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Franciele Quiquio Santiago Floriani

RESIN COMPOSITE COLOR STABILITY AFTER ACCELERATED AGING

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Tese submetida ao Programa de Pós-Graduação em Odontologia da Universidade Federal de Santa Catarina como requisito parcial para a obtenção do título de doutor em clínica odontológica.

Orientador: Prof. Dr. Guilherme Carpena Lopes
Co-orientadora: Prof. Dr. Dayane Oliveira

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O presente trabalho em nível de doutorado foi avaliado e aprovado no dia 15/06/2023, pela banca examinador composta pelos seguintes membros:

Prof., Dr, Dayane Oliveira,
Instituição University of Florida

Prof., Dr., Fabio Andretti,
Instituição Tufts University

Prof., Dr., Jean-Francois Roulet,
Instituição University of Florida

Prof. Mario Sinhoreti, Dr.
Instituição UNICAMP

Certificamos que esta é a versão original e final do trabalho de conclusão que foi julgado adequado para obtenção do título de Doutor em clínicas odontológicas pelo Programa de Pós-Graduação em Odontologia.

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Prof. Dr. Guilherme Carpena Lopes

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RESUMO EXPANDIDO

Introdução A estabilidade da cor é essencial para o sucesso a longo prazo da restauração final. Essa característica física do material pode ser definida como sua propriedade de reter a cor inicial por algum tempo em determinado ambiente. Dentre as características relacionadas à resina composta, ela tem se constituído como um dos parâmetros clínicos mais importantes para o sucesso estético das restaurações.
Objetivos Esta tese teve como objetivo estudar *in vitro* a estabilidade de cor de resinas compostas (*single-shade, universal e bulk-fill flow*) em restaurações Classe V realizadas em dentes de resina acrílica (Delara Acrílico Teeth, Heraeus Kulzer, Alemanha) nas cores A1. e A3.
Metodologia A avaliação foi realizada antes e após o protocolo de envelhecimento artificial envolvendo exposição à luz ultravioleta por 120 horas, simulando cinco anos clínicos. As medidas de estabilidade de cor foram realizadas utilizando um espectrofotômetro (CM-700d, Konica Minolta, Japão), um scanner intraoral (Trios T3s, 3Shape, Dinamarca) e um espectrofotômetro portátil (Vita Easyshade Compact, Vita North America, EUA). Estas medidas foram calculadas usando a fórmula CIEDE2000 sob iluminação D65. Além disso, foram analisadas a diferença de cor entre o Vita Classical Shade Guide e as facetas compostas realizadas pela técnica de restauração direta em duas camadas (dual layer). Após o envelhecimento artificial, as resinas compostas single-shade forneceram correspondência de cores aceitáveis em restaurações Classe V na cor A1.
Resultados e Discussão Entretanto, na cor A3 apenas duas resinas compostas obtiveram uma correspondência de cores aceitáveis, e foram semelhante ao grupo controle. Após o envelhecimento artificial, todas as resinas compostas bulk-fill flow na cor A1 apresentaram correspondência de cores e estabilidade aceitáveis ($\Delta E00 \leq 2,5$). A cor das resinas compostas bulk-fill flow na cor A3 modificou, impactando a correspondência geral de cores das restaurações Classe V em dentes de cor A3, exceto para uma marca comercial. A estratificação das tonalidades das resinas compostas de esmalte e dentina não alcançou uma correspondência de cores para todas as tonalidades padrão da escala Vita Classical Shade Guide. A precisão da análise de cor registrada através do *scanner* intraoral (Trios T3s Scanner, 3Shape) e do espectrofotômetro intra-oral (Vita Easyshade Compact) nas leituras de dentes na cor A1 foi de 80%. O *scanner* intraoral (Trios T3s) registrou maiores percentuais de correspondência de cores do que o espectrofotômetro portátil (Vita Easyshade Compact), embora sem diferença estatística significativa.
Considerações Finais Portanto, para restaurar restaurações de Classe V em dentes de cor A1, as resinas compostas *single-shade* (resinas de espelhamento) demonstraram correspondência de cores comparáveis à resina composta universal usada como controle após simulados cinco anos de tempo clínico. As resinas compostas universais continuam sendo o padrão ouro para restaurar restaurações Classe V em dentes de cor A3. A estabilidade da cor das resinas compostas após envelhecimento acelerado é um importante tópico para pesquisa científica em odontologia.

Palavras-chave: resina composita, restaurações de resina composta, Class V, c em odontologia, resina composta de espelhamento**,** resina composta de efei camaleão, resina composta de cor única; resina bulk-fill, resina bulk-fill flow; resir composta universal; faceta de resina composta estabilidade de cor

ABSTRACT

Introduction Color stability is essential for the long-term success of the final restoration. This physical characteristic of the material can be defined as its property of retaining the initial color for some time in a particular environment.

ObjectivesThis thesis aimed to study the in vitro color stability of resin composites (single-shade, universal, and bulk-fill flow) in Class V restorations performed on acrylic resin teeth (ART.Delara Acrylic Teeth, Heraeus Kulzer, Germany) in colors A1 and A3.

Materials and Methods The evaluation was conducted both in baseline and after an aging protocol involving exposure to ultraviolet light for 120 hours, simulating five clinical years. Color stability measurements were taken using a spectrophotometer (CM-700d, Konica Minolta, Japan), an intraoral scanner (Trios T3s, 3Shape, Denmark), and a portable spectrophotometer (Vita Easyshade Compact, Vita North America, USA). These measurements were calculated using the CIEDE2000 formula under D65 illumination. Additionally, the color difference between the Vita Classical Shade Guide and the composite veneers was assessed using the dual-layer technique.

Results and discussion After aging, single-shade resin composites provided acceptable color matching for Class V restorations in ART color A1. However, in ART color A3, only 2 resin composites achieved an acceptable color match, similar to the control group. Following artificial aging, all bulk-fill flow resin composites in color A1 showed acceptable color match and stability (ΔE00 ≤ 2.5). The color of bulk-fill flow in color A3 changed, impacting the overall color matching of Class V restorations in teeth of color A3, except for one brand. The layering of enamel and dentin composite shades could not achieve a color match for all Vita Classical Shade Guide standard shades. Interestingly, Interestingly, the precision of color analysis recorded by both the intraoral scanner (Trios T3s Scanner) and the spectrophotometer (Vita Easyshade Compact) for readings of artificial teeth in the A1 color was 80%.The intraoral scanner (Trios T3s, 3Shape) recorded higher percentages of color matching than the portable spectrophotometer (Vita Easyshade Compact), although without a statistically significant difference.

Considerations Therefore, to restore Class V restorations in teeth of color A1, single-shade resin composites demonstrated comparable color machting to the universal resin composite used as a control after simulated 5 years of clinical service. The universal resin composites remains the gold standard for restoring Class V restorations in teeth color A3. Resin composite color stability after accelerated aging is an important research topic.

Keywords: resin composite, composite, Class V, color matching, sing survival; universal composite; veneer; color stability, chameleon effect; dentistry; color; direct resin composite restoration

FIGURES

TABLES

SUMMARY

1 INTRODUCTION

The combination of optical properties determines tooth color. Four phenomena of light interaction with the tooth surface are described: (1) specular transmission of light through the tooth, (2) specular reflection on the surface, (3) diffuse light reflection on the surface, and (4) absorption and dispersion of the surface (JAHANGIRI *et al*., 2002). The tooth's color results from the volume of light scattering. The natural or unnatural illuminating light follows highly irregular light paths through the tooth before emerging on the incident surface and reaching the eye of the observer. Non-white colors are predominantly a result of absorption along these paths and the absorption coefficient of dental tissues (JOINER, 2004). The optical dimension is the result of primary properties (hue, saturation, and luminosity) and secondary properties (fluorescence, translucency, opacity, opalescence, iridescence, and surface gloss) (CORREIA, 2005). Integrating the primary properties, according to Nahsan *et al*. we arrive at the concept of "color", which is the interaction of the dimensions known as hue, chroma, and value (NAHSAN *et al*., 2012). Hue allows the distinction of color families and is specified as the dominant wavelength range in the visible spectrum. In dentistry, it is represented by the letters A, B, C, or D in the color guide (FONDRIEST, 2003). The value indicates the luminosity of a color ranging from pure black to pure white (JOINER, 2004). The decrease in value indicates a decrease in the light return of the illuminated object; that is, more light is being absorbed, scattered, or transmitted (FONDRIEST, 2003). Chroma, in turn, describes the intensity or vividness of a color (JOINER, 2004). The Commission International de l'Eclairage (CIE) color system is usually used to assess color differences.

The Commission International de l'Eclairage (CIE) color system is usually used to assess color differences. According to this system, the CIELAB color space represents a uniform color space on the three axes: L *, a *, and b *. The value of L * is a measure of the luminosity of an object (value). It is quantified on a scale from 0 to 100, where 0 would be perfect black, and 100 would be perfectly white. The a* is a measurement of red (a * positive) or green (a * negative) color. The value of b * is a measure of yellow (b * positive) or bluish (b * negative). The a* and b* coordinates approach zero for neutral colors (white, gray) and increase in magnitude for more saturated or intense colors. Furthermore, this system can mathematically combine the differences between L*, a*, and b*, generating the color difference (delta E - ΔE) between two materials. The advantage of the CIELAB system is that it can be expressed the color difference in units, which can be related to visual perception and clinical significance (BARUTCIGIL *et al*., 2011; JOINER, 2004; DE OLIVEIRA *et al*., 2015).

The secondary properties of the optical dimension include several aspects. Fluorescence, by definition, is the absorption of light by a material and the spontaneous emission of light at a longer wavelength (FONDRIEST, 2003). Iridescence is the change in hue with variation in viewing geometry or lighting. In addition, there is also opalescence which is the ability to reflect light at short wavelengths (associated with blue) and transmit light at long wavelengths (associated with orange). Translucency can be described as a state between total opacity and complete transparency (SALGADO, 2013).

Resin composites emerged to contribute to the aesthetic ideal desired by society (RUSCHEL VC, 2018). Since their initial development from the studies of Bowen (1962), resin composite has been modified to improve their physical and mechanical properties. Both properties are influenced by the size, shape, type, and concentration (quantity) of inorganic filler particles of different types of commercial resin composites.

Therefore, macroparticulate resin composites with average particle sizes >15µm were the first resin composites commercialized, but they are no longer commercialized due to relevant clinical problems, such as unsatisfactory surface smoothness (BARATIERI *et al.*, 1988). Then came the microparticulate resins (0.01 to 0.04µm), with excellent polishing characteristics, but with the inconvenience of having a high polymerization shrinkage index due to a low percentage of filler by weight (30 to 45% by volume). Hybrid and microhybrid resin composites combine different sizes of particles and present good polishing and polymerization shrinkage lower than that found in microparticulate resin composites and have a “universal” indication (anterior and posterior teeth). The nanoparticulate resin composites present the size of the particles of inorganic filler varying between 5 and 75 nm. Nanohybrid resin composites present in their composition an association of nanoparticles with larger particles, with the size of the inorganic particle ranging between 400 and 600 nm. Bulk-Fill resin composites have as their primary property low polymerization shrinkage, which allows their use in layers of 4.0 to 5.0 mm thick, while conventional composites are placed in increments of a maximum of 2.0 mm, and due to advantages, such as shorter operative time, these materials have gained popularity (MELO JUNIOR *et al.*, 2011; ROCHA MG *et al.*, 2021).

Recently, in 2019, the monochromatic resin composite was developed, which is idealized from the "Wide Color Matching" concept. With the use of monochromatic resin composite, it is possible to promote the reproduction of a range of natural colors, having the ability to mirror 16 colors present in the Vita Classical Shade Guide (Vita North America, CA, USA) with only one shade of the resin composite (LOWE, 2019). In addition, it allows the professional to reduce clinical time in procedures that involve stratification, as the technology eliminates the need to select the color of the resin composites that would be used. In addition to allowing the dentist to reduce the number of resin composites present in its stock of restorative materials, also to reduce the frequent errors regarding the selection of the combination of colors used in the layering (LOWE, 2019).

Color stability is essential for the long-term success of the final restoration. This physical characteristic of the material can be defined as its property of retaining the initial color for some time in a particular environment. Among the characteristics related to the resin composite, it has been constituted as one of the most important clinical parameters for the aesthetic success of restorations (MUNDIM *et al*., 2011). Composite restorations are expected color stability that will persist for as long as the material remains functional in the oral environment. However, discoloration and pigmentation of the material are still commonly present in the daily clinic due to its heterogeneous composition (filler particle + binding agent + organic phase), which is susceptible to chemical degradation (water, acids, and alcohol), physics (light, temperature), and mechanics (friction and stress fractures of the material) (KHOKHAR *et al*., 1991).

The color change that resin composites undergo is multifactorial and can be caused by intrinsic and extrinsic factors. Intrinsic factors involve discoloration of the material itself, such as alteration of the interface between the matrix and filler components, photoinitiators, and oxidation of the polymer matrix. Usually, this intrinsic discoloration occurs with the aging of the material due to various physicochemical conditions, such as thermal changes and humidity

(REN *et al*., 2012). Many methods are currently used to assess the color of teeth. These range from visual subjective comparisons with color scales to objective instrumental measurements using spectrophotometers, colorimeters, intraoral scanners, and image analysis techniques (BROWNING *et al*., 2009). Intraoral scanners have recently been introduced into a dental practice, and some are capable of capturing color images and making a clear distinction between soft and hard tissue structures. The results of color selections from intraoral scanners are also based on visual color scales (BRANDT *et al*., 2017).

The most commonly used color scale for color selection is Vita Shade guide (Vita Zahnfabrik, Bad Säckingen, Germany or Vita North America, CA, USA). However, this dental shade guide does not represent perfect shade patterns. Several studies have demonstrated differences between commercially available restorative compounds and the “Vitapan Classical” Vita Shade Guide (BROWNING *et al*., 2009; LEHMANN *et al*., 2010). According to Swift, 1994, the lack of correspondence in the color selection of a resin composite with the tooth structure is due to the color guide provided in many products. These shade guides are usually made of plastic (not the actual composite material) which, at best, approximates the color of the resin composite. Each Vita Shade Guide presents different cervical, middle, and incisal third colors. In addition, they are thicker (4.0 to 5.0 mm) than the thickness of resin composite increments used during restoration.

In a literature review, Lee *et al*. (2010) evaluated the color compatibility of esthetic restorative materials. They reported the existence of several limitations in the color shade guide that should be considered in the color selection. Among them the difference between color gamuts and color scale distributions and human teeth; the arrangements of scale units, not being ideally logical; and the color difference between the commercialized esthetic restorative materials and the respective color units of the scales. To explore color selection errors through color guides, recent studies have used the CIELAB system, which is the result of research by the International Commission on Illumination.

Thus, this *in vitro* study analyzed the color stability by the CIELAB system of different resin composite systems artificially aged through UV-LIGHT measured by spectrophotometer and intraoral scanner methods. The null hypothesis tested that there would not have color variation between the different systems of resin composites after artificial aging. The second null hypothesis was that there was repeatability of the utilized intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner, when shade determination was repeated three times for each tooth.

2 LITERATURE REVIEW

2.1 Resin composite color stability

Powers, Dennison, and Koran (1978) evaluated the color stability of seven commercial brands of resin composites, one unfilled resin, and three “glazers”, through the aging acceleration process, performed the simulation of color deterioration as a result of the conditions climate. The restorative treatments were maintained for 900 hours and 300 hours of aging, equivalent to 1 year of clinical use. Thus, spectrophotometric and visual evaluation was assessed after 10, 20, 50, 100, 300, and 900 hours of exposure. The authors concluded that after 900 hours, all materials showed significant color change compared to the initial condition.

Powers, Fan, and Raptis (1980), in an *in vitro* study, evaluated the color stability of three conventional and four microparticulate resin composites. The authors made three samples of each material with a metallic matrix, then stored them in an oven at a controlled temperature of 37ºC for 24 hours before the initial evaluation. The samples were submitted to acceleration aging by light, temperature, and humidity variation, in a 25-W3 chamber with measurements after 300, 600, and 900 hours of treatment. Measurements were performed by reflectance spectrophotometry. The authors observed that all materials became darker, more chromatic, and opaque during the initial aging. However, in continuity, conventional resin composites were affected by matrix erosion with consequent exposure to filler particles. The microparticulate resin composites showed better color stability, apparently not affected by erosion, leading them to conclude the color change occurred at different intensities according to the material studied.

In 1981, Asmussen evaluated the clinical relevance of color stability tests in resin composites. Samples of several resin composite commercial brands (chemical, and light-curing resins) were made, which were submitted to different types of tests: storage of samples in demineralized water at 37°C for 12 months; storage in demineralized water at 50, 60, and 70°C for 1 and 2 months. For each sample, color measurements were performed using a colorimeter before and after the artificial aging process. Color change of all resin composites was the same in both tests with storage for 12 months in demineralized water at 37°C, as in the tests for one month in water at 60°C, making the latter clinically acceptable for color stability tests through accelerated artificial aging of resin composites.

Inokoshi *et al*. (1996) evaluated the color stability and opacity of different direct restorative materials before and after artificial aging. Five specimens with 6.0 mm in diameter and 1.0 mm in thickness were made for each material studied (five chemically polymerized resin composite, seven light-cured resin composites, and three resin-modified glass ionomer cements). The artificial aging process used was the one proposed by Asmussen *et al.* in 1981, color stability was determined by a photoelectric colorimeter, according to the CIELAB colorimetry system. The total color change after aging was represented by the difference between values before and after artificial aging (ΔE). The authors found that all chemically polymerized resin composites experienced discoloration after four weeks of artificial aging. On the other hand, glass ionomer cement underwent an abrupt change in color and translucency in the early stages. Still, this change was minor in the later stages of artificial aging.

In 2001, Stober *et al.* examined the color stability of seven indirect resin composites with high inorganic matrix content (Columbus, Artglass, Sinfony, Targis, Zeta LC, Zeta HC, BelleGlass HP/dentine, BelleGlass HP/enamel). Twenty-one samples were made for each material, which was exposed to ultraviolet light for the artificial aging process for 24, 96, and 168 hours, and then immersed in pigmentation solutions (mouthwash, tea, coffee, red wine, and turmeric solution). Using a colorimeter according to the CIELAB system, color measurements were performed, and, red wine and turmeric solution caused the most severe discoloration ($\Delta E > 10$). Tea, coffee and ultraviolet irradiation caused non-visible ($\Delta E < 1$), visible ($\Delta E > 1$), and in some cases, clinically unacceptable (ΔE > 3.3) discolorations. With these results, the authors considered it an important reason to improve the color stability of the resin composite.

Paravina *et al*. (2004) verified the effects of artificial aging on color and translucency of microparticulate and microhybrid resin composites. Materials from ten different commercial brands were evaluated in different colors, and five specimens (10.0 mm in diameter by 2.0 mm in thickness) were made for each color studied. The specimens were taken to an artificial aging chamber, alternating exposure to ultraviolet light and humidity. The readings to verify the color change were performed with a reflectance spectrophotometer before and after the artificial aging process. The authors considered that an ΔE (color variation) equal to or greater than 3.7 would provide poor color stability of the resin composite studied. Therefore, they found ΔE values of 3.2, 4.0, and 4.7 (on average) for the microhybrid resin composite and ΔE of 2.0, 2.0, and 2.1 for the microparticulates resin composites. In relation to ΔTP (translucency variation), the authors found mean values of 0.07, 0.12, and 0.16 for microhybrid resin composites and mean values of 0.14, 0.11, and 0.0 for the microparticles. These data concluded that the color changes obtained were above the acceptable limit for most micro-hybrid resin composites, while the microparticulate resin composites were within the acceptable limit. The translucency values were relatively stable during aging for both classes of resin composites. Based on this, the authors recommend that resin composite restorations be constantly re-examined due to the color changes they may undergo due to the natural aging process.

2.2 Color analysis method

Alshiddi (2015), in a clinical study, compared color selection accuracy of the visual method using a shade-guide (Vitapan 3D-Master, Vita Zahnfabrik, Germany) with the spectrophotometric method. For this, students from the dentistry course were selected. They were separated into two groups: the group that received training to perform the analyzes and the group that did not receive the training. The ‘trained’ group received a presentation and training exercise on color science and color selection. The ‘untrained’ group received no information or training. Eight research participants (volunteer dental assistants and dental students, seven women and one man) were selected as the best match for the middle third of the maxillary right central incisor in eight research participants (volunteer dental assistants and dental students, seven women and one man). To avoid eye strain, a five-minute break after two color selections and a 20-minute break after four color selection procedures. As a result, the average ΔE for the spectrophotometric method in all operators was 3.6 compared to 4.2 for the visual way using the Vitapan 3D-Master shade guide (Vita Zahnfabrik). The Vita Easyshade spectrophotometer (Vita Zahnfabrik) matched more accurately than the Vitapan 3D-Master visual method.

Knezović Zlatarić *et al*. (2015) evaluated the intra-device repeatability and accuracy of the spectrophotometer (Vita Easyshade® Advance 4.0, Vita Zahnfabrik, Bad Sackingen, Germany) *in vitro* and *in vivo* models. For the *in vivo* repeatability assessment, two measurements were performed in the central region of the Upper Right Central Incisors on 10 participants using a spectrophotometer (Vita Easyshade® Advance 4.0). The following tooth colors were measured: B1, A1, A2, A3, C1, and C3. In the in-vitro model, the colors B1, A1, A2, A3, C1, and C3 of the Vitapan Classical were analyzed in the central region of each tab of the Vita Shade-guide. Three color options of the Vita Shade-guide tabs (Vitapan Classical) were measured once for accuracy assessment. The average color difference for the in-vitro and in-vivo models was 3.51 and 1.25 units. The tested accuracy of the Vita Easyshade® Advance 4.0 (Vita Zahnfabrik, Bad Sackingen, Germany or Vita North America, CA, USA) was 93.75%, proving to be a reliable and accurate dental device, which can be a valuable tool for determining tooth shades.

Parameswaran *et al*. (2016) evaluated through *in vitro* research, color matching of an intraoral spectrophotometer (Vita Easyshade™) and the conventional visual method using two shade-guides: VITAPAN Classical™ and VITAPAN 3D Master™. A comparison of accuracy between the selection methods revealed that the visual method obtained a superior result compared to the spectrophotometric method. However, the spectrophotometer showed better agreement rates between evaluators, regardless of the color shade-guide used. Regarding the visual method, VITAPAN 3D Master™ shade-guide was better than the VITAPAN Classical™ shade-guide.

In a clinical study, Brandt *et al*. (2017) compared the clinical suitability of conventional methods for visually determining tooth color to digital methods. The shade of 107 Maxillary Central Incisors (vital and natural) was visually determined by a dentist (DV) and a dental technician (VDT) using the Vita Shade Guide 3D-MASTER®, digitally by the VITA Easyshade Advance 4.0 spectrophotometer (reference instrument) and intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner (test subject). Reliability was examined by repeating digital measurements of 20 teeth three times. The analysis was based on the values recorded from the 3D-MASTER and on the parameters L*a*b/L*C*h. Measurement accuracy was 43.9% with the intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner, 35.5% for VD, and 34.6% for VDT. In 25.5% of the cases, the scanner results corresponded to the VD, and in 33.6% to the VDT. Visual methods corresponded with 45.8%. All mean values of color differences recorded were within the clinically acceptable range of $\Delta E \leq 6.8$. The intraoral scanner achieved a repeatability of 78.3% and the Vita Easyshade system of 76.6%.

Rutkunas *et al*. (2020) in a clinical study, evaluated the accuracy of tooth color measurement obtained with an intra-oral digital scanner *in vivo*. The shades of 120 anterior maxillary teeth were evaluated using a SpectroShade (SS) spectrophotometer and a intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner (T3) intraoral digital scanner on 20 participants. Correspondence of color readings between T3 and SS was used to estimate the accuracy of T3. The percentage of readings was calculated when the difference between the shades obtained by the two devices was visually perceptible ($\Delta E>3.7$). Each of the 120 teeth was measured 5 times to assess repeatability. The findings of this study revealed that the tooth color determined by T3 does not exactly coincide with that obtained by the SS and that an additional method of measuring tooth color is recommended.

Czigola *et al*. (2021) evaluated the effectiveness of color determination through the intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner in relation to visual and spectrophotometric methods. For this, ten dental students from Semmelweis University determined the tooth color of 10 volunteers using Vita A1-D4 (VC) and Vita Linearguide 3D-Master (LG) shade-guides, Vita Easyshade spectrophotometer (ES) and intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner (TR). For the visual analysis, four volunteers selected the colors of each tooth that were presented to the student, supervisor, and patient to select the best combination. Selection percentages were calculated. The supervisor's best match was the reference (ΔE_{00}). As a result, the median ΔE00 of the best correspondence between students and supervisors: LG 2.73; ES 4.29; TR 4.29; VC 16.35. TR was the most repeatable. The “best match color shade-guides” were selected using LG. The VC color was the least consistent with the teeth examined. The researchers concluded that TR can be used for shade selection with a 3D-Master tooth shade system with visual verification.

3 OBJECTIVES

3.1 General Objective

To evaluate by *in vitro* research the influence of color stability of different resin composite systems through artificial aging with ultraviolet light.

3.2 Specific Objectives

- Analyzed the color stability of the single-shade resin composite before artificial aging.
- Analyzed the color stability of bulk-fill flow resin composite before artificial aging.
- Analyzed the color stability of single-shade resin composite after artificial aging.
- Analyzed the color stability of bulk-fill flow resin composites after artificial aging.
- Analyzed the color match of resin composite veneers manufactured by the dual-layering method.
- Analyzed the color stability of single-shade resin composite class V restorations performed on artificial teeth before and after artificial aging.
- Analyzed the color stability of bulk-fill flow resin composite class V restorations performed on artificial teeth before and after artificial aging.
- Evaluated the repeatability of two digital color analysis methods.

4 JUSTIFICATION

Correct determination of tooth shade is one of the essential steps of esthetic restorations. New color-matching systems have been developed to overcome the visual method of color determination, for example, the new intraoral scanners with color measurement functions. In addition, digital methods of color determination are more independent of environmental circumstances, and with intraoral scanners, it is easy to measure tooth color by taking a fingerprint simultaneously. These new devices can be a reliable alternative method for visually verifying color selection. However, there is limited literature on the effectiveness of tooth color analysis using intraoral digital scanners.

5 MATERIALS AND METHODS

5.1 Study Design

To evaluate by *in vitro* research using digital tools the color stability of different resin composite systems before and after artificial aging with ultraviolet light.

5.2 Null Hypothesis

The null hypotheses are described separately in the following 4 documents: Research Article #1, Scientific Manuscript #2, Scientific Manuscript #3, and Scientific Manuscript #4.

5.3 Methodology Execution Locality

The Ph.D. qualification board exam was approved at the Federal University of Santa Catarina (Brazil). After the considerations, the Ph.D. research project was developed at the Department of Dental Materials at the University of Florida, United States of America and Federal Univesity of Santa Catarina, Brazil.

5.4 Sample Calculation

It was carried out based on previous studies (COOLEY et al., 1987; LUCE and CAMPBELL, 1988; VICHI et al., 2004), which resulted in five repetitions for each resin composite. These results in 15 single-shade resin composite specimens for each tooth shade A3 and A1, 10 universal resin composite specimens for each tooth shade A3 and A1, 30 bulk-Fill Flow resin composite specimens for each A1 and A3 tooth shade, and 49 composite veneer specimens by dual-layering technique.

5.5 Description of Methodology

5.5.1 Materials

Three single-shade resin composites were selected in the present research: Palfique Omnichroma (Tokuyama, Chiyoda-ku, Tokyo, Japan); Charisma One (Heraeus Kulzer, South

Bend Indiana, United States of America); and, Vittra APS Unique (FGM, Joinville, Santa Catarina, Brazil). Two universal composites were used as control: SimpliShade (Kavo Kerr, Brea, California, United States of America) color Light and color Medium, and 3M Filtek Universal Restorative (3M Oral Care, Saint Paul, Minnesota, United States of America) color A1 and color A3 (Table 1):

Table 1. Single-shade and universal resin composites used in this research

Universal resin composite and Single-shade resin composite				
Resin composite name	**Brand**	**Shades**	**Chemical Composition / Filler particles**	**Use/Indication**
SimpliShade 	Kerr	Light and Medium	Bis-EMA, Bis-GMA and TEDGMA monomers. Inorganic particle size: 40nm to 6microns. Light-cured increment size: 1.5-2mm (650-100mW/cm)	Combines all 16 VITA® Classica shades. Adaptive Response Technology (ART). Mimics tooth structure.
Palfique Omnichroma 	Tokuyama	One shade	1,6bis(methacryloethyloxycarbonylamino) monomers, trimethyl hexane (UDMA), triethylene glycol dimethacrylate (TEGDMA), mequinol, dibutyl hydroxytoluene and UV absorber. Designed to be used with any halogen or LED type curing light with a wavelength of 400-500 nm.	It is suitable for all types of cavities
Charisma One 	Kulzer	One shade		
3M Filtek Universal Restorative 	3M Oral Care	**A1 and A3**	AUDMA, AFM, diurethane-DMA, 1,12-dodecaneDMA, non-agglomerated/non-aggregated 20 nm silica filler and 4 to 11 nm zirconia filler, aggregated zirconia/silica cluster	Its universal composite with Natural-Match technology, creates natural-looking restorations with the surrounding dentition, providing a chameleon effect. Features 8 shades.
Vittra APS Unique 	FGM	One shade		Mimics the color of the dental substrate during the polymerization process, achieving perfect mimicry thanks to the chromatic mirroring characteristics of the resin. Direct restorations in anterior and posterior teeth (classes I, II,III, IV, V)

*Blank information was not released by the companies

Three bulk-fill flow resin composites were evaluated for color stability: Filtek Bulk-Fill (3M Oral Care, St. Paul, MN, USA), Venus Bulk-Fill (Kulzer, Hanau, Germany), Bulk-Fill Stylus (Tokuyama Corporation, Tokyo, Japan) (Table 2):

Table 2. Bulk-fill flow resin composites used in this research.

Bulk-Fill	Brand	System	Use/Indication
Filtek Bulk-Fill 	3M Oral Care	Flow A1 and A3	Increment of up to 4mm; Particles containing zirconia and silica; Class I and II direct restorations, fissure sealant, minimally invasive restorations (including small non-stress resistant occlusal restorations), class III and V restorations, repair of small enamel defects/small defects in indirect esthetic restorations.
Estelite Bulk-Fill 	Tokuyama	Flow A1 and A3	Increments of up to 4 mm. Higher wear resistance and lower polymerization shrinkage
Venus Bulk-Fill 	Kulzer	Flow A1 and A3	

*Blank information was not released by the companies

Two different types of resin composites made using the dual-layering technique were evaluated for color stability: Filtek Supreme Ultra (3M Oral Care, St. Paul, MN, United States) and Estelite Omega (Tokuyama, Taitou-ku, Tokyo, Japan). The veneers composite will be made using the dual-layering technique according to the following enamel/dentin layers (Table 3):

Table 3. Enamel/dentin layers used n this research.

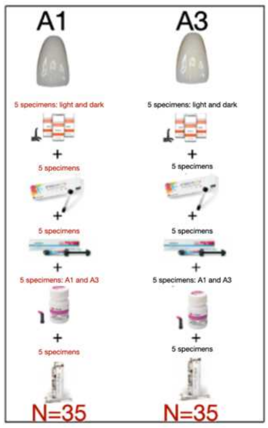
	Composite colors
Filtek Supreme Ultra (3M Oral Care, St. Paul, MN, United States)	EA1/DA1
	EA1/DA2
	EA1/DA3
	EA1/DA4
	EA1/BodyA1
	EA1/BodyA2
	EA1/BodyA3
	EA2/DA1
	EA2/DA2
	EA2/DA3
	EA2/DA4
	EA2/BodyA1
	EA2/BodyA2
	EA2/BodyA3
	EA3/DA1
	EA3/DA2
	EA3/DA3
	EA3/DA4
	EA3/BodyA1
	EA3/BodyA2
	EA3/BodyA3
Estelite Omega (Tokuyama, Taitou-ku, Tokyo, Japan	EB1/DA1
	EB1/DA2
	EB1/DA3
	EB1/DBL1
	EB1/DBL2
	EA1/DA1
	EA1/DA2
	EA1/DA3
	EA1/DBL1
	EA1/DBL2
	EA2/DA1
	EA2/DA2
	EA2/DA3
	EA2/DBL1
	EA2/DBL2

	EA3/DA1
	EA3/DA2
	EA3/DA3
	EA3/DBL1
	EA3/DBL2

- **Specimens of single-shade resin composite, universal resin composite and bulk-fill flow resin composite**

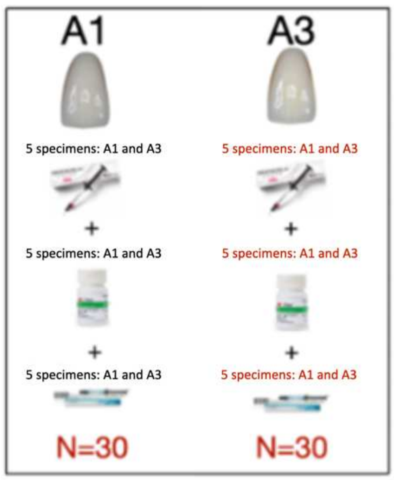
70 artificial teeth of anterior Superior Incisors were selected in colors A1 and A3 (Delara 6 Anterior Acrylic Teeth – T46 (Kulzer LLC, South Blend, USA). Of these, 5 specimens for each light and dark color of SimpliShade resin composite (KerrHawe AS , Bioggio, Switzerland), 5 specimens for each color A1 and A3 of 3M Filtek Universal Restorative resin composite (3M Oral Care, St. Paul, MN, USA), 5 species for the resin composite Charisma One (Kulzer LLC, South Blend, USA), 5 specimens for Palfique Omnichroma resin composite (Tokuyama Corporation, Tokyo, Japan), and 5 specimens for the resin composite Vittra APS Unique (Joinville, Santa Catarina, Brazil) (N=70) (Figure 1).

Figure 1. Illustration of single-shade and universal resin composite samples distribution



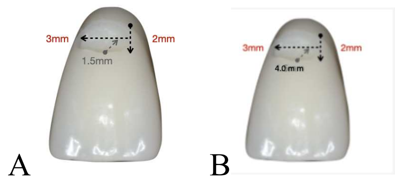
In addition to these, 60 Anterior Upper Central Incisors were selected in colors A1 and A3 (Delara 6 Anterior Acrylic Teeth – T46 (Kulzer LLC, South Blend, USA). Of these, 5 specimens were evaluated for each color A1 and A3 of the Filtek Bulk-Fill resin (3M Oral Care, St. Paul, MN, USA), 5 species for each color A1 and A3 of Venus Bulk-Fill resin (Kulzer, Hanau, Germany) and 5 species for each color A1 and A3 of Estilete Bulk-Fill resin (Tokuyama Corporation, Tokyo, Japan) (N=60) (Figure 2).

Figure 2. Illustration of bulk-fill flow resin composite samples distribution



Specimens of Class V restorations were made on the artificial teeth of the Maxillary Central Incisors in a standardized way. These were prepared on the buccal surface of each tooth with dimensions: 3 mm mesiodistal, 2 mm cervical occlusion, and 1.5 mm depth (Deb A, et al., 2021; Rocha MG, et al; 2021) (Figure 3).

Figure 3. Illustration of Class V cavity preparation. A) Dimensions for single-shade and universal resin composite restorations. B) Dimensions for bulk-fill flow resin composite restorations.



Subsequent washing and drying with air to achieve the enamel-etched appearance. The universal adhesive (AdheSE Universal, Ivoclar Vivadent) was spread and rubbed over the surface for 20 seconds. Then, an air stream was applied for 5 according to the manufacturer's instructions, with light curing for 60 seconds in two increments proper light-cured (16J/cm^2 /(Valo cordless, Ultradent®, South Jordan, Utah). The Single-shade and universal resin composite were used in two increments and proper light-cured applied on Class V preparation. Before light curing, a polyester matrix was inserted, followed by a microscope slide, to prevent irregularities formation or bubbles in the specimen and to avoid the formation of inhibition layers photopolymerization in contact with oxygen. Then, light curing will be performed for 20 s on the buccal surface and 20 s on the lingual surface (Valo cordless, Ultradent®, South Jordan, Utah). Studies report no statistical difference in the color stability of the resin composite light cured with this curing protocol (Strazzi-Sahyon *et al*., 2020; Rocha *et al*., 2018). The radiant power was 800 mW/cm^2, commonly reported by manufacturers and used in ISO 1065 (2018) to ensure the composite has adequately been photo-activated.

- **Direct resin composite veneers manufactured by the dual-layer method**

49 specimens of direct resin composite veneers were made using the dual layer method (enamel/dentin), using a customized matrix (Easy Layering Shade Guide Kit, 3M, St Paul, MN, United States) with standardized enamel and dentin thickness (Figure 3). A standardized protocol was used to make the samples. First, the enamel color layer was placed, in which a standardized thickness of 1.1 mm was obtained using a dentin spacer, as shown in Figure 4. The enamel color was light cured for 20 s on the buccal side and 20 s on the buccal or lingual side (Valo cordless, Ultradent®, South Jordan, Utah) (Strazzi-Sahyon *et al*., 2020; Rocha *et al*., 2018). Radiant power was 800 mW/cm^2, commonly reported by manufacturers and used in ISO 1065 to ensure the composite has adequately cured. Then, after removing the dentin spacer, the dentin layer was applied just above the cured enamel layer, with a clear plastic handle attached to the back. The total thickness of the dentin created by the dentin spacer was 1.5 mm in the middle and cervical thirds and 0.4 mm in the incisal third. The dentin layer will be light cured, following the same protocol described for the enamel layer (Figure 4).

Figure 4. Easy Layering Shade Technique

The resin composite veneer samples were refined in the proximal area with fine and extra fine diamond burs of the same size (drill head 1.6 mm/drill length 8.0 mm, # 2135F, # 2135FF, KG Sorensen), followed by medium, fine, and superfine abrasive discs, silicone tips (Jiffy Polisher; Ultradent Products Inc, South Jordan, Utah, USA) and polishing brushes. Finishing and polishing of the buccal surface were not carried out, as there was no excess on the buccal surface due to the customized matrix. This protocol was primarily designed not to change the color of composite veneers after finishing and polishing.

5.5.3 Devices for evaluating color

The color analysis was done using three digital devices: a standard non-portable spectrophotometer (CM-700d, Konica Minolta, Tokyo, Japan), a portable spectrophotometer (Vita Easyshade Compact, Vita Zahnfabrik, Bad Sackingen, Germany or Vita North America, CA, USA), and an intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner.

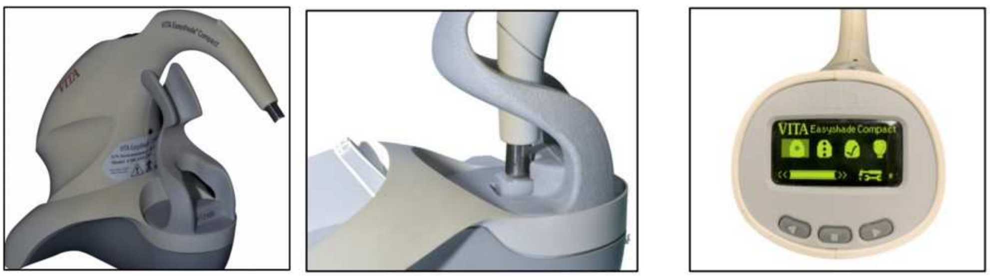
Some studies reported difficulty measuring the color guide because of irregular and curved surfaces. Therefore, a positioning guide will ensure that all measurements were the same, that is, in the same place and with the same inclination in all samples.

- **Spectrophotometer**

Spectrophotometers are the most used instruments for the objective evaluation of color in dentistry. They measure the amount of light reflected by the object in the visible spectrum. Data captured in spectrophotometers are expressed in a numerical value, L *, a *, b *, c * (Figure 5 and Figure 6).

Figure 5. CM-700d spectrophotometer, (CM-700d, Konica Minolta, Japan)

Figure 6. Vita Easyshade Compact Spectrophotometer



• Trios®Color intraoral scanning

The scanner photographs in high quality, scans, illuminates, records, and automatically measure the color of the test fields. The images obtained can be enlarged up to 60 times without noise or distortion. The intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner will be previously calibrated using the Trios3® Color intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner Calibration Kit and enabled for colors with TRIOS3® software 1.18.4.4.

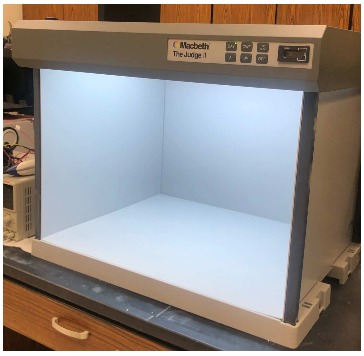
5.5.3.1 Color analysis

The color analysis was carried out in two steps. In the first step, 70 artificial teeth of anterior Superior Central Incisors were selected in colors A1 and A3 (Delara 6 Anterior Acrylic Teeth – T46 (Kulzer LLC, South Blend, USA). Of these, 5 specimens for each light and dark colors of SimpliShade resin composite (KerrHawe AS, Bioggio, Switzerland), 5 specimens for each color A1 and A3 of 3M Filtek Universal Restorative resin composite (3M Oral Care, St. Paul, MN, USA), 5 species for the resin composite Charisma One (Kulzer LLC, South Blend, USA), 5 specimens for Palfique Omnichroma resin composite (Tokuyama Corporation, Tokyo, Japan), and 5 specimens for the resin composite Vittra APS Unique (Joinville, Santa Catarina, Brazil) (N=70). Sixty samples of Bulk-Fill Flow class V restorations and 49 specimens of dual layering direct resin composite veneers were analyzed using a spectrophotometer (CM-700d, Konica Minolta, Japan). Analyzes were performed before artificial aging (BR 10 2014 019793-1) and after the artificial aging cycle.

The second step analyzed the color of 3M Filtek Universal Restorative Universal (A1 and A3) and Filtek Bulk-Fill Flow (A1 and A3) (N=20) resin composite Class V restorations through two digital devices: spectrophotometer (Vita Easyshade Compact, Vita North America, CA, EUA); and by intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner before artificial aging.

All analyses were carried out within Macbeth the Judge II (Figure 7) with a positioning guide to ensure that all measurements were the same, that is, in the exact location and with the same inclination in all samples.

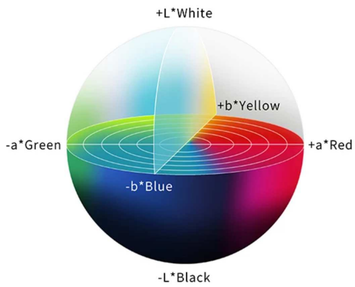
Figure 7. Macbeth The Judge II



5.5.4 Measurement of data

For measurements of coordinates and color differences, the CIELAB system was used. The Commission Internationale de l'E'clairage (CIE), an organization focused on standardization in areas such as color and appearance, defined in 1931 a standard light source and made it possible to calculate the values that represent how the human visual system responds to a given color. In 1976, the CIE further defined a color space, CIE Lab. The CIE Lab color space represents a three-dimensional color space, which has three axes L *, a *, and b * that evaluate the following coordinates: L* (brightness, ranging from 0 to 100), a* (ranging from green to red) and b* (ranging from blue to yellow) (Figure 8).

Figure 8. Representativeness of the CIE Lab three-dimensional color space. After collecting the data, using the CIELAB system, the color differences (ΔE*) will be calculated using the color coordinates L*, a*, and b*, with the following formula (JOHNSTON, 2009; LI *et al.*, 2010)



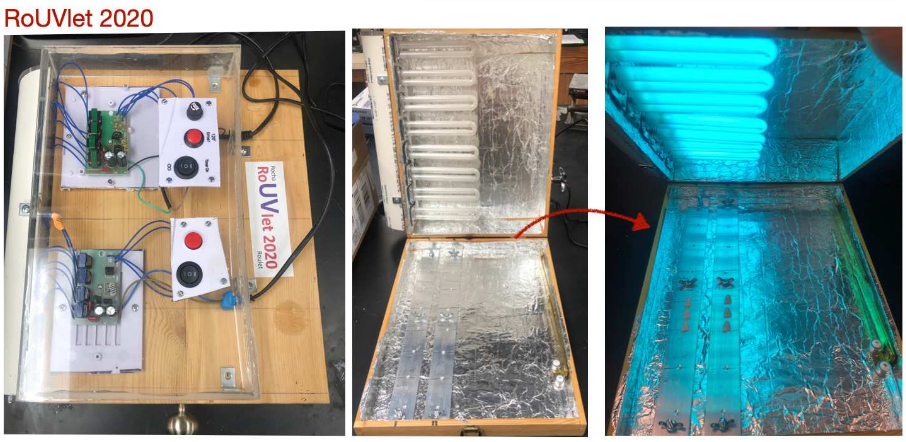
ΔE009,10: ΔE00 + [(ΔL / kL.SL) 2 + (ΔC / kC.SC) 2 + (ΔH / kH.SH) 2 + RT. (ΔC / kC.SC). (ΔH / kH. SH)] 0.5

5.5.5 Artificial aging

The machine used for artificial aging was BR 10 2014 019793-1. That consists of a box format, in which the upper part contains eight tubular-shaped fluorescent lamps (UV-LIGHT) with exposure to 37 °C, and the lower part is the space reserved for the samples (Figure 4).

After the initial color measurement, the samples were aging UV-LIGHT for three cycles. The first cycle is for five days, corresponding to a year of clinical use of the resin composite. The second cycle was five more days and corresponded to two years of clinical use. The last cycle was ten more days; these correspond to five clinical years. The device performed three cycles with UV-B exposure at 37°C. After each cycle, new color measurements were performed to assess the color match at an extended temperature.

Figure 9. Artificial Aging



After the initial color measurement, the samples aged by UV-LIGHT for three cycles. The first cycle was five days, corresponding to one clinical year of daily use. In the second cycle, another five days correspond to two clinical years. The last cycle was ten more days; these correspond to five clinical years. The device was performed three cycles with UV-B exposure at 37°C. After each cycle, new color measurements evaluated the color match at an extended temperature.

6 DEVELOPMENT

RESEARCH ARTICLE #1- Color difference between the Vita Classical Shade Guide and composite veneers using the dual-layer technique) published in June 2022.

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Color difference between the vita classical shade guide and composite veneers using the dual-layer technique

Franciele Floriani [1], Bryce-Arielle Brandfon [2], Nathalie J. Sawczuk [2], Guilherme-Carpena Lopes [3], Mateus-Garcia Rocha [4], Dayane Oliveira [4]

[1] PhD. Candidate at the Federal University of Santa Catarina, Florianópolis, Brazil
[2] Research Volunteer, Department of Restorative Dental Sciences, School of Dentistry, University of Florida, Gainesville, FL, United States
[3] Professor, Department of Operative Dentistry, Federal University of Santa Catarina, Florianópolis, Brazil
[4] Clinical Assistant Professor, Center for Dental Biomaterials, Department of Restorative Dental Sciences, College of Dentistry, University of Florida, Gainesville, FL, United States

Correspondence:
1395 Center Drive D9-6
Gainesville, FL, 32610, EEUU
ffloriani@dental.ufl.edu

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Abstract

Background: The purpose of this *in vitro* study was to evaluate the color difference between the Vita Classical Shade Guide and composite veneers using the dual-layer technique.

Material and Methods: Thirty samples were fabricated using a custom-made mold (Easy Layering Shade Guide Kit, 3M) using two resin composites: Filtek Supreme Ultra (3M); and Estelite Omega (Tokuyama) (n=3). The composite veneers were made by layering the different enamel and body or dentin shades from each composite. The color measurements were taken using a spectrophotometer (Vita Easyshade V®, Vita Zahnfabrik). The ΔE00 between the Vita Classical Shade Guide (Vita Zahnfabrik) and the composite veneers were calculated using the CIEDE2000 formula.

Results: For the composite veneers using Filtek Supreme Ultra, the best match for A1 Vita shade was achieved layering either EA1 with DA2 or DA3; EA2 with DA1 or DA2 (ΔE_{00}= 1.53 ~ 1.96 ± 0.4). For A2 Vita shade the best match would be EA3 with DA3 or EA3 with DA2 (ΔE_{00}= 1.40 ~ 1.85 ± 0.1); or for A3 Vita shade the best match would be EA3 with DA2 2.50±(0.6). For the composite veneers using Estelite Omega, the were no best match for neither A1, A2 or A3 Vita shade (ΔE_{00}> 2.5).

Conclusions: The combination of enamel and dentin shades from Filtek Supreme Ultra provided acceptable color match for A1, A2 and A3 shades from the Vita Shade Guide, while Estelite Omega did not provide acceptable color match for any of the Vita Shade Guide standard shades tested.

Key words: *Color, color matching, optical properties, resin composite, layering.*

Introduction

Color is generally described based on the Munsell System and the International Commission on Illumination (CIE) color/order system (1). According to the Munsell system (1), color has three dimensions: hue, value, and chroma. Hue is how the color is distinguished from another color (red, green, blue, yellow), chroma is the intensity or saturation of the hue, and value is defined as the quantity of light an object reflects when compared to a pure white diffuser and black absorber (amount of black and white) (1,2).

The most common method to select color in dentistry is the visual comparison using shade guides. Although it is a subjective method, it can be precise depending on the clinician's experience (3). However, most composite manufacturers do not have their custom-made shade guides for direct restorations. Instead, the most common practice is to use the Vita Classical Shade Guide as a standard (4). The main concern is that there is not a standard resin composite shade nomenclature (5). Although composite manufacturers name their shades similarly to the Vita Classical Shade Guide nomenclature, it does not necessarily correlate with the Vita shades (6,7). For example, 58% of dental educators complain about the mismatch between the shade guides and the resin composite (5). This discrepancy was tentatively explained by the fact that the shade guide is not made with the same material and thickness as the composite restoration (5,6). Thus, it becomes even more challenging to select and match colors for direct restorations (8).

Besides that, most shade guides do not demonstrate adequate optical properties due to the enamel and dentin layer not having the proper thickness of natural teeth (7). To achieve esthetics in restorations, the optical properties of both the restorative materials and natural teeth should match (8). Resin composite's optical properties are, in fact, strongly influenced by the composite-layering technique, which allows clinicians to emulate natural teeth biological appearance, producing more vital-looking restorations (9). However, with this technique, the shade for the final layer of the restoration is rarely predictable (6,7).

In addition, manufacturers generally do not determine the color thickness of the final enamel layer needed to produce a specific color (8,10). Maintaining the proper range of thicknesses in each layer is necessary for achieving a desirable shade, as changes in the thickness of each layer can significantly alter the final shade of the restoration (8,11). Therefore, this *in-vitro* research aimed to evaluate the color matching when layering enamel and dentin shades using two resin composites in comparison to the Vita Classical Shade Guide standard shades. The null hypothesis was that there would be no difference in color between the Vita Classical Shade Guide and composite veneers using the dual-layer technique with their respective enamel/dentin shades.

Material and Methods

-Composite Veneers using dual-layer technique

Two commercially resin-based composite were used in this study: Filtek Supreme Ultra (3M, St. Paul, MN, United States) and Estelite Omega (Tokuyama, Tokyo, Japan). The composite veeners were made layering the following enamel and dentin/body shades together: EA1/DA1; EA1/DA2; EA1/DA3; EA1/DA4; EA1/BA1; EA1/BA2; EA1/BA3; EA2/DA1; EA2/DA2; EA2/DA3; EA2/DA4; EA2/BA1; EA2/BA2; EA2/BA3; EA3/DA1; EA3/DA2; EA3/DA3; EA3/DA4; EA3/BA1; EA3/BA2; EA3/BA3.

All composite veneers were made using a custom matrix (Easy Layering Shade Guide Kit, 3M, St Paul, MN, United States) with standardized enamel and dentin layer thickness (Fig. 1). First, the enamel shade layer was placed, in which a standardized thickness of 1.1 mm was obtained by using a dentin spacer, as illustrated in Figure 1 (3,4). The enamel shade was light-cured for 20 seconds from the buccal side and 20 seconds from the lingual side (Valo Cordless, 1000 mW/cm^2, Ultradent®, South Jordan, UT, United States) (12,13,14). Then, after removing the dentin spacer, the dentin layer was applied right above the cured enamel layer, with a transparent plastic cable attached in the back. The overall dentin thickness created by the dentin spacer was 1.5 mm in the middle and cervical thirds and 0.4 mm in the incisal third (3,4). The dentin layer was light-cured, following the same protocol described for the enamel layer (3,4).

-Color Measurements

The color was measured according to the CIE L*a*b* color scale relative to the standard illuminant D65 (Macbeth Judge II, X-Rite, Grand Rapids, MI, USA) over a white background using a spectrophotometer (Vita Easyshade V®, Vita Zahnfabrik, Bad Sackingen, Germany) (15). The color coordinate "L*" is an achromatic coordinate and refers to the lightness ranging from black (0) to white (100) (15,16). The coordinate "a*" is a chromatic coordinate that represents the green-red axis, in which negative values indicate green and positive values indicate red hue/chromas. The coordinate "b*" is also a chromatic coordinate that represents the blue-yellow axis, in which negative values indicate blue and positive values indicate yellow hue/chromas (15,17). A Vita Classic shade guide (Vita Zahnfabrik, Bad Sackingen, Germany) was used as a gold standard for the standard shades A1, A2 and A3 (4). The color difference between the composite veneers and the Vita shade guide standard shades was calculated using the CIEDE2000 formula:

$$\Delta E00 =[(\Delta L/kL.SL)2 +(\Delta C/kC.SC)2 +(\Delta H/kH.SH)2 + RT.(\Delta C/kC.SC).(\Delta H/kH.SH)]0.5$$

Where, ΔL, ΔC and ΔH are the differences in lightness, chroma and hue, and R_T is a function (the rotation function) that accounts for the interaction between chroma and hue differences in the blue region (16,17). The weighting functions, S_L, S_C, and S_H are used to adjust the total color difference for variation in the location of the color difference pair in the L, a, and b coordinates. The parametric factors K_L, K_C, and K_H, are correction terms for the experimental conditions, which were set to 1.

Statistical Analysis

For the statistical analysis, data were collected and submitted to a two-way analysis of variance and Tukey's test. These tests were used to assess the mean differences between the

Vita Shade Guide standard shades A1, A2, and A3 and the composite veneers. The ΔE_{00} higher than 2.5 was considered statistically different (α=0.05) (18,19). A power analysis was conducted to determine the sample size to provide a power of at least 0.8 at a significance level of 0.05 (β = 0.2).

Results

Table 1 describes the ΔE_{00} values between the different enamel/dentin shades of the Filtek Supreme Ultra and the Vita Classical Shade Guide standard shades. The results show that for the A1 shade, the best match would be layering EA2 with DA1 or DA2 (ΔE_{00}= 1.53 ± 0.8 and ΔE_{00}= 1.83 ± 0.4, respectively), but layering EA1 with DA2 or DA3 would still provide an acceptable color match (ΔE_{00}= 1.92 ± 0.3 and ΔE_{00}= 1.96 ± 0.4, respectively). For the A2 shade, the best match would be layering EA2 with DA3 (ΔE_{00}= 2.00 ± 0.3) or EA3 with DA3, DA2 or DA1 (ΔE_{00}= 1.40 ± 0.4, ΔE_{00}= 1.85 ± 0.3 and ΔE_{00}= 2.08 ± 0.3, respectively). For the A3 shade, the acceptable color match was EA3 with DA2 2.50 ± (0.6); all others different enamel and dentin combinations provided a ΔE_{00} > 2.5.

Table 2 describes the ΔE_{00} values between the different enamel/dentin shades of the Estelite Omega and the Vita shade guide standard shades. The results show that there was not a satisfactory color match for any of the Vita Shade Guide standard shades. All enamel/dentin shades provided a ΔE_{00} > 2.5 when compared with the Vita Shade Guide standard shades tested.

Table 1: Color difference between Filtek Supreme Ultra enamel/dentin shades and the Vita shade guide standard shades.

Composite	**Vita Shade Guide**		
Shade	**A1**	**A2**	**A3**
EA1/DA1	4.00*±(0.2)	7.28*±(0.1)	8.63*±(0.1)
EA1/DA2	1.92±(0.3)	6.34*±(0.2)	6.83*±(1.2)
EA1/DA3	1.96±(0.4)	4.03*±(0.1)	5.38*±(0.1)
EA1/DA4	4.98*±(0.2)	4.87*±(0.0)	5.95*±(0.0)
EA1/BodyA1	8.04*±(0.4)	10.22*±(0.5)	11.46*±(0.6)
EA1/BodyA2	7.75*±(0.9)	9.60*±(0.6)	10.81*±(0.6)
EA1/BodyA3	6.79*±(0.4)	8.53*±(0.2)	9.73*±(0.2)
EA2/DA1	1.53±(0.8)	4,19*±(0.2)	4.06*±(0.3)
EA2/DA2	1.83±(0.4)	2.79*±(0.3)	3.33*±(0.3)
EA2/DA3	2.66*±(0.5)	2.00±(0.3)	4.41*±(0.1)
EA2/DA4	6.15*±(0.0)	3.84*±(0.1)	8.24*±(0.0)
EA2/BodyA1	6.06*±(0.1)	7.08*±(0.0)	6.67*±(0.3)
EA2/BodyA2	4.68*±(0.6)	5.59*±(0.1)	6.42*±(0.3)
EA2/BodyA3	4.35*±(1.0)	5.21*±(0.4)	3.17*±(0.1)
EA3/DA1	2.91*±(0.1)	2.08±(0.3)	2.96*±(0.1)
EA3/DA2	2.91*±(0.1)	1.85±(0.3)	2.50±(0.6)
EA3/DA3	3.36*±(0.8)	1.40±(0.4)	3.81*±(0.5)
EA3/DA4	5.95*±(0.9)	3.29*±(0.7)	5.13*±(0.4)

EA3/BodyA1	3.99*±(0.2)	5.13*±(0.1)	5.13*±(0.4)
EA3/BodyA2	3.93*±(0.7)	4.03*±(0.4)	2.96*±(0.1)
EA3/BodyA3	5.85*±(1.5)	4.36*±(1.1)	5.15*±(0.8)

*There is statiscal difference in comparison to a $\Delta E_{00} = 2.5$.

Table 2: Color difference between Estelite Omega enamel/dentin shades and the Vita shade guide standard shades.

Composite	**Vita Shade Guide**		
Shade	**A1**	**A2**	**A3**
EA1/DA1	9.33*±(0.0)	12.62*±(0.0)	13.80*±(0.0)
EA1/DA2	5.60*±(0.3)	7.09*±(0.2)	8.19*±(0.2)
EA1/DA3	5.55*±(0.3)	6.74*±(0.3)	7.85*±(0.3)
EA2/DA1	5.13*±(0.2)	5.08*±(0.2)	6.08*±(0.1)
EA2/DA2	5.96*±(0.1)	5.40*±(0.1)	6.24*±(0.2)
EA2/DA3	5.35*±(0.2)	4.48*±(0.5)	5.32*±(0.5)
EA3/DA1	8.95*±(0.0)	5.74*±(0.2)	5.57*±(0.3)
EA3/DA2	8.12*±(0.2)	4.49*±(0.3)	4.02*±(0.3)
EA3/DA3	10.05*±(0.0)	6.85*±(0.0)	6.48*±(0.0)

*There is statiscal difference in comparison to a $\Delta E_{00} = 2.5$.

Discussion

This study aimed to evaluate the color matching when layering different enamel and dentin composite shades and the Vita Classical Shade Guide standard shades A1, A2, and A3. The ΔE_{00} values between the Vita Classical Shade Guide shades and the enamel/dentin composite shades ranged from ΔE_{00}= 1.40 ~ 11.46 ± 0.2 for Filtek Supreme Ultra and from ΔE_{00}= 4.02 ~ 13.80 ± 0.3 for Estelite Omega. Our results agree with the *in-vitro* study by Ferraris *et al*. (2014) that changes in enamel layering can result in entirely different values of chroma, hue, translucency, and opalescence (11).

Although there was an extensive range in the color differences between the different enamel and dentin shades layered and the Vita Classical Shade Guide standard sha- de goal, many of these differences may not be clinically visible. Waller *et al*. (2000) (18) analyzed the perceptibility and acceptability of color differences in a single-tooth implant. In which, dentists perceived no color differences at the restoration level up to a ΔE_{00} of 2.5 (18). Khashayar *et al*. (2014) (20) showed that the color difference establishes an acceptable shade or how much the observer perceives the color difference up to the limit of acceptability, and this value can vary between 2.0 and 4.0. In this study, only a few layered composites matched the keyed Vita Shade Guide standard shade. Out of the 163 combinations, 14 (8.58%) resulted in ΔE_{00} below the 2.5 clinically perceptible limit. The Filtek Supreme Ultra (3M Oral Care) presented better results than the Estelite Omega (Tokuyama) when matching A1, A2, and A3 shades from the Vita Shade Guide. As it can be observed in Table 1, the results allow different clinical reflections, pertinently to the aims of the current study. It was expected for A1 Vita Classical Shade Guide, that the composite veneers with EA1/DA1 would represent a more approximate value to A1 than EA1/ DA2. Similarly, the A2 standard shade in the Vita Classical Shade Guide was closer to the combination of EA2 and DA3 (ΔE_{00} = 2.00 ± 0.3) than EA2 and DA2 (ΔE_{00}= 2.79 ± 0.3). The recommended color combinations of enamel/dentin layering shades were not necessarily the best matches compared to the respective shade of Vita Classical Shade Guide standard.

Moreover, the results showed in Table 2 showed that Estelite Omega (Tokuyama) had no satisfactory color match for any of the Vita Shade Guide standard shades tested. This proves that although composite manufacturers name their shades similarly to the Vita Classical Shade Guide nomenclature, it does not necessarily correlate with the Vita shades (6,7). Still, this can be an excellent composite to mimic lighter B-shades, but not darker A-shades. Therefore, the tested hypothesis that there would be no difference in color when layering enamel/dentin shades that correspond with the Vita Classical Shade Guide shades was rejected.

The final color appearance of a composite restoration depends on many factors, such as the composition of the composite itself (20), the composite's thickness according to the substrate's color underneath it (20,21), pigment amount and type are the main contributory factors for the hue and the chroma of the final shade of the composite (22) Filtek Supreme Ultra contains a combination of silica (20 nm) and zirconia (4-11 nm) as filler particles with clusters formation ranging from 0.6 to 20 microns. The amount of filler particles ranges from 72.5% by weight (55.5% by volume) for translucent shades to 78.5% by weight (63.3% by volume) for opaque shades (22). The Estelite Omega contains spherical filler particles with an average particle size of 200 nanometers. These results agree with the literature that the layering technique decreases translucency with the change in the chroma of the dentin layer (12). Moreover, the amount of filler directly affects the translucency and lightness of the composites (11). Although the composition of the composite can explain an abundance of information, manufacturers do not fully disclose their composites' composition. Indeed, it is known that the composition of composites from different manufacturers varies greatly (23,24).

A defining limitation of this study is that only one thickness of enamel layer at 1.1 mm was evaluated. However, it is known the enamel thickness of anterior teeth only varies between ~0.8 mm and ~1.0 mm (25). This study considered the thickness of 1.0 mm as anterior teeth require more esthetic attention to color matching than other teeth. Moreover, color matching in Dentistry has always been a concerning issue. It is also worthwhile to mention that the range of shades in the shade guides is not consistent with the range of shades in natural teeth (3,7). Dental shade guides typically contain a limited selection of colors compared with those found in human teeth (18). Thus, dentists can achieve better color matching by directly choosing the enamel and dentin shades according to the tooth’s natural enamel and dentin shades to be restored. Further studies are still needed to evaluate further the correlation between layering techniques using other composites and other Vita Shade Guide standard shades.

Conclusion

Within the limitations of this *in vitro* study, this study showed that composite shades do not directly correlate to the Vita Classical Shade Guide shades. Still, it was possible to combine different enamel and dentin shades from Filtek Supreme Ultra to provide acceptable color match for A1, A2 and A3 shades from the Vita Shade Guide. However, Estelite Omega did not provide acceptable color match for any of these Vita Shade Guide standard shades.

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SCIENTIFIC MANUSCRIPT #2: Word file formatted following the guidelines for publication in the Operative Dentistry

Franciele Floriani[1], Dayane Oliveira[2], Mateus Garcia Rocha[2], Guilherme Carpena Lopes[3]

1 PhD candidate, Federal University of Santa Catarina, Department of Dentistry, Florianopolis, SC, Brazil

Clinical Assistant Professor, Department of Prosthodontics, University of IOWA, Iowa City, IA, USA.

2 Clinical Assistant Professor, Center for Dental Biomaterials, Department of Restorative Dental Sciences, University of Florida, Gainesville, FL, USA.

3 Professor, Department of Dentistry, Federal University of Santa Catarina, Florianopolis, SC, Brazil.

*This study was part (chapter #2) of PhD research conducted by Franciele Floriani and the full thesis PDF file is currently in the digital repository at the Federal University of Santa Catarina

Clinical Relevance

Single-shade resin composites demonstrated comparable color matching to universal resin composites in Class V restorations performed on teeth with an A1 color. To restore Class V restorations on teeth with an A3 color, universal composites were still indicated.

SUMMARY

Objective: To evaluate the color stability of single-shade resin composites in Class V restorations after ultra-violet light artificial aging. **Methods and Materials:** Seventy upper central incisor acrylic resin tooth (ART) colors A1 (N=35) and A3 (N=35) were randomly assigned into 7 groups. The color difference (ΔE*) between baseline and after accelerated aging of ART was calculated. Then, standardized Class V cavities were bur-prepared with dimensions: mesio-distal=3.0mm, cervical-occlusal=3.0mm, and depth=1.5mm. Four resin composites were selected as test groups: 3 single-shade resin composites: Palfique Omnichroma (Tokuyama); Charisma One (Heraeus Kulzer); and, Vittra APS Unique (FGM); and, one simplified shade-options universal resin composite (SimpliShade, Kavo Kerr) color Light (indicated to restore tooth color A1) and color Medium (indicated to restore tooth color A3). Universal resin composite (3M Filtek Universal Restorative, 3M Oral Care) colors A1 and A3 was used as control. All cavities were restored using a universal adhesive system and the resin composites in two-increments oblique technique individually light-cured (16J/cm^2) using a poly-wave LED light-unit. After 24h, all specimens were finishing/polishing and underwent accelerated aging protocol through the ultraviolet light-box machine for 120 hours (simulating aprrox. 5 years of clinical service). Then, the color differences between resin composite Class V restorations in ART color A1 and A3 were evaluated in baseline and after aging using a spectrophotometer (CM-700d, Konica Minolta) under a standardized simulated daylight chamber and calculated using CIED2000. Data for the individual color parameters were submitted in baseline and after aging (ΔE) using t-test for paired samples ($\alpha=0.05$) and effect size (Cohen's d) through the Lakens spreadsheet. **Results**: All single-shade resin composites exhibited a blending effect in ART color A1, while universal resin composites demonstrated color matching in ART color A3. Palfique Omnichroma also displayed a blending effect in ART color A3. The aging protocol significantly influenced the color matching of the tested single-shade resin composites. In ART color A1, all single-shade resin composites exhibited acceptable color matching after aging (Palfique Omnichroma ΔE00=1.31, Charisma One ΔE00=2.07, and Vittra APS Unique ΔE00=2.54), which was similar to the control group (3M Filtek Universal Restorative ΔE00=2.44). However, in ART color A3, only Vittra APS Unique (ΔE00=2.4) and SimpliShade (ΔE00=2.23) achieved an acceptable color match, similar to the control group (3M Filtek Universal Restorative ΔE00=2.26). SimpliShade in the color 'Light' did not match ART color A1 (baseline ΔE00=5.07, and after aging ΔE00=4.54). In Class V restorations in ART color A3, there was a statistically significant difference with a large effect size when comparing baseline and post-aging measurements for Vittra APS Unique ($p=0.047$) and Palfique Omnichroma ($p=0.038$).

Conclusions: None of the resin composites achieved color matching in the four simulated combinations (baseline and after aging in ART colors A1 and A3). To restore Class V restorations in teeth of color A1, single-shade resin composites demonstrated comparable color machting to the universal resin composite used as a control after simulated 5 years of clinical

service. In fact, they even outperformed the universal composite in terms of color matching at baseline. Clinicians should avoid use the SimpliShade color Light to restore Class V in teeth color A1. However, they can use color Medium to restore Class V in teeth color A3 which resulted in similar color matching than universal composite. The universal resin composites remains the gold standard for restoring Class V restorations in teeth color A3.

INTRODUCTION

Resin composites are widely elected as dental restorative materials for being aesthetic, conservative, low-cost, and for having good mechanical properties, which makes them suitable for multiple clinical situations.[1] The resin composite optical properties are the central concern when trying to determine which resin composite will result in the most natural-looking restoration.[2-4] In order to reproduce the optical properties of natural teeth, present in enamel and dentin, resin composite materials come in various translucencies and colors. The enamel group has the highest translucency and dentin has the lowest.[5] Furthermore, the conventional resin composite, also known as multi-shade resin composite, has there classifications: “enamel”, “body/universal”, and “dentin”. Using a layering technique, with conventional resin composite, dentists are able to create direct restorations that are not recognized as such for the patients and sometimes for professionals.[5-9] By contrast, nowadays, the terminology of universal resin composite is making a simple and fast technique to accomplish the goal of placing a direct restoration with fewer shade options.[10]

One of the new commercial brands of universal resin composite is 3M Filtek Universal Restorative (3M Oral Care) available in a simplified eight-options Vita Shade Guide and one universal opaque.[11] It is a nanofiller resin composite with fillers combination of non-agglomerated and non-aggregated silica (20 nm) and zirconia (4 to 11 nm) particles and an agglomerated of ytterbium trifluoride filler (100 nm).[11] Accordingly, Paravina and others[12] are suitable options to restore Class I to Class VI cavities.[12] However, the aesthetic result of this material can be influenced by different classifications of cavity preparation.[12] Recently launched SimpliShade (Kavo Kerr, Brea, CA, USA) is a simplified shade-options universal resin composite available in three colors (Light, Medium and Dark) which can be used to restore teeth in all of the 16 Vita Shade Guide colors according to the manufacturer.[13] Only one laboratory study assessed the color match capability of SimpliShade (Kavo Kerr). It examined its three basic colors (Light, Medium, and Dark) against a diverse range of Vita Classic Shade Guide using specimens with a diameter of 10 mm and a thickness of 3 mm were prepared with Herculite XRV composites of various colors (A1E, A2E, A3E, B1E, C2E, C3E, C4E, D4E; n=5) and after light cured for 20 seconds were compared to SimpliShade (Kavo Kerr) in three colors (Light, Medium and Dark).[14] According to this study, SimpliShade (Kavo Kerr) can effectively match a broad spectrum of Vita Classic Shade Guide satisfying the esthetic requirements for a wide array of restorations.[14] However, any clinical trials and *in vitro* studies are available to evaluate color matching and color stability after artificial aging in different cavity classification.

More recently, single-shade build-up technique, the new resins contain nano-fillers, especially nano-spheres that try to mimic the light transmission, diffusion, and reflection of dentin, DEJ, and enamel.[15] This effect is known as the chameleon effect, blending effect or single-shade resin composite.[16] The "chameleon effect" is a term commonly used by manufacturers of resin composites and was first mentioned in a scientific paper in 1991.[12,16] Chameleons are types of lizards that have the ability to change the color of their skins as a protective mechanism.[12] And the term "chameleon effect" has also been used by psychologists to describe a social phenomenon where individuals mimic and take on the behaviors and values of others in order to adjust socially to a newgroup or society.[12] In 2006, a research group studying the perceptual aspect (i.e., the visual component) of color blending between a restoration and its surroundings, referred to the color-matching phenomenon of resin composite as the "blending effect".[12] Later in 2008, the focus of this group shifted toward studying the physical aspects of the blending effect, which are more objective and measurable properties. According to the English dictionary, "blending" refers to the physical mixing and integration between two substances, so they form one mass.[17]

The blending effect is a phenomenon in which a substance lacks pigment but gains color through the reflection of light based on a nanostructure (such as thin films, diffraction gratings, or photonic crystals) with a wavelength below that of visible light. This aesthetic property allows the restorative material to harmonize with its surroundings, and this technique is referred to as the "one-step" system.[12,16,17] This newly developed resin incorporates uniform spherical supra-nanoparticles with a diameter of 260 nm. It has also been reported that resin composites containing uniform spherical filler particles (with a diameter of 260 nm) display structural color and exhibit strong color compatibility with denture teeth of varying colors. The size of these nanoparticle fillers generates hues ranging from red to yellow, mirroring the color of natural human teeth. Furthermore, this filler contributes to a blending effect by diffusing the reflected light from both the filler and the base resin composite's chemical properties, in conjunction with the underlying tooth color.[18]

A variety of factors are known to affect the blending effect: the type and shade of the resin composite,[13,18,19] the amount of color difference between the tooth and the restoration, and the thickness of the restoration.[20,21] Another important consideration is the higher translucency of the resin composite achieved through the omission of pigments and/or the matching of the refractive indices of both the matrix and filler system, which is generally associated with an increased blending effect.[16,22] When the resin composite is placed into the cavity, its optical properties interact with the tooth structure, collectively influencing light interaction and resulting in the blending effect.[15,20,22] Palfique Omnichroma (Tokuyama) is a nanofilled resin composite considered a one-shade resin composite, indicated for use with a flexural strength of 100 MPa.[11,21,22] The composition consists of 75 to 80% filler by weight, with spherical particles ranging from 100 to 400 nm in size, reinforced by wide clusters of pre-polymerized particles spanning from 4 µm to 20 µm.[23] The final color appearance of a composite restoration depends on many factors, such as the composition of the composite itself, composite's thickness according to the substrate's color underneath it, pigment amount and type are the main contributory factors for the hue and the chroma of the final color of the composite.[24] The perceptibility of color differences of a single-tooth perceived no color differences at the level up to a $\Delta E00$ of 2.5. [25]

In an *in vitro* study, De Abreu and others[10] evaluated the color matching of three different resin composites: the single-shade Palfique Omnichroma (Tokuyama), the universal resin composite Filtek Universal (3M Oral Care), and the conventional resin composite Tetric Evoceram (Ivoclar Vivadent) in Class III restorations on central incisors. The study revealed that Palfique Omnichroma (Tokuyama) exhibited a greater color difference in comparison to the universal and conventional resin composites. Notably, the conventional resin composite demonstrated superior color matching when contrasted with both the single-shade and universal resin composites.[10]

In the existing literature, there is a scarcity of studies that have comprehensively examined the color compatibility of single-shade resin composites possessing distinct properties. Similarly, there is a limited body of work comparing different single-shade resin composites with each other, as well as with universal resin composites.[16] Hence, the objectives of this *in vitro* research were: 1) to assess the color match of single-shade resin composites in Class V restorations on teeth colors A1 and colors A3 using universal resin composites as a control group; and, 2) to verify the color match stability after exposure to artificial aging through ultra-violet light. The null hypothesis posited that the aging protocol would have no discernible (i.e., $\Delta E \leq 2.5$) impact on the color matching of resin composite Class V restorations.

Methods and Materials

Sample Size Calculation and Resin Composite Properties

The sample size was determined based on a prior study[26] resulted in five repetitions for each resin composite group. Consequently, a total of 35 specimens were generated for each of the seven groups, encompassing acrylic resin tooth (ART; Delara T8, Heraeus Kulzer, South Bend Indiana, IN, USA) in colors A1 (N=35) and A3 (N=35), as per the Vita Classical Shade Guide. For this research, three distinct single-shade resin composites were chosen: Palfique Omnichroma (Tokuyama, Tokyo, Japan); Charisma One (Heraeus Kulzer, South Bend Indiana, IN, USA); and Vittra APS Unique (FGM, Joinvile, Santa Catarina, Brazil). Additionally, a simplified shade-options universal resin composite, SimpliShade (Kavo Kerr, Brea, CA, USA), available in Light and Medium colors, was included, alongside 3M Filtek Universal Restorative (3M Oral Care, Saint Paul, MN, USA) in colors A1 and A3, serving as controls. These resin composites were employed in ART colors A1 and A3, as outlined in Table 1.

Table 1. Resin Composite characteristics and chemical properties

Resin Composite Brand	**Resin Composite Classification**	**Particle Classification**	**Monomer Matrix**	**Filler type/particle size**	**Filler Content**
Palfique Omnichroma (Tokuyama)	Single-shade composite	Supra-nano filled	UDMA, TEGDMA	Spherical SiO2-ZrO2 Particle size of 260 nm	79 wt%/ 68 vol%
Charisma One (Heraeus Kulzer)	Single-shade composite	Nano-filled composite	UDMA, TCD-DI-HEA, TEGDMA	silica and ytterbium trifluoride	81 wt%/ 64 vol%
Vittra APS Unique (FGM)	Single-shade composite	Nano-filled composite	TEGDMA UDMA	Zirconia fillers (200 nm)	72-80 wt%/ 52-60 vol%
SimpliShade (Kavo Kerr)	Universal composite	Nano-filled composite	Bis-EMA Bis-GMA TEGDMA	Barium glass filler, silica and ytterbium trifluoride	78.5 wt%/ 60 vol%
3M Filtek Universal Restorative (3M Oral Care)	Universal composite	Nano-filled composite	UDMA	Silane treated ceramic, silica, titanium oxide	Silane treated ceramic; (60-100 wt%); Silica; (1-5 wt%)

Abreviations: bis-GMA= bisphenol A glycol dimethacrylate; TEGDMA= triethylene glycol dimethacrylate; UDMA= urethane dimethacrylate; TCD- DI- HEA= 2-propenoic acid; (octahydro-4,7-methano-1H-indene-5-diyl)

A preliminary pilot study was conducted to assess the color stability of teeth (Delara, Heraeus Kulzer) in the standard colors A1 and A3. In this phase, five ART (Delara, Heraeus Kulzer) for colors A1 and A3 were examined at the outset and following an aging process. The findings revealed that the color stability of all ART remained within acceptable levels after aging (with $\Delta E00 \leq 2.5$), indicating that the color alteration was minimal and clinically satisfactory.

Specimens Preparation

Seventy Class V cavities on ART upper central incisor were bur-prepared using a high-speed handpiece (Synea Vision TK 94, W&H Dentalwerk Bürmoos GmbH, Bürmoos, Salzburgo, Austria) with water-coolant and a spherical diamond bur (bur head ø= 1.5 mm, # 1012, KG Sorensen, Barueri, SP, Brazil) was used to allow for the standardization of the cavity preparation. Removable plates were prepared using an silicone essix clear tray (1.0 mm width of Essix C; Dentsply, FL, USA) on a vacuum press machine (Ministar, Scheu, Iserlohn, Nordrhein-Westfalen, Germany with a standard windows (R = 3.0 mm) to standardize preparations position on the specimens.[28] The windows on the removable plates were used as a guide to standardize the bur-preparations, dimensions were verified using a digital caliper (Teknikel, Istanbul, Turkey) and a periodontal probe for depth of mesio-distal = 3.0 mm, cervical-occlusal = 3.0 mm, and depth = 1.5 mm. The teeth were randomly assigned into seven groups of two different colors of Vita Classical Shade Guide, A1 (N=35) and A3 (N=35) and restored with a combination of tested materials as indicated (Figure 1).

Figure 1. Representative image of Class V standard cavity with the following dimensions: mesio-distal = 3.0 mm, cervical-occlusal = 3.0mm, and depth = 1.5mm with removable plates using an silicone essix clear tray (1.0 mm width of Essix C; Dentsply, FL, USA) to standardize the color measurement position on the specimens.

The cavity preparations and restoration procedures were executed by a single operator (FF). After the preparations were completed, the cavities underwent cleaning using air/water spray, followed by drying with compressed air. Subsequently, a universal adhesive system (AdheSE Universal, Ivoclar Vivadent, Schaan, Liechtenstein, Germany) was applied to the cavities. The adhesive was spread and gently rubbed onto the surface for a duration of 20 seconds. An air stream was then directed onto the treated surface for 5 seconds to remove excess solvent, adhering to the guidelines provided by the manufacturer. Light curing was subsequently carried out for 20 seconds on the buccal surface using a Valo polywave light-curing device (Ultradent, South Jordan, Utah, USA) with a radiant power of 800 mW/cm². The radiant power was measured prior to use in each experimental group using a radiometer (Bluephase Meter II, Ivoclar Vivadent).[28] All Class V restorations were done in two oblique resin composite increments individualy light-cured for 20 seconds on the buccal surface. To avoid resin composte excess before the light curing step, a mylar matrix was positioned over the second increment of resin composite. Descrever o acabamento e polimento.

Device for evaluating color

Descrever quantas horas depois de restautado foi realizado a primeira medicao (ie.baseline). Color analysis was conducted using a digital device, specifically the CM-700d spectrophotometer (CM-700d, Konica Minolta, Chiyoda, Tokyo, Japan), as depicted in Figure 3. All color measurements were acquired within a standardized simulated daylight chamber (Model D65, Macbeth The Judge II, Grands Rapids, Michigan, USA), employing a consistent white (L^*=49.07, a^*=6.51, and b^*=8.17) background (L^*=69.07, a^*=7.51, and b^*=9.17). Throughout the analysis, the samples were consistently positioned in the same manner. The background within the standardized simulated daylight chamber (Macbeth The Judge II) was uniformly maintained. Additionally, a consistent operator, sample positioning, and lighting conditions were maintained throughout the process, ensuring standardized procedures were followed for all samples. To initiate the color analysis, white balance calibration was performed to ensure the accuracy of measurements (as illustrated in Figure 2A). Subsequently, a small aperture with a size of 3.0 mm was utilized, specifically tailored to the dimensions of Class V restorations (as shown in Figure 2B). A systematic method for color evaluation on Class V restorations was then executed using the spectrophotometer (Konica Minolta) alongside detachable plates. Prior to each measurement, the spectrophotometer (Konica Minolta) was calibrated to guarantee consistent positioning of readings. The aperture comprehensively encompassed all regions of the Class V restoration (depicted in Figure 2C). The CIELab color parameters (L, a, b) for each specific sample were displayed on the screen (as seen in Figure 2D).

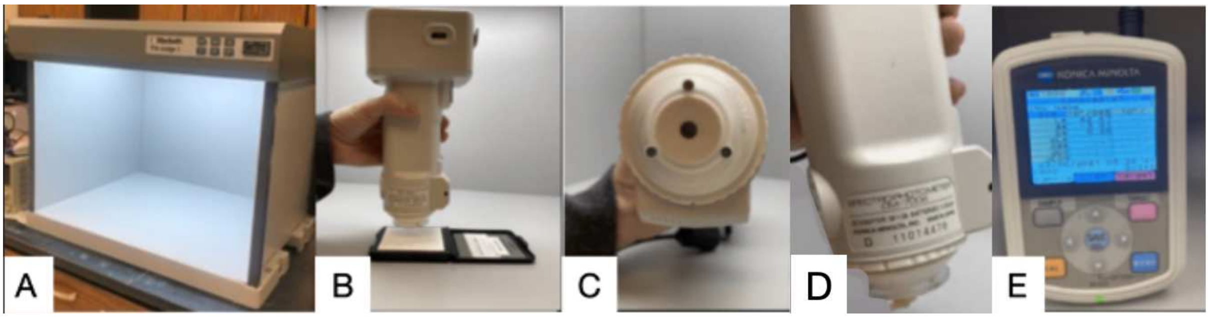

Figure 2. Device protocol sequence for color evaluation. A) Inside an standardized simulated daylight chamber (Macbeth The Judge II, D65) using spectrophotometer (CM-700d, Konica Minolta, Japan). B) First, calibrating the White balance before color analysis. After calibration, there should be a moment of beeps. These beeps mean the calibration is in process. C) Diameter of light color samples measurements in all analyses according to the size of the sample. In this research the bottom was small (3.0 mm). D) Standardized way color evaluation of Class V restorations. E) On the screen, the magnitudes CIELab color parameter, L, a, b for the specific sample.

Color Measurements

Unprepared ART (Delara, Heraeus Kulzer) in two different Vita Classical Shade Guide colors (A1 and A3) were employed for color comparison (n=3). The color variation between the restorations was calculated using the CIEDE2000 formula (ΔE00):[29]

$$\Delta E_{00}= [(\Delta L/k_L.S_L)^2 + (\Delta C/k_C.S_C)^2 + (\Delta H/k_H.S_H)^2 + R_T.(\Delta C/k_C.S_C)\cdot(\Delta H/k_H.S_H)]^{0.5}$$

ΔL, ΔC, and ΔH represent differences in lightness, chroma, and hue, respectively. R_T denotes a function (referred to as the rotation function) that addresses the interplay between chroma and hue discrepancies in the blue region. The weighting factors, S_L, S_C, and S_H, are applied to adjust the overall color difference to account for the color difference pair's positioning in the L, a, and b coordinates. The parameter factors K_L, K_C, and K_H are correction terms for experimental conditions, which were set at 1. In the computation using the CIEDE2000 color difference formula, discontinuities resulting from mean hue and hue-difference calculations were considered, following Sharma's observations.[29] The distinction in each inherent color parameter (ΔL, Δa, and Δb) was established by subtracting each coordinate parameter value pre-aging and immediately post-aging (+a*= red, -a*= green; +b*= yellow, -b*= blue; +L*= white, -L*= black).

Following the initial color measurement, artificial aging was conducted using the BR 10 2014 019793 apparatus.[28] This system comprises an enclosed box structure with eight tubular fluorescent lamps (UV-LIGHT) situated in the upper section, maintained at a temperature of 37 °C. The lower section accommodates the specimens. The samples underwent UV-LIGHT aging for three cycles: The first cycle spanned five days, equivalent to one year of clinical use for resin composites; the second cycle extended for an additional five days, corresponding to two years of clinical use; and the final cycle encompassed ten more days, representing five clinical years of UV-B exposure at 37°C. After each cycle, new color measurements were taken to assess the color match under extended temperature conditions.[31]

Data analyses

The assessment of color changes (ΔE) between the baseline and post-aging conditions was carried out using the t-test for paired samples (α=0.05). Additionally, the effect size (Cohen's d) was computed, employing the spreadsheet provided by Lakens.[32] The effect size scores were interpreted as follows: d=0.2 denoting a small effect size, d=0.5 indicating a moderate effect size, and d=0.8 representing a significant effect size.[33]

RESULTS

Table 2 and Table 3 describe the ΔE_{00} values of single-shade resin composites and universal resin composites in ART colors A1 and A3 and Light and Medium colors, restored in Class V restoration on the upper central incisor in baseline and after artificial aging. There was a statistically significant difference with a large effect size when comparing baseline and after aging for Vittra APS Unique (FGM) ART color A3 (p=0.047) and Palfique Omnichroma (Tokuyama) ART color A3 (p=0.038). There was no statistically significant difference comparing baseline and after aging in Charisma One in ART color A1 (p=0.983). For universal resin composites, SimpliShade Medium and Light colors (p=0.36) and 3M Filtek Universal Restorative colors A1 and A3 (p=0.75) showed no statistically significant difference comparing baseline and after aging in ART color A1. In ART color A3, the universal resin composites, SimpliShade (Kavo Kerr) colors Medium and Light (p=1.09), 3M Filtek Universal Restorative (3M Oral Care) colors A1 and A3 (p=0.47) showed no statistically significant difference comparing baseline and after aging (Table 4 and Figure 3).

Table 2 shows baseline, there was a correlation between the known clinical acceptable $\Delta E_{00} \leq 2.5$. However, it is worth while to mention that all clinically acceptable restorations were in Vittra APS Unique (FGM) (ΔE_{00}=2.01), Palfique Omnichroma (Tokuyama) (ΔE_{00}=1.31), and Charisma One (Heraeus Kulzer) (ΔE_{00}=2.08) in ART color A1. Palfique Omnichroma (Tokuyama) showed clinically acceptable Class V restorations in ART color A3. The universal resin composites, SimpliShade (Kavo Kerr) Medium color (ΔE_{00}=1.55) and 3M Filtek Universal Restorative (3M Oral Care) color A3 (ΔE_{00}=1.48) showed all clinically acceptable restorations in ART color A3.

After aging (Table 3), the color of single-shade resin composites changed, affecting overall color matching in ART colors A1 and A3. Although overall color reduced (p=0.005), single-shade resin composite restorations were still acceptable $\Delta E_{00} \leq 2.5$ in ART. Palfique Omnichroma (Tokuyama) and Charisma One (Heraeus Kulzer) showed clinically acceptable restorations in ART colors A1, ΔE_{00}=1.21 and ΔE_{00}=2.07 respectively. The single-shade resin composite Vittra APS Unique (FGM) showed clinically acceptable restorations in ART color A3 (ΔE_{00}=2.41). The universal composite (3M Filtek Universal Restorative) was clinically acceptable restorations in ART colors A3 (ΔE_{00}=2.26) and A1 (ΔE_{00}=2.44). Vittra APS Unique (FGM) and Palfique Omnichroma (Tokuyama) resin composites presented different color matching capacities (p=0.047 and p=0.038) respectively in ART color A3 (Figure 3).

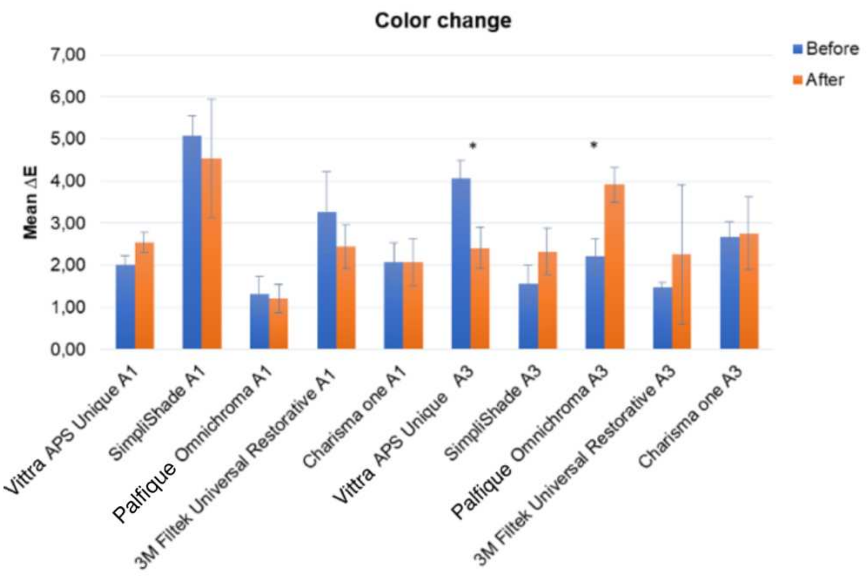

Figure 3. ΔE of before and after aging of single-shade resin-composite and universal resin composite.

DISCUSSION

The present study aimed to assess the initial and long-term color match between single-shade resin composites: 1) Palfique Omnichroma (Tokuyama); 2) Charisma One (Heraeus Kulzer); and, 3) Vittra APS Unique (FGM) and two universal resin composites: 1) SimpliShade (Kavo Kerr) Light and Medium colors; and, 2) 3M Filtek Universal Restorative (3M Oral Care) colors A1 and A3, in ART Class V restorations of colors A1 and A3. Significant disparities in color matching were observed between the single-shade and universal resin composites in Class V ART restorations. The present research failured to reject the null hypothesis, indicating significant differences in color matching between the single-shade and universal resin composites in Class V restorations both at baseline and after aging.

Notably, Palfique Omnichroma (Tokuyama) exhibited the most acceptable color matching at baseline for ART color A1, and continued to demonstrate the best color match in both ART colors A1 and A3 over the long term. For the baseline color matching, approximately 80% and 40% of the restorations showed a clinically imperceptible limit of $\Delta E \leq 2.5$ for A1 and A3 ART colors, respectively. It is worth mentioning that the results of the present study align with the findings of previous research by De Abreu and others[10] and Ersoz and others.[26] These studies reported varying color matching values for different tooth colors with single-shade resin composites in anterior restorations.[10,26] A recent publication suggested that single-shade resin composites exhibit superior color matching in low chroma teeth.[36] These results are in agreement with this present study, which indicate that single-shade resin composite showed a better blending effect in ART color A1 than in color A3. In contrast, the control group demonstrated that 3M Filtek Universal Restorative (3M Oral Care) colors A1 and A3 exhibited the best proper color matching in ART A3 colors. Furthermore, the universal resin composite SimpliShade (Kavo Kerr) in Light and Medium colors also demonstrated favorable color matching in ART color A3. The study by De Abreu and others[10] previously investigated the color matching of single-shade resin composite (Palfique Omnichroma, [Tokuyama]) restorations in anterior teeth, concluding that multi-shade resin composites (Tetric Evoceram, [Ivoclar Vivadent]; Filtek Universal Restorative, [3M Oral Care]; Spectra ST Universal Composite Restorative HV, [Dentsply Sirona]) resulted in higher color matching than single-shade resin composites.[10] The findings of this cited study revealed that Palfique Omnichroma (Tokuyama) exhibited the lowest color matching.[10] The authors posit that one plausible explanation for this outcome could be related to the classification of the cavity restorations. It is suggested that Class III restorations might possess the inherent capability to mitigate the impact of a darker background within the oral cavity. This natural characteristic of Class III restorations could potentially contribute to the observed discrepancy in color match for Palfique Omnichroma (Tokuyama) compared to other materials evaluated in the study.[10]

The current study aligns with a previous in vitro investigation[34] that assessed the color stability of five different materials, including Estelite Omega (Tokuyama), GC Kalore (GC Co.), Venus Pearl (Heraeus Kulzer), Harmonize (Kavo Kerr), and Palfique Omnichroma (Tokuyama). In that study, Palfique Omnichroma (Tokuyama) demonstrated superior color stability and exhibited the lowest overall color change when subjected to artificial aging. Furthermore, a randomized clinical trial was conducted to evaluate the color match, color stability, and retention of the single-shade resin composite Palfique Omnichroma (Tokuyama) in comparison to the nanohybrid resin composite Tetric-N-Ceram (Ivoclar Vivadent) in primary maxillary incisors of twenty-five children over six and twelve month intervals. The comparison revealed no statistically significant differences between the Palfique Omnichroma (Tokuyama) and Tetric-N-Ceram (Ivoclar Vivadent) groups in terms of color match at baseline (p=0.716), color stability (p=0.575 at 6 months and p=0.990 at 12 months), and retention (p=0.153 at 6 months and p=0.226 at 12 months). Interestingly, both groups exhibited better retention of restorations at six months of follow-up compared to one year of follow-up. These findings suggest that the clinical performance of Palfique Omnichroma (Tokuyama) in terms of color match, color stability, and retention was comparable to that of the nanohybrid composite Tetric-N-Ceram (Ivoclar Vivadent) after one year of follow-up.[35]

Iyer and others[33] conducted an in vitro study to assess the color match of three resin composite restorative materials to bi-layered acrylic teeth using both instrumental and visual methods. The instrumental evaluation, performed with a spectrophotometer (Konica Minolta), revealed that Palfique OmniChroma (Tokuyama) and Tetric Prime (Ivoclar Vivadent) exhibited an increase in ΔE00 values as the color value decreased from A3 to B1.[36] This observation suggests that single-shade resin composite systems might achieve better color matching with teeth of higher color values. However, these findings appear to diverge from our study's results, which showed the most favorable color matching for Palfique Omnichroma (Tokuyama) in ART color A1, as indicated in Table 2. This apparent inconsistency might be attributable to differences in experimental conditions, characteristics of the samples, or the particular resin composites that were examined.

Previous study compared color match between single-shade resin composite to multi-shade resin composite in Class I preparations (4.0 mm diameter, 2.0 mm depth) on 15 bi-layered acrylic molar tooth in colors B1, B2, A3, and C3. As a result, Tetric Evoceram (Ivoclar Vivadent) showed the best color match than Palfique Omnichroma (Tokuyama) and TPH Spectra (Dentsply). Palfique Omnichroma (Tokuyama) and TPH Spectra (Dentsply) showed lower ΔE00 values for lighter colors, whereas Tetric Evoceram (Ivoclar Vivadent) showed lower and similar ΔE00 values for all colors.[34] Islam and others[19] evaluated the blending effect of Palfique Omnichroma (Tokuyama) a single-shade resin composite, and, conventional multi-shade resin composite a Beautiful II Enamel (Shofu) in lighter colors (B1, A2, and B2) and darker colors (A3 and A3.5).[20] Their findings are inconsistent with the results reported in this present study, their study reported that Palfique Omnichroma (Tokuyama) blended with lighter colors such as B1, A2, and B2 and showed contrast with darker substrates with colors such as A3 and A3.5.[19] According to Saegusa and others[20] excellent color matching ability was confirmed regardless of artificial teeth color and the depth of the cavity for Palfique Omnichroma (Tokuyama) single-shade resin composite.[20] Moreover, the blending effect diminishes in cases where there is a large contrast between the restoration and the surroundings.[21]

The perceptibility of color differences of a single-tooth perceived no color differences at the level up to a $\Delta E00$ of 2.5. Waller and others[24] analyzed the perceptibility and acceptability of color differences of a single-tooth implant. In which, dentists perceived no color differences at the restoration level up to a ΔE_{00} of 2.5. Khashayar and others[25] showed that the color difference establishes an acceptable shade or how much the observer perceives the color difference up to the limit of acceptability, and this value can vary between 2.0 and 4.0.[25]

The color stability of resin composite materials is influenced not only by their organic matrix and filler composition but also by minor pigment additions and other chemical components. In the case of Palfique Omnichroma (Tokuyama), it is important to note that this particular resin composite does not contain pigments in its formulation, as stated by the manufacturer. As a result of this pigment-free composition, Palfique Omnichroma (Tokuyama) exhibits higher translucency and a closer match of the refractive indices between its matrix and filler system. This unique characteristic can contribute to its favorable color stability and blending effect. Research conducted by Vattanaseangsiri and others[11] delved into the impact of translucency in single-shade resin composite materials over a five-year follow-up period. High translucency materials were found to exhibit an immediate blending effect in resin composites.[11] Additionally, a previous study identified a strong correlation between the blending effect and higher translucency parameter, as well as maintenance of refractive indices. In the case of Palfique Omnichroma (Tokuyama), its refractive index (nd) is reported as 1.47 before polymerization and increases to 1.52 after polymerization.[17]

In addition, BisGMA is a commonly used monomer in resin composite matrices and generally exhibit less water absorption compared to those containing TEGDMA. Additionally, water sorption has been correlated with color differences in resin composites, highlighting the influence of monomer composition on color stability. In the context of specific resin composites, Vittra APS Unique (FGM) and Palfique Omnichroma (Tokuyama) both utilize TEGDMA and UDMA in their resin matrices, which have relatively lower molecular weights compared to BisGMA. Vittra APS Unique (FGM) resin matrix with zirconia fillers of 200 nm (72 % by weight).[21] Palfique Omnichroma (Tokuyama) also contains spherical silicon/zirconium dioxide fillers with a size of 260 nm (79 % by weight).[21] Previous investigations have found a strong correlation between the blending effect and color shifting of resin composites, particularly related to their translucency parameter values.[21] However, it's worth noting that Ersoz and others[23] observed more color change in single-shade resin composites like Palfique Omnichroma (Tokuyama) and Vittra Unique (FGM) compared to multi-shade resin composite systems such as G-aenial A'Chord (GC Co.) and Clearfil Majesty ES-2 Premium (Kuraray). The higher color change in the single-shade composites could be attributed to the presence of TEGDMA in their composition, which may contribute to greater discoloration over time. Overall, these findings emphasize the complex interplay between resin matrix, filler content, monomer composition, and filler size in influencing the color stability and blending effect of dental resin composites. Different studies may yield varying results due to variations in experimental conditions, sample compositions, and methodologies, highlighting the need for comprehensive research and consideration of multiple factors in evaluating dental materials.

These results are in agreement with an in vitro study by Alhamdan and others,[3] who concluded that Palfique Omnichroma (Tokuyama) exhibited comparable color stability to Filtek Z350 (3M Oral Care), a conventional resin composite.[39] A study by Sensi and others[33] demonstrated that Palfique Omnichroma (Tokuyama) showed the least discoloration when subjected to artificial aging.[34] Contradictory results were demonstrated by Bajabaa and others,[39] in which Palfique Omnichroma (Tokuyama) exhibited the highest microleakage compared to the nanohybrid composite Tetric N Ceram (Ivoclar Vivadent). This discrepancy may be explained by the presence of TEGDMA in the resin matrix of Palfique Omnichroma (Tokuyama), which has a lower molecular weight when compared to BisGMA and UDMA in Tetric N Ceram (Ivoclar Vivadent). This difference considerably reduces polymerization shrinkage and microleakage.[40] Microleakage can lead to water sorption, stain penetration,[34] and eventually, discoloration.[40] Palfique Omnichroma (Tokuyama) is also based on urethane dimethacrylate (UDMA) chemistry, a hydrophobic monomer that can increase the hydric stability of the restorative material, making it less susceptible to degradation and further color alteration.[34]

Suh and others[41] reported a positive relationship between filler content and blending effect. In their study, when the filler size remained unchanged, the blending effect of resin composites increased, especially when the filler content reached 80%. The filler contents of the single-shade resin composites in this study varied between 72 and 81 wt%, according to the manufacturers' reports. Charisma One (Heraeus Kulzer) contains UDMA and TEGDMA monomers in its resin matrix, with a filler content of over 80 wt%. An earlier study indicated that the color-matching abilities of experimental composites improved with an increase in filler content. Regarding tooth color perception, at baseline, Charisma One (Heraeus Kulzer) exhibited a ΔE00 of 2.08 in Class V restorations with acrylic tooth color.[41]

Poggio and others[43] conducted a comparison of the color stability of microfilled, nanofilled, nanohybrid, and Ormocer-based resin composites by simulating in vitro exposure to patient-consumed substances such as coffee, soft drink, and red wine, using spectrophotometry analysis. The authors concluded that resin composites exhibited low color stability when subjected to environments containing coffee, cola soft drink, and red wine. Further investigations are warranted to assess the performance of single-shade resin composites under these challenging conditions.[43]

In a previous study, single-shade resin composites demonstrated superior color stability and exhibited the lowest overall color change after accelerated aging.[34] The cited article employed the artificial aging process Q-sun Xenon Test Chamber, subjecting the samples to 102 minutes of light at 63°C black panel temperature followed by 18 minutes of light exposure and water spray per ASTM G155, totaling 300 hours (equivalent to 12.5 days) with no significant differences in color changes observed between accelerated aging times ranging from 300 hours. In current study, artificial aging was induced for 120 hours, reflecting the equivalent of five clinical years, conducted using a patented aging machine (BR 10 2014 019793) comprising a box format.[32] The upper part of the box housed eight tubular-shaped fluorescent lamps (UV-LIGHT) with exposure to 37°C, while the lower part reserved space for the samples.[30,32] The samples underwent aging under UV-LIGHT for three cycles, with the last cycle lasting an additional ten days, corresponding to the equivalent of five clinical years.[30,32] In the present in vitro study, the aging protocol had a discernible impact on the color matching of the single-shade resin composite tested. In ART color A1 all single-shade resin composite tested showed acceptable color matches after aging and in ART color A3 only Vittra APS Unique had an acceptable color match.

Limitations of the present study were the absence of an extremely dark color ART such as colors A4 or B4. However, clinicians frequently opt for resin composite color A3 when restoring the cervical region of teeth, such as resin composite veneers or Class V restorations, aligning with the simulation conducted in this research. In addition, this in vitro study was developed in acrylic teeth. Indeed, studies have explored the color stability of artificial teeth, as a means of reproducing the optical properties of natural teeth for their research.[37] In this context, a pilot study utilizing ART demonstrated color stability that was considered acceptable after aging for all the teeth involved in the study ($\Delta E00 \leq 2.5$). The specific denture acrylic resin teeth used in the study (Delara T8, Heraeus Kulzer) were chosen due to their ability to mimic the optical properties of natural teeth.[38] These acrylic teeth are designed to have a high degree of translucency, which can vary based on different regions of a tooth, such as the cervical, proximal, and incisal areas.[38] However, in the oral cavity, multiple factors influence the way color match is perceived, including the morphology of the tooth, the cavity classification, the influence of the surrounding soft tissues.[39] In addition, natural teeth are polychromatic, multilayered, translucent, and curved, which affects the way light is reflected or scattered.[42] All these factors may affect the way resin composite materials behave clinically as well as how they are evaluated in a research with an digital instrument. Visual thresholds play a crucial role as quality control tools, guiding the evaluation, selection, and assessment of dental materials' clinical performance.[44] Therefore, meticulous planning and execution of research on visual thresholds are imperative, especially when aiming to establish professional standards.[44]

Based on the initial and long-term color match results (as shown in Table 2 and Table 3), it is evident that, in general, the best color matching was achieved with Palfique Omnichroma (Tokuyama) Class V restorations in the ART color A1. Consequently, further investigations should explore the performance of single-shade resin composites in Class V preparations on teeth with darker colors.

CONCLUSIONS

Within the limitations of the present *in vitro* study, the following conclusions can be drawn:

In the context of our experimental study, none of the examined resin composites demonstrated a satisfactory level of color matching across all four simulated conditions, encompassing baseline conditions and after aging simulations involving ART colors A1 and A3. Concerning the Class V restorations in teeth of color A1, it was observed that single-shade resin composites exhibited color matching capabilities similar to the universal resin composite, used as a control, following a simulated of 5-year clinical service period. Notably, the single-shade composites outperformed the universal resin composite at baseline color matching, suggesting potential advantages in achieving superior aesthetic outcomes. However, caution is advised when selecting of SimpliShade resin composite in color Light for Class V restorations in teeth with color A1. Conversely, for teeth with color A3, SimpliShade resin composite color Medium is a viable option for clinicians when restoring Class V restorations. This choice yields color matching results comparable to those achieved using the universal resin composite in teeth of the same color, offering a practical alternative for achieving aesthetically pleasing outcomes in these specific clinical scenarios. It's worth noting that the universal resin composites remains the gold standard for restoring Class V restorations in teeth of color A3.

Tables

Table 2. The color difference between single-shade resin composite and universal resin composite Class V restorations color A1 and A3 at baseline.

Tooth Color		Resin Composite	Color Difference ΔE (±SD)
Class V	A1	Vittra APS Unique	**2.01±(±0.22)***
	A3	Vittra APS Unique	4.07± (0.41)
	A1	Palfique Omnichroma	**1.31± (0.43)***
	A3	Palfique Omnichroma	**2.21± (0.43)***

	A1	Charisma One	**2.08± (0.45)***
	A3	Charisma One	2.66± (0.37)
	A1	3M Filtek Universal Restorative A1	3.26± (0.96)
	A3	3M Filtek Universal Restorative A3	**1.48± (0.12)***
	A1	SimpliShade Light	5.07± (0.48)
	A3	SimpliShade Medium	**1.55± (0.46)***

*Bold there is statiscal difference in comparison to a ΔE_{00} = 2.5

Table 3. The color difference between single-shade resin composite and universal resin composite Class V restorations color A1 and A3 after aging protocol.

Tooth Color	Resin Composite	Color Difference ΔE (±SD)

Class V	A1	Vittra APS Unique	2.54± (0.24)*
	A3	Vittra APS Unique	**2.41± (0.50)***
	A1	Palfique Omnichroma	**1.21± (0.33)***
	A3	Palfique Omnichroma	3.92± (0.41)*
	A1	Charisma One	**2.07± (0.56)***
	A3	Charisma One	2.76± (0.87)
	A1	3M Filtek Universal Restorative A1	**2.44± (0.52)***
	A3	3M Filtek Universal Restorative A3	**2.26± (1.66)***
	A1	SimpliShade Light	4.54± (1.40)

	A3	SimpliShade Medium	**2.23± (0.55)***

*bold there is statiscal difference in comparison to a ΔE_{00} = 2.5.

Table 4. The statistical difference between single-shade resin composite and universal resin composite Class V restorations in ART (Delara, Heraeus Kulzer) colors A1 and A3 at baseline and after aging.

	Tooth Color	Before		After		p-value	Cohen's dz
		Mean	± SD	Mean	± SD		
Vittra APS Unique	**A1**	2.01	0.22	2.54	0.24	0.106	1.63
SimpliShade (Light)	**A1**	5.07	0.48	4.54	1.40	0.598	0.36
Palfique Omnichroma	**A1**	1.31	0.43	1.21	0.33	0.780	0.18
3M Filtek Universal Restorative (A1)	**A1**	3.26	0.96	2.44	0.52	0.323	0.75
Charisma One	**A1**	2.08	0.45	2.07	0.56	0.983	0.01
Vittra APS Unique	**A3**	4.07	0.41	2.41	0.50	**0.047***	**2.57***
SimpliShade (Medium)	**A3**	1.55	0.46	2.33	0.55	0.200	1.09
Palfique Omnichroma	**A3**	2.21	0.43	3.92	0.41	**0.038***	**2.88***
3M Filtek Universal Restorative (A3)	**A3**	1.48	0.12	2.26	1.66	0.502	0.47
Charisma One	**A3**	2.66	0.37	2.76	0.87	0.872	0.11

*Bold numbers represent statiscal difference in comparison to **p>0.05**

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SCIENTIFIC MANUSCRIPT #3: Word file formatted following the guidelines for publication of Journal of International Journal of Esthetic Dentistry

Color Stability of Bulk-Fill Flow Resin Composites After Artificial Aging

Franciele Floriani[1], Mateus Garcia Rocha[2], Dayane Oliveira[2], Guilherme Carpena Lopes[3]

1 Federal University of Santa Catarina, College of Dentistry, Florianópolis, SC, Brazil.

2 Center for Dental Biomaterials, Department of Restorative Dental Sciences, College of Dentistry, University of Florida, Gainesville, FL.

3 Federal University of Santa Catarina, College of Dentistry, Florianopólis, SC, Brazil.

Abstract

Objective: To evaluate the color stability of bulk-fill flow resin composites before and after artificial aging.

Materials and Methods: Three bulk-fill resin composites were selected in color A1 (N=30) and A3 (N=30): 1) Filtek Bulk-Fill Flow (3M Oral Care) color A1 and A3; 2) Venus Bulk-Fill Flow (Kulzer) color A1 and A3; 3) Estelite Bulk-Fill Flow (Tokuyama) color A1 and A3. Then, 60 Class V cavities on upper central incisor were bur-prepared in a standardized way (mesio-distal= 3.0mm, cervical-occlusal=2.0mm, and depth= 4.0 mm) in acrylic teeth (Delara Acrylic Teeth, Heraeus Kulzer) Vita shades color: A1 (N=35) and A3 (N=35). Cavities were restored using a universal adhesive system (AdheSE Universal, Ivoclar Vivadent, Schaan, Liechtenstein) and resin composite in two increments proper light-cured (800 mW/cm^2 / Valo LED Unit, Ultradent). The color difference between resin composite Class V restorations in Delara Acrylic Teeth (Heraeus Kulzer) color A1 and A3 were evaluated before and after aging (using an Ultra Violet light for 120 hours) using a spectrophotometer (CM-700d, Konica Minolta, Japan) under D65 illumination and calculated using CIEDE2000. Data for the individual color parameters were submitted before and after aging (ΔE) using t-test for paired samples and effect size (Cohen's d) through the Lakens spreadsheet. **Results:** Resin composite presented different color matching capacity ($p>0.05$). The color matching of resin composite Class V restorations acceptable after aging (considering $\Delta E_{00} \leq 2.5$) were: Filtek Bulk-Fill Flow color A1 ($\Delta E00=2.45$), Venus Bulk-Fill Flow color A1 ($\Delta E_{00}=2.37$) and Estelite Bulk-Fill Flow color A1 ($\Delta E_{00}=2.22$) in acrylic teeth color A1. There was no statistically significant difference when comparing before and after aging resins ($p>0.05$). **Conclusion**: After aging, all bulk-fill flow resin composites provided acceptable color matching for Class V restorations done on colors A1. The color of all composites changed, affecting the overall color matching of A3 Class V restorations with the exception of Venus Bulk-Fil Flow ($\Delta E_{00}=2.35$). Class V restored with Estelite Bulk-Fill Flow color teeth recorded the best color match ($\Delta E_{00}=2.22$) between the combinations evaluated.

Clinical Significance

The bulk-fill flow resin composites attempt to mimic light transmission. They provided acceptable color matching for Class V restorations done on colors A1 after artificial aging. On Class V teeth color A3, Venus Bulk-Fill Flow is a good option.

Introduction

In restorative dentistry, due to its limited depth of cure and polymerization shrinkage, conventional resin composite must be placed in small increments (2.0 mm).[1,2] This incremental technique provides sufficient light penetration, monomer conversion, and consequently, decreases the polymerization shrinkage.[3,4] Shrinkage stress is influenced by cavity size, cavity configuration, and (C-factor), cavities with a high C-factor will cause greater stresses owing to a greater number of bonded surfaces, as well as, the amount, size and shape of monomer structure, or chemistry of filler particles.[5] The polymerization shrinkage of the conventional resin composite has been associated with poor marginal adaptation, marginal discoloration, white line formation around the restoration, tubercule fractures, microleakage, secondary caries, and postoperative sensitivity.[1,2] Various strategies have been developed to increase the depth of cure. In particular, extensive efforts have been made with new monomers, initiator systems, and filler technology; translucency was also increased for better light penetration and polymerization.[6]

To overcome these problems, a new material class referred to as ‘‘bulk-fill resin composite’’ has been developed.[1,2] The strategy was developed improving: mechanical and biological key material properties, increasing the depth of cure by modifying certain material characteristics.[3] This is the result of incorporating larger filler particles, reducing the amount of pigments, and changing the monomer systems of the composites, thereby giving birth to a "new" resin bulk-fill resin composite category, namely bulk-fill composites.[1,2]

Most notably, increased light transmission through the composite was obtained by changes in material composition, mainly a reduction in filler content, an adjustment of filler size relative to the light wavelength, and an adaptation of the refractive index between the inorganic and organic fractions.[5] To allow the use of these materials in larger increments, changes to the chemistry of monomers, filler particle specifications, and the photoactivation system is required.[5] The bulk-fill resin composites can be placed in increments of up to 4.0 mm.[1,2,5] In other words, bulk-fill resin composites aim to decrease polymerization shrinkage, increase the depth of cure, and avoid the disadvantages of the incremental technique.

The bulk-fill resin composites have shown that depending on their viscosity (low and high). It is recommended that the high-viscosity version of these materials be preheated to improve flowability and adaptability. Abdulmajeed *et al*. *in vitro* research compared the wear and the color stability of high-viscosity bulk-fill resin composite to the conventional resin composites with and without preheating, using the CIEDE2000 formula. The high-viscosity of bulk-fill resin composite displayed superior wear resistance and similar color stability compared with its conventional counterpart.[7] Bilgili *et al* evaluate the color stability, surface microhardness and microhardness ratio of bulk-fill composite resin after immersion in commonly consumed beverages. For that, Color measurements of three bulk-fill (Viscalor, Tetric PowerFill, Fill Up) were performed after polymerization. The specimens were immersed in coffee, cola, red wine and distilled water. Discolorations were recorded after 24 h (T1), 10 days (T2) and 30 days (T3) of immersion. After 30 days, all bulk-fill composites immersed in distilled water, coffee and wine showed clinically unacceptable ΔE00. The resin composite Tetric PowerFill were the most discolored materials among all solutions.[8]

Correia *et al*. evaluated the influence of Class V cavity extension and restorative material on the marginal gap formation, before and after aging, and the theoretical polymerization shrinkage stress distribution in a tooth restoration. Marginal gaps in the specimens fell between approximately 12 µm and 17 µm. However, the regular bulk-fill composite showed less gap formation and better stress distribution around the cavity margin than the regular nano-filled resin composite, regardless of the cavity extension.[9] Baratieri *et al*. in a prospective clinical study with three years of follow-up, evaluated the clinical performance of microfilled (Durafill VS, Heraeus Kulzer) and flow (Natural Flow, DFL) resin composite restorations in Class V non-carious defects of one hundred and five cervical non-carious defects of canines and premolars. After three years of follow-up, Class V restorations using microfilled or flow resin composite achieved no marginal discoloration or secondary caries. The resin composite viscosity did not significantly affect the clinical performance of Class V non-retentive composite restorations.[10]

Kaisarly *et al*. in a randomized clinical trial control study investigate the effectiveness of bulk-fill versus veneered bulk-fill Class II composite restorations. For that, 80 subjects recruited for restoring Class II in one molar bilaterally in the same arch. While one molar was randomly restored with bulk-fill composite, Tetric N-Ceram Bulk-Fill, the contralateral was restored with a bulk-fill composite veneered with an increment of a microhybrid resin composite Tetric-Ceram HB. Over a 24-month interval, none of the test restorations were ranked as clinically unsatisfactory. In terms of functional criteria, clinically excellent restorations were significantly more prevalent in Tetric-Ceram HB than in Tetric N-Ceram Bulk Fill ($p<0.05$).[11]

Therefore, the color stability of the resin composite is an important property that influences its clinical longevity, which remains an inherent challenge to the material. This *in vitro* research aims to evaluate the color stability of bulk-fill flow resin composite after artificial aging in Class V restorations. The null hypothesis was that the color match of bulk-fill flow resin composite would be influenced by aging process in Class V restorations.

Materials and Methods

The sample size was performed using previous studies and resulted in 5 repetitions for each resin composite (COOLEY *et al*., 1987)[12] in a total of 60 specimens (Figure 1). Three bulk-fill resin composites were used: 1) Filtek Universal Bulk-Fill Flow (3M Oral Care, St. Paul, MN, USA) color A1 and A3; 2) Venus Bulk-Fill Flow (Kulzer, Hanau, Germany) color A1 and A3; 3) Estelite Bulk-Fill Flow (Tokuyama Corporation, Tokyo, Japan) color A1 and A3 (Figure 1).

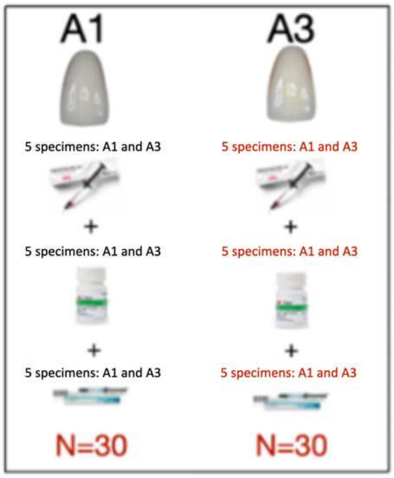

Figure1. Sample groups distribution of bulk-fill flow resin composites (color A1 and color A3) in acrylic teeth (Delara, Heraeus) of two different Vita Classical shades A1 (N=35) and A3 (N=35)

Specimens Preparation

Sixty Class V cavities on upper central incisor were bur-prepared with a spherical diamond bur (bur head ø= 0.1 mm, bur length 19.0 mm, # 1012, KG Sorensen, Barueri, SP, Brazil) at half depth and angled to the tooth long axis with a cervical around prepared (mesio-distal = 3.0 mm, cervical-occlusal = 2.0 mm, and depth = 4.0 mm) (Rocha *et al.*).[13] The measurements were done in a standardized way measured using a clinical probe in acrylic teeth (Delara, Heraeus Kulzer) of two different Vita Classical shades A1 (N=35) and A3 (N=35) (Figure 2).

Figure 2. Representative image of Class V preparation with mesio-distal = 3.0 mm, cervical-occlusal = 2.0 mm, and depth = 4.0 mm dimensions

After the preparations were performed, cavities were cleaned with air/water spray followed by compressed air drying. Then, the cavities were coated with a universal adhesive system (AdheSE Universal, Ivoclar Vivadent, Schaan, Liechtenstein). It was spread and rubbed over the surface for 20 seconds. Then, an air stream was applied for 5 seconds according to the manufacturer's instructions. Then, light curing was performed for 20 seconds on the buccal surface and 20 seconds on the lingual surface (Valo cordless, Ultradent®, South Jordan, Utah). Studies report no statistical difference in the color stability of Valo polywave curing resin composite (Ultradent®, South Jordan, Utah) with this curing protocol.[14] The radiant power was 800 mW/cm^2, commonly reported by manufacturers and used in ISO 1065 (2018) to ensure the composite has adequately been photo-activated.[13,14,15] The output irradiance of the light curing unit was monitored before the use in each group using a radiometer (Bluephase Meter II, Ivoclar Vivadent).

All bulk-fill flow resin composites were inserted in the Class V cavity in one increment and properly light-cured using Valo cordless curing unit (Ultradent®, South Jordan, Utah) applied on Class V composite resin restoration for 20 seconds on the buccal surface and 20 seconds on the lingual surface. Before light curing, a Mylar Matrix was inserted, to prevent irregularities formation or bubbles in the specimen and to avoid the formation of inhibition layers photopolymerization in contact with oxygen.

Device for evaluating color

The color analysis was evaluated through the digital spectrophotometer (CM-700d, Konica Minolta, Japan) (Figure 3). This device was set inside Macbeth The Judge II (Hong Kong, China) (Figure 4) in D65 light. First, calibrating the white balance before color analysis to guarantee the accuracy of the measurements (Figure 3-A). Second, a small 3.0 mm aperture size according to the Class V restoration size (Figure 3-B). After, a standardized way of the color evaluation in Class V restorations to ensure the reading is always in the same position. The aperture covers all areas of the Class V restoration (Figure 3-C). On the screen, the magnitudes CIELab color parameter, L, a, b for the specific sample (Figure 3-D).

The same background (inside Macbeth The Judge II), operator, sample position, and lighting conditions was considered for all samples in a standard way.

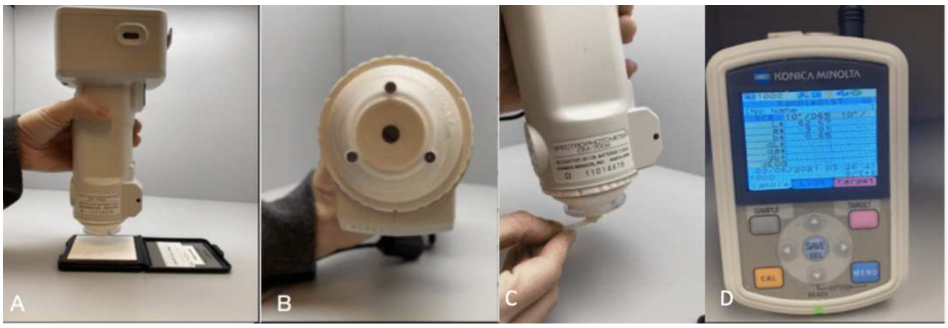

Figure 3. Spectrophotometer CM-700d(Konica Minolta, Japan). A) First, calibrating the White balance before color analysis. After calibration, there should be a moment of beeps. These beeps mean the calibration is in process.   B) Diameter of light color samples

measurements in all analyses according to the size of the sample. In this research the bottom was small. C) Standardized way color evaluation of Class V restorations. D) On the screen, the magnitudes CIELab color parameter, L, a, b for the specific sample.

Color Measurements

The unprepared acrylic teeth of two different Vita Classical shades A1 and A3 shade tested were used for color comparison (n=3). The color difference between the restorations were calculated using the CIED2000 formula (ΔE_{00}):[16,17]

$$\Delta E_{00} = [(\Delta L/k_L.S_L)^2 + (\Delta C/k_C.S_C)^2 + (\Delta H/k_H.S_H)^2 + R_T.(\Delta C/k_C.S_C)\cdot(\Delta H/k_H.S_H)]^{0.5}$$

Where ΔL, ΔC and ΔH are the differences in lightness, chroma and hue, and R_T is a function (the so-called rotation function) that accounts for the interaction between chroma and hue differences in the blue region. The weighting functions, S_L, S_C, and S_H are used to adjust the total color difference for variation in the location of the color difference pair in the L, a, and b coordinates. The parametric factors K_L, K_C, and K_H are correction terms for the experimental conditions, which were set to 1.

All color measurements were taken in a light chamber (Macbeth The Judge II, Hong Kong, China). The Macbeth Judge II lightbox (Figure 4) was used to produce Simulated Daylight (D65), Illuminant A (A), and Cool White Fluorescent (CWF) lighting. Under the standardized D65 illumination was used a spectrophotometer (CM-700d, Konica Minolta, Japan) under a standardized white (L*=49.07, a*=6.51 and b*=8.17) and background (L*=69.07, a*=7.51 and b*=9.17) and always keeping the samples in the same position.

To calculate using the CIEDE2000 color difference formula, discontinuities due to mean hue computation and hue-difference computation were taken into account, as pointed out and characterized by Sharma.[18] The difference in each inherent color parameter were determined as ΔL, Δa, and Δb by subtracting each pre-aged and immediately post-aged coordinate parameter value (+a*= red, -a*= green; +b*= yellow, -b*= blue; +L*= white, -L*= black).

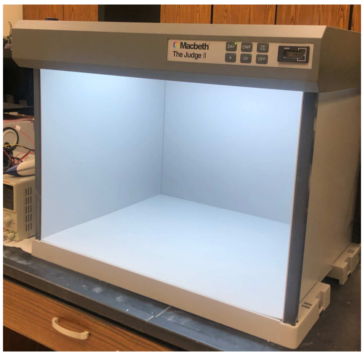

Figure 4. Macbeth The Judge II

After the initial color measurement, a machine (patent BR 10 2014 019793) was used for artificial aging [19] This device consists of a box format, in which the upper part contains eight tubular-shaped fluorescent lamps (UV-LIGHT) with exposure to 37 °C, and the lower part is the space reserved for the samples. The samples were aging UV-LIGHT for three cycles. The first cycle is for five days, corresponding to a year of clinical use of the resin composite.[16,19] The second cycle was five more days and corresponded to two years of clinical use.[16,19] The last cycle was ten more days; these correspond to five clinical years.[16,19] The device performed three cycles with UV-B exposure at 37°C.[19] After each cycle, new color measurements were performed to assess the color match at an extended temperature.

Data analyses

Power analysis was conducted to confirm the sample size to provide a power of 0.8 (a=0.05; b=0.2). Color matching was analyzed using two-way ANOVA and Tukey's test for pairwise comparisons (a=0.05). The two factors analyzed were "resin composite" and "aging process".

The comparison of color changes (ΔE) before and after aging was performed using the t-test for paired samples and effect size (Cohen's d) using the spreadsheet by Lakens (2013). The score for effect size was d=0.2 small; d=0.5 mean; and d=0.8 large (Cohen, 1992).

Results

Resin composites presented different color matching ability ($p>0.05$). Table 1 and Table 2 describe the ΔE_{00} values between the different bulk-fill resin composite (A1 and A3) restorations of the upper central incisor acrylic teeth in A1 and A3 Vita Color shades before/after artificial aging.

Table 1 shows that before aging, there was a correlation between the known clinically acceptable $\Delta E_{00} \leq 2.5$ and the bulk-fill resin composite restorations. However, it is worth while to mention that all clinically acceptable Class V restorations were in Filtek Bulk-Fill Flow Universal color A1 (ΔE_{00}=2.15), Venus Bulk-Fill color A1 (ΔE_{00}=2.47) and Estelite Bulk-Fill Flow color A1 (ΔE_{00}=2.12) in acrylic teeth color A1.

Table 2 shows that after aging, the color of bulk-fill resin composite restorations changed, affecting the overall color matching in A1/A3 acrylic teeth. Although overall color differences were reduced ($p=0.005$), some bulk fill resin composites restorations in acrylic teeth were still acceptable ($\Delta E_{00} \leq 2.5$). Filtek Universal Bulk-Fill Flow color A1 (ΔE_{00}=2.45), Venus Bulk Fill color A1 (ΔE_{00}=2.37) and Estelite Bulk-Fill Flow color A1 (ΔE_{00}=2.22) in acrylic teeth color A1 (Figure 5).

There was no statistically significant difference when comparing before and after aging ($p>0.05$) (Table 3).

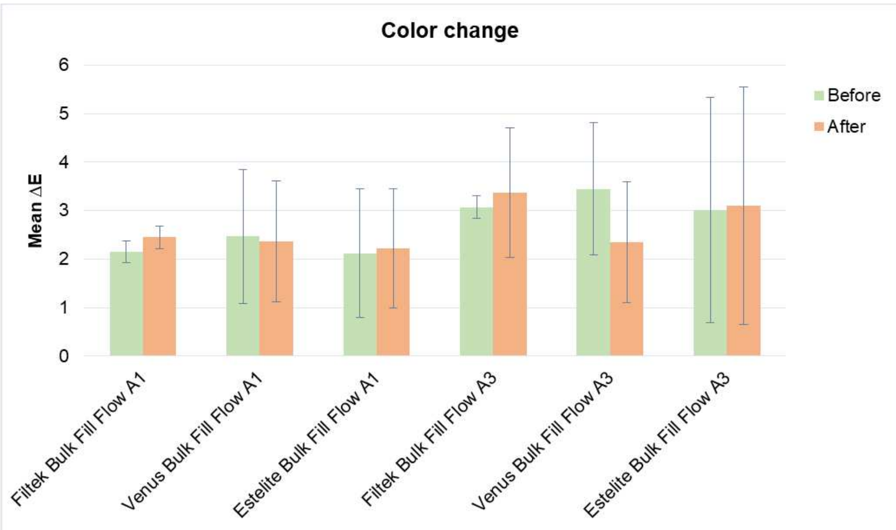

Figure 5. ΔE of before and after aging of Bulk Fill Flow resin composite

Discussion

This study aimed to evaluate the initial and long-term color match between bulk fill flow resin composites. Three bulk-fill flow resin composites (Filtek Universal Bulk Fill Flow [3M Oral Care], Venus Bulk-Fill [Heraeus Kulzer], and Estelite Bulk-Fill [Tokuyama Corporation]) were selected in colors A1 (N=30) and A3 (N=30) to restore Class V cavities in acrylic teeth

(Delara, Heraeus Kulzer) colors A1 and A3. The present study showed significant differences in color matching Class V bulk-fill flow resin composite restorations in acrylic teeth ($p>0.05$). The null hypothesis of this study was rejected, as the differences in color matching of bulk-fill flow resin composite in Class V acrylic teeth restorations.

Previous studies were considering the bulk-fill resin composite a viable option for posterior tooth-colored restorations.[20] Due to the mechanical and physical properties as a result of their unique chemical composition.[20] In Class V restoration, the regular viscosity bulk-fill resin composite showed less gap formation and better stress distribution around the cavity margin than the regular nano-filled resin composite, regardless of the cavity extension.[20] In Class II restoration, the clinical stability of bulk-fill resin composites in layers up to 4.0 mm is comparable to nanohybrid resin composites after 2 years.[21]

In addition, of the physical properties, the color stability of the bulk-fill resin composite is an important property that can characterize resin materials in terms of longevity. Low color stability may represent, indirectly, a low polymer conversion that depends on photoactivation process and may result in material degradation and compromise restoration's longevity.[22] Silva *et al.*[22] evaluated the color stability of bulk-fill resin composite using conventional resin composite as control. As a result, the control group had better color stability compared to bulk fill resin composite.[22]

In the present study, after aging the color of bulk-fill flow resin composite restorations had changed, affecting the overall color matching in Class V restorations in acrylic teeth color A1 and A3.

Although the prepared dimension in 4.0 mm depth designed in the present research may not affect the light-curing processes of the bulk-fill flow resin composite.[13,15] It can facilitate dye penetration by cracking the tooth/restorative interface, favoring microleakage and consequently decreasing the color stability of the resin composite, raising the susceptibility to staining.[22] De Abdulmajeed *et al. in vitro* study evaluated the color stability of bulk-fill resin composite compared with conventional resin composite after aging in samples with 2.0 mm in thickness. As a result, bulk-fill materials showed better color stability than conventional resin composite.[7]

In a clinical study, Balkaya *et al*.[21] evaluated the bulk-fill resin composite in terms of clinical performance in Class II restorations. Related to a margin discoloration, the bulk-fill resin composite showed acceptable clinical performance in Class II cavities.[21] Oter *et al*.[23] in a clinical study, evaluated the one year of clinical performance of bulk-fill resin composite in Class I restorations. In respect to marginal discoloration and marginal integrity, the bulk-fill resin composite restorations can be performed successfully.[23] Barkas *et al*.[25] evaluated the color stability of a bulk-fill (Filtek One Bulk-Fill, 3M ESPE) and a conventional (Filtek Z350 XT, 3M ESPE) composite resin light-cured at different distances, before and after being submitted to staining with a coffee solution. As a result, conventional composite resin presented a higher staining value than bulk-fill composite resin, regardless of the light-activation distance.[25]

Shamszadeh *et al*.[26] compared the color stability of bulk-fill (Tetric EvoCeram Bulk-fill, Ivoclar) and universal (Tetric EvoCeram Universal, Ivoclar) resin composite in different thicknesses simulating *in vitro* the patient consumption of coffee using spectrophotometry analysis. The authors concluded that universal resin composite resulted in higher color stability than bulk-fill resin composite after coffee staining. Also, the discoloration was increased with higher increment thickness. Further investigations should be done to compare bulk-fill flow resin composites in different thicknesses under this challenging environment.[26]

However, there is a lack of data comparing the wear and color stability of bulk-fill flow resin composites. It is possible to assume that, in the present *in vitro* study an acceptable color matching was more forgiven to be achieved in Class V restorations for Vita shade colors A1 regardless of the composite used. Due to the bulk-fill resin composite translucency and characteristics of Class V preparation has more dental structure surrounding.

Conclusion

Within the limitations of this *in vitro* study it was possible to conclude that:

1. The bulk fill flow resin composites tested did not provide acceptable color matching for all the different color A1/A3 of the acrylic teeth;
2. The bulk fill flow resin composite effect overall showed better results in Class V restorations in A1 acrylic teeth color before aging;
3. Color changes in long-term should not worsen initial color matching of bulk fill flow resin composite restorations.

Tables

Table 1. The color difference between bulk fill flow resin composite of Class V restorations in acrylic teeth (Delara Acrylic Teeth, Heraeus Kulzer) color A1/A3 before aging.

Teeth Shade		Composite	Color Difference ΔE (±SD)
Class V	A1	Filtek Bulk Fill Flow A1	**2.15± (0.23)***
	A3	Filtek Bulk Fill Flow A3	3.07± (0.23)
	A1	Venus Bulk Fill Flow A1	**2.47± (1.38)***
	A3	Venus Bulk Fill Flow A3	3.45± (1.36)*
	A1	Estelite Bulk Fill Flow A1	**2.12± (1.33)***
	A3	Estelite Bulk Fill Flow A3	3.01± (2.33)

*There is statiscal difference in comparison to a $\Delta E_{00} = 2.5$

Table 2. The color difference between bulk fill resin composite of Class V restorations in acrylic teeth (Delara Acrylic Teeth, Heraeus Kulzer) color A1/A3 after aging.

Teeth Shade		Resin Composite	Color Difference ΔE (±SD)
Class V	A1	Filtek Bulk Fill Flow A1	**2.45± (0.23)***
	A3	Filtek Bulk Fill Flow A3	3.37± (1.33)*
	A1	Venus Bulk Fill Flow A1	**2.37± (1.25)***
	A3	Venus Bulk Fill Flow A3	**2.35± (1.25)***
	A1	Estelite Bulk Fill Flow A1	**2.22± (1.23)***
	A3	Estelite Bulk Fill Flow A3	3.11± (2.45)*

*There is statiscal difference in comparison to a $\Delta E_{00} = 2.5$

Table 3. The statistical difference between Bulk Fill Flow resin composite of Class V restorations in acrylic teeth (Delara Acrylic Teeth, Heraeus Kulzer) color A1/A3 before and after aging.

	Before		After			
Teeth	**Mean**	**± sd**	**Mean**	**± sd**	**p-value**	**Cohen's dz**
Filtek Bulk Fill Flow A1	2.15	0.23	2.45	0.23	0.251	0.92
Venus Bulk Fill Flow A1	2.47	1.38	2.37	1.25	0.934	0.05
Estelite Bulk Fill Flow A1	2.12	1.33	2.22	1.23	0.933	0.06
Filtek Bulk Fill Flow A3	3.07	0.23	3.37	1.33	0.737	0.22
Venus Bulk Fill Flow A3	3.45	1.36	2.35	1.25	0.411	0.60
Estelite Bulk Fill Flow A3	3.01	2.33	3.11	2.45	0.964	0.03

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SCIENTIFIC MANUSCRIPT #4: Word file formatted following the guidelines for publication of Dental Materials Journal

Does an intraoral scanner properly measure the color matching of resin composite restorations?

Franciele Floriani[1], Guilherme Carpena Lopes[2], Mateus Garcia Rocha[3], Dayane Oliveira[3]

1 Federal University of Santa Catarina, College of Dentistry, Florianopolis, SC, Brazil.

2 Federal University of Santa Catarina, College of Dentistry, Florianopolis, SC, Brazil.

3 Center for Dental Biomaterials, Department of Restorative Dental Sciences, College of Dentistry, University of Florida, Gainesville, FL.

ABSTRACT

Objective: To compare two digital portable tooth color measurement methods (intraoral scanner and spectrophotometer) for resin composite restorations color matching after aging.

Materials and Methods: Twenty central incisor acrylic teeth (Delara, Heraeus Kulzer) colors A1 (N=10) and A3 (N=10) were randomly assigned into two groups: 1) Filtek Bulk Fill (3M Oral Care) color A1 and A3. Then, 20 Class V cavities on upper central incisor were bur-prepared in a standardized way (mesio-distal= 3.0mm, cervical-occlusal=2.0mm, and depth= 4.0 mm) in acrylic teeth (Delara Acrylic Teeth, Heraeus Kulzer) Vita color: A1 (N=10) and A3 (N=10). Cavities were restored using a universal adhesive system (AdheSE Universal, Ivoclar

Vivadent, Schaan, Liechtenstei) in two increments proper light-cured (800 mW/cm^2 / Valo cordless LED Unit, Ultradent). The color difference between resin composite Class V restorations in acrylic teeth color A1 and A3 were evaluated before and after aging (using an Ultra Violet light for 120 hours) using the spectrophotometers (Vita Easyshade Compact, Vita North America, CA, USA) and intraoral (Trios Color Scanner, 3Shape, Copenhagen, Denmark) intraoral scanner under D65 illumination and calculated using CIED2000 formula. Color matching (ΔE_{00}) was analyzed using two-way ANOVA "color measurement device" and "artificial aging" and Tukey's test for pairwise comparisons (a=0.05). **Results:** Before aging, Trios 3-shape intraoral (Trios T3s Scanner, 3Shape) scanner and Vita Easyshade Compact in artificial teeth colors A1 and A3 readings was 100% of repeatability. After aging, the percentage of trueness color recorded in Trios 3-shape intraoral (Trios T3s Scanner, 3Shape) scanner and Vita Easyshade Compact in artificial teeth color A1 readings was 80%. In Class V restoration color A1, Trios 3-Shape intraoral (Trios T3s Scanner, 3Shape) scanner recorded 80% and Vita Easyshade Compact recorded 60% of trueness before aging, in color A3, intraoral (Trios T3s Scanner, 3Shape) scanner recorded 60% and Vita Easyshade recorded 60% of trueness.

Conclusion: Before aging, intraoral (Trios T3s Scanner, 3Shape) scanner and spectrophotometers (Vita Easyshade Compact, Vita North America) in artificial teeth color A1 and A3 readings was 100% of repeatability. After aging, the percentage of trueness color recorded in intraoral (Trios T3s Scanner, 3Shape) scanner and Vita Easyshade Compact in artificial teeth color A1 readings was 80%. After aging, all bulk-fill flow resin composites provided acceptable color matching for Class V restorations done on colors A1.

Clinical significance:

The intraoral (Trios T3s Scanner, 3Shape) scanner can be used as a color evaluation device in resin composite restoration and teeth. However, a slight difference in reproducibility was found according to the color.

INTRODUCTION

The correct tooth color matching of restorations has an important role in the patient's acceptance and satisfaction since it is closely related to the final appearance of the restoration and its consequent mimicry to the rest of the tooth.[1] However, tooth color matching is challenging for both dentists and dental technicians.[2-4]

In general, tooth color can be evaluated by two distinct methods, including the visual method and the instrumental techniques.[5] In the visual method, conventional color guides are used as references, and the color matching is obtained by the unaided eye.[3,5] Despite the popularity of this method, it is highly subjective and inconsistent.[6,7] In addition, the visual method is influenced by the light source used during the procedure, the operator's experience,[3,8-11] the incompatibility and lack of standardization between the color guide and the restorative material,[12] among others. On the other hand, the instrumental color matching methods based on spectrophotometers and colorimeters are more precise.[5] Among the available machines, Vita Easyshade Compact (Vita North America, CA, USA) is one of the most popular equipment. It is wireless, small, and portable handheld[5] that presented superior results when compared to four other brands of 106 spectrophotometers.[7] A previous study[13] had also shown that this equipment is more precise and reliable for *in vitro* and *in vivo* tests. On the other hand, in comparison to the visual method, the spectrophotometer is expensive and complex, and the color measurement is operator dependent, i.e., persons trained to use the equipment achieve the correct color more precisely than a person not familiar with the instrument.[14] Additionally, the spectrophotometric analysis (SPM) is affected by the environment conditions including the light color and intensity, the background and quality of equipment.[15-18] Besides and most important, it is difficult to measure tooth color in a clinical environment.[7,19]

In order to overcome the difficulties related to the SPM, a different instrumental color matching method has been increasing popularity in the last fifteen years.[20,21] It is based on the analysis of standardized digital tooth photographs, providing a practical and consistent method of tooth color selection that can be easily transmitted to the dental laboratory technician.[2,4,22] A recent study reported[21] that color matching assisted by digital photographs and computer software may be significantly more reliable than the conventional visual method.

In this context, with the recent progression of the use of digital technology in dentistry, clinicians are given the opportunity to work in a virtual environment and to improve the diagnosis, planning, and treatment of cases using Intra-oral scan.[23] In addition, an Trios 3-shape intraoral scanner (Trios T3s Scanner, 3Shape, Copenhagen, Denmark), offers a color selection feature. With this device, it is possible to determine the color in various regions of the clinical crown of the tooth of the digital impression taken by the scanner.[24] Previous studies suggested that Trios 3-shape intraoral scanner (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) could be used for color determination as an alternative to a Vita Easyshade Compact spectrophotometer.[25]

However, whether an intraoral digital scanner with an integrated color-takin function can substitute for colorimeters or spectrophotometers is unclear.[25] Rutkunas *et al.* in clinical research revealed the Trios 3-shape intraoral scanner (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) does not exactly match color obtained by spectrophotometric (SPM) analysis.[25]

Thus, in order to standardize the method, the objective of this study was to compare and correlate the two digital tooth color matching methods Trios 3-shape intraoral scanner (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) and spectrophotometric analysis in an *in vitro* environment. The null hypothesis was that color coordinates would not be influenced by the color analysis methods.

Materials and Methods

The sample size was performed using previous studies and resulted in 5 repetitions for each resin composite (COOLEY *et al*., 1987; LUCE and CAMPBELL, 1988; VICHI *et al*., 2004)[26] in a total of 60 specimens Figure 1. Three Bulk Fill Resin Composite 1) Filtek Bulk Fill (3M Oral Care, St. Paul, MN, USA) color A1 and A3.

Specimens Preparation

Then, 20 Class V preparation on upper central incisor were bur-prepared in a standardized way depth of 2.9 mm, cervical/incisal distance of 4 mm, and margins located in the enamel 1 mm above the cement enamel junction were prepared in acrylic teeth (Delara , Heraeus Kulzer) colors: A1 (N=10) and A3 (N=10). The cavities' depths were validated using a periodontal probe, while the mesiodistal and cervical/incisal distances were measured using a stereomicroscope Figure 1.

Figure 1. Illustration of class V preparation

Subsequent washing and drying with air to achieve the enamel-etched appearance. The universal adhesive (AdheSE Universal, Ivoclar Vivadent) was spread and rubbed over the surface for 20 seconds. Then, an air stream was applied for 5 according to the manufacturer's instructions using a LED light-cure unit (Valo cordless, Ultradent®, South Jordan, Utah). The resin composite was inserted in one increment to restore Class V preparation. Before light curing, a polyester matrix was inserted, followed by a microscope slide, to prevent irregularities formation or bubbles in the specimen and to avoid the formation of inhibition layers photopolymerization in contact with oxygen. Then, light curing will be performed for 20 s on the buccal surface and 20 s on the lingual surface. Studies report no statistical difference in the color stability of Valo cordless curing composite resin (Ultradent®, South Jordan, Utah) with this curing protocol (Strazzi-Sahyon *et al*., 2020; Rocha *et al*., 2018).[27] The radiant power was 800 mW/cm^2, commonly reported by manufacturers and used in ISO 1065 (2018) to ensure the composite has adequately been photo-activated.[28]

Device for color evaluation

The color differences between composites in Class V restorations and unprepared Delara Acrylic Teeth (Heraeus Kulzer) color A1 and A3 were evaluated before and after aging (using an Ultraviolet light for 120 hours) using a spectrophotometer Vita Easyshade Compact (Vita North America, CA, USA) and intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner under D65 illumination and calculated using CIED2000 in teeth and in Class V restorations.

Intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) Scanner

First, the operating system of the scanner and the color determination module were calibrated. The corresponding central maxillary incisor was scanned from the vestibular, incisal and palatine aspect. After completing the recording, the central, vestibular area was marked and the 3D-MASTER color displayed. Following all measurements, the 3D-MASTER values from the visual methods and from the Trios®Color Intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner were converted into L, C, h, a and b values with the help of the conversion table.

Color Measurements

The unprepared acrylic teeth of two different Vita Classical colors A1 and A3 shade tested were used for color comparison (n=3). The color difference between the restorations were calculated using the CIEDE2000 formula (ΔE_{00}):[29]

$$\Delta E_{00} = [(\Delta L/k_L.S_L)^2 + (\Delta C/k_C.S_C)^2 + (\Delta H/k_H.S_H)^2 + R_T.(\Delta C/k_C.S_C)\cdot(\Delta H/k_H.S_H)]^{0.5}$$

Where ΔL, ΔC and ΔH are the differences in lightness, chroma and hue, and R_T is a function (the so-called rotation function) that accounts for the interaction between chroma and hue differences in the blue region. The weighting functions, S_L, S_C, and S_H are used to adjust the total color difference for variation in the location of the color difference pair in the L, a, and b coordinates. The parametric factors K_L, K_C, and K_H are correction terms for the experimental conditions, which were set to 1.

All color measurements were taken in a light chamber (Macbeth the Judge II, Hong Kong, China) (Figure 2). The Macbeth Judge II lightbox was used to produce simulated daylight (D65), illuminant A (A) and cool white fluorescent (CWF) lighting.Under the standardized D65 illumination was used a spectrophotometer (Vita Easyshade Compact (Vita North America, CA, USA) under a standardized white (L*=49.07, a*=6.51 and b*=8.17 and background (L*=69.07, a*=7.51 and b*=9.17 and always keeping the samples in the same position.

To calculate using the CIEDE2000 color difference formula, discontinuities due to mean hue computation and hue-difference computation were taken into account,[2] as pointed out and characterized by Sharma.[29] The difference in each inherent color parameter were determined as

ΔL, Δa and Δb by subtracting each pre-aged and immediately post-aged coordinate parameter value (+a*= red, -a*= green; +b*= yellow, -b*= blue; +L*= white, -L*= black).

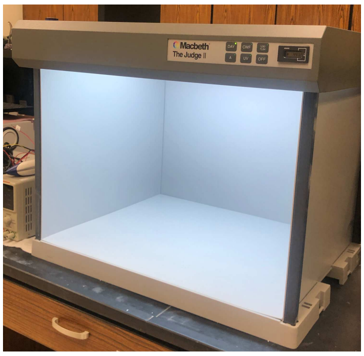

Figure 2. Macbeth The Judge II

After the initial color measurement, the machine used for artificial aging was BR 10 2014 019793.[24] That consists of a box format, in which the upper part contains eight tubular-shaped fluorescent lamps (UV-LIGHT) with exposure to 37 °C, and the lower part is the space reserved for the samples. The samples were aging UV-LIGHT for three cycles. The first cycle is for five days, corresponding to a year of clinical use of the composite resin.[30] The second cycle was five more days and corresponded to two years of clinical use.[30] The last cycle was ten more days; these correspond to five clinical years.[30] The device BR 10 2014 019793 performing three cycles with UV-B exposure at 37°C.[31] After each cycle, new color measurements were performed to assess the color match at an extended temperature.

Data analyses

Power analysis was conducted to confirm sample size to provide a power of 0.8 (a=0.05; b=0.2). Color matching was analyzed using two-way ANOVA "color measurement device" and "artificial aging" and Tukey's test for pairwise comparisons (a=0.05). The two factors analyzed were the teeth before and after aging.

Results

There was no statistically significant difference when comparing color measurement devices ($p>0.05$).

A slight difference was observed in the distributions of tooth color recorded as the spectrophotometer (Vita Easyshade Compact (Vita North America, CA, USA) and intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner under D65 illumination. The percentage of trueness in intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner and spectrophotometer (Vita Easyshade Compact (Vita North America, CA, USA) in artificial teeth colors A1 and A3 readings was 100%. When the color was recorded in Class V restoration, intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner recorded 80% of trueness, and spectrophotometer (Vita Easyshade Compact (Vita North America, CA, USA) recorded 60% of trueness before aging in color A1 and 60% in color A3 (Table 1).
After aging, the percentage of trueness color recorded in intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner and spectrophotometer (Vita Easyshade Compact (Vita North America, CA, USA) in artificial teeth color A1 readings was 80%, when the color was recorded in Class V restoration, intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner and spectrophotometer (Vita Easyshade Compact (Vita North America, CA, USA) recorded 60% of trueness. In artificial teeth color A3, intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner trueness was 60% in artificial teeth and Class V restoration;

spectrophotometer (Vita Easyshade Compact (Vita North America, CA, USA) showed 60% trueness in artificial teeth and 40% trueness in Class V restoration**.**

Tables

Table 1. The color difference between Delara Acrylic Teeth -T46 (Kulzer, South Blend, USA) color A1/A3 using spectrophotometer (Vita Easyshade Compact (Vita North America, CA, USA) and Intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner before artificial aging.

	TRIOS		VITA EASYSHADE COMPACT	
FILTEK BULK FILL A1	Teeth A1	Class V	Teeth A1	Class V
	2L1.5	2M2	2L1.5	1M2
	2L1.5	3L1.5	2L1.5	2L1.5
	2L1.5	3L1.5	2L1.5	3L1.5
	2L1.5	3L1.5	2L1.5	3L1.5
	2L1.5	3L1.5	2L1.5	3L1.5
FILTEK BULK FILL A3	Teeth A3	Class V	Teeth A3	Class V
	3L1.5	3L1.5	3L1.5	2L1.5
	3L1.5	2M2	3L1.5	1M2
	3L1.5	2M2	3L1.5	2M2
	3L1.5	2M2	3L1.5	1M2
	3L1.5	2M2	3L1.5	1M2

Table 2. The color difference between Delara Acrylic Teeth -T46 (Kulzer LLC, South Blend, USA) color A1/A3 using spectrophotometer (Vita Easyshade Compact, Vita North America, CA, USA) and Intraoral (Trios T3s Scanner, 3Shape, Copenhagen, Denmark) scanner Trios after artificial aging.

	TRIOS		**VITA EASYSHADE COMPACT**	
FILTEK BULK FILL A1	Teeth A1	Class V	Teeth A1	Class V
	2L1.5	4L1.5	2L1.5	4L1.5
	2L1.5	4M1	2L1.5	3L1.5
	3L1.5	3L1.5	3L1.5	4L1.5
	2L1.5	3L1.5	2L1.5	4L1.5
	2L1.5	3L1.5	2L1.5	3L1.5
FILTEK BULK FILL A3	Teeth A3	Class V	Teeth A3	Class V
	3L1.5	4L1.5	3L1.5	4L1.5
	3L1.5	3M2	3L1.5	3M2
	4L1.5	3M2	4L1.5	3M2
	3L1.5	4L1.5	3L1.5	3L1.5
	4L1.5	4L1.5	4L1.5	3L1.5

Discussion

The results of this *in vitro* study indicated that the trueness of using intraoral (Trios T3s Scanner,) scanner was more accurate than spectrophotometer (Vita Easyshade Compact) for color determination. The null hypothesis was rejected as color coordinates were influenced by the color analysis methods. In previous study, the scanner initially appears to attain a disappointing result with a measuring accuracy of 43.9% compared to the reference system spectrophotometer (Vita Easyshade Compact) (92.6%).[32] However, while improvements in scanner software were happening, digital intraoral scanners are playing an increasingly important role in color determination in dentistry.[25] High-precision digital color determination could facilitate the workflow in everyday dentistry and replace the conventional visual method.[33]

Literature research reveals a lack of investigation of different intraoral scanners regarding color determination, even though they assume an important role in clinical application. The intraoral (Trios T3s Scanner) scanner is considered a pioneer in the development of color determination software, and several studies investigate this tool in comparison with the visual method and/or with the spectrophotometer. [10,33,34]

The present study failure to reject the second research null hypothesis. Considering the repeatability of the utilized an intraoral (Trios T3s Scanner) scanner when color determination was repeated three times, Trios®Color scanner exhibits the percentage of trueness in intraoral (Trios T3s Scanner) scanner and spectrophotometer (Vita Easyshade Compact) in artificial teeth colors A1 and A3 readings was 100%. However, the results were better on artificial teeth than on Class V restorations a slightly higher reproducibility (80%) with corresponding to the Vita 3D-MASTER Shade Guide values than the spectrophotometer (Vita Easyshade Compact) (60%) before aging (Table 1). After aging, the percentage of trueness color recorded by an intraoral (Trios T3s Scanner) scanner and spectrophotometer (Vita Easyshade Compact) in artificial teeth color A1 readings was 80%. When the color was recorded in Class V restoration, an intraoral (Trios T3s Scanner) scanner and spectrophotometer (Vita Easyshade Compact) recorded 60% of trueness. In artificial teeth color A3, an intraoral (Trios T3s Scanner) scanner trueness was 60% in artificial teeth and Class V restoration; spectrophotometer (Vita Easyshade Compact) showed 60% trueness in artificial teeth and 40% trueness in Class V restoration. Therefore, different materials surfaces would interfere with the intraoral (Trios T3s Scanner) scanner trueness.

This present study agrees with a previous literature review that evaluated the accuracy, repeatability, and reproducibility of intra-oral scanners in digital color determination and revealed the absence of significant difference between color determination with intraoral (Trios T3s Scanner) scanner versus visual color determination in terms of accuracy and repeatability.[35] Despite differences in the study designs, in the present study, the use of the visual method was not evaluated. Brandt *et al.*[10] in a clinical study evaluated tooth color determination using an intraoral (Trios T3s Scanner) scanner and a spectrophotometer (Vita Easyshade Compact). It showed to be a comparable method of color tooth analysis to the reference instrument. Huang *et al.,* an in vivo study, evaluated the repeatability of an intraoral (Trios T3s Scanner) scanner and spectrophotometer (Vita Easyshade Compact). The repeatability of the spectrophotometer

(Vita Easyshade Compact) was the poorest ($p < 0.01$) than the intraoral (Trios T3s Scanner) scanner.[34]

Abu-Hossin *et al*. evaluated digital methods in color teeth selection and showed substantial agreement in repeatability for intraoral (Trios T3s Scanner) scanner ($p = 0.612$) and moderate agreement for Cerec Omnicam ($p = 0.474$).[33] Another in vitro study also investigated the repeatability and reproducibility of intraoral scanners, including intraoral (Trios T3s Scanner) scanner and Cerec Omnicam. The Cerec Omnicam showed the lowest accuracy when comparing the tested intraoral scanners, which could be related to lower scanning accuracy.[36]

Measurement using a spectrophotometer is associated with relatively few error sources owing to its easy handling and fully automated operation. It is not without reason that it is described in the literature as the most reliable instrument for tooth color determination.[37] A potentially erroneous setting of the instrument could be avoided through calibration before every measurement.[37] The instrument is furthermore used without a template in everyday practice. Nevertheless, the repeatability checked in this study may have potentially influenced negatively this. Overall, the two methods were conducted under similar conditions in order to represent a realistic comparison in everyday practice.

Future studies should continue to test the new digital scanner software in terms of accuracy and repeatability of color selection. In this context, future studies should be investigated whether newer intraoral scanners show a technical improvement in color determination and may adequately replace the visual method. Further, *in vivo* studies are needed to evaluate the color determination in different polish materials; and precise color selection in complete denture and keratinized tissue color selection, for example. Comparisons should be made between intraoral scanners, spectrophotometers, and visual determination by dental students.

Conclusion

Within the limitations of this *in vitro* study it was possible to conclude that:

1. Before aging, intraoral (Trios T3s Scanner) scanner and spectrophotometer (Vita Easyshade Compact) in artificial teeth colors A1 and A3 readings were 100% of repeatability.
2. After aging, the percentage of trueness color recorded in intraoral (Trios T3s Scanner) scanner and spectrophotometer (Vita Easyshade Compact) in artificial teeth color A1 readings was 80%.
3. After aging, the percentage of trueness color recorded in intraoral (Trios T3s Scanner) scanner and spectrophotometer (Vita Easyshade Compact) in artificial teeth color A3 readings was 60% and spectrophotometer (Vita Easyshade Compact) showed 60% trueness in artificial teeth.
4. In Class V restoration, color A1, intraoral (Trios T3s Scanner) scanner recorded 80% and spectrophotometer (Vita Easyshade Compact) recorded 60% of trueness before aging,
5. In Class V restoration, color A3, intraoral (Trios T3s Scanner) scanner recorded 60% and spectrophotometer (Vita Easyshade Compact) recorded 60% of trueness.

6. After aging, the color of the bulk-fill flow resin composite restorations changed, affecting the overall color matching in Class V restorations in acrylic teeth colors A1 and A3.

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