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Evaluation of the color stability of materials used in the resin infiltration technique for artificial white spot lesions

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Purpose: This study aimed to evaluate the color stability of a resin infiltration technique used for treating artificial white spot lesions (WSLs) through an accelerated aging test. **Materials and Methods:** Twelve human maxillary central incisors were prepared to create artificial WSLs and restored with an infiltration resin (ICON). Control groups were restored with conventional composite resins in shades A1 and A3.5. For the accelerated aging test, specimens were stored in distilled water at 60°C for 30 days to simulate over one year of clinical service. Color characteristics were measured at baseline, 5, 15, and 30 days using a spectrocolorimeter for Commission Internationale de l'Eclairage (CIE) L*, a*, b* values and a dental colorimeter for shade analysis. **Results:** All groups exhibited total color differences (ΔE*) exceeding the previously reported threshold (ΔE* = 3.3). At 30 days, the mean ΔE* values for the infiltration resin, composite resin A1, and composite resin A3.5 were 5.55, 6.45, and 4.0, respectively. Discoloration was primarily driven by a decrease in brightness (ΔL*) and an increase in yellowness (Δb*). No statistically significant differences in color stability were found between the infiltration resin and the conventional composite resin groups. **Conclusion:** Although the resin infiltration material demonstrated significant discoloration under accelerated aging conditions, no statistically significant differences were found compared with the tested composite resins. Overall, all materials exhibited ΔE* values exceeding the perceptibility threshold under the conditions of this study. **(J Dent Rehabil Appl Sci 2026;42(2):90-101)**

Key words: accelerated aging test; infiltration resin; composite resin; white spot lesion; color stability

Introduction

With improvements in the mechanical and chemical properties of composite resins, the frequency of their use in restorative dentistry has increased. Compared to direct or indirect restorative materials, the advantages of composite resins include little tooth preparation and minimally invasive technique.

The recently used resin infiltration technique has attracted attention as a more conservative restorative treatment for initial carious lesions without tooth preparation.[1] The currently commercialized resin infiltration technique involves the application of hydrochloric acid (for 120 s) instead of phosphoric acid to increase enamel permeability. This method enables resin infiltration into the porous lesions in the demineralized layer under relatively healthy enamel surfaces.[2] The infiltration resin consists of tetraethylene glycol dimethacrylate (TEGDMA), a monomer with low viscosity and good invasiveness. The resin infiltrates the intercrystalline spaces of demineralized enamel and polymerizes to fill the voids, preventing

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subsequent acid penetration and caries progression. Moreover, it physically reinforces the enamel structure by reducing microporosities.[3] The material is recommended for treating early enamel caries with the partial invasion of dentin.

Enamel white spot lesions (WSLs) are chalky white, opaque, and early carious lesions produced by enamel demineralization.[1] WSLs are early lesions undetectable on radiographs. Dentin remineralization through physiological compensatory mechanisms or preventive treatment may arrest the progression of WSLs; however, the subsurface enamel, where demineralization has already occurred, remains porous.[4-6] Previous studies have shown that a certain level of caries removal and esthetic improvement is achieved in all restorations using the resin infiltration method in WSL lesions.[1]

Due to various oral environmental factors, the physical stability of restorative materials is paramount, and color stability is crucial in esthetic restorative materials such as composite resins. Even restorations with acceptable esthetic results show discoloration over time, creating challenges for use as permanent restorative materials. Ruyter and Germain et al. reported that color stability was adversely affected in materials with fewer inorganic additives or higher content of resin substrates.[7,8] Kalachandra et al. showed that color changes in resins correlated to moisture absorption in the resin matrix.[9] Ferracane reported that TEGDMA had high water absorption due to the hydrophilic ether linkage.[10] As stated by the manufacturer, the monomer TEGDMA is the main component of infiltration resin that enables resin infiltration into porous WSLs. Limited studies have investigated the long-term color stability of infiltration resin. Asmussen assessed the factors affecting the color stability of composite resins. An accelerated aging test in which the composite resin was stored in water at 37°C for one year and 60°C for 30 days showed a high correlation between discoloration and TEGDMA.[11]

This study aimed to evaluate the color stability of the material by creating artificial WSLs on pure cotton enamel of maxillary anterior teeth, subsequently restored using infiltration resin. The teeth were subjected to an accelerated aging test in which it was stored in water at 60°C for 30 days. The color change was measured using a spectrocolorimeter, and color characteristics before and after the accelerated aging test were measured using a dental colorimeter to evaluate the clinical significance of the color change. The null hypotheses tested were that (1) the color of artificial white spot lesions restored with infiltration resin would not change before and after the accelerated aging test, and (2) the color difference between the artificial white spot lesion restored with infiltration resin and the control group would be changed after the accelerated aging test.

Materials and Methods

Sample Preparation and Grouping

This study was conducted under the approval of the Institutional Review Board of Chonnam National University Dental Hospital (CNUDH-2023-009). Each patient consented to the study and provided written informed consent. The human maxillary central incisors were obtained from patients who visited the Department of Oral and Maxillofacial Surgery at Chonnam National University Dental Hospital for tooth extraction due to periodontal reasons. Twelve extracted maxillary central incisors from male and female adult patients were selected. The exclusion criteria were as follows: teeth with fractures or caries, restored teeth, previous root canal-treated teeth, and teeth with defects or cracks. Intact twelve extracted maxillary central incisors were prepared as the test group.

For the experimental group (Fig. 1), these teeth were cut to leave a 2 mm thick dentin layer supporting the enamel parallel to the labial surface.[3] All areas of the specimens, except the labial enamel surfaces, were etched with 32% phosphoric acid (UNI-ETCH, Bisco, Schaumburg, USA). Adhesive resin (ALL-BOND II, Bisco) was applied and light-cured (Elipar DeepCure-S, 3M ESPE, St. Paul, USA). Next, the specimens were embedded in an acrylic block (30 mm in diameter and 3 mm thick) using self-curing orthodontic resin (Caulk Orthodontic Resin, Dentsp-

ly Caulk, St. Paul, USA), leaving the labial enamel surface exposed. The exposed enamel surfaces were demineralized to create artificial WSLs by immersing the specimens in a demineralization solution (1.5 mM $CaCl_2$, 0.9 mM KH_2PO_4, 50 mM acetate buffer, pH 4.8) for 24 h. After demineralization, the specimens were immersed in a remineralization solution (1.5 mM $CaCl_2$, 0.9 mM KH_2PO_4, 20 mM HEPES (4-(2-hydroxyethyl)-1-piperazineethane sulfonic acid), pH 7.0) for 1 h and then stored in distilled water again.[12] The demineralized lesions were restored using infiltration resin (ICON, DMG, Hamburg, Germany), following the manufacturer's instructions. After applying Icon-etch (15% hydrochloric acid in gel form) on the tooth surface for 2 min, each specimen was washed with water for 30 s and dried. Icon-Dry (an alcohol-based dehydrating agent) was applied to the dried specimen for 30 s to ensure complete dehydration. Icon-Infiltrant (resin material for infiltration) was applied for 3 min and light cured for 40 s. Then, Icon-Infiltrant was applied for 1 min and light cured for 40 s. The polymerized specimens were polished for 20 s under water injection using an abrasive disc (Sof-lex, 3M ESPE).

For the control group (Fig. 2), specimens were fabricated using composite resin shades A1 and A3.5 (Charisma, Heraeus Kulzer, Hanau, Germany). Composite resin was placed in acrylic molds with a diameter of 5 mm and a thickness of 3 mm, then light-cured to form standardized specimens. Each control group was subdivided into 5 samples per shade: 5 specimens of A1 and 5 specimens of A3.5. These specimens were subsequently stored in distilled water at room temperature.

This design allowed for a direct comparison between the infiltration resin-treated enamel surfaces in the test group and the standardized composite resin specimens in the control group. For the accelerated aging test, based on the research by Asmussen, the specimen was stored in distilled water at 60°C for 30 days in an unsealed thermostat with light blocked, and the distilled water was changed every 5 days.[11]

Measurement of Color

The test group was measured for color at 0, 5, 15, and 30 days under accelerated aging test. The control groups were subjected to color measurement twice before and after of the accelerated aging test for 30 days. The color characteristics of each specimen converted into CIE L*, a*, and b* values were measured using a spectrocolorimeter while a white standard was in contact with the back of the specimen.

In the CIE L*, a*, b* color system, the L* value represents the same brightness (lightness) perceived by human eyesight and consists of a scale from 0 to 100, with 0 representing black. The a* value is the chromaticity diagram, where +a* is red, 0 is gray, and

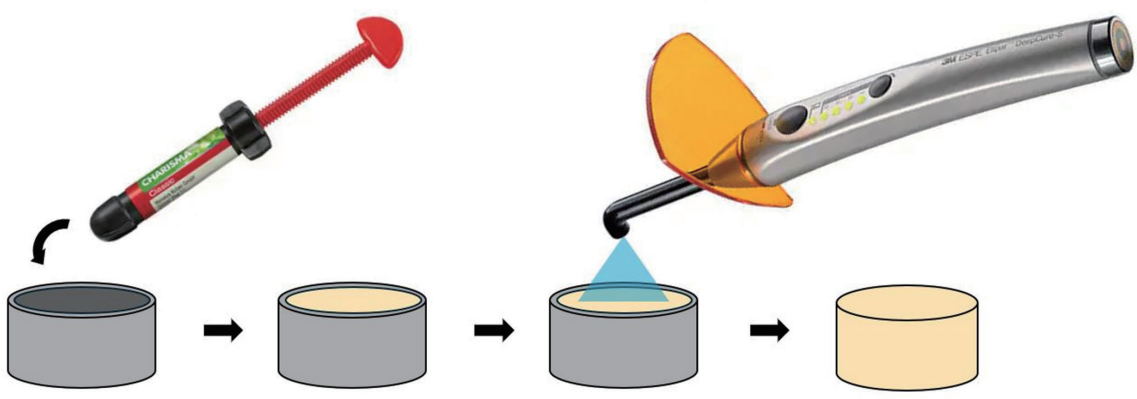

Fig. 1. Schematic diagram of the preparation process of the experimental group. Twelve maxillary central incisors were prepared with a 2 mm thick dentin layer and embedded in acrylic blocks, leaving the labial enamel surfaces exposed. The specimens were demineralized to create artificial white spot lesions and restored with infiltration resin (ICON, DMG, Hamburg, Germany) following the manufacturer's protocol.

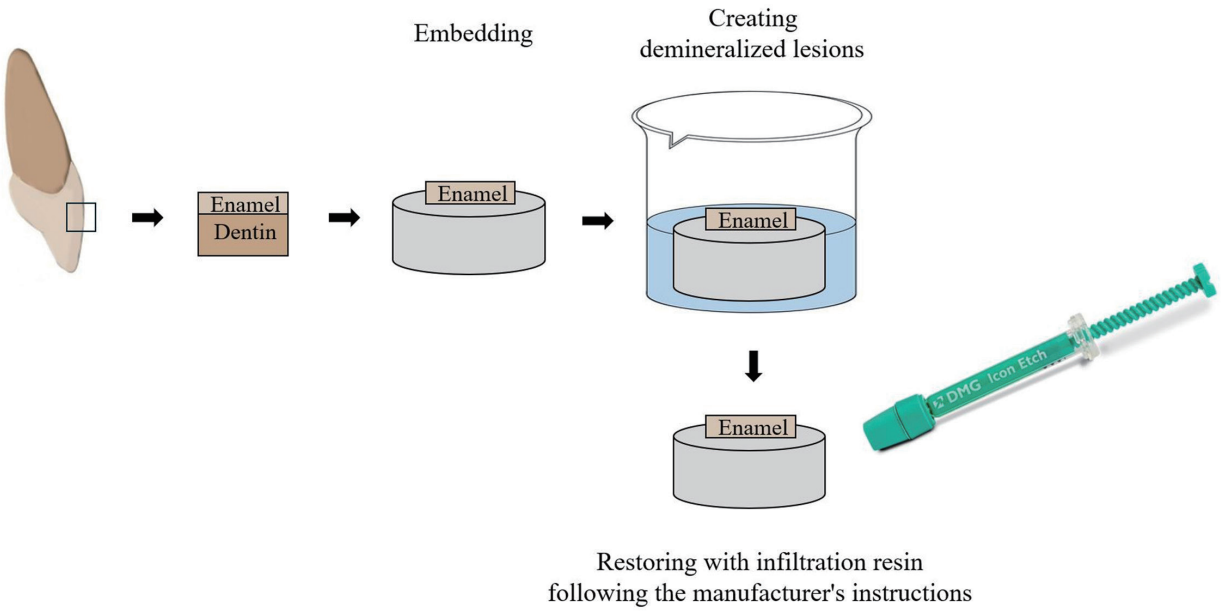

Fig. 2. Schematic diagram of the preparation process of the control group. Specimens were prepared using A1 and A3.5 composite resin (Charisma, Heraeus Kulzer) in acrylic molds, then light-cured.

-a* is the green direction. The b* values indicate the direction of the chromaticity diagram, where +b* is yellow, 0 is gray, and -b* is blue direction.

The spectrocolorimeter (NF999, Nippon Denshoku Industries, Tokyo, Japan) for color measurement uses a standard light source D_{65}; the diameter of the measuring sphere is 3.0 mm, and the diameter of the measuring range is 2.0 mm. This device is designed for narrow areas and curved surfaces.[13]

The dental colorimeter (ShadeEye NCC, Shofu, Kyoto, Japan) is a device that measures the color of teeth and porcelain in Tooth mode and Porcelain mode using standard light source D_{65}. For tooth mode, the measured color characteristics are calculated with the information of guide number (Vita classical shade), chroma (saturation), value (brightness), and hue (color). The color characteristics measured in porcelain mode are indicated as -1.5 ~ 6.0 (17 levels) for shade, -3 ~ +2 (6 levels) for value, and YⅢ ~ RⅢ (7 levels) for hue.[14] Before and after the accelerated aging test, the infiltration resin restoration test group was measured in Tooth mode, and the control group was measured in Porcelain mode.

The color difference (ΔE*) before and after accelerated aging test was calculated using the following formula.

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

Statistical Analysis

Statistical analyses were performed to address different analytical objectives of the experimental and control groups. For the infiltration resin-treated experimental group, repeated measurements were obtained from the same specimens over time; therefore, within-specimen temporal changes were evaluated using repeated measures analysis. When the assumptions of normality were satisfied, repeated measures analysis of variance (ANOVA) with the Student-Newman-Keuls post hoc test was applied. When normality assumptions were not met, the Friedman test was used as a nonparametric alternative ($P < 0.05$).

Comparisons between the infiltration resin-treated group and the composite resin control groups were conducted as between-group analyses at specific time points. Because of differences in sample size and data distribution between groups, the Kruskal-Wallis

test was used, followed by Dunn's post hoc test ($P < 0.05$). All statistical analyses were performed using GraphPad Prism 9 (GraphPad Software Inc., San Diego, USA), and statistical significance was set at $P < 0.05$.

Results

In the infiltration resin-treated experimental group, the averages of CIE L*, a*, b* values and ΔL*, Δa*, Δb*, ΔE* values of 12 specimens were recorded at the 0, 5, 15, and 30 days (Table 1). As a result of color change analysis using a spectrocolorimeter, the average color change ΔE* value for the infiltration resin-treated experimental group was 5.55 (1.84). The color change by the accelerated aging test was mainly caused by a decrease in ΔL* value and an increase in Δb* value (Fig. 3).

The average of the CIE L*, a*, b* values and the color change ΔL*, Δa*, Δb*, and ΔE* values of the five specimens before and after the accelerated aging test in the control group are shown in Table 1 and Fig. 4. The average color change ΔE* value for the control group was 6.45 (0.52) in the A1 shade and 4.0 (0.55) in the A3.5 shade. Values above the reported upper limit of 3.3 were measured in all groups.

A comparison of ΔE* values between each group is shown in Fig. 5. The change in color amount ΔE* value by the accelerated aging test showed a significant difference over time in all specimens ($P < 0.05$). In this case, there was no significant difference between the infiltration resin group and the composite resin A1 group, and between the infiltration resin group and the composite resin A3.5 group, but there was a significant difference between the composite resin A1 group and the composite resin A3.5 group ($P < 0.05$).

Table 2 shows the shade changes measured using a dental colorimeter before and after the accelerated aging test in the infiltration resin-treated experimental group. Table 3 shows the shade changes measured using a dental colorimeter before and after the accelerated aging test in the control group. There was no significant difference between the experimental

Table 1. Mean values (standard deviation) of L*, a*, b*, and ΔE* for the infiltration resin group (n = 12) and control groups (composite resin A1, n = 5; composite resin A3.5, n = 5) measured at baseline (0 days) and after accelerated aging testing (5, 15, and 30 days)

Group	Days	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE*
Infiltration resin (ICON)	0	54.42 (4.67)	-1.60 (0.52)	1.62 (2.11)	0.00	0.00	0.00	0.00
	5	53.24 (4.53)	-1.82 (0.45)	2.78 (2.09)	-1.18 (0.75)	-0.22 (0.14)	1.16 (0.70)	1.89 (0.66)
	15	52.15 (4.46)	-2.22 (0.45)	4.23 (1.52)	-2.27 (1.14)	-0.62 (0.35)	2.61 (0.75)	3.36 (1.01)
	30	50.74 (4.22)	-2.59 (0.49)	5.94 (1.40)	-3.68 (1.56)	-0.99 (0.28)	4.32 (1.69)	5.55 (1.84)
Composite resin A1 (Control)	0	57.88 (0.25)	-0.90 (0.04)	-3.95 (0.06)	0.00	0.00	0.00	0.00
	30	54.49 (0.95)	-3.30 (0.41)	1.22 (0.46)	-3.39 (1.53)	-2.40 (0.56)	5.17 (0.66)	6.45 (0.52)
Composite resin A3.5 (Control)	0	55.23 (0.37)	-0.73 (0.05)	2.69 (0.06)	0.00	0.00	0.00	0.00
	30	54.0 (0.55)	-2.61 (0.41)	5.82 (0.49)	-1.23 (0.38)	-1.88 (0.48)	3.13 (0.54)	4.0 (0.55)

ΔL*: brightness change; Δa*: red-green axis change; Δb*: yellow-blue axis change; ΔE*: total color difference.

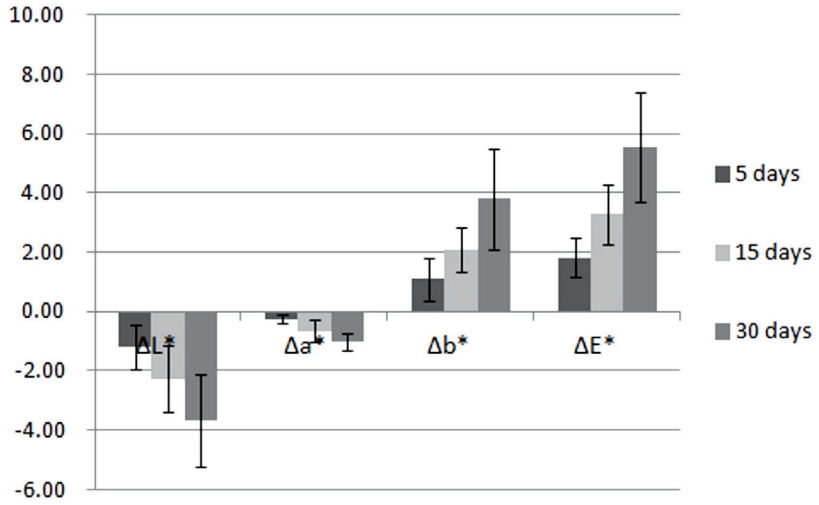

Fig. 3. Color changes (ΔL*, Δa*, Δb*, and ΔE*) in the infiltration resin group before and after the accelerated aging test for 5, 15, and 30 days. A consistent decrease in ΔL* values and an increase in Δb* values are observed, indicating a progressive yellowing effect as the dominant factor in the overall color change.
ΔL*: brightness change; Δa*: red-green axis change; Δb*: yellow-blue axis change; ΔE*: total color difference.

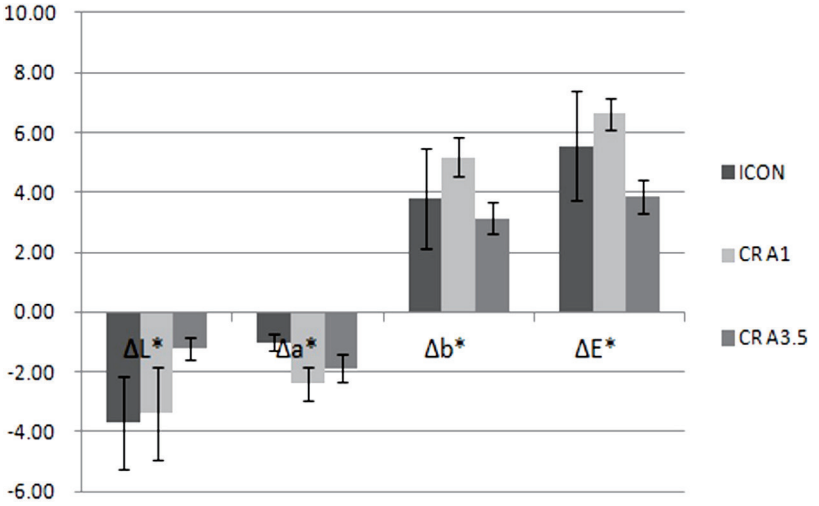

Fig. 4. Color changes (ΔL*, Δa*, Δb*, and ΔE*) in the infiltration resin group (ICON), composite resin A1 group (CR A1), and composite resin A3.5 group (CR A3.5) before and after the accelerated aging test for 30 days. The data illustrate material-dependent differences in color stability, with the infiltration resin group exhibiting performance comparable to the composite resin A1 group.
ΔL*: brightness change; Δa*: red-green axis change; Δb*: yellow-blue axis change; ΔE*: total color difference.

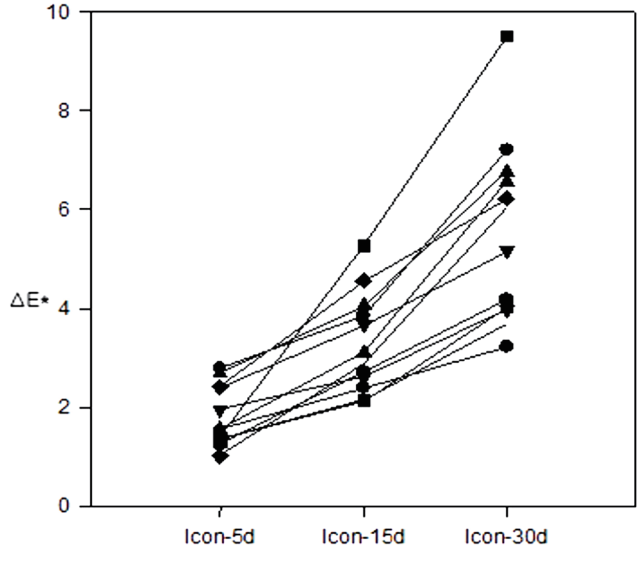

Fig. 5. Total color difference (ΔE*) in the infiltration resin group (twelve maxillary central incisors) for 5, 15, and 30 days. The progression of ΔE* values was depicted, showing significant changes in overall color. Each data line represents a specimen and showed consistent trends of increasing ΔE* values over time.
Icon: infiltration resin group; ΔL*: brightness change; Δa*: red-green axis change; Δb*: yellow-blue axis change; ΔE*: total color difference.

group and the composite resin A1 shade control group, the experimental group and the composite resin A3.5 shade control group; there was a significant difference between the composite resin A1 shade control group and the composite resin A3.5 shade control group (Table 2, 3). In the shade scan results before and after the accelerated aging test using a dental colorimeter, the Vita classical shade guide numbers increased in the infiltration resin group, and the shade value increased in the control group. The infiltration resin group showed increased Vita classical shade guide (Vita Zahnfabrik, Bad Säckingen,

Table 2. Changes in Vita Classical shades, chroma, and value of specimens in the infiltration resin group (n = 12) before and after the accelerated aging test (30 days)

Infiltration resin	Days	Colorimeter	Vita shade	Shade	Value
Sample 1	0	A1	A1	1	-1
	30	B2	B2	2	0
Sample 2	0	D4**	C2**	3.3	-2
	30	D4*	C3*	3.8	-2
Sample 3	0	C2	C2	3	-3
	30	D4*	C3*	3.5	-3
Sample 4	0	B2	B2	2	0
	30	B4	B4	3.5	-1
Sample 5	0	B1	B1	1.5	0
	30	B2	B2	2.5	0
Sample 6	0	C2	C2	3	-3
	30	B4	B4*	3.5	-1
Sample 7	0	D4*	C3*	3.5	-3
	30	C4	C4	4	-2
Sample 8	0	C4	C4	4.5	-3
	30	C4*	C4	5	-2
Sample 9	0	A1	A1	0.5	-1
	30	B2	B2	2	-1
Sample 10	0	VA1	A1*	1.5	2
	30	A2	A2	2.5	-1
Sample 11	0	B2	B2*	2	-1
	30	D4	C2**	3.3	-2
Sample 12	0	root B*	C4*	4	-3
	30	root C	C4*	5.5	-2

* indicates statistically significant differences within the same specimen between baseline (0 days) and 30 days after the accelerated aging test ($P < 0.05$). ** indicates statistically significant differences between different specimens at the same time point ($P < 0.01$).

Table 3. Changes in shade, value, and hue measured in control groups (composite resin A1 and A3.5) before and after the accelerated aging test (30 days)

Control groups	Days	Shade	Value	Hue
Composite resin A1	0	1	-3	R3
	30	2.5	-3	Y3
Composite resin A3.5	0	3.3	-3	Y1
	30	3.5	-2	Y3

Germany) numbers. The control group showed an increase in shade measurement values, and similar to the measurement analysis result of the spectrocolorimeter, the shade increase in the composite resin A1 group was higher than that in the composite resin A3.5 group. The findings indicated a clinically recognizable color change.

Discussion

The resin infiltration technique used in this experiment produced functionally and esthetically satisfactory findings for WSLs that had progressed to a certain depth without tooth preparation. The resin infiltration method is a relatively new technique, and while many studies have focused on its effectiveness, there are few studies on the durability of restorations. Among the factors determining the durability of a resin restoration, color stability significantly influences esthetics. This study used the resin infiltration technique to restore demineralized enamel. An accelerated aging test was performed using a conventional composite resin as control. The color stability of resin-infiltrated WSLs was evaluated using color measurements. The null hypotheses were as follows: (1) the color of artificial white spot lesions restored with infiltration resin would not change after the accelerated aging test, and (2) there would be no difference in color change between the infiltration resin group and the composite resin control groups after the accelerated aging test. Based on the present results, the first null hypothesis was rejected because a statistically significant color change occurred after aging, whereas the second null hypothesis was not rejected because no statistically significant differences in ΔE* were detected between the infiltration resin and composite resin groups.

Oysaed and Ruyter showed that the diffusion of the inorganic additive-substrate bonding surface or the resin matrix itself was mainly caused by the content of inorganic additives and water absorption. Moreover, moisture absorbed into the polymer matrix breaks the bond between the inorganic additive and the matrix or dissolves the inorganic additive, and resins with lower amounts of inorganic additive show more moisture absorption.[15] Kalachandra and Wilson reported that color changes in resins correlated to the changes inside the resin matrix that caused water absorption.[9] In addition to the study on high water absorption of TEGDMA reported by Ferracane, Vichi et al. reported higher color stability when TEGDMA was replaced with urethane dimethacrylate (UDMA).[10,16] Thus, absorption adversely affects color stability, and the TEGDMA monomer exhibits low color stability.

In addition to discoloration due to water absorption of the substrate, temperature also affects the color stability of resins. Asmussen evaluated the color stability of 15 self-curing resins and light-curing resins in an accelerated aging test when stored in water at 37°C for 12 months and 50°C, 60°C, and 70°C for 1 or 2 months. Findings showed that samples stored at 50°C for 2 months and 60°C for 1 month showed similar findings to samples stored for 12 months at 37°C.[11] In a study on the color change of two types of acrylic resins, Wozniak et al. reported that specimens stored in cold water showed less discoloration than those stored in hot water, and self-cured resins showed greater discoloration than heat-cured resins.[17]

This study was based on the accelerated aging test by Asmussen in which the color change of resins stored at 60°C for 1 month showed a high correlation with resins stored at 37°C for 12 months.[11] Accordingly, the color change was compared and observed after 24 h of polymerization and storage in distilled water at 60°C for 30 days. The 30-day period in distilled water at 60°C used in this study corresponds to more than one year when converted to the time applied to actual patients. However, greater discoloration may occur in actual clinical practice, as this experiment focused on intrinsic discoloration under accelerated aging conditions and excluded various external factors.[18]

The findings of the present study are consistent with those of previous studies that evaluated the color stability of resin-based materials under water aging or accelerated aging conditions. Consistent with the findings reported by Asmussen, storage in water at elevated temperatures for a relatively short period produced color changes comparable to those ob-

served after long-term storage at body temperature, supporting the validity of accelerated aging protocols for evaluating discoloration of resin materials.[19] In agreement with this observation, the present study demonstrated significant color changes after storage in distilled water at 60°C for 30 days, suggesting that the observed discoloration reflects intrinsic material-related changes rather than short-term experimental artifacts. Previous studies have also indicated that water sorption within the resin matrix plays a critical role in discoloration of resin-based materials. Kalachandra and Wilson reported a strong correlation between water uptake and color change in composite resins, while Ferracane demonstrated that monomers containing hydrophilic ether linkages, such as TEGDMA, exhibit increased water sorption and hydrolytic degradation.[9,10] Similarly, Vichi et al. showed that resin-based composites containing higher proportions of TEGDMA exhibited greater color changes after water aging compared with materials based on more hydrophobic monomers such as UDMA.[16] These findings provide a plausible explanation for the significant discoloration observed in the infiltration resin used in the present study, which is primarily composed of TEGDMA.

With respect to shade-dependent discoloration, Uchida et al. reported that lighter-shade composite resins exhibited greater color changes than darker-shade materials after aging.[20] This observation is consistent with the present results, in which the A1 shade composite resin demonstrated greater ΔE* values than the A3.5 shade composite resin. Taken together, these comparisons suggest that the discoloration behavior of the infiltration resin observed in this study is comparable to that reported for conventional resin-based restorative materials evaluated under similar aging conditions.

The degree of discoloration is assessed by ΔE*, which is the total amount of color change, and the Δ E* value has an important meaning in visually evaluating the degree of discoloration.[21] Gross and Moser reported that color differences were not perceptible to the naked eye if the ΔE* value ranged from 0 to less than 2. Color differences were noticeable from 2 to 3 and usually perceptible from 3 to less than 8.[22] Ruyter et al. reported that a ΔE* value of 3.3 was the upper limit of color tolerance, and color change was perceptible at a ΔE* value greater than 1.[23] In this study, all groups showed ΔE* values above the reported threshold, indicating that the color changes were perceptible. All tested groups exhibited ΔE* values exceeding 3.3, the upper threshold for perceptible color differences, underscoring the impact of accelerated aging test on color stability and its potential clinical relevance. Thus, the first null hypothesis of the study was rejected. However, analysis of the amount of color change between the infiltration resin experimental group and the clinically widely used control group revealed no significant difference between the two groups. Therefore, the second null hypothesis of the study was not rejected.

A study on the correlation between color stability and color of composite resins reported that more discoloration occurred in light-colored resins, and in particular, yellowing was the main contributing factor, and the b* value increased in CIE L*, a*, b* color system.[20] In this study, the bright color composite resin A1 shade group showed a more significant color change than the dark color composite resin A3.5 shade group ($P < 0.05$), and a high correlation was observed between the increase in b* value and the Δ E* value (Fig. 2).

This study confirmed a large amount of color change before and after the accelerated aging test, assumed due to the TEGDMA monomer of the infiltration resin before the experiment. However, there was no significant difference in the amount of color change compared to the existing light-cured composite resins widely used in clinical practice. The infiltration resin is indicated for early smooth surface caries in anterior teeth. Among composite resins, the products mainly used in the anterior region are bright colors. The findings showed a greater color change in the light-colored composite resin than in the infiltration resin, although within the significance level. The resin infiltration technique using infiltration resin showed a significant amount of color change before and after the accelerated aging test but did not show a significant difference compared to the color stability of the existing composite resin. Therefore, under

the conditions of this study, the magnitude of discoloration observed in the infiltration resin was not statistically different from that of the conventional composite resins tested under the present experimental conditions.

This study has several limitations. As an exploratory in vitro study, the sample sizes of the experimental and control groups were not identical, reflecting the different nature of specimen preparation for natural teeth and standardized composite resin samples. Therefore, statistical analyses were conducted separately to address within-specimen temporal changes and between-material comparisons. Because this study was not designed as a confirmatory analysis, a priori power analysis was not performed; accordingly, the results should be interpreted with caution, particularly with respect to comparisons between different material groups. Due to the limitations of the composite resins used as the control group in this experiment, future comparative studies using a wider range of commercially available composite resin products are warranted. In addition, further investigations considering external discoloration factors, such as stress, staining substances, light exposure, pH, and temperature changes in the oral environment, as well as studies on other physical properties related to material durability, are necessary.

Conclusion

Within the limitations of this in vitro study, the resin infiltration material demonstrated significant discoloration following accelerated aging, with ΔE* values exceeding the commonly accepted perceptibility threshold. Although no statistically significant differences were detected between the infiltration resin and the tested composite resins, all materials exhibited clinically perceptible color changes. These findings suggest that intrinsic discoloration of infiltration resin may occur over time under accelerated aging conditions. Furthermore, the present study was conducted under controlled laboratory conditions, and clinical factors such as saliva, dietary habits, and oral hygiene may influence discoloration differently in vivo.

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인공 백색 병소 수복을 위한 레진 침투 기법 재료의 색 안정성 평가

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목적: 본 연구는 가속 노화 시험을 통해 인공 백색 병소의 수복에 사용된 레진 침투 시스템의 색 안정성을 평가하고자 하였다.

연구 재료 및 방법: 12개의 인간 상악 중절치로 인공 백색 병소를 형성하고 침투 레진(ICON)으로 수복하였다. 대조군은 복합 레진 A1 및 A3.5 색상으로 수복하였다. 가속 노화 시험을 위해 시편을 60°C 증류수에 30일간 보관하여 1년 이상의 임상 기간을 재현하였다. 0, 5, 15, 30일에 분광광도계로 국제조명위원회(CIE)의 L*, a*, b* 값을, 치과용 색차계로 색조를 측정하였다.

결과: 모든 군에서 총 색 변화량(ΔE*)이 기존 문헌에서 제시된 색차 기준값(ΔE* = 3.3)을 초과하였다. 30일 후 평균 ΔE* 값은 침투 레진 5.55, 복합 레진 A1 6.45, A3.5 4.0으로 나타났다. 변색은 주로 명도(ΔL*) 감소와 황색도(Δb*) 증가에 의해 발생하였다. 침투 레진과 복합 레진 군 간의 색 안정성 차이는 통계적으로 유의미하지 않았다.

결론: 이러한 결과는 가속 노화 조건에서 침투 레진이 유의한 변색을 보였으며, 기존 복합 레진과 통계적으로 유의한 차이는 없었음을 시사한다. 모든 군에서 ΔE* 값은 지각 가능한 색차 기준을 초과하였다.

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주요어: 가속 노화 시험; 레진 침투; 복합 레진; 백색 병소; 색 안정성

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