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Review

Adhesion to Zirconia: Factors affect bonding to zirconia

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ABSTRACT

The aim of this article is to comprehensively review the adhesion of dental zirconia, including the factors that affect the bonding to zirconia in the literature. A comprehensive search of PubMed and Embase was conducted. The search was limited to manuscripts published in English. The final search was conducted in August 2024. Zirconia is a polycrystalline ceramic with exceptional high mechanical properties and optimum esthetic properties especially in recent generations however, due to it is nature of lacking silica-content the bonding to zirconia is difficult which is considered the main drawback of this material. According to the literature, bonding to zirconia is a multifactorial process; many factors could affect the final bond strength between the zirconia and the underlying structure. Parameters like cement type, additional use of primers, zirconia surface treatment and timing of surface treatment affect the bonding to zirconia. Among these factors, the surface treatment was found to be the most influencing factor on bond strength to zirconia. Many zirconia surface treatments that improve bonding to zirconia were described in the literature. However; still, there is no agreement about the best protocol to achieve better bonding to zirconia.

Keywords: Adhesion to zirconia – Air abrasion – Resin cement – Surface treatment– Zirconia

1. Introduction

In the second half of the 20th century, dentistry faced challenges to meet the escalated esthetic needs of patients with mechanically durable restorations, and different types of restoration were introduced to the dental practice. Since introduction of aluminous porcelain in the mid-1960s, there have been continuous improvements in strength, esthetics, and methods of fabrication, resulting in dozens of products for clinicians to choose from. (1,2)

In the late 1990s, with the development in CAD/CAM technology, the first zirconia coping was introduced to be veneered with porcelain due to the grey color and opaque nature of zirconia, it was introduced in the market as pre-sintered ceramic blocks to milled, then sintered at a high temperature or as fully sintered blocks, there were many benefits of pre-sintered chalk-like blocks used (in so-called 'green' stage), with porosity in their microstructure, as milling at such state is easier with less milling time and more life for milling burs, after milling the restoration should be sintered, which was accompanied by about 20-25 % shrinkage, which densities the structure of material by more than 99%, so final strength of the material could be achieved, to overcome this shrinkage, restoration design should be milled about 20-25 % larger than the desired design to compensate for sintering shrinkage. (3,4)

2. Search Strategy

A comprehensive search of the dental zirconia literature was conducted using the PubMed and Embase databases. The final search was conducted in August 2024. Additionally, journals specializing in dental materials, prosthodontics, and restorative dentistry were also explored. A manual search was conducted by reviewing articles and their references. Studies were included if they were published in English and provided data on the types, properties, applications, aging, cementation, and transformation toughening of dental zirconia.

3. Nature of Zirconia

Pure zirconia is a polymorphic material that occurs in three crystalline physical forms depending on temperature of material, this phenomenon is called allotropy, as different atomic arrangement of materials have the same chemical composition, monoclinic phase (m) occurs at room temperature up to 1170°C, while tetragonal phase (t) occurs from to 1170°C to 2370°C and cubic phase (c) occurs from 2370°C to 2680°C (melting point), transformation from tetragonal to monoclinic phase is accompanied by volume increase (about 5%), this increase can close cracks so, it increases the fracture toughness of the material, this transformation toughening is unique property of zirconia , which makes zirconia stands out among other dental ceramics.(3,5,6)

4. Generations of zirconia

Zirconia can be classified based on its chemical composition into 5 generations: (7)

- First generation: 3Y-TZP-A (3 mol% Y_2O_3 0.25% Al_2O_3) with flexural strength more than 1000 MPa and opaque nature.

- Second generation: 3Y-TZP-A (3 mol% Y_2O_3 0.05% Al_2O_3) with flexural strength 900 MPa and 5 % more translucent.

- Third generation 5Y-TZP (5 mol% Y_2O_3 0.05% Al_2O_3 - 53% cubic structure) with flexural strength 600 MPa and 15 % more translucent.

- Fourth generation 4Y-TZP (4 mol% Y_2O_3 0.05% Al_2O_3) with flexural strength 750 MPa and 10 % more translucent.

- Fifth generation: 3Y/4Y/5Y-TZP with flexural strength 550-1200 MPa and 1-15 % more translucent (Multilayer with translucency gradients).

5. Zirconia properties

5.1 Transformation Toughening

When metastable tetragonal zirconia is subjected to an external source of energy, the cracks may occur, so ZrO_2 grains are transformed from their tetragonal to the monoclinic, which is accompanied by a volumetric expansion of the grains, leading to limitation of crack propagation, because expansion is restricted by the surrounding material, so, the net result is compressive stress on the surfaces of the crack, This is the reason why this phenomenon is called “phase transformation toughening”, for utilizing this transformation toughening in practice, stabilization of tetragonal or cubic phases at room temperature is required, which can be achieved by adding oxides such as yttrium, magnesium, calcium, and cerium, so these oxides called zirconia stabilizers. (8)

These oxides will fully or partially stabilize the zirconia, their concentration will determine the phase at which zirconia will be stabilized. Based on the level of stabilization, zirconia can be categorized into three main categories, fully stabilized zirconia (FSZ), partially stabilized zirconia (PSZ), and tetragonal zirconia polycrystals (TZP). In FSZ which also known as cubic stabilized zirconia (CSZ), zirconia is in cubic phase and contains more than 8 mol% yttrium oxide (Y_2O_3) while, PSZ is formed by nano-sized tetragonal or monoclinic particles in a cubic matrix and stabilized by 3 - 8 mol% yttrium oxide (Y_2O_3), and TZPs are monolithic materials mainly of tetragonal phase stabilized with approximately 3 mol% yttrium oxide (Y_2O_3). (5,9,10)

5.2 Low temperature degradation (LDT)

It is also called the aging of zirconia, which is a continuous transformation of tetragonal phase to monoclinic phase at the surface of Y-TZP, due to exposure of surface to hygroscopic environment like oral cavity; as it was proven that water molecule infiltrate the zirconia structure at the surface, water infiltration to zirconia surface causes a lattice contraction, which leads to tensile stresses accumulation on the surface of the zirconia grains, inducing (t-m) transformation, which is accompanied by an increase in volume of grains, resulting in surface uplifts and grain pull out, this process finally cause surface microcracks, allowing more water molecules to enter the interior grains, so (t-m) transformation continue deeper and deeper within the bulk of the material, leading to decrease flexural strength, and subsequently fracture of zirconia, LTD could be minimized by using smaller grains with uniform yttria distribution, optimum quantity of Al_2O_3 (0.15 - 0.25 wt.%) and increasing cubic phase. (3,9)

6. Adhesion to zirconia

In the commercial market, zirconia competes with glass ceramics and silica-based feldspathic porcelains, which are preferred over zirconia due to their high glass content, excellent translucency, and natural enamel-like appearance. The capacity of silicate ceramics to be acid-etched and silanized promotes resin bonding and reinforcing. The zirconia framework's high mechanical properties may allow for adhesive bonding or traditional cementation. Bonding between resin cement and zirconia is difficult to achieve because of their chemical inertness and lack of silica content. Although zirconia restorations are deemed "cementable," some benefits from the use of composite resin-luting agents can be realized. Resin-bonded fixed prostheses or veneers are examples of zirconia restorations, which are thin, have minimal robustness, lack retention, or depend on resin bonding. The effectiveness of resin bonding is dependent on selecting suitable materials and treating the tooth and restorative bonding surfaces properly. Several bonding protocols have been recommended to improve the adhesion to zirconia. (3,11,12)

7. Factors affecting bond strength between zirconia and resin cement

The adhesion of zirconia to underlying resin cement is a multifactorial process, many factors could affect the bond strength between zirconia and resin cement, which include the type of cement, combined or separate use of MDP zirconia primer within cement, different zirconia surface treatments, timing of surface treatment either pre or post sintering and the aging of the bond. (3,11,12,13) Figure 1

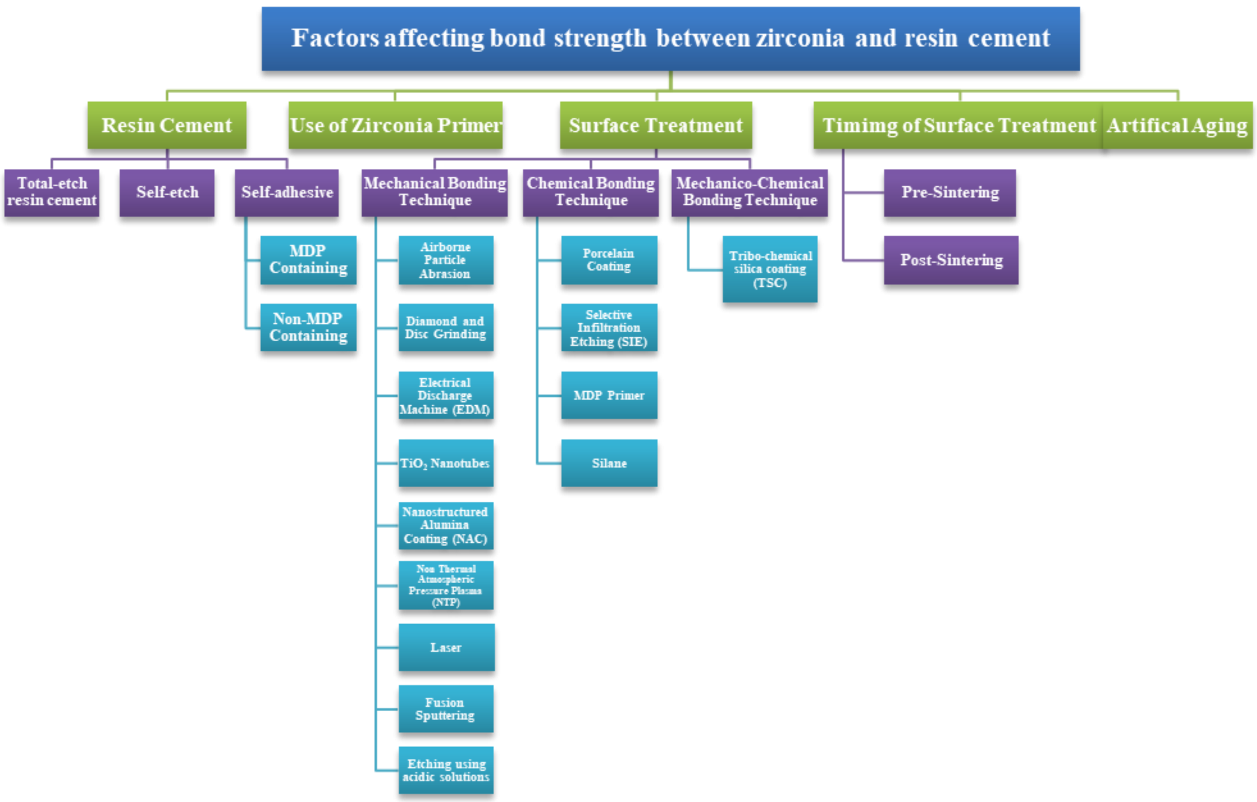

Figure (1): Diagram illustrating factors affecting bond strength between zirconia and resin cement.

7.1 Resin cements

Resin cements are methacrylate-based materials, which differ in terms of filler contents and photo-initiators, which have direct effect on the mechanical behaviors and clinical performances; they also defined as low-viscosity composite materials with filler distribution and initiator content adjusted to allow for a low film thickness and suitable working and setting times, it is difficult to classify the resin cement based on their chemical composition due to great variation in their chemical compositions which include: phosphoric acid esters, 10-MDP, HEMA, glycerolphosphate dimethacrylate (GPDM), 4-META, bis-GMA or triethylene glycol dimethacrylate (TEGDMA). (14,15)

7.1.1 Rational for using resin cement with zirconia

It was reported that glass ionomer cements and conventional Bis-GMA-based composites provided significantly lower bond strength with zirconia especially after ageing, although it was reported that Bis-GMA showed lower adhesion values, and better withstanding to hydrolytic degradation; only resin cement and resin cement containing MDP monomer relatively resist thermocycling, with the latter providing higher bond strength with zirconia. (11,14)

Based on their bonding mechanism resin cement could be categorized into: (16)

- Etch & Rinse resin cement: it relies on etching enamel and dentin using phosphoric acid, with removal of smear layer, allowing for infiltration of hydrophilic monomers into collagen fiber of dentin forming resin-dentin inter-diffusion zone.
- Self-etch resin cement: it was developed to overcome the undesirable effects associated with phosphoric acid use as a dentin-conditioning medium, which include decreased cohesive strength of dentin and increased post-operative pain. Self-etch adhesives contain acidic monomers that etch and prime dentin and enamel simultaneously, without the need to rinse, this system available in one-step or two-step options.
- Self-adhesive resin cement (SARCs): it is a one-step application system, that bond to tooth without requiring etching or bonding adhesives, it dissolves a portion of the smear layer without complete removal of the smear plug in the dentinal tubules. (16)

It was introduced in 2002, exhibiting unique properties of self-adherence to tooth structure, eliminating the need for prior surface treatment. This cement contains multifunctional phosphoric acid which is capable of interacting with the both basic fillers in cement and hydroxyl-apatite crystals in tooth structure, this innovation simplifying the luting procedures by enabling one-step application or allowing for use with primers and coupling agent, thus enhancing adhesion to different substructure. (16)

Type of resin cement used may affect bond strength to zirconia restorations. In a systematic review conducted to compare the bond strength of self-adhesive and self-etch or total-etch resin cement to zirconia. It was concluded that the immediate and delayed bond strength of self-adhesive resin cement to zirconia was significantly higher than those of total-etch resin cement; also no significant difference was found between the self-etched and self-adhesive resin cement in terms of bond strength to zirconia. (17)

7.1.2 MDP containing self-adhesive resin cement (SARCs)

It is the most recently introduced resin cement to dental practice; it gained a wide popularity since its introduction in 2002, due to ease of use as it doesn't require any additional surface treatment to the underlying structure, MDP primer was incorporated in recent generation of SARC to improve its bonding ability to oxide layer in most of restorative materials, through its active phosphate ester group with its triple bonding mechanism with zirconia oxides yielding higher bond strength, some author reported that use of air abrasion surface treatment for zirconia followed by 10-MDP primer is very effective method to improve bond strength as they considered such treatment as mechanico-chemical treatment to zirconia through Air abrasion as mechanical treatment, while chemical treatment by MDP, which has ability to bond chemically with zirconia surface with ionic and hydrogen bond, other authors mentioned that MDP primer better to be used as integrated part within the resin cement like MDP containing SARCs, third opinion recommend treating zirconia surface with MDP zirconia primer followed by use of MDP containing SARCs to provide better bond strength with zirconia. (18) So it was concluded that MDP containing SARC yielded significantly higher bond strength non-MDP containing SARCs. (18,19)

7.2 Use of zirconia primer

Some universal adhesives that contained either 10-MDP, saline or both together may have an effect on the bonding of resin cement to zirconia. It was reported that 10-MDP containing primer was effective in improving the bond strength to Y-TZP, also, it was reported that with the inert nature of zirconia and lack of glass matrix, silane has very limited effect on improving bond strength between zirconia and resin cement. (20) The interaction of both molecules and effect of silane contents on 10-MDP may affect the bonding of MDP to zirconia. As it was found that despite of action of silane in improving the hydroxylation of zirconia and exposing more Zr-OH molecules at surface, the silane impaired the adsorption of MDP to zirconia leading to inactivation of action of MDP in improving the bond strength. (21,22)

On the other hand, Non-MDP containing SARC showed improved bonding values with the addition of MDP primer to zirconia ceramics. However, MDP containing SARCs was not affected significantly by the use of additional zirconia primer due to the saturation of cement with this molecule by higher levels than primers. (11) The commercial 10-MDP-containing primers have more than 1wt% 10-MDP, whereas 10-MDP–containing resin cements contain higher concentrations of 10-MDP than primers. (18,19) Also thermocycling has a significant negative effect on the bond strength between resin cements either with or without MDP and zirconia, reducing bonding quality. (19)

7.3 Zirconia surface treatment

The use of hydrofluoric acid (HF) and silane coupling agent is well established method for providing durable bonding between silica-based ceramics and resin cement, however polycrystalline zirconia ceramic lacks glass phase and subsequently lacks silica content so, this method couldn’t be a valid method for providing a durable bonding between zirconia and resin cement, there were many different zirconia surface treatments described in the literature to improve bonding between zirconia and resin cement, zirconia surface treatments were classified into three main categories: mechanical, chemical and mechanico-chemical bonding techniques for condition zirconia surface. (13,14)

7.3.1 Mechanical Bonding technique

7.3.1.1 Airborne Particle Abrasion

Air abrasion is the most commonly used physical method in literature for treating zirconia surface before cementation; it increases the surface energy, wettability, roughness and allows for exposure of hydroxyl group, which promotes bonding with resin cement. Air abrasion enhances immediate bond strength to zirconia, (23) also a systematic review, reported that Air abrasion protocol includes particles size ranging from 30 to 110 μm, at 0.5 - 4 bar pressure at 10 - 20 mm distance. the increased particle size and pressure had a negative effect on the mechanical properties of the material, as it led to the formation of microcracks at the topmost layer of zirconia, and induction of transformation from tetragonal to monoclinic phase resulting in more weakening of zirconia, (14) however another study concluded that despite of (t-m) phase transformation caused by Air abrasion, this does not affect the stability and reliability of restorations made of 3Y-TZP over time. (24) Another systematic review concluded that Air abrasion surface treatment provide second higher shear bond strength values after tribo-chemical silica coating and higher shear bond strength than laser treatment. (6)

7.3.1.2 Diamond and Disc Grinding

It is a method used to increase surface roughness through mechanical abrasion using grinding diamond rotary instruments. The main drawbacks of grinding were aggressiveness and induction of microcracks and damage to the zirconia surface due to excessive mechanical force. (25) Comparing the effect of Air abrasion and wheel stone abrasion on shear bond strength between zirconia and resin composite, it was found that stone abrasion resulted in higher surface roughness Ra value (0.14 μm) than Air abrasion (0.9 μm), on contrary air abrasion provided significantly higher shear bond strength value than stone abrasion. (26)

7.3.1.3 Electrical Discharge Machine (EDM)

EDM is an unconventional method that causes erosion to the material and creates a desired shape using an electrical spark in a dielectric medium; it requires a special device and works only on conductive materials, with a resistivity of less than 100 Ω cm, while zirconia has a very high resistivity to electric current. In 2010, Kucukturk and Cogun developed a device capable of performing EDM to non-conductive surface like zirconia. The obstruction of non-conductive nature of zirconia surface limits the use of such method. Previous study concluded that EDM provides significantly the highest shear bond strength (17.05 MPa ± 2.71), followed by tribochemical silica coating (14.99 MPa ± 3.14), followed by Er: YAG laser (12.73 MPa ± 3.41) and finally Air abrasion (7.93 MPa ± 2.07), also SEM revealed that zirconia surface treated with EDM had the highest surface roughness among all treatments, with surface characterized by deep valleys and tall peaks. (27)

7.3.1.4 TiO_2 Nanotubes

This method is based on the idea of using material particles at the nanoscale level, nanoscale oxides like TiO_2 possess unique physical and chemical properties due to their small size and high density, the incorporation of these nanoscale particles will increase surface energy by increasing the number of surface atoms and interfaces, the specific use of nano TiO_2 particles was revealed to their large surface area, although a previous study found that no improvement in shear bond strength between zirconia and resin cement after incorporation TiO_2 nanotubes into zirconia surface. (28)

7.3.1.5 Nanostructured Alumina Coating (NAC)

It is a non-invasive zirconia surface treatment composed of many hundred nanometer thin alumina layer of lamellar-like topography, which add nano-roughening to zirconia surface without creating damage to the surface of the zirconia. It was reported NAC surface treatment provided significantly higher shear bond strength between zirconia cemented to composite using self-adhesive resin than 50 µm Air abrasion; also it was found that NAC had no negative effect on mechanical or optical properties of translucent zirconia. (29)

7.3.1.6 Non-thermal Atmospheric Pressure Plasma (NTP)

Plasma is known as the fourth state of matter, also it’s the most dominant state of matter in the universe. It is composed of neutral gas which is either fully or partially ionized containing ions, electrons and particles, plasma has the advantage of having the ability to modify the surface within nanometer level without affecting the material property, so it has no destructive effect on zirconia surface, NTP large number of reactive groups, which decrease carbon content of zirconia surface, thus improving surface wettability, there are many plasma gases that could be used like argon or oxygen gas or their combination. It was reported that NTP surface treatment showed significantly higher shear bond strength between zirconia and self-adhesive resin cement than 110 µm Air abrasion. Also, SEM showed minimal zirconia surface roughness in NTP groups without any negative effect on the zirconia surface. However, zirconia surface roughness with Air abrasion was high. Despite of minimal surface roughness associated with NTP surface treatment, it yielded higher bond strength which could be attributed to increased polar component by adding oxygen element and decreasing carbon-based contaminants, which led to formation of super hydrophilic surface. (30)

7.3.1.7 Laser

Laser is one of the most commonly documented methods in literature as zirconia surface treatment to improve surface roughness for better bonding. This technique is based on the removal of surface particles by creating micro-explosion and vaporization in a process called ablation (6). Many types of laser were listed in literature like carbon dioxide (CO_2) laser, Erbium-doped yttrium aluminum garnet (Er: YAG) laser and Neodymium-doped yttrium aluminum garnet (Nd: YAG) laser. A previous study investigated the effect of Air abrasion and three different laser treatments (CO_2 - Er: YAG - Er: YAG) on shear bond strength between the zirconia cemented to composite using dual-cured resin cement (Panavia F2.0). It was found that no significant difference occurred between Air abrasion and (Er: YAG) laser, no significant difference between (CO_2) laser and (Nd: YAG) laser, while Air abrasion and (Er: YAG) laser resulted in higher SBS than (CO_2) laser and (Nd: YAG) laser surface treatment. (31) However a systematic review concluded that laser surface treatment yielded the lowest shear bond strength between zirconia and resin cement after CoJet and Air abrasion, (6) although it was highlighted that the popularity of the use of laser treatment increased, as they minimized the negative effect of grit blasting associated with other types of treatment, no significant difference was found among different laser powers 2 W, 2.5 W and 3 W of Nd:YAG laser. (32)

7.3.1.8 Fusion Sputtering

Fusion sputtering is a zirconia pre-sintering surface treatment technique described by Aboushelib in 2012, which is performed by ejecting 50% ethyl alcohol spray containing 7–12 μm un-sintered zirconia particles using air brush to hit the surface of zirconia before sintering. Fusion sputtering resulted in significant microshear bond strength (μSBS) zirconia and self-adhesive MDP containing resin cement than 50 μm Al_2O_3 Air abrasion. (33) SEM revealed higher surface roughness of fusion sputtering with mean roughness value (Ra = 4.14 μm), while Air abrasion mean roughness value of (Ra = 0.68 μm), author attributed the increase in bond strength and surface roughness to SEM findings, where there were beads of zirconia particles incorporated within the surface. (33)

7.3.1.9 Etching using acidic solutions

Hydrofluoric acid (HF 4%–10%) etching is routinely used with glass ceramic to improve bond strength to resin cement by etching the glass matrix and exposing the silica particles which will bond later to bi-functional silane coupling agent, while this method seems to be ineffective for Y-TZP at room temperature due to its high crystalline content and silica-free nature, but many authors reported that use of strong acids for a prolonged time at high temperature could induce micro-morphological changes on zirconia that may improve rise the surface energy and improve bond strength with resin cement. (34) A 40% hydrofluoric acid etching for 10 min showed the most favorable wettability, the highest SBS and the lowest phase transformation compared to hot sulfuric acid (H_2SO_4) for 10 min and 50 μm Al_2O_3 sandblasting surface treatment.(35) Increasing etching time resulted in increased surface roughness and decreased contact angle. (34)

7.3.2 Chemical Bonding Technique

7.3.2.1 Porcelain Coating

The porcelain coating method is one of the methods that aims to chemically modify the zirconia surface using a silica contacting porcelain layer, which will be etched later on using hydrofluoric acid to expose silica particles, then silane couple agent will be applied to connect the silica particles with monomer within resin cement. One of the most commonly used techniques to apply this method of surface treatment by adding a thin layer of glazing porcelain to the fitting surface of zirconia is "glaze-on technique". A glass-ceramic spray deposition (GCSD) pre-sintered method showed significantly lower shear bond strength than Air abrasion. (36,37)

7.3.2.2 Selective Infiltration Etching (SIE)

SIE is a technique based on heat-induced maturation (HIM) process, which is performed by applying stresses at zirconia grain boundaries using two short thermal cycles, then a low fusing glass infiltrated in between the zirconia grain boundaries, the molten glass contains additives to control the viscosity and coefficient of thermal expansion, which should be matched with that of zirconia allowing, SIE significantly improved shear bond strength between zirconia and resin cement compared to 50μm Al_2O_3 sandblasting. (38)

7.3.2.3 10-MDP Primer

MDP (methacryloyloxydecyl dihydrogen phosphate) containing primer was proved to provide a direct chemically bonding between zirconia and resin cement, 10-MDP is a unique miraculous molecule consisted 3 parts: hydrophilic phosphate ester group as terminal end which originate from MDP molecule toward the zirconia, this phosphate group linked to hydrophobic 10 - carbon spacer chain of MDP and third terminal double bond polymerizable part, (23) three mechanisms of bonding was found between the MPD primer and zirconia, firstly MDP adsorbed on zirconia surface by forming hydrogen bond between P = O (oxo group) of MDP and hydroxyl group on zirconia surface (Zr - OH), secondly direct ionic bond (Zr-O-P) between partially positive (Zr^{4+}) and deprotonated ($P - O^{-}$), and finally as we mentioned (P-OH) group of the 10-MDP molecule interacts with zirconia, while the other OH group interacts with P = O of another neighboring 10-MDP molecule, leading to formation of intermolecular hydrogen bond between 10-MDP molecules, thus increasing MDP concentration, which resulted in increased intermolecular hydrogen bond, and subsequently increased bond strength between MDP primer and zirconia surface. MDP primer showed significantly higher surface energy (SE) and shear bond strength than airborne abrasion with and without aging. (39) However the main problem of 10-MDP primer is hydrolytic degradation, which causes a decrease in adhesion over time in all its application forms. (14)

7.3.2.4 Silane

Silane is commonly used as bonding agent with silica based ceramics because it's bi-functional monomer contained hydrophilic methoxy-silyl groups ($–Si–O–CH_3$), which can react with water and silica, forming a strong siloxane (–Si–O–Si–O–) network, on the other hand, it contains hydrophobic methacryloyl groups, which can react with those in the resin-based luting agent through a free radical polymerization process, resulting in the formation of a strong bond. However, silane has a limited effect on zirconia surface due to its polycrystalline nature and lack of glass content and its effect is limited to treating zirconia surface with silica coating. Silane improves surface hydroxylation, surface energy and wettability of zirconia. (21) It was reported the use of silane and MDP-based primers affects the bond strength of zirconia to resin cement, as chemical interaction between MDP and zirconia could be compromised when MDP is present in a multicomponent system with other primers like silane. (12,21,40)

7.3.3 Mechanico-Chemical Bonding Technique

Tribo-chemical silica coating (TSC) or deposition is mechanico-chemical way of improving the bonding to metal oxide; Tribo-chemistry means the creation of a chemical bond by the use of mechanical energy. Air blasting, grinding and rubbing could be the methods used to apply this mechanical energy. More than twenty years ago chair side porcelain repair system was introduced to the dental market by 3M™ Company under a commercial name CoJet, this system was preceded by a laboratory system based on a same principle called Rocatec system, the basic principle of both systems is sandblasting the surface with silica coated alumina particles, providing surface irregularities within it, silica particle could be incorporated.

TSC is one of the commonly reported surface treatments for zirconia in the literature; the particle size used with this technique ranged from 30 to 110 μm, at 0.8-4 bar pressure and at 10 mm distance, (14) the pressure used during the blasting of zirconia surface cause silica coated alumina particles to be embedded within the surface, which chemically alter the zirconia surface by incorporation of silica particles within the surface, thus allow the use of silane coupling agent to bond the embedded silica to resin cement improving bond strength to zirconia, by allowing for the appearance of chemical chains of siloxane between embedded silica and resin, also TSC enhanced surface roughness of zirconia, which improve the mechanical interlocking with the resin cement. Among TSC available systems, the Rocatec system provided higher bond strength when compared to the CoJet system. (22) This could be attributed to the additional step of air abrasion integrated into the Rocatec system, leading to increased surface roughness, in addition to large particle size of Rocatec system 110 μm compared to CoJet 30 μm. Also, it was reported that TSC induce the tetragonal to monoclinic transformation more than laser treatment without a great influence on bi-axial flexural strength of zirconia. (41)

One of the most effective methods used for enhancing the bond of zirconia to resin cement is an alteration of the surface through various treatments either mechanical, chemical and mechanico-chemical, air abrasion zirconia surface treatment was reported to be one of the most commonly used surface treatments. Air abrasion and CoJet yielded a stronger bond between zirconia and resin cement compared to HF acid and Er: YAG laser irradiation. (42) (43) The combined use of Zircos–E etching with Air abrasion increased the bond strength of zirconia to resin cement. (44) In a clinical simulation study, It was concluded that Alumina airborne-particle abrasion of the intaglio of zirconia created surface roughness compared to non-abraded which improved retention of crown regardless of cement type; also the non-abraded crowns demonstrated significantly lower retentive stress on crown removal. (45)

The combined use of CoJet and MDP adhesive yielded higher short and long-term bond strength than 25 μm aluminum oxide alone, alumina and MDP adhesive or CoJet alone, also Alumina and MDP adhesive resulted in similar bond strength that of CoJet alone. (46) Three systematic reviews found that airborne particle abrasion and tribo-chemical silica coating are methods with more evidence in the literature and choice of resin cement is less relevant to affect bond strength. (6,13,14)

In the most recent two systematic reviews in the literature evaluating effect of various surface treatment on bonding to zirconia, a systematic review which included 93 in vitro studies showing that tribochemical silica coating may lead to increased bond durability compared to sandblasting also, a combination of MDP cement with either tribochemical silica coating or sandblasting resulting in more durable bond after aging, (47) while the other systematic review which included 77 studies reported that analytically, the silica coating method exhibited a higher SUCRA ranking (surface under the cumulative ranking curve) in comparison to Air abrasion, although no statistically significant distinction was observed between these two techniques in pairwise comparisons, he also mentioned that bond strength between zirconia and resin decrease over time but both treatments could decrease this effect. (22)

7.4 Timing of surface treatment

Most of the surface treatments used for improving bond strength between zirconia and resin cement were post-sintering surface treatments like Air abrasion, laser and tribo-chemical silica coating, some pre-sintered surface treatment was reported to have a positive effect on bond strength to zirconia like fusion sputtering. It was concluded that fusion sputtering surface treatment enhanced the microshear bond strength of zirconia and resin cement, (33) it was reported that surface modification of pre-sintered zirconia is a promising method as long as no phase transformation or deep subsurface penetration occurs. (48)

7.5 Artificial aging

The widely used methods for artificial aging were liquid storage and thermocycling, liquid storage causes water uptake, and subsequently hydrolytic degradation, while thermocycling simulates in vitro hydrothermal aging. It was found that the most frequently used liquid was distilled/deionized water, while other types of solutions, such as esterase, acetic acid, alcohol, phosphoric acid or artificial saliva, were used to simulate various clinical scenarios. It was reported that the storage of specimens in a liquid medium significantly decreased bonding in comparison to control groups, also acetic acid, phosphoric acid and esterase had more influence in decreasing adhesion than distilled water. (14)

The number of cycles of thermocycling varied in the literature. The majority of studies followed the ISO 10477 or testing polymer-based crown and veneer materials (22) with the minimum number of cycles at 5000 representing about 6 months of clinical service, The number of cycles increases above 5000 was found to be of limited effect on shear bond strength value. (13,14) Although artificial aging aims to mimic and simulate the intraoral condition, still there are many oral conditions that affect bond strength and can’t be simulated, like salivary contamination of surfaces and para-functional habits, which adversely affect the bond strength. (11)

The aging by either liquid storage or thermocycling aimed to simulate the effect of intra-oral clinical conditions on bond strength between zirconia and resin cement. It was reported that 10000 cycles of thermocycling equivalent to one year of clinical service, there is agreement in literature that artificial ageing negatively affects the bond strength. The artificial aging decreased adhesion; therefore, storage in water for 30 days or thermocycling for 5000 cycles must be performed in laboratory studies, also it was reported that tribo chemical silica coating was the best surface treatment that resist the aging. (47).

8. Conclusion

There are many integrated factors that affect the bonding between zirconia and resin cement including; type of surface treatment, use of zirconia primer, artificial aging and type of resin cement, many zirconia surface treatments described in the literature, improve the bonding between zirconia and resin cement. Tribo-chemical silica coating surface treatment yielded the highest bond strength among different surface treatments. Zirconia surface treatment is more effective than resin cement in improving the bond. MDP containing resin cement possesses higher bond strength to zirconia than non MDP-containing resin cement, also additional use of MDP primer with MDP-containing resin cement is not effective due to the high level of saturation of this molecule within resin cement. Pre-sintering surface treatment is a promising method to improve bonding to zirconia, but still needs further investigations.

- **Conflict of Interest**

The author has no potential conflicts of interest to declare.

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