Original Research
Dental Materials

Role of adhesive systems on the luting interface's thickness of ceramic laminate veneers

Henrico Badaoui STRAZZI-SAHYON[a]
Eduardo Passos ROCHA[a]
Wirley Golçalves ASSUNÇÃO[a]
Paulo Henrique DOS SANTOS[a]

[a]Universidade Estadual Paulista – Unesp, Araçatuba School of Dentistry, Department of Dental Materials and Prosthodontics, Araçatuba, SP, Brazil.

Abstract: This *in vitro* study aimed to evaluate the effects of different luting protocols on the thickness of luting interface of ceramic laminate veneers. Thirty-six lithium disilicate blocks (7 × 8 × 0.6 mm) were cemented onto bovine enamel. They were divided into 6 groups based on the luting protocol (no previous photoactivation of the dental adhesive; previous activation of the dental adhesive only on enamel surface; and previous photoactivation of the dental adhesive on both the enamel surface and inner surface of ceramic laminate) and the luting materials used (Single Bond Universal/RelyX Veneer and Tetric N Bond/Variolink Veneer). The luting interface thickness of ceramic laminate veneers was evaluated using a laser scanning confocal microscope (n = 6). The luting interface measurements were analyzed using 2-way ANOVA and the Tukey least significant difference test (α = 0.05). Prior activation of the adhesive on the dental enamel and inside the ceramic laminate exhibited higher luting interface thickness than that with no prior photoactivation of both luting materials ($p < 0.05$). Specimens cemented with Tetric N Bond/Variolink Veneer, submitted for prior photoactivation of the adhesive on the dental enamel and on both dental enamel and inner surface of ceramic, exhibited lower luting interface thickness than those luted with Single Bond Universal/RelyX Veneer ($p < 0.05$). The prior photoactivation of dental adhesives influenced the thickness of luting interface in laminate restorations. Tetric N Bond/Variolink Veneer yielded more satisfactory results than Single Bond Universal/RelyX Veneer when the adhesive was light activated.

Keywords: Adhesives; Ceramics; Polymerization; Resin Cements.

Declaration of Interests: The authors certify that they have no commercial or associative interest that represents a conflict of interest in connection with the manuscript.

Corresponding Author:
Paulo Henrique dos Santos
E-mail: paulo.santos@unesp.br

https://doi.org/10.1590/1807-3107bor-2020.vol34.0063

Submitted: November 11, 2019
Accepted for publication: April 30, 2020
Last revision: May 21, 2020

Introduction

To avoid unnecessary dental damage, the current restorative dentistry concept recommends a conservative approach in all restorative procedures.[1] Therefore, ceramic laminate veneers associated with adhesive luting procedures are considered a satisfactory alternative since it allows minimum preparation during the treatment.[2,3,4] Ceramic veneer restorations reproduce polychromatism, translucency, and texture, resulting in a natural and harmonious smile.[5,6]

The use of dental adhesives and light-cured resin cements is a satisfactory choice for luting ceramic veneers and promoting retention and resistance

CC BY

to fracture,[2,3,7,8,9,10,11] besides the esthetic quality of the restorations.[12,13] The bonding effectiveness of luting materials is influenced by several factors related to the material itself, such as monomer composition, filler content,[14,15] and thickness and/or opacity of the ceramic restoration.[2,3] These could interfere with the efficiency of light-activated luting resin materials and directly affect the polymerization process.[2,3,13,16]

Adhesive system formulations have been constantly improved to simplify the clinical performance reducing application time. Universal adhesive systems are characterized as a multi-mode adhesive system containing silane and 10-MDP, which are compounds that can improve the bond strength between the ceramic and dental substrate.[17] Silane is a bifunctional molecule that connects the inorganic ceramic substrate with the organic resin matrix. However, materials with greater technical simplicity or fewer operative steps do not always exhibit better performance.[17,18,19] Moro et al.[18] and Romanini-Junior et al.[19] affirm that the silane incorporated in a universal adhesive does not produce the same adhesive strength as silane applied separately, recommending to apply additional silane in the lithium disilicate restorations.[18,19]

During the luting procedure, the requirement of prior photoactivation of dental adhesive on the enamel substrate and inside the ceramic laminate is unclear.[2,3,20] In some situations, it could be performed concomitantly with the activation of the resin cement.[21] The appropriate photoactivation of the materials used in the luting procedure is an essential step for esthetic and mechanical longevity of ceramic laminate restorations.[2,3]

Unfavorable discrepancy on the luting interface of the restorations could produce damage to the tooth and periodontal tissues and contribute to the longevity of oral rehabilitation.[22,23,24] Higher discrepancies could result in modification of the chemical, physical, and mechanical properties of the luting agents,[25] contributing to bacterial microleakage and their subproducts.[26] Moreover, the increased cement thickness of restorations can reduce fracture strength.[25,27,28] Thus, the tooth becomes more susceptible to post-operative sensitivity,[23] secondary caries, and marginal discoloration.[29,30]

Therefore, the purpose of this in vitro study was to evaluate the effect of different luting protocols on the luting interface thickness of lithium disilicate ceramic laminate veneers, using 2 luting material systems. The null hypotheses tested were: a) that the luting protocol would not promote any difference in the luting interface thickness of the ceramic veneers; and b) that different luting material systems would not result in a difference in the thickness of the adhesive interface.

Methodology

The luting agent materials tested are described in Table 1. This study was submitted and approved

Table 1. Materials, classification, composition, and batch number of materials tested.

Material	Classification	Composition	Batch
Single Bond Universal (3M ESPE)	Adhesive System	MDP, Bis-GMA, HEMA, photoinitiators, dimethacrylate, water, ethanol, silane.	1523700430
RelyX Veneer (3M ESPE)	Resin Cement	Bis-GMA and TEGDMA monomers. Particles of zirconia/silica and colloidal silica. Average particle size of 0.6 mm. Filler loading 66% by weight.	1529200384
RelyX Ceramic Primer (3M ESPE)	Ceramic Primer (silane)	MPS, ethanol, water	1400900844
Tetric N Bond (Ivoclar Vivadent)	Adhesive System	Bis-GMA, UDMA, dimethacrylate, HEMA, phosphonic acid acrylate, nanofillers (SiO_2), ethanol, initiators and stabilizers	U18895
Variolink Veneer (Ivoclar Vivadent)	Resin Cement	Dimethacrylates, inorganic fillers, ytterbium trifluoride, catalysts and stabilizers, pigments. Filler loading 60.1% by weight.	U13581
Monobond Plus (Ivoclar Vivadent)	Ceramic Primer (silane)	Ethanol, 3-trimethoxysilypropyl methacrylate, 10-MDP, disulfide acrylate	U29879

Bis-GMA: bisphenol-A glycidyl methacrylate; TEGDMA: triethylene glycol dimethacrylate; HEMA: 2-hydroxyethyl methacrylate; MDP: 10-methacryloyloxydecyl dihydrogen phosphate; MPS: methacryloxypropyltrimethoxysilane (pre-hydrolyzed silane); UDMA: urethane dimethacrylate.

by the Ethics Committee of the Araçatuba School of Dentistry, São Paulo State University (#15-00673).

Thirty-six ceramic slices (7 × 8 × 0.6 mm) were made from lithium disilicate blocks (HT B1 IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein) using a cutter machine (Isomet 5000; Buehler, Lake Bluff, USA) and low speed diamond saw under water cooling. The ceramic laminate veneers were sintered in a specific oven (Programat EP 5000; Ivoclar Vivadent, Schaan, Liechtenstein) for 1 hour at 780°C according to the recommendations of the manufacture.[2,3]

Thirty-six bovine incisors were used in this experimental study; teeth exhibiting fractures and/or cracks were excluded. The crowns of all the teeth were separated from the root, 1.0 mm above the cementum-enamel junction, using a low-speed diamond saw under water cooling. The surfaces of the enamel specimens (7 × 8 × 4 mm) were also planned using #600 grit silicon carbide paper (Extec Corp., Enfield, USA) under water cooling systems. The teeth were divided into 6 experimental groups according to the luting protocols and the luting materials (n = 6).[31]

In SBU_{WPA} group, the enamel surface was etched using 37% phosphoric acid (Dentsply, Mallefer, Ballaigues, Switzerland) for 30 seconds. The acid was removed with deionized water and the enamel was dried with air jets. A layer of dental adhesive (Single Bond Universal; 3M ESPE, St Paul, USA) was actively applied for 20 seconds. Solvent evaporation was performed using an air jet, from an oil-free air-water syringe, for 5 seconds without activation of the adhesive system. The air nozzle was positioned at 45° to the enamel surface at a distance of approximately 1.5 cm from the sample.[32] The intaglio surface of lithium disilicate ceramic was conditioned using 10% hydrofluoric acid (Dentsply, Mallefer, Ballaigues, Switzerland) for 20 seconds, washed with deionized water, and dried with air jet. The silane (RelyX Ceramic Primer; 3M ESPE, St Paul, USA) was actively applied to the etched surface for 60 seconds and dried with air jet for 5 seconds. The dental adhesive (Single Bond Universal; 3M ESPE, St Paul, USA) was applied for 20 seconds without activation, and the solvent evaporation was performed as described above. Translucent light-activated resin cement (RelyX Veneer; 3M ESPE, St Paul, USA) was applied on the intaglio ceramic surface and the restoration was positioned on the dental enamel substrate. To standardize the luting procedure, a load of 4.9 N was applied for 5 seconds on the restoration and then removed prior the photoactivation. The excess resin cement was removed with a microbrush and activated with a LED polywave unit (Valo polywave; Ultradent, South Jordan, USA) for 30 seconds inside a black box to prevent external light interference. A radiometer (Ecel RD7, Dabi Atlante, Ribeirao Preto, Brazil) was used to measure the luminous intensity of the polymerization light at 1584 mW/cm^2.[2,3]

SBU_{PAE} group specimens were treated as described for the SBU_{WPA}; however, the dental adhesive on the enamel surface was previously activated for 10 seconds. In SBU_{PAEC}, the dental adhesive on the enamel surface and inner surface of the ceramic laminate veneer was previously activated for 10 seconds.

TNB_{WPA} group specimens were similarly luted as described for the SBU_{WPA}; however, the luting materials used were Tetric N Bond dental adhesive, Monobond Plus silane agent, and medium value shade Variolink Veneer resin cement (Ivoclar Vivadent, Schaan, Liechtenstein). In TNB_{PAE} group, the specimens were submitted to a similar protocol realized in SBU_{PAE} group, while TNB_{PAEC} group protocol was similar to SBU_{PAEC} group, but the same materials as TNB_{WPA} group were used. All specimens were stored in distilled water for 24 hours at 37°C in light-protected recipients.

Specimens from each experimental group were submitted to an aging process using the EQUV UV-accelerated aging machine (Equilam, Diadema, SP, Brazil) with eight fluorescent lamps (40 W each) according to the ASTM –G154 test (American Society for Testing and Materials).[2,3] Alternating periods of exposure of UV-light and condensation with distilled water were established under conditions of 100% relative humidity and heat. The aging process was performed for 252 hours, totaling 21 aged cycles. For 168 hours, UV-light was used at 60 ± 3°C, while a condensation phase without light action was performed at 45 ± 3°C for 84 hours.[2,3,33,34]

All specimens were sectioned perpendicular to the occluso-apical direction of the restoration with a low-speed diamond saw under water cooling using

Isomet 5000 (Buehler, Lake Bluff, IL, USA) to obtain 3 slices of the central portion. The slices were fixed in acrylic resin (Classico, Sao Paulo, Brazil), finished with #320, #600, #800, and #1200 grit silicon carbide paper. The specimens were polished using diamond pastes (#6, #3, #1, and #0.25 µm) for 3 minutes each. They were cleaned in an ultrasonic unit (Cristofoli, Campo Mourao, Brazil) using deionized water for a period of 8 minutes, between the silicon carbide papers, diamond pastes, and at the end of the process. The specimens were stored in Hanks solution (Sigma Chemical Co., St. Louis, USA) to prevent cell degradation.[2,3,35]

The thickness of the adhesive interfaces were measured using a laser scanning confocal microscope (LEXT OLS4000; Olympus Schweiz AG, Switzerland).[31] The adhesive interface analysis was performed at low magnification to obtain an overview of the specimen topography and the specific area was localized using a high magnification. Nine measurements were carried out in 3 different regions; 3 measurements were done at each edge of the restoration specimen and other 3 were evaluated in the mid region. Representative images of the experimental groups were obtained using laser scanning confocal microscope to evaluate the adhesive interface subjected to different luting protocols. Adhesive interface thickness was analyzed using 2-way ANOVA and the Tukey least significant difference test ($\alpha = 0.05$).

Results

Table 2 shows the adhesive interface measurements of ceramic veneers analysis, which demonstrated that the restorations undergoing prior activation of dental adhesive on the dental enamel and ceramic exhibited higher luting interface thickness than those not undergoing prior activation for both luting systems evaluated ($p < 0.05$). Comparing the resin luting systems, no difference was observed between the Single Bond Universal/RelyX Veneer and Tetric N Bond/Variolink Veneer luting systems in the interface thickness of specimens submitted with no prior activation of the dental adhesive ($p = 0.08$). However, Tetric N Bond/Variolink Veneer exhibited lower luting interface thickness than Single Bond Universal/RelyX Veneer luting system ($p < 0.05$), when the dental adhesive was previously activated on both the enamel substrate as well as on the dental enamel and inner ceramic surface (Table 2).

Discussion

The luting protocol influenced the luting interface thickness of ceramic laminate veneers, and so the first null hypothesis was rejected. The use of different luting materials resulted in differences in adhesive interface measurements, leading to rejection of the second null hypothesis.

The adhesive interface consists of a luting line between the ceramic substrate and the dental surface, and the vertical thickness of this interface becomes a determining factor in establishing favorable characteristics of marginal adaptation.[36,37] A thicker luting interface exposed to the oral environment may facilitate bacterial adhesion and result in gingival inflammation, periodontal disease, and marginal staining, among other complications.[36,37]

From Table 2, it can be seen that the groups with no prior dental adhesive photoactivation exhibited lower adhesive interface thickness than those groups subjected to previous adhesive activation on the dental enamel and inside the ceramic laminate (Table 2). It is speculated that this result was due to the mixing of previously non-polymerized monomers of the dental adhesive with fillers and monomers from the light-activated resin cement,[2,3,38,39] which resulted in

Table 2. Mean ± standard deviation of luting interface thickness of ceramic laminate veneers (µm) as function of luting protocol and luting agent materials.

Variable	Without previous activation	With previous activation in tooth surface	With previous activation in tooth surface and ceramic
Single Bond Universal/RelyX Veneer	101.80 ± 51.81 Ac	252.43 ± 12.93 Ab	311.59 ± 27.99 Aa
Tetric N Bond/Variolink Veneer	109.89 ± 48.04 Ac	176.92 ± 39.46 Bb	263.34 ± 41.96 Ba

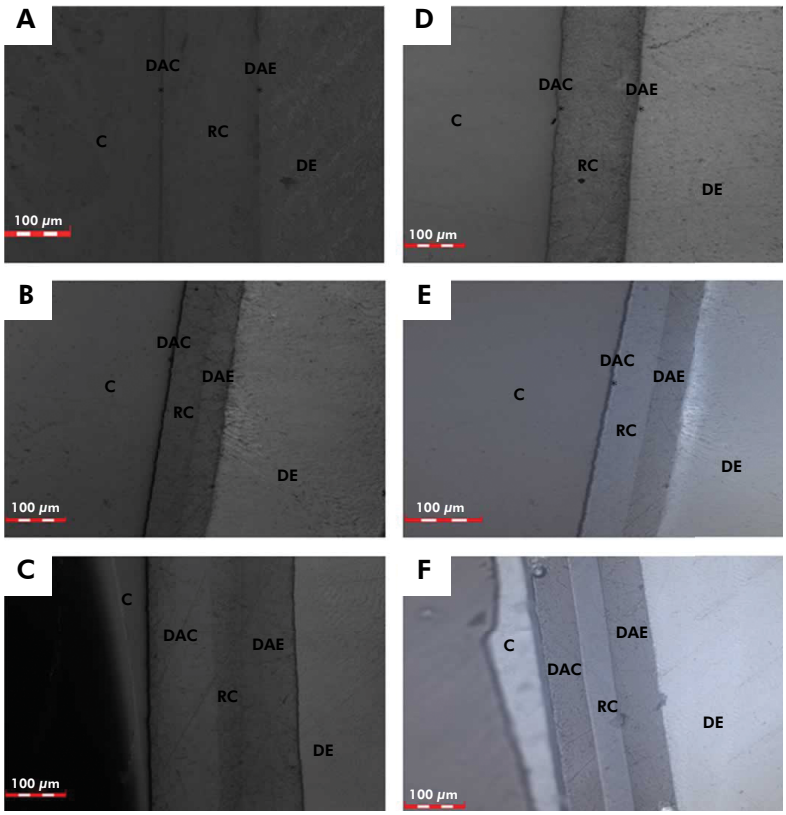
Different letters, uppercase in column and lowercase in row, indicate statistically significant differences ($p < 0.05$).

a thin adhesive interface between the ceramic and enamel substrate (Figure A and D).

In Figure C and D, it is possible to verify the increased thickness of the adhesive interface due to the previous adhesive activation. This could damage the chemical, physical, and mechanical properties of the luting agents,[22] besides reducing the adhesive interface fracture strength of the ceramic restorations.[24] According to Melo Freire et al.,[37] the adhesive interface of indirect restorations can be considered acceptable when it presents luting interface thickness values of approximately 120 µm and when the interface quality presents a uniform aspect with no crack or irregularities presence.[37] According to these requirements, the groups with no prior photoactivation of dental adhesives are within clinically acceptable limits.[37]

The thickness of the adhesive interface could vary according to the specific properties of the resin luting materials.[25] Variolink Veneer presents an approximate filler loading of 60% by weight, compared to 66% of RelyX Veneer (Table 1). This characteristic confers low viscosity to resin luting material, allowing higher flow of the light-activated resin cement in a veneer luting procedure. This fact could have contributed to the difference of measurements of the luting adhesive interface of ceramic restorations with different luting material systems (Table 2).

The solubility of resin agents is directly related to the presence and incorporation of water into the



C: ceramic laminate; DAC: dental adhesive in ceramic laminate; RC: resin cement; DAE: dental adhesive on the dental enamel; DE: dental enamel.

Figure. A. Adhesive interface of Single Bond Universal/RelyX Veneer luting materials with no prior dental adhesive photoactivation. B. Adhesive interface of Single Bond Universal/RelyX Veneer luting materials undergoing prior dental adhesive photoactivation on the dental enamel. C. Adhesive interface of Single Bond Universal/RelyX Veneer luting materials undergoing prior dental adhesive photoactivation on the dental enamel and inner surface of ceramic substrate. D. Adhesive interface of Tetric N Bond/Variolink Veneer luting materials with no prior dental adhesive photoactivation. E. Adhesive interface of Tetric N Bond/Variolink Veneer luting materials undergoing prior dental adhesive photoactivation on the dental enamel. F. Adhesive interface of Tetric N Bond/Variolink Veneer luting materials undergoing prior dental adhesive photoactivation on the dental enamel and inner surface of ceramic substrate.

resin matrix of the restorative material,[2,11] promoting unsatisfactory clinical behavior of these materials.[3] This is because significant concentration of water may result in irreversible damage, such as hydrolytic degradation of the chemical agents and hygroscopy of the resin interface.[1,2] Single Bond Universal contains water and ethanol as solvents in its composition (Table 1), as compared to Tetric N Bond that contains only ethanol as the solvent.[2,3] This favors volatilization during the luting process of ceramic veneers and avoids water sorption by hydrophilic monomers.[3,40] The previous activation of Tetric N Bond could have facilitated the solvent volatilization due to gradual increase in temperature from the polymerization light,[3,11] contributing to a relatively thin adhesive layer compared to the similar usage of Single Bond Universal. However, as Single Bond Universal dental adhesive contains water associated with ethanol,[2] the volatilization process of the ethanol solvent may have been minimized, thus promoting the formation of a relatively thicker adhesive layer with the residual water/solvent.[2,41] This could explain the difference between Tetric N Bond/Variolink Veneer and Single Bond Universal/RelyX Veneer luting systems in both luting protocols (Table 2).

Furthermore, RelyX Veneer light-activated resin cement comprises triethylene glycol dimethacrylate (TEGDMA) (Table 1),[2,39] which promotes water sorption into resinous matrix when combined with bisphenol A-glycidyl methacrylate (Bis-GMA) based resin materials.[1,2,5] Water sorption is directly proportional to the TEGDMA concentration,[1,2,5] and this could explain the hygroscopic increase in the adhesive interface and, consequently, the increased luting interface thickness. However, Tetric N Bond dental adhesive is comprised of the urethane dimethacrylate (UDMA) monomer (Table 1), a hydrophobic compound that allows minimal water sorption into the resinous interface.[1,3,15] This could explain the lower adhesive interface thickness seen in Tetric N Bond/Variolink Veneer luting system than Single Bond Universal/RelyX Veneer (Table 2).

The present study provides information about the discrepancies of luting interface thickness of lithium disilicate ceramic veneers. The results demonstrated that different luting protocols and systems influenced the adhesive interface thickness of ceramic laminate veneers, suggesting that the absence of prior activation of adhesive with Tetric N Bond/Variolink Veneer luting system is a satisfactory luting technique for ceramic laminates. However, as this study was in vitro, the transference of the laboratory results to clinical conditions must be carried out with precaution as in vitro evaluation cannot replicate conditions similar to that of the oral cavity.[42] Further studies are required to evaluate bond strength, permeability, and other physical properties to improve the luting techniques and clinical longevity of ceramic laminates.

Conclusion

Based on the methodology and results obtained in this study, it can be concluded that the prior photoactivation of dental adhesives influenced the thickness of luting interface in laminate restorations, and that the Tetric N Bond/Variolink Veneer yielded more satisfactory results than Single Bond Universal/RelyX Veneer when the adhesive was light activated.

Acknowledgements

This study was supported by the São Paulo Research Foundation (FAPESP) (Grant #2015/06355-0).

References

1. Marchionatti AM, Wandscher VF, May MM, Bottino MA, May LG. Color stability of ceramic laminate veneers cemented with light-polymerizing and dual-polymerizing luting agent: A split-mouth randomized clinical trial. J Prosthet Dent. 2017 Nov;118(5):604-10. https://doi.org/10.1016/j.prosdent.2016.11.013
2. Strazzi Sahyon HB, Chimanski A, Yoshimura HN, Dos Santos PH. Effect of previous photoactivation of the adhesive system on the color stability and mechanical properties of resin components in ceramic laminate veneer luting. J Prosthet Dent. 2018 Oct;120(4):631.e1-6. https://doi.org/10.1016/j.prosdent.2018.06.014

3. Strazzi-Sahyon HB, Chimanski A, Yoshimura HN, Dos Santos PH. Is it necessary to photoactivate the adhesive system inside ceramic laminate veneers in a luting procedure? Int J Prosthodont. 2019 Nov/Dec;32(6):533-40. https://doi.org/10.11607/ijp.6405
4. Aboushelib MN, Elmahy WA, Ghazy MH. Internal adaptation, marginal accuracy and microleakage of a pressable versus a machinable ceramic laminate veneers. J Dent. 2012 Aug;40(8):670-7. https://doi.org/10.1016/j.jdent.2012.04.019
5. Turgut S, Bagis B. Colour stability of laminate veneers: an in vitro study. J Dent. 2011 Dec;39 Suppl 3:e57-64. https://doi.org/10.1016/j.jdent.2011.11.006
6. Xing W, Jiang T, Ma X, Liang S, Wang Z, Sa Y, et al. Evaluation of the esthetic effect of resin cements and try-in pastes on ceromer veneers. J Dent. 2010;38 Suppl 2:e87-94. https://doi.org/10.1016/j.jdent.2010.05.007
7. Hill EE, Lott J. A clinically focused discussion of luting materials. Aust Dent J. 2011 Jun;56 Suppl 1:67-76. https://doi.org/10.1111/j.1834-7819.2010.01297.x
8. Haddad MF, Rocha EP, Assunção WG. Cementation of prosthetic restorations: from conventional cementation to dental bonding concept. J Craniofac Surg. 2011 May;22(3):952-8. https://doi.org/10.1097/SCS.0b013e31820fe205
9. AlShaafi MM, AlQahtani MQ, Price RB. Effect of exposure time on the polymerization of resin cement through ceramic. J Adhes Dent. 2014 Apr;16(2):129-35. https://doi.org/10.3290/j.jad.a30756
10. Calgaro PA, Furuse AY, Correr GM, Ornaghi BP, Gonzaga CC. Influence of the interposition of ceramic spacers on the degree of conversion and the hardness of resin cements. Braz Oral Res. 2013 Sep-Oct;27(5):403-9. https://doi.org/10.1590/S1806-83242013000500004
11. Malacarne-Zanon J, Pashley DH, Agee KA, Foulger S, Alves MC, Breschi L, et al. Effects of ethanol addition on the water sorption/solubility and percent conversion of comonomers in model dental adhesives. Dent Mater. 2009 Oct;25(10):1275-84. https://doi.org/10.1016/j.dental.2009.03.015
12. Harianawala HH, Kheur MG, Apte SK, Kale BB, Sethi TS, Kheur SM. Comparative analysis of transmittance for different types of commercially available zirconia and lithium disilicate materials. J Adv Prosthodont. 2014 Dec;6(6):456-61. https://doi.org/10.4047/jap.2014.6.6.456
13. Smith DS, Vandewalle KS, Whisler G. Color stability of composite resin cements. Gen Dent. 2011 Sep-Oct;59(5):390-4.
14. Ghavam M, Amani-Tehran M, Saffarpour M. Effect of accelerated aging on the color and opacity of resin cements. Oper Dent. 2010 Nov-Dec;35(6):605-9. https://doi.org/10.2341/09-161-L
15. Lührs AK, De Munck J, Geurtsen W, Van Meerbeek B. Composite cements benefit from light-curing. Dent Mater. 2014 Mar;30(3):292-301. https://doi.org/10.1016/j.dental.2013.11.012
16. Hooshmand T, Mohajerfar M, Keshvad A, Motahhary P. Microleakage and marginal gap of adhesive cements for noble alloy full cast crowns. Oper Dent. 2011 May-Jun;36(3):258-65. https://doi.org/10.2341/10-253-L
17. Maluly-Proni AT, Oliveira-Reis B, Jardim VR, Vasconcelos G, Assunção WG, Dos Santos PH. Influence of the application and light-curing of bonding adhesives inside lithium disilicate ceramic crowns. Eur J Prosthodont Restor Dent. 2020 Feb;: https://doi.org/10.1922/EJPRD_1975Maluly-Proni10
18. Moro AF, Ramos AB, Rocha GM, Perez CD. Effect of prior silane application on the bond strength of a universal adhesive to a lithium disilicate ceramic. J Prosthet Dent. 2017 Nov;118(5):666-71. https://doi.org/10.1016/j.prosdent.2016.12.021
19. Romanini-Junior JC, Kumagai RY, Ortega LF, Rodrigues JA, Cassoni A, Hirata R, et al. Adhesive/silane application effects on bond strength durability to a lithium disilicate ceramic. J Esthet Restor Dent. 2018 Jul;30(4):346-51. https://doi.org/10.1111/jerd.12387
20. Sideridou I, Tserki V, Papanastasiou G. Study of water sorption, solubility and modulus of elasticity of light-cured dimethacrylate-based dental resins. Biomaterials. 2003 Feb;24(4):655-65. https://doi.org/10.1016/S0142-9612(02)00380-0
21. Lührs AK, Pongprueksa P, De Munck J, Geurtsen W, Van Meerbeek B. Curing mode affects bond strength of adhesively luted composite CAD/CAM restorations to dentin. Dent Mater. 2014 Mar;30(3):281-91. https://doi.org/10.1016/j.dental.2013.11.016
22. Oliveira DC, Souza-Júnior EJ, Prieto LT, Coppini EK, Maia RR, Paulillo LA. Color stability and polymerization behavior of direct esthetic restorations. J Esthet Restor Dent. 2014 Jul-Aug;26(4):288-95. https://doi.org/10.1111/jerd.12113
23. Mounajjed R, Salinas TJ, Ingr T, Azar B. Effect of different resin luting cements on the marginal fit of lithium disilicate pressed crowns. J Prosthet Dent. 2018 Jun;119(6):975-80. https://doi.org/10.1016/j.prosdent.2017.08.001
24. Della Bona A, Kelly JR. The clinical success of all-ceramic restorations. J Am Dent Assoc. 2008 Sep;139 Suppl:8S-13S. https://doi.org/10.14219/jada.archive.2008.0361
25. Borba M, Cesar PF, Griggs JA, Della Bona Á. Adaptation of all-ceramic fixed partial dentures. Dent Mater. 2011 Nov;27(11):1119-26. https://doi.org/10.1016/j.dental.2011.08.004
26. Jacobs MS, Windeler AS. An investigation of dental luting cement solubility as a function of the marginal gap. J Prosthet Dent. 1991 Mar;65(3):436-42. https://doi.org/10.1016/0022-3913(91)90239-S
27. Tuntiprawon M, Wilson PR. The effect of cement thickness on the fracture strength of all-ceramic crowns. Aust Dent J. 1995 Feb;40(1):17-21. https://doi.org/10.1111/j.1834-7819.1995.tb05607.x

28. Rekow D, Thompson VP. Near-surface damage—a persistent problem in crowns obtained by computer-aided design and manufacturing. Proc Inst Mech Eng H. 2005 Jul;219(4):233-43. https://doi.org/10.1243/095441105X9363
29. Bergenholtz G, Cox CF, Loesche WJ, Syed SA. Bacterial leakage around dental restorations: its effect on the dental pulp. J Oral Pathol. 1982 Dec;11(6):439-50. https://doi.org/10.1111/j.1600-0714.1982.tb00188.x
30. Lang NP, Kiel RA, Anderhalden K. Clinical and microbiological effects of subgingival restorations with overhanging or clinically perfect margins. J Clin Periodontol. 1983 Nov;10(6):563-78. https://doi.org/10.1111/j.1600-051X.1983.tb01295.x
31. Turkistani A, Sadr A, Shimada Y, Nikaido T, Sumi Y, Tagami J. Sealing performance of resin cements before and after thermal cycling: evaluation by optical coherence tomography. Dent Mater. 2014 Sep;30(9):993-1004. https://doi.org/10.1016/j.dental.2014.05.010
32. Luque-Martinez IV, Perdigão J, Muñoz MA, Sezinando A, Reis A, Loguercio AD. Effects of solvent evaporation time on immediate adhesive properties of universal adhesives to dentin. Dent Mater. 2014 Oct;30(10):1126-35. https://doi.org/10.1016/j.dental.2014.07.002
33. Catelan A, Suzuki TY, Becker F Jr, Briso AL, Dos Santos PH. Influence of surface sealing on color stability and roughness of composite submitted to ultraviolet-accelerated aging. J Investig Clin Dent. 2017 May;8(2):e12203. https://doi.org/10.1111/jicd.12203
34. Catelan A, Briso AL, Sundfeld RH, Goiato MC, dos Santos PH. Color stability of sealed composite resin restorative materials after ultraviolet artificial aging and immersion in staining solutions. J Prosthet Dent. 2011 Apr;105(4):236-41. https://doi.org/10.1016/S0022-3913(11)60038-3
35. Anchieta RB, Machado LS, Martini AP, Santos PH, Giannini M, Janal M, et al. Effect of long-term storage on nanomechanical and morphological properties of dentin-adhesive interfaces. Dent Mater. 2015 Feb;31(2):141-53. https://doi.org/10.1016/j.dental.2014.11.010
36. Behr M, Hansmann M, Rosentritt M, Handel G. Marginal adaptation of three self-adhesive resin cements vs. a well-tried adhesive luting agent. Clin Oral Investig. 2009 Dec;13(4):459-64. https://doi.org/10.1007/s00784-009-0255-7
37. Melo Freire CA, Borges GA, Caldas D, Santos RS, Ignácio SA, Mazur RF. Marginal adaptation and quality of interfaces in lithium disilicate crowns - influence of manufacturing and cementation techniques. Oper Dent. 2017 Mar/Apr;42(2):185-95. https://doi.org/10.2341/15-288-L
38. Arrais CA, Giannini M, Rueggeberg FA. Kinetic analysis of monomer conversion in auto- and dual-polymerizing modes of commercial resin luting cements. J Prosthet Dent. 2009 Feb;101(2):128-36. https://doi.org/10.1016/S0022-3913(09)60008-1
39. Elmamooz N. Eskandarizadeh Ali, Rahmanian E, Azimzadeh SS. Evaluating the effect of ceramic veneer thickness on degree of conversion in three luting resin cements. J Dent Mater Tech. 2017;6:54-60. https://doi.org/10.22038/JDMT.2017.8508
40. Ito S, Hoshino T, Iijima M, Tsukamoto N, Pashley DH, Saito T. Water sorption/solubility of self-etching dentin bonding agents. Dent Mater. 2010 Jul;26(7):617-26. https://doi.org/10.1016/j.dental.2010.03.001
41. Yahagi C, Takagaki T, Sadr A, Ikeda M, Nikaido T, Tagami J. Effect of lining with a flowable composite on internal adaptation of direct composite restorations using all-in-one adhesive systems. Dent Mater J. 2012;31(3):481-8. https://doi.org/10.4012/dmj.2012-007
42. Contrepois M, Soenen A, Bartala M, Laviole O. Marginal adaptation of ceramic crowns: a systematic review. J Prosthet Dent. 2013 Dec;110(6):447-454.e10. https://doi.org/10.1016/j.prosdent.2013.08.003