The Effect of Physicochemical Surface Treatment Methods on Bond Strength of Zirconia to Resin Cement: A Review of the Literature

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Abstract

Objective: Zirconium oxide has gained the spotlight during the recent years as a high strength ceramic material. However, despite its mechanical superiorities, it forms a weak bond with different synthetic substrates and tissues due to its neutral nature and resistance against chemical agents. Therefore, it is important to improve the bonding technique in order to prevent microleakage and increase retention and fracture resistance of the restoration.

Literature Review: Since the discovery of zirconium oxide, several surface treatment methods have been evaluated to increase its bond strength to resin cement such as surface grinding with micro-abrasion, burs or abrasive papers, tribochemical silica coating, silicoating, glass micropearls, glaze-on technique, selective infiltration etching, hot etching and use of phosphate ester monomers. The mentioned techniques and related articles are reviewed and discussed in the present study.

Conclusion: Despite extensive studies, no consensus has been reached about a specific treatment as the standard protocol for improving the bond strength of zirconia restorations.

Key words: Bond strength, High strength ceramics, Neutral nature, Resin cement, Surface treatment, Zirconium oxide.

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Introduction:

Recent advancements in ceramic material science for dental purposes led to the production of a group of high strength dental materials especially zirconia(1). Following its introduction to the dental market, it quickly became popular due to its excellent mechanical properties and esthetics in comparison with metal and metal-ceramic restorations (2).

Zirconia or zirconium oxide was accidentally discovered by Martin Heinrich Klaproth, a German chemist, while working on thermal processes during solidification in jewelry casting. It was used for years as a rare pigment. Its first application as a ceramic biomaterial was in hip joint replacement (3).

Zirconia is a polycrystalline material and can exhibit more than one crystalline structure depending on pressure and temperature conditions. At room temperature, pure zirconia has a monoclinic structure; this form is stable up to 1170°C. At higher temperatures, it transforms to tetragonal phase. If 2370°C is passed, it transforms to the cubic phase (3). When cooling down, it transforms from the tetragonal crystalline structure to monoclinic phase; this process is associated with an increase in volume about 3-4%. This increased volume creates high stress leading to crack formation and crushing of the material (1).

In 1929, it was demonstrated that addition of small amounts of calcium oxide (CaO) can stabilize the cubic phase and thus zirconia became usable for engineering purposes (1). In the following years, other oxides such as CeO_2, MgO and Y_2O_3 were used to stabilize the tetragonal phase at room temperature (4); among which, zirconia-Yttria (Y_2O_3) ceramic composition gained more attention and is now commonly known as Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP).

Y-TZP, due to its favorable mechanical and dimensional stability and particularly its mechanical strength and toughness, has numerous applications in space shuttles, automobile industry, cutting devices and ignition motors. Also, this type of zirconia is commonly used in dentistry.

Y-TZP is a monophase ceramic material that is produced by direct sintering of the crystals together without any intervening matrix. By doing so, a compact, void-free polycrystalline structure is formed (3).

Stress-induced transformation is a unique characteristic of Y-TZP ceramics during which, tetragonal phase around the crack zone transforms to the monoclinic phase. Increased volume due to this transformation puts pressure on the crack (3, 5). This characteristic is responsible for the superior mechanical properties of this material and consequent use of the term “ceramic steel” for this material (6-8).

However, despite its superior mechanical properties, zirconia suffers a natural disadvantage: its weak bond to different synthetic substrates and tissues. Due to its neutral nature, conventional cementation and bonding techniques do not provide adequate bond strength for zirconia structures for many clinical applications (9-11). This characteristic also explains the resistance of zirconia to invasive chemical agents like acids, bases or organic and mineral solvents (9). Therefore, it is important to find effective bonding techniques for this material to obtain higher retention, prevent microleakage and increase fatigue resistance and fracture resistance of the restoration (12).

A strong bond is achieved by micromechanical retention and chemical bonding to the ceramic surface (11, 13, 14). In other words, surface roughness is required and should be created for mechanical retention and surface functionalization for chemical bonding to zirconia (12). Etching by phosphoric acid or hydrofluoric acid is a common technique to create surface roughness in silica-based ceramics (15). However, this technique is not applicable for non-silica-based ceramics like zirconia and therefore, surface roughness in this group of ceramics is difficult to achieve (8, 9). Furthermore, due to its neutral nature and non-polarized surface, zirconia has low ability for chemical bonding (16). Despite extensive studies, the only consensus reached is that hydrofluoric acid and silanization are not effective in zirconia ceramics and no consensus has been reached about a standard surface treatment to maximize bonding to zirconia (3). This study comprehensively reviews different methods used by researchers to increase bond strength of resin cements to zirconia.

Literature Review:

An electronic search was carried out on Medline using “zirconia”, “bond” and “strength” key words and relevant articles published during 1980-2013 were reviewed.

Surface treatment methods

Surface grinding:

This method is commonly used to create surface roughness in zirconia to enhance mechanical bond. Various techniques have been suggested for this purpose including grinding and abrasion with abrasive papers and rotary abrasive brushes (silicone carbide or aluminum oxide), air abrasion with aluminum oxide or other abrasive particles (17-19) and abrasion with a diamond bur (19). The main advantage of these techniques is their easy application in dental clinical setting (1). However, studies have demonstrated that surface grinding techniques have no significant effect on increasing bond strength to zirconia if resin cements are to be used (8, 11, 19-21). These techniques are recommended for application along with cements containing phosphated monomers (3).

Air abrasion or sand blasting:

This technique cleans the surface, eliminates the impurities and irregularities, increases surface roughness and surface energy and enhances wet ability through mechanical contact of particles with the surface. Shape, size and chemical composition of particles, blasting pressure and distance between the nozzle and surface all play a significant role in surface changes (22-27). The most common particles used for air abrasion are 50-250 micron alumina or silica-coated alumina particles (19, 9, 25-31). This process can be done in dental laboratory or chair side (32).

It has been reported that micro-abrasion causes the transformation of tetragonal phase to the monoclinic phase and creates sharp cracks and structural defects in zirconia that make it susceptible to radial cracks in service (33, 34). However, no consensus has been reached in this regard. Magne in his study in 2010 demonstrated that particles equal or smaller than 50 micron do not compromise zirconia strength (35). In recent studies, conduction of air abrasion before sintering has been recommended in order to prevent damage to zirconia microstructure. The results of these studies in terms of bond strength have been encouraging (36, 37). Moon *et al*. in 2011 demonstrated that sandblasting of zirconia significantly increased its microshear bond strength and order of sandblasting before or after sintering has no effect on bond strength; but, samples that were sandblasted before sintering showed a less monoclinic structure; which had a positive effect on the clinical efficacy of zirconia restorations (37).

Tribochemical silica coating:

In this method, the surface is changed by the contact of silica-coated alumina particles. Particles are sprayed against the surface and due to a sudden increase in temperature at the contact point (up to 1200°C) a silica layer is deposited on the surface. Thus, the surface containing silica will be able to react with silane coupling agent. Furthermore, micromechanical retention is increased due to the micro-abrasion process. The two available systems based on this technique are Rocatec system (3M ESPE) for laboratory application and Cojet(3M ESPE) for chair side application (38, 42).

However, a significant reduction in bond strength to conventional resin cements occurs in long-term that can be due to the low concentration of silica on the surface. This issue is due to the difficult abrasion of zirconia because of its high hardness (1).

Takeuchi *et al*. in 2010 revealed that co-application of phosphate ester monomers and tribochemical silica coating after 30,000 thermal cycles did not cause a significant reduction in shear bond strength (43).

Glass micropearls:

In this method, a suspension of glass micro-pearls is prepared and applied to the zirconia surface followed by the process of heating in a furnace. By doing so, surface roughness is increased and also, due to the presence of glass on the surface, silane coupling agent can be successfully used. Studies have reported high bond strength values for this method. However, two criteria have to be met in this technique: 1. The heating process should not interfere with the heating of crown because glass pearls should not undergo excess melting and 2. Thickness of the layer should not be more than 5μ (44, 45).

Alumina coating:

Jevnikar *et al*. in 2010 by a scanning electron microscope (SEM) and transmission electron microscope (TEM) showed that alumina coating of a zirconia surface creates a retentive surface for resin penetration. This coating perfectly covers the surface and forms a uniform thickness of 240 nm. In the mentioned study, bond strength values were higher in groups that received an alumina coating fabricated by exploiting the hydrolysis of aluminum nitride powder compared to controls. Thermo cycling could not decrease the bond strength (46).

Glaze-on technique:

This is a recent technique aiming at creating an intermediate etch able layer of the glaze material with low melting point for zirconia surface coating. Studies on the efficacy of this technique for increasing bond strength have yielded encouraging results (47-50). However, further studies are required to create a layer with minimum thickness.

Silicoating

Silicoating is applying a silica layer to zirconia ceramic surface. It includes pyrolytic application of the silica layer to the substrate surface followed by silanization (51, 52). In this technique, with the use of a special laboratory equipment, butane gas is burned with atmospheric oxygen and guided to a container filled with tetraethoxy silane.Via a thermal reaction, a layer of SiO_x-C is coated on the surface of the substrate (53).

The Silicoater system (Kulzer) commercially available in the market has yielded successful results for metals in several studies (54-56). However, this technique is expensive and complex and is not suitable for standard application in dental clinical setting (1).

Pyrosil® (SURA Instruments) is another silicoater designed for chair side use. Application of this device for zirconia ceramics has been evaluated as well. However, in order to be selected as a standard technique, it requires further investigations (1, 53).

Plasma spray is another type of silicoating to create a Siloxane coat on the surface. Plasma is an ionized gas that contains ions, electrons, atoms and neutral spaces. Application of plasma has been extensively studied in different materials and it seems that in the majority of cases, increase in bond strength occurs through the formation of covalent bonds (44). For zirconia, plasma application caused high bond strength in comparison with the control group. However, the resultant bond strength was lower than that of zirconia coated with porcelain micropearls (1, 44).

Piasick *et al*. in 2009 used an instrument called molecular vapor deposition tool (MVD) for deposition of vapor molecules in order to create a thin layer on zirconia surface (57, 58). In this method, chlorosilane in combination with steam was used to create a reactive surface with Si_xO_y groups and it was demonstrated that this technique could improve resin bond to zirconia surface. In the mentioned studies, Si_xO_ylayer with 26 nm thickness created a bond strength similar to that of cement to etched and silanized porcelain and the created bond strength value was greater than that caused by tribochemical silica coating (58).

Selective Infiltration Etching (SIE)

SIE is a new technique to obtain a surface with high retention by creating inter-grain nano porosities. Resin can infiltrate and lock in between these porosities.

In this technique, a special form of glass is used. By stressing the grain boundaries during a specific thermal reaction, glass is melted and infiltrates into the grain boundaries on the zirconia surface. In the next step, infiltrated glass is eliminated by hydrofluoric acid etching, forming a network of nano-porosities and enabling a nano-mechanical bond between the surface and resin cements (1, 3, 59-63). Despite high primary bond strength, this technique has shown optimal results after aging as well (59-61). In Aboushelib study in 2010 SIE caused a higher bond strength than microabrasion and maintained it after thermo cycling and water storage; whereas, the abrasion group showed a significant reduction in bond strength after water storage (61). Bond strength and interface quality can be further improved in this technique by the use of silane and special primers (3).

Hot etching:

Considering the metallic nature of pure zirconia, an experimental chemical solution was recently introduced for hot etching of zirconia (62, 63). Optimal temperature of this technique is 100°C for 10 minutes. Hot etching mechanism is mainly based on a controlled corrosion reaction that selectively changes the grain boundaries by removing peripheral atoms that have less regularity and more energy and thus, provides a surface for micromechanical retention (3, 64).

In a study by Caucci *et al*. in 2009 hot etching under Atomic Force Microscopy (AFM) caused greater surface roughness in comparison with SIE (62). However, more studies are required to confirm the efficacy of this technique for improving bond strength to resin cement (3).

Phosphate-ester primers:

There is evidence supporting the good bond strength of zirconia with the use of resin cements containing methacryloxydecyl dihydrogen phosphate (MDP) (8, 65-67).Phosphate ester group is chemically bonded to metallic oxides such as zirconium oxide (3). Lehmann in 2009 and Wegner and Kern in 2000 evaluated the durability of Bis-GMA- and MDP-based resin cement bonds to zirconia. MDP-based resin cement after 150 days of water storage showed higher bond strength (17, 66). In other words, MDP-based cements were hydrolytically more stable (1). Furthermore, if these monomers are used in combination with air abrasion or tribochemical silica coating and silane, they create higher bond strength (8, 11, 20, 68, 69).

The anhydride group present in 4-methacryloxyethyl trimellitate anhydride (4-META) and phosphoric methacrylate ester monomers also bonds to zirconia (65, 70). However, studies have reported that the bond strength of resin cements containing 4-META after aging was less than the required threshold (9, 70).

Lorenzoni *et al*. in 2012 applied basic NaOH solution to zirconia surface and suggested that application of NaOH alone or prior to MDP-based primers can increase bond strength by increasing surface reactivity/functionalization and availability of OH groups. However, this increase in bond strength was less than the clinically acceptable threshold (71).

Laser:

In a study by Usumez *et al*. in 2013, the effect of Nd:YAG laser on surface roughness of zirconia and bond strength of resin cement to zirconia was compared with sandblasting and glazing. In their study, the highest surface roughness and bond strength were obtained with short pulse Nd:YAG laser (72). Similar results were obtained by Paranhos *et al*. in 2011 (73). However, Akyl *et al*. in 2010 reported that Nd:YAG laser can increase bond strength to resin cement only if it is used along with microabrasion (74). In Usumez *et al*. study in 2013, short pulse Nd:YAG laser caused higher surface roughness due to having higher energy but this issue had no effect on increasing bond strength (72).

Another point regarding Nd:YAG laser is the related destructive changes caused in zirconia surface. In SEM analysis, inter-connected micro-cracks were detected after laser treatment of zirconia surface (72-74). These cracks are formed because of the stress created due to uncontrolled thermal changes during laser treatment that can induce transformation of tetragonal to monoclinic phase (72).

Comparison of the discussed techniques:

Methods that are currently used in clinical setting include surface grinding by microabrasion or burs, application of phosphated monomers that form weak bonds to ceramic oxides and tribochemical silica coating (75). The latter has been proposed as the gold standard by some manufacturers. However, the obtained bond strength values are significantly lower than that of cement to conventional glass ceramics (6, 49).

SIE and hot etching techniques although have the ability to create a strong and stable bond between the cement and zirconia, they are still laboratory techniques and have not been generalized to the clinical setting (3, 61, 62). Furthermore, the effect of these two techniques on the mechanical properties of zirconia has yet to be evaluated (71).

Glaze-on and glass coating methods have recently gained the spotlight but require further studies in order to be able to create a thin uniform layer (47-50).

Other described techniques are mostly not applicable as a routine technique due to their complexity or requiring expensive equipment (1, 53, 54).

Conclusion:

Despite a large body of studies and extensive data regarding methods to enhance the zirconia bond strength, comparison of the findings and drawing a conclusion are still not possible due to the differences in methodologies, used materials and bond strength measurement tests. On the other hand, the majority of studies have reported short-term outcomes and number of clinical studies is scarce. Therefore, no consensus has been reached about a specific treatment as the standard protocol to improve bonding to zirconia restorations. Future investigations are required to further elucidate this issue.

Conflict of Interest: “None Declared”

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