cement. Aluminum oxide sandblasting, hydrofluoric acid etching, tribochemical silica coating, laser, and etching with a combination of acids in the Zircos E system are micromechanical treatments that improve the bond strength between zirconia and resin cements. MDP silane agent is an effective chemical treatment to improve the bond strength between zirconia and resin cements. Coating exclusively with a silica layer does not improve the bond strength between zirconia and resin cement.

Keywords: Zirconia, Dental cement, Surface treatment, Zirconia adhesive, Zirconia oxide, Resin cement.

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1. INTRODUCTION

All the existing scientific literature has proven and admitted the most resistant cementation protocol for cementing vitreous ceramic and metal elements. However, as far as Zirconia is concerned, even though it is a ceramic, it has specific characteristics that make it impossible to etch with acids. Therefore, it is the subject of much controversy [1]. On the other hand, it is essential to consider that the growing concern for esthetics worldwide has also penetrated the area of dentistry in recent decades [2]. It is easy to see increasingly demanding patients in the offices with the image projected by their smiles. This has repercussions on professional activity since it is increasingly necessary to be prepared and informed about the new trends in materials and techniques to solve, or at least try to respond appropriately, to this concern. For this reason, there has been increasing interest in using zirconia oxide as the material of choice for fabricating dental restorations in recent years and in an ever-increasing manner [3]. The great advantage of not having to use prostheses with metal frameworks is that the appearance of grayish edges or tattoos on the gingival margin can be avoided, which darkens its color and alters the esthetic composition of the smile [4]. Furthermore, being metal-free, zirconia prostheses do not cause any allergy in the oral cavity, oral mucosa, or other mouth tissues [5]. All this, together with their white color, gives the prosthesis high esthetics and an optimum result in restorative treatment planning. In dentistry, yttria-stabilized tetragonal zirconia polycrystal (Y-TZP), a ceramic composed of zirconia polycrystals in the tetragonal phase, is specifically used, adding yttrium oxide as a stabilizing agent [6]. It is common knowledge that for the long-term success of a zirconia restoration, it is necessary to have sufficient bond strength to withstand functional masticatory stresses. Therefore, restorations' performance and bonding efficiency depend highly on the cementation procedure. Since recent studies propose resins as the material of choice for bonding with Zirconia due to better bond strength and durability properties [7], it is recommended that all cementation protocols use this type of material to improve their clinical performance [8]. Acid etching and silanization have been used extensively to improve the bonding of feldspathic ceramics to composite resins [9]. However, Zirconia's physical properties and composition differ substantially from silica-containing ceramics. Thus, the conventional acid etching procedure needs to sufficiently improve adhesion due to the poor chemical reactivity of Zirconia with acid [10]. This is due to Zirconia's polycrystalline tetragonal structure, in which no inherent glass content exists in its matrix. Therefore, Zirconia cannot be etched with acids, such as hydrofluoric or orthophosphoric acid, to form a rough surface to increase micromechanical retention [11]. Added to this problem is the absence of silica in the composition of the material, which makes it not susceptible to silanization, again preventing adequate adhesion [12]. This severe drawback of lack of etchability and silanization has caused confusion and much scientific discussion among clinicians. Since noting that zirconia restorations did not adequately resist dislodging forces, several proposals have been made for alternative protocols to improve the bond strength between resin cement, tooth structure, and zirconia restorations [13-15]. However, there is still no consensus among scientific community members on designing a suitable protocol for zirconia cementation. For this reason, the present systematic literature review has been proposed to determine the most resistant zirconia cementation protocol investigated in *in-vitro* studies.

2. MATERIALS AND METHODS

The present systematic review has followed the guidelines of the PRISMA 2020 statement (The Preferred Reporting Items for Systematic Reviews and Meta-Analyses).

2.1. Identification of Articles

Three search strategies were designed in PubMed, Medline, and Cochrane, using a combination of MeSH descriptors (Medical Subject Headings, thesaurus of the MEDLINE repertory) and a combination of accessible terms that allowed us to compile as exhaustive a collection as possible of *in-vitro* research papers related to this topic of study. The search strategies were: MeSH terms: ZIRCONIA AND DENTAL CEMENT. DENTAL CEMENT AND ZIRCONIA OXIDE ZIRCONIA AND ADHESIVE Free search: ZIRCONIA AND SURFACE TREATMENT ZIRCONIA AND BOND STRENGTH ZIRCONIA AND ADHESIVE ZIRCONIA AND RESIN CEMENT. The filters used, both for MeSH terms and for the free search, were as follows: Time interval: the period from 2019 to 2023 (5 years) was considered. Regarding the “type of document,” the search was limited to “articles,” excluding other types of publications such as reviews, letters to the editor, conference abstracts, *etc*. Finally, English and Spanish were chosen as the “languages” of the searched texts.

2.2. Selection of Articles

The total number of records obtained was downloaded as a “Pubmed” file and then exported to the COVIDENCE and RAYYAN bibliographic managers to eliminate duplicate works effectively.

2.3. Eligibility of Articles

2.3.1. Inclusion and Exclusion Criteria for Article Eligibility

In addition, to be considered eligible at the title and abstract reading stage, studies met the following inclusion criteria: *In vitro* studies on the bond strength of Zirconia to resin cement. *In vitro* studies comparing different adhesive luting protocols between zirconia and resin cement were included. *In vitro* studies used accelerated aging with thermocycling of the specimens. Studies that have been published from 2019 to the date of conducting this research were included. Studies in English and Spanish were also included. After the manual selection process by criteria, all those studies unrelated to the topic were eliminated, for which the RAYYAN reference manager was used in its “Keywords” tool. A complete list of keywords was prepared for manual inclusion in the bibliographic manager since the automatic list provided by the program did not meet the review's objectives.

2.3.1.1. Piloting and Assessment of Concordance among Reviewers

Moreover, to assess whether the reviewers who carried out the screening adequately understood the inclusion and exclusion criteria, a preliminary pilot test was performed to avoid discrepancies that could jeopardize the accuracy of the selection. Cohen's Kappa reliability coefficient was used for the exercise on 300 sample articles. An external coordinator external to the research analyzed the results and recommended the necessary adjustments to improve selection accuracy. The recommended concordance value was more significant than 0.70-0.80. Finally, once the best concordance was achieved, a face-to-face conflict resolution meeting was held between researchers. Furthermore, due to the high values of Cohen's Kappa, it was not necessary to repeat the piloting. A reading of the full text followed the selection process. Next, the full text of the selected articles was read, and each researcher carried out a phase independently. Finally, all those articles that did not meet the exclusion criteria established for the study were eliminated.

2.3.2. Exclusion Criteria

● Systematic and literature reviews, case reports, pilot studies, and any other type of study design that was not *in vitro*.

● Studies that have evaluated the adhesive bond strength of zirconia crowns on implants or partial restorations.

● Studies that have not detailed the methodology for observing the results.

● Studies that have not performed thermocycling.

● Articles that did not comply with any of the components of the PICOS question established for this study. Once the final articles were selected, the results and conclusions of each research were analyzed, and the risk of bias was evaluated using the Robvis tool.

4. RESULTS

Electronic searches yielded 1225 unduplicated articles (Fig. **1**), of which 388 were chosen after analysis of titles and abstracts. After examining the full texts of these articles, 340 more were excluded. This left 48 studies to which the selection by inclusion and exclusion criteria was applied, eliminating 31 articles, of which 17 were finally included for the qualitative study. The general characteristics of the selected studies are presented in Table **1**. All the selected studies were *in vitro* models with thermocycling. Three studies implemented hydrofluoric acid etching [16-18], two analyzed micro-sandblasting [14, 19], four analyzed silica tribochemical coating [20-23], five studies analyzed laser surface treatments [24-28], one study tested the first MDP [29], and finally, two studies analyzed a new acid etching system called Zircos-E [30, 31]. The year of publication, country of origin, type of thermal cycling, and tensile strength values in megapascals (Mpa) of both the control group and the group with the surface treatment under study are described in Table **2**.

5. DISCUSSION

Zirconia is a high-resistance material that can be used in simple and plural prostheses in the anterior and posterior sectors of the oral cavity [32]. Despite being a material with good resistance characteristics, its use remains complicated since difficulties are encountered in the adhesive interface with the resinous cement that holds it to the tooth [33].

Adhesion to Zirconia is not good, so a systematic review of the literature was carried out on what materials and techniques can be used to increase the durability of the restoration in the mouth.

Table 1. General characteristics of the selected studies.

1	**Title**	Innovation Glass-ceramic Spray Deposition Technology Improving the Adhesive Performance for Zirconia-based Dental Restorations.
	Journal	Int J Mol Sci
	Author	Kang CM
	Year	2022
	Country	Swiss
	Objectives	To evaluate the effects of different hydrofluoric acid (HF) etching times and glass ceramic spray deposition techniques on the bond strength of resin and Zirconia.
	Conclusion	The acid etching time and glass ceramic spray deposition technique significantly affect the bond strength between zirconia and resin cement.
2	**Title**	Silicon-based film on the yttria-stabilized tetragonal zirconia polycrystal: Surface and shear bond strength analysis.
	Journal	J Investig Clin Dent
	Author	Silva AM
	Year	2019
	Country	Australia
	Objectives	Analyze the effect of the silica layer deposited on the YTZP zirconia regarding bonding strength to the resin cement.
	Conclusion	The deposition of a layer of silica provides a lower bond strength to the resin cement than conventional surface treatments.
3	**Title**	Bond Strength Stability of Self-adhesive Resin Cement to Etched Vitrified Yttria-stabilized Tetragonal Zirconia Polycrystal Ceramic After Thermomechanical Cycling.
	Journal	Oper Dent
	Author	Maroun EV
	Year	2019
	Country	USA
	Objectives	To evaluate the influence of thermomechanical cycling on the bond strength of self-adhesive resin cement and etched and vitrified Zirconia.
	Conclusion	Even after thermomechanical cycling, low-fusing glaze followed by hydrofluoric acid etching significantly improves the adhesive interface with the resin cement.

(Table 1) contd.....

4	**Title**	Effects of Tribochemical Silica Coating and Alumina-Particle Air Abrasion on 3Y-TZP and 5Y-TZP: Evaluation of Surface Hardness, Roughness, Bonding, and Phase Transformation
	Journal	J Adhes Dent
	Author	Chen B.
	Year	2020
	Country	Germany
	Objectives	Determine and compare the effects of tribochemical silica coating and alumina sandblasting on tetragonal zirconia polycrystals stabilized with 3% and 5% Ytria.
	Conclusion	The bond strength between resin and 5Y TZP and 3Y TZP with sandblasting and tribochemical silica coating is similar without statistically significant differences.
5	**Title**	Influence of Surface Modification Protocol and Type of Luting Cement on Bonding of Monolithic Zirconia to Dentin Substrate
	Journal	J Contemp Dent Practice
	Author	Saker S
	Year	2020
	Country	India
	Objectives	This study evaluates the bond strength of two types of cement to monolithic Zirconia and dentin after various surface modifications and aging.
	Conclusion	Selective glass infiltration etching effectively altered the surface properties by creating a solid and durable bond with the monolithic Zirconia.
6	**Title**	Effect of Different Surface Treatments and Pressure Conditions on Shear Bond Strength of Zirconia Ceramic to Composite Resin.
	Journal	Front Dent
	Author	Kabiri S
	Year	2021
	Country	Iran
	Objectives	To evaluate the shear strength (SBS) of Zirconia ceramic to composite resin with various surface treatments after pressure changes
	Conclusion	Sandblasting and tribochemical preparation improve bonding compared to Er: YAG laser irradiation. The different pressures had no significant effect.
7	**Title**	Surface wettability and nano roughness at different grit blasting operational pressures and their effects on resin cement to zirconia adhesion.
	Journal	Dent Mater
	Author	Khan AA
	Year	2019
	Country	Japan
	Objectives	Investigate the effects of air pressure of tribochemical silica coating system on surface roughness, wetting, and adhesion of Zirconia to resin cement
	Conclusion	Sandblasting at different air pressures qualitatively and quantitatively improves the bond between zirconia and resin cement. 180Kpa was the most suitable compared to 280Kpa
8	**Title**	Influence of Particle and Air-Abrasion Moment on Y-TZP Surface Characterization and Bond Strength.
	Journal	J Prosthodont
	Author	Martins SB
	Year	2019
	Country	USA
	Objectives	To evaluate the influence of the sandblasting moment on the surface characterization and shear strength (SBS) of a Y-TZP ceramic with resin cement.
	Conclusion	Air abrasion with certain particles before and after zirconia sintering provides bond strengths similar to post-sintering sandblasting.
9	**Title**	Effect of the nanofilm-coated zirconia ceramic on resin cement bond strength.
	Journal	J Dent Res Dent Clin Dent Prospects
	Author	De Figueiredo VMG
	Year	2022
	Country	Iran
	Objectives	To evaluate the effect of silica and fluorine nanofilms on zirconia ceramic for bond strength with resin cement.
	Conclusion	Silica and fluorine nanofilms deposited by PECVD did not promote bonding between zirconia and resin cement.
10	**Title**	The Shear Bond Strength of Resin-Based Luting Cement to Zirconia Ceramics after Different Surface Treatments.
	Journal	Materials
	Author	Sokolowski G
	Year	2023
	Country	Swiss
	Objectives	Determine the effect of a new etching technique (Zircos-E) on the bond strength of Zirconia.
	Conclusion	The use of the Zircos-E system positively influences the shear resistance between zirconia and resin cement.

(Table 1) contd.....

11	**Title**	The effects of silane to 10-methacryloyloxydecyl dihydrogen phosphate (MDP) ratio in a primer on the bonding performance of silica-based and Zirconia ceramics.
	Journal	J Mech Behav Biomed Mater
	Author	Koko M
	Year	2020
	Country	Holland
	Objectives	To evaluate the effects of different silane concentrations at 1% by weight of 10-methacryloyloxydecyl dihydrogen phosphate (MDP) on the bonding to silica- and zirconia-based ceramics.
	Conclusion	Increasing the percentage of γ -MPTS up to 5% in the presence of MDP can improve the durability of the resin cement-ceramic bond.
12	**Title**	Assessing the Effects of Air Abrasion with Aluminum Oxide or Glass Beads on Zirconia Bond Strength of Cement.
	Journal	J Contemp Dent Practice
	Author	Mehari K
	Year	2020
	Country	India
	Objectives	To evaluate the effects of air abrasion with aluminum oxide or glass beads on three types of Zirconia.
	Conclusion	Air abrasion with glass beads resulted in significantly lower bond strength of resin cement to all three types of Zirconia than air abrasion with aluminum oxide.
13	**Title**	Different surface modifications combined with universal adhesives: the impact on the bonding properties of Zirconia to composite resin cement.
	Journal	Clin Oral Investig
	Author	Lumkemann K
	Year	2019
	Country	Germany
	Objectives	To analyze the impact of plasma and UA treatment on the bonding properties of Zirconia.
	Conclusion	Plasma treatment is not a substitute for suspended particle abrasion to improve the bonding of zirconia restorations to resin.
14	**Title**	Effect of zirconia etching solution on the shear bond strength between zirconia and resin cement.
	Journal	J Prosthet Dent
	Author	Sadid-Zadeh R
	Year	2021
	Country	USA
	Objectives	To evaluate the effect of acid etching with an acid solution for Zirconia on the bond strength between zirconia and resin cement.
	Conclusion	Acid etching with an acid solution for Zirconia (Zircos-E) does not significantly improve the bond between zirconia and resin cement.
15	**Title**	Ultrashort-pulse laser as a surface treatment for bonding between zirconia and resin cement.
	Journal	Dent Mater
	Author	Abu Ruja M
	Year	2019
	Country	England
	Objectives	To evaluate the effect of ultrashort pulse laser as a surface treatment that improves adhesive bonding to Y-TZP.
	Conclusion	Ultrashort pulse laser increases bond strength without compromising restoration strength.
16	**Title**	Effect of different laser treatments on the shear bond strength of Zirconia ceramic to resin cement.
	Journal	Dent Res J
	Author	Hatami M
	Year	2021
	Country	Iran
	Objectives	The purpose of this study is to evaluate and compare the effect of 3 types of lasers on the bond strength of Zirconia to resin cement.
	Conclusion	The Laser increases the adhesive bond values of the Zirconia to the resin cement compared to the untreated surface. The Er-YAG laser was the most effective, along with sandblasting.
17	**Title**	Nonthermal Plasma Treatment can eliminate sandblasting procedure For Zirconia–Resin cement bonding
	Journal	Int J Prosthodont
	Author	Merve A
	Year	2020
	Country	Türkiye
	Objectives	To evaluate the effects of nonthermal atmospheric plasma (NTAP) treatment, alone or in combination with sandblasting and primer application in bonding zirconia ceramics to resinous cement.
	Conclusion	NTAP application can be an alternative treatment method to sandblasting for the adhesive cementation of zirconia ceramics. Applying NTAP before primer improves adhesion.

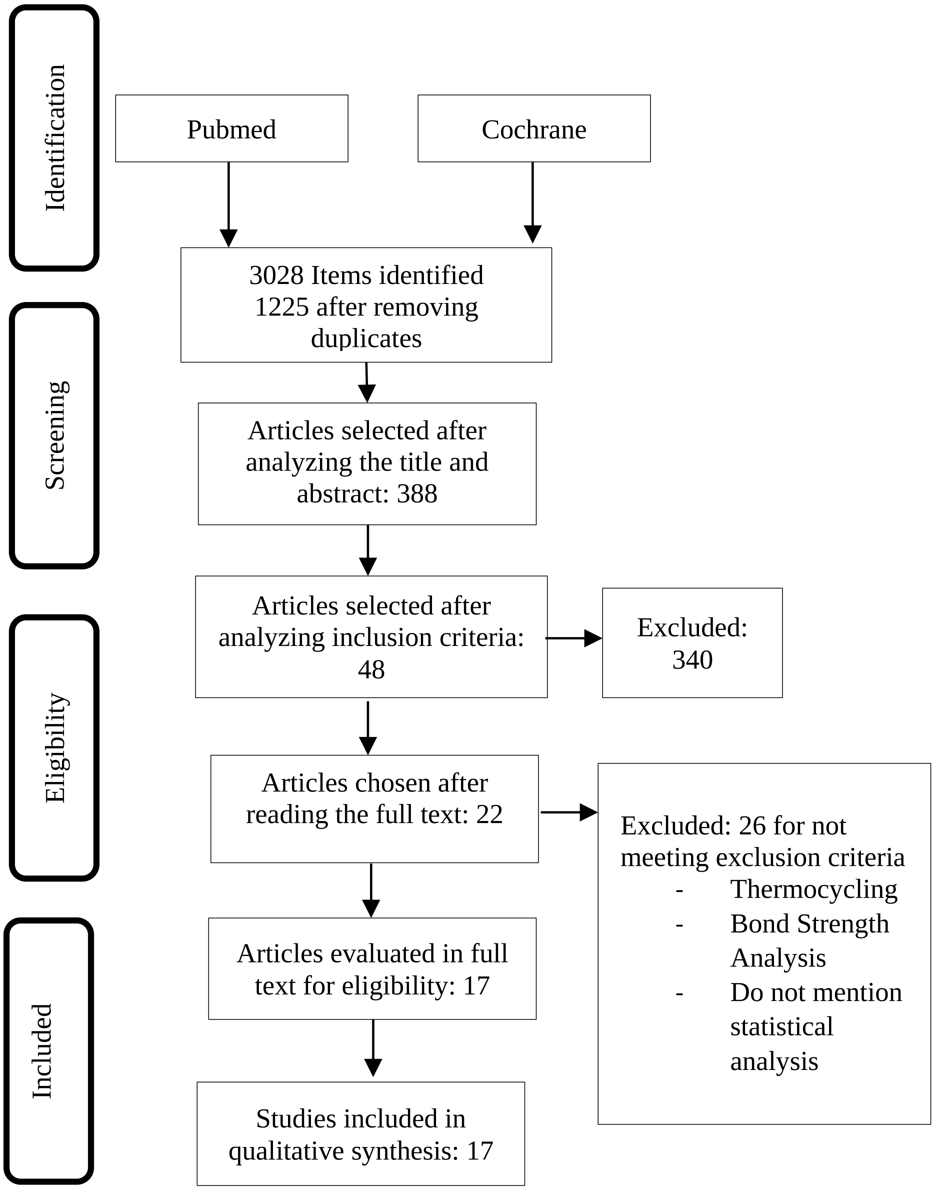

Fig. (1). PRISMA Search process diagram.

Table 2. Synthesis of results in Mpa after thermocycling

Author	T.C.	Control	M.P.A.	TTO	M.P.A.
Figueiredo V	5-55ºC 6000 cycles (30 sp)	without surface treatment	6.3	Silica nanofilms	0
Kabiri S	5-55°c – 1000 cycles	Sandblasted 50-micron aluminum oxide particles	6.96	Laser Ergon doped yttrium aluminum garnet.	4.83
Lumkemann K	5-55ºC - 5000 cycles	Without surface treatment	43.7	plasma laser	41.4
Abu Ruja M	5-55ºc - 5000 cycles	Alumina sandblasting	14.51	single pulse online laser 2.5um 4mj 6.7KHz	35.4
Hatami M	5-55th 5000 cycles (30 sp two se)	Without surface treatment	2.32	Laser Ergon doped yttrium aluminum garnet	6.63
Altuntas M	5-55º 5000 cycles	Without surface treatment	2	Ntap Laser + primer	7.2
Koko M	5-55ºC 5000 cycles	Silane Free	0	Silane 5% by weight of MDP	14.7
Sokolowski G	5-55ºC 5000 cycles	Without surface treatment	6.1	Zircos E etched + primer monobond plus	17.7
Sadid-Zadeh R	5th - 55th 1000 cycles	Sandblasting 50umAl2O3	9.9	Zircos E etched + sandblasted	eleven

(Table 2) contd.....

Author	T.C.	Control	M.P.A.	TTO	M.P.A.
Kang CM	5-55°c – 5000 cycles (30s p – 15s t)	Sandblasted with aluminum oxide (50um 3 bar pressure)	10.4	glass ceramic spray deposition + hydrofluoric acid etching 120 seconds	10.1
Maroun EV	5º to 55º - 3000 cycles (30s p – 2s t)	Lithium disilicate etched with 10% hydrofluoric acid for 20 seconds	34.8	Vitrified with ceramic glaze, then sintered and etched with 10% hydrofluoric acid	24.1
Saker S	5-55°c- 7500 cycles (30s p – 2s t)	No treatment	9.5	Ceramic glaze etched with 10% hydrofluoric acid for 60 seconds	25.1
Martins SB	5-55ºC-10000 cycles (30 sp)	Sandblasted with 50um alumina after sintering	3.10	Sandblasted with 120um alumina before sintering	9.70
Mehari K	5-55ºC - 2500 cycles	Without sandblasting	6.0	Sandblasted with 50-micron aluminum oxide particles	13.4
Silva Am	5-55°c – 6000 cycles (30s p – 2s t)	Polished Zirconia	19.06	Silica layer coating	8.45
Chen B.	10,000 thermocycles	Sandblasted with aluminum particles and 10mdp self-adhesive resin cement	14.4	Tribochemical silica coating followed by silanization	14.6
Khan AA	5-55ºc-6000 cycles (30 s p- 5 st)	Without surface treatment	7.6	coating with tribochemical silica powder (rocatec) at 280 kPa	21.4

Once the research was carried out, various surface treatments were analyzed to improve the micro retention between the monolithic Zirconia and the resin cement, and a solution to the impossibility of acid etching was found. Below are certain statements in this regard.

5.1. Resin Cements

It should be noted that there is great diversity in the use of resin cement by the authors of the selected studies. This is because there is no single protocol for selecting this type of material regarding adhesion to Zirconia. While it is recognized that recommendations vary regarding the selection of the specific cementation material, it is commonly agreed that resin cement should be used to bond the Zirconia to the tooth structure.

In the present review, it can be observed that all authors chose resin cement as the cementation material in their experiments, except for Saker [18], who used self-adhesive resin cement (RelyX Unicem, 3M ESPE, Seefled, Germany) and compares it with a resin-modified glass ionomer cement (RelyX Luting Plus, Houston, TX, USA) to check their bond strength.

Authors such as Figuereido [23], Hatami [27], Lümkemann [25], and Altuntas [28] used dual-curing resin cement with anaerobic properties (PANAVIA F Kuraray Medical Inc., Okayama, Japan) Kabiri [24] and Kang [16] also used a dual-polymerization resin cement (Variolink N Ivoclar Vivadent, Liechtenstein, Germany). On the other hand, Abu Ruja [26] used another dual-polymerization resin cement (RelyXMTUltimate, 3M ESPE, St Paul, MN, USA). In contrast, Chen [21] used a self-adhesive resin cement containing 10-MDP phosphate (Solocem Coltene) and a dual-curing cement (Variolink N, Ivoclar Vivadent) for comparison. For his part, Khan [22] used self-curing resinous cement with the option of photopolymerization (Multilink®Speed, Ivoclar Vivadent); Maroun [17] used self-adhesive dual resin cement (Relyx U 200, 3M ESPE) while Martins [14] used dual-polymerization resin cement (relyx ARC); On the other hand, Mehari [20] and Sokolowski [30] used Dual Curing Resin (NX3, Kerr); Silva [20] used self-adhesive resin cement (U100 3M ESPE) and finally Sadid - Zadeh [31] used the dual and self-adhesive resin cement (Speedcem Plus; Ivoclar Vivadent AG).

Furthermore, as can be seen, this variability in the use of cementing agents may have influenced the final bond strength of the Zirconia with the dental structure, together with the surface treatment protocols and adhesion-promoting chemicals.

5.2. Hydrofluoric Acid

The combination of ceramic glaze and hydrofluoric acid resulted in one of the highest bond strength values of monolithic Zirconia to resin cement. A study by Saker [18], in which zirconia blocks without surface treatment bonded to resin cement blocks were tested for bond strength, and blocks that before bonding were subjected to a ceramic glaze and etching with 10% hydrofluoric acid for 60 seconds, showed that after a thermocycling of 7,500 cycles that the control group had a significantly lower strength than the surface treated group, with a difference of almost 16 megapascals on average. This demonstrates that the combined surface treatment of ceramic glaze and acid etching to generate micro protectants is a valid and robust alternative when cementing zirconia prostheses in the oral cavity is desired.

On the other hand, studies by Kang [16] and Maroun [17] demonstrated very similar bond strength values in Megapascals between zirconia specimens bonded with 10% hydrofluoric acid etching and glazing for 120 seconds and the control group specimens, in the first case after sandblasting with 50um aluminum oxide and in the other, with lithium disilicate blocks etched with 10% hydrofluoric acid for 20 seconds. This means that the bond strength values between the hydrofluoric acid etched specimens and the “gold standard” comparison specimens are practically the same, which demonstrates that the combined technique of ceramic vitrification and subsequent etching with hydrofluoric acid is highly reliable for the cementation of monolithic zirconia restorations in the oral cavity.

5.3. Sandblasting

In two studies, Martins Sb [14] and Mehari K [19] tested the aluminum oxide sandblasting technique in two different variants; in the first study, the particle size was modified: 50um and 120um, respectively, and in the second, sandblasting with 50um aluminum oxide with zirconia blocks without sandblasting was compared. In both the first and second cases, the bond strength values in Megapascals were significantly higher when sandblasting was used on the zirconia surface and when the aluminum oxide particle size was 120um. In other words, sandblasting with aluminum oxide remains the most reliable surface treatment for achieving the strongest bond between monolithic Zirconia and resin cement. It should be noted that both studies used thermocycling before bond strength testing.

5.4. Tribochemical Silica Coating

Tribochemical silica coating has also been used to improve the resin bonding properties of non-silica materials, such as Zirconia and alumina-based ceramics. The tribochemical silica coating exerts a dual functionality: both increasing the silica content of the ceramic surface and roughening it, thus providing a surface for silanization and, therefore, chemical affinity with the resin [21].

It is developed in 3 steps: sandblasting, friction, and grinding. First, the roughness of the Zirconia is increased, and silica deposition is performed on the surface, which makes it more receptive to chemical bonding through silane coupling agents and the hydroxyl groups of the resin cement [34, 35]. Silva Am [21] showed that the simple application of a silica layer does not increase the retentive capacity of resin cement with Zirconia since the bonding values in Megapascals were significantly lower in the experimental group compared to polished Zirconia and without surface treatment as a control group. The study by Chen B [21], when comparing silica tribochemical coating followed by silanization, significantly increased the bond strength between zirconia and resin cement to values similar to those of the control group treated with sandblasting and self-adhesive cement. A study by Khan AA [22] in which the silica tribochemical coating system "Rocatec" at 280kpa is compared with zirconia blocks without surface treatment, shows a considerable difference in the bond strength of these two groups, even reaching an average of 13 Megapascals between one and the other. This demonstrates that the silica tribochemical coating system followed by silane placement promotes a highly reliable and resistant bond between zirconia and resin cement and can be considered a suitable surface treatment option during the clinical practice of prosthetic restoration. It should be emphasized that using a layer of silica nanoparticles without tribochemical treatment was insufficient to generate bond strength in Zirconia. This fact should be considered after the study by Figueiredo V [24] who observed premature de-cementation of the specimens even before they were subjected to tensile tests.

5.5. Laser

Another surface treatment option that has been widely tested is Laser. One of the most widely used in dentistry is Er: YAG (Ergon doped yttrium aluminum garnet), which has been shown to improve bond strength values between zirconia and resin cement compared to specimens without surface treatment. However, once it is tested with 50um aluminum oxide sandblasting, it tends to drop considerably in performance [24, 27], demonstrating that this is an up-and-coming field in adhesion but still needs more research to reach the necessary levels of clinical recommendation. On the other hand, in a study performed by Lumkemann K [25], using the plasma laser compared to specimens without surface treatment, a minimal difference was observed between the groups, confirming the above-mentioned study by Abu Ruja M [26] in which the single pulse laser was tested in comparison with sandblasting with aluminum oxide, observing a statistically significant difference between the two groups, showing values in Megapascals much higher to the Laser compared to sandblasting. This result is encouraging for the Laser as a surface preparation system for Zirconia. The same difference was observed in the Altuntas M [28] study between the Ntap laser followed by MDP primer placement and specimens without surface treatment, indicating, once again, that the combination of surface treatments is the key to achieving high bond strength values and thus ensuring the long-term success of zirconia restorations.

5.6. MDP

In an exciting study, Koko M 30 demonstrated MDP silane's excellent *in vitro* performance at 5% by weight compared to a control group without silane. The bond strength values in the control group were lower than those of the silanized group. This shows that MDP silane constitutes another essential tool in the arsenal of surface treatments to improve the bond between zirconia and resin cement.

5.6.1. Zircos E

Recently, the Zircos E etching system (ZSAT: Zirconia Surface Architecturing Technique, M&C Dental Co., Eunjin Chemical Co., Seoul, Korea), a mixture of nitric acid and hydrofluoric acid that can be applied at room temperature, has been introduced to the world of zirconia bonding. An increase in surface area by preconditioning could improve the interfacial adhesion and eventually increase the bond strength between the material and resin cement [36]. The results of the studies by Sokolowski G [30] and Sadid-Zadeh R [31] show that the Zircos E system, followed by priming and sandblasting, respectively, substantially improves the adhesive bond values between zirconia and resin cement. This result makes it possible to conceive the dual-acid system as a valid alternative when preparing the surface of monolithic Zirconia before undergoing resin cementation. However, more studies of this type are needed to corroborate the results of the Zircos E system as a surface preparation agent before cementation [37, 38].

CONCLUSION

Under the limitations of the present systematic review, we can conclude that:

- Zirconia is treated with mechanical and chemical surface-modifying agents, substantially improving its adhesive ability with resin cement.
- Aluminum oxide sandblasting, hydrofluoric acid etching, tribochemical silica coating, Laser, and etching with a combination of acids in the Zircos E system are micromechanical treatments that improve the bond strength between zirconia and resin cements.
- MDP silane agent is an effective chemical treatment to improve the bond strength between zirconia and resin cements.
- Coating exclusively with a silica layer does not improve the bond strength between zirconia and resin cements.

IMPLICATIONS FOR CLINICAL PRACTICE

Given that the clinical success of an indirect restoration depends on its correct cementation, it is essential to know the surface treatment that generates the most significant resistance between zirconia restorations and resin cement.

AUTHORS' CONTRIBUTION

It is hereby acknowledged that all authors have accepted responsibility for the manuscript's content and consented to itssubmission. They have meticulously reviewed all results and unanimously approved the final version of the manuscript.

LIST OF ABBREVIATIONS

HF = Hydrofluoric Acid

SBS = Shear Strength

MDP = Methacryloyloxydecyl Dihydrogen Phosphate

CONSENT FOR PUBLICATION

Not applicable.

STANDARDS OF REPORTING

PRISMA guidelines and methodology were followed.

AVAIALABILITY OF DATA AND MATERIALS

All the data and supportive information are provided within the article.

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CONFLICT OF INTEREST

The authors declared no conflict of interest, financial or otherwise.

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SUPPLEMENTARY MATERIAL

PRISMA checklist is available as supplementary material on the publisher's website along with the published article.

Supplementary material is available on the publisher's website along with the published article.

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