Chemical and Physical Evaluation of the Luting Systems for Veneers Submitted to Accelerated Artificial Aging

Lucia Trazzi Prieto[1], Cíntia Tereza Pimenta de Araújo[2], Josué Junior Araújo Pierote[1], João Victor Frazão Câmara[3]*, Isabel Ferreira Barbosa[1], Laura Nobre Ferraz[1], Amanda de Oliveira Pinto Ribeiro[4], Letícia Meinberg Pedrosa[5], Guilherme da Rocha Scalzer Lopes[4], Guereth Alexsanderson Oliveira Carvalho[6], Ericles Otávio Santos[7], Daniela Luzimar Claudino[8], Renato Feres de Carvalho Vianna[8], Hana Fried[8], Justine Monteiro Monnerat Tinoco[8], Amara Eulalia Chagas Santos[8], Gisele Damiana da Silveira Pereira[8], Luís Alexandre Maffei Sartini Paulillo[1], Flávio Henrique Baggio Aguiar[1]

1. Department of Restorative Dentistry, Piracicaba Dental School, State University of Campinas, Piracicaba, SP, Brazil.
2. Department of Dentistry, Faculty of Sciences of Health, Federal University of Jequitinhonha and Mucuri Valley, Diamantina, MG, Brazil.
3.Department of Biological Sciences, Bauru School of Dentistry, University of São Paulo, Bauru, SP, Brazil.
4. Department of Dental Materials and Prosthesis, Paulista State University, São José dos Campos, SP, Brazil.
5. Alberto Luiz Coimbra Institute for Graduate Studies and Engineering Research, Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil.
6. Department of Dental Clinic, Federal University of Piauí, Teresina, PI, Brazil.
7. Department of Pediatric Dentistry and Orthodontics, Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil.
8. Department of Dental Clinic, Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil.

Abstract

To evaluate the effect of accelerated artificial aging (AAA) on chemical and physical properties of four different resin cements and two flowable resins.

Forty-eight human incisors were prepared and the IPS Empress Esthetic laminate veneers were fabricated. The samples were randomly divided into the groups: dual-polymerizing cements (RelyX ARC and Variolink II), light-polymerizing cements (RelyX Veneer and Variolink Veneer) or flowable composite resins (Filtek Z350 Flow and Tetric N-Flow). The degree of conversion was determined in a Fourier transform infrared spectroscopy. The first cylinder was measuring the initial bond strength and, the remaining cylinder was submitted to AAA before bond strength test. The fracture pattern was analyzed by stereomicroscopy. The results were analyzed by one-way and two-way split-spot ANOVA/ Tukey's test (α =0.05).

There were clinically perceptible color changes for all materials. The degree of conversion, the following decreasing sequence was found: RelyX ARC> Variolink II> RelyX Veneer > Filtek Z350 Flow > Variolink Veneer = Tetric N-Flow. For the microshear bond strength, RelyX ARC = Variolink II > Variolink Veneer = RelyX Veneer > flowable composite resins.

AAA induced color change and decreased microshear bond strength for all luting systems evaluated.

Clinical article (J Int Dent Med Res 2020; 13(3): 1013-1020)
Keywords: Dental veneers, Resin cements, Aging, Color.
Received date: 15 June 2020 **Accept date:** 07 July 2020

Introduction

The characteristics of ceramic laminate veneers, such as preservation of dental structure, superior translucency,[1,2] color stability, clinical longevity and superficial texture, make them an excellent choice for aesthetic restorative treatments.[3] With the evolution of adhesive dentistry, resin-luting strategies have been widely used to bond these indirect restorations to tooth structure.[4]

The color stability of these luting agents can be influenced by a variety of extrinsic and intrinsic factors.[5] The extrinsic factors correspond to the absorption of stain from exogenous sources related to hygiene habits, smoking and diet.[6] The intrinsic factors involve alterations in the percentage of unreacted double bonds,

Corresponding author:
João Victor Frazão Câmara,
Alameda Doutor Octávio Pinheiro Brisolla, 6-65, CEP 17012-059, Bauru, São Paulo, Brazil.
E-mail: jvfrazao92@hotmail.com

composition of monomers used in the resin matrix and the type of photo-initiator system.[7]

Camphorquinone is the most commonly photo-initiator used for light- polymerized resin cements.[8] Although used in very small concentration (0.03-0.1 wt%), the camphorquinone influences significantly the material's color.[9] Other very important components of photo-initiator systems are tertiary aromatic or aliphatic amines,[10] which act as so-called co-initiators or accelerators. These accelerators are present in chemically activated systems such as dual- polymerized and auto-polymerized resin cements.

These amines are mainly responsible to form products during photoreaction process, which can cause yellow, red or brown discolorations under the influence of light or heat[10]. When color change becomes visible, it affects the aesthetic appearance of indirect restorations.[11]

The luting agents available for ceramic restorations can be dual-, light-, or auto-polymerizing resin cement. The color instability observed in dual- polymerized cements is due to the aromatic tertiary amine, which reacts with the benzoyl peroxide initiator in the catalyst, causes discoloration during polymerization, furthermore presents desirable characteristics of light-and chemically polymerized resin cements[12] as longer working time and effective polymerization.[13] The light- polymerized resin cement has better color stability and longer working time compared to chemically and dual-polymerized resin cements,[13] and the disadvantage of less effective polymerization. In order to take advantage of the properties of light-polymerized composite resins and the greater cost-effectiveness compared to the resin cements[14] some authors have started testing flowable resin composites to lute ceramic veneers.[14]

Clinical studies assessing the long-term behavior of flowable composite are very difficult. As it is impossible to standardize the oral conditions which hinders the prediction of durability and the comparison of dentals materials.[15] Laboratory aging methods have been standardized to facilities the comparisons among researches carried out by different authors.[16] Artificially accelerated aging methods may help predict the degradation of the materials in a short period that would otherwise take months or even years of use in the oral cavity.[17] Thus, it becomes relevant to investigate the color stability and chemical and physical properties of different flowable resin composites compared to resin cements in order to verify its effectiveness. The purpose of this study was to evaluate the color stability, the microshear bond strength and the degree of conversion of two dual- polymerized resin cements, two light- polymerized resin cements and two flowable resin composites submitted to accelerated artificial aging.

The hypothesis was that flowable resin composite wouldn't provide similar behavior to light- polymerized and dual- polymerized cements regarding color stability, microshear bond strength and degree of conversion.

Materials and methods

Ethics committee

The study protocol was approved - number 078/2012 by the review board of Ethics at Piracicaba Dental School- University of Campinas. Laminate veneers of shade ET1 were prepared using ceramic (IPS Empress Esthetic; Ivoclar Vivadent) and luting with six different luting systems in this study (Table 1).

Product	Material	Manufacturer	Shade	Composition*
RelyX ARC	Dual-polymerized resin cement	3M-ESPE St. Paul, MN, USA	A3	**Paste A**: - silane treated ceramic (60-70%), -TEGDMA (10-20%), -Bis-GMA (10-20%), -Silane treated silica (1-10%), - Functionalized dimethacrylate polymer (1-10%), - Triphenylantimony (<0,2%). **Paste B**: - silane treated ceramic (55-65%),-TEGDMA (10-20%),-Bis-GMA (10-20%), - Silane treated silica (1-10%), - Functionalized dimethacrylate polymer(1-10%), -2-benzotriazolyl-4-methylphenol(<1%),-Benzoyl peroxide <1%.
Variolink II	Dual-polymerized resin cement	Ivoclar Vivadent, Schaan, Liechtenstein	A3	**Base**: -Bis-GMA (10-25%), -Urethane dimethacrylate (2,5-10%), -Triethyleneglycol dimethacrylate (2,5-10%). **Catalyst**: -Bis-GMA (50-100%),-Urethane dimethacrylate (3<10%), -Triethyleneglycol dimethacrylate (3<10%), -Dizenzoyl peroxide (≤2,5%).
RelyX Veneer	Light-polymerized resin cement	3M-ESPE St. Paul, MN, USA	A3	Silane treated ceramic (55-65%), -TEGDMA (10-20%), -Bis-GMA (10-20%), -Silane treated silica (1-10%), -Funcionalized dimethacrylate polymer (<5%), -EDMAB (<0,5%), -Benzotriazol (<0,5%), -Diphenyliodonium hexafluorophospate (<0,5%), -Triphenylantimony (<0,2%).
Variolink Veneer	Light-polymerized resin cement	Ivoclar Vivadent, Schaan, Liechtenstein	High Value +3	-Urethane dimethacrylate (25-50%), -Decamethylane dimethacrylate (2,5-10%), -inorganic fillers (silica, barium glass, ytterbium trifluoride), catalyst and stabilizers, pigments.
Filtek Z350 XT Flow	Flowable composite	3M-ESPE St. Paul, MN, USA	A3	-Silane treated ceramic (50-60%), -Substituted dimethacrylate (15-25%), -Bis-GMA (5-10%), -Silane treated silica (5-10%), -TEGDMA (5-10%), -Ytterbium fluoride (<5%), -Funcionalized dimethacrylate polymer (<5%), -Titanium dioxide (<0,5%), - EDMAB (<0,5%), - Benzotriazol (<0,5%), -Diphenyliodonium hexafluorophospate (<0,5%).
Tetric N-Flow	Flowable composite	Ivoclar Vivadent, Schaan, Liechtenstein	A3	-Bis-GMA (27,8%), -Triethyleneglycol dimethacrylate (7,3%), -Barium glass, ytterbium trifluoride, mixed oxide, silicon dioxide (63,8%), -Additives, stabilizers, catalysts, pigments (1,1%).

Table 1. Name, materials type, manufacturers, shade and composition of tested materials.

Preparation of samples

Forty-eight non-carious, sound human maxillary incisors teeth extracted for orthodontics reasons were used in this in vitro study. After removal of calculus and dental plaque, the teeth were stored in 0.2 % thymol solution at 4°C until the preparation for the study. Human teeth presented varied dimensions, for these reason all teeth were measured and that present different sizes were divided among the experimental groups to show homogeneity. Depth cuts are obtained with diamond bur #2135 (KG Sorensen) under water cooling in a cavity preparation machine for the standardization preparations, providing a 0.5mm deep groove in the cervical third, a 0.6 mm deep groove in the middle third, and 0.6 mm for incisal third. Care should be taken to keep the tooth reduction inside the thickness of the enamel. The margins were beveled to have finish lines at the teeth levels without over contouring. The diamond bur was discarded after each 5 preparations.

Every angle of the preparation should be rounded, finished and polished. Single operator prepared all the teeth used in this study. A final was made using a 2- step impression techniques using Express XT (3M ESPE) and sent to the lab.

Ceramic veneer surfaces preparation and groups treatments

A total of forty-eight ceramics laminate veneers were fabricated from leucite glass-ceramic ingots (IPS Empress Esthetic; Ivoclair Vivadent) in ET1 shade, with 0.6 mm thickness, according to the manufacturer's recommendations.

All ceramic veneer surfaces were prepared with 5% hydrofluoric acid (FGM; Dental Materials) in gel, applied for 20 seconds and, washed thoroughly with water and gently dried with oil free air. In all ceramics veneers surface, a monocomponent silane (RelyX Ceramic Primer; 3M ESPE) was applied for 1 min and thorough scattered with air. The teeth specimens were randomly divided into six experimental groups (n=8) according to the different luting systems evaluated: G1- (SB/RVE) Single Bond 2/RelyX Veneer (3M ESPE); G2- (SB/ARC) Single Bond 2/RelyX ARC (3M ESPE); G3- (SB/FFL) Single Bond 2/Filtek Z350 XT Flow (3M ESPE); G4- (TB/VVE) Tetric N-Bond/Variolink Veneer (Ivoclar-Vivadent); G5- (TB/VAR) Tetric N-Bond/Variolink II (Ivoclar-Vivadent); G6- (TB/TFL) Tetric N-Bond/Tetric N-Flow (Ivoclar-Vivadent).

The prepared teeth were acid-etched with 37% phosphoric acid (Scotchbond Etchant; 3M ESPE) for 15 seconds, rinsed and dried. The adhesive system was applied to the tooth surface after the luting systems were manipulated according to the manufacturer's instructions for both (Table 2). Light-polymerizing cement and flowable resin were directly applied to the surface of the ceramic, while the dual- polymerizing cement was mixed before application. The luting systems was light- polymerized thorough the ceramic surface for 40 seconds using a visible light (Demetron LC; SDS Kerr). The light irradiance was measured with a radiometer and confirmed for all groups at 800 mW/cm^2. All the test specimens were stored in isolated receptacles at 37°C under high-humidity and kept in the absence of light for 24 hours before color analysis.

Luting Systems	Procedures for cementing
Single Bond 2/ RelyX Veneer **(G1)**	1-Acid etching of enamel with 37% phosphoric acid (15s) and washing with distilled water for 15s; 2-Application of two consecutives layer of adhesive system on enamel; 3-Mild air stream; 4-Resin cement application in ceramic surface and enamel; 5-Light curing for 40 s.
Single Bond 2/ RelyX ARC **(G2)**	1-Acid etching of enamel with 37% phosphoric acid (15s) and washing with distilled water for 15s; 2-Application of two consecutives layer of adhesive system on enamel; 3-Mild air stream; 4-Mix of the resin cement (10s); 5-Cement application in ceramic surface and enamel; 6-Light curing for 40 s.
Single Bond 2/ Filtek Z350 XT Flowable **(G3)**	1-Acid etching of enamel with 37% phosphoric acid (15s) and washing with distilled water for 15s; 2-Application of two consecutives layer of adhesive system on enamel; 3-Mild air stream; 4-Application of the flowable resin composite; 5- Light curing for 40 s.
Tetric N-Bond/ Variolink Veneer **(G4)**	1-Acid etching of enamel with 37% phosphoric acid (15s) and washing with distilled water for 15s; 2-Application of two consecutives layer of adhesive system on enamel; 3- mild air stream; 4-Resin cement application in ceramic surface and enamel; 5-Light curing for 40 s.
Tetric N-Bond/ Variolink II **(G5)**	1-Acid etching of enamel with 37% phosphoric acid (15s) and washing with distilled water for 15s; 2-Application of two consecutives layer of adhesive system on enamel; 3-mild air stream; 4-Mix of the resin cement pastes (base+catalyst for 15s); 5- Resin cement application in ceramic surface and enamel; 6-Light curing for 40 s.
Tetric N-Bond/ Tetric N-Flow **(G6)**	1-Acid etching of enamel with 37% phosphoric acid (15s) and washing with distilled water for 15s; 2-Application of two consecutives layer of adhesive system; 3- mild air stream; 4-Application of the flowable resin composite;5- Light curing for 40 s.

Table 2. Procedures for cementing systems adhesion.

Initial color measurements were recorded using a spectrophotometer (Easyshade; VITA). Before measuring the color of the specimens, the device was calibrated using a calibration block, according to the manufacturer's instructions (Vita Easyshade Manual). Measurements were recorded under standard illumination (MM-1eUV/D65).

Individualized silicone guides with a central window were positioned on the buccal surface of the incisors to standardize the initial and final positions for the color evaluation.

Color measurements

Were defined according to the CIE L*a*b system (Commission Internationale de l'Éclairage). The CIELAB system is an approximately uniform color space with coordinates for lightness, namely, white/black (L*), red/green (a*) and yellow/blue (b*).[18]

After the initial color measurement, all specimens were subjected to aging using the EQUV UV- accelerated aging chamber (Equilam Ind Com Ltda). The AAA (Accelerated Artificial Aging System) process consisted of a total of 300h (UV-B irradiation, with a 313 nm emission peak), alternating periods of ultra-violet light (4 hours) and water condensation (4 hours), under 50°C heat and 100% humidity.[19]

After the aging process, follow up color measurements were performed using similar conditions. The color stability (ΔE) were determined using the coordinates L*, a* and b*, by using formula: $\Delta E= \sqrt{}\ (L_F{*}-L_i{*})^2 + (a_F{*}-a_i{*})^2 + (b_F{*}-b_i{*})^{1/2}$. Values of ΔE below 3,5 were considered clinically acceptable.[20]

Microshear bond strength test

Another forty-eight non-carious, sound human maxillary incisors teeth extracted for orthodontics reasons were selected. After removal of calculus and dental plaque, the teeth were stored in 0.2 % thymol solution at 4°C until the preparation for the study. The buccal surfaces were machine ground (APL-4; Arotec), with #320 and #600 grit abrasive paper, under water irrigation to ensure a uniform flat enamel surface of 6mm^2. These teeth were observed using a stereomicroscope (Leica Microsystems) at 25x magnification to guarantee enamel integrity.

Ninety-six leucite glass-ceramic cylinders (IPS Empress Esthetic; Ivoclair Vivadent) in ET1 shade were obtained (1mm in diameter x 2mm thick). The ceramic cylinders were submitted to surface treatment with 5% hydrofluoridric acid (FGM; Dental Materials) for 20 seconds. The acid was removed with air/water spray, after drying the specimens, a layer of silane coupling agent (RelyX Ceramic Primer; 3M ESPE) was applied and left to react for 60 s.

The ceramic cylinders were randomly divided into six experimental groups (n=8), according to the resin luting systems evaluated, as previous described in Table 2. A previously perforated, double-faced adhesive tape (having circular perforations measuring the same as the ceramic cylinders to be built) was placed on each tooth surface in order to delineate the ceramic luting area (0,78 mm^2, two cylinders per teeth surface). The cylinders were positioned in parallel over the leucite glass surface, and fixed with the luting systems. The specimens were by using the Demetron LC (SDS Kerr) unit at 800 mW/cm^2 output for 40 seconds. All specimens were stored on distilled water at 37C for 24 hours, after the storage, one of the cylinders were attached on the platen of a universal testing machine (EZ-Test; Shimadzu Corp.) to perform microshear bond strength at a crosshead speed of 0.5mm/min. The resulting bond strength was calculated and expressed in MegaPascal (MPa = Maximum load (N)/Bonding surface area of the resin cement -mm^2). The remaining ceramic cylinder was submitted to aging before bond strength test.

Visual analyses of the fractured surfaces were performed using a stereomicroscope at 40x magnification (SMZ-10, Nikon), fracture classification was assigned using the following criteria: A- adhesive failure; B- ceramic cohesive; C- mixed failure, a mixture of different kinds of fractures within the same specimen.

Degree of conversion test

For the measurement of absorption spectrums for uncured resin cement, the light-polymerized material was put into circular matrix and covered by polyester matrix between two glass plates (n=10). For the dual activation mode, the catalyst and base of dual- polymerized materials were mixed according to the manufacture's instructions; the material was put into circular matrix and covered by polyester matrix between two glass plates. The readout of each uncured material was recorded in absorbance spectrum acquired by scanning the specimens 32 times with a resolution of 4cm^{-1} over a range from 1590 to 1660cm^{-1} band. After the IR spectral scans, a ceramic disk was placed over the polyester matrix. All materials were light-polymerized through the ceramic disks using a halogen light-curing unit Demetron LC (SDS

Kerr) at 800mW/cm^2 output for 40 seconds. Specimens were stored at 37°C, 100% relative humidity for 24 hours. The absorption spectrums for polymerized material were obtained as describe above (n=10).

Remaining unconverted double bonds were calculated using the standard method for monitoring the change in the ratio of aliphatic C = C absorption at 1638 cm^{-1} to aromatic carbon-carbon absorption at 1608cm^{-1} between polymerized and uncured specimens according to the following equation: DC= 100 x [1- (C/U)], where C and U are reasons of intensity between aliphatic and aromatic C = C absorptions, after and before the polymerization, respectively. The percentage of carbonic double linking that did not react during the polymerization reaction is determined. The DC is determined by the subtraction of the residual percentage of aliphatic C = C from 100%.

Statistical analysis

Color stability and degree of conversion values were performed using one-way analysis of variance (ANOVA). The microshear bond strength data were subjected to two-way split-spot ANOVA. Tukey *post hoc* tests were performed to determine differences among groups. Statistical significance level was 5%.

Results

Color stability

The mean color stability and standard derivation obtained for the luting systems are shown in the table 3. Significant differences were observed among the groups (α =0,4494). The materials had various ranges of color change after the aging for all the systems. The dual cements showed the highest values of color change follow by the light-cured materials and the lowest color change were presented by flowable resin composites. The ΔE data were analyzed in accordance with clinical color tolerance criteria, which allow clinicians to interpret color differences with the aid of detailed descriptions: 0= perfect; 0,5 to 1= excellent; 1 to 2=good; 2 to 3,5= clinically acceptable; ≥ 3.5[20] were considered clinically unacceptable because were detectable by the human eye.[21]

Microshear bond strength

The ANOVA showed significant differences for the factors "luting systems" (α ≤ 0.0001) and "artificial aging" (α ≤ 0.0001); the interaction between these factors was not significant (α = 0.8687). The results of the Tukey test are presented in Tables 4 and 5 respectively. All luting systems evaluated in this study showed no difference statistically in enamel bond strength means. Accelerated artificial aging decreased the bond strength values for all luting systems tested.

Luting Systems	N	Means (SD)/Tukey*
Tetric N-Bond/Variolink Veneer	8	9.338 (3.504)ᵃ
Single Bond 2/RelyX ARC	8	8.313 (3.622)ᵃ
Tetric N-Bond /Tetric N-Flow	8	7.875 (2.763)ᵃ
Tetric N-Bond /Variolink II	8	7.438 (2.644)ᵃ
Single Bond 2/RelyX Veneer	8	6.863 (3.052)ᵃ
Single Bond 2/Filtek Z350 XT Flowable	8	6.113 (3.779)ᵃ

Table 3. Mean±SD color change (ΔE) values for all groups.
*Means followed by different letters represent statistically significantly difference (α<0.05).

Luting Systems	N	Means (SD)/Tukey*
Single Bond 2/RelyX ARC	16	32.9 (7.6)ᵃ
Tetric N-Bond /Variolink II	16	28.5 (6.7)ᵃ
Tetric N-Bond/Variolink Veneer	16	18.5 (5.5)ᵇ
Single Bond 2/RelyX Veneer	16	18.1 (4.8)ᵇ
Single Bond 2/Filtek Z350 XT Flowable	16	12.1 (3.0)ᶜ
Tetric N-Bond /Tetric N-Flow	16	10.0 (1.6)ᶜ

Table 4. Mean microshear bond strength values and standard derivation in MPa for experimental groups.
*Means followed by different letters represent statistically significantly difference (α<0.05).

Different types of fractured surface of each group are revealed in figure 1. According to the data, mainly adhesive failures are presented in SB/RVE, TB/VVE, SB/FFL and TB/TFL groups and mainly cohesive failure in ceramic occurs in SB/ARC and TB/VAR groups.

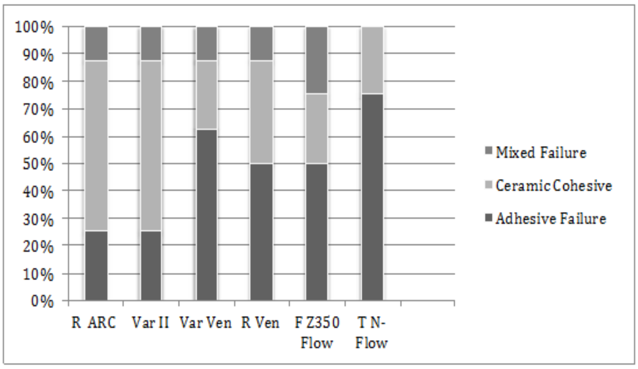

Figure 1. Fracture patterns (%) of tested materials.

Aging Test	N	Means (SD)/Tukey
Without Aging test	48	22.1[a]
With Aging test	48	18.0[b]

Table 5. Mean microshear bond strength after artificial aging independently of luting systems.
*Means followed by different letters represent statistically significantly difference (α<0.05).

Degree of conversion

The mean degree of conversion (%) obtained for the evaluated groups are presented in table 6. Significant differences were observed among the luting materials tested. The RelyX ARC showed highest DC values. Variolink II, RelyX Veneer and Filtek Z350 XT Flowable presented intermediate values with difference statistically between each other. The Variolink Veneer resin cement and Tetric N-Flow flowable resin showed the statistically significantly lowest degree of conversion means when compared with the others materials.

Luting Systems	N	Means (SD)/Tukey*
Relyx ARC	10	81.20% (4.38)[a]
Variolink II	10	59.99% (1.37)[b]
Relyx Veneer	10	54.00% (1.82)[c]
Filtek Z350 XT Flowable	10	51.70% (2.39)[d]
Variolink Veneer	10	49.04% (1.26)[e]
Tetric N-Flow	10	48.70% (0.93)[e]

Table 6. Mean degree of conversion (%) and standard deviation for evaluated materials.
*Means followed by different letters represent statistically significantly difference (α<0.05).

Discussion

In the present study, the color stability and microshear bond strength of flowable composite resin proved to have inferior behavior to the resin cements. The hypothesis, that the flowable resin composite wouldnt provide similar behavior to light-polymerized and dual-polymerized cements regarding color stability, microshear bond strength and degree of conversion, was accepted. Except in degree of conversion, flowable resin exhibited similar results to light- polymerized resin cement.

All the tested resin materials during the study showed the color changes to varying degree after accelerated artificial aging. The color change of resin materials induced by UV irradiation has been related to factors like chemical alterations in the activators, initiator systems, and the resin cement composition itself. Degradation of residual amine, and oxidation of residual unreacted carbon-carbon double bonds also result in the changes in color.[22] The color changes are also attributed to the properties of the resin matrix and filler concentration. The presence of UDMA can contribute to a reduction in the concentration of TEGDMA, which is the monomer that release higher quantities of monomers into aqueous environments,[23] added to this is the monomer responsible for higher rates of water sorption in resin-based materials due to its hydrophilic ether linkages.[24] If the matrix is hydrophilic, increased water sorption occurs, resulting in a more white and opaque shade.[25] The replacement of TEGDMA for UDMA may improve color stability.[20] Compared with BIS-GMA, UDMA appears to be less susceptible to staining.[26]

RelyX ARC and RelyX Veneer contains BIS-GMA and TEGDMA, Variolink II is composed of BIS-GMA, TEGDMA and UDMA, Variolink Veneer contains UDMA and decamethylene dimethacrylate, Tetric N-Flow contains BIS-GMA and TEGDMA and Filtek Z350 XT Flow is basically composed of BIS-GMA, TEGDMA and BIS-EMA. The results showed that the monomers contained in the resin matrix might not influence in the staining.

The mean color changes observed among all the materials tested were ΔE 6.11 to 9.33, higher than 3.5 were considerable perceptible and clinically unacceptable based on previous reports.[27,28,29]

Previously researches have found better color stability of the light polymerized cements as Variolink Venner and RelyX Veneer. The aliphatic anime are used as initiators in light polymerized resin cements.[22] The aromatic tertiary amines have more tendencies for oxidation than the aliphatic amines. Hence, the light polymerized materials are expected to have better color stability. However, in this study, the ΔE value for the light- polymerized cements was similar when compared to the others tested cements.

The degree of conversion of a resin material depends on factors such as the chemical structure of the monomers, the curing conditions, including light intensity and photo-initiator concentration.[30] The light exposure that reaches dual- polymerized cements is an extremely important factor to ensure an effective polymerization;[29] they have a chemical activator to complete the reaction.[13] The dual- polymerized resin cement RelyX ARC evaluated in this study showed higher degree of conversion values than the others materials.

The accelerated artificial aging significantly affects the bond performance of the luting systems, once a decrease on microshear bond strength values was found after aging compared to the groups tested 24 hours after bonding procedures. This can be justified because the water uptake and hygroscopic expansion may have an adverse impact on the longevity of the cementing systems.[30] Study have reported that smaller interface bonding area (1.0 mm^2) as used in this study may allow higher water-ion diffusion through the hybrid layers, thus accelerating the bond degradation.[27] Another possible explanations can be attributed to stress concentration in the resin-filler interface during the temperature variation, which can cause loss of filler particles and exposure of the resin matrix.[28] Accelerated artificial aging with temperature changes can cause dimensional changes of the material, forming fracture lines in the bonding interface and in the resin cement line. This may lead to fractures in the material, decreasing the bond strength of the composite restorative.[29]

The mechanical properties of resin materials aren't influenced by type and composition of the resin matrix, filler type and curing mode.[30,31,32] All luting systems tested presented similar microshear bond strength values.

The failure analysis mode revealed a higher prevalence of adhesives fractures. The Filtek Z-350 XT Flowable and RelyX Veneer groups resulted both in 50% adhesives failures and Tetric N-Flow and Variolink Veneer groups presented in 75% and 62,5% adhesive failures, respectively. The RelyX ARC 62,5% and Variolink II 62,5% predominantly presented cohesive failures in the ceramic surface and produced the highest mean microshear bond strength, confirming the efficiency of these materials. Dual- polymerized resin luting agents associate some of the desirable characteristics of light- polymerized luting, their chemical components seem to ensure complete polymerization when light intensity is attenuated by restorative material and tooth substrate.[30,33,34] Dual- polymerized resin cements shown superior mechanical properties, compared to the others luting systems,[12] this can explained by the results of failure patterns.

Methodological limitations for in vitro studies are inherent in the assessment of clinical performance of materials thus more in vivo studies are necessary to help clarify the better luting systems indicated to laminate veneers.

Conclusions

- The light- and dual-polymerizing materials presented similar color changes after accelerated artificial aging. Color alterations clinically unacceptable were observed for all the materials tested.
- All luting systems evaluated during the study showed the significant decreased of microshear bond strength after the accelerated artificial aging. The dual-polymerized cements Variolink II and RelyX ARC presented a degree of conversion higher than the others tested luting systems.

Acknowledgements

This research was supported by the São Paulo State Research Foundation (FAPESP #2011/11937-8).

Declaration of Interest

The authors report no conflict of interest.

References

1. Kermanshah H, Borougeni AT, Bitaraf T. Comparison of the microshear bond strength of feldspathic porcelain to enamel with three luting resins. J Prosthodont Res. 2011; 55(2):110-16.
2. Feire A, Archegas LRP. Porcelain laminate veneer on a highly discolored tooth: A case report. J Can Dent Assoc. 2010;76a:126.
3. Marchionatti AME, Wandscher VF, May MM, Bottino MA, May LGM. 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;118 (5):604-10.
4. Prieto LT, Souza-Júnior EJ, Araújo CTP, Lima AF, Dias CT, Paulillo LAMS. Nanoleakage evaluation of resin luting systems to dental enamel and leucite-reinforced ceramic. Microsc Res Tech. 2012;75(5):671-76.
5. Mundim FM, Garcia LF,Cruvinel DR,Lima FA,Bachmann L, Pires-de-Souza FCP.Color stability, opacity and degree of conversion of pre-heated composites. J Dent. 2011; 39(Suppl 1):25-29.
6. Topcu FT, Sahinkesen G, Yamanel K, Erdemir U, Oktay EA, Ersahan S. Influence of different drinks on the colour stability of dental resin composites. Eur J Dent. 2009;3(1): 50–56.
7. Sarafianou A, Iosifidou S, Papadopoulos T, Eliades G. Color stability and degree of cure of direct composite restoratives after accelerated aging. Oper Dent. 2007;32(4):406-11.
8. Segreto DR, Naufel FS, Brandt WC, Guiraldo RD, Correr-Sobrinho L, Sinhoreti MAC. Influence of photoinitiator and light-curing source on bond strength of experimental resin cements to dentin. Braz Dent J. 2016;27 (1):83-9.

9. Eliades T, Gioka C, Heim M, Eliades G, Makou M. Color stability of orthodontic adhesive resins. Angle Orthod. 2004;74(3):391-3.
10. Janda R, Roulet J-F, Latta M, Steffin G, Ruttermann S. Color stability of resin-based filling materials after aging when cured with plasma or halogen light. Eur J Oral Sci. 2005;113(3):251-7.
11. Kucukesmen HC, Usumez A, Ozturk N, Eroglu E. Change of shade by light polymerization in a resin cement polymerized beneath a ceramic restoration. J Dent. 2008;36(3):219-23.
12. Nathanson D, Banasr F. Color stability of resin cements- an in vitro study. Pract Proced Aesthet Dent. 2002;14(6):449-5.
13. Braga RR, Cesar PF, Gonzaga CC. Mechanical properties of resin cements with different activation modes. J Oral Rehab. 2002;29(3):257-62.
14. Archegas LRP, Freire A, Vieira S, Caldas DBM, Souza EM. Color stability and opacity of resin cements and flowable composites for ceramic veneer luting after accelerated ageing. J Dent. 2011;39(11):804-10.
15. Mjör IA, Gordan VV. Failure, repair, refurbishing and longevity of restorations. Oper Dent. 2002;27(5):528-34.
16. Loomans BAC, Cardoso MV, Roeters FJM, et al., Is there one optimal repair technique for all composites? Dent Mater. 2011;27(7):701-9.
17. Goiato MC, Santos DM, Haddad MF, Pesqueira AA. Effect of accelerated aging on the microhardness and color stability of flexible resins for dentures. Braz Oral Res. 2010;24(1):114-9.
18. Alandia-Roman CC, Cruvinel DR, Sousa ABS, Pires-de-Souza FCP, Panzeri H. Effect of cigarette smoke on colour stability and surface roughness of dental composites. J Dent. 2013;41(Suppl 3):73-9.
19. Astm standards G154-00A. Standard practice for operating fluorescent light apparatus for UV exposure of nonmetallic materials. Annual Book of ASTM Standards. Pennsylvania: United States. 2006;646-54.
20. Yilmaz B, Karaagaclioglu L. In vitro evaluation of color replication of metal ceramic specimens using a visual and instrumental color determinations. J Prosthet Dent. 2011;105(1):21-7.
21. Seong-Min L, Yu-Sung C. Effect of ceramic material and resin cement systems on the color stability of laminate veneers after accelerated aging. J Prosthet Dent. 2018;120(1):99-106.
22. Haralur SB, Alfaifi M, Almuaddi A, Al-Yazeedi M, Al-Ahmari A. The effect of accelerated aging on the colour stability of composite resin luting cements using different bonding techniques. J Clin Diagn Res. 2017;11(4):57-60.
23. Moharamzadeh K, Hooshmand T, Keshvad A, Van Noort R. Fracture toughness of a ceramic-resin interface. Dent Mater. 2008;24(2):172-7.
24. Sideridou ID, Karabela MM, Vouvoudi ECh. Dynamic thermomechanical properties and sorption characteristics of two commercial light cured dental resin composites. Dent Mater. 2008;24(6):737-43.
25. Buchalla W, Attin T, Hilgers R, Hellwig E. The effect of water storage and light exposure on the color and translucency of a hybrid and a microfilled composite. J Prosthet Dent. 2002;87(3):264-70.
26. Turgut S, Bagis B. Color stability of laminate veneers: An in vitro study. J Dent. 2011;39(Suppl 3):57-64
27. Ghavam M, Amani-Tehran M, Saffarpour M. Effect of accelerated aging on the color and opacity of resin cements. Oper Dent. 2010;35(6):605-9.
28. Magalhães APR, Cardoso PC, Souza JB, Fonseca RB, Pires-de Souza FC, Lopes LG. Influence of activation mode of resin cement on the shade of porcelain veneers. J Prosthodont. 2014;23(4):291-5.
29. Marchionatti AME, 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;118(5):604-610
30. Sideridou I, Tserki V, Papanastasiou G. Effect of chemical structure on degree of conversion in light-cured dimethacrylate-based dental resins. Biomaterials. 2002;23(8):1819-29.
31. Turkaslan SS, Deger Y. Degree of conversion of luting cements under fiber-reinforced composite resins. Journal of International Dental and Medical Research. 2016;9(1):18-22.
32. Al-Shekhli ABWR. Solubility of four dental luting cements. Journal of International Dental and Medical Research. 2010;3(3):104-107.
33. Delania M, Tanti I, Odang, RWL, Nelwan LC. The Effect of Light and Dual Cured Resin Cement to the Color of Porcelain Laminate Veneer. Journal of International Dental and Medical Research. 2017;10(3):964-969.
34. Bashi E, Callea M, Ince B, Montanari M, Dalli M, Batteli F, Akdogan M, Gabriella C, Toptance IR, Gabriela P, Yavuz I.A Composite Laminate Veneer Technique for Diastema Closure: A Report of Ten Cases. International Dental Research. 2012;2(3):67-74.