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Effect of Surface Treatment of Zirconia on The Shear Bond Strength of Resin Cement: A Narrative Review

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Abstract

This study aimed to evaluate how various treatments, on the surface affect the strength of bonding between zirconia and resin cement compared to untreated samples. The research explored the impact of surface treatments on the bond strength between zirconia and resin cement through a search on platforms, like Google Scholar, MEDLINE/PubMed, Web of Science and Science Direct reviewing both research papers and review articles. A total of 101 studies that met criteria and directly addressed the research question were selected for analysis.

A total of 101, in vitro studies were included based on the specified criteria. The results from these studies consistently pointed out that silica coating was found to have the bond strength (SBS) with sandblasting, laser treatments, plasma treatment and Tribochemical silica coating following in decreasing order of effectiveness.

Among the treatments studied it was observed that silica coating on zirconia had the significant impact on enhancing the bond strength, between zirconia and resin cement. However controlled laboratory experiments and clinical trials are necessary to validate these findings and explore potential factors influencing the outcomes of these surface treatments.

Introduction:

Zirconia, a polycrystalline ceramic restoration that its proper adhesion to dental elements, is the key for their success. Good adhesion plays a very important role in micro-leakage prevention, marginal adaptation achievement, better retention and increasing fracture resistance (1–4).

In the past all-metal restorations were used and due to the advancement in life and need for more esthetic restoration the introduction of porcelain-fused the upgrade to all ceramics. The need for aesthetic requirements besides improved other properties, especially strength led to the development of zirconia. As the glassy content decrease an improvement in the mechanical properties happen, which influence on bond strength with resin as its resistant to acid etch and silane as compared to other types of zirconia (5,6)

Currently, no literature has had brief recent zirconia surface treatments that improve bond strength to resin cement, hence the aim of the study of this article is to present an overview of recent dental zirconia surface treatments and tend to classify the recent zirconia surface treatment in dentistry. This article is useful for dentists, dental technicians, prosthodontists, academicians, students and researchers in the field of dental zirconia.

Zirconia is an inert material with no glassy matrix free from silica, so the effect of conventional ceramic acid etching is hardly mentioned(7). many surface treatments focused on getting a reliable bond to the substrate but still controversial (8,9), in general the best method for testing the bond value between any two matetial is the shear bond strength(10)

Intensive sandblasting, with 250mm alumina particles, at 0.4MPa can result in the reduction of stabilizing oxides, increasing the chances of faster phase transformation toughening (PTT) and early aging of the material. Therefore, it is advisable to choose a milder sandblasting method using 110mm alumina particles at 0.2MPa for treating zirconia surfaces. This approach may bring advantages for stabilized zirconia (PSZ). Could potentially compromise the strength of fully stabilized zirconia (FSZ) material (9,11–13). Agents, like silane can be used after treating silica coated alumina particles with a step or by applying a layer of glassy ceramics on the zirconia surface. It's worth mentioning that the second approach could lead to excessive thickness and the bond strength, between the glassy material and the polycrystalline structure is not clearly established (14). Blending mechanical and chemical methods, on zirconia surfaces has proven to result better outcomes. Specifically utilizing primers and adhesion enhancing substances with components like 10 MDP along with silane can create a combined impact improving the effectiveness of adhesive procedures(11)

Taking into account the chemical characteristics of zirconia in relation to retentive preparation shapes and full coverage prostheses conventional water based bonding agents such as glass ionomer and zinc phosphate cements, as well as hybrid cements like resin modified glass ionomer cements can be considered suitable options for cementing(15).

In situations where there are restorations, preparations, with minimal retention features (like abutment teeth with reduced height from top to bottom) or when dealing with chewing pressures in addition to the treatments mentioned for preparing zirconia surfaces it is possible to use traditional resin cement or simpler self-adhesive bonding agents. These substances help enhance the absorption of resin spread out the forces on the surface and increase resistance against tiny cracks, on the inside of the restorations as described in citation (16).

Survey Methodology:

Articles on advances in dental zirconia ceramics were searched from -2000 using Google Scholar, MEDLINE/PubMed, Web of science, and science direct resources, research and review articles in the English language were only included in this review. The search strategy was based on MeSH terms. The key words that were used (“Zirconia’’ OR “lithium disilicate” OR “MDP”) AND (“Silica” OR “Coating agent” OR “Laser”). A total of

100 articles were selected and included in this review

Methods of zirconia surface conditioning

Surface treatment of dental zirconia categories into either mechanical, chemical and combined technique Figure (1).

1. Mechanical Techniques

A. Airborne particle abrasion

Airborne particle abrasion is essential for adequate bonding of composite cement to zirconia. The grit blasting resulted in an increase in surface roughness, accompanied by the loss of surface material.(10,17,18)The surface roughness is due to phase transition from tetragonal to monoclinic, resulting in tensile stress and failure.(19)When grit blasted with larger alumina particles (≥ 110 μm) at higher air pressure (2.8 bars or more) with a distance of the nozzle from the surface was 10 mm, the SBS between composite cement and zirconia increased significantly. (20). High SBS could be attributed to the increase in surface area due to grit blasting, and the formation of micromechanical interlocking (17,21) and the appearance of hydroxyl groups that will facilitate bonding with the primer/universal adhesive/cement (17). The abrasive process removes the loose contaminated layers, increases the surface area available for bonding, and improves the wettability of the luting material (20,22). However, recent studies have expressed concern about surface flaws produced by airborne particle abrasion, which may become the source of stress concentration and accelerate the development of failures in the clinic. (23)this Airborne abrasion with Al_2O_3 can also be done before sintering is one method claimed to achieve higher initial bond strength. However, most of the studies have shown that sandblasting or APA may create surface defects and sharp cracks that lead to a decrease in the mechanical properties of zirconia under function (24,25).

As airborne-particle abrasion (APA) can be applied to roughen the surface of zirconia as a way of increasing mechanical interlock and total contact area(26,27) also may result in the embedding of alumina particles in the surface(22). Parameters in APA with alumina are grain size (25 to 250 mm), propulsion pressure (0.05 to 0.45 MPA), distance (5 to 20 mm) from the nozzle to the specimen, and time of APA (5 to 30 seconds). The micromechanical retention of zirconia surfaces treated by abrasion with small (25 mm, 50 mm) or larger grains (110 mm) was not significantly different despite the different roughness produced. Although a larger grain size creates a rougher zirconia surface, bond strength is not significantly influenced(28). Some report that APA increases surface roughness without improving micromechanical retention.(29) Other researchers have observed smoother surface topography but improved bond strength with resin cements after APA with alumina grains (50 mm)(30,31). The effect of APA on surface roughness also depends on the type of zirconia material(24) . Removing the waste alumina from the surface seems particularly important(32).

The kinetic energy of a grain as it collides with the surface is directly proportional to the mass of the granule, which in turn increases with the cube of the diameter(33). Reducing the pressure during APA does not seem to affect long-term bond strength when adhesive surface activators are used (adhesive primers) (34). APA increases surface energy and reduces organic contaminants, thus improving the wettability of the surface. The use of APA raises 2 main concerns: the possible creation of surface microcracks and the activation of phase transformation from tetragonal to monoclinic (t/m) at the surface and subsurface, which in turn can reduce the mechanical properties of the material. For this reason, manufacturers suggest heating after APA to reverse the (m/t) conversion or using APA before the final sintering. Some manufacturers do not recommend its use with alumina grain up to 50 mm.(35) Significant phase conversion (t/m) appears to be caused by aggressive APA increasing the monoclinic phase (24)

B. Grinding with disc and diamond rotary instrument

The main disadvantage of grinding methods is again the possible creation of microcracks in the surface. The high hardness of zirconia necessitates grinding with coarse diamond rotary instruments (120 to 200 mm grain size).(36) Previously, a coarse-grained diamond grinding method had been tested, producing a rougher surface than other techniques and improved bond strength but was not acceptable because it is an aggressive method that can induce microcracks and cause damage to zirconia surfaces(4,37). Grinding conditions also seem important in that wet grinding with a 91-mm diamond wheel did not dramatically diminish flexural strength.(38) Grinding tests with 100-mm diamond rotary instruments on 3 different zirconia materials showed that in only 1 case was roughness significantly increased (24)

C. Laser

Several types of lasers used to cut hard dental substances have been used by researchers to improve zirconia bonding capacity (39). A neodymium-doped yttrium aluminum garnet (Nd:YAG) laser improved roughness and wettability of the zirconia for bonding with adhesive luting(40,41) The energy of the laser beam is absorbed by the zirconia/ceramic. This energy creates a heat induction process that produces shell-like ruptures on the ceramic surface, providing micromechanical interlocking for enhanced bonding(42). The output power of the laser and the energy level are crucial for micromechanical interlocking and have a direct influence on the SBS, but the point of application left a silver spot or greatly increased the monoclinic phase at the surface (26.5% and 30.5%)(24).
A carbon dioxide (CO2) laser is suitable for ceramics because its emission wavelength (2.3 to 10.6 mm) is absorbed by ceramics. Improved bonding was found after this laser application at a setting of 3 W and 4 W with various settings(43). At 4.5 W for 60 seconds, increased roughness and deep grooves were observed(44) while measuring the effects at power settings from 2 to 5 W (2, 3, 4, 5 W) observed that shear bond strength was improved at 2 W and negatively affected at 5 W. In other studies, a CO_2 laser improved both roughness and the zirconia-porcelain bond(45).
An Erbium-doped yttrium aluminum garnet laser (Er:YAG) laser had been used for various clinical uses in operative dentistry and its action on high-strength ceramics had been studied extensively(46). At high settings (600 MJ), extensive destruction of the material occurred, but increased roughness was observed; at low settings (200 or 400 mJ), the results were similar to those of airborne-particle abrasion(46). In different settings (150 MJ, 1 W, low power for 20 seconds), Er:YAG seemed to improve bond strength.(47)
Femtosecond technology is an innovative laser technology that uses a laser based on titanium/sapphire crystals, producing wavelengths near the infrared (795 nm). This laser produces ultra-short light pulses, below the picosecond scale, in the femtosecond domain (1fs = 10^{-15}s), it was reported that the femtosecond laser irradiation formed more regular pits on the zirconia surface and better bonding to resin cement(48).

D. Elective discharge machine

Electrical discharge machining (EDM) is a process, that creates a desired shape by eroding material with electrical sparks in a dielectric medium(49). Any electrically conductive material can be machined via this method, regardless of its hardness, shape or strength (50). Zirconia categorized as a nonconductive material for EDM purposes as this process need a material with resistivity lower than 100V and zirconia s resistivity is nearly 109 – 1010 V cm. Subsequently, Kucukturk and Cogun developed a new method in 2010 by using graphite powder (51)mixed with the dielectric liquid and the maching was achieved via a conductive coating layer to machine of electrically nonconductive work pieces with EDM. EDM treatment always produced a rougher surface than the sandblasting treatment with higher shear bond strength but the sandblasted and tribochemical silica coated specimens had higher flexural strength than the EDM treated specimens beside graphite powder mixed into the dielectric medium caused the blackening of the surfaces, but many methods successfully cleaned the surfaces of the work pieces by using a K2CrO4 + H2SO4 mixture after machining.

Other drawbacks of the EDM process include unsatisfying rates of material removal, poor surface finish and also surface cracks (52)

E. Selective infiltration technique

It is the technique that transforms the relatively smooth non-retentive surface of Y-TZP into a highly retentive surface which uses principles of heat-induced maturation and grain boundary diffusion.(53)

Heat-induced maturation (HIM) is a method which results in stressing the grain boundary regions by 2 short thermal cycles, but does not provide sufficient energy to allow for grain growth or cubic grain formation. The zirconia is heated to 750°C for 2minutes, cooled to 650°C for 1minute, reheated to 750°C for an additional 1minute, and then cooled to room temperature. After this heat treatment, the grain boundaries become pre-stressed and can be more easily infiltrated by other materials. The concentration of yttrium, which is the primary stabilizing element of the zirconia used in dental restorations, was found to be higher at grain boundaries and surfaces compared with the grain interior. Yttrium also contributes to other dynamic properties such as grain sliding, rearrangement movements, and plastic deformation.(54). Additionally, increased grain boundary mobility was observed when the surface of zirconia was in contact with different dopant phases at adequate temperature ranges. When heated to a temperature range between 700°C and 810°C for 1minute, small dopants, such as silica or titanium, were able to diffuse at grain boundary regions in fully sintered zirconia materials. Controlled diffusion of dopants or secondary phases along the grain boundary interfaces is enhanced for small grain-sized zirconia, which has a higher grain boundary surface area. Using secondary ion mass spectroscopy, grain boundary diffusion of calcium and magnesium was also observed at a temperature of 799°C.29, Such findings indicate that the surface of fully sintered zirconia could be infiltrated with dopant agents by heating zirconia for a few minutes at relatively low temperature ranges (700-900°C)(55).

2. Chemical techniques

A- Silicization

1**- Depositing a thin layer of lithium di silicate (LDs)**

Depositing a thin layer of lithium di silicate (LDs) on the surface of Y-TZP via a process such as spray deposition would solve the problem of insufficient bond strength between Y-TZP and natural teeth or other restorations, while retaining its excellent material properties. Spray deposition is a scalable, fast, low-cost, simple, and high-throughput process for fabricating thin films on substrates to ultimately modify the surface and produce desirable properties, such as roughness, affinity, wear resistance, and corrosion resistance (56). In addition, LDs belong to a series of glass-ceramics, which can be made into powders. Therefore, a thin layer of glass-ceramic powder can be easily deposited on the Y-TZP substrate through spray deposition. Subsequently, only tempering steps are required to form a dense glass-ceramic layer, so dental furnaces are used with no additional equipment. Glass-ceramic spray deposition (GCSD) is therefore a useful and effective surface treatment method for strengthening the bond between Y-TZP and resin cement. The GCSD process resulted in the generation of a dense LD coating layer of 11.78 μm .In general, the cement gap of Y-TZP restorations designed via CAD/CAM have indicated that the acceptable cement thickness ranges from 50 to 100 μm [35]. Therefore, the produced LD coating layer would not affect the fit of Y-TZP restorations (57). This addition technique", which incorporates a submicron-thick layer of porcelain on zirconia, seemed to be promising compared to conventional "subtraction techniques", which may lead to a damaged zirconia surface layer. Several ceramic coating methods have also been investigated. It has been reported that the application of a layer of silica glaze creates a more reactive and etchable glass surface that can be treated as a glass-ceramic. The HF etching removes the glassy matrix, creating a porous surface with high surface energy, ideal for cement penetration

Another technique for creating chemical bonds is silicoating (Silicoater; Heraeus Kulzer GmbH), which is based on the pyrolytic deposition of silicon to form SiOx-C coating with a thickness of 0.1 mm. This surface can then be silanated to provide stronger bonds with metal and resin cements

The method of "addition technique," which involves applying a layer of porcelain, on zirconia at a submicron scale has displayed potential when compared to subtraction techniques" that could potentially harm the zirconia surface layer as detailed in citation (20).

Moreover various approaches to coating have been examined. One approach includes the application of a silica glaze layer resulting in a glass surface that's more reactive and etchable similar to glass ceramic. Subsequent treatment with acid (HF) eliminates the glassy structure creating a surface with high surface energy that is conducive for cement infiltration as mentioned in citation (17)

Another method called silicoating (Silicoater; Heraeus Kulzer GmbH) utilizes the deposition of silicon to form an SiOx C coating around 0.1 mm(58). This coated surface can then be subjected to silanation to establish connections, with metal and resin cements as outlined in citation (59).

2- Sol gel technique

The process of forming a silica network typically involves two steps; hydrolysis and polycondensation of tetraethyl orthosilicate (60). In the hydrolysis stage tetraethyl orthosilicate decomposes to produce silanols. Each two silanols then combine to form a siloxane linkage, which undergoes polycondensation to create the silica network. The silica network chemically interacts with the zirconia surface by connecting the hydroxyl groups of silica particles, with the surface hydroxyl groups of zirconia leading to the formation of a silica layer on the zirconia surface(6). Moreover hydrolyzed tetraethyl orthosilicate may initially condense on the zirconia surface. Gradually accumulate to form a silica layer, on it.

This method is recognized as cost effective sol gel technique that has been employed for introducing silica into zirconia. (61)

The sol gel technique has advantages, over particle abrasion especially in the field of dental ceramics. One key benefit is that it helps prevent surface defects or imperfections that can occur with sandblasting. Sandblasting may result in surface irregularities that cause stresses on the surface layer potentially affecting the long term performance of ceramics (25)

Moreover the sol gel method is more cost effective, than particle abrasion. Sol gel processing requires less working space. Uses cheaper equipment and chemicals compared to the large and expensive sandblasting units and silica coated alumina sand particles commonly employed in airborne particle abrasion techniques(60).

B. Functional monomers

1- Methacrylate Di hydrogen phosphate (MDP)

Successfully bonding with zirconia using primers that contain a monomer, such, as 10 methacryloyloxydecyl dihydrogen phosphate (10 MDP) has been achieved in studies. This specific monomer, 10 MDP plays a role in creating an robust bond with Y TZP substrates resulting in highly effective bonding results (62).

The structure of 10 MDP includes a

phosphate group at one end a methacrylate group at the second end and a spacer ester chain consisting of ten carbon atoms that separate these active groups. The presence of the vinyl group (methacrylate) aids in polymerization and facilitates chemical coupling with carbon links within the resin matrix of the substrate. Notably the phosphate group is essential for enhancing adhesion with hydroxyapatite or metal oxides, like alumina or zirconia. It is this component that enables 10 MDP to form chemical bonds with non-polar and chemically inert zirconia surfaces (62,63)

The connection, between the 10 MDP primer and zirconia surface is formed through a combination of hydrogen bonds .Various research studies have proven that utilizing MDP primed zirconia leads to higher bonding compared to other priming agents or untreated zirconia surfaces (64,65). To simplify the bonding procedure certain bonding agents have been adjusted by incorporating 10-MDP in a single bottle composition to improve bonding with zirconia and different indirect restorations(66,67).

Research indicates that resin cement based on 10 MDP offers bond strength to zirconia; however factors, like surface treatment, type of cement used, testing methods employed and aging conditions can impact the bond strength results (68).

Air abrasion typically improves the immediate bond strength. The long term durability of the bond may be compromised without the application of primers or adhesives containing 10-MDP. Research indicates that cement bond strength decreases after cycling when applied without a 10-MDP containing primer or adhesive whereas those, with 10 MDP maintain their bond strength (69).This holds true for cements that necessitate an application of a 10-MDP containing primer or adhesive (63,70). These findings suggest that relying on surface treatments like air abrasion may not be adequate for establishing a durable resin zirconia bond.Primer and composite cements, with 10 methacryloyloxy decyl dihydrogen phosphate (10 MDP) have shown bond strength and durability underscoring the importance of using products containing 10 MDP to ensure a resin zirconia bond(71).

The reason, behind the bond between cements and primers containing 10-MDP and zirconia is explained by a chemical reaction between 10-MDP and zirconium oxide(72). During this chemical process one P OH group of the 10 MDP molecule interacts with zirconia while the other OH group connects with the P=O group of another 10 MDP molecule. With an amount of 10 MDP present interactions among 10 MDP molecules can take place through intermolecular hydrogen bonding and this bonding impact relies on the concentration of 10 MDP utilized (69). (Figure 4).

3. Chemo mechanical technique

A. Tribochemical silica coating

Tribochemical silica coating, in which silica is deposited on the surface of zirconia by bombardment with silica-coated alumina particles to produce a silica coating and increase the surface roughness(73,74),. Better bonding to zirconia coated with silica is achieved by using a primer that further enhances the chemical bonding, especially when the primer contains methacryloyloxydecyl dihydrogen phosphate (MDP) that adheres to the zirconia part (17,48,75) and a silane coupling agent that adheres to the silica coated on the surface of the zirconia (76).

Tribochemistry is a technique that involves forming chemical bonds by applying energy through sandblasting, without requiring extra heat or light. In dentistry methods like silica coating or silicatization using products such as Cosil and CoJet TM are commonly used to prepare surfaces for cementation.(77)

This method of cold silicatization uses kinetic energy from sandblasting to create localized heat at the impact point. The process occurs on a scale without a temperature change. It entails using blasting sand, specifically silica coated aluminum trioxide to develop a reactive silica rich outer layer on ceramics. This modification helps enhance the ceramics compatibility, with resin composites for adhesion during cementation(77).

Various forms of zirconia, like 3Y TSZ, 4Y PSZ and 5Y PSZ, display surface characteristics internal arrangements, grain sizes, shapes, compositions and levels of hardness. As a result the impact of any surface modification and the resultant bonding strength with materials can differ greatly. Hence it is not suitable to apply conclusions from one zirconia type, to another (48,78).

Some suggests that resin bonding protocols successfully applied to conventional zirconia are also the most successful for high and extra high-translucent zirconia (1), others stated that the microstructure and phase content of zirconia material seem to have an impact on bond strength as well. Micro tensile bond strength of airborne particle-abraded conventional zirconia (3 mol% Y_2O_3) was shown to be significantly higher than that of airborne particle-abraded translucent zirconia (5 mol% Y_2O_3) (79) (1), this could be also related to the higher number of cubic grains in the material(80).

Also shear bond strength of conventional zirconia with specific surface treatment differ from the shear bond strength of the translucent zirconia and that the bond strength analysis revealed higher bond strength for 3Y-TSZ–Al_2O_3 and 3Y-TSZ–tribochemical silica coating groups compared to 5Y-TSZ–Al_2O_3 and 5Y-TSZ–tribochemical silica coating, respectively(79), this is due to the differences in compositional and physical properties among types of zirconia. So we cannot generalize one protocol of a type of zirconia to other types(81)

Tribo-chemical silica coating was invented in an attempt to increase the bond strength without affecting the physical and mechanical properties of zirconia (Kern and Thompson 1994; 1995). The internal surface of the zirconia restoration was air-abraded by aluminum tri-oxide particles with silica to coat the internal surface of zirconia restoration with silica aluminum. This claimed that chemically adhere occurs between the internal surface of the restoration and the resin cement[82,83].

TBC is a process, to airborne particle abrasion. With the difference that the aluminum oxide utilized is layered with silica (84,85). This coating leads to an increase in silicon concentration on the surface. However it's crucial to mention that this silica engaged on the surface removed by ultrasonic cleaning (86) .

Research indicates that elevating the pressure during TBC treatment results in heightened surface roughness an increased number of particles coming into contact with the surface and a larger quantity of silicon ultimately enhancing bond strength(87).

Some research studies discovered high bonding when using only tribochemical silica coating[85,88]. Conversely other research suggests that a combination of mechanical (tribochemical silica coating) and chemical pretreatment is ideal[89,90], Nevertheless many researchers argue that relying on treatment without the use of a silane coupling agent may not guarantee durable adhesion [91].

B. Airborn particle abrasion with functional monomer

Airborne-particle abrasion (APA) followed by the application of 10-methacryloloxydecyl dihydrogen phosphate (MDP) has been reported to greatly improve the zirconia bond strength and durability of zirconia bonding to resin cement because the APA could increase surface roughness and surface energy , and the MDP facilitated the formation of P-O-Zr bonds by MDP (21) and to offer durable, long-term efficacy(22)

Recently, attention has been shifted to a less aggressive, lower grit-blasting air pressure of 1 bar (0.1 MPa), which proved to be as effective as the conventional grit-blasting air pressure of 2.8 bars(92). A study conducted by Attia and Matthias[93] revealed achievement of high and durable bonding with air pressure set at 0.05 MPa. Moreover, other grit-blasting materials with a high hardness value, such as artificial diamond abrasive particles or cubic boron nitride particles, have recently been introduced. (94)

C. Dip coating technique with nano particles

Another technique is dip-coating technique: dip-coating is a simple, appropriate method to form a homogeneous coating on objects with different shapes (6). Which is used to create a porous coating on a zirconia substrate for improving the bond performance of zirconia. Creating a stable nanoparticle suspension of a mixture of silica, zirconia and other nanoparticles was the key step enabling dip-coating to form a silica-zirconia coating, suitable dispersion methods are very important during the formation of nanoparticle suspensions, since nanoparticles are able to agglomerate. So many steps should be accomplished, grinding, dispersant, and sonication in order to get a stable well dispersed nanoparticles suspension. Suitable solvent is very important for completing the requirements of the suspension(6,95).

Then these coated surfaces are treated with suitable prime to produce the highest SBS(95). This demonstrates that silica-zirconia coating is an effective method to improve resin-zirconia bond strength. This might be attributable to micro-interlocking and silanization at the resin-zirconia interface(61). Numerous micro-gaps among the particles on the silica-zirconia coating layer can be seen at the microscopic level. This supports the suggestion that micro-interlocking between zirconia and resin beside additional silica elements on the zirconia surface provides a silanizable surface for improving bond strength. Therefore, the silica-zirconia coating not only promotes micro-interlocking, but also chemical bonding.

Conclusion

Within the limitations of this review, the following conclusions were drawn:

-Zirconia surface cleaning must be performed before pretreatment methods to adhesion.

-Mechanio-chemical surface pretreatments offered the best adhesive results. Tribochemical silica coating at a pressure of 1.8–2.8 bar has proved to achieve a significant increase in adhesion to zirconia.

-New methods as feldspathic ceramic sandblasting and silane application or YAG laser combined with silane seem to be promising alternatives in adhesion to zirconia.

-The dip-coating technique is straightforward and laboratory-friendly, overcoming limitations of traditional abrasive blasting or complex vapor deposition methods.

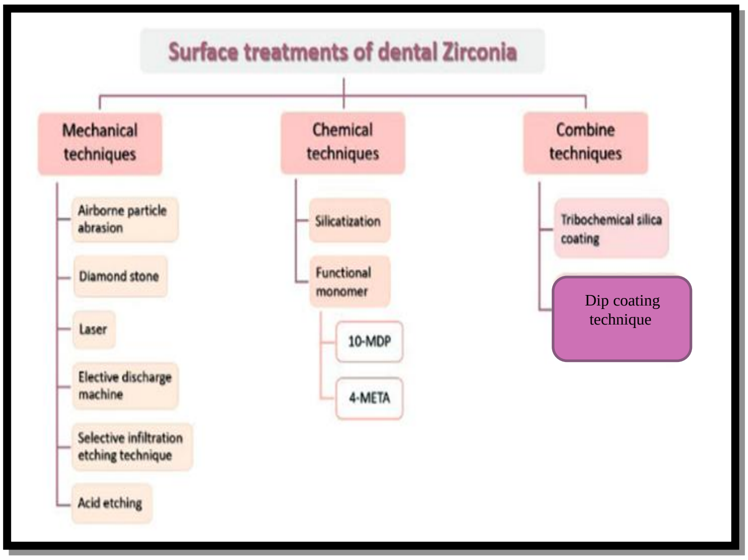

Fig (1): Classification of zirconia surface treatment

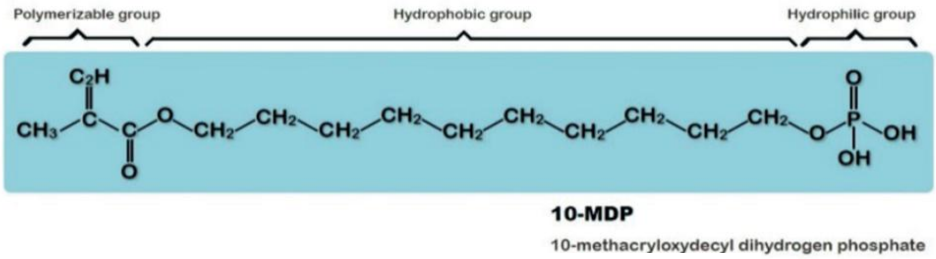

Fig (2): 10 -MDP chemical structure

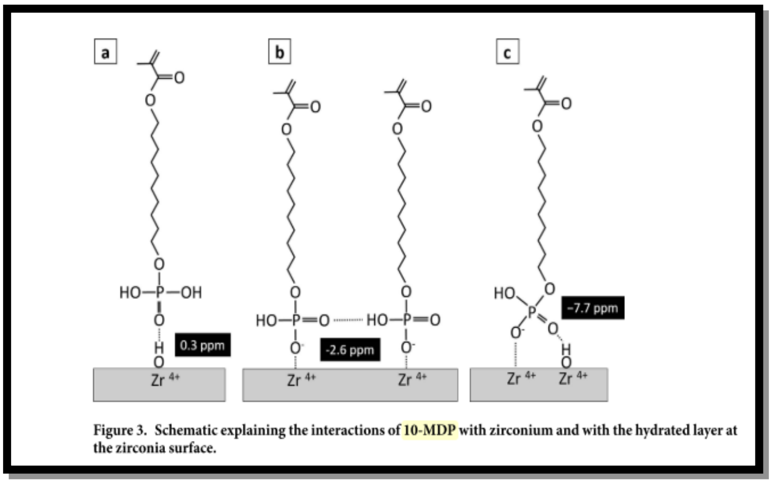

Fig (3): interaction of different 10-MDP concentration with zirconia surface

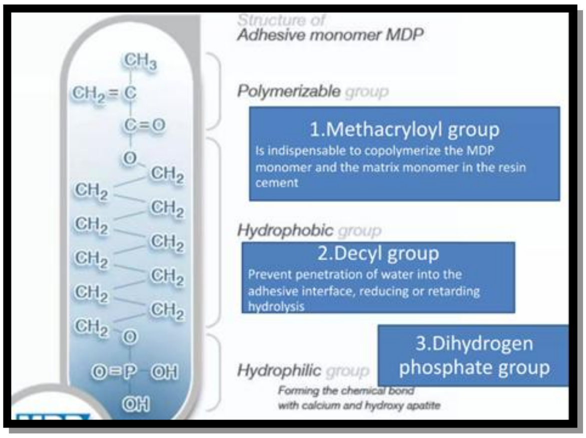

Fig (4): Structure of adhesive monomer MDP

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