Clinical and Experimental Health Sciences

Effect of Pediatric Liquid Dietary Supplements on the Color Stability of Restorative Materials: An in Vitro Factorial Study

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ABSTRACT

Objective: This in vitro study evaluated the time-dependent color stability of three restorative materials commonly used in pediatric dentistry following cyclic exposure to frequently consumed pediatric dietary supplements.

Methods: A 3×6 factorial design was applied using three restorative materials (glass hybrid, compomer, and nanohybrid resin composite) and six immersion solutions (distilled water, multivitamin, iron, zinc, omega-3, and elderberry-based supplement), resulting in 18 groups (n = 10). Specimens underwent a 7-day accelerated cyclic immersion protocol (10 minutes/day at 37 °C). Color measurements were recorded at baseline (T0) and after 1, 3, and 7 days using a digital spectrophotometer. Color differences were calculated with the CIEDE2000 (ΔE_{00}) formula. Data were analyzed using two-way ANOVA and Friedman tests ($\alpha = .05$) and interpreted according to established perceptibility (0.8) and acceptability (1.8) thresholds.

Results: Significant material–solution interactions were detected at all time points ($p < 0.001$). At T7, clinically unacceptable discoloration ($\Delta E_{00} \geq 1.8$) was observed in several combinations, particularly nanohybrid composite–multivitamin (3.095), nanohybrid composite–elderberry (2.555), compomer–omega-3 (2.097), and glass hybrid–zinc (1.941). No material demonstrated consistent resistance across all supplements. Discoloration patterns showed exposure-specific and non-linear progression over time.

Conclusion: Pediatric dietary supplements influence restorative color stability in a material – and solution-dependent manner. Pigment-rich multivitamin and elderberry formulations posed the greatest esthetic risk, highlighting the importance of considering supplement use when selecting restorative materials in pediatric patients.

Keywords: Colorimetry, Dental materials, Dietary supplements, Pediatric dentistry, Spectrophotometry

1. INTRODUCTION

Dental caries remains one of the most prevalent chronic diseases of childhood and continues to impose a substantial global public health burden (1). Early onset of caries frequently requires restorative interventions during the primary and mixed dentition periods (2). Consequently, pediatric dentistry emphasizes restorative materials that provide adequate mechanical performance while also fulfilling clinical demands for esthetics, simplified handling, and, in some cases, fluoride or ion release (3,4).

Tooth-colored restorative materials commonly used in pediatric dentistry include resin composites, compomers, and glass ionomer–based systems. Glass hybrid materials and compomers have gained popularity due to simplified placement protocols and potential caries-preventive benefits, whereas nanohybrid resin composites are widely preferred for their superior esthetic performance (4,5). In addition to mechanical durability, long-term clinical success depends on the ability of these materials to maintain color stability under oral environmental challenges (6,7).

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Color stability is a key determinant of esthetic longevity, particularly in pediatric patients where parental perception strongly influences treatment acceptance (7). Discoloration may compromise esthetics and ultimately necessitate premature restoration replacement. In children, this risk may be increased by frequent exposure to colored liquid products administered during early childhood (8).

Pediatric dietary supplements—including multivitamins, iron and zinc preparations, omega-3 products, and herbal syrups—are commonly consumed for extended periods (3,9). These formulations may contain organic acids, sweeteners, colorants, and metal ions that interact with restorative material surfaces and contribute to pigment adsorption and color change (3). Unlike short-term medications prescribed for acute illness, dietary supplements are often taken daily over prolonged periods, potentially increasing cumulative discoloration risk (3,8).

Color alteration of restorative materials is a multifactorial phenomenon influenced by both intrinsic material characteristics and environmental exposure conditions. Proposed mechanisms include surface adsorption of pigments, absorption and diffusion of chromogenic molecules into the restorative matrix, water sorption–mediated structural changes, and surface degradation induced by acidic formulations (6,10,11). Material composition plays an important role in these processes. Resin-based materials may absorb water and pigments through the organic matrix, whereas glass ionomer–based and glass hybrid materials may be affected by ionic exchange processes and surface dissolution (6,12). In addition, factors such as surface roughness, filler characteristics, matrix hydrophilicity, and the presence of protective surface coatings may influence susceptibility to staining by altering pigment retention and penetration (3,11,12). Consequently, restorative materials with different compositions may demonstrate distinct discoloration patterns when exposed to the same chromogenic challenge (6,7,12).

Previous in vitro studies have demonstrated that pediatric liquid medications can induce clinically perceptible color changes in restorative materials; however, most available evidence focuses on antibiotics, analgesics, and therapeutic syrups prescribed for short-term use (5,7,9,10,12,13). Comparatively fewer studies have investigated the discoloration potential of pediatric dietary supplements despite their frequent long-term consumption during childhood (3,14,15). Furthermore, existing studies often evaluate a limited number of supplements or restorative materials and use heterogeneous immersion protocols, making direct comparison difficult (3,7,12,15). Consequently, the relative discoloration effects of commonly used pediatric dietary supplements across different restorative material classes under standardized experimental conditions remain insufficiently understood. In addition, differences in color assessment methods among previous studies may further complicate interpretation and comparison of findings. Contemporary research therefore recommends the CIEDE2000 (ΔE00) formula as a perceptually more accurate method for evaluating color differences in dental materials (16).

Therefore, this in vitro study aimed to evaluate and compare the color stability of a glass hybrid restorative system, a compomer, and a nanohybrid resin composite after cyclic exposure to commonly used pediatric dietary supplements under standardized experimental conditions. Color changes were assessed instrumentally and expressed using the CIEDE2000 (ΔE00) formula. The null hypothesis was that restorative material type, immersion solution, and exposure time would not significantly influence color stability and that no interaction would occur between material and supplement type.

2. METHODS

2.1. Study Design

This in vitro experimental study evaluated the color stability of pediatric restorative materials following exposure to commonly consumed pediatric dietary supplements. A factorial design was employed based on restorative material (3 levels) and immersion solution (6 levels), resulting in 18 experimental groups. Each group consisted of ten specimens (n = 10). Similar factorial designs have been used in previous color stability studies (7,13). Following specimen preparation, each specimen was assigned a unique identification number. A computer-generated randomization sequence was generated using IBM SPSS Statistics software (version 26.0; IBM Corp., Armonk, NY, USA). Based on this sequence, specimens were randomly allocated to the immersion groups, ensuring equal numbers of specimens in each material–solution subgroup. The overall experimental workflow, including specimen preparation, random allocation, immersion procedures, evaluation time points, and statistical analysis, is summarized in Figure 1.

2.2. Sample Size Calculation

The sample size was determined by an a priori power analysis performed using G*Power software (version 3.1.9.4; Heinrich Heine University Düsseldorf, Düsseldorf, Germany). The effect size was derived from the statistically significant 7-day color difference data reported in a comparable in vitro study evaluating the effect of pediatric dietary supplements on restorative materials (3). Specifically, the 7-day color change values of a glass hybrid restorative material exposed to five different dietary supplements were used to calculate an effect size of $\eta^2 = 0.184$, corresponding to Cohen's $f = 0.475$. Using a fixed-effects omnibus ANOVA model with an alpha level of 0.05, a statistical power of 95%, and 18 experimental groups, the minimum required total sample size was calculated as 143 specimens. The present study included 180 specimens, with 10 specimens in each material–solution subgroup, thereby exceeding the calculated minimum sample size.

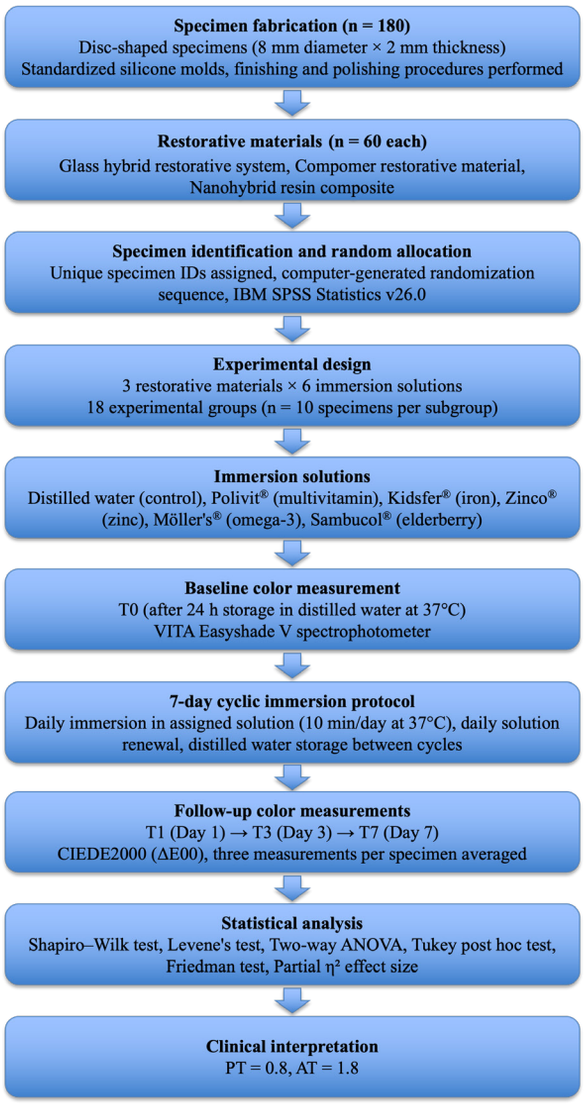


Figure 1. *Study flowchart of the experimental design and procedures.*

2.3. Restorative Materials

Three restorative materials commonly used in pediatric dentistry were evaluated:

- Glass hybrid restorative system (Riva Self Cure, SDI, Victoria, Australia)
- Compomer restorative material (Dyract XP, Dentsply Sirona, Konstanz, Germany)
- Nanohybrid resin composite (Clearfil Majesty Esthetic, Kuraray Noritake Dental Inc., Tokyo, Japan)

All materials were tested in shade A2 to standardize baseline color characteristics and ensure comparability across groups. Materials were used before expiration and handled according to manufacturers' instructions.

2.4. Specimen Preparation

Disc-shaped specimens (8 mm diameter × 2 mm thickness) were fabricated using standardized silicone ring molds. A Mylar strip was placed on a glass slide, the mold was filled with restorative material, and a second Mylar strip and glass slide were applied with gentle pressure to obtain flat surfaces.

Nanohybrid composite and compomer specimens were light-polymerized through the glass slide using an LED curing unit (D-Light Pro; GC, Tokyo, Japan; 1400 mW/cm²) for 20 s. The curing tip was positioned perpendicular to the surface at approximately 1 mm distance.

The glass hybrid restorative material was mixed according to the manufacturer's instructions and allowed to chemically set for approximately 2 min. A resin-based protective coating (Riva Coat, SDI) was subsequently applied.

After removal from the molds, specimens were inspected for defects, and thickness was verified using a digital caliper (±0.01 mm). Specimens outside a tolerance range of ±0.1 mm were excluded. All specimens underwent standardized finishing and polishing using a two-step diamond-impregnated spiral system (EVE Diacomp Plus Twist, EVE Ernst Vetter GmbH, Germany). Each spiral was applied for 10 s using a low-speed handpiece (≈10,000 rpm). After polishing, specimens were ultrasonically cleaned in distilled water for 5 min and air-dried. All specimen preparation and polishing procedures were performed by the same calibrated operator under standardized laboratory conditions to minimize operator-related variability.

2.5. Storage and Baseline Standardization

All specimens were stored individually in distilled water at 37 °C for 24 h prior to baseline color measurements (T0). During the experimental period, specimens were kept in an incubator (Nüve EN 120, Nüve A.Ş., Ankara, Türkiye) at 37 °C except during immersion and measurement procedures.

2.6. Immersion Solutions

Six immersion solutions were evaluated: distilled water (control), Polivit® (multivitamin syrup; Abdi İbrahim, Istanbul, Türkiye), Kidsfer® (iron supplement drops; Wellcare, Istanbul, Türkiye), Zinco® (zinc supplement syrup; Berko, Istanbul, Türkiye), Möller's® (omega-3 supplement; Orkla Health, Oslo, Norway), and Sambucol® (elderberry-based syrup; PharmaCare Europe Ltd., London, UK). The composition of the solutions is summarized in Table 1. All products were obtained from local pharmacies and used as supplied by the manufacturers without dilution or modification. Fresh solution (10 mL per specimen) was prepared daily and renewed every 24 h.

Table 1. *Composition of the immersion solutions used in the experimental protocol*

Solution	Type	Main active ingredients	Manufacturer
Distilled water	Control	—	—
Polivit®	Multivitamin syrup	Vitamin A, B1, B2, B6, nicotinamide, d-panthenol, vitamin C, vitamin D3, vitamin E (per 5 ml)	Abdi İbrahim, Istanbul, Türkiye
Kidsfer®	Iron supplement drops	Iron (as Lipofer™) 8.5 mg (per 1 mL)	Wellcare, Istanbul, Türkiye
Zinco®	Zinc supplement syrup	Zinc sulfate heptahydrate (equivalent to 15 mg zinc) (per 5 mL)	Berko, Istanbul, Türkiye
Möller's®	Omega-3 oil-based supplement	Omega-3 fatty acids, DHA, EPA, vitamins A, D3, E (per 5 mL)	Orkla Health, Oslo, Norway
Sambucol®	Elderberry-based syrup	Black elderberry extract, rosehip extract, vitamin C (per 1 mL)	PharmaCare Europe Ltd., London, UK

2.7. Immersion Protocol

A 7-day accelerated cyclic immersion protocol was used to simulate repeated short-term intraoral exposure. Specimens were immersed daily in 10 mL of the assigned solution for 10 min at 37 °C. Immersion time was based on cumulative exposure principles used in in vitro discoloration studies (17).

After immersion, specimens were rinsed with distilled water for 10–15 s and stored in distilled water at 37 °C for the remainder of the day. This cycle was repeated for seven consecutive days. Mechanical brushing procedures were not performed to isolate the chemical staining potential of the solutions.

2.8. Color Measurement

Color measurements were obtained using a digital spectrophotometer (VITA Easyshade V, VITA Zahnfabrik, Germany) based on the CIE Lab* system. The device was calibrated before each measurement session according to the manufacturer's instructions. Measurements were performed against a neutral gray background with the measurement tip positioned perpendicular to the specimen surface. All measurements were conducted by the same operator under standardized laboratory conditions. Color measurements were recorded at four time points: T0 (baseline), T1 (1 day), T3 (3 days), and T7 (7 days).

For each specimen, three consecutive measurements were taken and averaged to obtain L*, a*, and b* values. Color differences were calculated using the CIEDE2000 (ΔE_{00}) formula (18). Clinical interpretation followed established perceptibility (PT = 0.8) and acceptability (AT = 1.8) thresholds ΔE_{00} values <PT were considered imperceptible, PT–AT perceptible but clinically acceptable, and ≥AT clinically unacceptable (19).

2.9. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics software (version 26.0; IBM Corp., Armonk, NY, USA). Data distribution was evaluated using the Shapiro–Wilk test, and homogeneity of variances was assessed using Levene's test. The effects of restorative material (three levels) and immersion solution (six levels) on ΔE_{00} values were analyzed separately at each time point (T1, T3, and T7) using two-way analysis of variance (ANOVA). When significant main or interaction effects were detected, pairwise comparisons were conducted using Tukey's post hoc test. Effect sizes were expressed as partial eta squared (partial η^2). Because repeated-measures assumptions (normality of within-subject differences) were not met, within-group time-related changes were evaluated using the Friedman test. The level of statistical significance was set at $p < .05$.

3. RESULTS

Mean ΔE_{00} values (±SD) for all restorative material–solution combinations at T1, T3, and T7 are presented in Table 2. At T1, discoloration varied substantially across material–solution combinations, with the highest early color change observed in the compomer exposed to the iron supplement, whereas nanohybrid composite specimens stored in distilled water and multivitamin solution exhibited the lowest ΔE_{00} values at T1.

At T3, overall discoloration levels showed moderate variability across groups, with iron – and elderberry-based preparations generally inducing higher color changes compared with distilled water. By T7, discoloration increased notably in specific combinations, particularly for the nanohybrid composite exposed to multivitamin and elderberry solutions, which demonstrated the highest ΔE_{00} values among all groups (Table 2).

Two-way ANOVA results are summarized in Table 3. A statistically significant interaction between restorative material and immersion solution was detected at all evaluation periods (T1, T3, and T7; $p < .001$ for interaction at each time point). The interaction effect demonstrated moderate to large effect sizes (partial η^2 ranging from 0.190 to 0.315), indicating that the discoloration response of restorative materials was strongly dependent on the specific supplement type.

Table 2. *Mean ΔE_{00} (±SD) values of restorative materials after cyclic immersion in pediatric dietary supplements for 1, 3, and 7 days*

T1 (1 day)						
Material	**Distilled water**	**Multivitamin**	**Iron**	**Zinc**	**Omega-3**	**Elderberry**
Nanohybrid composite	0.304 ± 0.162^{aA}	0.304 ± 0.162^{aA}	0.742 ± 0.246^{bA}	0.410 ± 0.195^{aA}	0.450 ± 0.201^{aA}	0.706 ± 0.283^{bA}
Compomer	0.474 ± 0.246^{aA}	2.186 ± 1.941^{bB}	2.946 ± 1.311^{bB}	1.264 ± 0.881^{aB}	0.848 ± 0.250^{aB}	0.464 ± 0.284^{aA}
Glass hybrid restorative material	0.992 ± 0.488^{aB}	0.815 ± 0.468^{aA}	0.903 ± 0.607^{aA}	1.053 ± 0.713^{aA}	0.750 ± 0.473^{aA}	1.272 ± 0.758^{aB}
T3 (3 days)						
Material	**Distilled water**	**Multivitamin**	**Iron**	**Zinc**	**Omega-3**	**Elderberry**
Nanohybrid composite	0.545 ± 0.160^{aA}	0.545 ± 0.160^{aA}	0.525 ± 0.404^{aA}	0.654 ± 0.260^{aA}	0.878 ± 0.162^{bA}	1.321 ± 0.305^{cA}
Compomer	0.638 ± 0.250^{aA}	0.517 ± 0.448^{aA}	0.366 ± 0.181^{aA}	0.809 ± 0.530^{aA}	1.586 ± 0.686^{bA}	1.481 ± 0.904^{bA}
Glass hybrid restorative material	0.918 ± 0.446^{aB}	1.220 ± 0.694^{aB}	1.677 ± 0.906^{aB}	1.518 ± 0.926^{aB}	1.404 ± 1.119^{aA}	0.994 ± 0.492^{aA}
T7 (7 days)						
Material	**Distilled water**	**Multivitamin**	**Iron**	**Zinc**	**Omega-3**	**Elderberry**
Nanohybrid composite	0.535 ± 0.150^{aA}	3.095 ± 1.495^{bB}	0.782 ± 0.475^{aA}	0.775 ± 0.246^{aA}	1.115 ± 0.228^{aA}	2.555 ± 0.249^{bA}
Compomer	1.028 ± 0.454^{aB}	0.926 ± 0.644^{aA}	0.683 ± 0.380^{aA}	1.758 ± 2.418^{aA}	2.097 ± 0.799^{aB}	1.820 ± 0.970^{aA}
Glass hybrid restorative material	1.141 ± 0.452^{aB}	1.585 ± 0.517^{aA}	1.756 ± 1.018^{aB}	1.941 ± 1.083^{aA}	1.357 ± 0.778^{aA}	1.810 ± 0.896^{aA}

Values sharing different lowercase superscript letters within the same row indicate significant differences among solutions within the same material. Values sharing different uppercase superscript letters within the same column indicate significant differences among materials within the same solution (Tukey, $p < .05$). Lowercase superscripts represent within-material comparisons, whereas uppercase superscripts represent between-material comparisons. n = 10 per group.

Table 3. *Two-way ANOVA results for ΔE_{00} values at each evaluation time point*

T1				
Effect	**df**	**F**	**Partial η^2**	**p**
Material	2.162	2.605	.031	.077
Solution	5.162	0.760	.023	.580
Material × Solution	10.162	7.466	.315	**< .001**
T3				
Effect	**df**	**F**	**Partial η^2**	**p**
Material	2.162	1.109	.014	.332
Solution	5.162	2.863	.081	**.017**
Material × Solution	10.162	3.803	.190	**< .001**
T7				
Effect	**df**	**F**	**Partial η^2**	**p**
Material	2.162	1.251	.015	.289
Solution	5.162	13.913	.300	**< .001**
Material × Solution	10.162	5.930	.268	**< .001**

Partial η^2 values represent effect size estimates. Statistical significance was set at $p < .05$.

At T3 and T7, immersion solution significantly influenced ΔE_{00} values irrespective of material type. In contrast, when averaged across all immersion solutions, restorative material alone did not significantly affect ΔE_{00} values at any evaluation period. However, the significant material–solution interaction observed at all time points indicated that discoloration behavior depended on the specific combination of restorative material and supplement type. Post hoc comparisons are indicated in Table 2 using superscript letters.

Within-group time-dependent analysis using the Friedman test (Table 4) revealed significant temporal changes in most material–solution combinations. The nanohybrid composite demonstrated significant color progression across all immersion solutions. For the compomer material, significant time-dependent changes were observed in all groups except the zinc supplement. In the glass hybrid material, significant temporal variation was detected primarily in multivitamin, zinc, and elderberry exposure groups, while distilled water, iron, and omega-3 solutions did not show statistically significant progression over time.

For clinical interpretation, mean ΔE_{00} values at T7 were categorized according to established perceptibility and acceptability thresholds (Table 5). Clinically unacceptable discoloration ($\Delta E_{00} \geq$ acceptability threshold) was observed predominantly in elderberry-, multivitamin-, zinc-, and omega-3–exposed specimens depending on material type. In contrast, distilled water and certain iron or zinc combinations remained within the clinically imperceptible range. The remaining groups demonstrated perceptible but clinically acceptable discoloration.

Table 4. *Within-group comparison of ΔE_{00} values over time (T1–T3–T7) using the Friedman test*

Material	Solution	T1	T3	T7	χ^2 (df=2)	p
Nanohybrid composite	Distilled water	0.304	0.545	0.535	9.8	**.007**
	Multivitamin	0.304	0.545	3.095	18.2	**< .001**
	Iron	0.742	0.525	0.782	6.2	**.045**
	Zinc	0.410	0.654	0.775	11.4	**.003**
	Omega-3	0.450	0.878	1.115	16.2	**< .001**
	Elderberry	0.706	1.321	2.555	18.2	**< .001**
Compomer	Distilled water	0.474	0.638	1.028	10.4	**.006**
	Multivitamin	2.186	0.517	0.926	9.6	**.008**
	Iron	2.946	0.366	0.683	14.6	**< .001**
	Zinc	1.264	0.809	1.758	1.8	.407
	Omega-3	0.848	1.586	2.097	18.2	**< .001**
	Elderberry	0.464	1.481	1.820	16.8	**< .001**
Glass hybrid restorative material	Distilled water	0.992	0.918	1.141	4.2	.123
	Multivitamin	0.815	1.220	1.585	9.8	**.007**
	Iron	0.903	1.677	1.756	4.2	.123
	Zinc	1.053	1.518	1.941	6.2	**.045**
	Omega-3	0.750	1.404	1.357	4.2	.123
	Elderberry	1.272	0.994	1.810	7.8	**.020**

n = 10 per group. Mean ΔE_{00} values are presented for descriptive purposes. The Friedman test was performed on paired specimen-level data to compare ΔE_{00} values across T1, T3, and T7 (df = 2). χ^2 values represent Friedman test statistics. Bold p values indicate statistical significance (p < .05).

Table 5. *Clinical classification of ΔE_{00} values after 7 days of immersion according to clinical perceptibility and acceptability thresholds*

Material	Solution	ΔE_{00} (T7)	Clinical category
Nanohybrid composite	Distilled water	0.535	Imperceptible (<PT)
Compomer	Iron	0.683	Imperceptible (<PT)
Nanohybrid composite	Zinc	0.775	Imperceptible (<PT)
Nanohybrid composite	Iron	0.782	Imperceptible (<PT)
Compomer	Multivitamin	0.926	Perceptible but clinically acceptable (PT–AT)
Compomer	Distilled water	1.028	Perceptible but clinically acceptable (PT–AT)
Nanohybrid composite	Omega-3	1.115	Perceptible but clinically acceptable (PT–AT)
Glass hybrid restorative material	Distilled water	1.141	Perceptible but clinically acceptable (PT–AT)
Glass hybrid restorative material	Omega-3	1.357	Perceptible but clinically acceptable (PT–AT)
Glass hybrid restorative material	Multivitamin	1.585	Perceptible but clinically acceptable (PT–AT)
Glass hybrid restorative material	Iron	1.756	Perceptible but clinically acceptable (PT–AT)
Compomer	Zinc	1.758	Perceptible but clinically acceptable (PT–AT)
Glass hybrid restorative material	Elderberry	1.810	Clinically unacceptable (≥AT)
Compomer	Elderberry	1.820	Clinically unacceptable (≥AT)
Glass hybrid restorative material	Zinc	1.941	Clinically unacceptable (≥AT)
Compomer	Omega-3	2.097	Clinically unacceptable (≥AT)
Nanohybrid composite	Elderberry	2.555	Clinically unacceptable (≥AT)
Nanohybrid composite	Multivitamin	3.095	Clinically unacceptable (≥AT)

PT: perceptibility threshold (0.8); AT: acceptability threshold (1.8). ΔE_{00} values were categorized as imperceptible (<PT), perceptible but clinically acceptable (PT–AT), or clinically unacceptable (≥AT) according to previously established CIEDE2000 thresholds (17). Classification was based on the mean ΔE_{00} value of each material–solution group at T7.

4. DISCUSSION

This in vitro study investigated the time-dependent discoloration behavior of three restorative materials after cyclic exposure to pediatric dietary supplements. The findings showed that discoloration was not determined solely by material type but varied according to supplement composition and exposure duration. Significant material–solution interactions were detected at all evaluation periods, and several combinations reached clinically unacceptable (≥AT) ΔE_{00} values at T7. Accordingly, the null hypothesis that restorative materials would demonstrate similar color stability regardless of supplement type and exposure time was rejected.

Previous in vitro studies have shown that pediatric liquid medications may induce measurable color changes in restorative materials, with the magnitude depending on both material composition and solution characteristics (7,10,11). However, most available evidence focuses on antibiotics and short-term therapeutic syrups administered during acute illness. In contrast, dietary supplements are frequently consumed over prolonged periods. The present findings therefore extend existing knowledge by demonstrating that commonly used pediatric supplements—including multivitamin, iron, zinc, omega-3, and elderberry preparations—can produce distinct time-dependent discoloration patterns that differ from those observed in short-term medication models.

Clinical interpretation using CIEDE2000 perceptibility and acceptability thresholds enables translation of laboratory color differences into clinically relevant outcomes (19). Within this framework, clinically unacceptable ΔE_{00} values at T7 occurred in specific material–supplement combinations, particularly in glass hybrid exposed to zinc and elderberry solutions, compomer exposed to omega-3 and elderberry supplements, and nanohybrid composite exposed to multivitamin and elderberry preparations. These findings indicate that discoloration risk is primarily governed by interactions between material composition and supplement chemistry rather than by restorative category alone.

Color alteration in restorative materials is considered a multifactorial process involving surface adsorption of chromogens, water sorption–mediated matrix changes, and diffusion of pigments into microstructural porosities (6,10). The relative contribution of these mechanisms depends on resin hydrophilicity, filler distribution, ionic composition, and surface protection systems (11,12). Pediatric supplements often contain organic acids, sweeteners, metal ions, and colorants that may promote pigment uptake and surface alteration (3,8). The heterogeneous discoloration patterns observed across materials are therefore consistent with a chemical–structural interaction model rather than intrinsic superiority of a particular restorative material.

Temporal trends also differed among restorative systems, indicating that cumulative susceptibility is material-specific rather than uniformly progressive. Some materials exhibited gradual increases in color change across exposure periods, whereas others demonstrated selective or relatively stable behavior depending on the solution. These findings suggest that color change dynamics depend on both matrix composition and the chemical characteristics of the exposure medium.

Iron-containing preparations are frequently associated with staining due to the formation of pigmented complexes after metal ion interaction with restorative surfaces (20). Previous studies have reported greater discoloration in iron-exposed groups compared with controls (11,14). The early color change observed in the compomer group following iron exposure is consistent with this mechanism. However, the subsequent reduction in discoloration suggests that initial staining may reflect superficial adsorption rather than progressive intrinsic discoloration. Under cyclic immersion conditions, loosely bound pigments may be partially removed during rinsing and storage, resulting in stabilization of ΔE_{00} values.

A similar pattern has been described in composite materials exposed to chromogenic beverages, where the most pronounced color change occurs during the initial exposure phase before reaching a plateau (21). Such non-linear behavior indicates that early staining may not predict long-term discoloration.

Formulation-dependent factors may also influence discoloration behavior. Encapsulated iron formulations have been reported to produce lower discoloration than conventional preparations (22,23), suggesting that free ionic iron availability may influence pigmentation intensity.

Multivitamin formulations represent another important source of chromogenic exposure. These preparations often contain complex pigment mixtures and acidic additives that may increase susceptibility of resin-based materials to color alteration (14,24). Although Arregui et al. (15) reported lower discoloration in composites than in resin-modified glass ionomers, prolonged multivitamin exposure in the present data resulted in clinically unacceptable discoloration in the nanohybrid composite at T7. One possible explanation is water sorption–mediated matrix plasticization that facilitates diffusion of chromogenic molecules into the resin matrix (6). Previous investigations have similarly reported increased color change in resin-based materials exposed to multivitamin syrups (24,25).

Elderberry-based supplements represent a particularly strong chromogenic challenge due to their high anthocyanin content. These pigments have a strong affinity for hydrophilic matrices and may penetrate surface irregularities, especially under acidic conditions. Consistent with previous reports of progressive discoloration after Sambucol exposure (3,15), clinically unacceptable values were observed in all restorative systems at T7 following elderberry exposure, indicating a substantial esthetic risk during repeated intake of highly pigmented herbal supplements.

The literature presents conflicting findings regarding the inherent color stability of glass ionomer–based and resin-based materials. Some studies report greater stability for high-viscosity glass ionomer systems (7,12), whereas others demonstrate superior performance of resin composites (11,26). These discrepancies likely reflect differences in material formulation, filler content, surface coating, and experimental protocols. The absence of a consistent superiority pattern between the glass hybrid and nanohybrid composite in the present dataset supports the interaction-driven nature of discoloration behavior.

Overall, esthetic durability appears to result from the interplay between matrix composition, surface characteristics, and environmental exposure. Notably, even recently introduced esthetic restorative systems are not immune to supplement-related optical alteration. Saisree et al. (27) reported

statistically significant color changes in Bioflx pediatric crowns following exposure to commonly prescribed syrups, although the magnitude of change remained below visual perceptibility thresholds. This observation suggests that improvements in material design may reduce—but not eliminate—the risk of discoloration under repeated pediatric drug exposure. The present findings, in which certain combinations exceeded clinical acceptability limits despite contemporary material formulations, further emphasize that esthetic durability appears to reflect exposure-specific material behavior rather than intrinsic material superiority.

Compomers, combining resin matrix characteristics with glass ionomer–derived ionic components, have been described as exhibiting a dual response profile (28). Stability in neutral media but increased susceptibility under acidic or chromogenic conditions has previously been documented (6,29). The heterogeneous pattern observed—initial iron-related discoloration followed by stabilization, contrasted with progressive staining under omega-3 and elderberry exposure—supports this dual structural interpretation and highlights the importance of evaluating compomers within specific exposure contexts. Consistent with the within-group analysis, the zinc supplement did not produce a significant temporal shift in compomer discoloration, suggesting a comparatively stable trajectory under this exposure despite the broader interaction-driven behavior observed across supplements.

Surface-related changes may further contribute to supplement-induced discoloration. Aktaş et al. (3) demonstrated that exposure to pediatric dietary supplements increased not only color change but also surface roughness in restorative materials, particularly in glass ionomer–based systems. Increased roughness may create micro-retentive sites that facilitate pigment accumulation and enhance chromogenic adsorption. Although surface roughness was not evaluated in the present study, the clinically unacceptable ΔE_{00} values observed in specific material–supplement combinations may partially reflect underlying surface alterations induced by acidic or pigment-rich formulations.

Interestingly, although the main effect of solution was not significant at T1, it became progressively more pronounced at later evaluation periods, reaching a large effect size at T7. This finding suggests that supplement chemistry becomes a dominant determinant of discoloration under cumulative exposure conditions. Similar conclusions have been reported in previous in vitro studies highlighting the interaction between restorative composition and environmental challenges as a key factor influencing color stability (3,7,10).

The strengths of this study include its factorial design and the simultaneous evaluation of multiple restorative materials and commonly consumed pediatric dietary supplements within a standardized experimental framework. Repeated measurements at multiple time points enabled assessment of temporal discoloration dynamics, while interpretation using CIEDE2000 perceptibility and acceptability thresholds improved clinical relevance.

As with other in vitro studies, this study has certain limitations that should be considered when interpreting the results. As an in vitro investigation, the study cannot fully reproduce the biological complexity of the oral environment, including salivary buffering, pellicle formation, biofilm activity, temperature fluctuations, and mechanical loading. In addition, physicochemical characteristics of the tested supplements—such as pH, titratable acidity, and chromogen concentration—were not independently measured. Only optical color change was evaluated; additional analyses including surface roughness, microhardness, or microstructural assessment could provide deeper mechanistic insight.

Future studies integrating chemical characterization of pediatric supplements, aging simulations such as thermal cycling, and multi-parameter surface analyses may further clarify the mechanisms underlying supplement-related discoloration. Ultimately, clinical investigations in pediatric populations receiving long-term dietary supplementation are required to determine whether the in vitro patterns observed translate into clinically meaningful esthetic outcomes.

5. CONCLUSION

Pediatric dietary supplements influence the color stability of restorative materials in a material – and solution-dependent manner. Repeated exposure to certain supplements, particularly multivitamin and elderberry-based formulations, may result in discoloration exceeding clinical acceptability thresholds in specific restorative systems. No single restorative material demonstrated universal resistance across all supplement exposures, indicating that esthetic durability is governed by the interaction between restorative composition and supplement type. Pigment-rich multivitamin and elderberry preparations posed the highest esthetic risk, while omega-3 exposure exceeded acceptability thresholds in compomer specimens. Consideration of anticipated supplement use patterns may therefore support more informed restorative material selection and improved long-term esthetic outcomes in pediatric patients.

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