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Evaluation of Color Stability of Composite Resin Used to Characterize Acrylic Teeth—An In Vitro Study

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Abstract: The durability and patient acceptability of prosthesis can be gauged by the capacity of visible light curing lab composite resins to maintain color stability through time and use. Consequently, this study's goal was to assess the color stability of three layering materials, incisal, dentin, and gingiva of SR Nexco lab composite, with exposure to coffee, Coca-Cola, and turmeric solution using a spectrophotometer. A total of 60 specimens (10 × 2 mm) of SR Nexco paste were prepared and were divided into three groups based on the layering material used. Five specimens of each group were immersed in staining solutions, namely, coffee, cola, and turmeric solution. Each group's last five specimens were submerged in distilled water (control). The incubator that housed the samples was set to 37 °C. The CIE L*a*b* method was used to quantify the color differences (E) of specimens using a spectrophotometer at baseline and after two weeks of immersion. Using ANOVA testing, the average color change for each specimen was examined. Tukey tests were used for post hoc comparisons. The calculated mean color difference (ΔE) for incisal ranges from 3.73 (distilled water) to 28.70 (turmeric). The mean color difference (ΔE) for dentin ranges from 2.66 (distilled water) to 41.19 (turmeric). The mean color difference (ΔE) for gingiva ranges from 1.72 (distilled water) to 23.88 (turmeric). The results are statistically significant. The maximum color difference is noted for dentin specimens, and turmeric stains all three layering materials to a maximum. The color stability of SR Nexco paste layering materials is significantly affected by the discoloring agents used. The comparison of color change between the three layering materials of SR Nexco paste (dentin, incisal, and gingiva) is statistically not significant. Turmeric solution exhibits more discoloration followed by cola and coffee solution.

Keywords: composite resin; staining; prosthesis; coffee; turmeric; Coca-Cola; color stability; incubator

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1. Introduction

In order to meet the cosmetic needs of restorative dentistry, tooth-colored restorative materials have evolved [1]. Dentistry theory and philosophy of aesthetics is concerned with beauty and the beautiful, particularly as it relates to the appearance of a dental restoration as achieved through its form and/or color; these subjective and objective elements and principles that underlie the beauty and attractiveness of an object, design, or principle [2]. For many edentulous individuals today, dental aesthetics are a top priority. Modern dental prosthesis must seem natural and be appropriate for the patient's age and lifestyle [3]. Dental prostheses and restorations manufactured with 3D technology are precisely crafted to complement the adjacent oral anatomy [4].

Two basic characteristics of a complete denture may be stated [5]:

1. Characterization by selection, arrangement, and modification of artificial teeth;
2. Characterization by tinting the denture bases.

Artificial teeth have a big role in the overall aesthetic of removable dentures [6]. Manufacturers' stock artificial teeth lack a natural aesthetic appearance because of the consistency of hue and tint that is inherent in their fabrication. Techniques for altering acrylic resin teeth have been developed that incorporate realistic denture teeth for characterization and coloring [7]. Dental experts have been able to construct restorations that are lifelike and vibrant due to advancements in dental technology, the qualities of dental materials, and a greater knowledge of the optical characteristics of real teeth [8].

Numerous prosthodontic applications, such as the replacement of missing or broken denture teeth, the construction of composite denture teeth on removable partial metal frameworks, the characterization of acrylic resin denture teeth, and the treatment of acrylic resin denture teeth wear, have made visible light-cured indirect lab composites very popular [9,10]. In dentistry, SR Nexco paste, a more recent pure light-curing lab composite, has been created. It provides a lifelike look, layer thickness tolerance, long-lasting shade stability, long-lasting gloss, and flexibility of polymerization. The use of SR Nexco paste is recommended for framework-supported and framework-free prosthetic solutions, veneering restoratives utilizing the layering approach, veneering gingival areas in fixed–removable implant superstructures, and characterizing or modifying acrylic resin denture teeth [11].

Choosing long-lasting and color-stable biomaterials is related to the value of aesthetics. A crucial factor in determining the durability and patient acceptance of a prosthesis is the capacity of composite restorations to maintain their color through time and wear [6]. Turmeric is added in abundance in Indian cuisine for color, taste, and inherent therapeutic properties. Studies show that turmeric has a greater tendency to stain the resin composites [12]. An evaluation of the long-term consequences of ageing and staining is required with the introduction of this newer composite.

Visual examination is a purely irrational physiological and psychological process that evaluates color changes. In contrast, the spectrophotometer, when utilized as a tool for color evaluation, not only does away with subjective interpretations but also makes it possible to spot subtle color changes [13]. Colorimetry, which is based on the digital expression of the color perceived from the item, may be used to evaluate color. The Munsell colorimetric system and the standard CIE L*a*b* colorimetric system are two of the colorimetric methods used to evaluate chromatic difference. The a* value indicates the red or green chroma, the b* value represents the yellow or blue chroma, and the L* coordinate represents the brightness of an object. The CIE L*a*b* scheme is advised by the ADA. In accordance with this theory, red, blue, and green—the three primary colors—are blended in certain ratios to create all the colors seen in nature. Researchers in dentistry frequently employ this method to examine the color of dental materials [14].

The primary objective of our study is to address the esthetic considerations and color accuracy and durability. One of the most important features of restorative dental materials is color stability, and any changes under color stability indicate aging or damaged materials. Methods for determining color stability manually (visual) and instrumental (hardware) visual assessment are quite subjective and bring the need for quantitative analysis of the data, which was performed by color calibration using spectrophotometer. With this background information, the goal of this study is to use a spectrophotometer to assess the color stability of three layering materials from an SR Nexco lab composite, namely, incisal, dentin, and gingiva, after exposure to coffee, Coca-Cola, and a turmeric solution (a food coloring agent).

2. Materials and Methods

2.1. Method of Collection of Data

The commercially available incisal, dentin, and gingiva layering materials of SR Nexco paste by Ivoclar Vivadent AG, Schaan, Liechtenstein, Germany were used for this study (Figure 1).

Figure 1. SR Nexco paste layering materials—incisal, dentin, and gingiva.

A total of sixty cylindrical specimens were prepared using a brass metal mold of dimension 70 × 30 × 2 mm containing 10 circular holes of 10 mm diameter. The composite material was syringed into the mold cavity in 2 × 1 mm thickness increments, followed by 20 s of intermittent LED light curing (Guilin Woodpecker Medical Instrument Co. Ltd., Guilin, Guangxi, China). The light intensity of this LED light-curing unit is 850–1000 mW/cm^2 (as per user manual). During the curing step, a glass slide wrapped in a cellophane sheet was placed at the bottom and top of each mold to regulate the flow of material (Figure 2).

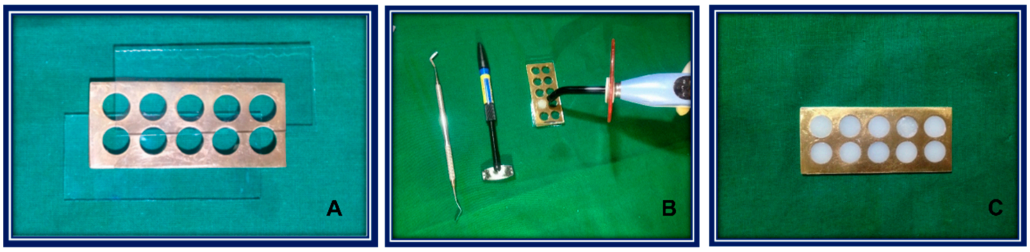


Figure 2. (**A**) Custom-made brass mold with glass plate and cellophane sheet for specimen fabrication. (**B**) Preparation of specimen. (**C**) Specimens in brass mold.

As directed by the manufacturer for final polymerization, all of the specimens in the mold were put in a light-curing unit (Lumamat 100, Ivoclar Vivadent AG, Schaan, Liechtenstein, Germany) for an additional 11 min. The surface to be measured was finished and polished using silicon abrasive polishers, polishing brush, and polishing buff with universal polishing paste

Each specimen was numbered by making a 1 mm indentation on the unpolished surface using carbide bur. Based on the layering material employed, the sixty specimens were grouped into three groups, Group A, group B, and group C, each consisting of twenty specimens.

2.2. Procedure

To imitate the first day of service for restoration in the oral environment, all specimens from the three groups were kept in an incubator at 37 °C for 24 h. All samples were taken out after 24 h, washed with distilled water, and blot-dried before baseline color analysis.

Following initial measurement, each group's composite resin samples were divided into 4 groups (n = 5) based on the immersion media: distilled water (control), coffee, turmeric, and cola beverage. A total of 400 mL of boiling distilled water and 8 gm of coffee powder were used to make coffee. A total of 400 mL of boiling distilled water and 2 gm of turmeric powder were combined to create the turmeric solution. Coca-Cola® was the beverage utilized, and pH indicator paper was used to determine its pH (around 2.5). All the specimens were stored in staining solutions in 12 glass beakers as mentioned above at 37 °C for duration of 2 weeks in incubator (Figure 3).

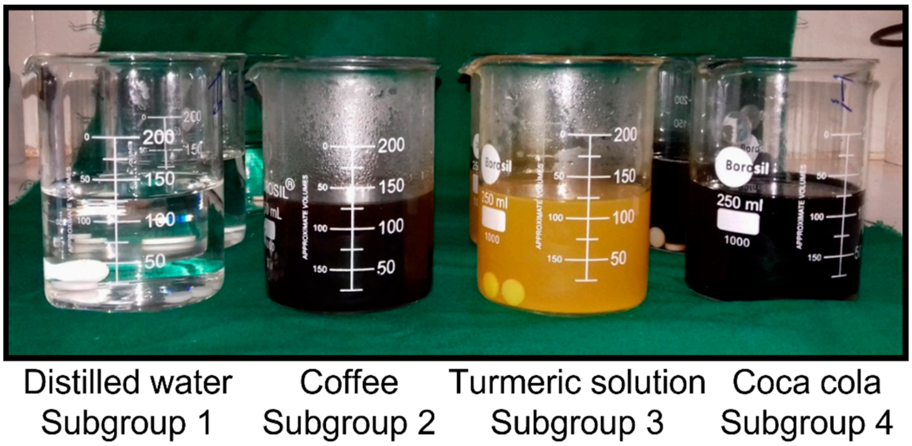


Figure 3. Specimens immersed in staining solutions.

The solutions were changed every 24 h in order to prevent any potential chemical alterations in the substance. After two weeks, the color change following staining was measured and quantified (Figure 4).

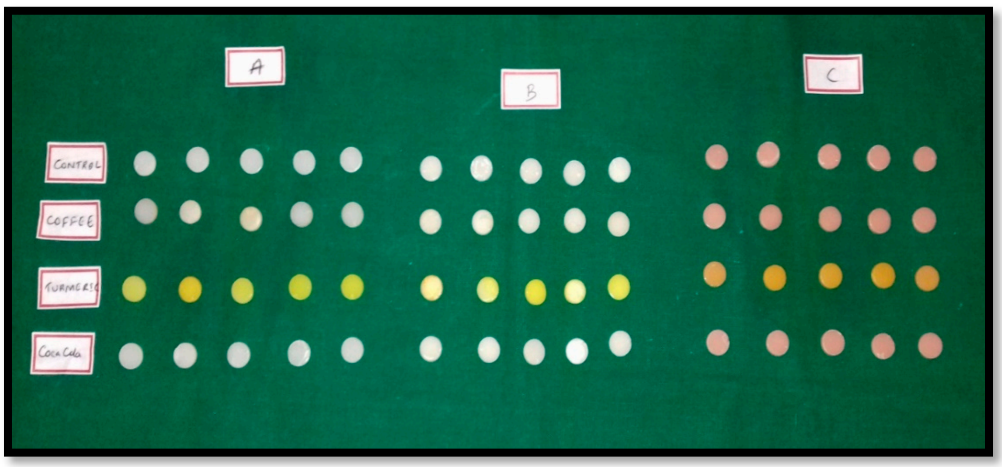


Figure 4. Specimens after 2 weeks of immersion in staining solution. (**A**) Incisal, (**B**) Dentin, (**C**) Gingiva.

Before each measurement, samples were cleaned for 10 s with an electric toothbrush and toothpaste, gently rinsed in distilled water, and then dried with tissue paper (Figure 5A). The toothpaste used in this study was Colgate Total (Colgate Palmolive Ltd., Chharodi, India). According to ISO specification, a toothpaste should not exceed a relative dentin abrasiveness (RDA) value of 250, which is considered as a safe limit for hard tissues. Hence, the toothpaste used in the present study was Colgate Total, whose RDA value was 70.

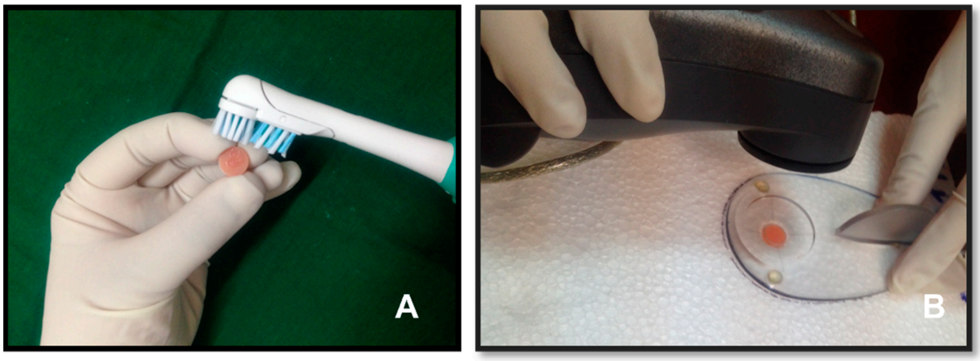


Figure 5. (**A**) Specimen cleaned using electric toothbrush and toothpaste. (**B**) Spectrophotometer used to measure the color change of specimen after 2 weeks of immersion in staining agents.

A spectrophotometer (X-Rite i1 Eye-One Pro Rev D Spectrophotometer, Althardstrasse, Regensdorf, Switzerland) unit attached to a computer was used to measure the specimens' color, and the programme Measure tool i1 pro Profilemaker version 5.0.10 was used to record the spectrophotometric data and total color difference E for each disc sample. On a white backdrop, colorimetric measurements of the samples were made using the CIELab color space, capturing the L*, a*, and b* values. For each specimen, a mean value for the L*, a*, and b* values was calculated using three measurements. After two weeks of immersion in the three staining solutions and the water control, color measurements were carried out once again. All L*, a*, and b* value recordings were performed by a single examiner. Utilizing Hunter's equation, $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$, values for E were determined (Figure 5B).

A single value, ΔE, was used to determine the overall color difference between the two places (baseline and after two weeks of storage in staining agents) in the three-dimensional L*a*b* color space. The schematic representation of the study design is shown in Figure 6.

2.3. Statistical Analysis

The statistical analysis was performed using the software SPSS for Windows 17.0; Statistical Package for Social Sciences. The Wilcoxon signed rank test was used to compare the two points before and after the staining agent immersion. One-way ANOVA was used to compare the specimens from group 1, group 2, and group 3 groups, each of which had been dyed with coffee, turmeric solution, and Coca-Cola. Using ANOVA with a post hoc Tukey test, a pairwise intergroup comparison was performed between Coca-Cola, coffee, turmeric solution, and distilled water. It was deemed statistically significant when the p value was less than 0.05.

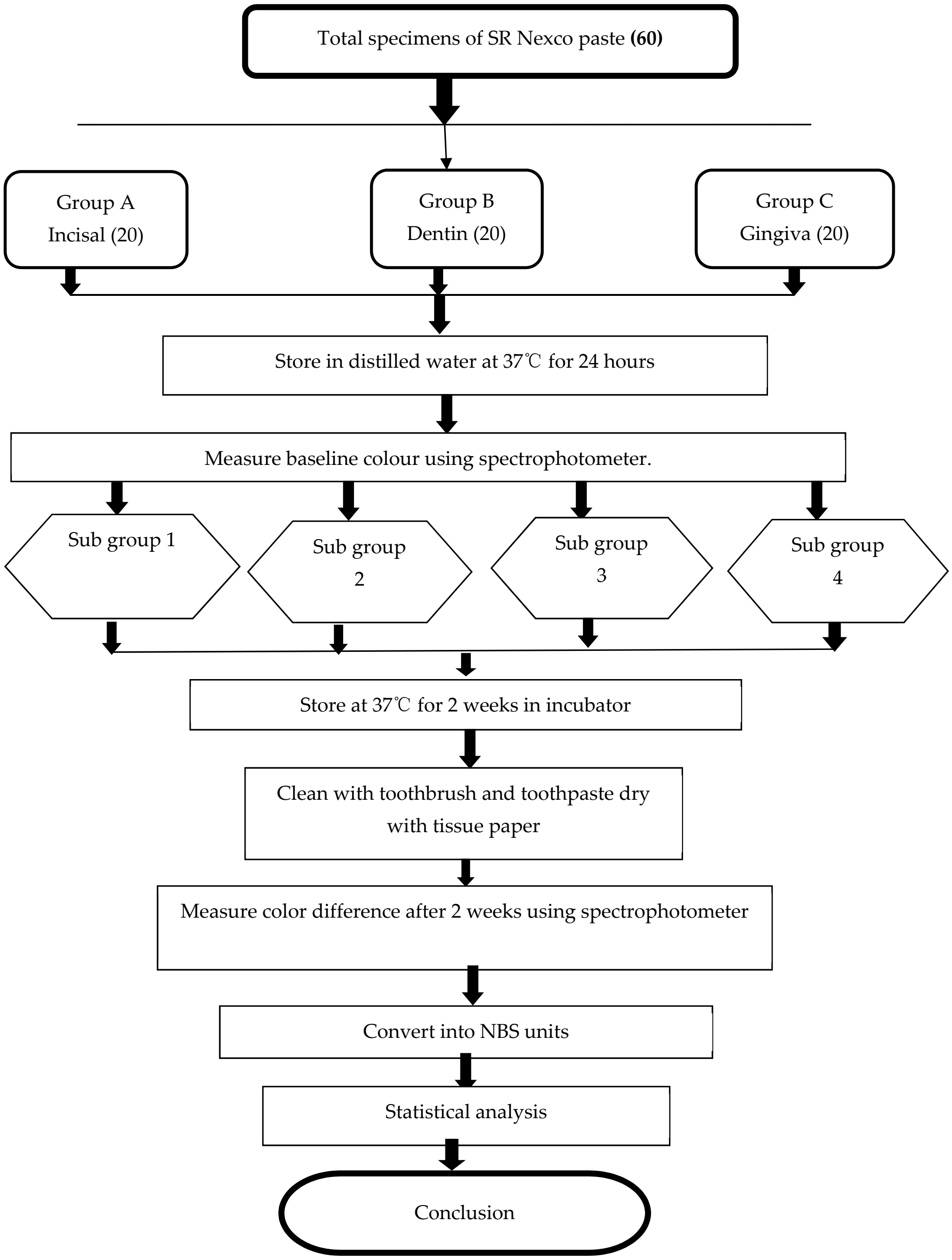
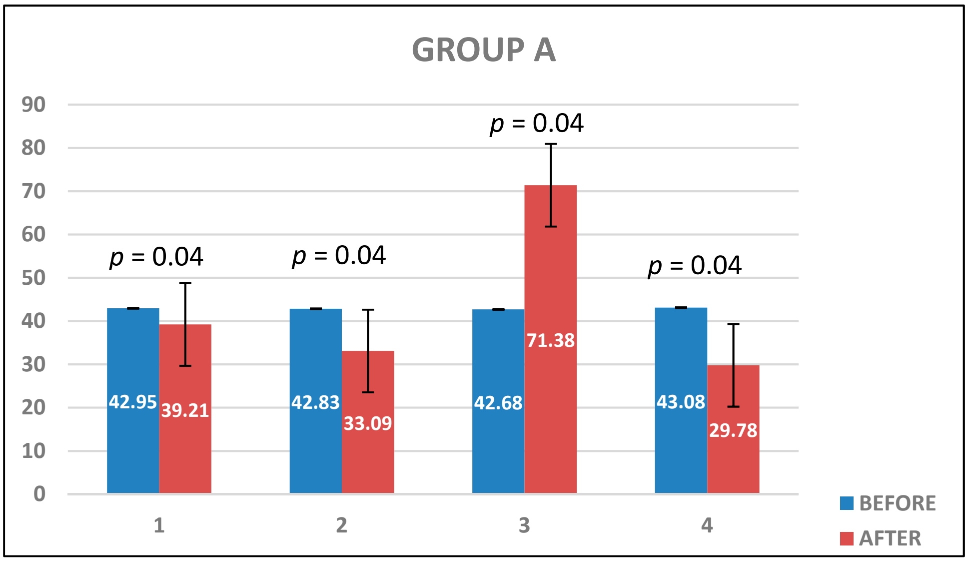


Figure 6. Schematic representation of the study.

3. Results

Supplementary Table S1 depicts a comparison of ΔE values for group A (incisal), group B (dentin), and group C (gingiva) in distilled water (1), coffee (2), turmeric (3), and Coca-Cola (4). The p value is found to be <0.05, which is statistically significant.

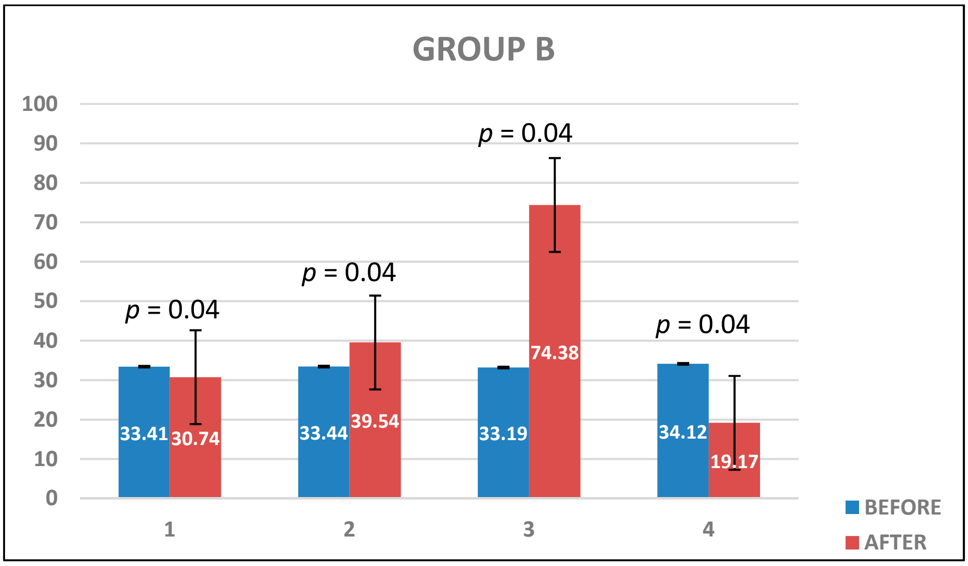
The greatest color change for group A specimens is seen in turmeric with ΔE = −28.70 (Scheme 1).



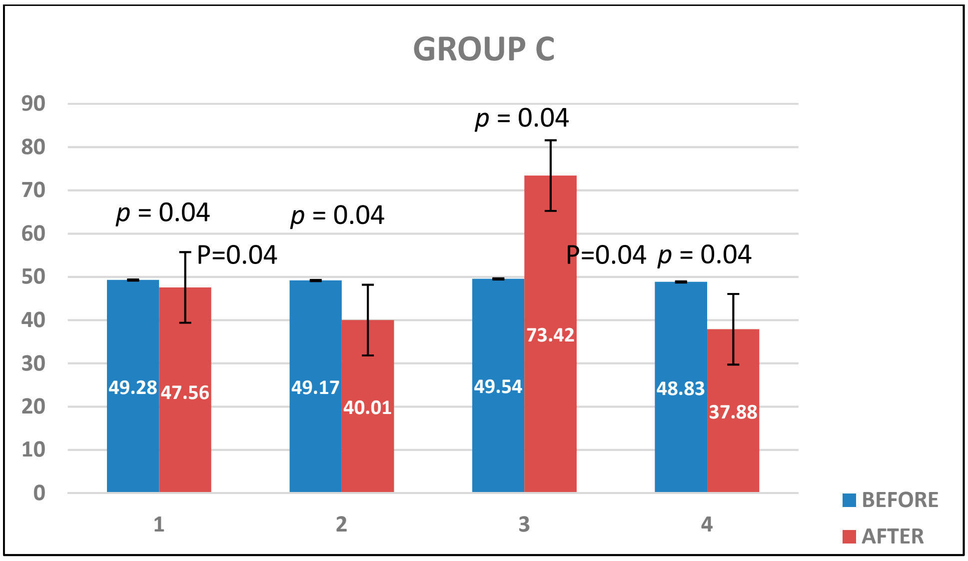
Scheme 1. Changes in ΔE values in group A.

The greatest color change for group C specimens is seen in turmeric (ΔE = 23.88). Wilcoxon signed rank test shows that there is a statistically significant color change of materials in the staining agent tested ($p < 0.05$).

The highest ΔE values are seen for group B specimens in turmeric with ΔE = −41.19 (Scheme 2), and the lowest ΔE values are seen for group C in distilled water, with ΔE = 1.72 (Scheme 3).

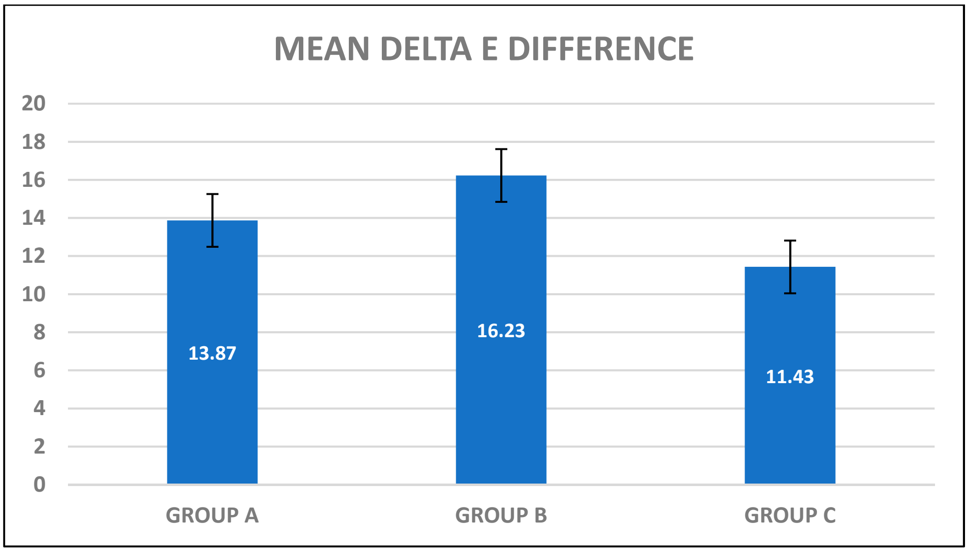


Scheme 2. Changes in ΔE values in group B.



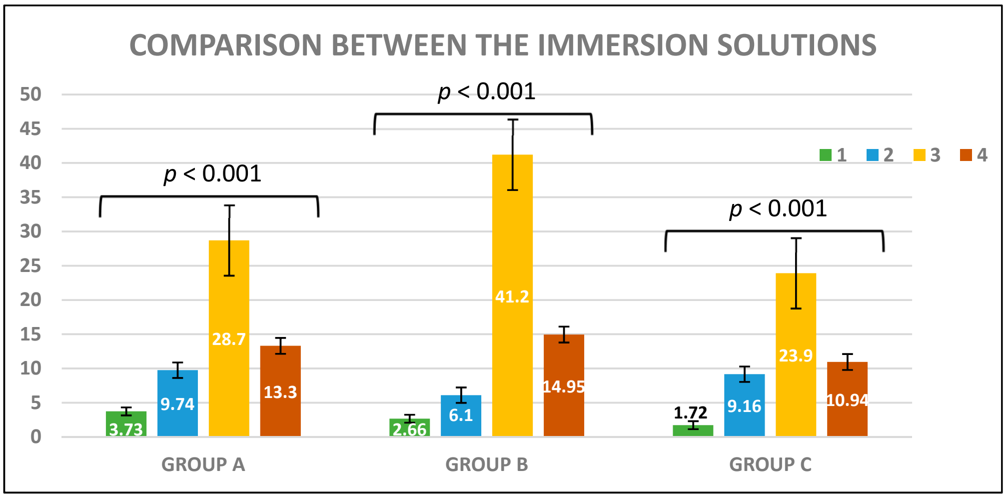
Scheme 3. Changes in ΔE values in group C.

Supplementary Table S2 shows a comparison of ΔE values for group A, group B, and group C. With a p value greater than 0.05, the one-way ANOVA demonstrates that the difference in color between the groups is not statistically significant (Scheme 4).



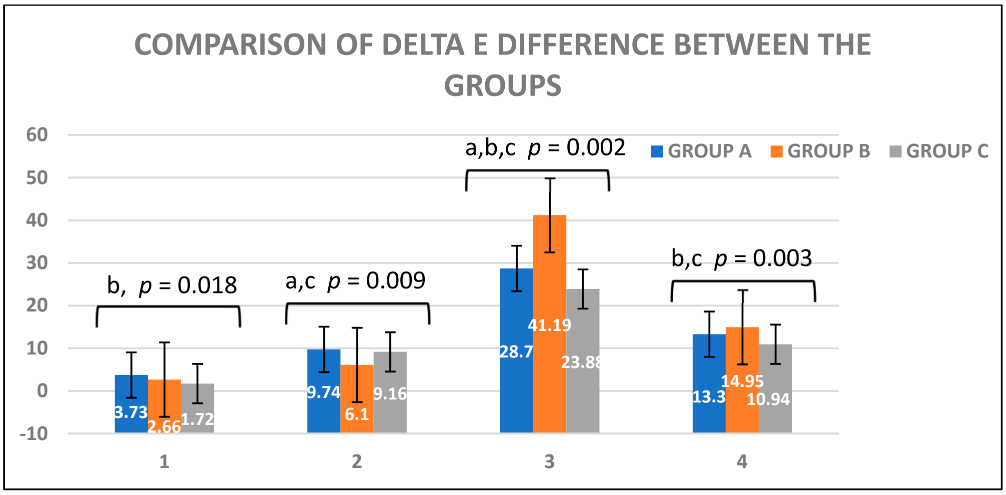
Scheme 4. Mean ΔE difference between the groups.

Supplementary Table S3 shows a comparison of ΔE values between the subgroups. The results of the Tukey post hoc test for Supplementary Table S3 (for pairwise comparison between the subgroups) reveal a significant difference between each group's subgroups 1, 2, 3, and 4, with the exception of group C, where the difference between subgroup 2 and group 4 is not significant. Scheme 5 depicts the results of Supplementary Table S3. From these results, it can be concluded that the type of staining agent affects the color stability.



Scheme 5. Comparison between the immersion solutions.

Supplementary Table S4 shows a comparison of delta E difference in each staining solution between composite materials. Between group A and group B in coffee and turmeric, between group A and group C in coffee and Coca-Cola, and between group B and group C in coffee, turmeric, and Coca-Cola, there is a statistically significant difference. (Scheme 6).



Scheme 6. Comparison of ΔE difference between the groups. a- difference between A and B, b- difference between A and C, c- difference between B and C.

To determine if the color variations of the tested groups were clinically discernible, the mean ΔE values of all specimens were converted to NBS units. The conversion's formula is NBS unit = ΔE × 0.92 for NBS units. The clinical significance of the effect on color change was "very much" (3.43 NBS to 26.40 NBS units) for group 1 specimens, as shown by the conversion of the mean ΔE values to NBS units (Supplementary Table S5). Clinically, the effect on color change was "very much" (2.44 NBS to 37.89 NBS units) for group 2 specimens, according to the conversion of the mean ΔE values to NBS units. Clinically, the effect on color change was "very much" (1.58 NBS to 21.96 NBS units) for group 3 specimens, according to the conversion of the mean ΔE values to NBS units.

4. Discussion

Patients are making increasingly exacting aesthetic requirements as a result of greater patient awareness of dental appearance [3]. Light-cured indirect composite systems with color modifiers permits the characterization of acrylic resin teeth creating natural-looking removable dental prostheses [10]. Indirect composites used for modification of denture teeth include SR Nexco, Sinfony (3 M ESPE), Ceramage (Shofu), Gradia gum shades (GC), Signum (Heraeus Kulzer), Solidex (Shofu), SR Adoro (Ivoclar Vivadent), and Twiny (Yamakin) [15]. Their erratic color stainability and stability are some of the issues connected to the failure of cosmetic restorations. Dental plaque buildup, pigmentation from staining agents, dehydration, water absorption, surface roughness, chemical degradation, and oxidation of unreacted carbon double bonds are a few causes for color changes in resins [16].

It is abundantly evident that it is neither practical nor even feasible to assess color changes and differences just through eye inspection [17]. It has been suggested and proven that quantitative evaluations of the color stability of dental direct composite resins using standardized tools, such as colorimeters and/or spectrophotometers [1,4,6,12–14,18–32] are more practical. The degree of water absorption in resin-based composite materials directly correlates to stain sensitivity, which is influenced by the resin matrix's hydrophilic/hydrophobic properties [26]. The commonly used monomers for composite resins include Bis GMA, TEGDMA, and UDMA [33]. Both Bis GMA and TEGDMA contain hydroxyl groups and are relatively hydrophilic. On the other hand, composites with UDMA matrix do not contain hydroxyl groups and are hydrophobic and, therefore, demonstrate less water sorption and decreased propensity for discoloration [4]. Most of the indirect composites used for characterizing acrylic teeth are composed of UDMA resin matrix [26,34].

The chemical makeup of drinks may also have an impact on color stability, since they absorb water-soluble pigments, which causes composite discoloration. Over the years, several colorants (food and other coloring agents) that may modify the color of dental materials have been researched, including tea and coffee (with or without sugar and milk), drinks, grape juice, wine, cherry juice, soy sauce, nicotine, and the disinfectants in mouthwashes. [1,4,6,12–14,18–32]. Turmeric has the strongest staining ability of all the composite resins evaluated in this investigation. This is as a result of turmeric's well-known strong colorant nature and inherent staining potential [13,30,31].

In the present study, immersion in distilled water results in noticeable color changes in the composite used with 2.48 ΔE = 2.28 NBS units. It is shown that water accumulation and photo-oxidation affect the internal color of provisional restorative materials and change their optical properties. Immersion in distilled water causes the composite material used with 2.48 ΔE = 2.28 NBS units in the study to noticeably change color. It is demonstrated that photo-oxidation and water buildup modify the optical characteristics and interior color of temporary restorative materials [14].

Low pH media such as cola (pH 2.7) have been proven to influence the surface integrity of materials such as resins by softening the matrix and triggering a loss in structural ions from the glass phase, including calcium, aluminum, silicone, and other elements [35]. Previous research demonstrates that adding sugar and milk powder to tea and coffee causes a greater shift in color, with the changes being determined to be significant [4]. Alhotan A (2022) investigated the effect of different solutions on color stability of nano particles or fiber-reinforced PMMA using the NBS system, which showed significant different color changes between all tested groups (ZrO_2 nanoparticles, E-glass fibres, and TiO_2 nanoparticles) and across different time points. In this study, coffee appears to have an extreme influence on the CF (coffee) change in comparison to the denture cleaner STD (Steradent)/CF. TiO2-reinforced PMMA in coffee showed the lowest color stability, while the E-glass-fiber-reinforced PMMA in STD/CF showed the highest color stability [36].

Alshehri A (2022) compared the color stability and surface roughness of conventional and self-blending resin composites before and after staining and aging. Composites used in the study were three conventional composites (Filtek Z350, IPS Empress Direct, and Estalite Palfique LX5) and one self-bending composites (Omnichroma). All groups showed significant decrease in all color parameters (L*,a*, and b*), and after polishing, all groups showed enhancement in color, thus, matching pre-experiment baseline colors [37]. Kammath SK (2021) comparatively evaluated the effect of three different beverages (Dasamoolaristam (an ayurvedic medicine), tea, grape juice, and distilled water) on color stability of two brands of acrylic denture teeth (Acryrock and Rolex) exposed to four immersion times. A1 shade maxillary right central incisors of two brands were used. The study showed maximum color change on exposure to Dasamoolaristam for the Rolex teeth set. The highest color mean difference was obtained in the Dasamoolaristam on day 30 of measurement of the Rolex teeth set [38].

Altiparmak ET (2022) observed the color change of cold beverages consumed on resin containing restorative materials. There was no statistically significant difference in color changes of the resin containing dental materials at the end of the 1st day ($p > 0.05$) but, at the end of the 7th and 30th day, cold tea caused statistically higher color change ($p < 0.05$). Composite resins showed more color change than resin-based CAD/CAM blocks [39]. Alfouzan AF (2021) evaluated and compared the color stability of 3D-printed and conventional heat-polymerized acrylic resins following aging, mechanical brushing, and immersion in staining medium. The autonomous factors, namely, material, staining medium, and immersion time, and interaction between these factors significantly influenced ΔE ($p < 0.001$). Irrespective of the materials, treatments, and time, the highest and the lowest mean ΔEs were observed for poly methyl methacrylate (PMMA) in lemon juice and DB (3D-printed DentaBASE) in artificial saliva [40].

Evaluating long-term consequences of aging and staining are required with the introduction of the newer composite SR Nexco paste (Ivoclar). There is no evidence in the literature about the color stability of layering materials (incisal, dentine, and gingiva) of this newer composite. Knowing the color stability of SR Nexco paste indirect composite helps us to know the durability and acceptability of artificial teeth on which the composite is used to layer the acrylic teeth. The main application of this novel method helps the clinician to evaluate the color stability of different layering materials of laboratory-processed composite resin that is used for characterizing acrylic denture teeth. This latter method, using indirect composite materials, produces a more lifelike appearance in acrylic teeth over the denture base in edentulous patients. The hypothesis of this study was rejected, as all the staining agents used, along with distilled water, caused statistically significant color change of the SR Nexco indirect composite.

Limitations of the study: The acrylic teeth that must be characterized in clinical settings have an uneven form with convex and concave surfaces, making effective polishing and plaque management more difficult to achieve than the experimental specimens, which are flat. The use of a single measurement for each specimen under the test conditions might have influenced the results. The study's findings might have been impacted by the smaller sample size of the composite resin specimens employed in the investigation. In the oral environment, dentures are exposed to saliva containing different proteins and enzymes, brushing, hot and cold food and drink, and maybe smoking. Changes in color may also be caused by these elements. As a result, future study should take a full review of these issues into account.

5. Conclusions

Physical appearances of denture teeth mainly rely on their glossy presence with color durability. The loss of surface gloss suggests an increase in the color change value. Full or partial removable dentures with an impressive natural appearance can be produced by individual characterization of prefabricated prosthetic teeth. Characterization of the complete process is necessary to give the dentures a life-like appearance, to make them look more natural.

The following conclusions may be drawn from the study within its constraints:

- ➢ Statistically, significant color change is reported for SR Nexco paste (dentin, incisal, and gingiva) exposed to coffee, turmeric, and cola;
- ➢ The comparison of color change between the three layering materials of SR Nexco paste (dentin, incisal, and gingiva) is statistically not significant;

➢ The color change of SR Nexco paste (dentin, incisal, and gingiva) is more prominent following exposure to turmeric, followed by the Coca-Cola and coffee solutions.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app13031498/s1, Table S1: Within group comparisons of ΔE values before and after immersion. Table S2: Overall comparison of difference in ΔE between the groups. Table S3: Comparison of difference in ΔE in between the subgroups. Table S4: Comparison of ΔE difference in each staining solution between composite materials. Table S5: National Bureau of Standards (NBS) system of expressing color differences.

Author Contributions: Conceptualization, S.A.S.A., S.A.R. and M.A.B.; methodology, S.A.S.A., S.A.R., M.A.B. and M.K.; software, M.H. and S.K.B.; validation, M.A.B., S.K.B., M.H. and S.A.R.; formal analysis; investigation, S.A.R. and M.A.B.; resources, S.A.S.A., N.M.A., R.T and G.K.B.; data curation, S.A.S.A., M.A.B. and S.K.B.; writing—original draft preparation, S.A.S.A., S.A.R., and S.K.B.; writing—review and editing, S.A.S.A., N.M.A., R.T., S.K.B. and M.K.; visualization, M.H. and S.K.B.; supervision, M.K., M.H., and S.K.B.; project administration, M.K. and S.K.B.; funding acquisition, N.M.A., R.T. and G.K.B. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The dataset used in the current study is available upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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