



Dealing with the Internal and External Surfaces of Zirconia Restorations; between Past and Present Trends. A Review of Literature

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Abstract

Objectives: The optimum zirconia bonding protocol have been always a mystery to be solved throughout the past years. The purpose of this review is to go through the innumerable surface treatment methods and protocols concerned with the both internal and external zirconia surface treatment.

Study selection, Data and Sources: An electronic Pubmed, Medline and Google scholar search was done to attain In-vitro studies on zirconia surface treatments published in english, with time frame between 2013 and 2020.

Results: Hundred thirty-two *in vitro* studies and systematic reviews were surveyed in this appraisal. Numerous techniques were used for zirconia surface modifications, these methodologies were categorized and grouped in this review according to the surface modified. Laboratory test studies discuss internal surface treatments including micro-mechanical bonding, chemical bonding and external surface treatment including different core surface treatment, glazing and polishing.

Conclusions: With respect to the heterogeneity of the included studies; the internal surface treatment, most of the included studies verified the air particle abrasion as the generally approved micro-mechanical topographic modification protocol. Other internal surface treatment protocols as chemical etching showed promising results in laboratory studies with inadequacy of clinical application. The external surface studies verified different methods over others. However, self-glazed zirconia studies are scarce.

Keywords: Zirconia; Internal Surface Treatment; Polishing; Glazing; Bonding; Primers; Chemical Etching

1. Introduction

Over the past few years, several studies evaluated internal surface treatments, primers, and various protocols for external surface finishing for zirconia restorations. Most of these studies are In-vitro lab research with limited clinical credibility. Additionally, it is difficult almost impossible to compare between their results, due to their diversity in their methodology. It is challenging to take

a broad view over the results in regards of the zirconia sample, materials used, and method of testing. Unlike glass matrix ceramics, zirconia is not susceptible to etching and this makes it challenging to achieve chemical adhesion. Various treatments of the zirconia intaglio, application of primers or adhesives, and countless types of resin cements have been investigated. However, a standardized adhesive cementation protocol, that offers univocal and consistent

results, has not been identified. The aim of this review is to present the possible available data regarding different zirconia surface treatments and challenges. The zirconia treatments are assembled in figure 1.

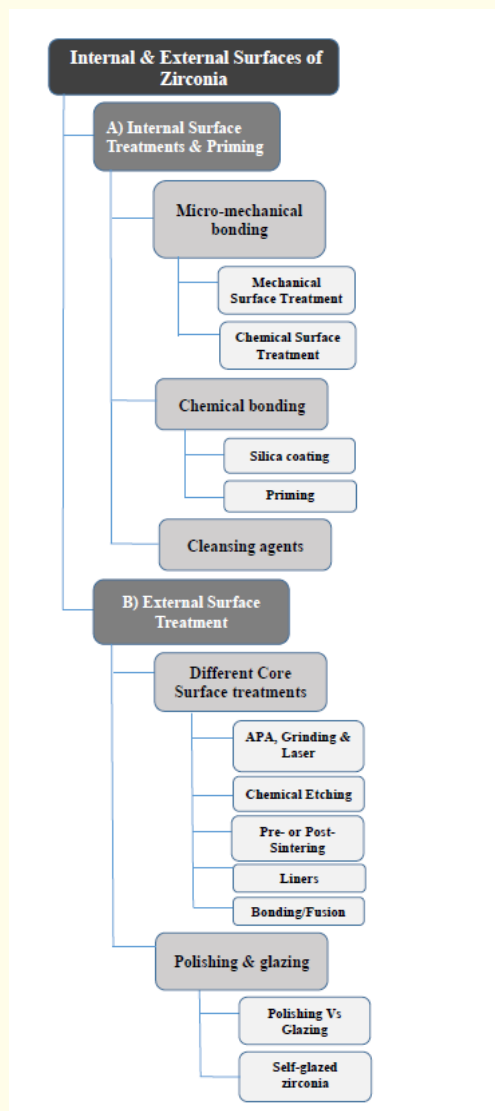


Figure 1: Schematic diagram of the internal and external surface treatments of zirconia restorations.

2. Materials and Methods

2.1 Search strategy

Google scholar and PubMed databases were used to review the available literature. The research was done on 3 March 2020. The review included studies published from 1 January 2013 to 1 January 2020. In this review included research papers investigated

the available methods on the subject of the internal and external surface treatments of zirconia restorations. The research includes *In vitro* studies, review of literature, systematic reviews and meta-analysis. The following keywords and their combination were seek out: “Zirconia,” “Surface treatment,” “chemical etching,” “Priming, and “Bonding.” (Table 1).

Topics	Criteria
Data base	Google scholar, PubMed
Date range	2013-2020
Keywords	Zirconia, Surface treatment, chemical etching, priming and bonding.
Language	English
Type of paper	Invitro studies, Review of literature, systematic review and meta-analysis
Type of journal	Dental Journals

Table 1: Criteria for research selection for this review.

2.2 Articles reviewed and data extraction

The included articles were individually revised by two assessors. Inclusion criteria were *in vitro* studies that evaluated different adhesion protocols between the resin cement and zirconia. In addition to, studies assessed different bonding protocols for layering porcelain to zirconia framework, external surface of zirconia regarding polishing, glazing and laboratory tests

Exclusion criteria were studies on: (1) glass-matrix ceramic; (2) orthodontic brackets; (3) ceramic repair; (4) implant superstructure.

3. Results

After searching and screening the databases, a total of 83 articles were included. Owing to the high heterogeneity of research papers in terms of specimen design, testing methods and outcome variables, it was not feasible to assess the data quantitatively. Articles are summarized in figure 1 regarding the surface treatment methods.

4. Discussion

4.1 Internal surface treatment and priming

4.1.1 Micro-mechanical bonding techniques

4.1.1.1 Mechanical treatment

Grinding tests with 100-um diamond rotary instruments on 3 different zirconia materials showed that in only 1 case was rough-

ness significantly increased. Grinding with a 91-um diamond wheel did not affectedly reduce flexural strength. Tzanakakis., *et al.* the main disadvantage of grinding methods is the surface damage and creation of micro-cracks in the surface [1].

Sandblasting or air-borne particle abrasion (APA)

Sandblasting is a process that uses the energy released by the impact of alumina particles (Al₂O₃), emitted by a high-speed source. It is advisable to carry out sandblasting according to suitable parameters with regard to pressure, distance from the source, and particle size [1]. Ruyter., *et al.* found volume expansion due to transformation from cubic to tetragonal to monoclinic thus inhibiting micro-cracks and enhancing strength of zirconia [2].

Sandblasting can also lead to the formation of surface damage, defects, and cracks. Özcan., *et al.* proposed a protocol for blasting zirconia, with alumina particles with diameter between 30 and 50 um, pressure between 0.5 and 2.5 bar, duration of at least 20 s with distance from the blast jet 10 mm from the target, and kept in motion, so as not to create defects [3]. Kern., *et al.* There is a general protocol agreement, that airborne particle abrasion with 50-110 µm alumina particles at 0.25 - 2.8MPa for 10-15 seconds is effective in roughening and cleaning the bonding surface of zirconia [4]. According to Pereira., *et al.* the third-generation zirconia materials as the ultra-translucent and super translucent have higher grain size when compared to high translucent zirconia of the second generation [5]. San., *et al.* recorded aggressive surface roughness values of ultra-translucent at a pressure of 0.4 MPa [6]. This can be attributed to the large grain size of ultra-translucent zirconia pulled out by the alumina sandblasting process. Large grains left a surface defect which subsequently gave greater the surface roughness [5].

Tribochemical silica coating (TBS)

The main Concept behind this method is to convert silica-free into silica-rich zirconia surface, for utilizing the chemical bonding provided by Silanation. Based on the deposition of silicon to form a SiO_x-C coating with a thickness of 0.1 mm. This surface can be silanated to provide stronger bonds with resin cements [4,7]. Compared to sandblasting with alumina oxide particles, several studies agree that TBS, followed by the application of silane-containing primer, is more stable than alumina sandblasting followed by the application of 10-methacryloyloxydecyl-dihydrogen-phosphate (10-MDP)-based primers. TBS treated groups appears to be more resistant to thermocycling than other treatments [7,8].

Sandblasting with feldspathic ceramic powder appears to have promising results in terms of shear bond strength when compared to the use of silica-coated alumina (TBS), with a lower tetragonal-monoclinic transformation rate and stable results after thermocycling [8].

There are controversies about tribochemical silica coating bond stability. Others agreed that does not afford stable resin-Zirconia bond strength. This could be attributed to the silica layer on the zirconia ceramic prevented the MDP containing luting resin from directly bonding to the zirconia surface. The deposited silica was probably attached on the Zirconia surface via weak physical force, such as Vander-Waals forces, which might not be stable enough in a clinical situation [4,7].

Russo., *et al.* study concluded that the use of a silane primer and resin cement containing 10-MDP allows the achievement of a better bond with zirconia compared to the application of silane alone. With the tribological-chemical method, the silica-ation process is not uniform on the surface of the zirconia. Where there are still areas not covered by silica, 10-MDP acts on the surfaces [1].

Electrical discharge machine (EDM)

It's an unconventional method that leads to erosion of material through electrical impulses in a dielectric medium. Rona., *et al.* compared sandblasting, tribochemical silica coating (TBS), Erbium: YAG (Er: YAG) laser and EDM, In terms of Shear Bond Strength (SBS) and Flexural strength. The EDM process improved the SBS. Moreover, there was no significant unfavourable effect of EDM on the flexural strength of zirconia. Bond strength of the EDMG was significantly higher than those of the Sandblasting group and Laser treatment group [1,10].

The main privilege of EDM over TBS and Sandblasting is surface micro-cracking were scarce with maximum surface roughness. However, EDM apparatus currently it is not suitable for clinical use. In the literature, the published work on EDM treated zirconia surface are limited [1].

Mesoporous zirconia coating (MZ)

Also called "Zirconia Particle Deposition" using a milling residue suspension seems promising and effective as airborne particle abrasion. The technique is done by an aqueous solution of Zr (SO₄)₂·4H₂O in which the sample is hydro-thermally treated for 48

h at 110°C. Then dissolved in 98% H₃PO₄; later calcined at 500°C for 6h. This procedure resulted in the mesoporous zirconia was sintered onto the specimen surfaces [1]. Zhang, *et al.* A mesoporous zirconia coating (MZ) have higher micro-tensile bond strength when compared to airborne-particle abrasion treatment. Also, the MZ surface treatment is not applicable because, it requires specific equipment and long heating cycles [11].

Lasers

Lasers are used as a mechanical conditioning technique. The objective is to enhance the surface roughness, in order to create a micro-mechanical interconnection with the resin. Neodymium-doped yttrium aluminum garnet (Nd: YAG) laser was not able to achieve the needed roughness and adhesion values. Nd: YAG laser led to Zirconia overheating causes cracks, residual stress, and monoclinic transformation. With reference to Erbium-YAG (Er: YAG) laser, a setting of 2 W produces good roughness, comparable to alumina sandblasting treatment. Unlikely, surface cracks, defects were evident and the bond strength was compromised [1]. 4W Er, Cr: YSGG laser radiation showed significantly the highest flexural strength values than the 2W and 3W groups. These values were comparable to post-sintered airborne-particle abrasion group. Post-sintered 2W and 3W groups showed higher values than post-sintered 5W and 6W groups. FE-SEM imageries showed deeper cracks for 5W and 6W post-sintered laser treated zirconia samples than the 2W, 3W, and 4W. This may indicate that higher laser energy levels increase the temperature and subsequently weaken the structure of zirconia [12].

The ultra-short pulse lasers are the newly introduced to literature. Ex. Femtosecond and Picoseconds lasers. An ultra-short pulse laser (Yb: YAG) emits impulses in the order of 6 picoseconds, with a power of 9W. The advantage of its shortness of the impulses allows the rapid removal of small amounts of material that have absorbed the energy of the laser without overheating, surface defects and thermal damage. Thus, obtaining a rough surface without surface defects. Oliveira, *et al.* concluded that, in terms of micro-tensile bond strength, the ultra-short pulse laser treatment seems to be superior to tribo-chemical silica-coating and alumina-sandblasting after a month of water storage. In the scanning electron microscopy (SEM) analysis, adequate, uniform, controlled surface roughness patterns was obtained by the ultra-short impulse laser without structure defects and over-heating [13].

4.1.2. Chemical treatment

One of the many zirconia etching trials were carried on for years. Some of these studies used Hydrofluoric acid (HF) and Phosphoric acids. Their results showed that phosphoric acid did not etch or alter the surface morphology, while HF showed minor changes yet promising [1].

Some authors adjusted the concentration of HF acid, immersing time and temperature to etch the zirconia. By adjusting the conditions in which the HF solution is applied, zirconia surfaces can be etched. 9.5% HF solution with immersion time up to 24 hours and temperature is increased up to 80°C [13]. 40% HF for 30 minutes in ultrasonic bath [13]. 48% HF solution at 100 C for 25 min [16]. All of the previous studies verified that surface roughness and good initial bonding were achieved.

Piranha Solution or Sulfuric acid in solution with hydrogen peroxide appeared to have a positive effect on the bonding of zirconia with resin cement. The rationality is to create hydroxylation, which will increase the conc. of OH groups on the zirconia surface and so, increased the bond strength between zirconia and resin cements. Lohbauer, *et al.* from the treatment of zirconia ceramics with piranha solution mixture. These hydroxyl groups react with silanols resulting from hydrolyzed 3-methacryloyloxypropyltrimethoxysilane. This reaction produces hydrogen bonds which may progress into covalent bond between organopolysiloxane and the zirconium atoms in the zirconia surface, providing higher stable chemical bond than hydrogen bonds [17,18].

Other studies preferred the hot chemical etching solutions for altering the surface topography and enhance bonding to zirconia. The theory behind this is to selectively etch the zirconia and create micro-retentions on the surface by modifying the grain boundaries via removal of the less arranged atoms. This technique significantly increased roughness and increases initial bond strength and wettability. From the mentioned hot etching solutions in literature, combinations of highly corrosive acids (HNO₃, H₂SO₄, and HF), Methanol, 37% Hydrochloric acid, and Ferric chloride for 30 minutes and hot hydrochloric acid (HCl) solution. Xie, *et al.* Heated the previously mentioned acids at 100°C and immersed the samples for 30 minutes. The results showed improved both initial bond strengths and durability [17].

Although the hot acid etching and Piranha solutions showed promising initial bond results, the hazardous of the acids and the heating for a long duration compromises its use clinically. However, further research is required for long term bond strength after aging.

Recently, Hot Acid etching or "HF etching" is one of the chemical etching surface treatments for zirconia treatments. Attempts at etching with a higher concentration of HF and longer application time (48% HF solution at 100 C for 25 minutes) was found to widen the inter-grain regions and increase the surface roughness significantly [16].

Another etching trial was achieved by the combination of HF acid and Nitric acid blend solution. The blend solution consists of 69% nitric acid and 48% hydrofluoric acid at 100 C for 25 min. Liu., *et al.* the surface roughness of HF + Nitric acid was only 21% of that of HF alone. The HF acid etched group showed higher bond strength after aging [16].

"Etching with low melting fluoride" or Low melting potassium hydrogen difluoride (KHF₂) and ammonium hydrogen difluoride (NH₄HF₂) were used as etching agents. As Ruyter, *et al.* described the procedure, zirconia with KHF₂ is heated at a temperature of 280 C for 10 minutes, while zirconia with NH₄HF₂ at 170 C for 10 min. The KHF₂ and NH₄HF₂ created surfaces roughness similar to the HF etching when used in high conc. and longer time. The initial bond strength values were higher than the silanized, sandblasted control groups. It is projected that during low melting fluorides treatment, the surface of zirconia is fluoridated, which subsequently cleaned by steam and ultrasonic water, come to be hydrolyzed producing an active hydroxyl site [2]. Hydroxylation process of zirconia is carried out similar as Lohbauer, *et al.* designated in their piranha solution chemical etching study [17,18].

Although the chemical etching of zirconia is now possible by the previously mentioned techniques, it is not feasible nor safe. During the laboratory work and in particular during heating these hazardous acids in the oven, proper safety protocols has to be maintained as good ventilation and personal protective gear. This could be attributed to the released fumes and the toxicity of fluorine compounds and the aggressive nature of hydrofluoric acid. There are limited researches regarding the long term stability of the bond achieved by low melting fluorides [2].

Newly introduced zirconia etchants systems were introduced in the past years to aid the feasibility of chemical etching. HF acid is the common constituent, which varies in concentration from one system to the other. These systems showed promising results with less hazard in both internal and external surface treatments. The Smart Etching solution is a combination of 21.8 - 23.7% HF, H₂SO₄, H₂O₂, CH₃OH and H₂O. This zirconia etching blend is applied with heating heated to 70°C-80°C in a water bath and the Zr. is immersed in the heated solution afterwards for 10 minutes. Yu., *et al.* etching for 10 minutes with the SE solution significantly increased the Shear bond strength [19]. Zir Etchant Cloud System is another lately developed etchant system, with 9% HF is applied to the surface and the specimen is placed inside the incubator. The etching process and the chemical reaction is contained inside a vessel. On top of this vessel is an opening in which the HF neutralizing agent in applied. This will lead to a cloud formation inside the incubator, which produce powerful heat and fast reaction [1,19].

Other were Zirconia etching solutions are applied at room temperature with no heat required. These systems require longer duration of application to reach the desired surface roughness than the previously mentioned systems. Zeta Etching Solution is applied to zirconia for 60 minutes in an ultrasonic bath at room temperature. Zircos E etching system has the highest HF concentration. It has unique composition. 40% HF, HCL, H₂SO₄, HNO₃, H₂PO₄. This fusion is applied to zirconia for 2-3 hours at 25°C. Zircos E etching system induce surface changes on zirconia and increase shear bond strength with resin cements [1].

Further research is needed to obtain a more detailed understanding of the effect of long-term water storage and thermal cycling on the bonding surface and the problems encountered in clinical applications.

4.1.2.1. Chemical bonding via silica coating

Zirconia 'Glaze-on technique" theory is to put on thin coatings of acid-etchable glasses/porcelain on the fitting surface of zirconia restoration, followed by HF-etching and silane treatment. This technique resulted in a significantly enhanced initial bond strength values. On the other hand the major drawback of this technique was large thickness (120 mm) coating. Some authors mark a reduction in the bond strength after artificial aging methods, this could be attributed to the fact that the glass ceramic layer is not well

bound to zirconia [1]. The bond take place through weak micromechanical interlocking and Van der Waals links liable to hydrolysis. Liu., *et al.* recommended that the coating method conducted on the pre-sintered zirconia surface showed better integration between the silica particles and zirconia. Due to the high temperature applied in the final sintering procedures [2].

Plasma spraying/gas phase fluorination, used to deposit a siloxane coating on zirconia to increase hydroxylation on the surface to allow for covalent bonding between Zirconia surface and resin cement. Chemical bonding of resins to zirconia has been attained by fluorination treatment in a plasma reactor with SF₆ gas. The fluorinated zirconia surface come to be hydrolysed with the development of reactive hydroxyl groups on the surface. These hydroxyl groups can react with phosphate ester containing monomer of an adhesive cement. The initial bond strengths with these primers were high but declined rapidly after 90 days in water [2].

Selective Infiltration Etching technique (SIE) concept based on coating zirconia surface with a glass-containing conditioning infiltrating agent and heated above its glass transition temperature. The infiltration agent composed of low temperature melting glass with different additives such as titanium, alumina, potassium, rubidium, and magnesium in different percentages. The surface is coated with silica-based material, with a thermal expansion coefficient similar to the zirconia one. During the glass fusion, when the temperature of 960 C is reached, Heat-induced maturation (HIM) and grain boundary diffusion of molten glass is applied to a selection of areas of zirconia to produce nano-mechanical retention. The hydrofluoric acid is applied for about 10 to 15 minutes in order to remove the glass component completely. This allows the creation of rougher surface which in turn provides nano-mechanical interlocking to resin cements. In addition, the silica layer fused on zirconia surface can bond chemically to silane primers [1].

As previously mentioned, Tribochemical silica coating technique is one of the most reliable method in developing chemical bonding between resin cements and zirconia. Pyrochemical techniques as Silano-Pen system, consists of a heat source containing the silane compound which decomposes into fragments that adhere to zirconia, which can be silanized. Still, this method is not sufficiently effective to promote a stable and lasting bond to the resin [1]. A solid-gel process (sol-gel) is impractical because it takes

many hours to create a silicate network in the surface (24 to 141 hours) However, sol-gel showed same shear bond strength, higher silicon content, and better durability compared with conventional Tribochemical method [7].

4.1.2.2. Chemical bonding via primers

Primers are responsible for the actual chemical bond. 10-methacryloyloxydecyl-dihydrogen-phosphate monomer (10-MDP) or Phosphate ester monomer. MDP is adhesive functional monomers form chemical hydrogen bonds with hydroxyl groups of zirconium oxides at the resin/zirconia interface, improving the wettability and achieving a chemical interaction. As a result a covalent bond formation by way of Zr-O-P. The 10-MDP represents a terminal functional group with phosphoric acid, which reacts with zirconia and forms P-O-Zr bonds. The other end of the molecule is engaged by a vinyl terminal group, which permits the copolymerization with the resin cements [1,7]. Mixture of organophosphate and carboxylic acid monomers also increases bond strength of different resin-based luting agents and zirconia [7].

Primers with intermixed monomers are primers contain both MDP and VBATDT (6-N-4-vinylbenzylpropylamino-1, 3, 5-triazine 2,4dithione). These primers showed higher bond strengths than MDP alone. Aggarwal., *et al.* recommended the use of a primer with both MDP and VBATDT monomers, to achieve the highest initial bond strength with long term stability. This could be attributed to bond between the vinyl groups in the VBATDT molecules and the methacrylate-based resin cement, minimizing water penetration at the primer/resin cement interface [20].

Unlike the previous blend, 3-methacryloyloxypropyltrimethoxysilane (MPS) silane and MDP did not improve the bond strength. On contrary, both monomers affected each other's reaction. Chuang., *et al.* evaluated the use of MPS silane and 10-MDP base primers, in their combined or sequential applications. The combined saline + MDP showed rapid deterioration of bond strength when compared to the sequential use. Chuang., *et al.* justified their findings to the acidity of the MDP causing rapid hydrolysis of Silane. The OH- group of the Silane will adsorb water, causing rapid bond degradation. Silane also adversely affects MDP as it hinders the deep infiltration of functional ions to interact with zirconia. The study concluded that there is no synergistic effect from mixing these two primers in treating zirconia was found [21].

Dipentaerythritol penta-acrylate phosphate (PENTA) is considered a promising monomer, Chen., *et al.* reported that PENTA monomer should have higher chemical affinity to Zr than MDP. As the Conc. of PENTA increased, the higher Zr-O-P bond formation. 20% PENTA should have the highest shear bond strength. Although PENTA proved itself as a great monomer for chemical bonding with zirconia, studies evaluating its performance in literature are limited [22].

4.1.3. Cleansing agents

After the Try-in procedure, cleansing the surface is mandatory. Phosphates, in the form of phospholipids, are found in saliva. This is problematic as Phospholipids have affinity to zirconium oxide and create a reaction with ZrO which hinders the MDP primer from bonding to the zirconia surface. Various zirconia cleansing agents were evaluated in literature. Zirconia oxide (Zr-oxide) solution as a cleansing agent [23]. This 20-second process optimizes adhesion by drawing the phosphate groups away from the Zr-oxides and leaving a fresh bonding surface for priming and/or cementing. MDP Salt surfactant is applied for 10-seconds, the MDP salts binds to the phosphate contaminates and rinsed with water. It can be used both intra and extra orally (pH 4.5) [24]. Cleaning zirconia surface with phosphoric acid is contra-indicated, similar to salivary phospholipids, the affinity of zirconia with the phosphate group is known, so when phosphoric acid is applied to a zirconia surface, its phosphate group will bond to the zirconia surface, thus inactivating the zirconia surface [7]. In a similar way scrubbing with NaCl and Hydrogen for reactivating zirconia surface was also evaluated in few studies. Micro-brush used to apply 1% NaCl for 20 seconds, followed by rinsing with water-spraying for 15 seconds and air-drying for another 15 seconds. Same manner was used with 1% Hydrogen Peroxide. Kim., *et al.* concluded that 1% NaCl cleaning solution is effective in removing saliva contamination and enhancing the resin bond strength. While, H₂O₂ exhibited the lowest bond strength value due to the more extensive bubble formations on the zirconia surface [25].

4.2. External surface treatments

4.2.1. Different core surface treatment methods

4.2.1.1. Air particle abrasion, grinding and laser

A bi-layered zirconia restoration requires various framework/core surface treatments to enhance the bonding of the veneered layers. Grinding, air particle abrasion and Er, Cr: YSGG are con-

sidered mechanical surface treatments for zirconia frameworks. However, studies showed that higher laser energy densities were needed for the laser irradiation to improve the bond strength between the veneering ceramic and zirconia. Similar values were obtained by air particle abrasion and Laser. The grinding method recorded the least value [25]. Laser radiation surface treatment at pre-sintered stage was thought to be efficient to improve veneering ceramic and zirconia core adhesion. However, Yilmaz., *et al.* found significant decrease in flexural strength values of the laser treated pre-sintered samples [12]. Unlike the pre-sintered samples, 4W Er, Cr: YSGG laser radiation showed the highest flexural strength values with post-sintered airborne-particle abrasion zirconia samples. Post-sintered sandblasted and Post-sintered 4W Er, Cr: YSGG laser revealed higher flexural strength values when compared to 5W, 6W and pre-sintered groups [12]. In Abdullah., *et al.* study, the CO₂ laser provided higher surface roughness of zirconia and provided better bond strength between core/veneer. This finding may be attributed to the effect of energy transmission and adsorption property [26]. In Lui., *et al.* study, the CO₂ laser improved both roughness and the zirconia-porcelain bond [27].

4.2.1.2. Chemical etching

Her., *et al.* evaluate the bond strength between veneering porcelain and zirconia ceramic after the chemical etching using Zircos-E. (HF + nitric acid). The findings showed that zircos-E increased the surface roughness of zirconia, and increased interfacial bond strength between zirconia and veneering porcelain. The optimum etching time was 2 hours [28].

4.2.1.3. Pre-sintering and post sintering surface treatments

Other investigations were conducted on pre-sintering and post-sintering surface treatment of zirconia frameworks. Skienhe., *et al.* findings showed that the airborne particle abrasion (APA) treated zirconia significant difference between the pre and post sintering, regarding surface roughness [29]. In agreement with Zhang., *et al.* findings. Airborne-particle abrasion before sintering is a useful method of increasing the surface roughness of zirconia [30].

Regarding flexural strength, complete transformation of monoclinic phase back to tetragonal occurred after sintering when the zirconia surface was treated in the pre-sintered stage. Monoclinic phase increased, this was accompanied by an increase in the biaxial flexural strength (BFS) [31] According to, Kurtulmus-Yilmaz.,

et al. surface treatments performed at post-sintering stage had a favourable effect on the flexural strength than pre-sintered regardless the surface treatment method [31]. Although, the veneering firing temperatures are within the phase stability range temperature of zirconia, the tetragonal phase stability may be altered. Heat treatments induce reverse phase transformation with no monoclinic phase content, this explains the decrease in flexural strength of the pre-sintered and heat-treated zirconia in Yilmaz, *et al.* study [12]. The subsequent reverse phase transformation results is the absence of compressive stress layer on the surface thus, decreasing the flexural strength of zirconia [12]. Ebeid, *et al.* evaluated the surface roughness and flexure strength of zirconia pre and post-sintering. Air particle abrasion, and Tri-bochemical surface treatments were performed after and before sintering. For the pre sintered used 0.5 bar while, for the post sintered used 2.8 bar. Air abrasion in the pre-sintered stage produced higher surface roughness values of zirconia. While the post-sintering groups showed higher flexural strength than pre-sintering groups [32].

4.2.1.4. Liners

Liner is a ceramic based intermediate layer between the veneer layer and zirconia core. Commonly in the form of slurry, spread on the surface of the zirconia core and sintered at a high temperature 970 °c (according to the manufacture). Newly introduced Spray liners are available in the market. The liners application compensate for the difference in the coefficient of thermal expansion, Increase the wettability, Increases intimate contact between core and veneer, increased bond strength between the core and veneer and basically, improves the flexural strength of bi-layered zr:by the elimination of micro-gaps at the interface. Mijoska, *et al.* the liner treated group showed higher bond strength between zirconia core and lithium disilicate veneer. Thus the application of porcelain liners is a procedure that has a positive impact on shear bond strength [33]. Jang, *et al.* findings showed increased the fracture resistance in the spray liner treated groups due to the elimination of micro-gaps at the interface which decreased the stresses at the interface [34]. Kim, *et al.* compared the use of air particle abrasion before liner application, with liner application alone. Although the liner alone recorded higher values than the APA + liner, the author recommends the use of APA prior to liner application [35]. He, *et al.* reported that the failure mode in lined bi-layered zirconia is material dependent. The complete detachment may occur if the liner is not compatible with the veneer composition [28]. Alghazzawi,

et al. recommended the use of liners with the press on technique rather layering technique [36].

4.2.1.5. Bonding/fusion of CAD/CAM veneer layer

CAD/CAM produced veneer layer can be bonded to the zirconia core via cementation (HF/adhesive resin cementation protocol) or via Fusion (Low-fusing glass), other researchers studied combination between resin cementation and glaze porcelain.

Many studies evaluated and compared these bonding methods, Al-Wahadni, *et al.* reported adhesive failures at the core/veneer interface with CAD/CAM produced veneers cemented with resin cement compared to layering [37]. Lanza, *et al.* added silane primer to the HF etched veneered layer and concluded that the silane primers combined with HF surface pre-treatment of CAD fabricated veneer Increase adhesion strength between core and veneer [38]. Tanis, *et al.* opposed the combination of resin cement and a glaze layer, as it showed lower bond strength than conventional layering [39]. Unlike the etching the veneering material surface with HF acid increased bond strength and showed similar results to layering. Walker, *et al.* evaluated the adhesion strength of CAD on using low fusing glass. The findings showed that the interfacial fracture toughness of "CAD-on" adhesive interfaces was higher than the "press-on" [40]. Previously mentioned studies concluded that, low-fusing porcelain forms a stronger and more homogenous bond than resin cement due to higher flexural strength. While the resin cement is weaker and can lead to tensile stresses inside the veneer material. Additionally, resin cement can become discoloured over time.

4.2.2. Comparison between different surface treatments

4.2.2.1. Polishing versus glazing

External surface treatment of monolithic zirconia targets a smooth, uniform surface, to prevent plaque accumulation and optimize the optical properties of the restoration. Stawarczyk, *et al.* study showed that, the polished monolithic zirconia showed least enamel wear when compared to spray glazed and veneered zirconia recorded the highest enamel wear values [41]. In agreement with Janyavula, *et al.* the polished zirconia is more enamel friendly to than veneering porcelain or glazed zirconia. The glazing should be avoided unless there is a high aesthetic demand [42]. In this case, zirconia should be polished and then re-glazed. Additionally, polishing monolithic zirconia is preferred over glazing, Gun-

dugollu., *et al.* stated that glazed zirconia causes more wear than polished zirconia [43]. Glaze layer wears off, act as third-body abrasives leading to greater wear of the opposing.

While, polished surface of monolithic zirconia show a crack-free no fragment or particle chipping. Clinically, the glaze layers have shown to be worn after 6 months of function. Gundugollu., *et al.* recommended the polishing prior to glazing during the earlier application of glaze layer. Possible reason might be that worn out glazed layer exposes underlying well-polished smooth and hard surface which decreases further wear [43].

Unlike the glass matrix ceramics, Over-glazing of zirconia might adversely affect its mechanical properties. Mohammadi-Bassir, *et al.* evaluated the over-glazing and polishing of zirconia of the flexural strength. The results showed that glazing after grinding decreased the flexural strength of zirconia [42]. In accordance with Yener., *et al.* glazing significantly decreased the biaxial flexural strength of zirconia restoration. They justified the decrease in strength, due to "Reverse Transformation Phenomena" and "Low Thermal Degradation". Additionally, the heat treatment of the glazing process after the grinding with water coolant will aid in the development of aging. Reverse transformation occurs due to the heat treatment of glazing after grinding 930 C for 1 minute. Tetragonal-Monoclinic phase transformation of zirconia when subjected to thermal stresses [44,45].

Laboratory polishing and chairside polishing proven comparable values, Chong., *et al.* investigated the effect of laboratory and clinical finishing procedures for zirconia on antagonistic enamel wear. The surface roughness values were comparable. The study recommends clinical adjustment and re-polishing of zirconia restorations following with diamond burs; effective in reducing antagonistic enamel wear [46].

4.2.2.2. Self-glazed zirconia

On the topic of the new self-glazed zirconia, Ji., *et al.* found that the polishing efficiency of a novel self-glazed zirconia is significantly higher than that of the conventional zirconia [45]. The self-glazed zirconia restorations have a very smooth surfaces that may protect the opposite natural teeth from excessive wear. Liu., *et al.* compared between non-polished self-glazed zirconia restoration and polished monolithic conventional zirconia restoration against

enamel. The findings showed that both tested group were enamel friendly. The author recommended the use of the self-glazed zirconia as an aesthetic alternative [48].

5. Conclusion

Achieving a Zirconia- resin cement bond has always been a challenge in the clinical practice. Micro-mechanical internal surface treatment via air particle abrasion followed by MDP priming, was generally approved for resin-zirconia bonding in most of the included studies. Recent studies confirmed the validity of chemical bonding between resin and zirconia, which has been improved substantively in the recent years. However, *in vitro* studies on chemical etching of zirconia are inconclusive and the relevant clinical studies are deficient. Studies evaluating the various external surface treatments are limited yet signify some external surface methodologies over others. Self-glazed zirconia is a promising alternative to conventional glazing, yet studies evaluating the difference between them are few.

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