BONDING TO ZIRCONIA CERAMIC: A REVIEW

Authors:

Sumanjit[1]*
Anuva Bhardwaj[2]
Irina Singh[3]
Jyoti Yadav[4]
Kantya Malik[5]
Anitha Varghese[6]

ABSTRACT

Reliable bonding between resin composite cements and high strength ceramics is difficult to achieve because of their chemical inertness and lack of silica content that makes etching impossible. The purpose of this review is to classify and analyze the existing methods and materials suggested to improve the adhesion of zirconia to dental substrate by using composite resins, in order to explore current trends in surface conditioning methods with predictable results.

Keywords: Bonding, Ceramic, Material, Zirconia.

[1]Senior Lecturer,
Department of Prosthodontics,
Rayat Bahra Dental College and Hospital,
Mohali, Punjab

[2]Senior Lecturer,
Dept. of Pedodontics,
Rayat Bahra Dental College and Hospital,
Mohali, Punjab

[3]Empanelled Consultant-
Dental Sciences,
Fortis Escorts Hospital, Amritsar, Punjab

[4]PG Student,
Dept of Prosthodontics and Crown and Bridge,
Dr. Harvansh Singh Judge Institute of
Dental Sciences and Hospital, Chandigarh

[5]Consultant Dental Surgeon, Karnal, Haryana
Consultant Endodontist, Thiruvankulam P.O.,
Ernakulam District, Kerala

Corresponding Author:
Dr. Sumanjit
Senior Lecturer,
Dept. of Prosthodontics,
Rayat Bahra Dental College and Hospital,
Mohali, Punjab

INTRODUCTION

In present scenario, in order to improve aesthetical outcome of Fixed Partial Denture restorations dental researches are more directed towards metal-free prosthetic restorations, as these restorations allow to preserve soft tissue color more similar to the natural one than porcelain fused to metal restorations.[1] Many ceramics such as spinel, alumina, and ceramic reinforced with lithium disilicate, have been proposed for the construction of metal-free restorations.[2] Developments over the last 10 years in ceramic materials science for dental applications have led to a class of high strength materials (e.g., alumina and zirconia-based ceramics) that potentially provide better fracture resistance and long-term durability than traditional porcelain and other ceramic alternatives.[3] Raigrodski analyzed different all ceramic systems and concluded that reinforced ceramics can only be used to replace anterior teeth with single crown restorations or maximum with three units FPDs.[4] On the other hand, Zirconium dioxide restorations have a wider application field. Main advantage of Zirconia-ceramic FPDs is that these can be used in case of molars in contrary to other ceramic technologies which only allow the construction of structures that are resistant to chewing stresses on anterior teeth.[5]

DISCUSSION

Bonding is an adhesive technique in dentistry involving conditioning of enamel and/or dentin so as to create tags in the tooth structure for mechanical retention of restorative material.

A strong, durable resin bond provides:

1. high retention

2. improves marginal adaptation and prevents microleakage

3. increases fracture resistance of the restored tooth and the restoration.[6]

Bonding to zirconia ceramic: Adhesion methods and durability

Adhesive bonding techniques for zirconia[7]

1. Zirconia primers

2. MDP monomer based resin cements

3. Airborne particle abrasion

4. Tribochemical surface modification

5. Selective infiltration etching technique

6. Vapour phase deposition technique

Zirconia primers[8,9,10]

Organofunctional trialkoxysilane coupling agents (briefly silanes). Silanes form a large group of organic compounds that essentially contain a silicon (Si) atom or atoms. Organosilanes are either hydrophilic or hydrophobic. Silanes resemble orthoesters, and they can be bifunctional, ie, they have a dual reactivity. The organic functional part (eg, vinyl -CH=CH2, allyl -CH2CH=CH2, amino -NH2, isocyanato -N=C=O) can polymerize with an organic matrix. The alkoxy groups (eg, methoxy -O-CH3, ethoxy -O-CH2CH3) can react with an inorganic substrate, in both cases forming covalent bonds between the matrices.

Generally, silanes may or may not contain reactive groups. A reactive group can also be -chloride (-Cl). There can be a propylene link (-CH2CH2CH2-) between Si and the organic functionality, especially when the silane is used for metal pretreatment. Silanes may be monofunctional or bisfunctional, Trisfunctional silanes with three Si atoms also exist. Silanes, hybrid organic-inorganic compounds, can function as mediators and promote adhesion between dissimilar, inorganic and organic, matrices through dual reactivity.

They are called primers, coupling agents, or sizes, depending on their function and substrates. They can also be used as filler surface treatment agents and able to act as coupling agents in the interface between organic-inorganic substances, silanes must first be hydrolyzed (activated) and condensed. At about pH 4 (for organotrialkoxysilanes), the rate of condensation between silanol groups of monomeric silane molecules to larger oligomers is at the minimum, and the silane solutions have the highest stability. Acetic acid is often used for the pH adjustment. The hydrolysis time varies depending on the silane concentration, solution, and temperature, but usually 0.5 to 2.0 hours is enough.

During the condensation reaction, silane molecules react with each other, forming dimmers followed by condensation to form

siloxane oligomers. Also, hydrogen bonding between the siloxane monomers and oligomers occurs in the solution. Silane oligomers react with each other, forming branched hydrophobic siloxane bonds, -Si-O-Si-, and with an inorganic matrix (eg, silica, metal oxides that contain hydroxyl-OH groups) they can form -Si-O-M- bonds (M = metal).

According to the latest theories, there will be a film, a hydrophobic and branched polysiloxane layer that may also contain free hydrogen-bonded oligomers. Also, free water molecules can appear in the film. If the substrate is silica (quartz, Si02) or silicate, only a siloxane layer; -Si-O-Si-, will be formed. The branched siloxane layer (film) thickness is dependent on the concentration of the silane solutions. lf the substrate is aluminum, -Si-O-;AI- bonds seem to have poor hydrolytic stability. The silane most commonly applied in dental laboratories and chairside is a monofunctional methacryloxypropyltrimethoxysilane. Usually dilute, often less than 2 wt% in water-ethanol solution, with its pH of 4 to 5, adjusted with acetic acid, being prehydrolyzed. MPS is used to optimize and promote the adhesion, through chemical and physical coupling, between metal-composite, ceramic-composite, and composite-composite.

• Silanes are applied in:

1. Polar aqueous alcohol solutions (eg, ethanol, isopropanol) and in ethyl acetate

2. Nonpolar solutions (eg, n-pentane, n-hexane) have also been investigated

The silanes used in dentistry are usually in 90% to 95% ethanol or isopropanol solutions, but more dilute alcohol solutions, about 20% or even 40% to 50%, are also used. Acetone-ethanol mixture is also known.

MDP monomer based resin cements[11,12,13]

Organophosphate monomers have an organofunctional part, most often a methacrylate group. The phosphate monomers also contain phosphoric acid groups that can develop the bond with the metal oxides in the substrate. The application of MDP-containing silane/cement system (Clearfil Esthetic Cement) attained the best overall results. The adhesive potential of 10-MDP to densely sintered zirconia may depend on the presence of a passive coating of zirconium oxide on the

ceramic surface. Chemical reactions involving the hydroxyl groups of the layer and the phosphate ester monomers of the MDP may occur at the interfacial level. Moreover, the functional monomer has been rated as relatively hydrolysis stable, due to the presence of a long carbonyl chain.

Conventional silanes are not as effective on zirconia as on silica-based ceramics. Nonetheless, the silane molecule (3-MPS) mixed with 10-MDP in the coupling solution (Clearfil Ceramic Primer) may have promoted the bonding mechanism, improving surface wettability and forming cross-linkages with methacrylate groups as well as siloxane bonds with the Oh groups of the ceramic substrate. Such a reaction may be promoted and sustained by the acidity of the substrate treated with the coupling solution. A relatively strong poly-molecular layer may be responsible of the ceramic-resin cement bond.

Like silanes, organophosphate monomers have an organofunctional part, most often a methacrylate group that can be co-polymerized with the monomers of a composite resin system. The phosphate monomers also contain phosphoric acid groups that can develop the bond with the metal oxides in the substrate. The other monomers in Zirconium Phosphide, such as the carboxylic acid monomer, are cooperating in the development of the bond.

Airborne particle abrasion[14,15]

Air-particle abrasion is a prerequisite for achieving sufficient bond strength between the resins and high-strength ceramics that are reinforced either with alumina or zirconia. The air abrasion systems rely on air-particle abrasion with different particle sizes ranging from 30 to 250µm. The abrasive process removes loose contaminated layers and the roughened surface provides some degree of mechanical interlocking or 'keying' with the adhesive. While these mechanisms explain some of the general characteristics of adhesion to roughened surfaces, it may also introduce physico-chemical changes that affect surface energy and wettability. Such conditioning systems could be applied either at the laboratory or chairside, using large or small size particles. However, there is limited knowledge as to whether micromechanical retention using large or small particle size increase resin

bond to high-strength ceramics of different microstructures and chemical compositions.

A high and reliable resin bond to alumina and zirconia ceramics was also achieved with airborne particle abrasion and by using a phosphate monomer (MDP) containing resin composite luting cement. Air-abrasion seems to be a prerequisite to achieve high and durable bond strengths to zirconia ceramics. This method can significantly improve resin-zirconia ceramic bond strength and its durability by increasing surface roughness, cleaning and activating the ceramic surface when combined with adhesive monomer-containing primers such as 4-methacryloxyethyl - trimellitate - anhydride (4-META) or 10-methacryloxydecyl-dihydrogenphosphate (MDP). However, air-abrasion might compromise the mechanical strength of ceramic itself by initiating surface defects. Therefore, reducing the pressure during air-abrasion or omitting air abrasion completely might be recommended in combination with new ceramic primers in order to improve the bonding durability and reduce the negative influence of high-pressure air-abrasion on the mechanical properties of zirconia ceramic.

Tribochemical surface modification[16,17,18]

Modern surface conditioning methods require airborne particle abrasion of the surface before bonding in order to achieve high bond strength. One such system is silica coating. In this technique, the surfaces are air- abraded with aluminum oxide particles modified with silisic acid. The blasting pressure results in the embedding of silica particles on the ceramic surface, rendering the silica- modified surface chemically more reactive to the resin through silane coupling agents. Silane molecules, after being hydrolized to silanol, can form polysiloxane network or hyroxyl groups cover the silica surface. Monomeric ends of the silane molecules react with the methacrylate groups of the adhesive resins by free radical polymerization process.

Application of a silica coat on ceramics with high crystalline (low silica) content.

This technology was initially developed for metals to increase bonding to resins. The silica coating systems include:

- Rocatec and Cojet from ESPE (Germany) and
- the Silicoater MD from Heraeus Kulzer (Germany).

Cojet is an in-office silica coating system that uses 30-μm silica-modified Al2O3 particles (Cojet-Sand) blasted to the surface, followed by the application of a silane agent (ESPE-Sil). These silica coating systems have showed adequate bond strength values. COJET Sand is a specially developed sand for coating all conventional dental materials intraorally such as, for example, metal, ceramic and composite surfaces. In addition to providing microretentive roughening, silicatized COJET Sand allows a ceramic-type coating of the surface of the material. Combined with ESPE SIL, the surface silicatized by COJET Sand provides the foundation for the adhesive bond. Because of its fine particle size (30 μm), the abrasion rate is much lower than with conventional abrasives. Even fine crown edges can therefore be treated without damage.

Mechanism of Adhesion

The coating step during repair work is performed by sandblasting with silicatized COJET coating sand. Blasting causes the ceramic coating to be tribochemically anchored. Tribochemistry means the creation of a chemical bond by the use of mechanical energy. This energy can be supplied by rubbing, grinding or blasting. If corundum particles, modified by silica, with a mean particle size of 30 μm strike the surface to be silicatized with great energy, very high temperatures are produced by the energy of impact (triboplasma). During this process, components of the blasting abrasive are incorporated into the metal down to a depth of 15 μm. Since this effect is limited to microscopically small areas of the surface, no temperature increase over the entire metal frame can be observed.

The surfaces modified in this way are conditioned in the next step - silanization. Silanization with ESPE SIL first allows a chemical bond between the ceramic bonding agent layer and the opaquer or any other commercial methacrylated monomer system. The anchoring thus produced corresponds in broad outlines to the chemical binding of silanized fillers in the composite. The silane used in ESPE SIL is distinguished by two

different polar ends on the molecule. The alkoxy groups of the silanol unit, (RO)3Si group on the left side will form a chemical bond with the silicatized surface. The methacrylate groups (right side of the silane) can then be copolymerized with the monomers of the resin. In this way, a chemical bond is achieved between metal frame and resin.

Vapour phase deposition technique[19,20]

It is a unique deposition technique whereby chloro-silane is combined with water vapor to form a more reactive, SixOy-functionalized surface. The process utilizes a molecular vapor deposition (MVD) tool, developed specifically to deposit conformal, thin films to serve as hydrophobic, hydrophilic, biocompatible, protective, ordering, or otherwise reactive coatings. This flexible system allows deposition of numerous materials from simple liquid precursors. Examples of materials include fluoropolymers for hydrophobicity, silanes for polymer and metal adhesion or hydrophillicity, and PEG-based coatings for biocompatibility.

Deposition conditions and precursor chemistry can also be modified to produce a range of surface characteristics. This process is a very simple and fast method for producing thin, high quality, conformal coatings of almost any organic material with a boiling point below 150°C. As the silicon tetrachloride (SiCl4) and water vapor react with the substrate surface, active hydroxyl groups are formed on the surface subsequently forming a silicon oxide layer on the substrate surface. This treatment serves as a primer step for subsequent reactions with organo-silanes, used as adhesion promoters in conventional resin bonding applications. It is thus hypothesized that the chloro-silane pretreatment process will allow for conventional silanation and resin bonding techniques to be a viable option for high strength ceramics.

Selective infiltration etching technique[21,22,23]

Additional structural changes occur on the grain level, which tends to mature and grow in size when given sufficient time and temperature. Grain growth and cubic grain formation were observed when zirconia was heated to 1450°C for 2 hours. When heated for 30 minutes at relatively lower temperatures (700-900°C), the surface of zirconia was reported to undergo a thermal aging process, especially in the presence of water vapor. On a microscopic level, thermal aging resulted in the creation of surface elevations, grain pullout and detachment, and increased grain boundary thickness. During thermal etching of zirconia at a temperature of 1350°C for 12 minutes, surface elevations, rippled grain surfaces, and vertical grooves at grain boundaries were reported using atomic force microscopy.

These observations were related to the tetragonal monoclinic transformation of zirconia crystals at the surface grains, which can accommodate the accompanying increase in volume, a state determined by grain boundaries and surface energies. However, deeper grains are restrained and constrained by the bulk of the materials and, thus, become strained. This thermo-dynamic behavior indicates that the structure the surface grains could be manipulated by controlling both temperature and heating time.

Heat-induced maturation (HIM) is a new method which results in stressing the grain boundary regions by 2 short thermal cycles. But it does not provide sufficient energy to allow for grain growth or cubic grain formation. The zirconia is heated to 750°C for 2 minutes, cooled t 650°C for 1 minute, reheated to 750°C for an additional 1 minuet state, and then cooled to room temperature. After this heat treatment, grain boundaries become prestressed and can be more easily infiltrated by other materials.

When heated to a temperature range between 700°C and 810°C for 1 minute, small dopants, 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 bigger grain boundary surface area.

A novel surface treatment method developed by the authors, selective infiltration etching (SIE), uses principles of heat-induced maturation and grain boundary diffusion to transform the relatively smooth non retentive surface of Y-TZP into a highly retentive surface. In combination with heat induced maturation, which is used to prestress the grain boundary regions, these regions could be further widened

by applying a thin layer of an infiltration glass over the surface of treated zirconia. In the semiliquid state, the molten glass infiltrates selectively between the boundaries of the surface grains and exerts surface tension and capillary forces, allowing rearrangement movements of the surface grains, and results in the creation of 3-dimensional network of inter grain porosity. This surface treatment is selective because it involves only the surface grains in contact with the infration glass. Thus, the operator can control the area of the zirconia that needs to be treated.

Other Methods[24]

• Plasma spraying technique.

• Fusing glass (porcelain) pearls to the zirconia surface.

• Nobel bond.

Plasma Spraying Technique[24]

The plasma spraying techniques may give improved bonding values even though its bonding energy still remains unknown. Plasma is a partially ionized gas containing ions, electrons, atoms, and neutral species. To enable the gas to be ionized in a controlled and qualitative manner, the process is carried out under vacuum conditions. A high frequency generator-which can be in the kilohertz, Megahertz, or microwave range is then used to ionize the gas into plasma. The plasma-spray technique may give a good bond even if the bonding energy is still hard to explain. This technique has been widely tested together with various materials in various situations. In most cases it seems to improve the bond strength to several materials, explained by covalent bonds.

Fusing glass (porcelain) pearls to the zirconia surface[25,26]

Another way to establish a firm bond between the zirconia surface and the resin luting material could be by fusing glass (porcelain) pearls to the zirconia surface. This treatment should, however, be done with caution in order not to jeopardize either the crown build up or the fit of the reconstruction to the tooth. However, two pre-requisites must be fulfilled with this technique.

1. It should not interfere with the crown fusing and should be incorporated in that scheme to avoid additional fusing.

2. It must not create an increase in thickness over approximately 5 µm.

Low fusing porcelains (or glasses) attached by electrostatic bonds mainly depend on contact area and different isoelectric points on the material. This is noted to be 8.2 (pH) for zirconia but for most glasses lower, around 3.5. Together with van der Waals interaction the electrostatic forces contribute to the attachment of the glass pearls. Bond strength values were increased by a factor of 10. These pearls can be successfully silanized prior to cementation and with this one, even higher bond strength values obtained.

Nobel Bond[27,28]

Recently, a new approach for modifying zirconia surfaces (tentatively named NobelBond; Nobel Biocare AB, Goteborg, Sweden) was introduced. The new modified ceramic surface, currently not commercially available, is purported to have a unique adhesive surface replete with intricate microporosities. The modified zirconia surface does not require further post manufacture surface treatment, being ready for adhesive cementation as is. It has been suggested that the combination of the zirconia mechanical properties with the new adhesive surface would be advantageous for the fabrication of RBFPD frameworks.

The modified zirconia surface has abundant and intricate microporosities, ranging from 27.3 to 69.9 µm in breadth and 19.9 to 46.9 µm in depth. Therefore, the resin cement penetrates into the microporosities, providing mechanical interlocking for micromechanical retention. The modified surface is produced by coating a presintered or a fully sintered and milled zirconia framework with slurry containing zirconia ceramic powder and a pore former. Then the slurry-coated ceramic is sintered while the pore former burns off, leaving a porous surface. The porosities of the surface can be modified by using different sizes of pore formers or repeating the coating process. The modified surface showed increased bond strengths compared to airborne-particle abraded or intact zirconia surfaces. In addition, because of the intricate surface, no special monomer, such as 10-methacryloyloxydecyl

dihydrogen phosphate (MDP), is necessary for bonding to this high-strength ceramic. Therefore, the use of conventional bis-GMA resin cements is possible.

Zirconia Bond with Veneering Ceramic[29,30]

Clinical failures of veneered Y-TZP frameworks due to chipping of the veneering ceramic are reported to be 13.0% after an observation period of three years) and 15.2% after five years). Sufficient bond strength between the veneering ceramic and the substructure is therefore a concern for the long term clinical success of zirconia restorations.

Bond strength is determined by a host of factors:

1. Strength of the chemical bonds
2. Mechanical interlocking
3. Type and concentration of defects at the interface
4. Wetting properties
5. Degree of compressive stress in the veneering layer due to a difference in the coefficients of thermal expansion between zirconia and the veneering ceramic

On enhancing bond strength, sandblasting is a popular means used to achieve this purpose by increasing surface roughness and providing undercuts. However, sandblasting also initiates phase transition, thus affecting mechanical strength and most probably, the bonding capacity of the material.

For veneering zirconia, silicate ceramics are used. Silica coating of zirconia, therefore, may be considered to enhance bond strength. Due to the high kinetic energy of the particles at the impact, silica is fused to the substrate surface. Depending on the bond strength of the silica layer to zirconia, the bond strength of the veneering ceramic might also be enhanced.

SUMMARY AND CONCLUSION

The original roughness produced by the milling during fabrication is not sufficient to promote adhesion and it seems important to mention that not only cleaning, but roughening and activating the surface are important to achieve durable resin bond to densely sintered zirconia ceramic. It has been demonstrated that, besides increasing surface roughness of y-TZP ceramics, air abrasion also leads to the transformation from tetragonal to monoclinic phase. Tribochemical silica coating has also been recommended on zirconia as a roughening procedure and presents good immediate results especially when combined to silanes, associating the micromechanical with the chemical retention via siloxane bonds. When focussing on the topographical modification of zirconia, however, similar surface roughness can be created with Al2O3 airborne-particle abrasion and silica coating methods.

REFERENCES

1. Manicone PF, Iommetti PR, Raffaelli L. An overview of zirconia ceramics: Basic properties and clinical applications. J Dent 2007;35(11): 819-26.

2. Pollington S, Noort RV. An update of ceramics in dentistry. Int J Clin Dent 2009;2(4): 3-27.

3. Valjakova EB, Stevkovska VK, Kapusevska B, Gigovski N, Misevska CB, Grozdanov A. Contemporary dental ceramic materials, A review: Chemical composition, physical and mechanical properties, indications for use. Open Access Maced J Med Sci 2010;6(9): 1742-55.

4. Raigrodski AJ. Contemporary materials and technologies for all ceramic fixed partial dentures: a review of the literature. J Prosthet Dentist 2004;92(6):557-62.

5. Kumar CG, Shruthi DP, Raj KS, Kalpana D, Harish G. Zirconia: Substitute for metal ceramics. J Orafac Res 2014;4(4): 209-12.

6. Sofan E, Sofan A, Palaia G, Tenore G, Romeo U, Migliau G. Classification review of dental adhesive systems: from the IV generation to the universal type. Ann Stomatol (Roma) 2017;8(1): 1-17.

7. Russo DS, Cinelli F, Sarti C, Giachetti L. Adhesion to zirconia: A systematic review of current conditioning methods and bonding materials. Dent J 2007;7: 74-92.

8. Matinlinna JP, Lassila L, Ozcan M, Urpo AY, Vallittu PK. An introduction to silanes and their clinical applications in dentistry. Int J

Prosthodont 2004;17(2): 155-64.

9. Antonucci JM. Chemistry of slianes: Interfaces in dental polymers and composites. J Res Natl Inst Stand Technol 2005;110(5): 541-58.

10. Goyal S. Silanes: Chemistry and applications. J Ind Prosthodont Soc 2006;6(1): 14-18.

11. Mattiello RDL, Coelho TMK, Insaurralde E, Coelho AAK, Terra GP, Kasuya AVB et al. A review of surface treatment methods to improve the adhesive cementation of zirconia-based ceramics. Hindawi ISRN Biomaterials 2013.

12. Chuang SF, Kang LL, Liu YC, Lin JC, Wang CC, Chen HM et al. Effects of silane- and MDP-based primers application orders on zirconia–resin adhesion—A ToF-SIMS study. Dental materials: official publication of the Academy of Dental Materials 2017;33(8): 1-9.

13. Peutzfeldt A. Resin composites in dentistry: the monomer systems. Eur J Oral Sci 1997;105(2): 97-116.

14. Valandro LF, Ozcan M, Bottino MC, Bottino MA, Scotti R, Bona AD. Bond Strength of a Resin Cement to High-alumina and Zirconia-reinforced Ceramics: The Effect of Surface Conditioning. J Adhes Dent 2006;8:175-81.

15. Kulunk S, Kulunk T, Ural C, Kurt M, Baba S. Effect of air abrasion particles on the bond strength of adhesive resincement to zirconia core. Acta Odontol Scand 2011; 69: 88–94.

16. Park JH, Choi YS. Microtensile bond strength and micromorphologic analysis of surface-treated resin nanoceramics. J Adv Prosthodont 2016;8(4): 275-84.

17. De Almeida-Junior AA, Fonseca RG, Haneda IG, Abi-Rached FO, Adabo GL. Effect of surface treatments on the bond strength of a resin cement to commercially pure titanium. Braz Dent J 2010;21(2): 11-16.

18. COJET System. 3M ESPE.

19. Piascik JR, Swift EJ, Thompson JY, Grego S, Stoner BR. Suface modification for enhanced silaanation of zirconia ceramics. Dent Mater 2009;25(9): 1116-21.

20. Kobrin B, Chinn J, Ashurst RW. Durable anti stiction coatings by molecular vapor deposition (MVD) NSTI Nanotech. 2005;2:247-50.

21. Aboushelib MN, Kleverlaan CJ, Feilzer AJ. Selective infiltration-etching technique for a strong and durable bond of resin cements to zirconia-based materials. J Prosthet Dent 2007;98(5): 379-88.

22. Hamdy AM, Hashem ABH. Effect of surface treatment and artificial aging on microtensile bond strength of zirconia to resin cement. Egy Dent J 2017;63: 2487-94.

23. Mostafa D, Aboushelib M. Bioactive hybrid zirconia implant surface for enhancing osseointegration: an in vivo study. Int J Implant Dent 2018;4(20): 1-7.

24. Derand T, Molin M, Kvam K. Bond strength of composite luting cement to zirconia ceramic surfaces. Dent Mater 2005;21(12): 1158-62.

25. Gowida MA, Aboushelib MN. Bonding to zirconia (A systematic review). Open Access J Dent Sci 2016;1(1): 1-20.

26. Pugal N, Rajesh P, Preethe PM, Padhmaraj SN, Chakravarthy D. Surface conditioning and silanization for ceramic adhesion. J Scientific Dent 2018;8(2): 32-37.

27. Cionca N, Hashim D, Mombelli A. Zirconia dental implants: where are we now, and where are we heading? Periodontol 2000. 2017;73(1):241-258.

28. Garayoa RC, Pelaez J, Tobar C, Rodriguez V, Suarez MJ. Adhesion to Zirconia: A Systematic Review of Surface Pretreatments and Resin Cements. Materials 2021;14: 2751-64.

29. Kirmali O, Kapdan A, Kustarci A, Kursat E. Veneer Ceramic to Y-TZP Bonding: Comparison of Different Surface Treatments. J Prosthodont 2016;25(4): 324-9.

30. Fischer J, Grohmann P, Stawarczyk B. Effect of Zirconia Surface Treatments on the Shear Strength of Zirconia/Veneering Ceramic Composites.