ORIGINAL ARTICLE E-ONLY AJO-DO

Evaluation of the color stability of attachments made with different resin composites

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Introduction: Coloring solutions—such as coffee and cola, frequently consumed daily—cause coloration of attachments made with resin composites. This may reduce the motivation for clear aligner treatment, often preferred by patients with esthetic concerns. This study aimed to compare color changes of orthodontic attachments made with 3 different composite resins. **Methods:** A total of 90 premolar teeth (n = 10) extracted for orthodontic reasons were used. All teeth were embedded in plaster models to imitate the arch shape and scanned with an intraoral scanner. Horizontal rectangular attachments were placed on each tooth by printing the attachment template obtained using digital models. Three composite resins: Omnichroma, GC Aligner Connect, and Tetric PowerFlow were used to prepare the attachments. The models prepared in arc-shaped in each composite group were divided into subgroups and kept in 3 different solutions (coffee, cola, and distilled water) in the incubator at 37 ± 1°C. The models were photographed at baseline and 28 days later with the Smile-Lite MDP device. L, a, and b values were obtained with Digital Color Meter (version 5.22; Apple, Cupertino, Calif). CIEDE2000 formula (ΔE00) was used to evaluate color changes. In addition, models were scanned for color determination at baseline and 28 days later with the 3Shape intraoral scanner. **Results:** There were significant color differences between solutions ($P < 0.05$). **Conclusions:** Attachments can be colored easily. Patients should be warned against coloring solutions at the beginning of the treatment, and their eating and drinking habits should be regulated. (Am J Orthod Dentofacial Orthop 2023;164:e121-e128)

In the last 2 decades, there have been developments in modern orthodontics with new materials and new techniques.[1] Clear Aligners, one of the latest developments, is increasing in popularity by offering a more esthetic, hygienic, and comfortable treatment option.[2] In addition, another advantage is it can be removed while eating and teeth cleaning, so it is thought that clear aligners are better for periodontal health than fixed orthodontic appliances.[3] Clear aligner treatment is a good alternative for adult patients with esthetic concerns and high demands for treatment with invisible devices because of the increasing living standards in recent years.[4] Attachments are often needed support elements to increase the predictability and effectiveness of tooth movement during treatment with clear aligners.[5] They are made of resin composites bonded to tooth enamel to create a connection point for the aligner.

Their designs are predetermined at the planning stage and transferred to the tooth surface with the attachment templates. Esthetics and high mechanical properties are required for attachments. In addition, it should be in the same shade as the applied tooth or translucent enough to reflect its color and be resistant to discoloration.[6] During this application, resin attachments are not subjected to traditional polishing as they actively support the tooth movement.[7] Surface roughness may cause further discoloration of composite resins.[8]

Ward et al[9] reported that the conventional light device (1200 mW/cm^2) and the intense light device (3000-3200 mW/cm^2) were found to be similar bond failure rates. It is thought that using composite resins that polymerize quickly with intense light devices will provide an advantage in time. However, it may cause an increase in the amount of residual monomer.[10]

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Table I. Materials used in this study

Materials	*Composition*	*Filler, w/v%*	*Manufacturer*
Omnichroma	UDMA, TEG-DMA, Uniform size supra-nano spherical fillers (260 nm spherical SiO_2-ZrO_2)	79/68	Tokuyama Dental Corporation, Tokyo, Japan
GC Aligner Connect	Octahydro-4,7-methano-1H-(indenediyl) bis (methylene) bismethacrylate, 1,3,5-Triazine-2,4,6-triamine, polymer with formaldehyde, 2,2'-ethylenedioxydiethyl dimethacrylate, 2-(2H-benzotriazol-2-yl)-p-cresol, UDMA... (Not all content is shared)	NA	GC Corporation, Tokyo, Japan
Tetric PowerFlow	Bis-GMA, Bis-EMA, UDMA, Bis-PMA, DCP, D3MA. Fillers; Barium glass, Ytterbium, Trifluoride, Copolymer, Mixed oxide (SiO_2/ZrO2)	79/53-54	Ivoclar Vivadent Ltd, São Paulo, Brazil)

UDMA, urethane dimethacrylate; *TEG-DMA*, triethyleneglycol dimethacrylate; *SiO_2*, silicon dioxide; *ZrO_2*, zirconium dioxide; *Bis-GMA*, bisphenol A-glycidyl methacrylate; *Bis-EMA*, ethoxylated bisphenol A-dimethacrylate; *Bis-PMA*, bisphenol A-dimethacrylate; *DCP*, tricyclodecane dimethanol dimethacrylate; *D3MA*, decandiol dimethacrylate; *NA*, not available.

When the literature is examined, both in vivo and in vitro studies have been performed to evaluate the color stability of resin composites used for restorations. There are several studies in the literature to evaluate the color stability of attachments made with resin composites.[6,11-13] However, reducing the chairside time by using an intense light device will provide an advantage for the clinician and the patient.

There is no comparative data on the color stability of the attachments made with single-shade resin composites, which provide easy attachment production with their fluid forms and have increased color compatibility. The hypothesis was that there are significant differences in discoloration between Tetric PowerFlow cured in 3 seconds in PowerCure mode and other materials.

METHODS

A power analysis was performed on the condition of statistical significance with the G* Power analysis program (version 3.1.9.7; Franz Faul University, Kiel, Germany). The analysis was performed with 95% power and a 5% error. The calculated total sample was 90, with 10 samples for each group.

Extracted teeth with caries-free and intact enamel were used in the study. The exclusion criteria included teeth obtained from patients with craniofacial anomalies or mental disorders and teeth with congenital enamel defects, hypomineralization, various buccal restorations, caries, cracks, or infections. Teeth were stored in 0.1% thymol solution in a refrigerator at 4°C. All extracted teeth were cleaned from debris, calculus, and soft tissues with an intraoral scaler and polished with a polishing paste.

The materials used in this study are given in Table I.

Ten premolar teeth were embedded in plaster models to imitate the dental arch shape. In the first stage of this study, the models were scanned with iTero intraoral scanner (Align Technologies, San Jose, Calif), and digital models were created with a computer-aided software program (Exocad DentalCAD; exocad GmbH, Darmstadt, Germany). Attachment templates were made on 3D printed models with the Biostar (SheuDental GmbH, Germany) device using a 0.6 mm Duran plate.

Orthophosphoric acid (37%) was applied to the middle third of the teeth for 30 seconds. Then, rinsed with water for 30 seconds and dried with air spray.

An adhesive system (Adhese Universal; Ivoclar Vivadent, Ltd, São Paulo, Brazil) was applied with an applicator for 20 seconds, dry with a mild air spray for 5 seconds, and polymerized with a light-emitting diode curing unit (Bluphase PowerCure; Ivoclar Vivadent, Ltd, São Paulo, Brazil) in Power mode for 3 seconds. The attachments were placed on the middle third of the buccal surfaces of the premolar teeth. Omnichroma and GC Aligner Connect were polymerized for 5 seconds in Turbo mode (2000 mW/cm^2), and Tetric PowerFlow was polymerized for 3 seconds in PowerCure mode (3000 mW/cm^2).

After placing the composite attachments, the models were kept in distilled water for 24 hours to complete polymerization. Then, the photographs for the initial color measurements were taken using the SILKYPIX Camera Shot (Ichikawa Soft Laboratory, Japan) in combination with a mobile dental photography device with a polarizing filter (Smile-Lite MDP; Smile Line, St-Imier, Switzerland) and a smartphone (iPhone 14 Pro; Apple, Cupertino, Calif). The photographs were taken at a white balance of 5500K, 25 cm distance, and x2 camera zoom. All measurements were standardized light sources using a black background and taken in the same room. In addition, the simultaneous 3Shape Trios intraoral scanner (3Shape, Copenhagen, Denmark) was used for color detection (Fig 1).

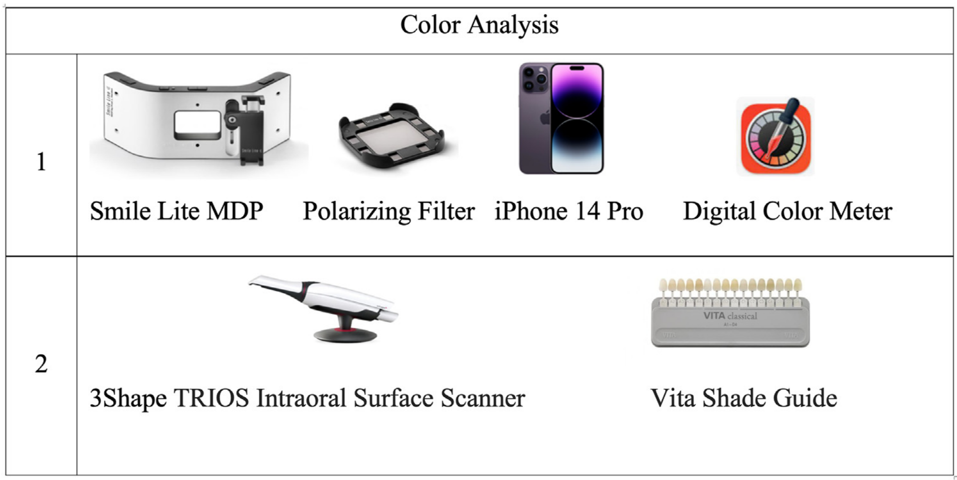

Fig 1. Color analysis procedure.

Models were divided into subgroups using 3 different discoloration solutions (coffee, cola, and distilled water): (1) Coffee solution was obtained (pH = 5) by mixing 1 tablespoon of granulated coffee (Nescafe Classic; Nestle, Vevey, Switzerland) with 100 mL boiled water, (2) cola (The Coca-Cola Company, Istanbul, Turkey) solution (pH = 3), and (3) distilled water (pH = 6) (Fig 2 and 3).

The solutions were changed daily, and the samples were immersed in the solution and kept in the incubator at 37 ± 1°C. The pH of the solutions was measured with MQuant pH indicator strips (Fig 4) (Merck KGaA, Darmstadt, Germany).

At the end of the 28th day, color measurements for each device were repeated, and L, a, and b values were recorded with Digital Color Meter (version 5.22; Apple) (Fig 5). The CIEDE2000 formula (ΔE_{00}) was used to evaluate the color changes with the following formula:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L^*}{K_L S_L}\right)^2 + \left(\frac{\Delta C^*}{K_C S_C}\right)^2 + \left(\frac{\Delta H^*}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C^*}{K_C S_C}\right) + \left(\frac{\Delta H^*}{K_H S_H}\right)}$$

Statistical analysis

The data obtained in this study were analyzed with the SPSS software (version 22.0; IBM, Armonk, NY). Kruskall-Wallis H test was used to compare ≥3 groups in nonnormally distributed data ($P < 0.05$).

RESULTS

The coloration values of the tested materials according to the different solutions are shown in Tables II and III. In Table II, positive numbers stated that materials become darker, and negative numbers stated that the materials become lighter according to the color measurements.

The most discoloration was observed in coffee solutions: Tetric PowerFlow (10.8), GC Aligner Connect (9), and Omnichroma (6.8). Color measurements in the Omnichroma group were significantly lower than Tetric PowerFlow and GC Aligner Connect groups ($P < 0.05$).

In the cola and distilled water groups, although there was no difference in color measurements between Omnichroma and Tetric PowerFlow ($P > 0.05$), there were significant differences between GC Aligner Connect and the other tested materials ($P < 0.05$).

Similar to the 3Shape results, the most colorations were observed in coffee solutions: Tetric PowerFlow (14.1), GC Aligner Connect (8.58), and Omnichroma (7.07). Color changes in the Tetric PowerFlow group were significantly higher than Omnichroma and GC Aligner Connect groups ($P < 0.05$).

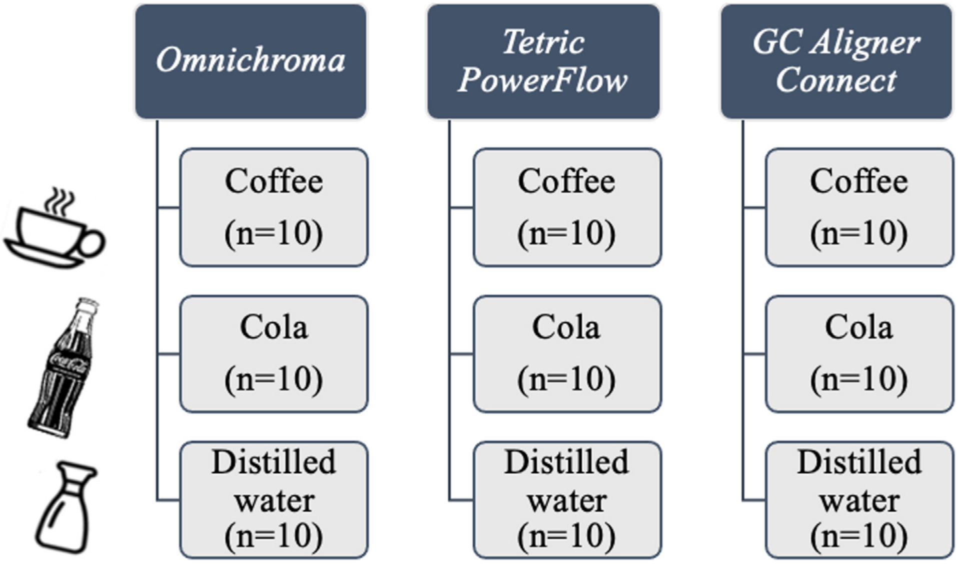

Fig 2. Distribution of composite attachments into subgroups.

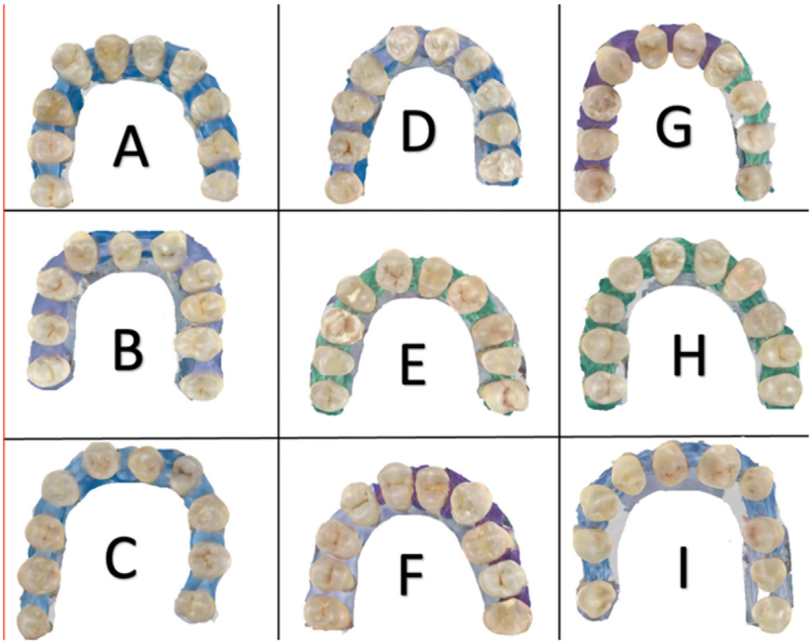

Fig 3. Distribution of subgroups: **A,** Omnichroma and Coffee; **B,** Omnicroma and Cola; **C,** Omnicroma and Distilled Water; **D,** Tetric PowerFlow and Coffee; **E,** Tetric PowerFlow and Cola; **F,** Tetric PowerFlow and Distilled Water; **G,** GC Aligner Connect and Coffee; **H,** GC Aligner Connect and Cola; **I,** GC Aligner Connect and Distilled Water.

In the cola solution, the color changes in Tetric PowerFlow were significantly lower than in GC Aligner Connect (P <0.05).

In the water solution, the color changes in Omnichroma were significantly lower than in GC Aligner Connect (P <0.05).

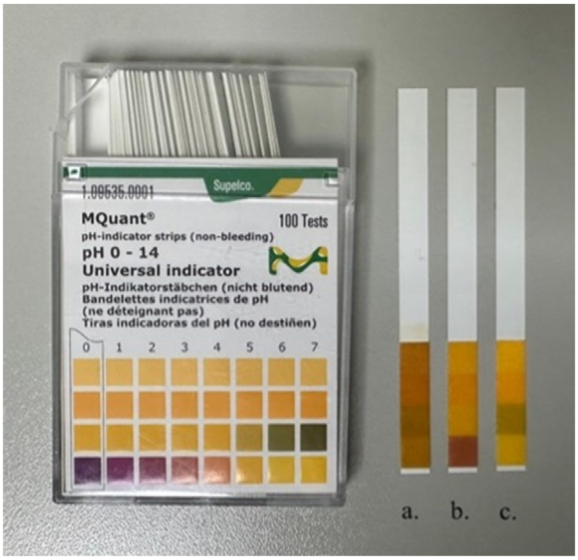

Fig 4. The pH of the solutions was measured with MQuant pH indicator strips. *a*, Coffee; *b*, Cola; *c*, Distilled water.

DISCUSSION

With the increase in the esthetic demands of patients, clear aligners are becoming a popular treatment option in orthodontics.[14] Therefore, attachments should exhibit good mechanical properties and color stability. In addition to having high color stability, the attachments should be in the same shade as the applied tooth or translucent enough to reflect its color.[6]

Resin composites are constantly exposed to coloring agents because of food and beverage pigments in the general diet.[15] When the literature is reviewed, the color stability of resin composites may be due to internal factors such as incomplete polymerization, residual monomer, water sorption, and external factors such as chemical reactivity, dietary coloring nutrients, and surface finishing protocols.[15-17] Because orthodontic attachments are made to actively support the movement, their shape should not be changed, and their surfaces should not be polished.[5] Increased surface roughness from unpolished surfaces and also oxygen inhibition layer causes more plaque formation and greater absorption of water and beverages. Smooth restorations show better color stability.[13,18]

Cola, coffee, and distilled water are frequently used as dyeing solutions for in vitro color-changing studies. These solutions have the feature of staining the tooth and composite surfaces. It has been shown in the literature that the pH of the solutions affects the color change potentials. In various studies in which the coloring effect of cola was tested, the low pH of cola because of the phosphoric acid containing it would cause the matrix to soften and deteriorate on the composite surfaces; therefore, high coloration was expected.[19] Cola has phosphoric acid content, whereas coffee has coloring pigments.[13,20] In this study, the pHs of coffee, cola, and distilled water were 5, 3, and 6, respectively. It was observed that coffee was the most coloring solution than cola. These results may be due to the presence of yellow pigments in coffee.[13] In addition, the attachments were not polished according to the manufacturer's instructions, and the oxygen inhibition layer formed may have reacted with the coloring pigments there, causing discoloration.

Flowable and packable resin composites are widely used to create orthodontic attachments.[21] Flowable resin composites have low viscosity as they contain lower amounts of inorganic fillers. With these low viscosity properties, they can penetrate irregularities smoothly, but reduced fillers also worsen their mechanical properties.[22,23] Flowable bulk-fill resin composites were introduced to improve their mechanical properties. In recent research, these flowable bulk-fill resin composites have demonstrated high flexibility, the ability for layers of minimum thickness, good handling, and ease of placement.[24]

It is supported in the literature that Omnichroma, as a single-shade resin composite, has a chameleon effect and can adapt to all colors, and has good mechanical properties.[25-27] Tetric PowerFlow as a flowable bulk-fill resin composite has many advantages, such as 3-second polymerization and increased mechanical properties. GC Aligner Connect is produced as a build-for-attachment composite. There was no study in the literature to evaluate this attachment composite. This study evaluated 3 different flowable composites (orthodontic, single-shade, and bulk-fill). Tetric PowerFlow polymerizes in 3 seconds, providing an advantage by reducing the time spent chairside during orthodontic treatment, whereas Omnichroma can adapt to all shades of human teeth.

This study found that Tetric PowerFlow causes more discoloration in coffee solutions than Omnichroma and GC Aligner Connect. These findings may be due to the formation of more residual monomers caused by 3-second polymerization. In contrast, Tetric PowerFlow was more resistant to coloration in the cola solution. This result suggests that the phosphoric acid in cola may have removed residual monomers while degrading the composite matrix. In addition, GC Aligner Connect, manufactured as an attachment composite, did not outperform other materials tested.

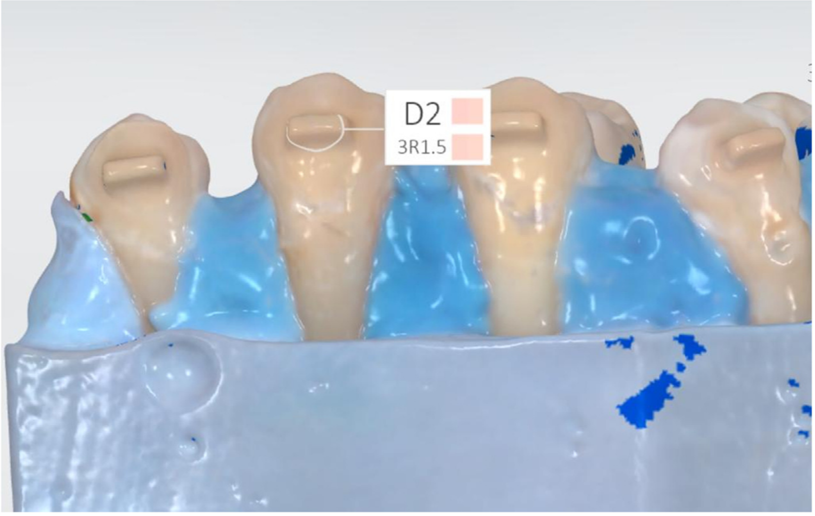

Fig 5. 3Shape Trios intraoral scanner color software according to Vita Shade Guide.

Table II. Mean color differences and standard deviations of tested materials

3Shape	*Coffee*	*Cola*	*Distilled w*
Omnichroma	6.80 ± 2.74^{a,A}	2.70 ± 4.37^{a,B}	−0.20 ± 2.74^{a,B}
Tetric PowerFlow	10.80 ± 2.53^{b,A}	−0.60 ± 1.90^{a,B}	0.20 ± 0.63^{a,B}
GC Aligner Connect	9.00 ± 3.16^{b,A}	−6.20 ± 2.74^{b,B}	−6.60 ± 2.50^{b,B}

Note. Different uppercase letters (A, B) indicate statistically significant differences in the row. In contrast, different lowercase letters (a, b) indicate statistically significant differences in the column. P <0.05 as a statistically significant difference.

Table III. Mean color differences and standard deviations of tested materials

Smile-Lite MDP (ΔE_{00})	*Coffee*	*Cola*	*Distilled water*
Omnichroma	8.58 ± 1.47^{a,A}	5.51 ± 1.18^{ab,B}	2.65 ± 1.32^{a,C}
Tetric PowerFlow	14.10 ± 2.69^{b,A}	4.70 ± 0.91^{a,B}	3.19 ± 0.69^{ab,C}
GC Aligner Connect	7.07 ± 2.80^{a,A}	6.44 ± 1.71^{b,A}	3.83 ± 0.72^{b,B}

Note. Different uppercase letters (A, B, C) indicate statistically significant differences in the row. In contrast, different lowercase letters (a, b) indicate statistically significant differences in the column. P <0.05 as a statistically significant difference.

Chami et al[11] investigated the color stability of 4 different resin composites as a disc-shaped specimen (2 × 5 mm). In that study, coffee, white wine, red wine, beer, dark beer, and deionized water were used for staining solutions. Red wine is the most coloring solution, followed by coffee, and these results support the results of the present study. This study differs from the other study by placing attachments with attachment templates on the extracted tooth to imitate oral conditions. In their study, Transbond XT was the most resistant to discoloration. These findings may be because Transbond XT is an orthodontic bracket adhesive composite.

Feinberg et al[6] used 2 dental restorative composites (Filtek TM Supreme Ultra, Tetric EvoCeram) and 3 orthodontic adhesives (Light Cure Retainer, Transbond XT, and Phase II Dual Cure) in their study. Accordingly, their study Light Cure Retainer and Phase II Dual Cure showed greater stain resistance than Transbond XT, whereas all the other materials were statistically similar. They concluded that orthodontic adhesives may have suitable esthetic properties for aligner attachments. In this study, GC Aligner Connect as an attachment composite was more resistant to coffee staining than Tetric PowerFlow in both measurement methods. It can be thought that the esthetic properties of the specific attachment composite may be more.

Özsoy et al[21] stated that the color change of the packable nanocomposite was more pronounced than that of the flowable nanocomposite for both attachment designs when aimed to compare the color changes of 2 different nanocomposites used for 2 different designs of clear aligner attachments. They concluded that clear aligner attachments created using flowable nanocomposite could be recommended, especially in the anterior region in which esthetics are important for the patient. In this study, 3 different types of flowable composites were evaluated, and a statistically significant difference was observed in the comparison between groups, so not only the viscosity of the material but also the structure of the composite is important.

Color determination can be measured in different ways, such as spectrophotometric, photographic, and intraoral scanning devices.[28] Because everyone has a smartphone, the mobile dental photography idea was born, and Smile-Lite was developed. This system provides ideal light conditions (5500 K = daylight) and a polarizing filter in one device.[29] Intraoral scanners can capture colored images and distinguish between soft- and hard-tissue structures. In addition, some of them identify tooth color based on visual shade guides.[30] Two different color determination devices were used in the present study. 3Shape can measure color in Vita Classic and 3D master shade guide. However, the Vita 3D Master Shade Guide has a three-dimensional, complex color scale and cannot properly identify color changes. In the Vita Classical shade guide, the darkest shade is C4. Based on these results, 3Shape has some limitations, such as its inability to detect darker colors and changing the lightness of the sample can cause results to be complicated. 3Shape was unable to measure the shadow of the samples when the materials were darker than C4.

CONCLUSIONS

Within the limitations of this study, Omnichroma, as a single-shade resin composite, stained significantly less than the other resin composites when exposed to coffee as measured by a 3Shape Trios Scanner. Coffee significantly stained all the attachments as compared with distilled water and cola. One of the main limitations of this study was the lack of stimulation of the oral environment. Further studies are needed in oral conditions and simulating the aging procedure.

AUTHOR CREDIT STATEMENT

Özlem Erçin contributed to conceptualization, methodology, software, supervision, and manuscript review and editing; Merve Kurnaz contributed to data curation, original draft preparation, software, and validation; and Dilan Kopuz contributed to visualization, investigation, software, and validation.

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