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Zirconia Adhesion: A Systematic Review

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Abstract

Introduction: Zirconia is the most widely used indirect restorative material in the present scenario. The luting of Zirconia is most commonly done in the traditional way by many dentists due to lack of reliable scientific data on the best materials and methods to lute Zirconia for its increased longevity. Though type I GIC is the preferred luting agent, reliable bonding between resin composite cements and Zirconia ceramics has been the advised luting agent. But it is difficult to achieve Zirconia-Resin bond because of their chemical inertness and lack of silica content that makes etching impossible. The purpose of this review is to classify and analyze the existing methods and materials suggested to improve the adhesion of zirconia to dental substrate by using composite resins, in order to explore current trends in surface conditioning methods with predictable results.

Methods: The current literature, examining the bond strength of zirconia ceramics, and including in vitro studies, clinical studies, and a systematic review, was analyzed. The research in the literature was carried out using PubMed and Cochrane Library databases, only papers in English, published online from 2012 to 2021. The following keywords and their combinations were used: Zirconia, 3Y-TZP, Adhesion, Adhesive cementation, Bonding, Resin, Composite resin, Composite material.

Results: Research, in PubMed and Cochrane Library databases, provided 398 titles with abstracts. From these, a total of 94 publications were chosen for analysis. After a full text evaluation, seven articles were discarded.

Therefore, the final sample was 86, including in vitro, clinical studies, and one systematic review. Various adhesive techniques with different testing methods were examined.

Conclusions: Airborne-particle abrasion and tribo-chemical silica coating are the pre-treatment methods with more evidence in the literature. Increased adhesion could be expected after physico-chemical conditioning of zirconia. Surface contamination has a negative effect on adhesion. There is no evidence to support a universal adhesion protocol.

Keywords: zirconia, composite resin, adhesion, bond strength, systematic review

Introduction

In recent decades, the increasing aesthetic needs in dentistry have led to the progressive overcoming of metal-ceramic prosthesis and led to a focus on indirect metal-free restorations. Zirconia has occupied an increasingly important role, thanks to its excellent mechanical [1] and biocompatible characteristics [2]. Unfortunately, zirconia, unlike glass ceramics, is not susceptible to etching and this makes it impossible to realize the adhesive procedures. Realizing safe and standardized adhesive cementation protocols of zirconia is necessary in order to adequately complete the conservative/prosthetic treatment plan, especially when the preparation is not retentive, (due to the characteristics of the abutment or of the prosthesis design), or when it is necessary to improve the mechanical characteristics of the tooth-prosthesis complex.

Over the last few years, many adhesion techniques have been studied. Different treatments of the zirconia surface, application of primers or adhesives, and various types of resin cements have been tested. However, a standardized adhesive cementation protocol, that provides univocal and reliable results, has not been identified [7,8,9].

The data we have available today come mostly from laboratory studies that, although they are useful for guiding subsequent clinical trials, have limitations in terms of clinical evidence. Furthermore, the results obtained from such a large number of tested techniques are not directly comparable. It is difficult to generalize the results in relation to the zirconia sample, or to the materials used, considering the wide range of products available on the market.

The aim of the review is, therefore, to compare different treatments of the zirconia surface, in order to determine a valid operative protocol for adhesive cementation. The main zirconia treatments are summarized in Figure 1.

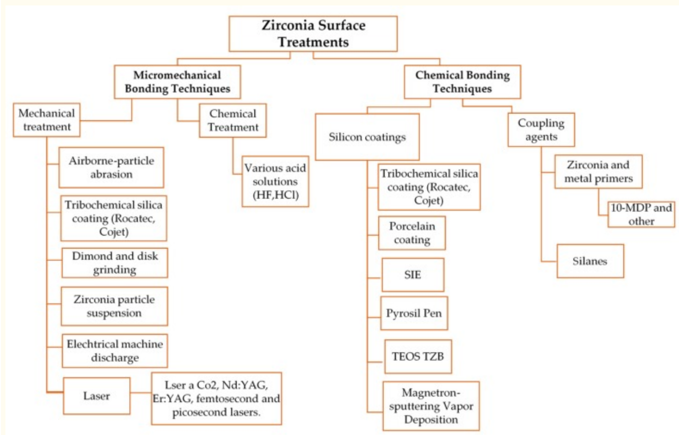

Figure 1

Zirconia surface treatments.

Materials and Methods

Search Strategy: To review the literature, the National Library of Medicine database was consulted using PubMed. The studies published from 1 January 2012 to 1 June 2021 were selected. The Cochrane Library database was also analyzed with a limitation on publication year . The following terms and their combination were searched: “Zirconia,” “3Y-TZP,” “Adhesion,” “Adhesive cementation,” “Bonding,” “Resin,” “Composite resin,” “Composite material,”. The research includes laboratory studies, clinical studies, and systematic reviews.

Eligibility Criteria

Regarding laboratory studies, no exclusion criteria were set in relation to the type of test performed for the evaluation of the bonding strength. However, it is important to evaluate the ability of the adhesive bond to resist over time. In this regard, studies in which samples are subjected to at least 5000 thermocycles or at least one month of H_2O storage are included in the review. Regarding clinical trials, RCTs and observational studies were included, with a follow-up, at least, of 5 years. The examined articles evaluate the clinical performance of adhesively cemented zirconia prostheses, in particular anterior cantilever prostheses, and prosthesis on inlays in the posterior sector. Studies that analyze traditional bridges with full crowns on the abutment teeth have been excluded. Inclusion criteria are listed in Table 1.

Table 1: Inclusion & Exclusion criteria.

Database	PubMed, Medline; Cochrane Library.	Type of paper	In vitro studies, clinical articles, systematic reviews.
Publication date	1 January 2013–31 December 2018	Inclusion criteria	Studies evaluating adhesion between zirconia and composite.
Keywords	Zirconia, 3Y-TZP, Adhesion, Adhesive cementation, Bonding, Resin, Composite resin, Composite material, Dentin, Enamel.	Exclusion criteria	In vitro studies: absence of bonding strength evaluation, insufficient aging (TC <5000 or storage <one month), complete crown specimens; Clinical articles: Case Report, Follow up < 5 years, studies on complete crowns.
Language	English	Journal category	All

Results

The research carried out in PubMed (Table 2 and Table 3) and the Cochrane Library (Table 4), 370, 77, and 31 studies are obtained, respectively. The duplicates are eliminated, obtaining a total number of 390 studies. By reading the abstract, studies that are not considered relevant, those that do not meet the aging requirements, or do not meet the inclusion criteria are discarded. Regarding in vitro studies, the most common reasons for elimination were the absence of the evaluation of the bond strength and the lack of evaluation of the aging effect (no TC or TC <5000). Some studies have been eliminated because they are not relevant (e.g., adhesion of zirconia brackets or posts) or not pertinent because they do not evaluate zirconia-resin bond (e.g., bacterial adhesion to zirconia). Pilot studies and case reports have also been discarded. After this screening, 93 studies are subjected to a full-text examination.

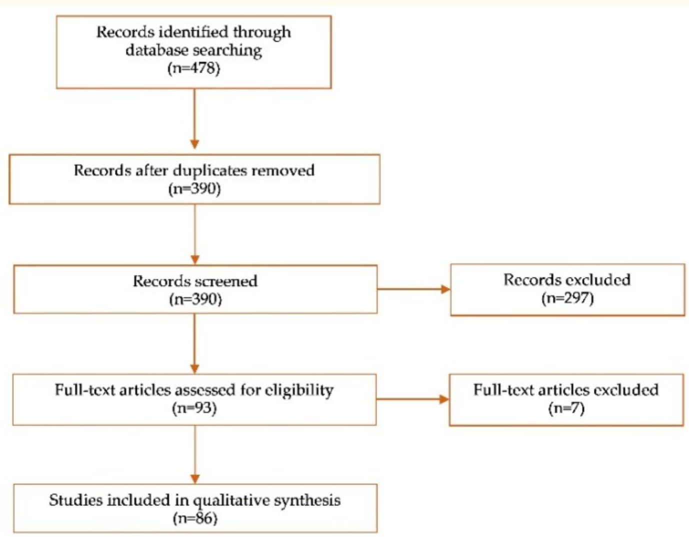

Figure 2

Discussion

The studies examined in this review mainly consist of laboratory studies. Different types of tests are performed to estimate the bond strength. The most widely used is the Macro Shear, which is the easiest to set up. Given the heterogeneity of the results, it was decided not to directly compare the bond strength values obtained in the studies. Long-term water storage and thermocycling are commonly used methods of artificial aging that affect the resin bond to ceramic [67,73]. This review includes both methods because, although thermocycling seem to be more reliable [67]. Several studies used the same aging protocol, observed a significant decrease in bond strength between the ceramic-cement interface, which proved that this time interval is sufficient to promote a degradation of this interface [16].

Regarding in vitro studies, the main zirconia adhesion protocols involve a mechanical conditioning phase and then the application of chemical adhesion promoters. The use of silane is rationally justified where a layer of silica (e.g., silica-coating, glaze on technique) was created [55], while, on polycrystalline zirconia, solutions based on functional monomers are used [47]. Sandblasting is a process that uses the energy released by the impact of alumina particles (Al_2O_3), emitted by a high-speed source [49]. Souza [101] recommends to carry out the sandblasting process using small particles (30 µm) with moderate pressure (2.5 bar) in order to avoid material damages. In 2013, Ozcan [102] proposes a protocol for blasting zirconia, with alumina particles with a diameter between 30 and 50 µm, at a pressure between 0.5 and 2.5 bar for a duration of at least 20 s. The blast jet must be positioned 10 mm from the target, and kept in motion, so as not to create defects.

The laser is proposed in zirconia adhesion as a mechanical conditioning technique. Nd: YAG laser is not able to guarantee satisfactory roughness and adhesion values, which also modifies the power set and time of application [80]. Zirconia overheating causes cracks, residual stress, and monoclinic transformation. Regarding Er: YAG laser, a setting of 2 W produces good roughness, like alumina sandblasting treatment, but the surface shows cracks and defects [35]. Laser application with energy intensity of 400 or 600 mJ is associated with material deterioration, while, with lower values (200 mJ), satisfactory adhesion is not obtained [72,79]. In terms of µTBS, the laser treatment seems to be superior to tribo-chemical silica-coating and alumina-sandblasting after a month of water storage [34].

Electrical Discharge Machine (EDM) is an unconventional method that leads to erosion of material through electrical impulses in a dielectric medium. In terms of Shear Bond Strength (SBS), the EDM technique obtains good results. However, by SEM analysis, surface cracks can be highlighted [35].

Zirconia is considered to be an inert material. The surface cannot be activated with hydrofluoric acid etching because it does not act on the crystalline component. Anyway, various acid solutions have been proposed to etch zirconia, based on hydrofluoric and nitric acid applied at a temperature of 100 °C. Acid etching of the zirconia surface with these modalities is less effective than Tribological-chemical treatment [52]. Other authors get positive results for some experimental solutions. Xie [71] obtains good results for adhesion protocols involving hot etching and application of 10-MDP primers. In another study [31], an experimental acid solution (800 mL of ethanol, 200 mL of 37% HCl, and 2 g of ferric chloride) is tested. It seems to be able to dissolve the surface of the zirconia and guarantee good adhesion. The solution is applied at a temperature of 100 °C for 1 hour. Xie [22] gets good results by the use of a 40% HF solution.

Although these techniques seem, in some cases, able to promote adhesion [22,31,71], it must be evaluated by the possible negative effects of the use of these methods, which are linked mainly to clinical safety [22].

Sandblasting, like other exclusively mechanical treatments, is able to modify the zirconia surface. However, it is essential to associate these treatments with the use of chemical promoters, capable of improving adhesion. Today 10-MDP-based cements and primers are used for this purpose [14]. Primers contain organophosphate monomers, including 10-MDP, 6-MHPA, or 4-META. The 10-MDP presents a terminal functional group with phosphoric acid, which reacts with zirconia and forms P-O-Zr bonds. The other end of the molecule is occupied by a vinyl terminal group, which allows the copolymerization with the resin. These two functional groups are separated by a carbon chain, which is responsible for characteristics such as viscosity, rigidity, hydrophobicity, and solubility. Solutions containing 10-MDP can promote better adhesion than those containing 4-META, MAC-10, or 3-TMSPMA [24,25,40,47,68]. Chemical adhesion increase occurs as well with a self-adhesive composite cement. However, the use of 10- MDP primer alone does not seem to be able to maintain good adhesion levels after thermocycling [46,49,76]. The use of a 10-MDP based primer is able to increase the bond strength both with a self-adhesive composite (based on 10-MDP or other functional monomers) and traditional composite cement [40,44,46,66]. It seems to be important to use a sufficiently fluid cement to benefit from the effects of sandblasting, despite the kind of composite. Regardless of the results obtained by the various studies, the authors agree that thermocycling strongly affects the bond between sandblasted zirconia and 10-MDP-based materials, which puts the long-term reliability of this adhesion protocol at risk [30,37,81].

Tribochemical silica-coating (TBS) is another method used to promote adhesion to zirconia. This is a sandblasting process that is carried out using alumina-particles covered with silica, which impacts against the surface of the ceramic, as well as creates an irregular surface while releasing silica [55]. TBS is carried out mainly by two methods: the Rocatec system consists of a traditional sandblasting pretreatment, and a subsequent use of silica-coated alumina particles (110 µm). The Cojet system uses coated alumina particles of silica (30 µm) and can be applied by the chair. The size of the particles used for alumina sandblasting (50 µm and 120 µm) or for tribological-chemical treatment (30 µm and 110 µm) does not affect SBS [57]. The use of a primer containing silane and 10-MDP allows the achievement of a better bond between composite and zirconia compared to the application of silane alone [32,38,85]. TBS appears to be more resistant to thermocycling than other treatments. According to thermodynamic calculations, the bond between silica and silane is more resistant to hydrolysis than the bond between zirconia and 10-MDP [45]. Several studies agree that TBS, followed by the application of silane-containing primer, is more stable than alumina sandblasting followed by the application of 10-MDP-based primers [28,71]. Sandblasting with feldspathic ceramic powder appears to have promising results in terms of SBS when compared to the use of silica-coated alumina, with a lower t-m transformation rate and stable results after thermocycling [33]. The use of rotary tools, discs, and diamond burs is not suitable for the treatment of zirconia [8,49]. The zirconia hardness involves the use of aggressive techniques, that inevitably lead to cracks and surface damage.

Zirconia is a polycrystalline ceramic, not conventionally etched with acid [54]. In order to promote adhesion, it can be treated like a glass ceramic. It is etched with hydrofluoric acid and the silane is applied as a coupling agent. This molecule has two different functional groups: the -SiOH group binds to the hydroxyl groups of silica coated surface forming a siloxane bond (Si-O-Si) and other functional groups of the silane (>C=C<) bind to the methacrylate of the resin [56]. There is a superiority of spray application systems rather than powder/liquid systems with a clinically acceptable marginal misfit (≈10 μm) [52,78,83,85]. Some authors mark a reduction in the bond strength after artificial aging methods, explained by the fact that the glass ceramic layer is not well bound to zirconia. The bond occurs through weak micromechanical interlocking and Van der Waals interactions susceptible to hydrolysis [97].

Silica deposition on zirconia, which allows the use of silane as a coupling agent, is also pursued by Magnetron-sputtering Physical Vapor Deposition (PVD). This method of SiO_2 deposition on the zirconia surface does not guarantee adhesion results comparable to those obtained with traditional treatments [63,86].

The silicatization of the zirconia surface is also obtained through "pyrochemical" techniques. The Silano-Pen system, for example, consists of a lighter containing a solution of butane and silane. When the butane is burned, the silane compound decomposes into SiOx-C fragments that adhere to zirconia, which can be silanized. This method is not sufficiently effective to promote a stable and lasting bond to the composite [8,49].

Zirconia can be modified with a technique called Selective Infiltration Etching (SIE): the ceramic is coated with silica-based material, with a thermal expansion coefficient similar to the zirconia one. During the fusion (when the temperature of 960 °C is reached), this material diffuses in the zirconia structure. Then hydrofluoric acid is applied for about 10 minutes in order to dissolve the glass component completely. The surface of the zirconia appears to be irregular [41,54].

With regard to the cementation phase, the main alternative to composites is the use of a traditional glass ionomer cement, or a CVI modified with resin. In terms of adhesion, the composite cements have better results [10,73]. Regarding the class of resin cements, the choice can essentially fall into two categories: traditional cements or self-adhesive cements. With traditional composites, the bond strength is linked to the effectiveness of preliminary treatments. For mechanical treatment and primer association, they are also less viscous, which may favor penetration into surface micro-porosities and resistance over time. Self-adhesive cements can bind to zirconia, but are not able to, alone, maintain stable long-term adhesion, which are more susceptible to hydrolysis. The association of mechanical conditioning and chemical promoters is essential [37,57,67]. Self-adhesive cement composition can be made of different functional monomers. According to some authors, the 10-MDP self-adhesive cements give better adhesion values [79,87]. In other studies, there is no clear superiority of a cement category [58].

The zirconia prosthesis can be contaminated during the clinical phases: blood, saliva, impression materials [43]. Cements and primers, by the presence of phosphate groups in their structure, interact with the surface of the zirconia. If contaminants are present, sites that could be occupied by the phosphate monomers become inactive [8]. Some treatments such as cleansing with H_2O, H_2O_2, ethanol, or acetone, the application of orthophosphoric acid, ethyl cellulose-based paints, ultrasonic cleaning, or plasma treatment are all ineffective in removing contaminants [13,43,51,53,62]. Sandblasting with Al_2O_3 powder is the most effective method for removing contaminants, even though it can weaken the structure of zirconia if carried out several times on the material.

Cleansing with NaOCl-solutions or with the cleaning paste Ivoclean (Ivoclar Vivodent, Schaan, Liechtenstein) (sodium hydroxide, ZrO_2, water, polyethylene glycol, pigments) seem a valid alternative in the consideration of costs and practicality, and the possible deterioration of the zirconia structure [20,51,53]. Furthermore, if phosphoric acid treatment or Ivoclean application are carried out after primer application, the Shear Bond Strength values decrease, likely to remove the coating of MDP either from a chemical interaction, mechanical debridement from the micro-brush, or both [43].

The introduction of translucent zirconia on the market allowed the realization of monolithic prosthetic products. Results show that bonding of highly translucent zirconia exhibits behavior similar to that of traditional 3Y-TZP [12,24].

To date, there are still few clinical studies on the realization of Resin Bonded Fixed Dental Prosthesis (RBFDP). Only five articles were found that meet our inclusion criteria and no one involves full zirconia restorations. Two clinical studies [91,92] concern the outcome of posterior inlay-retained fixed dental prosthesis. The results are contrasting. Other clinical studies, regarding the realization of incisors cantilever resin-bonded fixed dental prostheses, show good clinical longevity [90,93,94].

Regarding the systematic review included, Thammajaruk [103] collected papers only up to 2016. The meta-analysis compares bond strength results from different kinds of tests (micro and macro). Notwithstanding that, the present review partly agrees with their results.

Conclusions

In literature, we find a variety of adhesion protocols, including the use of different zirconia treatment methods, various adhesion media, different tests, and storage times. The results are difficult to compare.

The combination of a mechanical and chemical treatment is essential for good adhesion. Protocols with greater evidence in the literature include sandblasting with silica-coated particles (that allows the association of silane primers) and traditional alumina sandblasting (combined with the use of chemical promoters like 10-MDP-based products). The latter has less evidence of long-term stability. Other methods involving the silicatization of zirconia obtain promising results that must be validated by further studies.

The choice of the composite cement is less relevant.

Surface contamination has a negative effect on adhesion.

New highly traslucent zirconia shows a similar behavior, in terms of adhesion, to traditional 3Y-TZP.

An adhesion protocol that provides unequivocal results has not yet been identified.

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