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Review

Adhesive Cementation of Zirconia Based Ceramics-Surface Modification Methods Literature Review

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Abstract: Introduction: The conditioning procedures for glass-based ceramic restorations before adhesive cementation are generally recognized. In the case of polycrystalline ceramics, which include zirconium oxide, there is still no standardized protocol. The aim of this work was to present conditioning methods of the cementation surface of zirconium oxide fixed dentures. The new generation high translucency zirconia has been also considered. Material and method: The following keywords for the PUBMED and EMBASE databases were used: zirconium oxide, zirconium oxide with increased translucency, bond strength, bending strength, surface treatment. The inclusion criteria were original papers in English published between 2015–2021. Results: Out of 1537 publications, 53 articles were selected for the study, covering methods of conditioning zirconium ceramics, including new materials with increased translucency. These procedures were divided into 5 main groups. Summary: Due to the widespread use of zirconia ceramics and the introduction of new zirconia-based materials, the use of a predictable and standardized cementation protocol is one of the most important factors contributing to the long-term clinical success of prosthetic restorations. Therefore, the research showed differences in the properties of the covered materials after conditioning. It suggests the need to create separate conditioning protocols for highly translucent and traditional zirconia.

Keywords: high translucency zirconia; bond strength; surface treatment

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1. Introduction

Due to the growing aesthetic requirements of prosthetically treated patients, all-ceramic restorations are gaining more and more popularity in restorative dentistry [1]. All-ceramic systems are not only aesthetically better than metal-ceramic restorations, but also characterized by higher biocompatibility and chemical durability [2]. Undoubtedly, one of the most popular materials used in all-ceramic restorations is zirconium dioxide. It presents high bending strength (800–1200 MPa) and fracture toughness (4–6 MPa·$m^{1/2}$). The above-mentioned features of the material make it possible to perform a prosthetic reconstruction without a metal base [3,4]. Pure zirconium oxide is a polymorphic material that occurs in three allotropic forms: monoclinic (m) at room temperature; tetragonal (t) above 1170 °C; and in the cubic form (c) above 2370 °C. The most preferred in terms of physical properties is the high temperature tetragonal form. Its stability at room temperature is achieved by adding 3 mol% yttrium oxide (3Y-TZP) [5]. Conventional zirconium ceramic 3Y-TZP (3 mol% Yttria-stabilized Tetragonal Zirconia Polycrystal), due to its excellent mechanical properties, but also the milky color and opacity that does not meet the aesthetic requirements, is commonly used in all-ceramic prosthetic restorations as a framework veneered with translucent ceramics [6,7].

Despite the high 5-year period of operation rate for all-ceramic restorations on zirconium substructure, systematic reviews describe also complications such as veneering ceramic damage, known as chipping (crowns 3.1%, bridges 20.4%) [8,9]. In order to avoid this clinical problem, translucent zircon was introduced. It enables the fabrication of aesthetic, monolithic prosthetic restorations that do not require veneering [5,10].

The literature indicates various technologies for improving the translucency of zirconium oxide. The latest method is to increase the cubic phase by introducing higher contents of 4–5 mol% yttrium oxide (4 or 5 mol% partially stabilized zirconia; 4Y-PSZ or 5Y-PSZ) [5,6,10–12]. Despite the improvement in the transparency of zircon, along with the increase in the content of yttrium oxide and the cubic phase, the bending strength of the material decreases (550–800 MPa) [7,10,13].

Another problem encountered during the clinical observation of zirconium oxide fixed dentures is the loss of retention of the prosthetic restoration [8]. A number of reasons cause this complication; one is the inability to adhesively cement zirconium oxide prosthetic restorations. The lack of a glass phase in the structure and the chemical inertness of the material causes zirconium oxide to not be susceptible to traditional etching procedures [3,10,14,15]. Moreover, the hydrophobic nature of zircon results in the low wettability of the material surface by resin cements [16]. Due to the widespread use of traditional zirconia ceramics and the introduction of a new generation of high-translucency zirconia materials, the amount of research on the optimal protocols for the conditioning of zirconia surfaces is observed. Their purpose is to improve the quality of the bond with resin cements without deteriorating the mechanical properties [5,14]. As the research results show, adhesive cementation compared to conventional cementation of zirconium oxide crowns improves the mechanical strength of the material, marginal tightness and retention of prosthetic works, which has an impact on the favorable clinical prognosis of prosthetic reconstruction [17,18].

2. Materials and Methods

The literature review was carried out using the PUBMED database and the EMBASE database using the key words: 'zirconium oxide', 'zirconia with increased translucency', 'monolithic zirconium oxide', 'bond strength', 'flexural strength', and 'surface treatment'. The inclusion criteria were original research papers, available in English, published between 2015–2021. Identifications of records from the databases was performed separately by two researchers. Duplicates were removed. Further exclusion based on title and abstract was performed. Detailed selection process was presented on Figure 1.

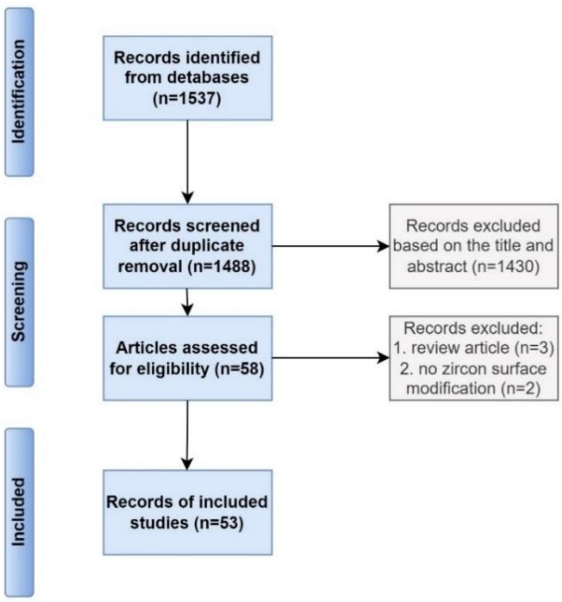

Figure 1. Flow diagram of review protocol.

The aim of this study was to present the methods of preparing the inner surface of zirconium oxide fixed dentures before adhesive cementation. All prior systematic reviews were excluded. This study demonstrates the differences in the possibility of conditioning traditional zirconium ceramics and new zirconium oxide-based materials.

3. Results

As a result of the literature review, 1537 works meeting the keyword criteria were included in the evaluation. After analyzing abstracts and then the full text, 53 articles were qualified for evaluation. The obtained results were divided by the method of zirconia dioxide cementation surface preparation.

In order to obtain a high bond strength between zirconium ceramics and resin cement, it is necessary to obtain a micromechanical and chemical bond. Numerous studies confirm that the zirconium surface should be prepared before the resin cement application, as all conditioning methods improve the quality of the zirconium-resin bond strength [2,4,10,19–22]. Various surface treatment methods are recommended for micromechanical and chemical combination, including mechanical treatment, laser irradiation, chemical treatment, coupling agents and ceramic coatings [15,20,23–25]. Figure 2 summarizes the main methods covered in this review, and emphasizes the most promising ones.

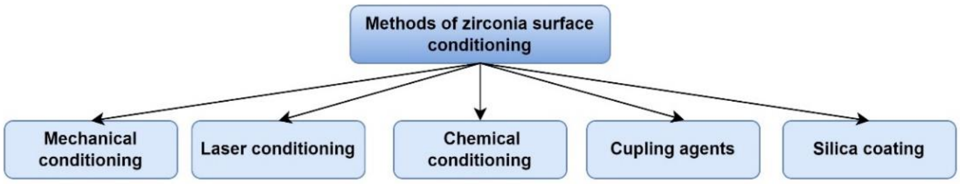

Figure 2. Surface modification methods.

3.1. Mechanical Conditioning Methods

The traditional and most frequently used method of mechanical treatment of the inner surface of a restoration made of zirconium oxide is abrasive blasting [10]. This method consists of striking the ceramic surface of alumina (Al_2O_3) particles at high speed. As indicated in the literature, the sandblasting process can positively affect the quality of the connection of zirconium oxide with the composite cement by increasing roughness, cleaning the ceramic surface and improving its wettability [10,19,26]. Sandblasting can also improve the mechanical properties of the material due to the transformation hardening phenomenon characteristic of zirconium oxide. The mechanism of enhancing transformation is based on the transformation of a metastable tetragonal form into a stable monoclinic form under the influence of external stress. It is accompanied by a local increase in the volume of grains from about 3 to 5%. It causes compressive stresses that inhibit the process of crack propagation at the site of transformation [13].

The research also showed a negative effect of sandblasting on zirconia ceramics. Overly intensive blasting can lead to an increase in the monoclinic phase, surface roughness, the formation of microcracks and gaps in the material structure, and the sticking of alumina particles into the surface. Incorrectly performed sandblasting weakens both the mechanical properties of the material, and adversely affects the quality of the bond between the resin cement and zirconium ceramics [10,27,28]. Therefore, the literature recommends sandblasting with aluminum oxide. However, the parameters of time, pressure, distance from the source and grain size should be taken into account [10]. In order to maintain the beneficial effect of sandblasting, the balance between the size of the damage to the material and the compressive stresses resulting from the transformation of tetragonal into monoclinic phases in the surface layer of zirconium ceramics needs to be obtained [2].

This is confirmed by a study conducted by Kwon et al. comparing the effect of sandblasting with aluminum oxide with a grain diameter of 50 and 110 μm at a pressure of 0.2 and 0.4 MPa on the residual stresses and the bond strength of resin cement (Panavia F 2.0) to the oxide zirconium (Cercon® ht). In the test, along with the increase in the size of the alumina grains and the sandblasting pressure, the surface roughness of the material and the size of the residual stresses increased (from 451 to 905 MPa). However, it has also been noticed that with increasing sandblasting pressure, there is an increase in the undesirable monoclinic phase on the zirconium oxide surface. In the above test, before artificial aging by thermocycling, the samples sandblasted with 50 and 110 μm alumina under a pressure of 0.4 MPa showed the highest shear strength of the zirconium oxide/resin cement bond. However, after thermocycling, no significant differences in wall strength were found between the groups of sandblasted zirconium. It was shown that the increased roughness of the zirconium surface and the amount of residual stresses did not affect the quality of the composite cement bond with zirconium oxide. Therefore, researchers recommended sandblasting with 50 μm alumina at 0.2 MPa pressure, which causes slight damage to the material, limited to the area of compressive residual stresses [4].

Similar results were obtained by Okada et al. They noticed that with increasing pressure of traditional Y-TZP (Lava Frame) blasting, the surface roughness of the material increases. On the other hand, microcracks will appear at a high sandblasting pressure of 0.40 MPa. To increase the bending strength of Y-TZP, they found the optimal sandblasting of 50 μm under a pressure of 0.20–0.35 MPa for a period of 10 s [29]. Kim et al. suggested 3Y-TZP as the most advantageous sandblasting protocol with the use of alumina grains with a diameter of 110 μm to a pressure of 0.2 MPa for a period of 10 s/cm^2, at a distance of 10 mm and at an angle of 90° [10]. In addition, alumina blasting has been shown to increase the flexural strength of zirconia ceramics [23]. On the other hand, omitting the sanding step before applying the primer may contribute to the weakening of the zirconium oxide bond with the composite cement. It has been found that sandblasting both develops a micromechanical bond with the resin cement, but can also generate hydroxyl groups of the Y-TZP ceramic, facilitating a chemical reaction with the phosphate monomers [19].

Discrepancies in the phase composition and microstructure of the translucent zirconia translucency and the traditional 3Y-TZP result in a possible different blasting effect. Sandblasting protocols for high translucency zirconia ceramics have not yet been well studied [10,12]. Several studies have compared the effects of alumina abrasion of different types of zirconia ceramics [2,10,30–32]. In the work of Kim et al., the surface topography and the size of residual stresses for three types of zirconium oxide after sandblasting with different sizes of alumina grains at a specific pressure, time, distance and impact angle were examined, respectively: 0.2 MPa, 10 s/cm^2, 10 mm and 90°. The test results show that the most favorable value of residual stresses with minimal damage to the material surface occurs when using Al_2O_3 sand with grain size of 110 μm for conventional 3Y-TZP, 90 μm for 4Y-PSZ and 25 μm for 5Y-PSZ [10]. Test by Yoshida involved sandblasting with 50 μm alumina grains at a pressure of 0.1, 0.15, 0.2, 0.3 MPa for 15 s at a distance of 10 mm of high translucency zirconia (Y-PSZ) samples. It proved that with increasing sandblasting pressure, the surface roughness of the material increases, while its bending strength decreases. The decrease in flexural strength was attributed to the reduced tetragonal to monoclinic conversion and the presence of a high cubic phase content. Additionally, the appearance of a new rhombohedral phase was noticed, and it increased after increasing the sandblasting pressure. The difference in the preservation of flexural strength between conventional Y-TZP and Y-PSZ was related to the lack of transformation hardening for high-speed Y-PSZ. The results of this study suggest that conditioning of the tooth surface of a high-performance zirconia restoration by sandblasting at 0.2 MPa and the use of a resin cement containing MDP will ensure a permanent bond to the tooth abutment [2]. Similar results were obtained by Aung et al., which showed that a durable and reliable bond of high-translucency zirconia ceramics with a resin cement can be achieved by sandblasting at a pressure of 0.2 MPa, and applying a primer containing the compound 10-MDP [32]. On the other hand, AlMutairi et al. have shown that blasting with 50 μm alumina at 2 bar pressure has an adverse effect on the flexural strength of 5Y-PSZ [33]. In other studies from 2020, Chen et al. proved that 5Y-TZP and 3Y-TZP after blasting show similar bond strength to composite cement [30]. A different opinion was published by Ruales-Carrera et al., according to which sandblasted clear zirconium oxide exhibits a lower, weaker bond strength to resin cement compared to sandblasted conventional zirconium [31].

It is worth mentioning the unconventional technique of conditioning the cementation surface of the zirconium oxide restoration, which is air abrasion with the use of spherical glass particles. Due to the fact that the glass particles are softer than the alumina grains, the literature indicates that they can be used to treat zirconium oxide with high translucency [34]. The authors of Khanlar et al. demonstrated in their work that air abrasion with glass particles can be an alternative to traditional alumina sandblasting and tribo-chemical siliconization. It also improves the bond strength of composite cement with zirconium ceramics with increased translucency [35]. A different opinion was published by Tzanakakis et al. in a study from 2021, in which they did not recommend glass particle conditioning in the case of 5Y-TZP, as this method, compared to sandblasting and femtosecond laser ablation (FEMTO), gives a much lower bond strength 5Y-TZP with resin cement [33]. In addition, in their study, AlMutairi et al. proved a negative effect on the flexural strength of 5Y-PSZ zirconium ceramics after conditioning the material surface with glass particles of 50 μm [36].

3.2. Laser Conditioning

Structuring the surface of zirconia ceramics by air abrasion often leaves contaminants in the surface layer of the material, which can adversely affect the surface properties and mechanical strength of the zirconia ceramics. Therefore, an alternative method of zirconium surface treatment, laser conditioning, has been proposed [36]. After laser application, as after sandblasting, a rough material surface with increased wettability is obtained, which is micromechanically bonded with the resin cement [37]. The literature describes the modification of the zirconium oxide surface with lasers such as: Er: YAG, Nd: YAG, Yb: YAG, Er, Cr: YSGG, Yb: KGW, CO_2 with different power, energy consumption, distance and time parameters duration [20,21,36,38,39]. However, the use of lasers to treat zirconium oxide is debatable. Studies confirming the effectiveness of the above method of conditioning zirconium oxide are available in the literature. One of them is the research work of Hatami et al., in which it was proven that the treatment with Er: YAG, Nd: YAG and CO_2 lasers on the surface of zirconia ceramics improves the shear bond strength (SBS) of the material to the resin cement. Researchers noticed that the zirconium surface irradiated with Er: YAG laser and sandblasted with particles of 50 μm Al_2O_3 showed comparable bond strength to cement [20].

In their research from 2021, Yahyazadehfar et al. compared the effect of different types of surface treatment (sandblasting, diamond drill grinding and Er, Cr: YSGG laser ablation) on the surface roughness of zirconium oxide. They assessed the relative percentage of monoclinic phase in the treated samples by means of X-ray diffraction (XRD). In addition, they tested the biaxial bending strength of the specimens. The study proved that the laser can be an effective method of modifying the zirconium oxide surface, as the laser treatment gives the required surface roughness of the zirconium oxide, thus improving the micromechanical retention. Additionally, a lower percentage of monoclinic phase was observed in the samples subjected to laser ablation compared to sandblasted samples, with comparable flexural strength. Moreover, it was found that the distribution of defects in the material created during laser processing is controlled and homogeneous [21]. Furthermore, in-vitro results confirm that both the femtosecond laser (FEMTO) surface treatment of high translucency zirconia and sandblasting with alumina of different grain sizes (50 and 90 μm) gives similar bond strengths with resin cements. Research confirms that laser irradiation is a promising alternative method to improve the bond strength between high-translucency zirconia ceramics and composite resins [36]. It is worth noting that the literature also indicates research works that negate the effectiveness of the described method. In their study, Aras et al. showed that laser treatment did not increase the shear bond strength (SBS) between zirconium oxide and composite cement [38]. On the other hand, the micromorphological evaluation of the zirconium oxide surface after CO_2 laser treatment by means of SEM shows that the surface roughness is related to microcracks that may affect the mechanical properties of the material [39]. Discrepancies between research results can be attributed to the use of different types of laser and their settings, as well as a comparison to different surface treatments and zirconia types [21].

3.3. Chemical Conditioning Methods

In the case of prosthetic restorations made of glass ceramics, in order to obtain a proper bond with resin cement, the cementation surface is modified with hydrofluoric acid (HF), and then silanized. Hydrofluoric acid selectively removes the glass phase, exposing the crystalline phase of the ceramic. As a result of etching, porosities are formed which give a micromechanical bond between porcelain and cement [34]. Zirconia ceramics are not amenable to conventional etching techniques. This is due to the fact that it is a silicon-free ceramics made of a high-temperature crystalline phase [1]. However, attempts are made to etch zirconia ceramics. Zirconium ceramics were subjected to etching with solutions of acids and acid mixtures, including hydrofluoric acid, hydrochloric acid (HCl), sulfuric acid (H_2SO_4) and nitric acid (HNO_3) at various concentrations, temperatures and application times [22,28,34]. In their research, Kim et al. assessed the effect of the application time of a solution containing a mixture of 25% hydrofluoric acid, 16% sulfuric acid, hydrogen peroxide, methyl alcohol and purified water on the surface properties and the biaxial flexural strength of sintered 3Y-TZP not previously treated and 3Y-TZP after sandblasting. All 3Y-TZP samples after treatment with the acid mixture showed additional increased surface roughness. The sand-blasted zirconium oxide samples showed the highest bending strength, which gradually decreased with the time of application of the solution, not exceeding the original value for the untreated samples. The probable cause was the formation of critical cracks in the material and the generation of hydroxyl groups (OH), which accelerate the low-temperature degradation (LTD) of zircon. Researchers suggested that the application of an acid mixture to the surface of zirconia ceramics could be an effective conditioning method, as it increases the surface roughness of the zirconia ceramics without compromising its original flexural strength [28]. In another study, Kim et al. proved that pre-treatment with 20% HF solution at 70–80 °C or 40% HF solution at room temperature and 70–80 °C effectively etches the surface of Y-TZP with acid, providing improved bonding. Y-TZP with composite cement [22]. Zircos E is a new system for etching zirconia ceramics at room temperature in laboratory conditions. It is a mixture of nitric acid and hydrofluoric acid. Pre-treatment of the zirconia surface with the Zircos E system for 2 h was proven to be effective in increasing the surface roughness of the material. Moreover, it is an alternative to sandblasting and tribo-chemical siliconization [23].

3.4. Coupling Agents

Sandblasting and other mechanical treatments, applied alone, can modify the zirconium surface. However, it is recommended to combine these treatments with the use of chemical promoters found in primers, bonding systems and cements. The chemical surface conditioner improves the adhesion of the zirconia to the resin cement, creating a bond that is more stable over time [12,39]. It has been shown that some chemical promoters based on acid functional monomers, including 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP), 4-methacryloyloxyethyl trimellitate anhydride (4-META) and 6-methacryloyloxyhexyl phosphonoacetate (6-MHPA) improve bond strength after blasting with alumina [19,24,40,41]. Currently, 10-methacryloyloxydecyl dihydrogen phosphate monomer (10-MDP) is the most commonly used. The MDP molecule has two functional ends. At one end, the hydrophilic phosphate ester groups form a strong bond with Y-TZP. The other, on the other hand, is occupied by vinyl groups that react with the monomers of the composite cement. These two functional groups are separated by a carbon chain responsible for properties such as hydrophobicity, viscosity, stiffness and solubility [19]. Numerous research studies confirm that primers without 10-MDP show a lower bond strength of zirconium ceramic/resin composite. One of them is the work of Ahn et al., who compared the effect of the use of different primers containing phosphate monomers on the shear strength of the joint between a self-adhesive composite cement containing MDP and the Y-TZP surface. The authors found that Z-PRIME Plus containing the MDP compound exhibited a significantly higher zirconium oxide/composite cement bond strength than the Metal/Zirconia primer based on phosphonic acid [19]. Another study by Yagava et al. found that the application of Clearfil Ceramic Primer Plus, Alloy Primer containing hydrophobic phosphate monomer (MDP) enabled the higher strength of the bond of resin cement with zirconium material with increased translucency (Katana Zirconia UT) after thermocycling than after using primers containing carboxylic monomer (4-META or MAC-10) [42]. Despite numerous observations, the positive effect of 10-MDP on the bond strength of zirconium ceramics with resin cement. The 10-MDP monomer found in primers, bonding systems and cements undergoes hydrolytic degradation over time, which contributes to the long-term reliability of this adhesion protocol [43,44].

3.5. Silica Coating

The use of a silane promoter is not effective for high strength ceramics without a glass phase. Therefore, various methods of coating the surface with a layer of silica have been proposed, such as tribo-chemical siliconization, plasma spraying hexamethyldisiloxane (plasma spraying hexamethyldisiloxane), glass melting ("Internal Coating" and "Glaze-on" techniques) and selective infiltration etching [25,41]. One of the most popular is the technique of modifying the zirconium oxide surface by air abrasion with silica-modified alumina particles (Al_2O_3 + SiO_2). The above method, called tribo-chemical silica coating (silicization), creates micro-retention depressions on the zirconium oxide surface. In addition, it chemically activates the ceramics through silica particles deposited on the zirconium surface, which react with the resin cement by means of a silane coupling agent [45]. The silicatization can be done with the Rocatec system, in which the zirconia ceramics are pretreated by conventional sandblasting followed by the use of alumina coated with 110 μm silica grains. Another tribo-chemical system is Co-Jet, which uses alumina with silica with a grain size of 30 μm for abrasive blasting [45–48]. In the literature, you can find research papers in which tribo-chemical treatment with Al_2O_3/SiO_2 particles improved the bond strength of zirconium ceramics with composite cements to a greater extent than traditional sandblasting [45,49]. In addition, it was characterized by higher resistance to thermocycling compared to other surface treatment methods. Another research study showed that the combination of silica with a silane coupling agent is more resistant to hydrolysis than the combination of zirconium oxide with 10-MDP [50]. In contrast, in their study, Ruales-Carrera et al. found that tribo-chemical siliconization was effective in increasing the bond strength of resin cement to both conventional and highly transparent zirconium oxide [31]. Another method of silicating the zirconium oxide surface is the use of a pyrochemical technique, e.g., the Silano-Pen system, which consists of a lighter filled with a solution of butane and silane (tetraethoxysilane). During the combustion of butane, the tetraethoxysilane contained in the gas breaks down into SiOx-C fragments, which, by van der Waals forces, connect with the zirconium oxide surface. The resulting silicate layer can thus be silanized with 3-methacryloyloxypropyl trimethoxy silane (MAPS), which chemically bonds to the silicate layer and the resin cement. However, it has been found that the present method is not effective in improving the bond strength between zirconia ceramics and composite resins [48]. Another method to improve the adhesion of composite resin to zirconia ceramics is Selective Infiltration Etching (SIE). In this technique, zirconium ceramics are coated with a thin layer of low-melting glass with a thermal expansion coefficient (WRC), similar to zirconia ceramics. After firing at 750 °C, the low-melting glass particles infiltrate the surface of the zirconium dioxide grains and form a glassy mesh. After the application of hydrofluoric acid and dissolution of the glass component, a rough and reactive surface of the zirconium ceramics is obtained, which gives a better micromechanical bond strength to the composite resin. The above method of surface conditioning, compared to blasting, develops three-dimensional retention features into which the adhesive resin can penetrate without applying external mechanical stresses and damaging the material structure [15]. Other coating methods with glass ceramics were also investigated, such as "Glaze-on" (Zenostar Magic Glaze Spray (ZM), IPS e.max Ceram Glaze Spray (IPS) or Hotbond zirconnect Spray (HB)). After the surface of the zirconium ceramic has been sprayed on until the glass is uniform, it is fired in a furnace followed by HF etching and silanization. In this technique, the glass-ceramic layer forms the inner coating of the prosthetic restoration, unlike the SIE technique, in which the applied glass layer is completely dissolved with the help of a conditioning agent. The test results show no practical benefits of the above conditioning method, both due to the need for additional work with the "glaze on" method compared to the sandblasting technique and the lack of improvement in the bond strength of zirconium ceramics with resin cement [25].

4. Discussion

A predictable, standardized cementation protocol is one of the most important factors contributing to the long-term clinical success of any type of restoration, including zirconium oxide [19]. The adhesive cementation protocols for silica-based ceramics are widely known and accepted. However, despite the high popularity of prosthetic restorations made of traditional zirconium oxide and the development of a new generation of zirconia ceramics, the adhesive cementation technique still raises some controversy [13].

Adhesive cementation is recommended in the case of insufficient mechanical retention, and in order to improve marginal adaptation of the prosthetic restoration. In addition, in the case of a fixed denture made of high-performance zirconia ceramics with weaker mechanical properties compared to conventional zirconium ceramics, it aims to increase the fracture resistance [42]. It is important to use such a treatment of the surface of the restoration adjacent to the abutment tooth, which ensures micromechanical and chemical connection of zirconium ceramics to resin cement, and at the same time does not adversely affect the mechanical properties of the material. The surface treatment may favorably affect the quality of the bonding of zirconium ceramics with the resin cement, but also have a negative effect on the mechanical properties of the material such as its bending strength, hardness and modulus of elasticity [51].

The aim of the above review was to present the methods of preparing the tooth surface of fixed dentures made of zirconium oxide before cementing, but also to draw attention to the differences in the possibility of conditioning traditional zirconia ceramics and new materials based on zirconium oxide. The main drawback of this review is a lack of further metanalysis. However, a number of different methodologies observed in analyzed scientific works made this impossible. Data suggest that optimal protocol of preparation for adhesive cementation might differ between traditional and translucent zirconia. Further research in this area are required, investigating the properties of those materials after conditioning separately. The relatively short presence of high-translucent zirconia ceramics on the market results in the lack of restorations of long-term clinical observations. Research covering this topic should also take into account the extent and location of restorations next to at least 5-year survival rates. It is important to mention that in the literature, other alternative methods of modifying the surface of zirconia ceramics have been proposed in order to improve the micromechanical connection with resin cement, including coating with nanostructured alumina, electro erosion treatment, the use of oxygen or argan plasma, or the application of titanium dioxide nanotubes to the surface of zirconia before sintering. Limited date about those methods made impossible to cover them closely, which also suggest a need for further research [16,46,52–54].

Despite numerous positive results of research on most methods of surface treatment of zirconia restorations, currently the most effective technique, confirmed by in-vitro and clinical tests, is sandblasting at moderate pressure, combined with the application of a primer containing MDP [19,24,31] monomer or tribochemical-siliconization with the Rocatec system [25,47], and Co-Jet with the use of silane [31,45,48,49]. It should be remembered, however, that prosthetic materials science is one of the most dynamically developing fields in dentistry, and thus the methods of zirconium surface treatment, considered to be the most effective today, may be subject to modification. Dentists who specialize in prosthetics have a difficult duty to constantly update this knowledge, which will ensure professional development and patient satisfaction, and consequently, therapeutic success, which is of key importance in the treatment process for both the doctor and the patient.

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References

1. Kimura, T.; Aoyagi, Y.; Taka, N.; Kanatani, M.; Uoshima, K. Metallization by Sputtering to Improve the Bond Strength between Zirconia Ceramics and Resin Cements. *J. Funct. Biomater.* **2021**, *12*, 62. [CrossRef] [PubMed]
2. Yoshida, K. Influence of Alumina Air-Abrasion for Highly Translucent Partially Stabilized Zirconia on Flexural Strength, Surface Properties, and Bond Strength of Resin Cement. *J. Appl. Oral Sci.* **2020**, *28*, e20190371. [CrossRef]
3. Srikanth, R.; Kosmac, T.; Della Bona, A.; Yin, L.; Zhang, Y. Effects of Cementation Surface Modifications on Fracture Resistance of Zirconia. *Dent. Mater.* **2015**, *31*, 435–442. [CrossRef] [PubMed]
4. Kwon, S.-M.; Min, B.K.; Kim, Y.K.; Kwon, T.-Y. Influence of Sandblasting Particle Size and Pressure on Resin Bonding Durability to Zirconia: A Residual Stress Study. *Materials* **2020**, *13*, 5629. [CrossRef] [PubMed]
5. Zhang, Y.; Lawn, B.R. Evaluating Dental Zirconia. *Dent. Mater.* **2019**, *35*, 15–23. [CrossRef] [PubMed]
6. Kim, H.-K. Optical and Mechanical Properties of Highly Translucent Dental Zirconia. *Materials* **2020**, *13*, 3395. [CrossRef] [PubMed]
7. Kolakarnprasert, N.; Kaizer, M.R.; Kim, D.K.; Zhang, Y. New Multi-Layered Zirconias: Composition, Microstructure and Translucency. *Dent. Mater.* **2019**, *35*, 797–806. [CrossRef]
8. Sailer, I.; Makarov, N.A.; Thoma, D.S.; Zwahlen, M.; Pjetursson, B.E. All-Ceramic or Metal-Ceramic Tooth-Supported Fixed Dental Prostheses (FDPs)? A Systematic Review of the Survival and Complication Rates. Part I: Single Crowns (SCs). *Dent. Mater.* **2015**, *31*, 603–623. [CrossRef]
9. Pjetursson, B.E.; Sailer, I.; Makarov, N.A.; Zwahlen, M.; Thoma, D.S. Corrigendum to "All-Ceramic or Metal-Ceramic Tooth-Supported Fixed Dental Prostheses (FDPs)? A Systematic Review of the Survival and Complication Rates. Part II: Multiple-Unit FDPs". *Dent. Mater.* **2017**, *33*, e48–e51. [CrossRef]
10. Kim, H.-K.; Ahn, B. Effect of Al_2O_3 Sandblasting Particle Size on the Surface Topography and Residual Compressive Stresses of Three Different Dental Zirconia Grades. *Materials* **2021**, *14*, 610. [CrossRef]
11. Mao, L.; Kaizer, M.R.; Zhao, M.; Guo, B.; Song, Y.F.; Zhang, Y. Graded Ultra-Translucent Zirconia (5Y-PSZ) for Strength and Functionalities. *J. Dent. Res.* **2018**, *97*, 1222–1228. [CrossRef] [PubMed]
12. Kim, H.-K. Effect of A Rapid-Cooling Protocol on the Optical and Mechanical Properties of Dental Monolithic Zirconia Containing 3–5 Mol% Y_2O_3. *Materials* **2020**, *13*, 1923. [CrossRef] [PubMed]
13. Blatz, M.B.; Vonderheide, M.; Conejo, J. The Effect of Resin Bonding on Long-Term Success of High-Strength Ceramics. *J. Dent. Res.* **2018**, *97*, 132–139. [CrossRef]
14. Yu, M.-K.; Oh, E.-J.; Lim, M.-J.; Lee, K.-W. Change of Phase Transformation and Bond Strength of Y-TZP with Various Hydrofluoric Acid Etching. *Restor. Dent. Endod.* **2021**, *46*, e54. [CrossRef] [PubMed]
15. Anand, S.; Ebenezar, A.V.R.; Anand, N.; Rajkumar, K.; Mahalaxmi, S.; Srinivasan, N. Microshear Bond Strength Evaluation of Surface Pretreated Zirconia Ceramics Bonded to Dentin. *Eur. J. Dent.* **2015**, *9*, 224–227. [CrossRef] [PubMed]
16. Kaimal, A.; Ramdev, P.; Shruthi, C.S. Evaluation of Effect of Zirconia Surface Treatment, Using Plasma of Argon and Silane, on the Shear Bond Strength of Two Composite Resin Cements. *J. Clin. Diagn. Res.* **2017**, *11*, ZC39–ZC43. [CrossRef]
17. Campos, F.; Valandro, L.F.; Feitosa, S.A.; Kleverlaan, C.J.; Feilzer, A.J.; de Jager, N.; Bottino, M.A. Adhesive Cementation Promotes Higher Fatigue Resistance to Zirconia Crowns. *Oper. Dent.* **2017**, *42*, 215–224. [CrossRef]

18. Indergård, J.A.; Skjold, A.; Schriwer, C.; Øilo, M. Effect of Cementation Techniques on Fracture Load of Monolithic Zirconia Crowns. *Biomater. Investig. Dent.* **2021**, *8*, 160–169. [CrossRef]
19. Ahn, J.-S.; Yi, Y.-A.; Lee, Y.; Seo, D.-G. Shear Bond Strength of MDP-Containing Self-Adhesive Resin Cement and Y-TZP Ceramics: Effect of Phosphate Monomer-Containing Primers. *Biomed Res. Int.* **2015**, *2015*, 389234. [CrossRef]
20. Hatami, M.; Lotfi-Kamran, M.; Davari, A.; Molazem, M. Effect of Different Laser Treatments on the Shear Bond Strength of Zirconia Ceramic to Resin Cement. *Dent. Res. J.* **2021**, *18*, 56.
21. Yahyazadehfar, N.; Azimi Zavaree, M.; Shayegh, S.S.; Yahyazadehfar, M.; Hooshmand, T.; Hakimaneh, S.M.R. Effect of Different Surface Treatments on Surface Roughness, Phase Transformation, and Biaxial Flexural Strength of Dental Zirconia. *J. Dent. Res. Dent. Clin. Dent. Prospect.* **2021**, *15*, 210–218. [CrossRef] [PubMed]
22. Kim, H.-E.; Lim, M.-J.; Yu, M.-K.; Lee, K.-W. Changes in Bond Strength and Topography for Y-TZP Etched with Hydrofluoric Acid Depending on Concentration and Temperature Conditions. *Medicina* **2020**, *56*, 568. [CrossRef]
23. Cho, J.H.; Kim, S.J.; Shim, J.S.; Lee, K.-W. Effect of Zirconia Surface Treatment Using Nitric Acid-Hydrofluoric Acid on the Shear Bond Strengths of Resin Cements. *J. Adv. Prosthodont.* **2017**, *9*, 77–84. [CrossRef] [PubMed]
24. De Lucena, P.L.; Fernanda, C.; De Oliveira, D.P.A.M.; Daniel, G.L.; De Assunção, S.R.O.; Özcan, M. Can Application of Universal Primers Alone Be a Substitute for Airborne-Particle Abrasion to Improve Adhesion of Resin Cement to Zirconia? *J. Adhes. Dent.* **2015**, *17*, 169–174. [CrossRef]
25. Franz, A.; Winkler, O.; Lettner, S.; Öppinger, S.; Hauser, A.; Haidar, M.; Moritz, A.; Watts, D.C.; Schedle, A. Optimizing the Fitting-Surface Preparation of Zirconia Restorations for Bonding to Dentin. *Dent. Mater.* **2021**, *37*, 464–476. [CrossRef]
26. Tostes, B.O.; Guimarães, R.B.; Noronha-Filho, J.D.; Botelho, G.D.S.; Guimarães, J.G.A.; Silva, E.M. da Characterization of Conventional and High-Translucency Y-TZP Dental Ceramics Submitted to Air Abrasion. *Braz. Dent. J.* **2017**, *28*, 97–104. [CrossRef]
27. Hallmann, L.; Ulmer, P.; Wille, S.; Polonskyi, O.; Köbel, S.; Trottenberg, T.; Bornholdt, S.; Haase, F.; Kersten, H.; Kern, M. Effect of Surface Treatments on the Properties and Morphological Change of Dental Zirconia. *J. Prosthet. Dent.* **2016**, *115*, 341–349. [CrossRef]
28. Kim, J.-E.; Kwon, Y.-C.; Kim, S.; Park, Y.-B.; Shim, J.-S.; Moon, H.-S. Effect of Acid Mixtures on Surface Properties and Biaxial Flexural Strength of As-Sintered and Air-Abraded Zirconia. *Materials* **2021**, *14*, 2359. [CrossRef]
29. Okada, M.; Taketa, H.; Torii, Y.; Irie, M.; Matsumoto, T. Optimal Sandblasting Conditions for Conventional-Type Yttria-Stabilized Tetragonal Zirconia Polycrystals. *Dent. Mater.* **2019**, *35*, 169–175. [CrossRef]
30. Chen, B.; Yan, Y.; Xie, H.; Meng, H.; Zhang, H.; Chen, C. 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. *J. Adhes. Dent.* **2020**, *22*, 373–382. [CrossRef]
31. Ruales-Carrera, E.; Cesar, P.F.; Henriques, B.; Fredel, M.C.; Özcan, M.; Volpato, C.A.M. Adhesion Behavior of Conventional and High-Translucent Zirconia: Effect of Surface Conditioning Methods and Aging Using an Experimental Methodology. *J. Esthet. Restor. Dent. Off. Publ. Am. Acad. Esthet. Dent.* **2019**, *31*, 388–397. [CrossRef] [PubMed]
32. Aung, S.S.M.P.; Takagaki, T.; Lyann, S.K.; Ikeda, M.; Inokoshi, M.; Sadr, A.; Nikaido, T.; Tagami, J. Effects of Alumina-Blasting Pressure on the Bonding to Super/Ultra-Translucent Zirconia. *Dent. Mater.* **2019**, *35*, 730–739. [CrossRef] [PubMed]
33. Tzanakakis, E.-G.C.; Beketova, A.; Papadopoulou, L.; Kontonasaki, E.; Tzoutzas, I.G. Novel Femto Laser Patterning of High Translucent Zirconia as an Alternative to Conventional Particle Abrasion. *Dent. J.* **2021**, *9*, 20. [CrossRef] [PubMed]
34. Martins, A.R.M.; Gotti, V.B.; Shimano, M.M.; Borges, G.A.; Gonçalves, L. de S. Improving Adhesion between Luting Cement and Zirconia-Based Ceramic with an Alternative Surface Treatment. *Braz. Oral Res.* **2015**, *29*, 54. [CrossRef] [PubMed]
35. Khanlar, L.N.; Abdou, A.; Takagaki, T.; Mori, S.; Ikeda, M.; Nikaido, T.; Zandinejad, A.; Tagami, J. The Effects of Different Silicatization and Silanization Protocols on the Bond Durability of Resin Cements to New High-Translucent Zirconia. *Clin. Oral Investig.* **2022**, *26*, 3547–3561. [CrossRef]
36. AlMutairi, R.; AlNahedh, H.; Maawadh, A.; Elhejazi, A. Effects of Different Air Particle Abrasion Protocols on the Biaxial Flexural Strength and Fractography of High/Ultra-Translucent Zirconia. *Materials* **2021**, *15*, 244. [CrossRef]
37. Esteves-Oliveira, M.; Jansen, P.; Wehner, M.; Dohrn, A.; Bello-Silva, M.S.; de Paula Eduardo, C.; Meyer-Lueckel, H. Surface Characterization and Short-Term Adhesion to Zirconia after Ultra-Short Pulsed Laser Irradiation. *J. Adhes. Dent.* **2016**, *18*, 483–492. [CrossRef]
38. Aras, W.M.F.; Barroso, J.S.M.; Blay, A.; Rodrigues, J.A.; Cassoni, A. Er,Cr:YSGG Laser Irradiation Influence on Y-TZP Bond Strength to Resin Cement. *Ceram. Int.* **2016**, *42*, 13790–13795. [CrossRef]
39. Kasraei, S.; Rezaei-Soufi, L.; Yarmohamadi, E.; Shabani, A. Effect of CO_2 and Nd:YAG Lasers on Shear Bond Strength of Resin Cement to Zirconia Ceramic. *J. Dent.* **2015**, *12*, 686–694.
40. Pitta, J.; Branco, T.C.; Portugal, J. Effect of Saliva Contamination and Artificial Aging on Different Primer/Cement Systems Bonded to Zirconia. *J. Prosthet. Dent.* **2018**, *119*, 833–839. [CrossRef]
41. Shimoe, S.; Hirata, I.; Otaku, M.; Matsumura, H.; Kato, K.; Satoda, T. Formation of Chemical Bonds on Zirconia Surfaces with Acidic Functional Monomers. *J. Oral Sci.* **2018**, *60*, 187–193. [CrossRef] [PubMed]
42. Yagawa, S.; Komine, F.; Fushiki, R.; Kubochi, K.; Kimura, F.; Matsumura, H. Effect of Priming Agents on Shear Bond Strengths of Resin-Based Luting Agents to a Translucent Zirconia Material. *J. Prosthodont. Res.* **2018**, *62*, 204–209. [CrossRef] [PubMed]

43. Zhao, L.; Jian, Y.-T.; Wang, X.-D.; Zhao, K. Bond Strength of Primer/Cement Systems to Zirconia Subjected to Artificial Aging. *J. Prosthet. Dent.* **2016**, *116*, 790–796. [CrossRef] [PubMed]
44. Chen, C.; Chen, Y.; Lu, Z.; Qian, M.; Xie, H.; Tay, F.R. The Effects of Water on Degradation of the Zirconia-Resin Bond. *J. Dent.* **2017**, *64*, 23–29. [CrossRef]
45. Altan, B.; Cinar, S.; Tuncelli, B. Evaluation of Shear Bond Strength of Zirconia-Based Monolithic CAD-CAM Materials to Resin Cement after Different Surface Treatments. *Niger. J. Clin. Pract.* **2019**, *22*, 1475–1482. [CrossRef] [PubMed]
46. Akay, C.; Tanış, M.Ç.; Mumcu, E.; Kılıçarslan, M.A.; Şen, M. Influence of Nano Alumina Coating on the Flexural Bond Strength between Zirconia and Resin Cement. *J. Adv. Prosthodont.* **2018**, *10*, 43–49. [CrossRef]
47. Sciasci, P.; Abi-Rached, F.O.; Adabo, G.L.; Baldissara, P.; Fonseca, R.G. Effect of Surface Treatments on the Shear Bond Strength of Luting Cements to Y-TZP Ceramic. *J. Prosthet. Dent.* **2015**, *113*, 212–219. [CrossRef]
48. Yenisey, M.; Dede, D.Ö.; Rona, N. Effect of Surface Treatments on the Bond Strength between Resin Cement and Differently Sintered Zirconium-Oxide Ceramics. *J. Prosthodont. Res.* **2016**, *60*, 36–46. [CrossRef]
49. Elsaka, S.E. Influence of Surface Treatments on the Bond Strength of Resin Cements to Monolithic Zirconia. *J. Adhes. Dent.* **2016**, *18*, 387–395. [CrossRef]
50. Xie, H.; Li, Q.; Zhang, F.; Lu, Y.; Tay, F.R.; Qian, M.; Chen, C. Comparison of Resin Bonding Improvements to Zirconia between One-Bottle Universal Adhesives and Tribochemical Silica Coating, Which Is Better? *Dent. Mater.* **2016**, *32*, 403–411. [CrossRef]
51. Sundh, A.; Kou, W.; Sjögren, G. Effects of Pretreatment, Specimen Thickness, and Artificial Aging on Biaxial Flexural Strength of Two Types of Y-TZP Ceramics. *Oper. Dent.* **2019**, *44*, 615–624. [CrossRef] [PubMed]
52. Rona, N.; Yenisey, M.; Kucukturk, G.; Gurun, H.; Cogun, C.; Esen, Z. Effect of Electrical Discharge Machining on Dental Y-TZP Ceramic-Resin Bonding. *J. Prosthodont. Res.* **2017**, *61*, 158–167. [CrossRef] [PubMed]
53. Tabari, K.; Hosseinpour, S.; Mohammad-Rahimi, H. The Impact of Plasma Treatment of Cercon® Zirconia Ceramics on Adhesion to Resin Composite Cements and Surface Properties. *J. Lasers Med. Sci.* **2017**, *8*, S56–S61. [CrossRef] [PubMed]
54. Dos Santos, A.F.; Sandes de Lucena, F.; Sanches Borges, A.F.; Lisboa-Filho, P.N.; Furuse, A.Y. Incorporation of TiO_2 Nanotubes in a Polycrystalline Zirconia: Synthesis of Nanotubes, Surface Characterization, and Bond Strength. *J. Prosthet. Dent.* **2018**, *120*, 589–595. [CrossRef] [PubMed]