Zirconia

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Zirconia is one of the indirect metal-free restorations used in dental medicine.

resin bonding dental bonding zirconia 3Y-TZP ceramic cement

1. Introduction

In recent decades, the increasing aesthetic needs in dentistry have led to the progressive overcoming of metal-ceramic prostheses and led to a focus on indirect metal-free restorations. Yttrium-stabilized zirconia has occupied an increasingly important role and offers a wide variety of clinical applications, such as root posts, implant abutments or as a material of choice for indirect ceramic restorations. It has the most favorable mechanical properties compared to other high-strength ceramics with flexural strengths of 700–1200 MPa, fracture resistance of more than 2000 N and fracture toughness of 7–10 MPa [1][2][3][4]. However, not only strength is important but also cementation and the adhesion of cement both to the dental tissues and to the restorative material is critical for the long-term success of the restorations [5].

Surface treatment with hydrofluoric acid (HF) and silane coupling agent application of the silica-based ceramics is a well-established method to achieve durable adhesion to resin-based materials [6]. However, this process has failed for adequate resin bond to zirconia ceramics because they do not contain a silica phase making adhesion impossible [7][8][9]. Therefore, in the last few years, several zirconia surface pretreatments have been suggested to enhance the bond strength of luting cement to zirconia ceramics. Some of these methods facilitate an increase of surface roughness, improving micro-mechanical retention of the resin cement employing airborne particle abrasion with alumina particles [10][11], tribochemical silica coating (TSC) [1][12][13]. laser irradiation or chemical etching [14][15][16][17]. However, it has been reported that possible damage on the zirconia surface is created by air-abrasion methods [18][19][20][21]. To solve this problem, alternative methods have been introduced, such as chemical promoters and resin cement based on organophosphate/carboxylic acid monomers specific for zirconia [22] that have been considered as chemical surface treatments. Among them are functional monomers as 10-methacryloyloxydecyl dihydrogenphosphate (10-MDP), phosphonic acid acrylate or anhydrides [23][24][25]. Furthermore, silane deposition [26], selective infiltration etching (SIE) [27], ceramic coating and the use of cement-containing MDP are proposed chemical methods [28]. However, hydrolytic degradation is still problematic [29].

Several methods have been used to evaluate the bond strength of resin-based materials to dental ceramics, including macroshear, microshear, macrotensile and microtensile tests. Furthermore, methods to evaluate bond durability simulating the oral conditions include short- and long-term water storage and thermocycling at diverse temperatures, dwell time, and number of cycles. Therefore, it is difficult to compare different studies on the same materials even when the same test method was employed [5][30].

Due to the great increase in in vitro studies in recent years and the lack of consensus on resin-bonding protocols for zirconia restorations, it is necessary to evaluate the current data to unify criteria and provide clinicians with relevant information for their daily activity.

2. Adhesion to Zirconia: Surface Pretreatments and Resin Cements

2.1. Zirconia Surface Pretreatments

Pretreatment techniques were classified into three groups: (1) mechanical: studies that used air-abrasion protocols, laser, ceramic coating, or chemical etching, (2) chemical: studies that employed coupling agents such as adhesive resins, silanes or primers, (3) mechanicochemical: when both mechanical and chemical conditioning methods were applied. Control groups were defined as zirconia substrates with no surface pretreatment.

The studies agree that the zirconia surface needs to be prepared before applying the resin cement since all the pretreatments increased the bond strength, improving the values of the control group [31][32][33]. The first requirement for adhesion is to achieve a surface free of contaminants. Most of the studies started the surface conditioning protocol by polishing with papers, sprays or milling cutters of silicon carbide ranging between 220 to 4000 grit. Although several studies did not mention this step, they may have done it too. Ultrasonic cleaning before surface conditioning or the resin cement is also widely used [34][33][35][36][37][38][39][40][41][42][43][44][45][46][47]. Likewise, several solutions were used, including distilled water, alcohol, acetone, ethanol, and isopropanol, with a usage time between 1 and 10 min. In almost no studies, the effect of cleaning methods on adhesion to zirconia has been considered, but all authors considered it as a beneficial element [35][40][42][46].

Several mechanical pretreatments have been investigated. Sandblasting with alumina particles improved the bond strength values due to the increase in surface energy, wettability, roughness, and the appearance of hydroxyl groups that will facilitate bonding with the primer/universal adhesive/cement [31][36][39][41][46]. The particle size used ranged from 30 to 110 µm, at 0.5–4 bar for 10–20 mm [30][48][31][32][33][36][37][38][39][41][42][43][44][46][47][49][50][51][52][53][54][55][56][57][58][59][60][61][62][63][64][65][66][67][68][69][70][71]. An increase in particle size and pressure had long been associated with the formation of microcracks and weakening the mechanical properties of the material [32][37][39][47][57][60][61][64][66][67][69]. However, the bond strength was not affected by the variation in particle size and pressure [46]. It has also been reported that sandblasting before sintering caused fewer phase transformations than after sintering. However, sandblasting before or after sintering had no influence on adhesion [46][66].

The application of lasers to the surface of zirconia is based on the same principle as sandblasting, obtaining a rough surface and an increase in wettability that allows micromechanical retention with the resin [42]. Different types of lasers have been described (Er: YAG, Nd: YAG, Yb: YAG, CO_2), with different parameters of power, energy intensity, distance, and duration. Most of the studies concluded that the application of laser did not increase the bond strength compared to sandblasting and did not obtain acceptable adhesion values [33][38][41][50] due to the appearance of microcracks on the surface of the zirconia, leading to a phase transformation and weakening the mechanical properties [50]. Therefore, the laser is not currently considered a valid mechanical pretreatment [33][41].

An electrical discharge machine (EDM) described by Rubeling et al. [72] was used in one study, obtaining better adhesion values than sandblasting and TSC, but the presence of microcracks was also seen on the surface of zirconia [37].

2.2. Resin Cements

The classification of resin cement was complicated because of the great variation in their chemical compositions: phosphoric acid esters, 10-MDP, HEMA, glycerolphosphate dimethacrylate (GPDM), 4-META, bis-GMA or triethylene glycol dimethacrylate (TEGDMA). In addition, the exact composition or percentage of each component is hardly shown due to the lack of information from manufacturers. Therefore, their classification was structured in self-adhesive, cement with 10-MDP, and Bis-GMA cement (without 10-MDP or were not self-adhesive). In general, within the same group, the cement had great variability due to both the percentage of the different components and the viscosity of the cement, which can interfere with micromechanical interpenetration [59]. There is no consensus on which cement is above another, except for Bis-GMA, which showed lower adhesion values than the other two groups. However, this molecule better withstands hydrolytic degradation [31][59]. The relationship to the addition of a primer containing 10-MDP is unclear. Different studies have reported an increase in adhesion when previously applying a 10-MDP primer, especially with self-adhesive cement [39][51][52]. Conversely, another study reported the opposite in cement with 10-MDP due to the saturation of this molecule [52]. Nevertheless, there is consensus on the need for previous mechanical surface conditioning to increase their adhesive values [50][57][59][69]. Regarding the degradation of cement after artificial aging, no consensus exists. Thus, more studies are needed to demonstrate the ideal resin cement [30][59].

2.3. Test

Different types of tests have been used to assess the bond strength between zirconia and composite cement that can be explained by the lack of an international standard. The most used was the macroshear test, probably due to its simplicity of use. Otani et al. [73] described the macro tests (macroshear and macrotensile) as those that presented more heterogeneity in the distribution of stress and loads due to the greater adhesion surface. On the other hand, the micro tests (microshear and microtensile) showed less variation and higher adhesive values due to a smaller adhesion area and less possibility of finding defects in the cementing. However, the number of premature failures in the specimen preparation step was higher. Nevertheless, the variability of the tests and their influence on the results make it very difficult to compare the results among the studies.

2.4. Artificial Aging

The most used method for artificial aging was liquid storage and thermocycling. Liquid storage allows the evaluation of hydrolytic degradation, and thermocycling reproduces in vitro hydrothermal aging [5][74]. The most frequently used liquid was distilled/deionized water, but other types of solutions were used, such as esterase, acetic acid, alcohol, phosphoric acid or artificial saliva, to reproduce different clinical scenarios [32][44][61]. Studies concluded that storage in a liquid medium significantly reduced adhesion compared to control groups. Acetic acid, phosphoric acid and esterase were the solutions that caused a greater effect [34][32][40][44][63][64]. The number of cycles showed a great variation among the studies with thermocycled groups, which makes it impossible to compare the results. In this systematic review, the ISO 10477 standard was followed concerning metal–resin bond, which established the minimum number of cycles at 5000 [75]. Thermocycling decreased adhesion values due to hydrothermal aging [45][50][51][67]. However, it has been reported that the number of cycles above 5000 does not decrease the values significantly [32][45][76]. Other studies used a combination of storage in liquid medium and thermocycling, which caused a significant decrease in the adhesive values [57][63][66]. This combination may be the one that causes greater degradation at the interface but requires much more time to complete [57][63][66].

3. Conclusions

The following conclusions were drawn:

-There are a great variety of zirconia surface pretreatments, cement, artificial aging method and tests used in the studies that make it difficult to compare the results.

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

-Mechanicochemical 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.

-There is great variability in the percentage of components and the viscosity of the resin cement. Self-adhesive cement and those containing 10-MDP obtained the best results in adhering to zirconia, without clarification of which is the best.

-The use of a 10-MDP primer is still controversial.

-Standardization of test to evaluate the bond strength between zirconia and resin cement is needed

-Artificial aging decreased adhesion; therefore, storage in water for 30 days or thermocycling for 5000 cycles must be performed in laboratory studies.

-A clinical protocol for adhesive cementation to zirconia has not yet been performed.

References

1. Atsu, S.S.; Kilicarslan, M.A.; Kucukesmen, H.C.; Aka, P.S. Effect of zirconium-oxide ceramic surface treatments on the bond strength to adhesive resin. J. Prosthet. Dent. 2006, 95, 430–436.
2. Phark, J.-H.; Duarte, S., Jr.; Blatz, M.; Sadan, A. An in vitro evaluation of the long-term resin bond to a new densely sintered high-purity zirconium-oxide ceramic surface. J. Prosthet. Dent. 2009,

101, 29–38.

3. Hjerppe, J.; Vallittu, P.K.; Fröberg, K.; Lassila, L.V. Effect of sintering time on biaxial strength of zirconium dioxide. Dent. Mater. 2009, 25, 166–171.
4. Kim, M.-J.; Ahn, J.-S.; Kim, J.-H.; Kim, H.-Y.; Kim, W.-C. Effects of the sintering conditions of dental zirconia ceramics on the grain size and translucency. J. Adv. Prosthodont. 2013, 5, 161–166.
5. Özcan, M.; Bernasconi, M. Adhesion to zirconia used for dental restorations: A systematic review and meta-analysis. J. Adhes. Dent. 2015, 17, 7–26.
6. Calamia, J.R. Etched porcelain veneers: The current state of the art. Quintessence Int. 1985, 1, 5–12.
7. Inokoshi, M.; de Munck, J.; Minakuchi, S.; van Meerbeek, B. Meta-analysis of Bonding Effectiveness to Zirconia Ceramics. J. Dent. Res. 2014, 93, 329–334.
8. Kern, M. Resin Bonding to Oxide Ceramics for Dental Restorations. J. Adhes. Sci. Technol. 2009, 23, 1097–1111.
9. Kern, M. Bonding to oxide ceramics—Laboratory testing versus clinical outcome. Dent. Mater. 2015, 3, 8–14.
10. Qeblawi, D.M.; Muñoz, C.A.; Brewer, J.D.; Monaco, E.A., Jr. The effect of zirconia surface treatment on flexural strength and shear bond strength to a resin cement. J. Prosthet. Dent. 2010, 103, 210–220.
11. Foxton, R.M.; Cavalcanti, A.N.; Nakajima, M.; Pilecki, P.; Sherriff, M.; Melo, L.; Watson, T.F. Durability of Resin Cement Bond to Aluminium Oxide and Zirconia Ceramics after Air Abrasion and Laser Treatment. J. Prosthodont. 2011, 20, 84–92.
12. Blatz, M.B.; Chiche, G.; Holst, S.; Sadan, A. Influence of surface treatment and simulated aging on bond strengths of luting agents to zirconia. Quintessence Int. 2007, 38, 745–753.
13. Heikkinen, T.T.; Lassila, L.V.J.; Matinlinna, J.P.; Vallittu, P.K. Effect of operating air pressure on tribochemical silica-coating. Acta Odontol. Scand. 2007, 65, 241–248.
14. Da Silveira, B.L.; Paglia, A.; Burnett, L.H.; Shinkai, R.S.A.; de Paula Eduardo, C.; Spohr, A.M. Micro-Tensile Bond Strength Between a Resin Cement and an Aluminous Ceramic Treated with Nd:YAG Laser, Rocatec System, or Aluminum Oxide Sandblasting. Photomed. Laser Surg. 2005, 23, 543–548.
15. Usumez, A.; Hamdemirci, N.; Koroglu, B.Y.; Simsek, I.; Parlar, O.; Sari, T. Bond strength of resin cement to zirconia ceramic with different surface treatments. Lasers Med. Sci. 2013, 28, 259–266.

16. Akin, H.; Tugut, F.; Akin, G.E.; Guney, U.; Mutaf, B. Effect of Er:YAG laser application on the shear bond strength and microleakage between resin cements and Y-TZP ceramics. Lasers Med. Sci. 2012, 27, 333–338.

17. Ural, Ç.; Külünk, T.; Külünk, Ş.; Kurt, M. The Effect of Laser Treatment on Bonding Between Zirconia Ceramic Surface and Resin Cement. Acta Odontol. Scand. 2010, 68, 354–359.

18. Hallmann, L.; Ulmer, P.; Wille, S.; Polonskyi, O.; Köbel, S.; Trottenberg, T.; Bornholdt, S.; Haase, F.; Kersten, H.; Kern, M. Effect of surface treatments on the properties and morphological change of dental zirconia. J. Prosthet. Dent. 2016, 115, 341–349.

19. Hallmann, L.; Ulmer, P.; Reusser, E.; Hämmerle, C.H. Surface characterization of dental Y-TZP ceramic after air abrasion treatment. J. Dent. 2012, 40, 723–735.

20. Yamaguchi, H.; Ino, S.; Hamano, N.; Okada, S.; Teranaka, T. Examination of bond strength and mechanical properties of Y-TZP zirconia ceramics with different surface modifications. Dent. Mater. J. 2012, 31, 472–480.

21. Moon, J.-E.; Kim, S.-H.; Lee, J.-B.; Ha, S.-R.; Choi, Y.-S. The effect of preparation order on the crystal structure of yttria-stabilized tetragonal zirconia polycrystal and the shear bond strength of dental resin cements. Dent. Mater. 2011, 27, 651–663.

22. Lohbauer, U.; Zipperle, M.; Rischka, K.; Petschelt, A.; Müller, F.A. Hydroxylation of dental zirconia surfaces: Characterization and bonding potential. J. Biomed. Mater. Res. Part B Appl. Biomater. 2008, 87, 461–467.

23. Yoshihara, K.; Yoshida, Y.; Nagaoka, N.; Hayakawa, S.; Okihara, T.; de Munck, J.; Maruo, Y.; Nishigawa, G.; Minagi, S.; Osaka, A.; et al. Adhesive interfacial interaction affected by different carbon-chain monomers. Dent. Mater. 2013, 29, 888–897.

24. Chen, L.; Suh, B.I.; Brown, D.; Chen, X. Bonding of primed zirconia ceramics: Evidence of chemical bonding and improved bond strengths. Am. J. Dent. 2012, 25, 103–108.

25. Özcan, M.; Nijhuis, H.; Valandro, L.F. Effect of Various Surface Conditioning Methods on the Adhesion of Dual-cure Resin Cement with MDP Functional Monomer to Zirconia after Thermal Aging. Dent. Mater. J. 2008, 27, 99–104.

26. Jevnikar, P.; Krnel, K.; Kocjan, A.; Funduk, N.; Kosmač, T. The effect of nano-structured alumina coating on resin-bond strength to zirconia ceramics. Dent. Mater. 2010, 26, 688–696.

27. Aboushelib, M.N.; Kleverlaan, C.J.; Feilzer, A.J. Selective infiltration-etching technique for a strong and durable bond of resin cements to zirconia-based materials. J. Prosthet. Dent. 2007, 98, 379–388.

28. White, S.N.; Miklus, V.G.; McLaren, E.A.; Lang, L.A.; Caputo, A.A. Flexural strength of a layered zirconia and porcelain dental all-ceramic system. J. Prosthet. Dent. 2005, 94, 125–131.

29. Abel, M.L.; Allington, L.D.; Digby, R.P.; Porritt, N.; Shaw, S.J.; Watts, J.F. Understanding the relationship between silane application conditions, bond durability and locus of failure. Int. J. Adhes. Adhes. 2006, 26, 2–15.

30. Yang, L.; Chen, B.; Meng, H.; Zhang, H.; He, F.; Xie, H.; Chen, C. Bond durability when applying phosphate ester monomer–containing primers vs. self-adhesive resin cements to zirconia: Evaluation after different aging conditions. J. Prosthodont. Res. 2020, 64, 193–201.

31. Bömicke, W.; Schürz, A.; Krisam, J.; Rammelsberg, P.; Rues, S. Durability of Resin-Zirconia Bonds Produced Using Methods Available in Dental Practice. J. Adhes. Dent. 2016, 18, 17–27.

32. Saade, J.; Skienhe, H.; Ounsi, H.F.; Matinlinna, J.P.; Salameh, Z. Evaluation of the Effect of Different Surface Treatments, Aging and Enzymatic Degradation on Zirconia-Resin Micro-Shear Bond Strength. Clin. Cosmet. Investig. Dent. 2020, 12, 1–8.

33. Altan, B.; Cinar, S.; Tuncelli, B. Evaluation of shear bond strength of zirconia-based monolithic CAD-CAM materials to resin cement after different surface treatments. Niger. J. Clin. Pract. 2019, 22, 1475–1482.

34. Khan, A.A.; Mohamed, B.A.; Mirza, E.H.; Syed, J.; Divakar, D.D.; Vallittu, P.K. Surface wettability and nano roughness at different grit blasting operational pressures and their effects on resin cement to zirconia adhesion. Dent. Mater. J. 2019, 38, 388–395.

35. Ruales-Carrera, E.; Cesar, P.F.; Henriques, B.; Fredel, M.C.; Özcan, M.; Volpato, C.A.M. Adhesion behavior of conventional and high-translucent zirconia: Effect of surface conditioning methods and aging using an experimental methodology. J. Esthet. Restor. Dent. 2019, 31, 388–397.

36. Grasel, R.; Santos, M.J.; Rêgo, H.C.; Rippe, M.P.; Valandro, L.F. Effect of Resin Luting Systems and Alumina Particle Air Abrasion on Bond Strength to Zirconia. Oper. Dent. 2018, 43, 282–290.

37. Rona, N.; Yenisey, M.; Kucukturk, G.; Gurun, H.; Cogun, C.; Esen, Z. Effect of electrical discharge machining on dental Y-TZP ceramic-resin bonding. J. Prosthodont. Res. 2017, 61, 158–167.

38. Yenisey, M.; DeDe, D.Ö.; Rona, N. Effect of surface treatments on the bond strength between resin cement and differently sintered zirconium-oxide ceramics. J. Prosthodont. Res. 2016, 60, 36–46.

39. Ahn, J.-S.; Yi, Y.-A.; Lee, Y.; Seo, D.-G. Shear Bond Strength of MDP-Containing Self-Adhesive Resin Cement and Y-TZP Ceramics: Effect of Phosphate Monomer-Containing Primers. BioMed Res. Int. 2015, 2015, 389234.

40. Lima, R.B.W.; Barreto, S.C.; Hajhamid, B.; de Souza, G.M.; de Goes, M.F. Effect of cleaning protocol on silica deposition and silica-mediated bonding to Y-TZP. Dent. Mater. 2019, 35, 1603–1613.

41. Ozel, G.S.; Okutan, Y.; Oguz Ahmet, B.S.; Ozdere, E. Effect of Combined Surface Treatments on Surface Roughness and Resin Bond Strength to Y-TZP Ceramic and Nickel–Chromium Metal Alloy. Photobiomodul. Photomed. Laser Surg. 2019, 37, 442–450.
42. Esteves-Oliveira, M.; Jansen, P.; Wehner, M.; Dohrn, A.; Bello-Silva, M.S.; Eduardo, C.P.; Meyer-Lueckel, H. Surface Charac-terization and Short-term Adhesion to Zirconia after Ultra-short Pulsed Laser Irradiation. J. Adhes. Dent. 2016, 18, 483–492.
43. Lopes, G.C.; Spohr, A.M.; de Souza, G.M. Different Strategies to Bond Bis-GMA-based Resin Cement to Zirconia. J. Adhes. Dent. 2016, 18, 239–246.
44. Aboushelib, M.N.; Ragab, H.; Arnaot, M. Ultrastructural Analysis and Long-term Evaluation of Composite-Zirconia Bond Strength. J. Adhes. Dent. 2018, 20, 33–39.
45. Noda, Y.; Nakajima, M.; Takahashi, M.; Mamanee, T.; Hosaka, K.; Takagaki, T.; Ikeda, M.; Foxton, R.M.; Tagami, J. The effect of five kinds of surface treatment agents on the bond strength to various ceramics with thermocycle aging. Dent. Mater. J. 2017, 36, 755–761.
46. Okutan, Y.; Yucel, M.T.; Gezer, T.; Donmez, M.B. Effect of airborne particle abrasion and sintering order on the surface roughness and shear bond strength between Y-TZP ceramic and resin cement. Dent. Mater. J. 2019, 38, 241–249.
47. Ahn, J.-J.; Kim, D.-S.; Bae, E.-B.; Kim, G.-C.; Jeong, C.-M.; Huh, J.-B.; Lee, S.-H. Effect of Non-Thermal Atmospheric Pressure Plasma (NTP) and Zirconia Primer Treatment on Shear Bond Strength between Y-TZP and Resin Cement. Materials 2020, 13, 3934.
48. Cheung, G.J.K.; Botelho, M.G. Zirconia Surface Treatments for Resin Bonding. J. Adhes. Dent. 2015, 17, 551–558.
49. Zhao, L.; Jian, Y.-T.; Wang, X.-D.; Zhao, K. Bond strength of primer/cement systems to zirconia subjected to artificial aging. J. Prosthet. Dent. 2016, 116, 790–796.
50. Kasraei, S.; Rezaei-Soufi, L.; Yarmohamadi, E.; Shabani, A. Effect of CO2 and Nd:YAG Lasers on Shear Bond Strength of Resin Cement to Zirconia Ceramic. J. Dent. 2015, 12, 686–694.
51. Salem, R.S.T.; Ozkurt-Kayahan, Z.; Kazazoglu, E. In Vitro Evaluation of Shear Bond Strength of Three Primer/Resin Cement Systems to Monolithic Zirconia. Int. J. Prosthodont. 2019, 32, 519–525.
52. Go, E.J.; Shin, Y.; Park, J.-W. Evaluation of the Microshear Bond Strength of MDP-containing and Non-MDP-containing Self-adhesive Resin Cement on Zirconia Restoration. Oper. Dent. 2019, 44, 379–385.
53. Ali, N.; Safwat, A.; Aboushelib, M. The effect of fusion sputtering surface treatment on microshear bond strength of zirconia and MDP-containing resin cement. Dent. Mater. 2019, 35, e107–e112.

54. Lümkemann, N.; Eichberger, M.; Stawarczyk, B. Different surface modifications combined with universal adhesives: The impact on the bonding properties of zirconia to composite resin cement. Clin. Oral Investig. 2019, 23, 3941–3950.
55. Yoshida, K. Influence of cleaning methods on resin bonding to saliva-contaminated zirconia. J. Esthet. Restor. Dent. 2018, 30, 259–264.
56. Elsayed, A.; Younes, F.; Lehmann, F.; Kern, M. Tensile Bond Strength of So-called Universal Primers and Universal Multimode Adhesives to Zirconia and Lithium Disilicate Ceramics. J. Adhes. Dent. 2017, 19, 221–228.
57. Passia, N.; Mitsias, M.; Lehmann, F.; Kern, M. Bond strength of a new generation of universal bonding systems to zirconia ceramic. J. Mech. Behav. Biomed. Mater. 2016, 62, 268–274.
58. De Lucena Pereira, L.; Campos, F.; dal Piva, A.M.; Gondim, L.D.; de Assunção Souza, R.O.; Özcan, M. Can application of universal primers alone be a substitute for airborne-particle abrasion to improve adhesion of resin cement to zirconia? J. Adhes. Dent. 2015, 17, 169–174.
59. Liu, X.; Jiang, X.; Xu, T.; Zhao, Q.; Zhu, S. Investigating the shear bond strength of five resin-based luting agents to zirconia ceramics. J. Oral Sci. 2020, 62, 84–88.
60. Lee, Y.; Oh, K.C.; Kim, N.-H.; Moon, H.-S. Evaluation of Zirconia Surfaces after Strong-Acid Etching and Its Effects on the Shear Bond Strength of Dental Resin Cement. Int. J. Dent. 2019, 2019, 3564275.
61. Kim, D.-H.; Son, J.-S.; Jeong, S.-H.; Kim, Y.-K.; Kim, K.-H.; Kwon, T.-Y. Efficacy of various cleaning solutions on saliva-contaminated zirconia for improved resin bonding. J. Adv. Prosthodont. 2015, 7, 85–92.
62. Saleh, N.E.; Guven, M.C.; Yildirim, G.; Erol, F. Effect of different surface treatments and ceramic primers on shear bond strength of self-adhesive resin cement to zirconia ceramic. Niger. J. Clin. Pract. 2019, 22, 335–341.
63. Pitta, J.; Branco, T.C.; Portugal, J. Effect of saliva contamination and artificial aging on different primer/cement systems bonded to zirconia. J. Prosthet. Dent. 2018, 119, 833–839.
64. Chen, C.; Chen, Y.; Lu, Z.; Qian, M.; Xie, H.; Tay, F.R. The effects of water on degradation of the zirconia-resin bond. J. Dent. 2017, 64, 23–29.
65. Xie, H.; Li, Q.; Zhang, F.; Lu, Y.; Tay, F.R.; Qian, M.; Chen, C. Comparison of resin bonding improvements to zirconia between one-bottle universal adhesives and tribochemical silica coating, which is better? Dent. Mater. 2016, 32, 403–411.
66. Ebeid, K.; Wille, S.; Salah, T.; Wahsh, M.; Zohdy, M.; Kern, M. Bond strength of resin cement to zirconia treated in pre-sintered stage. J. Mech. Behav. Biomed. Mater. 2018, 86, 84–88.

67. Xie, H.; Cheng, Y.; Chen, Y.; Qian, M.; Xia, Y.; Chen, C. Improvement in the Bonding of Y-TZP by Room-temperature Ultrasonic HF Etching. J. Adhes. Dent. 2017, 19, 425–433.
68. Yang, L.; Chen, B.; Xie, H.; Chen, Y.; Chen, Y.; Chen, C. Durability of Resin Bonding to Zirconia Using Products Containing 10-Methacryloyloxydecyl Dihydrogen Phosphate. J. Adhes. Dent. 2018, 20, 279–287.
69. Lee, J.-J.; Choi, J.-Y.; Seo, J.-M. Influence of nano-structured alumina coating on shear bond strength between Y-TZP ceramic and various dual-cured resin cements. J. Adv. Prosthodont. 2017, 9, 130–137.
70. Kim, D.-S.; Ahn, J.-J.; Bae, E.-B.; Kim, G.-C.; Jeong, C.-M.; Huh, J.-B.; Lee, S.-H. Influence of Non-Thermal Atmospheric Pressure Plasma Treatment on Shear Bond Strength between Y-TZP and Self-Adhesive Resin Cement. Materials 2019, 12, 3321.
71. Chen, B.; Yan, Y.; Xie, H.; Meng, H.; Zhang, H.; Chen, C. Effects of Tribochemical Silica Coating and Alumina-Particle Air Abrasion on 3Y-TZP and 5Y-TZP: Evaluation of Surface Hardness, Roughness, Bonding, and Phase Transformation. J. Adhes. Dent. 2020, 22, 373–382.
72. Rubeling, G. Funkenerosion in der zahntechnikmoglichkeiten und grezen. Dent. Labor. 1982, 30, 1697–1702.
73. Otani, A.; Amaral, M.; May, L.G.; Cesar, P.F.; Valandro, L.F. A critical evaluation of bond strength tests for the assessment of bonding to Y-TZP. Dent. Mater. 2015, 31, 648–656.
74. Scaminaci Russo, D.; Cinelli, F.; Sarti, C.; Giachetti, L. Adhesion to Zirconia: A Systematic Review of Current Conditioning Methods and Bonding Materials. Dent. J. 2019, 7, 74.
75. International Organization for Standardization. Metal-Resin Adhesion, Amendment 1; ISO 10477; ISO: Geneva, Switzerland, 1996.
76. Wandscher, V.F.; Fraga, S.; Pozzobon, J.L.; Soares, F.Z.M.; Foletto, E.L.; May, L.G.; Valandro, L.F. Tribochemical Glass Ceramic Coating as a New Approach for Resin Adhesion to Zirconia. J. Adhes. Dent. 2016, 18, 435–440.