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Strengthen of Zirconia Bonding: As A Review

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Abstract
Zirconia is a cost-effective material that has been specifically engineered to meet both aesthetic and functional needs, offering various advantages to users. The increasing demand for aesthetics has facilitated the promotion of new products that do not contain any metal. This study aimed to assess the existing information on zirconia, zirconia fused to dental veneer restoration, and various surface treatments that facilitate effective bonding to zirconia.
Material and Methods: we conducted a comprehensive search across various electronic databases of Google Scholar, PubMed, Science Direct, Web of Science, and other electronic systematic reviews. They were solicited for their perspectives on this issue and contributed to a manual exploration of the scientific literature. The review includes a selection of relevant articles obtained from a comprehensive analysis of published works ranging from 2016 to 2024. A total of seventy studies were selected for this review.
Results: A range of adhesive approaches were investigated to improve the bonding to zirconia using different testing methodologies. This results in persistent adhesion.
Conclusion: Zirconia ceramic exhibits advantageous physical, mechanical, and optical properties, rendering it well-suited for ceramic restorations. However, to enhance the bonding between zirconium and veneering ceramic, it is essential to employ specialized laboratory treatment and follow a specific protocol.

Introduction:

The need for dental aesthetics in the field of dentistry has recently increased (1). Reports indicate that all-ceramic restorations exhibit a survival percentage ranging from 88% to 100% within a two- to five-year period. Furthermore, this rate has the potential to increase to 97% over a period of five to fifteen years. Zirconia is the most superior all-ceramic restoration currently available, despite significant progress in all-ceramic restorations (2). Two major zirconia restoration categories include zirconia-based and monolithic zirconia restorations (3). Zirconia restorations have a wide range of applications in restorative and prosthetic dentistry; nevertheless, their clinical performance is influenced by the strength and longevity of the bond between the tooth structure and the zirconia a (4). PVZ prostheses, which consist of a Y-TZP core and a ceramic outer layer (also known as a bilayer structure), resemble natural teeth more closely despite being susceptible to cracking and delamination (5). zirconia ceramic surfaces must be improved to improve physical and chemical bond strength (6). Conventional and laser surface preparation techniques can make surfaces rough. HF etching, sandblasting, silanization, and combinations of these are conventional treatments. Laser protocols use Nd: YAG and Er: YAG lasers (7). Wear and even clinical failure of the coating material are cited by the majority of studies as the most significant drawbacks of zirconia so the goal of this evaluation was to assess the existing information on zirconia and zirconia fused to dental veneer restoration as well as various surface treatments that facilitate effective bonding to zirconia, in order to assess the debonding mechanism between lithium disilicate and zirconia.

Structure of zirconia

Zirconia is a type of ceramic material that consists of many crystalline structures. In the absence of a separating matrix, it exhibits a pronounced crystalline structure and possesses ceramic properties. The chemical name is zirconium dioxide (8). Adding oxygen to the pure, elemental metal of zirconium results in the formation of zirconium dioxide (ZrO_2), a glass-free ceramic substance (9). In 1975, Garvie et al. first recognized it as a high-performance ceramic, which they referred to as "ceramic steel"(10).

Due to their high melting point, zirconia ceramics face heat well. Material polymorphism is tetragonal, monoclinic, and cubic. The alkali fusion technique can make ZrO_2 from zircon ($ZrSiO_4$). Purifying zircon sand yields ZrO_2 in amorphous, tetragonal, and monoclinic forms. Additional compounds, like SiO2, are obtained (11).

At low temperatures, normally, the monoclinic (m) structure is a thermodynamically stable phase at room temperature (12). As shown in Figure (1). Stress and temperature can modify its phase. Zirconia's cubic phase (c phase) crystallizes while cooling below 2,680°C without chemical change. At 2,370°C, it becomes tetragonal (t phase), and at 1,770 °C, it becomes monoclinic. The latter phase change causes a 4% volumetric expansion (13). Mechanical characteristics and Zirconia phase transformation are affected by sintering, microstructure, heating and cooling rate, grain size, reduced thermal conductivity and diffusivity, and mechanical surface treatment (14).

-The aesthetic value of zirconia

matching the color of teeth is an important challenge in the field of cosmetic dentistry (15). For restorations to have a color match that is clinically acceptable, transparency and color stability are crucial qualities to consider (16). Patients increasingly value aesthetics, resulting in clinicians having a greater responsibility to accurately match colors. Precise color matching has become more crucial for the successful outcome of an aesthetic crown (15). The ideal framework material is important to appearance. Framework material translucency, opacity, color, opalescence, light absorption, reflection, and transmission are essential for a natural look and aesthetic requirements. The framework material's optical properties affect restoration color. The color of the porcelain veneer may be affected by the shade of the framework material (17).

Zirconia and lithium disilicate ceramic restorations have replaced metal-ceramic restorations for aesthetics and biocompatibility. Both ceramics outperform metal-ceramic restorations in color stability, clarity, gloss, and fluorescence (18).

Zirconia has been proven to possess the most limited degree of translucency among all ceramic materials. Zirconia restorations are often combined with a veneer layer of feldspathic ceramic to fix the issue of opacity that comes from the material's low ability to let light through. Zirconia restorations have enhanced translucency as a result of the veneering ceramic, hence giving a more natural appearance to the restorations (19). Yttria-stabilized Tetragonal Zirconia Polycrystalline (Y-TZP) is the most commonly employed ceramic material in dentistry among the various novel options available (20). Translucent zirconia materials were employed to reduce the risk of chipping in the veneering ceramic. These materials can be employed monolithically without the necessity of veneering on ceramic (21).

Various methods have been employed to match zirconia materials with teeth. Metallic pigments can be added to the original zirconia powder, either before or after pressing the milling blocks. Zirconia restorations can be enhanced with colors that create exterior characteristics. The utilization of rare earth element chloride solutions in coloring liquids enables the production of cores with varying hues (22). Polychromatic zirconia blocks that mimic dentin and enamel and stainable blocks were introduced. In 2013, Kuraray Noritake (Tokyo, Japan) introduced Katana Zirconia ML, the first polychromatic zirconia block (23).

Adhesion between zirconia and veneering material

There are two types of zirconia restorations: zirconia-based restorations and monolithic or full-contour zirconia restorations (24).

The first version of dental zirconia, known as 3Y-TZP, is employed as a primary material. It features a high-strength tetragonal crystalline phase that is stabilized with 3 mol% yttria and enhanced with 0.25% alumina. Because this kind of zirconia isn't very clear, a thick layer of felspathic porcelain needs to be added using CAD/CAM technology, the old-fashioned layering method, or the press-on method (25).

The adhesion between the zirconia core and porcelain is an essential factor that determines the long-term stability of zirconia-based restorations (26). Veneer-core dental restorations exhibit a remarkably high rate of failure. Prior studies have shown that the presence of veneer layer chipping and cracking accounted for 15–25% of failures in all-ceramic restorations (27).

Most instances of clinical failures in restorations made from zirconia have been recorded in the most sensitive area of veneering glass ceramics. If there is a crack in the outer layer of the tooth, it can generate a sharp and uneven edge. You can either polish it or fix the crack to fix this. However, if the crack affects the appearance of the tooth or causes problems with its function, it may be necessary to replace the tooth (28). Zirconia has chemical stability and bio inertness. The absence of an adhesive connection between the zirconia core and veneering material is due to the bio-inertness of zirconia. This results in weak resistance to delamination at the zirconia-ceramic interface (29).

Research has found that there is a greater occurrence of veneering ceramic fractures. However, clinical investigations have demonstrated that fixed partial dentures (FPD) made with 3Y-TZP frameworks have very low rates of failure. (Sailer et al., 2018; Suarez et al., 2019) (30).

Chipping or fractures are frequently seen as technical issues in zirconia ceramic veneering, occurring in around 8–25% of cases. 28 to 29 Adhesive fracture at the zirconia-porcelain contact is a somewhat rare occurrence (31).

Chipping refers to the full detachment of relatively large pieces of material (chips) due to fracture caused by concentrated forces from contact with a deliberately sharpened object (32).

Multiple attempts have been undertaken to resolve the problems related to chipping. To effectively resist chipping, it is advisable to utilize monolithic designs. Monolithic restorations not only address the issue of chipping but also necessitate little tooth preparation and allow for efficient CAD/CAM production, resulting in time and cost savings (33). There is a suggestion to modify the framework design in order to enhance the durability of ceramic restorations and reduce the likelihood of breakage. It is often recommended to attach a lingual collar to the proximal struts in order to enhance the support of the veneering ceramic in these important regions (34). In order to enhance the adhesive's strength, an alternative method of surface treatment is necessary (35).

An ideal bonding technique should provide a chemical and mechanical interaction between the adhesive and the surface being joined (36).

-Causes of veneering porcelain chipping (39)

Several factors contributed to the chipping of the veneering porcelain that include firstly, Improper framework supporting the veneering of porcelain and Improper handling in the laboratory and Improper application technique for veneering porcelain finally, Mismatch in mechanical and thermal properties such as fracture toughness, flexural strength, The coefficient of thermal expansion, and elastic modulus (37).

-Zirconia-based ceramics bonding techniques

As dentistry becomes more conservative, restorative materials must be aesthetically pleasing and chemically bondable. Zirconia restorations have struggled with these two properties. Bonding zirconia is difficult since it cannot be etched and silanized like glass and ceramics. Creating a chemical relationship with zirconia has taken a lot of work and research (38).

Adhesion refers to the process of two surfaces being joined together through interfacial connections (39). The surface of zirconia can be altered using three primary techniques: roughening, surface activation, and coating (40). It is advisable to employ both chemical and micromechanical bonding techniques to connect zirconia substructures. Chemical bonding is reinforced by micromechanical retention, and relying just on chemical components for bonding may result in partial detachment in moist environments such as the mouth (41). Hence, several surface modification techniques were created to enhance the roughness, contact area, and surface energy of zirconia (42).

-Micromechanical bonding techniques

A method of mechanical treatment called "airborne particle abrasion" entails applying pressure on alumina particles (50–100 μm) onto the zirconia intaglio surface. This leads to an augmentation in surface roughness, facilitates micromechanical adhesion, and expands the available surface area for bonding. In addition, air abrasion alters the wettability and surface energy of zirconia, enhancing its binding strength (43). when there is evidence of initial touch or inaccurate shaping in the restoration. When diamond burs are used for chairside correction, the removal of the glazing layer and the loss of surface smoothness that follows could cause surface faults to appear (44). The air abrasion device shows resemblance to a small sandblaster. The device operates by forcefully pushing a mixture of air or gas and high-quality abrasive particles (such as sodium bicarbonate, aluminum/silicon oxide, or bioactive glass) from the handpiece onto the surface of the tooth (45). Lasers operate in continuous wave (CW) or pulsed mode (PM), which sends energy to the material in milli- to nano-seconds or pico-to-femto-seconds. Various laser sources with different pulse lengths and wavelengths have been researched to change zirconia ceramic surfaces: Nd: YVO_4, Er: YAG, CO2, Er, Cr: YSGG (46). The mode and intensity of laser irradiation can cause zirconia cracks. Pico- and femtosecond lasers have been used to modify zirconia surfaces with minimal flaws and impurities (47). In tribochemical silica coating, aluminum oxide particles modified by silica are worn down by airborne particles. This makes the surface rough, which can respond to salinization (48). Enhancing the surface properties of biomaterials—which are typically used as strong mechanical supports—is the aim of coating, a common surface modification approach (49). Zirconia particles deposition It seems like using a suspension of milling waste to deposit zirconia particles could be a good and effective alternative to airborne particle abrasion (41). Electric discharge machining has been proposed as an alternative to mechanical surface modification techniques for modifying implant surfaces in medical applications. Nevertheless, the presence of surface imperfections resulting from EDM reduces the longevity of the implant. Scientists have achieved numerous breakthroughs in the past to improve the performance of EDM (Electrical Discharge Machining) (50).

-Chemical bonding techniques

Zirconia bonding techniques typically involve two main steps: surface pre-treatment and the application of a chemical bonding agent (51). Zirconia is a unique type of ceramic material that is resistant to etching with hydrofluoric acid (HF) due to its composition, which does not contain silica. Various acid mixes, including hydrochloric acid, phosphoric acid, and sulfuric acid, have been developed for treating the zirconia surface (52). At high temperatures, the hot etching solution selectively etches the zirconia ceramic surface, creating a rough surface that promotes mechanical interlocking with resin cements. Etchants adjust grain boundaries by removing less-ordered, high-energy grain boundaries (53). Selective infiltration etching (SIE) is a novel process that has recently been investigated for the purpose of roughening the surface of zirconia. SIE has improved the bonding strength with zirconia in comparison to the air-borne particle abrasion method (54).

Applying a silica layer using pyrochemical methods. This technique, exemplified by the silicated and silicoater TM classic, relies on the use of elevated temperatures. The surface of the substrate undergoes sandblasting and exposure to flames. This leads to the formation of a pyrochemical silica coating with a thickness ranging from approximately 0.1 to 1.0 micrometers. The coating solution consists of tetra-ethoxy silane (55). Pyrosilpen employs flame treatment to oxidize the surfaces of polymeric materials, generating polar reactive groups like hydroxyl and carboxyl groups. This process enhances the wettability and surface-free energy of the materials, facilitating bonding (37). A cost-effective, efficient, and scalable technique for applying thin coatings onto surfaces results in surface modifications that enhance desired properties such as resistance to wear, corrosion, roughness, and adhesion. This approach involves spray deposition, enabling high-throughput production (56). Silanes are efficient in enhancing the adhesion between resin composites and silica-coated indirect restorative ceramics by forming a siloxane linkage (-O-Si-O-) (57). Modern zirconia surface modification procedures like glass-ceramic spray deposition and fusion sputtering are easy to apply in dentistry labs. These unique surface modifications coat zirconia with a thick lithium disilicate glass-ceramic coating. The coating makes zirconia more hydrophilic and produces a large micro-mechanical interlock, enhancing its bond to resin cement (58).

-Other methods for surface treatment

Nevertheless, the amalgamation of chemical and mechanical procedures, such as utilizing alumina particles for air abrasion, proves to be efficacious in enhancing the adhesion between zirconia and tooth. (in conjunction with the utilization of chemical enhancers, such as solutions containing 10-MDP) (59). Tribochemical silica coating, followed by silanization, is a well-established method that effectively improves adhesion to Y-TZP (60). The sol-gel technique is an effective method for producing uniform coatings on various surfaces, ensuring strong adhesion and precise control over the synthesis process's stoichiometry(61). Due to its simple to use nature, the sol-gel approach is extremely versatile in terms of sample shape and coating composition, and it is also very cost-effective. One further advantage of sol-gel is its ability to provide a superior adhesive coating layer, leading to a firm bond between the substrate and the coating (62). application of a sprinkle method, or the use of the nanofluorapatite veneering ceramic during wash firing, enhances both the depth of shade and the binding strength (63). The procedure involves applying a layer over the entire framework by combining suitable liquids with shade and glaze until the desired consistency is achieved. The repair is then coated with nanofluorapatite veneering ceramic dentin powder using a dry brush (63). A retention device in the form of zirconia beads, similar to those used for resin-veneered metal crowns, was created by fusing them onto zirconia frameworks using an intermediate feldspathic porcelain. Nevertheless, research has not yet examined the surface modification of zirconia beads or conducted a comparison between nonzirconium and zirconia beads (64).

Results and Discussion

A different surface treatment method is necessary in order to achieve the desired increase in binding strength (37). The most popular are mechanical procedures like sandblasting and grinding. Nevertheless, these procedures are intrusive and result in an unfavorable transition from the tetragonal to the monoclinic phase, which lowers the restoration's endurance and leads to the face material chipping and cracking when the prosthesis is being used (65). Stable bond strengths between layering materials and zirconia frameworks can be achieved by surface treatments with lasers, such as carbon dioxide (CO_2), neodymium-doped yttrium aluminum garnet (Nd: YAG), and erbium-doped yttrium aluminum garnet (Er: YAG), according to numerous research (66). NTP processing in the field of dentistry has been well-established, offering potential benefits in enhancing the retentive strength of zirconia copings (67). The utilization of ultrasonic cleaning is commonly incorporated as a standard procedure in the production of Y-TZP ceramic samples, with limited consideration given to its potential impact on experimental outcomes (68). Crystalline ceramics, which lack a glassy phase, require stronger etchants. For additional applications, use 45% HF or a 1:3 volume ratio of 98% H_2SO_4 and 65% HNO_3. Results depend on etching agent kind, exposure time, and concentration. Direct ceramic repair during clinical management requires effective ceramic surface etching (65). The optimal choice of material and the most effective method for achieving a strong bond between the two components are subjects of continuing debate (69).

Conclusion

This review discusses many adhesion protocols and tests whose results are hard to compare. Strengthening the adhesion between dental porcelain and zirconia is essential for enhancing the durability of a prosthesis. Surface treatment is necessary to enhance the surface area and adhesive strength between dental ceramic and zirconia. The best method is mechanochemical treatment. The bonding method utilized to reinforce the zirconia must not have an adverse effect on its strength.

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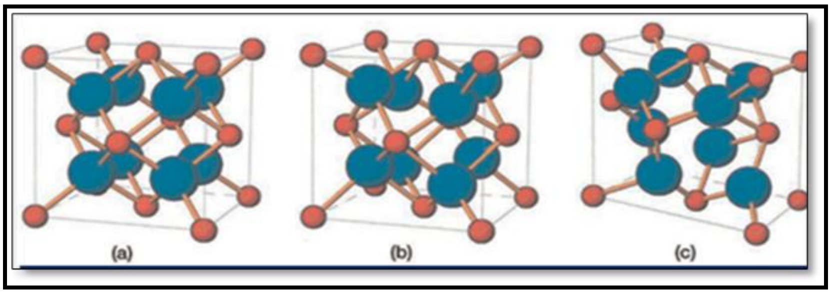

Fig.1 The following is a schematic representation of the three ZrO_2 polymorphs: (a) cubic, (b) tetragonal, and (c) monoclinic (14).

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