Mechanical properties of dual-cured resin luting agents for ceramic restoration.

Keiichi Yoshida*, Yukiko Tsuo, Mitsuru Atsuta

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*Corresponding author:

Dr. K. Yoshida, Division of Fixed Prosthodontics and Oral Rehabilitation, Nagasaki University, Graduate School of Biomedical Sciences, 1-7-1, Sakamoto, Nagasaki 852-8588, Japan

Tel.: +81-95-849-7688

Fax: +81-95-849-7689

E-mail address: keiichi@net.nagasaki-u.ac.jp

Abstract: Purpose: The aim of the present study was to evaluate the mechanical properties including surface hardness, flexural strength, and flexural modulus of two dual-cured resin luting agents (New Resin Cement [NRC] and Variolink II [VLII]) irradiated through four different thickness of leucite ceramics (0, 1, 2, and 3 mm) and their shear bond strength to zirconia ceramic (Cercon) using each ceramic primer. **Materials and Methods:** Knoop hardness was measured on a thin layer of resin luting agent on the ceramic surface. Three-point bending tests were performed after 24 h storage at 37°C. Two different-shaped zirconia ceramic specimens with or without sandblasting with alumina were treated with each primer. The specimens were then cemented together with each resin luting agent. Half of the specimens were stored in water at 37°C for 24 h and the other half were thermocycled 5,000 times. **Results:** VLII revealed statistically higher Knoop hardness and flexural modulus than NRC for each thickness of ceramic. No significant differences in flexural strength were observed between VLII and NRC for each ceramic spacer. Reduction of the mechanical properties with increase of ceramic thickness varied for each property. However, these properties were similar between the two materials. Blasting with alumina was significantly effective for increasing shear bond strength of both resin luting agents before and after thermal cycling. The use of New Ceramic Primer showed the highest shear bond strength and maintained bond durability after 5,000 thermocycles. **Conclusion:** Mechanical properties of NRC dual-cured resin luting agent appear adequate for ceramic

restorations.

Introduction

It is well known that patient demand for aesthetic and metal-free restorations has increased, and then the excellent resin bonding systems (combination of silane coupling agent and resin luting agent) have been developed.[1-5] Regarding feldspathic[6] or silica-based glass ceramics[7,8] and CAD/CAM ceramics[9-11], hydrofluoric acid etching followed by application of a ceramic primer containing a silane coupling agent is a common and clinically successful procedure. In recent years, new high-strength ceramics, such as glass-infiltrated[12-14] and CAD/CAM-fabricated densely sintered high-purity alumina[15,16] ceramics and zirconia ceramics, are more commonly in restorative dentistry. Dental application of zirconia materials involve all-ceramic cores and post systems[17,18] and coping for complete coverage of all-ceramic crowns and fixed partial dentures.[19-21] Neither etching with hydrofluoric acid nor a silane coupling agent for silica-based ceramics or glass can reliable improve bond strength between zirconia ceramics with no silica content and resin cements because of the high resistance of acids.[22] Therefore, other bonding techniques such as tribochemical silica-coating using the Rocatec system[23-27] and special small hand-held fire lighters containing a mixture of butane gas and a silane called PyrosilPen[28] are required to strongly lute zirconia ceramics using resin bonding system. An experimental primer mixture of phosphoric acid ester monomer and zirconate coupling agent significantly improved the bond strength between zirconia ceramic stabilized by yttrium oxide and exists as yttria-tetragonal zirconia polycrystals (Y-TZP) at room temperature and dual-cured resin cement.[29]

Apart from bonding systems for ceramics, the clinical success of ceramic restorations is heavily dependent on the cementation procedure. Resin luting agents should be easy to handle, lack complicated pretreatment steps, have good mechanical properties, favorable esthetics, and strong adhesion to both tooth structure and ceramics. Dual-cured luting agents are widely used for cementing ceramic restorations in clinics because they provide these desirable properties. Dual-cured resin luting agents vary in mechanical characteristics between brands such as 1) microleakage of ceramic inlays influenced by their viscosities,[30] 2) tensile strength to copy-milled ceramics influenced by light source direction,[31] and 3) surface hardness cured through machinable ceramics.[32] Adequate polymerization is a crucial factor in obtaining optimal physical properties of resin luting agent and a clinically satisfying initial management of the restoration such as finishing and occlusal adjustment. Inadequate polymerization diminishes the physical properties, affecting mechanical characteristics such as hardness and flexural strength. It is important for dual-cured resin luting agents to be capable of achieving a sufficient degree of hardening of with light-curing. This is to ensure adequate polymerization of the resin cement layer that is not readily accessible to the curing light due to the thickness of the ceramic restoration.[32] Limited information is available regarding the mechanical characteristics of developed dual-cured resin bonding systems with one-bottle ceramic primer containing silane and phosphoric acid ester monomer for most types of ceramics, including zirconia, and not only for silica-based ceramics. Therefore, we evaluated and compared flexural strength and surface hardness of two dual-cured luting agents polymerized through different thicknesses of machinable ceramics, which simulates the clinical situation and their shear bond strength to commercially available zirconia ceramic using each bonding system.

Materials and Methods

Dual-cured resin luting agents with ceramic bonding system

Two dual-cured resin luting agents (New Resin Cement [NRC, NAC-100, Kuraray Medical Inc., Kurashiki, Japan] and VariolinkII HV [VLII, Ivoclar/Vivadent, Schaan, Liechtenstein]) were prepared. Two one-bottle ceramic primers (New Ceramic Primer [NCP, SCP-100] and Monobond S [MBS], respectively) were components of each bonding system. Descriptions of these materials are summarized in Table 1.

Preparation of specimens for Knoop hardness and test procedures

Three thicknesses of machinable ceramic plates (10 X 8 mm squares with 1.05, 2.05, and 3.05 mm thicknesses) were prepared from CAD/CAM blocks (GN-I, shade A3, GC Corp., Tokyo, Japan) using a low-speed cutting saw (Isomet, Buehler Ltd., Lake Bluff, IL, USA). Prefabricated ceramic material was mainly composed of SiO_2, K_2O, and Al_2O_3 and the main precipitated crystal was leucite $K_2O{\cdot}Al_2O_3{\cdot}4SiO_2$. The ceramic plates were sanded to a flat surface by hand grinding on wet 320-, 400-, 600-, and 800-grid silicon carbide paper and cleaned ultrasonically in distilled water for 5 min. The final thickness of each ceramic plate was 1.0, 2.0, and 3.0 mm.

The preparation of test specimens for Knoop hardness and the procedure for measurements of Knoop hardness were previously described.[32] A piece of adhesive polyethylene tape with a circular hole 5 mm in diameter was positioned on the surface of each thickness of machinable ceramic plate to control the cement layer, which had a thickness of approximately 50 μm. A small amount of product was placed on each thickness of ceramic surface within the circle. The ceramic plate with resin cement paste was placed on a clear micro cover glass (thickness 0.15 mm, Matsunami Glass Ind., Ltd., Tokyo, Japan) over a zirconia ceramic block (thickness 2 mm) to obtain a flat surface. A thin layer of resin cement was sandwiched between each thickness of ceramic plate with adhesive polyethylene tape and glass.

The dual-cured resin cement material was polymerized through on each thickness of machinable ceramic using a halogen visible-light-curing unit (Candelux VL-5, J Morita Mfg., Corp., Kyoto, Japan) with intensity of 800 mW/cm^2 and an 11-mm tip at irradiation times of 40 s. After curing, the adhesive tape was removed carefully on the ceramic surface. Other specimens were made directly with visible-light irradiation on the clear glass for 40 s (not through machinable ceramic, 0 mm thickness) to establish a controlled hardness for each resin material. Each group contained five specimens.

Five measurements of hardness in the layer of resin luting agent on the ceramic surface were recorded at post-irradiation time of 24 h from each specimen using a microhardness tester (MVK-E, Akashi Co., Ltd., Tokyo, Japan). A Knoop diamond indenter was applied under a load of 50 g for 30 s and the length of the indentation’s long diagonal was measured after the applied load was removed. The specimens were stored dry in light-proof container at 25°C except for during measurements.

Preparation of specimens for bending tests

Rectangular cross-sectional area specimens with a 25-mm length, 2-mm width, and 2-mm height were obtained using a Teflon split mold (thickness 2.0 mm) according to ISO 4049.[33] Equal amounts of base and catalyst pastes of resin luting agent were mixed according to the manufacturers' directions and inserted into the mold placed on a micro cover glass. Each of the three thicknesses of machinable ceramic plates was placed between the micro cover glass and the tip of the halogen visible-light-curing unit. Photo-activation was performed only on the upper surface of the specimen, and the luting agent was irradiated through ceramics divided by three sections for 40 s each to polymerize the full length of the specimens. Other specimens were made directly with visible-light irradiation on the clear glass (not through machinable ceramic, 0 mm thickness) to establish the controlled properties for each luting agent material. Each group contained seven specimens.

According to ISO 4049, specimens of photo-activated materials should be irradiated by placing the tip of the light source at the center of the specimen and activating for the recommended exposure time. Then, this procedure should be continued for the entire length of the specimen and repeated on the other side of the specimen. However, in this study, only one side of the specimens was irradiated, which simulates the clinical situation.

Bending tests procedure

The specimens prepared were allowed to stand for 30 min at room temperature, and then stored in distilled water at 37°C for 24 h. The flexural strength was then measured with a universal testing machine (DCS-500, Shimadzu Corp., Kyoto, Japan) at a cross-head speed of 1.0 mm/min. Flexural strength testing was performed in a 3-point bending mode with a span length of 20 mm. Flexural modulus values were also calculated from the normal linear portion of the force-deflection curve.

The means and standard deviations for the Knoop hardness, flexural strength, and flexural modulus were computed and compared using two-way analysis of variance (ANOVA) and Student-Newman-Keuls tests with the type of resin luting agent and the ceramic thickness as independent factors at a significance level of 0.05. The Pearson's correlation coefficient and corresponding level of significance were calculated to analyze a possible correlation between each property.

Preparation of specimens for shear bond tests

Two different-sized zirconia disks (diameter of 10 mm and 8 mm and a thickness of 2.5 mm) of yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) with Cercon (DeguDent GmbH, Hanau, Germany) were fabricated according to the manufacturers' directions. Half of ceramic specimens were air-abraded with 50 µm alumina particles at an air pressure of 0.4 MPa (Air-Jet, Morita Corp., Osaka, Japan) for 15 s at a distance of 10 mm, and then ultrasonically cleaned in distilled water for 5 min (SB). A piece of polyethylene tape with a circular hole 4 mm in diameter was positioned on the surface of the 10 mm diameter x 2.5 mm thick zirconia ceramic specimen to control the area of the bond. On two sizes of zirconia ceramic specimen surfaces sanded or unsanded, each ceramic primer was applied according to the manufacturers' directions, air-dried for 5 s and then bonded together with each resin luting agent. A sample holder secured the bonded specimens in a rigid position during bonding and controlled the cement film thickness to approximately 50 µm. Excess cement was removed before complete hardening of the resin luting agent.

The dual-cured resin luting agent was irradiated from four directions for 20 s, for a total exposure time of 80 s using the visible-light-curing unit. The specimens were allowed to stand for 30 min at room temperature. The specimens were assigned randomly to one of four test groups: NCP/NRC, SB+NCP/NRC, MBS/VLII, and SB+MBS/VLII, and divided into two subgroups of seven specimens each. One of the two subgroups was stored in distilled water at 37°C for 24 h. The remaining subgroup was stored in distilled water at 37°C for 24 h and followed by 5,000 thermocycles between water baths (Rika-Kogyo, Hachioji, Japan) held at 4°C and 60°C with a dwell time of 1 min in each bath. Thermal cycling was performed to evaluate the durability of the bond.

Shear testing procedure

Each specimen was embedded in an acrylic resin mold and arranged in an ISO/TR 11405 shear testing jig. Shear tests were performed, using a method previously described[29], with the universal testing machine at a crosshead speed of 0.5 mm/min. The calculated shear bond strength was determined by dividing the force at which bond failure occurred by the bonding area. The means for each group were analyzed by two-way ANOVA with the shear bond strength as the dependent variable and the combinations of surface treatment and resin luting agent and storage conditions of specimens as independent factors. The Student-Newman-Keuls test with $p < 0.05$ was used to establish significance.

Results

Table II shows the mechanical properties of two dual-cured resin luting agents through different thicknesses of machinable ceramic. Variolink II revealed statistically higher Knoop hardness and flexural modulus than New Resin Cement for each thickness of machinable ceramic, while no significant difference was seen in flexural strength. No significant differences in flexural strength were observed between VLII and NRC for each ceramic thickness. Reduction of the mechanical properties with increase of ceramic thickness varied for each property. However, these properties were similar between the two materials. Statistically significant correlations could be detected between hardness and flexural modulus in NRC ($r = 0.973$, $p = 0.0323$) and hardness and flexural strength in VLII ($r = 0.964$, $p = 0.0459$) with Pearson's correlation coefficient and respective P values (Table III).

Table IV shows the shear bond strengths of two resin luting agents to Cercon zirconia ceramic with or without sandblasting with alumina using each one-bottle ceramic primer (NCP or MBS) at 0 and 5,000 thermocycles. Sandblasting (SB) was significantly effective for increasing shear bond strength of both resin luting agents compared with and without sandblasting before and after thermal cycling. The use of New Ceramic Primer (NCP) could maintain shear bond strength after 5,000 thermocycles. There were significant differences between bond strength before and after thermal cycling for the MBS/VLII and SB+MBS/VLII groups ($p < 0.05$).

Discussion

Dual-cured resin luting agents have been recommended for luting ceramic or resin composite restorations to compensate for the attenuation of the curing light and to allow complete polymerization of the resin luting agent even at the bottom of the cavity or at abutting teeth, where limited curing light reaches. Evaluation of the mechanical properties for resin luting agents has been done in photo-activation through a 2.5-mm-thick ceramic[34] or a 2.0-mm composite[35] spacer, which was used to approximate the conditions of the experiment to those found in clinical practice. However, restorations with different thicknesses are clinically luted to the cavity or abutment teeth mostly using dual-cured resin luting agents. It is well known that the light intensity reaching the resin luting agent is greatly reduced when light is transmitted through a ceramic or composite restoration. The intensity decreases exponentially as a function of the restoration thickness. An intensity of 800 mW/cm^2 was reduced to approximately 310, 160, 80 mW/cm^2 when light was transmitted through 1-, 2-, and 3-mm-thick machinable ceramic spacers.[32] Therefore, longer exposure[36,37] or multiple directed exposures[31] are recommended to diminish the effects of the attenuation of the light that reaches the dual-cured resin luting agents.

The mechanical properties of resin luting agents are influenced by the type and composition of the matrix resin, type and content of the filler, and mode of polymerization. The filler particles incorporated in the matrix provide better mechanical properties than the matrix itself. A correlation between filler content and hardness has been reported.[38] The Variolink II (VLII) material, which contains higher filler load than the New Resin Cement (NRC) material, also showed higher hardness and flexural modulus than NRC, regardless of ceramic thickness. However, in this study, differences observed in hardness and flexural modulus values between VLII and NRC did not correspond to differences in flexural strength in all ceramic thickness spacers. VII and NRC showed similar flexural strength for each ceramic spacer. After the threshold network to produce resin with high strength is formed, the strength becomes less dependent on the degree of polymerization.[39] Irradiation through porcelain significantly reduced the hardness of only light-cured composites.[36,40] With the dual-cured resin cement, our results were in agreement with other studies[34]. In contrast, no reduction of the mechanical properties irradiated through machinable ceramic was observed for Knoop hardness of both resin luting agents because of the irradiation through 0- or 1-mm-thick ceramic, flexural strength through 0-, 1-, or 2-mm-thick, and flexural modulus through 2- or 3-mm-thick. Strong performance of both resin luting agents in flexural strength was observed, considering the low light intensity that reached the cement up to the 2-mm-thick ceramic. Therefore, dual-cured resin luting agents may be preferred even for clinically aesthetic restorations.

Sandblasting is effective for improving bond strength of two resin luting agents because of the increase of the adhesive area on the zirconia ceramic surface. The bond between silica-based ceramics to resin luting agents is well established because etching with hydrofluoric acid and application of a silane coupling agent provides good bonding. A silane coupler has the property of increasing the wettability of the ceramic surface for the resin luting agent, thus improving the ability of the ceramic surface to adhere to the resin luting agent. In addition, this facilitates the bonding between the silica in the ceramic and the matrix resin monomer in the resin luting agents. However, Monobond S (MBS) containing silane coupler could not maintain bond strength between zirconia ceramic with no silica content and resin luting agents after thermal cycling. Hydroxyl groups in 10-methacryloyloxydecyl dihydrogen phosphate (MDP) monomer may react with hydroxyl groups on the zirconia ceramic surface by dehydration-condensation, as seen in the reaction between silane couplers and hydroxyl groups on the silica surface.[29] As a result, New Resin Cement (NRC) showed significant shear bond strength after thermal cycling using New Ceramic Primer (NCP) containing MDP monomer.

Conclusion

Under the conditions of this study, VLII revealed higher Knoop hardness and flexural modulus than NRC for each thickness of ceramic. No significant differences in flexural strength were observed between VLII and NRC for each ceramic spacer. Reduction of the mechanical properties with increase of ceramic thickness varied for each property. However, these properties were similar between the two materials. The bond strength of resin bonding system including NCP of one-bottle ceramic primer appears adequate for ceramic restorations.

References

1. Aida M, Hayakawa T, Mizukawa K: Adhesion of composite to porcelain with various surface conditions. J Prosthet Dent 1995;73:464-470
2. Della Bona A, Van Noort R: Shear vs. tensile bond strength of resin composite bonded to ceramic. J Dent Res 1995;74:1591-1596
3. Burke FJT, Watts DC: Effect of differing resin luting systems on fracture resistance of teeth restired with dentin-bonded crowns. Quintessence Int 1998;29:21-27
4. Frankenberger R, Sindel J, Kramer N, Petschelt A: Dentin bond strength and marginal adaptation: direct composite resins vs. ceramic inlays. Oper Dent 1999;24:147-155
5. Bremer BD, Geurtsen W: Molar fracture resistance after adhesive restoratation with ceramic inlays or resin-based composites. Am J Dent 2001;14:216-220
6. Blatz MB, Sadan A, Maltezos C, Blatz U, Mercante D, Burgess JO: In vitro durability of the resin bond to feldspathic ceramics. Am J Dent 2004;17:169-172
7. Chang JC, Nguyen T, Duong JH, Ladd GD: Tensile bond strengths of dual-cured cements between a glass-ceramic and enamel. J Prosthet Dent 1998;79:497-503

8. Shimada Y, Yamaguchi S, Tagami J: Micro-shear bond strength of dual-cured resin cement to glass ceramics. Dent Mater 2002;18:380-388

9. Kamada K, Yoshida K, Atsuta M: Effect of ceramic surface treatments on the bond of four resin luting agents to a ceramic material. J Prosthet Dent 1998;79:508-513

10. Chang JC, Hart DA, Estey AW, Chan JT. Tensile bond strengths of five luting agents to two CAD-CAM restorative materials and enamel. J Prosthet Dent 2003;90:18-23:

11. Attia A, Kern M: Fracture strength of all-ceramic crowns luted using two bonding methods. J Prosthet Dent 2004;91:247-252

12. Scotti R, Catapano S, D’Elia A: A clinical evaluation of In-Ceram crowns. Int J Prosthodont 1995;8:320-323

13. Pröbster L: Four year clinical study of glass-infiltrated, sintered alumina crowns. J Oral Rehabil 1996;23:147-151

14. Haselton DR, Diaz-Arnold AM, Hillis SL: Clinical assessment of high-strength all-ceramic crowns. J Prosthet Dent 2000;83:396-401

15. Oden A, Andersson M, Krystek-Ondracek I, Magnusson D: Five-year clinical evaluation of Procera AllCeram crowns. J Prosthet Dent 1998;80:450-456

16. Odaman P, Andersson B: Procera AllCeram crowns followed for 5 to 10.5 years: A prospective clinical study. Int J Prosthodont 2001;14:504-509

17. Meyenberg KH, Lüthy H, Schärer P: Zirconia posts: A new all-ceramic concept for nonvital abutment teeth. J Esthet Dent 1995;7:73-80
18. Lopes GC, Baratieri LN, Caldeira de Andrada MA, Maia HP: All-ceramic post, core, and crown: Technique and case report. J Esthet Restor Dent 2001;13:285-295
19. Luthardt R, Herold V, Sandkuhl O, Reitz B, Knaak JP, Lenz E: Kronen aus Hochleistungskeramik, Zirkonoxid-Keramik, ein neuer Werkstoff in der Kronenprothetik. Dtsch Zahnärztl Z 1998;53:280-285
20. McLaren EA: All-ceramic alternatives to conventional metal-ceramic restorations. Compend Contin Educ Dent 1998;19:307-312
21. Blatz MB: Long-term success of all-ceramic posterior restorations. Quintessence Int 2002;33:415-426
22. Borges GA, Sophr AM, de Goes MF, Sobrinho LC, Chan DCN: Effect of etching and airborne particle abrasion on the microstructure of different dental ceramics. J Prosthet Dent 2003;89:479-488
23. Kern M, Wegner SM: Bonding to zirconia ceramic: adhesion methods and their durability. Dent Mater 1998;14:64-71
24. Dérand P, Dérand T: Bond strength of luting cements to zirconium oxide ceramics. Int J Prosthodont 2000;13:131-135
25. Wegner SM, Kern M: Long-term resin bond strength to zirconia ceramic. J Adhes Dent 2000;2:139-147

26. Bottino MA, Valandro LF, Scotti R, Buso L: Effect of surface treatments on the resin bond to zirconium-based ceramic. Int J Prosthodont 2005;18:60-65

27. Piwowarczyk A, Lauer H-C, Sorensen JA: The shear bond strength between luting cements and zirconia ceramics after two pre-treatments. Oper Dent 2005;30:382-388

28. Janda R, Roulet J-F, Wulf M, Tiller H-J: A new adhesive technology for all-ceramics. Dent Mater 2003;19:567-573

29. Yoshida K, Tsuo Y, Atsuta M: Bonding of dual-cured resin cement to zirconia ceramics using phosphoric acid ester monomer and zirconate coupler. J Biomed Mater Res in press 2006

30. Hahn P, Attin T, Grofke M, Hellwig E: Influence of resin cement viscosity on microleakage of ceramic inlays. Dent Mater 2001;17:191-196

31. Faxton RM, Pereira PNR, Nakajima M, Tagami J, Miura H: Effect of light source direction and restoration thickness on tensile strength of a dual-curable resin cement to copy-milled ceramic. Am J Dent 2003;16:129-134

32. Meng X, Yoshida K, Atsuta M: Hardness development of dual-cured resin cements through different thickness of ceramics. Dent Mater J 2006;25:132-137.

33. ISO 4049: Dentistry-Polymer-based filling, restorative and luting materials, 2000. International Organization for Standardization, Geneva, Switzerland.

34. Hofmann N, Papsthart G, Hugo B, Klaiber B: Comparison of photo-activation versus chemical or dual-curing of resin-based luting cements regarding flexural strength, modulus and surface hardness. J Oral Rehabil 2001; 28: 1022-1028
35. Braga RR, Cesar PF, Gonzaga CC: Mechanical properties of resin cements with different activation modes. J Oral Rehabil 2002; 29: 257-262
36. Blackman R, Barghi N, Duke E: Influence of ceramic thickness on the polymerization of light-cured resin cement. J Prosthet Dent 1990; 63: 295-300
37. Rueggeberg FA, Caughman WF: The influence of light exposure on polymerization of dual-cure resin cements. Oper Dent 1993; 18: 48-55
38. Pilo R, Cardash HS: Post-irradiation polymerization of different anterior and posterior visible light-activated resin composites. Dent Mater 1992;8:299-304
39. Ferracane JL, Greener EH: The effect of resin formulation on the degree of conversion and mechanical properties of dental restorative resins. J Biomed Mater Res 1986;20:121-131
40. Warren K: An investigation into the microhardness of a light cured composite when cured through varying thickness of porcelain. J Oral Rehabil 1990; 17: 327-334

Table 1. Resin bonding systems (combination of ceramic primer and resin luting agent) used in this study

Product	Abbreviation	Component
Resin luting agent		
New Resin Cement (universal)	NRC	Monomer: Bis-GMA, dimethacrylate monomers Filler: 70 wt% hybrid, 2.0 μm SiO_2, Ba-glass, colloidal silica
Variolink II (A3, high viscosity)	VLII	Monomer: Bis-GMA, UDMA, TEGDMA Filler: 75.3 wt% hybrid, 0.7 μm Ba-glass, YTF-glass, Ba-Al-F-Si-glass
Ceramic primer		
New Ceramic Primer (single-liquid)	NCP	ethanol MDP MPTS
Monobond S (single-liquid)	MBS	52% ethanol 47% water 1% MPTS

Bis-GMA:bis-phenol-A-diglycidylmethacrylate, TEGDMA: triethyleneglycol dimethacrylate, UDMA: urethane dimethacrylate, MDP: 10-methacryloyloxydecyl dihydrogen phosphate, MPTS: 3-methacryloxypropyl trimethoxysilane,
Ba: barium, YTF: ytterbium, Al: aluminium, F: fluorine, Si: silicon

Table 2. Mechanical properties of two dual-cured resin luting agents through different thicknesses of machinable ceramics

Property	Machinable ceramic thickness (mm)	Resin luting agent	
		New Resin Cement (NRC)	Variolink II (VLII)
Knoop hardness number mean ± SD (KHN)	0	37.3 ± 0.9^{b}	*40.5 ± 0.5^{d}
	1	36.3 ± 1.2^{a,b}	*40.4 ± 0.8^{d}
	2	34.8 ± 1.6^{a}	*38.8 ± 0.3^{c}
	3	34.8 ± 0.9^{a}	*37.5 ± 0.5^{b}
Flexural strength mean ± SD (MPa)	0	167.9 ± 5.5^{c}	162.6 ± 20.1^{c}
	1	163.2 ± 7.2^{c}	161.8 ± 7.2^{c}
	2	157.9 ± 5.9^{b,c}	154.9 ± 17.4^{b,c}
	3	145.0 ± 10.8^{a,b}	137.9 ± 10.1^{a}
Flexural modulus mean ± SD (GPa)	0	8.81 ± 0.44^{c}	10.82 ± 0.52^{e}
	1	7.85 ± 0.49^{b}	10.28 ± 0.45^{d}
	2	7.32 ± 0.60^{a}	10.01 ± 0.22^{d}
	3	7.16 ± 0.41^{a}	9.80 ± 0.31^{d}

Identical letters were not significantly different at each property by Student-Newman-Keuls test ($p > 0.05$).

*Reference #32.

Table 3. Pearson's correlation coefficient and respective P value between each property

Material	Knoop hardness-flexural strength	Knoop hardness-flexural modulus	Flexural strength/flexural modulus
New Resin Cement (NRC)	0.841, p = 0.2204	0.973, p = 0.0323	0.845, p = 0.2150
Variolink II (VLII)	0.964, p = 0.0459	0.870, P = 0.1827	0.803, p = 0.2678

Table 4. Shear bond strength (mean ± SD) of resin luting agent to zirconia ceramic at 0 and 5,000 thermocycles

Group	Thermocycle 0	Thermocycle 5,000
NCP/NRC	51.0 ± 3.0^{d}	51.5 ± 6.7^{d}
SB+NCP/NRC	82.2 ± 1.8^{f}	80.0 ± 7.2^{f}
MBS/VLII	27.2 ± 2.2^{b}	8.4 ± 2.2^{a}
SB+MBS/VLII	68.2 ± 6.0^{e}	34.0 ± 1.9^{c}

Identical letters were not significantly different by Student-Newman-Keuls test ($p > 0.05$).