BJOS
Brazilian Journal of Oral Sciences

Original Article

Volume 19
2020
e206155

Effect of surface treatments on repair strength, roughness and morphology in aged metal-free crowns

Yançanã Luizy Gruber[1], Thaís Emanuelle Bakaus[1], Bruna Fortes Bittencourt[1], João Carlos Gomes[1], Alessandra Reis[1], Giovana Mongruel Gomes[1,*]

[1] Department of Restorative Dentistry, School of Dentistry, State University of Ponta Grossa, PR, Brazil.

Corresponding author:
Giovana Mongruel Gomes
Avenida Carlos Cavalcanti 4748 – Uvaranas, Ponta Grossa, Paraná, Brazil. 84030-900
Telephone: 005542988463753
Email: giomongruel@gmail.com

Received: August 06, 2019
Accepted: March 28, 2020

Aim: The roughness and micromorphology of various surface treatments in aged metal-free crowns and the bond strength of these crowns repaired with composite resin (CR) was evaluated *in vitro*. Methods: A CR core build-up was confectioned in 60 premolars and prepared for metal-free crowns. Prepared teeth were molded with the addition of silicone, and the laboratory ceromer/fiber-reinforced crowns (SR Adoro/Fibrex Lab) were fabricated. Subsequently, the crowns were cemented and artificially aged in a mechanical fatigue device (1.2 X 10^6 cycles), then divided into 4 groups (n = 15) according to the surface treatment: 1) phosphoric acid etching (PA); 2) PA + silane application; 3) roughening with a diamond bur + PA; and 4) sandblasting with Al_2O_3 + PA. After the treatments, the crowns (n = 2) were qualitatively analyzed by scanning electron microscope (SEM) and surface roughness (n = 5) was analyzed before and after the surface treatment (Ra parameter). The remaining crowns (n = 8) received standard repair with an adhesive system (Tetric N-Bond) and a nanohybrid CR (Tetric N-Ceram), and the microshear bond strength (SBS) test was performed (0.5 mm/min). Roughness and SBS data were analyzed by one- and two-way ANOVA, respectively, as well as Tukey's post-test (α = 0.05). Results: Sandblasting with Al_2O_3 + PA resulted in the highest final roughness and SBS values. The lowest results were observed in the PA group, whereas the silane and diamond bur groups showed intermediate values. Conclusion: It may be concluded that indirect ceromer crowns sandblasted with aluminum oxide prior to PA etching promote increased roughness surface and bond strength values.

Keywords: Ceramics. Composite resins. Electron microscope tomography. Shear strength. Surface properties.

Introduction

Indirect restorations, also known as "ceromer," "polymeric glass porcelain," or "second-generation laboratory CR," are widely used in clinical practice because they minimize the adverse effects of direct restorations, such as polymerization shrinkage[1], poor marginal adaptation, and postoperative sensitivity[2] In addition, they can provide better standards of translucency and can be low-cost alternatives to all-ceramic restorations[3].

Although indirect resins possess high mechanical strength, these restorations are subject to fractures as any other material. This type of failure should be carefully evaluated to define the best treatment. Clinically, the affected crowns can be classified according to the extent of the fracture. A fracture can be minimal (e.g., cracks) or extensive (e.g., displacement of more than half of the crown)[4,5].

Corroborating *in vitro* studies[6-8], clinical studies show that most cases of crown fractures are repairable[9,10]. This is advantageous because complete replacement of indirect restorations may present more disadvantages than advantages, such as the treatment complexity and expense[11]. With the evolution of adhesive techniques, adhesive repair has been widely used and can be considered beneficial, allowing good longevity in this type of dental restoration[12,13].

For proper repair, the surface of the indirect restoration should be subjected to a pre-treatment to create micromechanical retention with the repair material[14]. In the available literature, several surface treatments techniques are described for the repair of composites. Roughening with diamond burs, sandblasting with aluminum oxide, conditioning with hydrofluoric acid etching or PA etching, and silanization are the most frequently reported[11,15,16].

The current literature presents several studies comparing different surface treatments; however, the best pre-treatment technique still generates controversial results[17-19]. Thus, the present study aimed to evaluate the surface roughness, morphology, and repair strength of aged indirect resin restorations with SEM, microshear bond strength test, and digital roughness meter. The tested hypothesis was that differences would exist in morphology, surface roughness, and bond strength after various surface treatments.

Material and Methods

Sixty extracted human mandibular premolars, with the protocol number 1871/10 from the research ethics committee of the State University of Ponta Grossa (Brazil), were stored in distilled water at 4ºC and used within 6 months after extraction. To be included in the study sample, teeth should be sound, without cracks, and not submitted to previous endodontic treatment. Teeth were transversally sectioned 2 mm above the cement-enamel junction using a low-speed diamond saw (Isomet 1000, Buehler, Lake Bluff, IL, USA) and received a standardized endodontic treatment.

After 1 week, the root canals were prepared to receive glass fiber posts (Whitepost DC # 0.5, FGM, Joinville, SC, Brazil), which were cemented with the Excite DSC (Ivoclar-Vivadent, Schaan, Liechtenstein) adhesive system and Variolink II (Ivoclar-Vivadent) resin cement in accordance with the manufacturer's instructions.

After the post-luting procedures, cores were built-up with a nanohybrid CR (Tetric N-Ceram, Ivoclar-Vivadent). An incremental technique was used to place the CR, and each 2 mm increment was light cured for 20 s.

Indirect composite crowns cementation

The composite cores were prepared to receive a full indirect composite restoration using a high-speed hand piece under water cooling. In all roots a ferrule was made in the coronal ending with 2.0 mm height, 1.2 mm depth, and 1.5 mm occlusal reduction.

Full indirect composite restorations were fabricated with the SR Adoro (Ivoclar-Vivadent) restorative system reinforced by fibers (Fibrex-Lab Coronal, Angelus, Londrina, PR, Brazil). After fitting and adjustment, the restorations were adhesively cemented with Excite DSC and Variolink II according to the manufacturers' recommendations.

Teeth were then embedded in acrylic resin (Duralay, Reliance, Worth, IL, USA) and periodontal ligament was simulated using a polyether impression material (Impregum™ Soft, 3M ESPE, St Paul, MN, USA), according to the method described by Soares et al. 2005[2].

Mechanical aging

To increase the study's reliability[20], the samples were subjected to mechanical fatigue in a controlled chewing simulator (Elquip, São Carlos, SP, Brazil). The samples were placed at the base of a material-fatigue-testing machine at a 90° angle in relation to the horizontal plane and were subjected to repetitive impacts directed on the occlusal surface of the crown. A lower force of 40 N (to avoid possible fractures) at a frequency of 2 Hz was applied for 1.2 X 10^6 cycles, which represents 5 years of clinical service[21,22]. During the cycles, the samples were kept at 37°C in relative humidity.

Surface treatments of the indirect restorations and experimental groups

The specimens were then randomly divided into 4 groups, according to the surface treatments. Each treatment was performed on a square delimited area (3 mm x 3 mm) on the buccal surface of each crown. In the PA group, the buccal surfaces of the indirect CR were treated with 35% PA for 2 min according the manufacture's recommendation, washed for 2 min with distilled water, and gently air dried for 5 s at 2 cm.

For the silane group—after PA treatment as reported above—a silane coupling agent (Prosil, FGM, Joinvile, SC, Brazil) was applied for 1 min with a disposable applicator, and the surface was dried with compressed air for 5 s at 2 cm.

The buccal surfaces of the diamond bur group were roughened with a diamond bur (# 3195, KG Sorensen, São Paulo, SP, Brazil) using a high-speed hand piece under water cooling for 5 s, with weak movements and minimal wear. Then, the surface was conditioned with PA as reported in the first group.

For the sandblasting group, the surfaces were sandblasted with 50 μm Al_2O_3 (Microblaster Standard Model, Bio-Art, São Carlos, SP, Brazil) for 10 s and then conditioned with PA as reported in the first group.

Surface roughness test

After mechanical aging, the initial roughness (IR) of five random buccal surface restorations per group was obtained with a digital roughness meter (Mitutoyo Surftest-301, Mitutoyo-Kawasaki, Kanagawa, Japan). Three measures were performed on each specimen, and the arithmetic mean was obtained from these values. The mean represents the IR. Surface roughness reading was performed using the Ra parameter (μm) and the ISO 2001 measuring profile[23], a 0.25 mm cut-off, 1.25 mm in length and 0.1 mm/s speed. Afterward, the specimens were submitted to the abovementioned surface treatments and stored at 37°C in artificial saliva, simulating oral condition. After 48 h of the surface treatments procedures, we measured the final roughness (FR) in the same way as the initial evaluation.

SEM analysis

Two restorations per group were prepared for the SEM (SSX – 550; Shimadzu, Tokyo, Japan). The surfaces were sputter coated with gold in a vacuum evaporator (Belzers SCD 050 SputterCoater, Bal-Tec, Germany) and photomicrographs of representative areas were taken at 1.000x magnification.

Bond strength test

After surface treatment, eight crowns per group were submitted to microshear bond strength test. For this purpose, one coat of the adhesive system (Tetric N-Bond, IvoclarVivadent) was applied on the delimited area (3 mm x 3 mm) of the treated buccal surfaces and then gently air dried for 5 s and light-cured for 10 s (Table 1).

Three Tygon tubes, approximately 0.75 mm in diameter and 1 mm high, were used for each crown. The tubes were positioned on the flattest areas of the treated buccal surface (3 mm x 3 mm) of the indirect restorations, filled with CR (Tetric N-Ceram, IvoclarVivadent), and individually photoactivated for 40 s. Each light-cured specimen was protected with aluminum strip to afford protection from additional polymerization, as well as the unpolymerized specimens. All specimens were checked with an optical microscope (OLYMPUS-BX 51, Olympus, Tokyo, Japan) at 10x magnification to discard any specimens with air bubbles or evident gaps at the interface.

Table 1. Manufacturer, composition and instructions for each material used in the study.

Material (Manufacturer)	Composition	Instructions for use
Tetric N-Bond (Ivoclar Vivadent)	Phosphoric acid acrylate, HEMA, BisGMA, urethane dimethacrylate, ethanol, film-forming agent, catalysts and stabilizers.	Apply a thick layer of Tetric N-Bond for at least 10 seconds. Remove excess material and the solvent by a gentle stream of air and light-cure for 10 seconds.
Tetric N-Ceram (Ivoclar Vivadent)	Dimethacrylates (19-20 wt.%); barium glass, ytterbium trifluoride, mixed oxide, copolymers (80-81 wt.%); additives, catalysts, stabilizers and pigments are additional contents (< 1 wt.%). The total content of inorganic fillers is 55–57 vol.%. The particle size of inorganic fillers is between 40 nm and 3000 nm	Apply Tetric N-Ceram in layers of max. 2 mm or 1. Polymerize each layer individually for 40 seconds.

All light-curing procedures of this study were performed with a LED light-curing device (Radii Plus, SDI Limited, Victoria, Australia) using a 1200 mW/cm^2 power density. The specimens were mounted in acrylic resin and placed in a universal testing machine (Kratos, São Paulo, SP, Brazil), and a microshear force was applied using a shearing blade as close as possible to the adhesive interface. The load was applied to the interface at a crosshead speed of 1 mm/min until failure, and the bond strength values were recorded in MPa.

Statistical analysis

Before running parametric statistical analysis, we tested whether the assumptions of normality of the data and equality of variances were valid, using the Shapiro-Wilk and Barlett tests at an alpha of 5%. The data from surface roughness and bond strength were statistically analyzed by one- and two-way ANOVA, respectively, and Tukey's test was used for pairwise comparisons at a 5% significance level.

All calculations were performed using SPSS® statistical software (Statistical Package for the Social Sciences, version 21.0 Mac, SPSS Inc., Chicago, IL, USA).

Results

The means and standard deviations of surface roughness (Ra parameter) and microshear bond strength values (MPa) for the experimental groups are demonstrated in Table 2.

In relation to the surface roughness, two-way ANOVA showed that the cross-product interaction between the factors time and experimental groups were statistically significant ($p < 0.001$). At baseline, all groups were statistically similar ($p > 0.05$). Roughness increased significantly after the treatments in all groups ($p < 0.001$). The final roughness was higher in the sandblasting group and lower in the PA group, whereas the silane and diamond bur groups showed intermediate values.

For the microshear bond strength, one-way ANOVA showed significant statistical differences between the experimental groups ($p < 0.0001$). The lowest repair strength was observed for the PA group and the highest was observed in the sandblasting group. The silane and diamond bur groups were statistically similar and had an intermediate performance.

In the SEM images (Figure 1), the diamond bur and sandblasting groups showed very irregular surfaces. However, they differed in the direction of the grooves and depres-

Table 2. Mean values ± standard deviation of roughness (Ra parameter) and microshear bond strength (MPa) for each experimental group (*).

Experimental Groups	Roughness		Shear bond strength
	Baseline	Post treatment	
Phosphoric acid	0.24 ± 0.08 ^{E}	0.42 ± 0.14 ^{D}	9.4 ± 3.1 ^{C}
Silane	0.21 ± 0.07 ^{E}	0.64 ± 0.15 ^{C}	20.3 ± 6.1 ^{B}
Diamond bur	0.25 ± 0.07 ^{E}	0.86 ± 0.11 ^{B}	18.3 ± 4.9 ^{B}
Sandblasting	0.21 ± 0.09 ^{E}	1.28 ± 0.13 ^{A}	37.1 ± 8.7 ^{A}

** Comparisons are valid just for the same property. Distinct letters show significant differences ($p < 0.05$).*

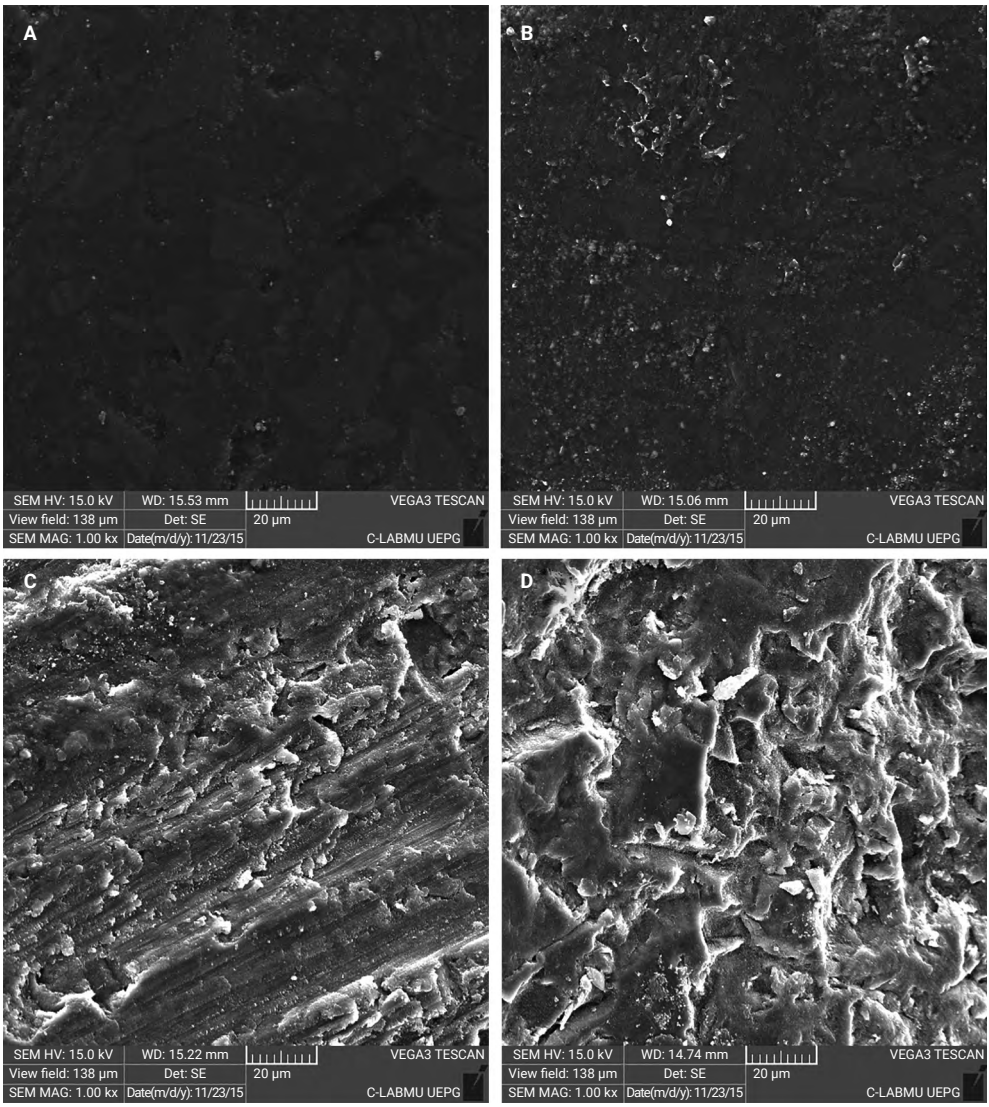

Figure 1. Images of the surface roughness obtained by the SEM (x 1,000). *A: phosphoric acid group; B: silane group; C: diamond bur group: D: sandblasting group.*

sions. Grooves are unidirectional in the diamond bur group, probably resulting from the direction of the bur roughening, whereas in the sandblasting group they do not follow a pattern due to the abrasion of aluminum oxide particles on the surface.

Discussion

Fatigue studies can mimic the effect of mechanical and thermal cycles, as well as a wet oral environment[24]. Mechanical aging better reproduces the clinical reality, because failures and fractures in indirect CR restorations occur only after years of clinical service[13]. Although previous studies have already investigated different surface treatment techniques for the repair of indirect restorations[25-27], most did not sim-

ulate three important clinical features found in this study's protocol: cementation of a fiber post to stabilize the final restoration, simulation of the periodontal ligament, and simulation of mechanical aging.

In a clinical scenario, the core and post are placed to retain the final restoration in endodontically treated teeth, improving their integrity[28]. The presence of the periodontal ligament and tooth-supporting structures partially absorb the masticatory loads; therefore, studies that did not simulate these structures may have obtained unreliable values[21]. Finally, post-retained indirect crowns are subject to repetitive ordinary chewing forces over time, as well as other environmental challenging factors[29]. Thus, mechanical aging is essential to simulate closely the clinical conditions to which these indirect restorations are subjected. In this study, all specimens were submitted to 1.2 X 10^6 cycles of mechanical fatigue, which is commonly assumed to correspond to 5 years of clinical service[22].

In this study, the results showed that air abrasion with aluminum oxide promoted the highest bond strength values[30,31] and higher roughness. Although some authors have reported that pre-treatment with diamond burs can yield higher repair strengths than air abrasion with aluminum oxide[32,33], other studies[30,34,35] have shown the opposite, with results similar to our observations.

The higher surface roughness produced by aluminum air abrasion increases the surface area and wetting for the adhesive penetration[36,37], which may have yielded the highest bond strength values. This positive correlation between increased surface roughness and improved repair strength has already been demonstrated in other studies[38 39].

Indeed, the bond repair strength observed in the PA etching group might be lowest because this procedure produced the lowest surface roughening on the aged resin surface. Previous studies have demonstrated that acid etching alone is not enough to guarantee adequate repair strength[40].

Although surface treatment with silane does not generate the roughest surfaces, this group presented intermediate bond strength values, similar to that achieved by the asperization with diamond bur. The chemical bond produced by this bifunctional molecule between the inorganic particles of glassy substrates (silica filler particles) and the adhesive CR matrix[19] probably compensated for the reduced surface area. This bonding agent has a general chemical structure, $R'Si(OR)_3$, where R' is the organ functional group (typically a methacrylate) that reacts to the adhesive system or the composite cement, creating a covalent bond after polymerization. The alkyl group (R) is hydrolyzed to a silanol (SiOH), creating a covalent bond with the inorganic silicon particles[41].

This study has some limitations, due to which not all clinical conditions could be reproduced. In addition, only a resin cement was used, the chewing forces of an occlusion were not applied in the mechanical aging, and the treatments were performed on a flat surface rather than a cusp area. In summary, the results of the present study demonstrated that aged indirect CRs should be pre-treated with aluminum oxide + PA prior to repair to increase the surface roughness and consequently the bond strength repair. Thus, the tested hypothesis was accepted.

Sandblasting aged indirect resin restorations with aluminum oxide prior to PA etching increases the surface roughness and repair bond strength values.

Conclusions

Sandblasting aged indirect resin restorations with aluminum oxide prior to PA etching increases the surface roughness and repair bond strength values.

References

1. Chun KJ, Lee JY. Comparative study of mechanical properties of dental restorative materials and dental hard tissues in compressive loads. J Dent Biomech. 2014 Oct 11;5:1758736014555246. doi: 10.1177/1758736014555246.
2. Soares CJ, Pizi EC, Fonseca RB, Martins LR. Influence of root embedment material and periodontal ligament simulation on fracture resistance tests. Braz Oral Res. 2005 Jan-Mar;19(1):11-6.
3. Likai W, Yanan L, Yan Z, Pingping L. [Color stability of ceromer of different thicknesses and resin adhesive materials of different types after accelerated aging]. Hua Xi Kou Qiang Yi Xue Za Zhi. 2015 Apr;33(2):201-5. Chinese.
4. Mak M, Qualtrough AJ, Burke FJ. The effect of different ceramic materials on the fracture resistance of dentin-bonded crowns. Quintessence Int. 1997 Mar;28(3):197-203.
5. Heintze SD, Rousson V. Fracture rates of IPS Empress all-ceramic crowns--a systematic review. Int J Prosthodont. 2010 Mar-Apr;23(2):129-33.
6. Aggarwal V, Singla M, Miglani S, Kohli S. Comparative evaluation of fracture resistance of structurally compromised canals restored with different dowel methods. J Prosthodont. 2012 Jun;21(4):312-6. doi: 10.1111/j.1532-849X.2011.00827.x.
7. Hurst D. Indirect or direct restorations for heavily restored posterior adult teeth? Evid Based Dent. 2010;11(4):116-7. doi: 10.1038/sj.ebd.6400760.
8. Koczarski MJ. Utilization of ceromer inlays/onlays for replacement of amalgam restorations. Pract Periodontics Aesthet Dent. 1998 May;10(4):405-12; quiz 414.
9. Sequeira-Byron P, Fedorowicz Z, Carter B, Nasser M, Alrowaili EF. Single crowns versus conventional fillings for the restoration of root-filled teeth. Cochrane Database Syst Rev. 2015 Sep 25;(9):CD009109. doi: 10.1002/14651858.CD009109.pub3.
10. Fennis WM, Kuijs RH, Roeters FJ, Creugers NH, Kreulen CM. Randomized control trial of composite cuspal restorations: five-year results. J Dent Res. 2014 Jan;93(1):36-41. doi: 10.1177/0022034513510946.
11. Loomans BA, Mesko ME, Moraes RR, Ruben J, Bronkhorst EM, Pereira-Cenci T, et al. Effect of different surface treatment techniques on the repair strength of indirect composites. J Dent. 2017 Apr;59:18-25. doi: 10.1016/j.jdent.2017.01.010.
12. Opdam NJ, Bronkhorst EM, Loomans BA, Huysmans MC. Longevity of repaired restorations: a practice based study. J Dent. 2012 Oct;40(10):829-35. doi: 10.1016/j.jdent.2012.06.007.
13. Demarco FF, Correa MB, Cenci MS, Moraes RR, Opdam NJ. Longevity of posterior composite restorations: not only a matter of materials. Dent Mater. 2012 Jan;28(1):87-101. doi: 10.1016/j.dental.2011.09.003.
14. Arami S, Hasani Tabatabaei M, Namdar F, Safavi N, Chiniforush N. Shear bond strength of the repair composite resin to zirconia ceramic by different surface treatment. J Lasers Med Sci. 2014 Fall;5(4):171-5.

15. Komine F, Kobayashi K, Saito A, Fushiki R, Koizumi H, Matsumura H. Shear bond strength between an indirect composite veneering material and zirconia ceramics after thermocycling. J Oral Sci. 2009 Dec;51(4):629-34.

16. Loomans B, Ozcan M. Intraoral Repair of Direct and Indirect Restorations: Procedures and Guidelines. Oper Dent. 2016 Sep;41(S7):S68-S78.

17. Campos F, Almeida CS, Rippe MP, de Melo RM, Valandro LF, Bottino MA. Resin Bonding to a Hybrid Ceramic: Effects of Surface Treatments and Aging. Oper Dent. 2016 Mar-Apr;41(2):171-8. doi: 10.2341/15-057-L.

18. Eslamian L, Borzabadi-Farahani A, Mousavi N, Ghasemi A. The effects of various surface treatments on the shear bond strengths of stainless steel brackets to artificially-aged composite restorations. Aust Orthod J. 2011 May;27(1):28-32.

19. Foxton RM, Nakajima M, Hiraishi N, Kitasako Y, Tagami J, Nomura S, et al. Relationship between ceramic primer and ceramic surface pH on the bonding of dual-cure resin cement to ceramic. Dent Mater. 2003 Dec;19(8):779-89.

20. Kelly JR. Clinically relevant approach to failure testing of all-ceramic restorations. J Prosthet Dent. 1999 Jun;81(6):652-61.

21. Naumann M, Sterzenbach G, Rosentritt M, Beuer F, Frankenberger R. In vitro performance of self-adhesive resin cements for post-and-core build-ups: influence of chewing simulation or 1-year storage in 0.5% chloramine solution. Acta Biomater. 2010 Nov;6(11):4389-95. doi: 10.1016/j.actbio.2010.05.023.

22. Gomes GM, Gomes OM, Gomes JC, Loguercio AD, Calixto AL, Reis A. Evaluation of different restorative techniques for filling flared root canals: fracture resistance and bond strength after mechanical fatigue. J Adhes Dent. 2014 Jun;16(3):267-76. doi: 10.3290/j.jad.a31940.

23. Bittencourt BF, Gomes GM, Trentini FA, Azevedo MRd, Gomes JC, Gomes OMM. Effect of finishing and polishing on surface roughness of composite resins after bleaching. J Braz J Oral Sci. 2014;13(2):158-62. doi: 10.1590/1677-3225v13n2a15.

24. Amaral FL, Colucci V, Palma-Dibb RG, Corona SA. Assessment of in vitro methods used to promote adhesive interface degradation: a critical review. J Esthet Restor Dent. 2007;19(6):340-53; discussion 354.

25. Barragan G, Chasqueira F, Arantes-Oliveira S, Portugal J. Ceramic repair: influence of chemical and mechanical surface conditioning on adhesion to zirconia. Oral Health Dent Manag. 2014 Jun;13(2):155-8.

26. Lee SJ, Cheong CW, Wright RF, Chang BM. Bond strength of the porcelain repair system to all-ceramic copings and porcelain. J Prosthodont. 2014 Feb;23(2):112-6. doi: 10.1111/jopr.12064.

27. Cotes C, Cardoso M, Melo RM, Valandro LF, Bottino MA. Effect of composite surface treatment and aging on the bond strength between a core build-up composite and a luting agent. J Appl Oral Sci. 2015 Jan-Feb;23(1):71-8. doi: 10.1590/1678-775720140113.

28. Skupien JA, Cenci MS, Opdam NJ, Kreulen CM, Huysmans MC, Pereira-Cenci T. Crown vs. composite for post-retained restorations: A randomized clinical trial. J Dent. 2016 May;48:34-9. doi: 10.1016/j.jdent.2016.03.007.

29. Ferro MC, Colucci V, Marques AG, Ribeiro RF, Silva-Sousa YT, Gomes EA. Fracture Strength of Weakened Anterior Teeth Associated to Different Reconstructive Techniques. Braz Dent J. 2016 Sep-Oct;27(5):556-61. doi: 10.1590/0103-6440201602452.

30. Costa TR, Ferreira SQ, Klein-Junior CA, Loguercio AD, Reis A. Durability of surface treatments and intermediate agents used for repair of a polished composite. Oper Dent. 2010 Mar-Apr;35(2):231-7. doi: 10.2341/09-216-L.

31. Su N, Yue L, Liao Y, Liu W, Zhang H, Li X, et al. The effect of various sandblasting conditions on surface changes of dental zirconia and shear bond strength between zirconia core and indirect composite resin. J Adv Prosthodont. 2015 Jun;7(3):214-23. doi: 10.4047/jap.2015.7.3.214.

32. Petridis H, Garefis P, Hirayama H, Kafantaris NM, Koidis PT. Bonding indirect resin composites to metal: Part 1. Comparison of shear bond strengths between different metal-resin bonding systems and a metal-ceramic system. Int J Prosthodont. 2003 Nov-Dec;16(6):635-9.

33. Ozcan M, van der Sleen JM, Kurunmaki H, Vallittu PK. Comparison of repair methods for ceramic-fused-to-metal crowns. J Prosthodont. 2006 Sep-Oct;15(5):283-8.

34. Al-Shehri EZ, Al-Zain AO, Sabrah AH, Al-Angari SS, Al Dehailan L, Eckert GJ, et al. Effects of air-abrasion pressure on the resin bond strength to zirconia: a combined cyclic loading and thermocycling aging study. Restor Dent Endod. 2017 Aug;42(3):206-15. doi: 10.5395/rde.2017.42.3.206.

35. Grasel R, Santos M, Rêgo HC, Rippe M, Valandro LJOd. Effect of resin luting systems and alumina particle air abrasion on bond strength to zirconia. Oper Dent. 2018 May/Jun;43(3):282-90. doi: 10.2341/15-352-L.

36. Hallmann L, Ulmer P, Reusser E, Hammerle CH. Surface characterization of dental Y-TZP ceramic after air abrasion treatment. J Dent. 2012 Sep;40(9):723-35. doi: 10.1016/j.jdent.2012.05.003.

37. Medvedev AE, Ng HP, Lapovok R, Estrin Y, Lowe TC, Anumalasetty VN. Effect of bulk microstructure of commercially pure titanium on surface characteristics and fatigue properties after surface modification by sand blasting and acid-etching. J Mech Behav Biomed Mater. 2016 Apr;57:55-68. doi: 10.1016/j.jmbbm.2015.11.035.

38. Jain S, Parkash H, Gupta S, Bhargava A. To evaluate the effect of various surface treatments on the shear bond strength of three different intraoral ceramic repair systems: an in vitro study. J Indian Prosthodont Soc. 2013 Sep;13(3):315-20. doi: 10.1007/s13191-013-0270-x.

39. da Costa TR, Serrano AM, Atman AP, Loguercio AD, Reis A. Durability of composite repair using different surface treatments. J Dent. 2012 Jun;40(6):513-21. doi: 10.1016/j.jdent.2012.03.001.

40. Lucena-Martin C, Gonzalez-Lopez S, Navajas-Rodriguez de Mondelo JM. The effect of various surface treatments and bonding agents on the repaired strength of heat-treated composites. J Prosthet Dent. 2001 Nov;86(5):481-8.

41. Anusavice KJ, Shen C, Rawls HR. Phillips' science of dental materials. 12.ed. Elsevier Health Sciences; 2012.