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A Comparative Analysis of Fluorescence Properties in Composite Restorative Materials: An In Vitro and In Vivo Study

Shivangi Trivedi [1], Shivani Khandelwal [1], Unmesh Khanvilkar [2], Surekha Puri Bhat [1], Anuj Bhardwaj [1], Ajinkya M. Pawar [3,*], Rodolfo Reda [4,*], Luca Testarelli [4] and Dario Di Nardo [4]

[1] Department of Conservative Dentistry and Endodontics, College of Dental Science and Hospital, Indore 453331, Madhya Pradesh, India; akashgroup91@gmail.com (S.T.); shivanikhndlwl13@yahoo.com (S.K.); surekasmile@gmail.com (S.P.B.); dranuj_84@yahoo.co.in (A.B.)
[2] Department of Microdentistry, Mumbai Regional Centre, Maharashtra University of Health Sciences, Mumbai 400001, Maharashtra, India; unmesh22@yahoo.com
[3] Department of Conservative Dentistry and Endodontics, Nair Hospital Dental College, Mumbai 400008, Maharashtra, India
[4] Department of Oral and Maxillo-Facial Sciences, Sapienza University of Rome, Via Caserta 06, 00161 Rome, Italy; luca.testarelli@uniroma1.it (L.T.); dario.dinardo@uniroma1.it (D.D.N.)
* Correspondence: ajinkya@drpawars.com (A.M.P.); rodolfo.reda@uniroma1.it (R.R.)

Abstract: In the field of dentistry, achieving a natural look in dental restorations is crucial. This relies significantly on the ability of composite materials to mimic the optical characteristics of natural teeth, particularly their fluorescence. Fluorescence plays a vital role in giving teeth their lifelike appearance and varies widely among different materials, impacting their long-term performance in clinical settings. This study aims to assess and compare the fluorescence properties of four advanced composite restorative materials against natural dental enamel through both laboratory and clinical evaluations. The research involved an in vitro examination of 50 samples categorized into five groups, with one control group (natural dental enamel) and four experimental groups (G-Aenial, GC Essentia, Brilliant Flo, and Omnichroma). Fluorescence intensity was measured both visually and through photographic techniques immediately after application and again after 30 days. Furthermore, a randomized clinical trial was conducted with 40 participants to evaluate the in vivo fluorescence of these composites used in cervical restorations. Statistical analyses were performed using the Kruskal–Wallis test and Wilcoxon signed rank test. The analysis revealed significant differences in fluorescence levels across all groups ($p < 0.05$). Among the composites tested, Omnichroma exhibited the closest resemblance to natural enamel fluorescence at both baseline and after 30 days, with p-values of 0.01 for in vitro and 0.02 for in vivo assessments. Notably, all composite materials, except for the control group (natural enamel), showed a decrease in fluorescence over time, with G-Aenial and GC Essentia experiencing more pronounced reductions compared to Omnichroma ($p = 0.03$). Omnichroma was found to most effectively replicate the fluorescence of natural enamel, leading to better esthetic results. However, it is important to note that all composite materials demonstrated a decline in fluorescence over time, indicating a need for ongoing development to enhance their durability.

Keywords: composite resins; dental enamel; fluorescence intensity; restorative dentistry

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1. Introduction

To achieve optimal esthetics in restorative dental treatments, composite resin materials have emerged as the preferred choice for restoring teeth. These materials are not only versatile but also photo-activated, which enhances both their physical and esthetic properties. The esthetic appeal of composite resins is significantly influenced by their degree of naturalness, which refers to how closely they can mimic the appearance of natural teeth. This naturalness is affected by several factors, including the observer's perception, local lighting conditions, and the dynamics of light interacting with the restorative material [1].

When evaluating the optical properties of composite resin, it is crucial that these materials replicate the optical characteristics of natural teeth while also possessing adequate mechanical properties [2]. The wavelength of light to which composite materials are exposed plays a significant role in determining their optical characteristics, such as opalescence and fluorescence. Fluorescence refers to the ability of a material to emit light when exposed to ultraviolet (UV) radiation or other forms of energy like cathode rays or X-rays. This property is particularly important as it relates to how well the restorative material can reproduce the optical qualities of vital teeth [3].

The fluorescence observed in natural teeth must also be replicated in composite resin restorations to impart a sense of vitality and luminosity. This fluorescence is influenced by various factors, including the specific characteristics of the tooth itself, the restorative material used, and the duration of exposure to UV light [4]. Such exposure can occur under different lighting conditions, whether natural daylight or artificial sources such as fluorescent lamps or black lights commonly found in nightclubs. In instances where fluorescence is lacking, the esthetic quality of a restoration can be severely compromised. Under UV lighting conditions, for example, restorations may appear as dark voids or holes, detracting from their intended appearance [5].

Numerous studies have been conducted to assess whether the fluorescence levels in composite resins align with those found in natural teeth [4–9]. The intensity of dental fluorescence is primarily attributed to organic components that are sensitive to UV light; thus, dentin typically exhibits greater fluorescence intensity than enamel. This phenomenon indicates that higher levels of mineralization correlate with reduced fluorescence characteristics. Interestingly, the fluorescence behavior observed in composites does not necessarily mirror that of dental tissues [10].

In response to growing demands for faster and more esthetically pleasing clinical procedures, researchers and manufacturers have developed advanced types of composite resins. These innovative materials are designed to exhibit fluorescence characteristics similar to those found in natural teeth, effectively mimicking the natural behavior of dental structures [11].

Composite resins are composed of a polymer matrix reinforced with inorganic filler particles such as silica. This combination allows for a material that is not only esthetically pleasing but also strong and durable. One of the key advantages of composite resins is their ability to match the natural shade of teeth closely, making them an ideal choice for visible restorations in anterior regions where esthetics are paramount [12].

The evolution of composite resin technology has led to significant improvements in both handling and application techniques. Modern composites come in various shades and translucencies, enabling dentists to select materials that blend seamlessly with a patient's natural dentition. This capability is crucial for achieving restorations that are virtually indistinguishable from surrounding teeth [13].

Light plays a pivotal role in how we perceive color and esthetics in dental restorations. The interaction between light and restorative materials affects not only their appearance but also their functional performance over time [14]. For instance, when light strikes a tooth or restoration, it can be reflected, refracted, or absorbed depending on the material's properties. The translucency and opacity levels within composite resins can be manipulated during application to enhance esthetic outcomes [15]. By layering different shades and opacities during placement, dentists can recreate the complex interplay of colors found in natural teeth. This artistic approach requires a thorough understanding of both dental anatomy and optical principles [16].

Technological advancements have led to the development of new composite materials that offer improved mechanical properties alongside enhanced esthetic features. These innovations allow for more conservative treatment options that preserve healthy tooth structure while providing excellent esthetic results [17]. The introduction of nanofilled composites has further revolutionized restorative dentistry by offering superior strength without compromising esthetics. These materials exhibit excellent polishability and color stability over time, ensuring that restorations maintain their appearance even under challenging conditions [18].

Achieving esthetic excellence in restorative dentistry hinges on understanding both the optical properties of restorative materials and their interaction with light. Composite resins have proven themselves as an invaluable tool for dentists striving for optimal esthetics while preserving tooth structure. As research continues into enhancing these materials' properties further, it is expected that future innovations will yield even more effective solutions for restoring smiles naturally and beautifully.

Based on the above background, the objective of this study was to evaluate the fluorescence intensity of various advanced composite materials and compare them with that of natural dental enamel. This evaluation was carried out using qualitative visual methods, photographic analysis, and numerical criteria for assessing fluorescence intensity. This study's findings will contribute valuable insights into selecting appropriate composite materials based on their fluorescence characteristics relative to natural enamel. By advancing our knowledge in this area, we can continue improving patient outcomes in restorative dentistry through enhanced esthetic results.

2. Materials and Methods

2.1. Ethical Clearance

This research was conducted at the College of Dental Science and Hospital, RAU, Indore (M.P.), adhering strictly to ethical standards and guidelines. Ethical clearance for the in vivo investigation was granted by the Institutional Ethics Committee (approval number: CDSH/5102/2023). Furthermore, the study was duly registered with the Clinical Trial Registry of India (CTRI/2023/09/057973), ensuring compliance with national regulations and transparency in clinical research.

2.2. Sample Size

The sample size for this study was calculated using G*Power 3.1.9.7 software. Based on an effect size of 0.4, a significance level (α) of 0.05, and a power (1-β) of 0.80, the sample size was determined for five groups with two measurements per group. The analysis yielded a critical F-value of 2.68, indicating a minimum required sample size of 35 participants with at least seven individuals per group. Hence, the sample size calculated for the in vitro study was 10 samples in each group (n = 10) and total sample size of 40 for the in vivo study. This calculation aligns with established statistical guidelines for ensuring sufficient power to detect meaningful differences.

2.3. Preparation of Specimens

2.3.1. Control Group

For the control group (Group 1), ten enamel specimens, each measuring 8×2 mm, were sourced from the permanent central incisors of healthy individuals who had recently undergone periodontal extractions. Prior to sample collection, ethical approval and informed consent were obtained to ensure adherence to ethical standards.

The selection process involved meticulously sectioning the buccal and palatal surfaces of the teeth using a double-sided diamond disk (Microdont) operated at high speed, with continuous water cooling to prevent heat buildup and protect the enamel structure. The use of water as a coolant was essential for preserving the enamel's integrity and reducing thermal artifacts during the cutting process.

To achieve consistent specimen dimensions, an electronic digital caliper (Themisto TH-M61, Themisto Corp, JIPVI ECOMMERCE Pvt. Ltd., Delhi, India) was utilized. This precise measurement ensured the standardization and reproducibility of results, in line with methodologies established in previous studies on enamel specimen preparation for fluorescence analysis.

2.3.2. Preparation of Experimental Groups (Composite Resin Specimens)

For the experimental groups, composite resin specimens were prepared using addition silicone molds (GC Flexseed Putty, GC India Dental Pvt. Ltd., Telangana, India) with precise dimensions of 8 × 2 mm. This method was chosen to ensure consistency across all samples, thereby minimizing variability in the experimental results.

To prepare each composite sample, a single increment of resin was placed into the mold with the help of a composite filling instrument. A mylar strip was then applied to the surface to create a smooth finish, followed by a light-curing process that lasted for 40 s using an LED curing unit (DENTSPLY Caulk QHL75; DENTSPLY INDIA PRIVATE LIMITED, New Delhi, Inida). The curing tip was positioned directly against the mylar strip to standardize the distance for polymerization and enhance curing efficiency.

Following curing, the superficial oxygen-inhibited layer was removed using sanding disks (SHOFU Super Snap Mini Kit; Shofu Inc., Kyoto, Japan), exposing the bulk material and improving the optical properties relevant to the study. The dimensions of each specimen were rechecked with an electronic digital caliper to maintain consistency. Finally, the specimens were hermetically sealed in individual plastic containers filled with water and stored in an incubator at 37 °C ± 2 °C to simulate oral conditions and ensure hydration (Figure 1).

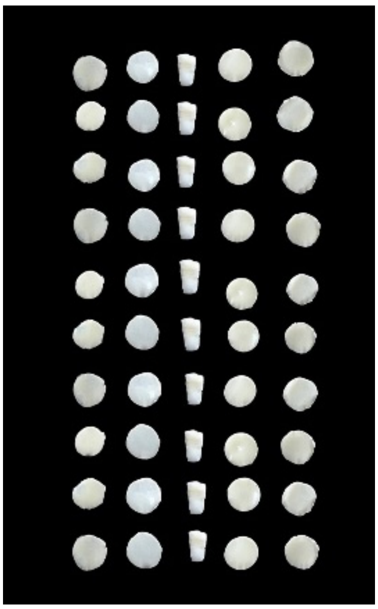


Figure 1. Preparation of composite resin samples that were placed along side of natural teeth samples (center row).

2.3.3. Preparation for Fluorescence Photography

To evaluate fluorescence levels, photographs of all prepared specimens were captured under controlled conditions. A custom-designed cardboard box (0.22 × 0.26 × 0.37 m) painted matte black was used to eliminate external light interference and reflections.

The experimental and control group specimens were placed adjacent to one another at equal distances within the box. A digital camera (Canon EOS 3000D DSLR; Canon Inc., Tokyo, Japan) was positioned 0.10 m away from the samples. A blue light bulb (26 W, 127 V, Bluex Bulbs; Signify Innovations India Limited, Mumbai, India) was mounted directly above the camera to illuminate the specimens uniformly.

The acquired images were analyzed to assess fluorescence intensity, and all data were systematically tabulated for subsequent statistical evaluation (Figure 2).

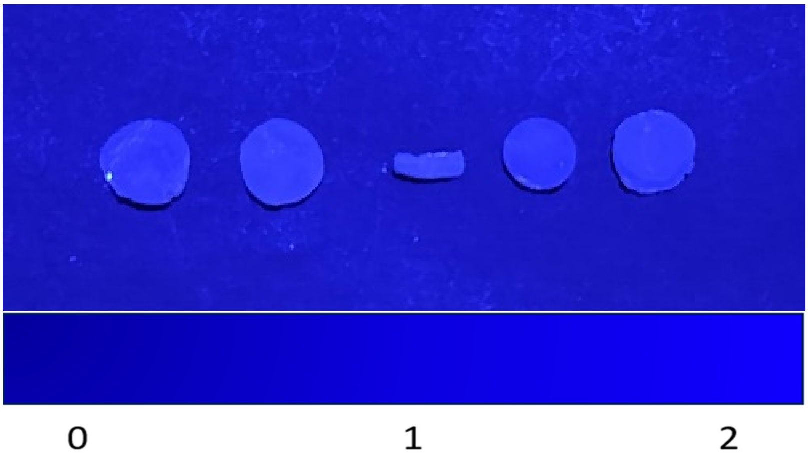


Figure 2. Photograph of prepared samples under blue light.

2.3.4. Visual Analysis of Fluorescence

To evaluate fluorescence levels, photographs of all prepared specimens were taken under standardized conditions. A custom-designed cardboard box (0.22 × 0.26 × 0.37 m) painted matte black was used to eliminate external light interference and reflections.

The fluorescence intensity of the specimens was evaluated using a qualitative visual method. Three calibrated evaluators independently assessed the fluorescence levels to minimize subjective bias. Calibration involved training sessions to ensure consistency in interpretation, as outlined in similar studies by Busato et al. [19] and Lopes et al. [20] (Table 1).

Table 1. Fluorescence values ranging from zero to two.

Photographs	Score	Fluorescence
	0	Resin without fluorescence
	1	Resin with fluorescence
	2	Very fluorescent resin

The evaluations were conducted immediately and after a 30-day interval to assess changes over time. This dual-assessment approach ensured a comprehensive understanding of the material's fluorescence behavior.

2.3.5. Inter-Rater Reliability

To maintain uniformity in qualitative evaluations, the inter-rater reliability among the three trained evaluators was assessed. Before starting the main evaluations, a preliminary analysis was performed on 20 randomly chosen samples, where the evaluators independently assigned fluorescence scores using a predetermined scale. The evaluators' level of agreement was measured with Cohen's kappa coefficient, resulting in a kappa value of 0.81. According to standard interpretation guidelines, this value signifies excellent agreement. The high inter-rater reliability highlights the strength and reproducibility of the qualitative fluorescence evaluations carried out in this study.

2.4. In Vivo Study

2.4.1. Study Design

This investigation employed an in vivo randomized clinical trial, utilizing a segmented triple-blind experimental model focused on oral health. A cohort of 40 volunteers, each presenting with four cervical lesions, was selected based on stringent inclusion criteria. These lesions were then restored with four distinct restorative materials assigned to the following treatment groups:

Group 1 (Control): Dental Enamel.
Group 2: G-Aenial.
Group 3: GC Essentia.
Group 4: Brilliant Flo.
Group 5: Omnichroma.

2.4.2. Participant Selection

Volunteers were recruited from the Department of Conservative Dentistry and Endodontics at CDSH, Rau, Indore. Each participant was thoroughly informed about the study's procedures, potential risks, and strict data confidentiality measures. Written consent was obtained following clinical and radiographic evaluations to ensure no pre-existing oral complications.

Inclusion criteria required the presence of upper anterior teeth (central and lateral incisors and canines) with adjacent cervical lesions of approximately 0.003×0.003 mm in area and a depth of at least 0.0002 mm. Exclusion criteria included periodontal disease, poor dental hygiene, and systemic illnesses. A Williams periodontal probe was employed to ensure a precise measurement of cervical lesion dimensions, emphasizing methodological rigor and accuracy.

2.4.3. Group Assignments

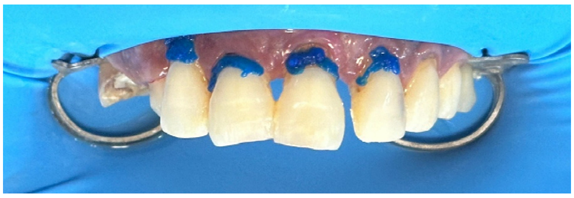
After the selection of volunteers, the anterior teeth were randomly allocated into different treatment groups using random.org software (Randomness and Integrity Services Ltd., Dublin, Ireland). For each volunteer, the four selected cervical abrasions were treated with one of the four restorative materials under study (Groups 2–5) (Figure 3). The intact dental enamel adjacent to the treated areas served as the control group, facilitating a comparison of fluorescence intensity.

Figure 3. Representation of cervical abrasions restored with different composites according to their respective groups.

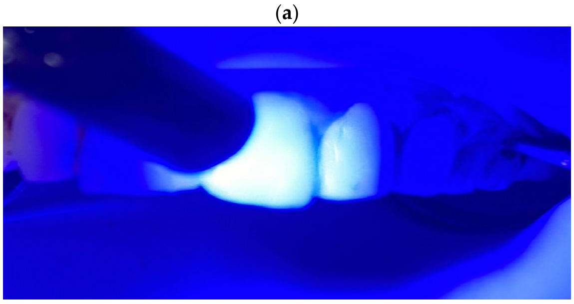
2.4.4. Restorative Procedure

Following oral prophylaxis, the selected teeth were isolated using a Nic Tone (India Viking Impex Private Ltd., New Delhi, India) dental dam sheet. The smear layer was removed with a prophy taper brush, pumice stone, and water. A bevel was prepared at the cavosurface angle of each lesion using a diamond point, and a No. 000 retraction cord was applied to enhance access and control crevicular fluid.

The cavities were cleansed with 2% chlorhexidine (Cerkamed Gluco-Chex-2%), dried with absorbent paper, and selectively etched for 30 s with 37% phosphoric acid (Figure 4a). After rinsing and drying, Single Bond Universal Adhesive (3M ESPE, Minnesota, USA) was applied per the manufacturer's guidelines and light-cured for 20 s. Each restorative material was then applied and light-cured for 40 s (Figure 4b). Final finishing and polishing were conducted using the Shofu Composite Finishing and Polishing Kit (Shofu Inc., Kyoto, Japan) (Figure 4c).



(**a**)



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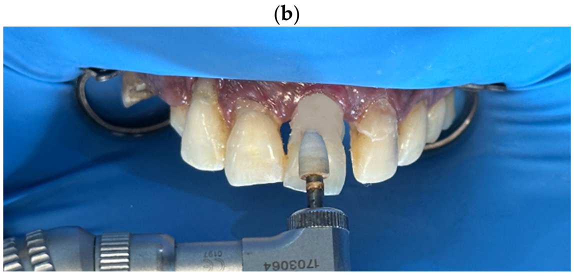


(**c**)

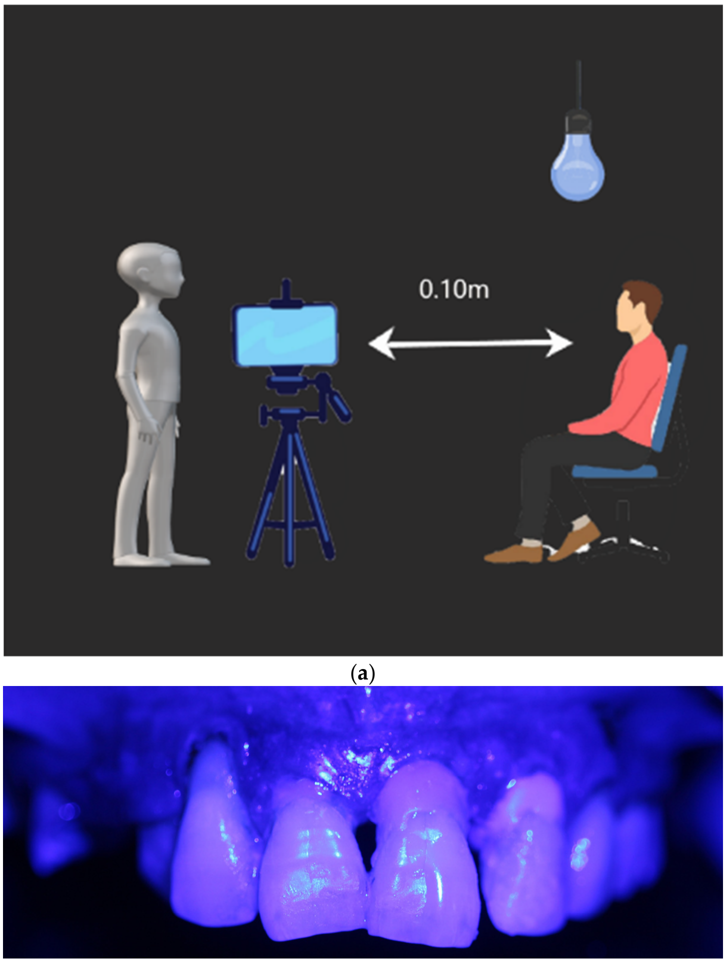
Figure 4. (**a**) Prepared enamel was etched for 30 sec with 37% phosphoric acid. (**b**) After placing composite material in prepared tooth, it was light cured for 40 s. (**c**) Finishing and polishing of the final restoration.

2.4.5. Fluorescence Analysis

Fluorescence intensity was assessed both immediately and 30 days post-restoration using a qualitative visual method. A team of three calibrated evaluators categorized the fluorescence intensity previously mentioned. The restored areas were compared to the surrounding natural enamel to determine relative fluorescence performance over time.

2.4.6. Fluorescence Analysis

High-quality photographs of each restoration were captured in a controlled dark room environment using a standardized setup (Figure 5a). Images were taken with a OnePlus 9 smartphone under ultraviolet light (26 W, 127 V Bluex Bulbs) positioned directly above the sample. These images provided visual documentation for qualitative fluorescence analysis (Figure 5b).



(**a**)

(**b**)

Figure 5. (**a**) Diagrammatic representation of dark room with selected parameters for photography. (**b**) Photograph analysis of composite restoration under blue light.

All collected data were compiled and subjected to statistical analysis, ensuring a robust interpretation of outcomes.

2.5. Statistical Analysis

To evaluate the fluorescence characteristics of the materials under study, the Kruskal–Wallis statistical test was employed. This non-parametric test revealed a statistically significant difference in fluorescence intensity among the different groups, both in the in vitro and in vivo segments of the study.

Further analysis of the mean differences in fluorescence across the resin materials was conducted using the Wilcoxon signed rank test. This test was applied to compare fluorescence values at baseline and 30 days post-restoration, offering insights into the temporal changes in fluorescence performance under both in vitro and in vivo conditions. A *p*-value of <0.05 was regarded as statistically significant.

3. Results

The fluorescence intensity of the restorative materials was assessed using SPSS Version 25.0. The data did not follow a normal distribution (Shapiro–Wilk Test, $p < 0.05$); hence, non-parametric statistical tests were used. The Kruskal–Wallis test, a non-parametric test used to compare the medians of two or more independent groups, was performed for intergroup comparisons, and the Wilcoxon signed rank test, a non-parametric test used to compare two related samples, was utilized to calculate mean fluorescence differences between baseline and 30 days. Descriptive statistics were provided as the mean and standard deviation (SD), with $p < 0.05$ indicating statistical significance.

3.1. In Vitro Fluorescence Intensity

Table 2 summarizes the mean fluorescence intensity (±SD) of the control group (enamel) and experimental groups (G-Aenial, GC Essentia, Brilliant Flo, and Omnichroma) at baseline and after 30 days. Enamel fluorescence remained constant over time, while significant reductions were observed for all composite materials. Omnichroma and Brilliant Flo demonstrated closer fluorescence levels to enamel at baseline but showed notable decreases over 30 days.

Table 2. Mean fluorescence intensity (±SD) of different restorative materials at baseline and 30 days in the in vitro study.

Material	Mean ± SD	
	At Baseline	After 30 Days
Enamel	1.07 ± 0.74	1.07 ± 0.74
G Aenial	1.20 ± 0.88	0.70 ± 0.51
GC Essentia	0.87 ± 0.76	0.50 ± 0.51
Brilliant flo	1.17 ± 0.75	0.67 ± 0.55
Omnichroma	0.93 ± 0.69	0.50 ± 0.51

3.2. In Vivo Fluorescence Intensity

In the in vivo study, the fluorescence intensity of the restorative materials was also assessed at baseline and 30 days later. The average fluorescence intensity (±SD) for every group is shown in Table 3. Over the course of 30 days, all experimental groups showed a considerable drop in fluorescence, although enamel fluorescence stayed constant.

Table 3. Mean fluorescence intensity (±SD) of different restorative materials at baseline and 30 days in the in vivo study.

Material	Mean ± SD	
	At Baseline	After 30 Days
Enamel	1.07 ± 0.73	1.07 ± 0.73
G Aenial	1.10 ± 0.87	0.62 ± 0.55
GC Essentia	0.97 ± 0.75	0.60 ± 0.49
Brilliant flo	1.16 ± 0.73	0.69 ± 0.46
Omnichroma	0.93 ± 0.68	0.58 ± 0.50

3.3. Comparative Analysis

The fluorescence differences between the composite groups were not statistically significant at baseline according to a comparison analysis utilizing the Kruskal–Wallis test (in vitro: $p = 0.741$ and in vivo: $p = 0.121$), as presented in Table 4. Nonetheless, a notable disparity was noted between the composite materials after 30 days (in vitro: $p = 0.003$ and in vivo: $p = 0.000$), suggesting the fluorescence intensity of different materials decreased at different rates (Table 4).

Table 4. The results of a Kruskal–Wallis test conducted to evaluate potential differences among the mean ranks of five materials.

Material	Kruskal–Wallis H	df	*p*-Value
	In vitro		
Baseline	1.972	4	0.741 (NS)
30 days	16.011	4	0.003 * (S)
	In vivo		
Baseline	7.305	4	0.121 (NS)
30 days	44.253	4	0.000 * (S)

df: degree of freedom. * Statistically statistically significant at $p < 0.05$.

3.4. Inter-Group Comparisons (In Vitro)

Table 5 shows the pairwise comparison of differences in mean fluorescence between baseline and 30 days computed by the Wilcoxon signed rank test. Except the control group (enamel), all four materials showed significant change in their fluorescence.

Table 5. The results of the Wilcoxon signed rank test, analyzing the mean differences in fluorescence intensity between baseline and 30 days in in vitro evaluation.

Material	Mean ± SD	*p*-Value
Enamel	0.00 ± 0.00	1.000
G Aenial	0.63 ± 0.37	0.000 *
GC Essentia	0.47 ± 0.25	0.000 *
Brilliant flo	0.50 ± 0.25	0.001 *
Omnichroma	0.43 ± 0.18	0.000 *

Statistical test used: Wilcoxon signed rank test; * statistically significant at $p < 0.05$.

3.5. Inter-Group Comparisons (In Vivo)

Table 6 shows that intergroup comparison was carried out using the post hoc Dunn test to see which of the materials showed significant change in their fluorescence after 30 days. All four tests groups showed statistically significant differences in their fluorescence when compared with the control group after 30 days in vivo ($p < 0.05$).

Table 6. The results of the Wilcoxon signed rank test, analyzing the mean differences in fluorescence intensity between baseline and 30 days in in vivo evaluation.

Material	Mean ± SD	*p*-Value
Enamel	0.00 ± 0.00	1.000
G Aenial	0.48 ± 0.32	0.000 *
GC Essentia	0.37 ± 0.26	0.000 *
Brilliant flo	0.47 ± 0.27	0.000 *
Omnichroma	0.35 ± 0.18	0.000 *

Statistical test used: Wilcoxon signed rank test; * statistically significant at $p < 0.05$.

4. Discussion

The compatibility of esthetic restorative materials with natural teeth is a cornerstone of successful restorative dentistry. Achieving harmony between dental restorations and natural teeth necessitates a deep understanding of the materials' optical properties, including fluorescence. Fluorescence, defined as the emission of light at longer wavelengths when exposed to an external light source, is particularly important in creating restorations that blend seamlessly with the surrounding dentition [21]. The spectral composition and fluorescence intensity of restorative materials must closely align with those of natural enamel to ensure optimal esthetic outcomes. However, as this study reveals, these properties often vary significantly among materials, leading to potential discrepancies in esthetic results [22].

Natural enamel naturally fluoresces when exposed to ultraviolet (UV) and high-energy visible light. Restorations that lack this fluorescence can appear dull, flat, or visually mismatched, even if the color match is otherwise perfect. This discrepancy in fluorescence becomes especially evident and problematic in UV-rich environments, thus affecting the desired esthetic harmony [10]. This mismatch can impact both esthetic outcomes and patient satisfaction and confidence, particularly in social or professional settings where appearance is important. More importantly, people who are regularly or frequently exposed to UV light, such as outdoor workers, athletes, lifeguards, or photography enthusiasts, are likely to face lighting conditions that highlight the difference in fluorescence between natural teeth and restorations. For these individuals, restorations that do not closely replicate the natural enamel fluorescence may seem out of place, potentially requiring replacement or adjustment. Similarly, patients with photosensitivity or those undergoing treatments that increase UV sensitivity can benefit from restorations that maintain a natural look under various lighting conditions. Additionally, for those often exposed to intense artificial light, such as celebrities, models, or people attending nightclubs or discos, optimizing fluorescence is essential to prevent restorations from looking unnatural under strong or UV-heavy lighting. Enhancing fluorescence, especially in new composite resins using nanotechnology, can result in restorations that are both mechanically and biologically successful while maintaining a natural appearance in all lighting conditions. By exploring the functional and esthetic roles of fluorescence in different lighting environments, clinicians can provide more context-specific, customized restorative solutions that enhance patient satisfaction and overall esthetic treatment success.

Our findings revealed that certain composite resins exhibited fluorescence levels either significantly lower or higher than those found in natural enamel. Such disparities present a considerable challenge in achieving esthetic harmony. Notably, Omnichroma demonstrated fluorescence characteristics that closely resembled those of natural enamel when exposed to UV light. This result aligns with the literature [23,24], which recognized Omnichroma as a "smart monochromatic composite" leveraging advanced chromatic technology to adapt to surrounding tooth colors.

The effectiveness of Omnichroma's fluorescence can be attributed to its innovative filler particle size of approximately 260 nm, which optimizes light interaction [25]. Additionally, its refractive index alignment—1.47 before curing and 1.52 after curing—ensures consistent light scattering and absorption, further enhancing its natural appearance [26]. Despite these strengths, research by Khayat [27] noted that Omnichroma lacks Bisphenol A diglycidyl dimethacrylate (Bis-GMA) resin, a component that enhances translucency and opalescence. The absence of certain metal oxides critical for color and opalescence might also limit its optical properties under specific conditions, underscoring the complexity of designing a universally effective composite material.

Another significant finding was the performance of the Brilliant Flo group, which exhibited fluorescence values notably higher than those of natural enamel. This result corroborates the observations of Bradocz-Verez et al. [10]. However, contrasting studies, such as that by Garrido et al. (2020) [4], have reported lower fluorescence levels for Brilliant Flo compared to natural enamel, highlighting variability across different research contexts. Experimental groups like G-Aenial and GC Essentia also demonstrated substantial differences in fluorescence when compared to natural enamel. These discrepancies often stem from a lack of transparency in manufacturer-reported compositions, particularly regarding the types and concentrations of fluorophores used.

The interaction of light with restorative materials is influenced by multiple factors, including physiological aging, the mineral composition of teeth, and environmental conditions such as lighting [28]. For example, dentin, the primary determinant of tooth color, has greater fluorescence intensity compared to enamel. Changes in mineral content and structural integrity over time can alter light transmission, affecting shade matching. Additionally, the lighting environment—whether natural daylight, artificial light, or UV light—profoundly impacts how restorative materials appear. Composite resins that fail to replicate natural fluorescence under varying conditions may compromise the esthetic outcomes of dental restorations [29].

The role of fluorophores in dental composites is central to understanding their fluorescence properties. Fluorophores absorb light at one wavelength and emit it at another, creating the optical effect necessary for mimicking natural enamel [3,5,22]. Variations in the type, concentration, and distribution of these fluorophores among different materials account for the observed differences in fluorescence. For instance, Omnichroma's advanced filler design and refractive index alignment enable it to replicate natural fluorescence more effectively than other materials. However, the degradation of organic components or structural changes over time can diminish these properties, as observed in all tested composite resins in this study.

From a clinical perspective, the variability in fluorescence among composite materials emphasizes the importance of informed material selection. Dental practitioners must consider not only the initial esthetic results but also the long-term stability of these properties. There are several methods available for assessing fluorescence, such as visual inspection, spectrophotometry, and fluorometry. However, the visual approach stands out as the best option due to its ease of use, practicality, and affordability. It is the most dependable and accessible method for use at the chairside. In the realm of anterior restorations, where appearance is paramount, it is crucial to choose materials that maintain consistent fluorescence across various lighting conditions. Settings with ultraviolet light, like nightclubs or outdoor areas, can significantly highlight the visual disparities between natural teeth and restorations made with low-fluorescence composites, leading to unwanted contrasts. Thus, selecting materials that ensure a seamless esthetic blend is vital for achieving the desired visual harmony.

The findings also highlight the limitations of existing materials. While advancements in nanotechnology have improved the mechanical properties, polishability, and color stability of composite resins, their fluorescence stability remains a challenge. The observed decline in fluorescence intensity over 30 days raises concerns about the long-term esthetic durability of these materials. This issue is particularly pronounced in anterior restorations, where visual harmony with natural teeth is crucial for patient satisfaction.

Addressing these challenges requires continued innovation in materials science. The development of composite resins with enhanced fluorescence stability is imperative. Incorporating more stable fluorophores or designing materials with self-healing properties to counteract aging effects could significantly improve the performance of restorative materials.

Additionally, increased transparency from manufacturers regarding material compositions would facilitate a better understanding and comparison of fluorescence properties.

One significant advantage of employing fluorescence in dental practices is its capability to safely remove old restorations or orthodontic adhesives without damaging healthy enamel. Under ultraviolet light, fluorescent materials are more easily distinguished from the natural tooth structure, enabling more conservative and precise removal. The advent of new fluorescence filters for dental microscopes enhances this differentiation, making procedures faster and more accurate. This is particularly advantageous in orthodontic debonding, where enamel loss can vary from 0.02 to 0.61 mm^3 per tooth [30]. As the optimal method to minimize such loss is still under discussion, fluorescence-guided removal provides a dependable means to preserve tooth structure.

Nevertheless, the exclusive reliance on subjective visual assessments rather than standardized instruments, the use of rudimentary photographic techniques, and the limited 30-day follow-up period necessitate further investigation. Additionally, the absence of control over external variables such as dietary habits and oral hygiene is also recognized as a limitation. Future research should examine the in vivo effects of fluorescence fluctuations under diverse conditions by evaluating restorations in various environments. This approach would yield valuable insights into the performance of materials beyond laboratory settings and provide more robust clinical guidelines. Furthermore, standardizing the measurement and reporting of fluorescence properties is crucial for enabling more favorable comparisons between material types and facilitating evidence-based decisions in restorative dentistry.

5. Conclusions

Considering the constraints of this study, the following conclusions can be drawn:

- Omnichroma effectively replicated the natural fluorescence of enamel in both laboratory and real-world conditions, making it ideal for use in anterior tooth restorations.
- Fluorescence plays a vital role in achieving esthetic harmony, particularly when exposed to ultraviolet or strong lighting, as any inconsistencies in restorations become readily apparent.
- All the composites that were tested experienced a decline in fluorescence over time, indicating a requirement for materials with improved long-term durability.
- When choosing materials, it is important to take into account their fluorescence properties in addition to their initial appearance to ensure results that are both long-lasting and naturally appealing.
- Future research should aim to enhance both the persistence of fluorescence and the clarity of material composition to support evidence-based decision-making.

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