©Operative Dentistry, 2012, 37-2, 188-194

In-Depth Polymerization of a Self-Adhesive Dual-Cured Resin Cement

RM Puppin-Rontani • RG Dinelli • AB de Paula
SBP Fucio • GMB Ambrosano • FM Pascon

Clinical Relevance

Polymerization of a dual-cured resin cement is significantly affected by ceramic thickness but not affected by activation modes. Increased irradiation times could potentially lead to higher hardness values in applications where light is not completely blocked by the overlying restoration.

SUMMARY

The aim of this study was to assess Knoop hardness at different depths of a dual-cured self-adhesive resin cement through different thicknesses of Empress Esthetic® ceramic. Flattened bovine dentin was embedded in resin. The cement was inserted into a rubber mold (0.8 × 5 mm) that was placed between two polyvinyl chloride plastic films and placed over the flat dentin and light cured by Elipar Trilight-QTH (800 mW/cm^2) or Ultra-Lume light-emitting diode (LED 5; 1585 mW/cm^2) over ceramic disks 1.4 or 2 mm thick. The specimens (n=6) were stored for 24 hours before Knoop hardness (KHN) was measured. The data were submitted to analysis of variance in a factorial split-plot design and Tukey's test (α=0.05). There was significant interaction among the study factors. In the groups cured by the QTH unit, an increase in ceramic thickness resulted in reduced cement hardness values at all depths, with the highest values always being found in the center (1.4 mm, 58.1; 2 mm, 50.1) and the lowest values at the bottom (1.4 mm, 23.8; 2 mm, 20.2). When using the LED unit, the hardness values diminished with increased ceramic thickness only on the top (1.4 mm, 51.5; 2 mm, 42.3). In the group with the 1.4-mm-thick disk, the LED curing unit resulted in

*Regina M Puppin-Rontani, DDS, MS, PhD, Piracicaba Dental School, Pediatric Dentistry, Piracicaba, São Paulo, Brazil

Roberto Galvão Dinelli, dentistry student, Piracicaba Dental School, Piracicaba, Brazil

Andréia Bolzan de Paula, PhD student, Piracicaba Dental School, University of Campinas, Dental Materials, Piracicaba, São Paulo, Brazil

Suzana Beatriz P Fucio, DDS, MS, Piracicaba Dental School, Dental Materials, Piracicaba, São Paulo, Brazil

Glaucia Maria Bovi Ambrosano, DDS, MS, PhD, State University of Campinas, Community Dentistry Departament, Piracicaba, São Paulo, Brazil

Fernanda Miori Pascon, DDS, MS, PhD, Piracicaba Dental School, Pediatric Dentistry, Av. Limeira, 901, Piracicaba, Brazil

*Corresponding author: Piracicaba Dental School, Pediatric Dentistry, Av. Limeira, 901, Piracicaba, São Paulo 13414-903, Brazil; e-mail: rmpuppin@fop.unicamp.br

DOI: 10.2341/10-288-L

similar values on the top (51.5) and center (51.9) and lower values on the bottom (24.2). However, when the cement was light cured through the 2-mm disk, the highest hardness value was obtained in the center (51.8), followed by the top (42.3) and bottom (19.9), results similar to those obtained with the QTH curing unit (center > top > bottom). The hardness values of the studied cement at different depths were dependent on the ceramic thickness but not on the light curing units used.

INTRODUCTION

Resin cements have been widely used for cementation of indirect restorations,[1] as they have improved mechanical, physical, and adhesive properties when compared with conventional luting agents.[2] Furthermore, when used for cementing ceramic systems, resin cements increase the fracture strength and stability and show excellent esthetic results.[3,4] However, when this material is inadequately polymerized, clinical problems may arise, such as inadequate biocompatibility,[5] microleakage and recurrent caries,[6] susceptibility to degradation, marginal ditching,[7] discoloration, and reduction of mechanical properties.[8] Therefore, the clinical success, longevity, and biocompatibility of indirect restorations are largely dependent on an appropriate degree of conversion of the resin cement.

Nevertheless, in several clinical situations, the resin composite used for cementation is only partially polymerized, or adequate polymerization is impossible to achieve with visible light. Metal or ceramic restorations or even intraradicular abutments attenuate the transmission of visible light to begin the polymerization reaction of resin cement.[9] They can also interfere in the light spectrum transmitted.[10] In these cases, an appropriate degree of conversion with greater polymerization depth and hardness will be obtained by increasing the time of light exposure[11] or by using dual-cured resin cements with a chemical reaction that would theoretically ensure maximum conversion of monomers. However, any dual-cured resin material used for cementation is dependent on the action of visible light with adequate irradiation to obtain an optimum degree of conversion.[12-14]

A resin cement with dual-cured self-adhesive components, RelyX™ Unicem (3M ESPE, Seefeld, Germany), was introduced in 2002. According to the manufacturer, the cement contains new dimethacrylate monomers and innovative technology for initiating polymerization in an acid medium by exposure to visible light or the mechanism of oxyreduction.[15] However, when this self-adhesive cement was polymerized by the chemical system of oxyreduction alone, a reduced degree of conversion of between 30% and 54% was shown when compared with polymerization performed by visible light and measured in the first minutes after polymerization begins.[14,16] Substantial evidence of chemically induced polymerization after light curing has been confirmed after 24 hours and more intensely after seven days.[17] Other studies conducted with different dual-cured resin cements have shown the need to wait 24 hours before fixed indirect restorations are submitted to masticatory forces when using these types of materials when they have been activated mainly by the chemical system.[18-20]

Until recently, most studies conducted with this self-adhesive cement have analyzed its adhesive properties on different substrates (enamel, dentin, ceramic, and intraradicular abutments, among others).[21-24] Some of the chemical and physical properties were also analyzed,[25,26] and the degree of conversion was assessed by Fourier transform spectrophotometry.[14,16,17] However, those studies did not examine the influence of different light curing units and the interference of ceramic materials in the polymerization efficiency of RelyX™ Unicem.

Therefore, the aim of this study was to investigate the influence of ceramic thickness and light curing units on the dual-cured resin cement RelyX™ U100 polymerization at different depths by means of the Knoop hardness test. It should be remembered that, according to the manufacturer, the only difference between the self-adhesive cements RelyX™ Unicem and RelyX™ U100 is the distribution system. While Unicem requires an activator, triturator, and applicator, U100 can be manipulated manually because of its clicker system.

MATERIALS AND METHODS

Fabrication of Ceramic Disks

Empress Esthetic® covering ceramic (Ivoclar Vivadent, Schaan, Liechtenstein) was used to make two disks measuring 8 mm in diameter and 1.4 mm thick or 2 mm thick in shade ETC2. Metal matrixes were used to make the disks. The ceramic powder was mixed with the modeling liquid on a glass plate using a flexible ceramic spatula (KOTA) until the mixture was homogeneous and a pasty, shiny consistency was obtained. The ceramic was inserted into the matrix with the use of a no. 3 hair paint brush (Ivoclar Vivadent) wet with deionized water. The ceramic condensation process was carried out under vibration, the excess material was removed, and sintering was performed in an EP600 furnace (Ivoclar Vivadent) in accordance with the temperatures recommended by the manufacturer. The ceramic disks were stored in a dry place at room temperature.

Substrate Preparation

To simulate the condition of cementing an indirect restoration using dentin reflectance, a bovine tooth was used. The root was removed using a diamond disk mounted on a bench lathe (Nevone, São Paulo, Brazil), making it possible to remove the coronal pulp tissue with a no. 5 probe (Duflex, São Paulo, Brazil). The incisal and proximal surfaces of the crown remnants were ground using a universal polishing machine APL-4 (Arotec, Cotia, Brazil) with 120- and 200-SiC abrasive paper (Carborundum Saint-Gobain, Recife, Pernambuco, Brazil), in sequence, under water cooling, in order to fit the specimens in the three-quarter-inch polyvinyl chloride (PVC) matrixes. The bovine incisors were embedded in polypropylene resin with the buccal surface facing out, which was ground flat using 200-, 400-, and 600-SiC abrasive papers under water cooling.

Fabrication of Samples

The samples were fabricated from self-adhesive dual-cured resin cement RelyX™ U100 (3M ESPE), which was light cured with either a halogen light appliance (QTH, Elipar Trilight, 3M ESPE) that emitted a light intensity at 800 mW/cm^2 and using a light curing time of 40 seconds or a blue light-emitting diode (LED) fitted with additional ultraviolet lamps (5 Ultralume, Ultradent Products, South Jordan, UT, USA) emitting light intensity at 1585 mW/cm^2 and using a light curing time of 20 seconds. It should be noted that both light curing units produced nearly equivalent light energy (LED = 31.7 J/cm^2 and QTH = 32 J/cm^2).

On the dentin surface, a PVC packaging film (PVC Film, Goodyear do Brasil Produtos de Borracha Ltda, São Paulo, Brazil) was seated, and over this a rubber mold (0.8-mm height and 5-mm diameter) was bulk filled with the cement prepared following the manufacturer's recommendations. Another plastic film was seated over this set, and a ceramic disk of one of the predetermined thicknesses (1.4 or 2 mm) was digitally compressed to promote extrusion and removal of excess material. The PVC films were used to prevent the cement samples from adhering to the substrate and to the ceramic. Next, the cement was light activated with either a QTH or an LED appliance, resulting in cement specimens 800 μm thick. The experimental groups were formed by combinations between the factors of ceramic disk thickness and light curing appliance, totaling four groups with n=6. Figure 1 shows the experimental setup of the study.

After light curing, the samples were stored in a dry oven at 37°C for 24 hours. To measure the Knoop hardness of the cement, a water-cooled diamond disk was used to section the samples longitudinally (Extec model 12205, Extec Corp, Enfield, CT, USA). The cut surface resulting from sectioning was polished under water cooling in a universal polishing machine model APL-4, using 400-, 600-, and 1200-grit silicon carbide abrasive paper for 15, 30, and 60 seconds, respectively.

Knoop Hardness Measurement Data and Statistical Analysis

After polishing, indentations were made on the samples with a microhardness tester model HMV-2 (Shimadzu, Tokyo, Japan). A 50-gf load was applied for 15 seconds. Three equidistant indentations were made at each predetermined depth from the surface, which was in contact with the PVC film closest to the ceramic disk (top, 50 μm; center, 400 μm; bottom, 750 μm) in the center and periphery of the longitudinal section. For each sample, the direction in which the indentations began was inverted so that no region would be favored.

A mean hardness was obtained for each depth in each sample (three measurements). The data were submitted to analysis of variance applied in a split-plot factorial design. The plots represented the light

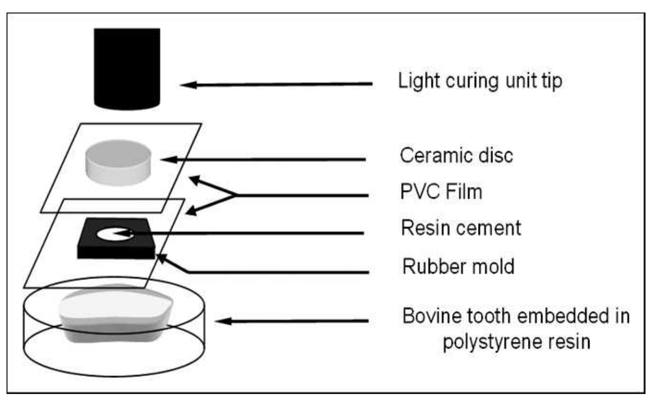

Figure 1. *Schematic representation of specimen preparation.*

Table 1: *Mean Hardness Values (Knoop Hardness Test) of RelyX™ U100 with Regard to the Light Curing Unit, Thickness of the Interposed Ceramic, and Cement Depth Assessed (Standard Deviation)[a]*

Light Curing Unit	Depth	Thickness	
		1.4 mm	2 mm
QTH	Top	42.0 (3.5) Ab	40.6 (5.4) Bb
	Center	58.1 (9.1) Aa	50.1 (5.7) Ba
	Bottom	23.8 (4.4) Ac	20.2 (2.7) Bc
LED	Top	51.5 (7.6) Aa	42.3 (5.5) Bb
	Center	51.9 (4.8) Aa	51.8 (6.6) Aa
	Bottom	24.2 (2.3) Ab	19.9 (3.3) Ac

[a] *Means followed by different letters differ within each light curing unit by analysis of variance and Tukey tests ($p \leq 0.05$); capital letters in the horizontal and lowercase letters in the vertical. There was no significant difference between the curing modes ($p=0.4484$).*

curing unit × ceramic thickness, and subplots represented the measured depths. The level of significance considered was 5%.

RESULTS

The hardness results are shown in Table 1. Statistical analysis showed that the factors "ceramic thickness" ($p=0.0057$) and "measurement depths" ($p<0.0001$) were significant, while the factor "light curing unit" ($p=0.4484$) was not. There was a significant interaction among the three factors ($p=0.0109$). Table 1 shows the result obtained by breaking down the interactions.

In the groups light cured with the halogen lamp, an increase in ceramic thickness reduced the hardness values (KHN) of the cement at all depths, with the highest values always being found in the center (1.4 mm, 58.1; 2 mm, 50.1) and the lowest values at the bottom (1.4 mm, 23.8; 2 mm, 20.2). When the LED appliance was used, an increase in ceramic thickness resulted in diminished hardness values only on the top (1.4 mm, 51.5; 2 mm, 42.3). In the group in which the 1.4-mm disk was used, LED induced similar values at the top (51.5) and center (51.9) and lower values at the bottom (24.2). However, when the 2-mm disk was used, the highest hardness value was obtained in the center (51.8), followed by the top (42.3) and bottom (19.9), results that were similar to those obtained with the halogen light curing unit (center > top > bottom).

DISCUSSION

A hardness test is commonly used as a simple and reliable method for indirectly indicating the degree of conversion of resin cements[6], and the Knoop microhardness test is the most indicated for polymeric materials since the dimensions used as reference for this calculation do not undergo elastic recovery after removing the load.[27] The degree of conversion in a polymerization reaction depends on the energy supplied during light polymerization, characterized by the product of light intensity and exposure time.[11] Additionally, the location of the indentation made in laboratory tests is extremely important since hardness values are usually higher in the center of the material than at its extremities or edges. This can be explained by the fact that, in the center of the material, the free radicals of the monomer are tridimensionally surrounded by possible reactive partners, whereas a free radical located at the extremity of the test specimen will find reactive partners located on only one side of the hypothetical sphere in which the free radical is the center.[28] This study assessed the polymerization depth of an 800-μm film in order to indicate its conversion potential, although the film thickness obtained in accordance with the ISO 9917 specification for RelyX™ Unicem cement was 23.2 μm.[29]

When cured by QTH unit, the 2-mm-thick ceramic disk decreased the hardness values of RelyX™ U100 at all depths studied. The lowest hardness values and, consequently, the lowest degree of conversion are usually attributed to the attenuation of light caused by the distance from curing light tip[30,31] and by the increase in opacity of the material resulting from the increase in thickness of the prosthesis.[8,10,14,19,32] The translucence of ceramics is related to their thickness, microstructure (crystalline content), number of firing cycles carried out in their processing, and the presence of porosities.[33] Empress Esthetic, used in this current study, is a leucite-reinforced vitreous ceramic, with higher translucence, smaller grain size, and more homogeneously distributed leucite crystals than its predecessor, Empress.[34] Pazin and others[32] found that the Empress Esthetic ceramic, at the thicknesses of 1.4 and 2 mm, showed no influence on the emission spectrum of halogen and LED curing units (including the same brands used in this present study), maintaining the peak wavelength of the curing units in the same position in the curve. However, this ceramic was capable of reducing the level of irradiance of a QTH unit to approximately 50% at the same thicknesses as those used in the current study.[35] Further studies are necessary to assess the activation of RelyX™ U100 through other ceramics of different colors and opacities and with the use of other levels of irradiance of light curing appliances.

Regardless, all the test specimens light cured by the halogen light curing unit through 1.4- and 2-mm-thick disks showed higher hardness values in the center region (400 μm) followed by the top (50 μm) and finally the bottom of the material (750 μm). The lower hardness values found in the bottom region may be attributed to two possible causes: 1) the attenuation of incident light, resulting from the absorption and scattering promoted by the ceramic spacer[33] and the organic and inorganic components of the resin cement,[11] and 2) the impossibility of the polymerization reaction continuing because of the increase in viscosity of the resin caused by the initial polymerization and entrapment of radicals and chemical promoters in the polymer network.[36] Thus, development of the polymer network could be affected both by the reduction in the conversion of monomers and by an interference in the type and degree of cross-linking.[37]

In places where the light arrives with less intensity, a lower number of polymer growth centers is generated, and this is unfavorable to the formation of polymer networks that are more densely composed of cross-links.[37] Therefore, lower hardness values in the bottom region of the resin cement could also be related to its lower cross-link density. Thus, debonding of the prosthesis could occur clinically as a result of a cohesive failure of the luting agent.[38] In addition, one must consider that the present study analyzed the hardness values after 24 hours of dry storage, while the setting reactions via oxyreduction and acid base present in RelyX™ Unicem have been shown to be capable of modifying the values of the degree of conversion seven days after light activation.[17] Further investigations are necessary to determine how important the chemical setting of this dual-cured cement in longer periods is with regard to the durability of indirect restorations cemented with RelyX™ U100.

Since the layer inhibited by oxygen usually does not exceed 20 μm,[39,40] it was not a factor with the topmost region evaluated in the current study (50 μm). The intermediate hardness values observed on the top region for QTH curing, compared to the center and bottom regions, could be attributed to the migration of the organic polymer to the top of the luting agent, which occurs because of the compression exerted on the ceramic disk while seating it on the tooth preparation and light activation, promoting a superficial layer rich in resin both in modified ionomer materials and in resin materials.[41] Clinically, one should be concerned about the additional use of light at the restoration margins in order to minimize the oxygen inhibition on the resin cement surface.

When the cement RelyX™ U100 was light cured by a LED light curing unit, one could observe two different situations with regard to the polymerization depth of the cement: 1) the hardness values on the top were similar to those found in the center when light cured through the 1.4 mm thick ceramic disk, and 2) hardness values on the top were dependent on the disk thickness, which does not occur with the center and bottom values. Therefore, the top region of RelyX™ U100 would be more dependent on the level of irradiance during light curing/activation/polymerization by LED. UltraLume LED 5 is a high-powered, third-generation LED (1585 mW/cm^2), with a broader spectrum band than the second-generation LEDs.[32] It is known that high-intensity light emission during the first seconds of light activation causes the rapid formation of the polymer network on the top layer of the composite, characterized by the formation of cross-links,[42] which could increase the hardness values found under the previously mentioned conditions, including values at the top similar to those found in the center. Thus, it is expected that the reduction in mobility of the monomers in the body of the specimens would occur, making polymerization of the center and bottom regions dependent on the additional acid-base setting reactions, that is, the reaction between the metal ions of the vitreous particles of nonsilanized aluminum fluorine silicate and methacrylate phosphate radical.[15]

It is also known that the polymerization reactions via free radical and the acid base present in hybrid materials, such as in resin-modified glass ionomers and even RelyX™ U100, compete with and inhibit one another.[43] This is most likely the reason why the thickness of the ceramic disk did not influence the hardness values of the center and bottom regions when light cured by the LED curing unit in this current study. Therefore, an increase in light intensity could improve the polymerization efficiency of the luting agent and shorten the irradiation time, contributing to patient comfort and reducing clinical time for professionals. The additional polymerization reactions present in RelyX™ U100 will occur slowly, but they will contribute to the formation of a polymer network with a high molecular weight.[15] Therefore, the patient must be instructed to take care when exerting masticatory effort in the first 24 hours (or even seven days)[17] after prostheses have been cemented with this cement.

CONCLUSIONS

Based on the results of the present study and considering its limitations, it was concluded that the thickness of the ceramic restoration negatively influenced the polymerization of the self-adhesive cement RelyX™ U100 when cured by QTH at all analyzed depths. However, only the top region of the specimens cured by the LED unit was affected by the ceramic thickness.

(Accepted 17 August 2011)

REFERENCES

1. El-Mowafy O (2001) The use of resin cements in restorative dentistry to overcome retention problems *Journal of the Canadian Dental Association* **67(2)** 97-102.
2. Atta N, Tam LE, & McComb D (2004) Mechanical and physical properties of contemporary dental luting agents *Journal of Prosthetic Dentistry* **89(2)** 127-134.
3. Burke FJ (1995) The effect of variations in bonding procedure on fracture resistance of dentin-bonded all-ceramic crowns *Quintessence International* **26(4)** 293-300.
4. Blatz MB (2002) Long-term clinical success of all-ceramic posterior restorations *Quintessence International* **33(6)** 415-426.
5. Ergun G, Egilmez F, & Yilmaz S (2011) Effect of reduced exposure times on the cytotoxicity of resin luting cements cured by high-power led *Journal of Applied Oral Science* **19(3)** 286-292.
6. Darr AH, & Jacobsen PH (1995) Conversion of dual cure luting cements *Journal of Oral Rehabilitation* **22(1)** 43-47.
7. Van Meerbeek B, Inokoshi S, Willems G, Noack MJ, Braem M, Lambrechts P, Roulet JF, & Vanherle G (1992) Marginal adaptation of four tooth-coloured inlay systems in vivo *Journal of Dentistry* **20(1)** 18-26.
8. Uctasli S, Hasanreisoglu U, & Wilson HJ (1994) The attenuation of radiation by porcelain and its effect on polymerization of resin cements *Journal of Oral Rehabilitation* **21(5)** 565-575.
9. Asmussen E, & Peutzfeldt A (2006) Bonding of dual-curing resin cements to dentin *Journal of Adhesive Dentistry* **8(5)** 299-304.
10. Linden JJ, Swift EJ Jr, Boyer DB, & Davis BK (1991) Photo-activation of resin cements through porcelain veneers *Journal of Dental Research* **70(2)** 154-157.
11. Rueggeberg FA, Caughman WF, & Curtis JW (1994) Effect of light intensity and exposure duration on cure of resin composite *Operative Dentistry* **19(1)** 26-32.
12. Tarle Z, Knezevic A, Demoli N, Meniga A, Sutaloa J, Unterbrink G, Ristic M, & Pichler G (2006) Comparison of composite curing parameters: Effects of light source and curing mode on conversion, temperature rise and polymerization shrinkage *Operative Dentistry* **31(2)** 219-226.
13. El-Bradawy WA, & El-Mowafy OM (1995) Chemical versus dual curing of resin inlay cements *Journal of Prosthetic Dentistry* **73(6)** 515-524.
14. Tezvergil-Mutluay A, Lassila LV, & Vallittu PK (2007) Degree of conversion of dual-cure luting resins light-polymerized through various materials *Acta Odontologica Scandinavica* **65(4)** 201-205.
15. 3M ESPE US (2010) RelyX™ Unicem – Self-Adhesive Universal Resin Cement. Technical Product Profile Retrieved online July 10, 2010 from: http://multimedia.mmm.com/mws/mediawebserver.dyn?6666660Zjcf6lVs6EVs66S3IACOrrrrQ-
16. Vrochari AD, Eliades G, Hellwig E, & Wrbas KT (2009) Curing efficiency of four self-etching, self-adhesive resin cements *Dental Materials* **25(9)** 1104-1108.
17. Bandéca MC, El-Mowafy O, Saade EG, Rastelli ANS, Bagnato VS, & Porto-Neto ST (2009) Changes on degree of conversion of dual-cure luting light-cured with blue LED *Laser Physics* **19(5)** 1050-1055.
18. Burrow MF, Nikaido T, Satoh M, & Tagami J (1996) Early bonding of resin cements to dentin – effect of bonding environment *Operative Dentistry* **21(5)** 196-202.
19. Borges GA, Agarwal P, Miranzi BAS, Platt JA, Valentino TA, & Santos PH (2008) Influence of different ceramics on resin cement Knoop hardness number *Operative Dentistry* **33(6)** 622-628.
20. Reges RV, Moraes RR, Correr AB, Sinhoreti MA, Correr-Sobrinho L, Piva E, & Nouer PR (2008) In-depth polymerization of dual-cured resin cement assessed by hardness *Journal of Biomaterials Application* **23(1)** 85-96.
21. Duarte S Jr, Botta AC, Meire M, & Sadan A (2008) Microtensile bond strengths and scanning electron microscopic evaluation of self-adhesive and self-etch resin cements to intact and etched enamel *Journal of Prosthetic Dentistry* **100(3)** 203-210.
22. Hiraishi N, Yiu CK, King NM, & Tay FR (2009) Effect of 2% chlorhexidine on dentin microtensile bond strengths and nanoleakage of luting cements *Journal of Dentistry* **37(6)** 440-448.
23. de Oyagüe RC, Monticelli F, Toledano M, Osorio E, Ferrari M, & Osorio R (2005) Influence of surface treatments and resin cement selection on bonding to densely-sintered zirconium-oxide ceramic *Dental Materials* **25(2)** 72-79.
24. Giachetti L, Grandini S, Calamai P, Fantini G, & Scaminaci Russo D (2009) Translucent fiber post cementation using light- and dual-curing adhesive techniques and a self-adhesive material: Push-out test *Journal of Dentistry* **37(8)** 638-642.
25. Kumbuloglu O, Lassila LV, User A, & Vallittu PK (2004) A study of the physical and chemical properties of four resin composite luting cements *International Journal of Prosthodontics* **17(3)** 357-363.

26. Gerth HU, Dammaschke T, Züchner H, & Schäfer E (2006) Chemical analysis and bonding reaction of RelyX Unicem and Bifix composites—A comparative study *Dental Materials* **22(10)** 934-941.

27. Anusavice KJ (2007) *Philips, Materiais Dentários* 11th edition. Elsevier, Rio de Janeiro.

28. Hofmann N, Papsthart G, Hugo B, & Klaiber B (2001) Comparison of photo-activation versus chemical or dual-curing of resin-based luting cements regarding flexural strength, modulus and surface hardness *Journal of Oral Rehabilitation* **28(11)** 1022-1028.

29. Han L, Okamoto A, Fukushima M, & Okiji T (2007) Evaluation of physical properties and surface degradation of self-adhesive resin cements *Dental Materials* **26(6)** 906-914.

30. Felix CA, & Price RB (2003) The effect of distance from light source on light intensity from curing lights *Journal of Adhesive Dentistry* **5(4)** 283-291.

31. Dunne SM, & Millar BJ (2008) Effect of distance from curing light tip to restoration surface on depth of cure of composite resin *Primary Dental Care: Journal of the Faculty of General Dental Practitioners* **15(4)** 147-152.

32. Pazin MC, Moraes RR, Gonçalves LS, Borges GA, Sinhoreti MA, & Correr-Sobrinho L (2008) Effects of ceramic thickness and curing unit on light transmission through leucite-reinforced material and polymerization of dual-cured luting agent *Journal of Oral Science* **50(2)** 131-136.

33. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, & Vargas MA (2002) Relative translucency of six all-ceramic systems. Part II: Core and veneer materials *Journal of Prosthetic Dentistry* **88(1)** 10-15.

34. Bühler-Zemp P (2004) IPS Empress Esthetic scientific documentation. Ivoclar Vivadent AG, Schaan 3-5.

35. Moraes RR, Brandt WC, Naves LZ, Correr-Sobrinho L, & Piva E (2008) Light- and time-dependent polymerization of dual-cured resin luting agent *Acta Odontologica Scandinavica* **66(5)** 257-261.

36. Rueggeberg FA, & Caughman WF (1993) The influence of light exposure on polymerization of dual-cure resin cements *Operative Dentistry* **18(2)** 48-55.

37. Schneider LF, Moraes RR, Cavalcante LM, Sinhoreti MA, Correr-Sobrinho L, & Consani S (2008) Cross-link density evaluation through softening tests: Effect of ethanol concentration *Dental Materials* **24(2)** 199-203.

38. Vaz RR (2008) Bond strength and interface morphology of dual-cure, auto-cure and self-adhesive resin cement to dentin. Thesis (Phd in Dental Materials). Piracicaba Dental School, University of Campinas, Piracicaba, SP 80p.

39. Manabe A, Kanehira M, Finger WJ, Hisamitsu H, & Komatsu M (2009) Effects of opacity and oxygen inhibition of coating resin composites on bond strength to enamel *Dental Materials* **28(5)** 552-557.

40. Shawkat ES, Shortall AC, Addison O, & Palin WM (2009) Oxygen inhibition and incremental layer bond strengths of resin composites *Dental Materials* **25(11)** 1338-1346.

41. Carlén A, Nikdel K, Wennerberg A, Holmberg K, & Olsson J (2001) Surface characteristics and in vitro biofilm formation on glass ionomer and composite resin *Biomaterials* **22(5)** 481-487.

42. Soh MS, & Yap AU (2004) Influence of curing modes on crosslink density in polymer structures *Journal of Dentistry* **32(4)** 321-326.

43. Berzins DW, Abey S, Costache MC, Wilkie CA, & Roberts HW (2010) Resin-modified glass-ionomer setting reaction competition *Journal of Dental Research* **89(1)** 82-86.