Cover Story

Influence of home or in-office tooth bleaching on the color stability of white-spot lesions after resin infiltration

An in vitro comparison

Supplemental material is available online.

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ABSTRACT

Background. The authors investigated the color stability of resin-infiltrated white-spot lesions (WSL) after in-office tooth bleaching (IB) or home tooth bleaching (HB) and assessed the potential for staining and rebleaching.

Methods. Sixty caries-free third molars were demineralized to create WSLs and then divided into 4 groups: (1) no treatment (control) group; (2) demineralization plus resin infiltration group; (3) demineralization plus resin infiltration plus IB group; (4) and demineralization plus resin infiltration plus HB group. After exposure to coffee solution to simulate 12-month staining potential, a second bleaching procedure was performed. Color measurements were obtained at 10 defined time points using standardized digital imaging and analyzed in the Commission Internationale de l'Eclairage-L*a*b* (lightness, red-green axis, yellow-blue axis) color space. To precisely document color changes, time points included baseline, after WSL creation, after resin infiltration, after bleaching procedures, after thermocycling (aging), after coffee exposure, and after rebleaching.

Results. No significant differences in bleaching effectiveness were observed between IB and HB after initial ($P = .127$) or subsequent ($P = .111$) bleaching. Similarly, there were no significant differences ($P = .867$) in staining potential between the IB and HB groups after 12 days. Both bleaching methods restored the WSL color close to the baseline after staining.

Conclusions. Both IB and HB restored the color of resin-infiltrated WSLs to near-baseline levels after staining in vitro, with no significant differences between the 2 methods. Although results of the treatments showed responsiveness to whitening protocols, color stability under staining conditions remained limited, highlighting the need for further investigation into long-term maintenance strategies.

Practical implications. Both IB and HB approaches may be clinically viable for maintaining the esthetic stability of treated WSLs over time once sufficient evidence from clinical studies becomes available.

Key Words. Color stability; home bleaching; in-office bleaching; resin infiltration; white-spot lesions.

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White-spot lesions (WSLs) in enamel occur when calcium and phosphate ions are leached out via organic acids produced by cariogenic bacteria. This process results in internal porosities that affect the refractive index of the enamel surface.[1] The incident light is no longer reflected uniformly but instead is refracted multiple times within the caries lesion, leading to visible whitish opacities. These esthetic irregularities pose an esthetic issue and can affect the self-esteem of patients.[2,3]

Children and adolescents are at a higher risk of developing WSLs than adults, particularly during orthodontic treatments, when the prevalence can reach up to 50%.[4] In light of the growing

importance of esthetics in the age of social media, adolescents and young adults increasingly place value on their external appearance, particularly their teeth.[5] Researchers have found that white opacities, including WSLs, are often perceived as blemishes, especially in the visible area of the anterior teeth.[3] These esthetic concerns can negatively affect self-confidence. The health aspects are also important, as WSLs represent weakening of the enamel structure and can be the starting point for a future cycle of dental treatments.[6]

The primary goal of WSL therapy, therefore, is to arrest the existing caries lesions, ensure stabilization of microporosities, and achieve esthetic rehabilitation of the whitish opacities.[7] Resin infiltration (RI) (Icon System, DMG) is a minimally invasive method used primarily for the esthetic treatment and stabilization of WSLs. The camouflaging effect of RI, as described by Kielbassa and colleagues,[8] is achieved through the infiltration of the porous lesion body with a low-viscosity resin. This process alters the refractive index of the lesion to closely match that of healthy enamel, thereby masking whitish opacities. The main component of RI, triethylene glycol dimethacrylate (TEGDMA), penetrates deeply into the lesion through capillary forces, effectively sealing it and protecting the infiltrated enamel from further demineralization. The refractive index of RI (1.47) is close to that of natural enamel (1.62) and enhances this camouflaging effect by means of filling the microporosities and rendering the lesion nearly invisible.[9]

In the long term, TEGDMA may exhibit discoloration due to its yellowing tendency and its susceptibility to water absorption, which can contribute to potential color changes.[10,11] However, such changes are not inevitable and depend on various factors, including the skill of the performing dentist (eg, achieving full penetration) and the characteristics of the lesion. These variables should be considered when interpreting potential outcomes. This leads to a cyclical process in which the optical condition of the treated tooth is further influenced by external factors, such as the consumption of staining beverages and foods. This is problematic, given the increasing worldwide popularity and accessibility of coffee.[12]

Due to these factors and the discoloration potential of RI, many patients desire tooth bleaching even after RI. Researchers have reported that infiltrated and discolored enamel lesions can be satisfactorily bleached, suggesting that the optical appearance can be restored.[12-14] Bleaching can be performed as either in-office tooth bleaching (IB) chairside, using high concentrations of hydrogen peroxide and optional light activation, or home tooth bleaching (HB), with customized trays and bleaching agents containing lower concentrations of carbamide peroxide.[14] However, which bleaching method yields the best long-term results and to what extent restaining might occur has yet to be determined. To our knowledge, a direct comparison between the 2 bleaching methods (IB, HB) after RI has not been conducted. Furthermore, data on the postbleaching staining potential of already infiltrated and bleached lesions and their potential for rebleaching are lacking.

Therefore, we aimed to track the natural discoloration cycle of resin-infiltrated WSLs in vitro and investigate the interactions between RI and different bleaching techniques to establish clinically relevant insights for the esthetic rehabilitation and long-term care of resin-infiltrated WSLs. We proposed the following 2 null hypotheses: (1) there would be no difference in the bleaching effect of resin-infiltrated WSL between the 2 bleaching methods (IB, HB) and (2) the staining potential and rebleaching of resin-infiltrated WSLs would be identical for both bleaching methods.

ABBREVIATION KEY

- **ΔE:** Total color difference.
- **a*:** Red-green axis.
- **b*:** Yellow-blue axis.
- **CIE:** Commission Internationale de l'Eclairage.
- **DRI:** Demineralization plus resin infiltration.
- **HB:** Home tooth bleaching.
- **IB:** In-office tooth bleaching.
- **L*:** Lightness.
- **RI:** Resin infiltration.
- **T0:** Baseline.
- **T1:** After white-spot lesion creation.
- **T2:** After resin infiltration.
- **T3:** After tooth bleaching in the in-office and home bleaching groups.
- **T4:** After a waiting period of 14 days.
- **T5:** After thermocycling.
- **T6:** After artificial coffee staining at 6 days.
- **T7:** After artificial coffee staining at 12 days.
- **T8:** Immediately after poststaining bleaching of all groups.
- **T9:** After a further waiting period of 2 weeks.
- **TEGDMA:** Triethylene glycol dimethacrylate.
- **WSL:** White-spot lesion.

METHODS

Approval for our in vitro study was obtained from the Ethics Committee of the University of Cologne, Germany (23-1472, approval date March 28, 2024). The study design is illustrated in Figure 1. The table provides detailed information on the materials used. Full methodological details can be found in the Appendix (available online at the end of this article).

Sample size

On the basis of pilot study practices,[15] a sample size of 60 experimental teeth was deemed feasible to provide 80% power.

Sample preparation and grouping

Sixty caries-free third molars were extracted, cleaned, and vertically embedded in acrylic up to two-thirds of their root; the crown surfaces were polished and rinsed with water. All teeth (15 per group)

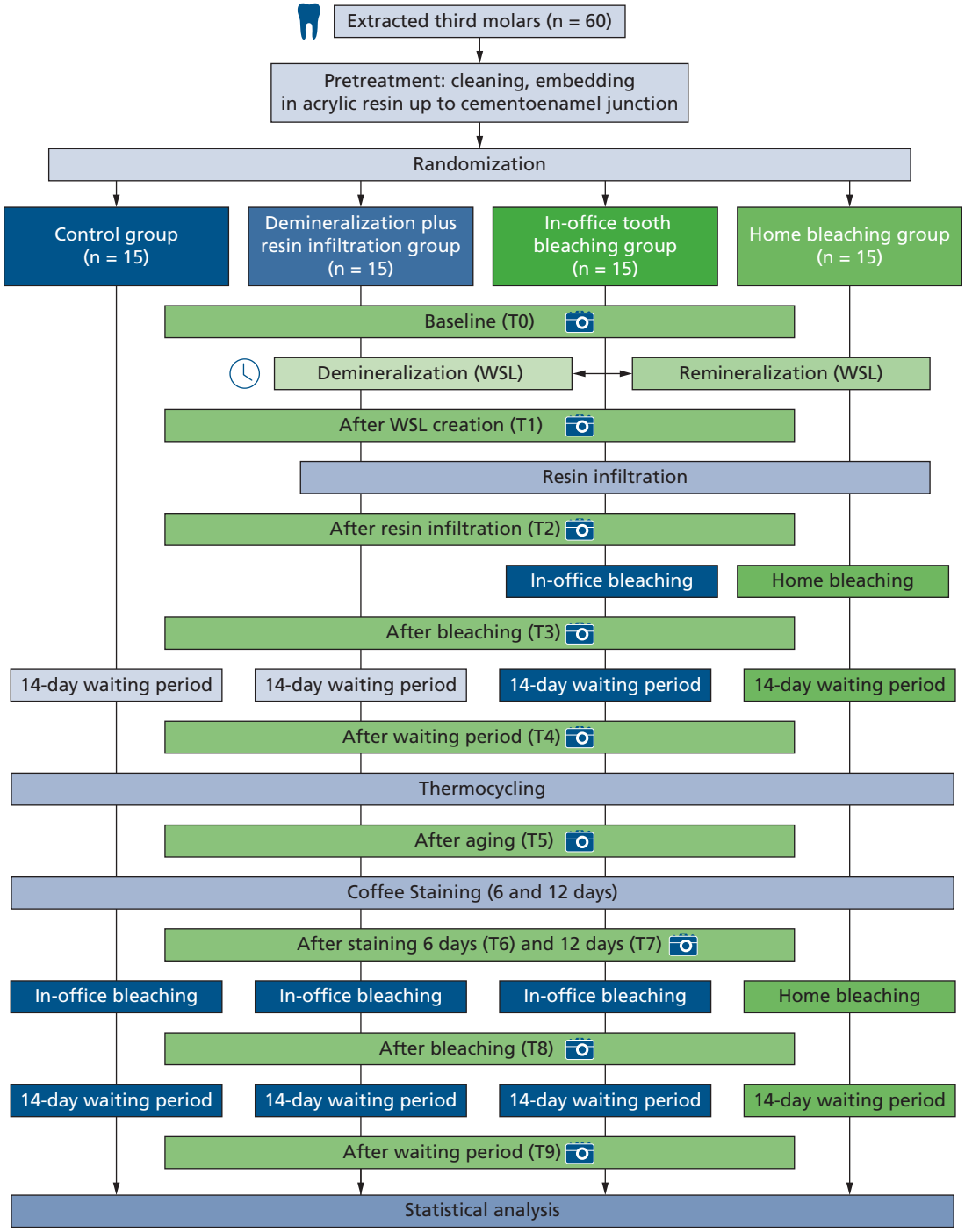

Figure 1. Study flowchart illustrating the different intervention groups, treatments performed, and measurement time points for color evaluation. WSL: White-spot lesion.

were randomly assigned to 1 of 4 groups: (1) control group (no treatment); (2) demineralization plus RI (DRI) group; (3) IB group (DRI plus IB); and (4) HB group (DRI plus HB).

WSL creation

Apart from controls, all groups were exposed to a cariogenic environment to induce WSL formation. Crowns were demineralized in solution (16 hours) and then remineralized (8 hours)[16]; this demineralization-remineralization cycle was repeated for 21 days.[17] Teeth were then stored in artificial saliva (37 ± 1 °C) for 56 hours,[18] and WSLs were quantitatively confirmed.[19]

Table. Materials, manufacturers, composition, and lot numbers of the products used in this study.

MATERIAL	MANUFACTURER	COMPOSITION	LOT NO.
Opalescence PF 10%	Ultradent Products, Inc	5.8% hydrogen peroxide equivalent, glycerin, water, urea peroxide, xylitol, carbomer, polyethylene glycol 6, sodium hydroxide, potassium nitrate, 0.11% fluoride ion	BXJ83
ZOOM!	Discus Dental Europe	25% hydrogen peroxide, potassium hydroxide, eugenol, 2,6-di-tertiary-butyl-4-methylphenol	23279010
Icon Etch	DMG	15% hydrochloric acid	261396
Icon Dry	DMG	99% ethanol	261396
Icon Infiltrant	DMG	Triethyleneglycol dimethacrylate, initiators, additives	261396
Nepresso Volluto coffee capsule	Nestlé Nespresso S.A.	100% arabica coffee Origin: South America Roast: light Intensity: 4/13 Quantity: 5 g per capsule	3147098306

RI

Apart from controls, the induced WSLs were treated with the Icon System, that is, application of Icon infiltrant (ie, TEGDMA) to pretreated surfaces followed by light curing and then followed by a repeat of this infiltration and curing process. Teeth were immersed in distilled water for 24 hours before color measurement.[12]

Tooth bleaching

Bleaching gel was applied evenly (thickness of 0.5-1 mm) in both groups (HB group: Opalescence 10% PF [Ultradent Products, Inc] for 8 hours [in an incubator at 37 °C[13]] over 5 days; IB group: ZOOM! [Discus Dental Europe] for 4 cycles of 15 minutes each).[20] Samples were then stored in distilled water for 14 days.

Thermocycling

All samples (all groups) underwent thermocycling (total of 5,000 cycles) to simulate aging of approximately 6 months.[21]

Staining

All samples were immersed in a coffee-staining solution (at 37 °C) for 12 days to mimic 12 months of coffee consumption.[12] The coffee was freshly brewed and replaced daily.

Poststaining bleaching

Subsequently, all samples underwent another round of tooth bleaching. The control, DRI, and IB groups received 4 cycles, 15 minutes each of IB, and the HB group received 8 hours over 5 days of HB. Samples were then stored in distilled water for another 14 days.

Color measurement

Standardized digital photographs were obtained at 10 different time points under standardized environmental conditions.[5] A patch analysis ensured that the same area was consistently analyzed. Time points for photo capture were: baseline (T0); after WSL creation (T1); after RI (T2); after tooth bleaching in the IB and HB groups (T3); after waiting 14 days (T4); after thermocycling (T5); after artificial coffee staining at 6 days (T6) and 12 days (T7); immediately after poststaining bleaching of all groups (T8); and after a further waiting period of 2 weeks (T9) (Figures 2-5).

After calibration, color values were measured using image analysis software (Photoshop CC 2024, Adobe). Red, green, blue values were determined for each tooth and transformed into the Commission Internationale de l'Eclairage (CIE)-L*a*b* (lightness, red-green axis, yellow-blue axis) color space, then color distributions were analyzed.[22] Color values for each time point were calculated, and the total color difference (ΔE) was determined using the following formula:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2},$$

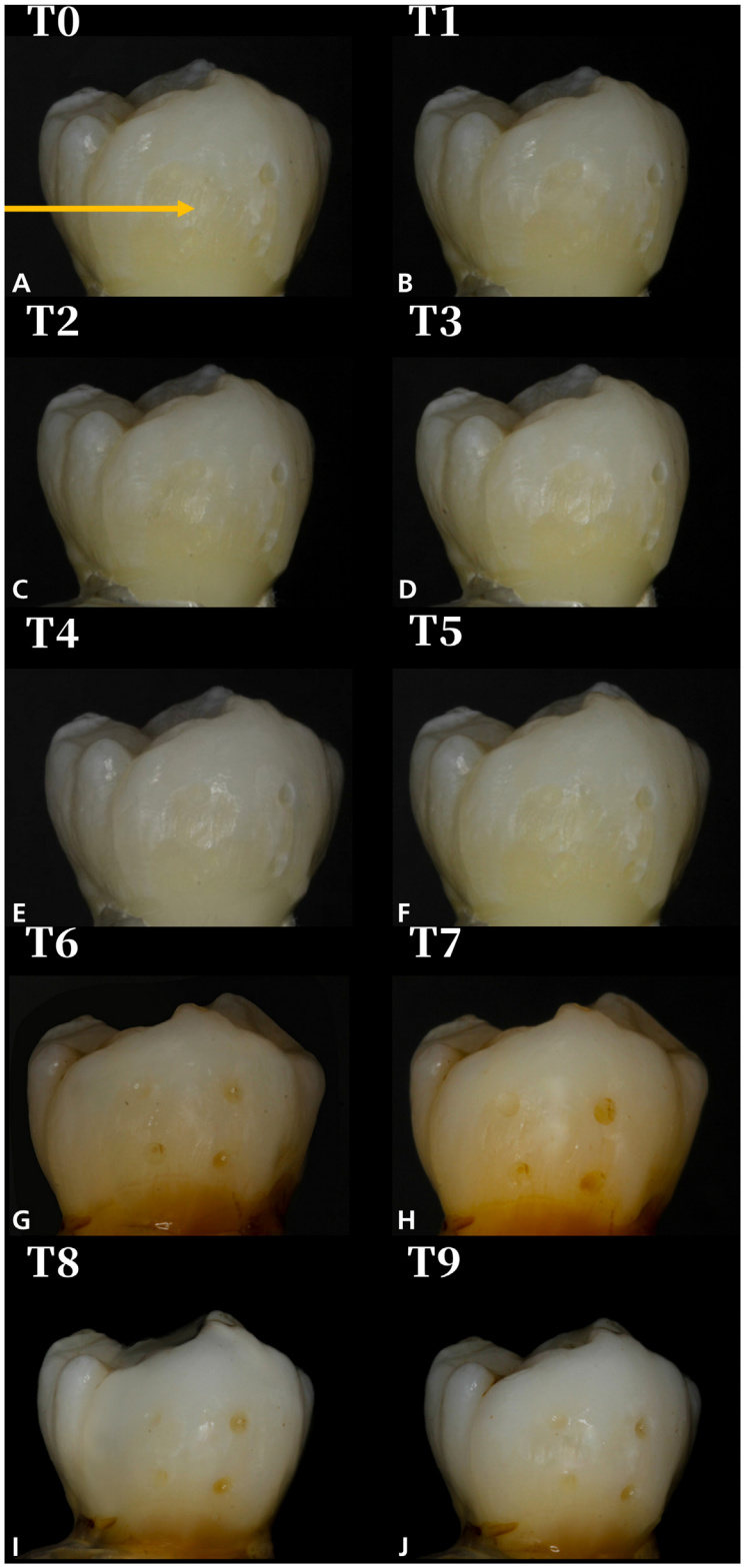

Figure 2. Photographic documentation of control group, illustrating the 10 distinct time points (T0-T9) throughout the experimental timeline. **A.** T0: Baseline; point of interest within the standardized square is marked with an arrow. **B.** T1: After white-spot lesion creation. **C.** T2: After resin infiltration. **D.** T3: After tooth bleaching in the in-office and home bleaching groups. **E.** T4: After a waiting period of 14 days. **F.** T5: After thermocycling. **G.** T6: After artificial coffee staining at 6 days. **H.** T7: After artificial coffee staining at 12 days. **I.** T8: Immediately after poststaining bleaching of all groups. **J.** T9: After a further waiting period of 2 weeks.

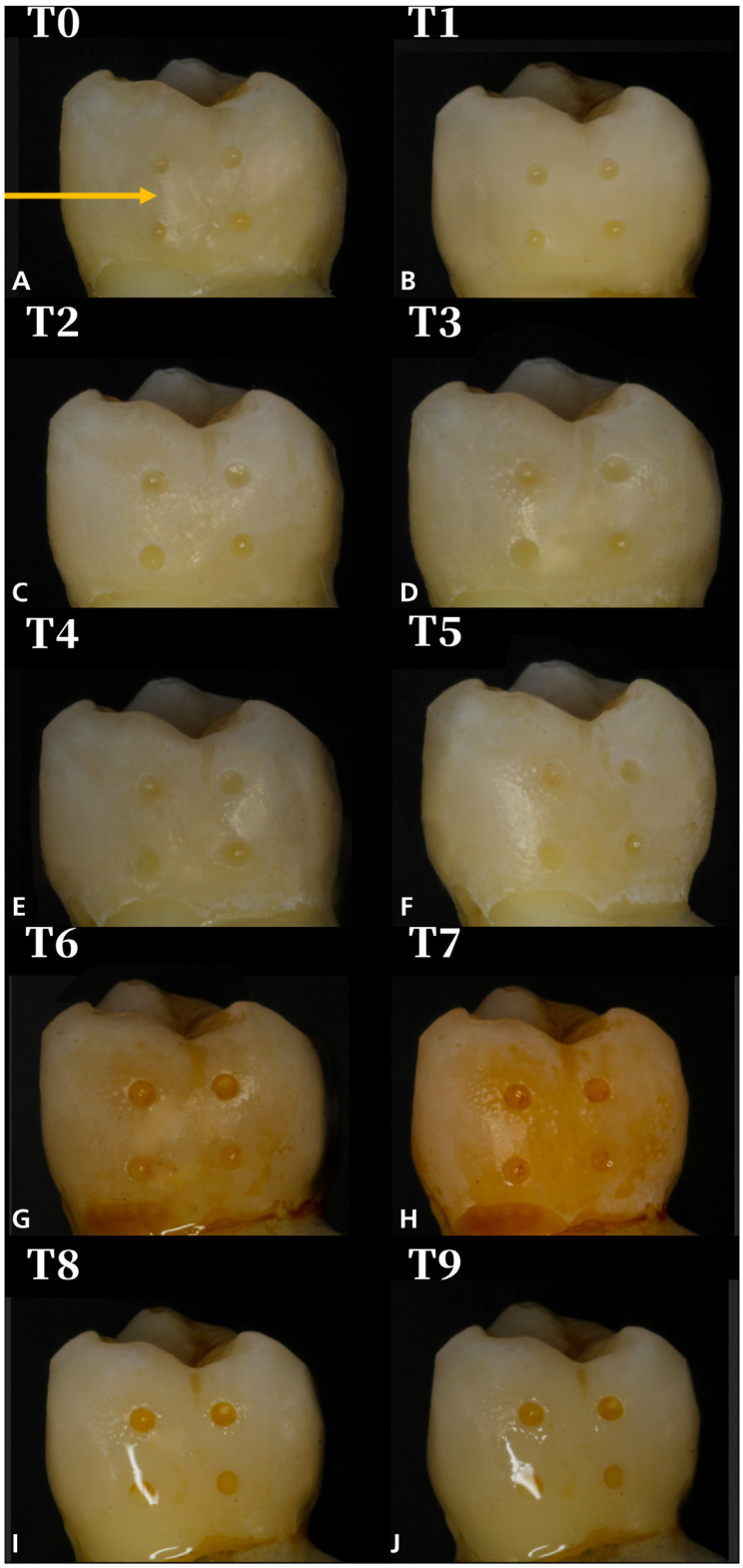

Figure 3. Photographic documentation of the demineralization plus resin infiltration group, illustrating the 10 distinct time points (T0-T9) throughout the experimental timeline. **A.** T0: Baseline; point of interest within the standardized square is marked with an arrow. **B.** T1: After white-spot lesion creation. **C.** T2: After resin infiltration. **D.** T3: After tooth bleaching in the in-office and home bleaching groups. **E.** T4: After a waiting period of 14 days. **F.** T5: After thermocycling. **G.** T6: After artificial coffee staining at 6 days. **H.** T7: After artificial coffee staining at 12 days. **I.** T8: Immediately after poststaining bleaching of all groups. **J.** T9: After a further waiting period of 2 weeks.

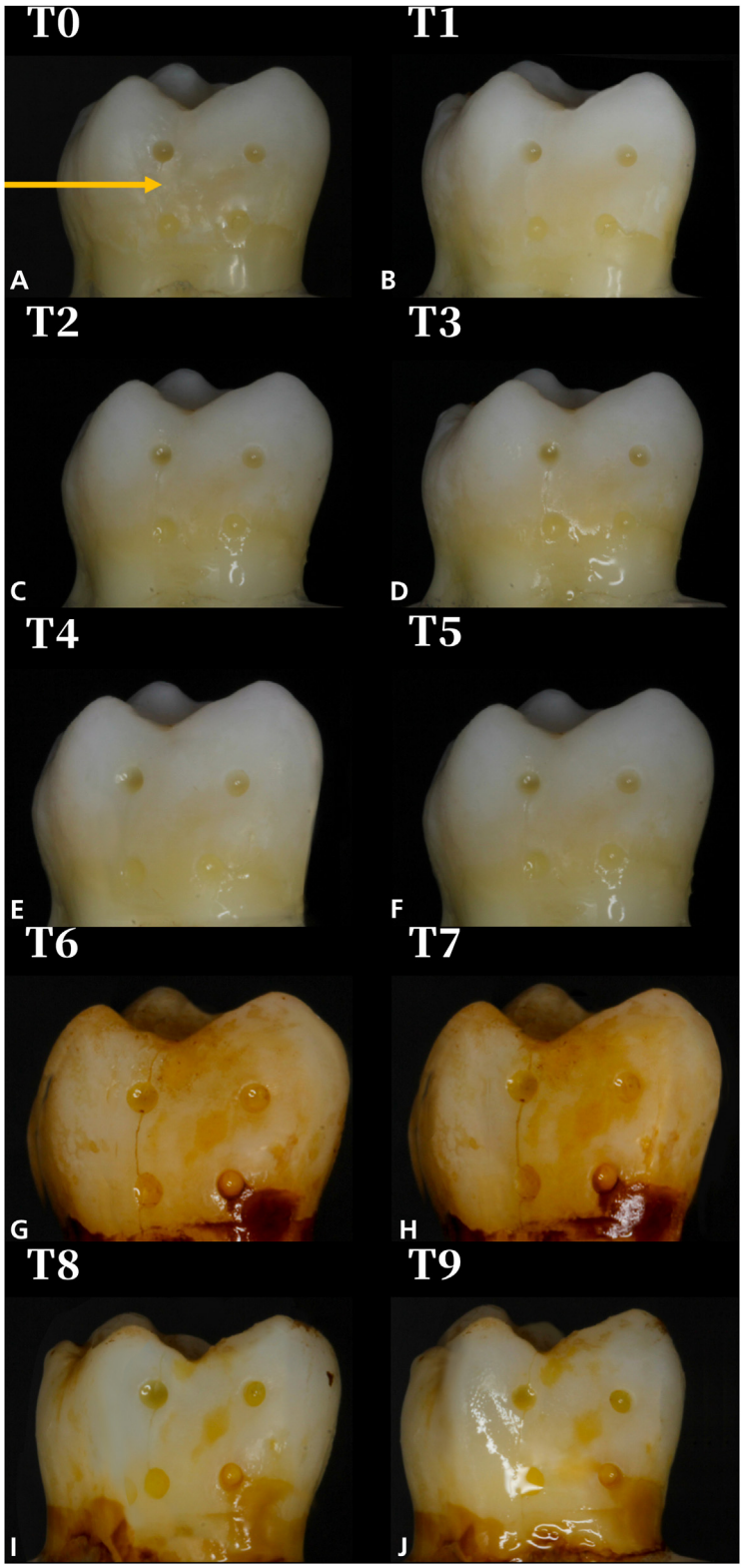

Figure 4. Photographic documentation of in-office tooth bleaching group, illustrating the 10 distinct time points (T0-T9) throughout the experimental timeline. **A.** T0: Baseline; point of interest within the standardized square is marked with an arrow. **B.** T1: After white-spot lesion creation. **C.** T2: After resin infiltration. **D.** T3: After tooth bleaching in the in-office and home bleaching groups. **E.** T4: After a waiting period of 14 days. **F.** T5: After thermocycling. **G.** T6: After artificial coffee staining at 6 days. **H.** T7: After artificial coffee staining at 12 days. **I.** T8: Immediately after poststaining bleaching of all groups. **J.** T9: After a further waiting period of 2 weeks.

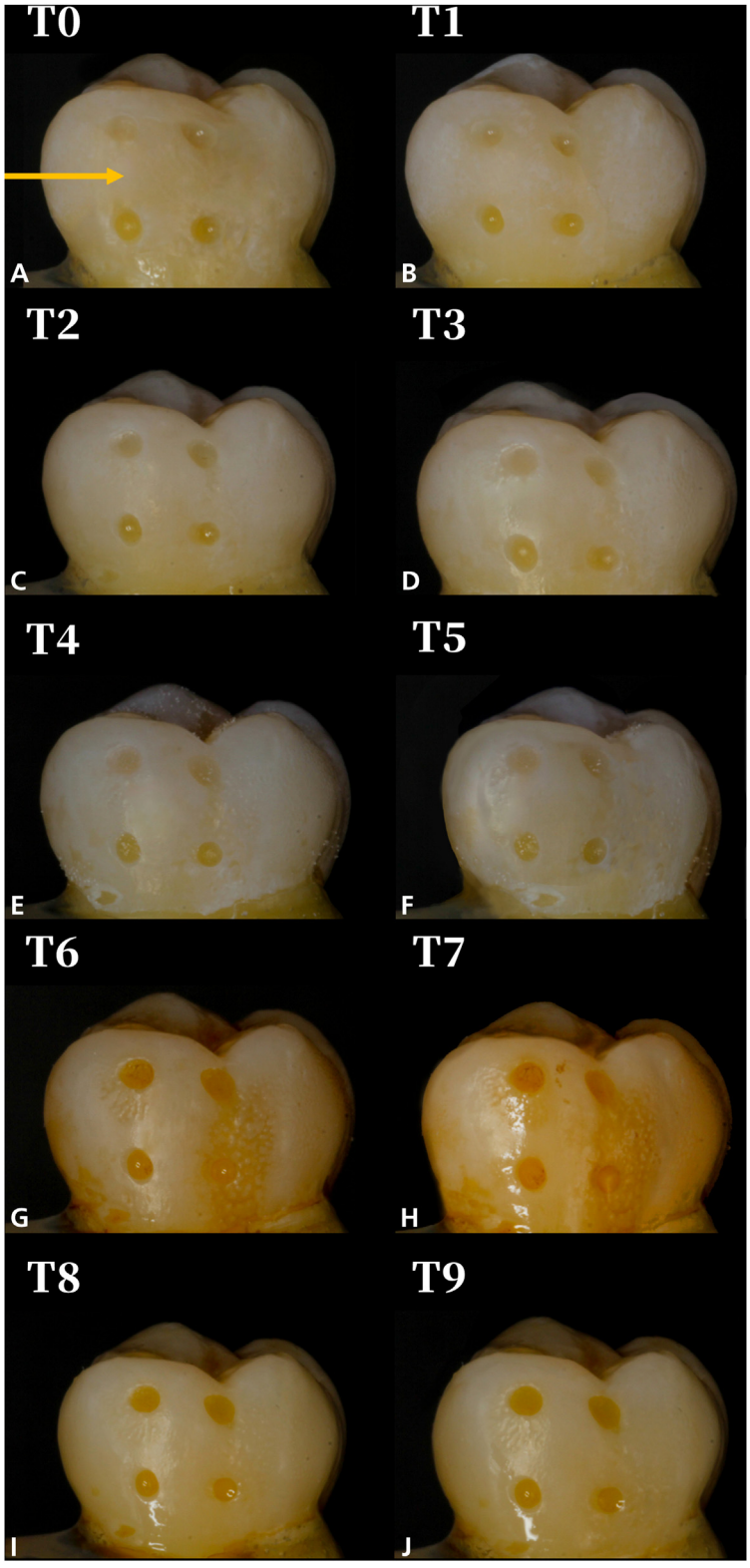

Figure 5. Photographic documentation of home tooth bleaching group, illustrating the 10 distinct time points (T0-T9) throughout the experimental timeline. **A.** T0: Baseline; point of interest within the standardized square is marked with an arrow. **B.** T1: After white-spot lesion creation. **C.** T2: After resin infiltration. **D.** T3: After tooth bleaching in the in-office and home bleaching groups. **E.** T4: After a waiting period of 14 days. **F.** T5: After thermocycling. **G.** T6: After artificial coffee staining at 6 days. **H.** T7: After artificial coffee staining at 12 days. **I.** T8: Immediately after poststaining bleaching of all groups. **J.** T9: After a further waiting period of 2 weeks.

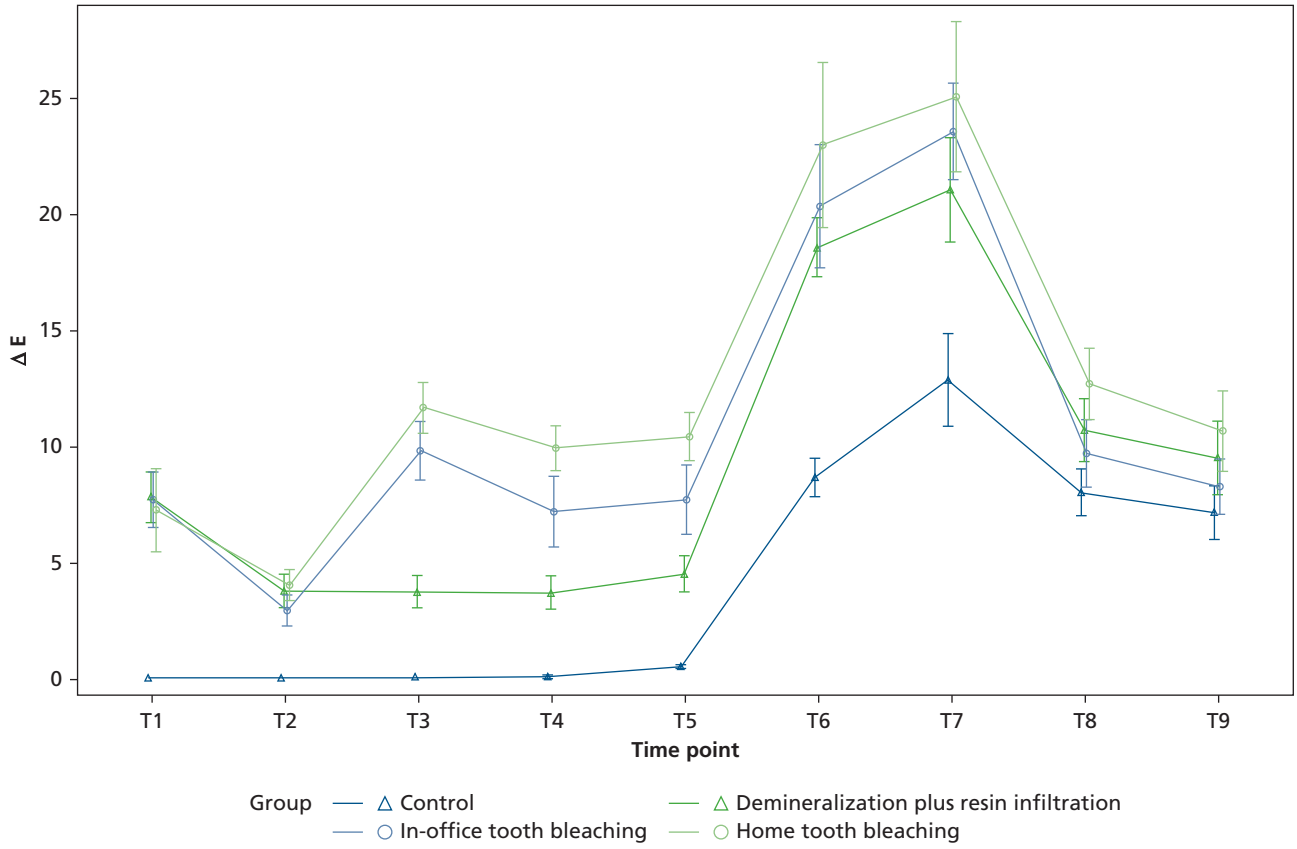

Figure 6. Total color difference (ΔE) values (mean [SD]) for the 4 treatment groups at the various time points (T1-T9) throughout the experimental setup. T1: After white-spot lesion creation. T2: After resin infiltration. T3: After tooth bleaching in the in-office and home tooth bleaching groups. T4: After a waiting period of 14 days. T5: After thermocycling. T6: After artificial coffee staining at 6 days. T7: After artificial coffee staining at 12 days. T8: Immediately after poststaining bleaching of all groups. T9: After a further waiting period of 2 weeks.

where L* means lightness (perceptual brightness or darkness of the color on a scale from 0 [black] through 100 [white]), a* means the red-green axis and b* means the yellow-blue axis. A ΔE value of 1 represents the smallest color difference that human eyes can perceive when directly comparing 2 adjacent objects.[23] Under clinical conditions, a higher ΔE value is required for color differences to be recognized from a normal conversation distance; ΔE 3.7 is considered clinically relevant.[24] All color measurements were obtained by the same investigator (M.J.).

Statistical analysis

Statistical analyses were performed using R software, Version 4.3.2 (R Foundation for Statistical Computing), as described in the Appendix. Descriptive statistics (ie, mean, variance, SD, and minimum and maximum values for ΔE values) were calculated for each group at each time point. A generalized least-squares model was used to account for both heteroscedasticity and autocorrelation.[25]

RESULTS

The reliability of the ΔE measurements was verified through repeated measurements of the final CIE L*a*b* values.[22] The intraclass correlation coefficient was 0.92, indicating good reproducibility of the results. The model residuals exhibited normality, and a mean model R^2 of 0.852 indicated a substantial fit to the data.

After tooth bleaching (T3), HB had a mean ΔE of 11.7 compared with 9.8 for IB, which was not significantly different (ΔE = –1.857; $P = .127$) (Figure 6). The exact ΔE values for all time points are provided in the eTable (available online at the end of this article) for reference, with the corresponding CIE L*a*b* color values in eFigure (available online at the end of this article).[22] Similarly, no significant differences in staining potential were found between the IB and HB groups after 12 days (T7) (ΔE = –1.50; $P = .867$). There were also no significant differences

between the 2 groups after rebleaching (T9) (ΔE = –2.393; P =.111). At time point T9, only the control group had significant differences from the HB group (ΔE = –3.511; P = .005), but no group achieved a ΔE value less than 3.7. The creation of WSLs resulted in similar bleaching values across all groups as well as the masking performance of RI. The analysis of effect sizes (Cohen d) for the IB and HB groups revealed medium to large differences between the groups at time points T3, T4, T7, and T9. At time points T3 (Cohen d = 0.8) and T9 (Cohen d = 0.82), there was a substantial difference in ΔE. At time point T4, the difference between the groups was great (Cohen d = 1.1). At T7, however, Cohen d was 0.28 between the IB and HB groups.

DISCUSSION

To our knowledge, we are the first to compare the bleaching effectiveness, staining potential, and rebleaching capability of the 2 primary bleaching methods (IB and HB) on resin-infiltrated WSLs. The initial null hypothesis was not rejected, as the results indicated that there were no differences in bleaching effectiveness between the 2 bleaching methods.

The effects of bleaching procedures on teeth that have undergone RI are not well understood. Although the Icon resin can penetrate enamel to a depth of several hundred micrometers, it does not completely occlude all pores. Consequently, discoloration might still occur, and bleaching agents can penetrate residual pores to some extent, facilitating partial stain removal or whitening effects.[26]

Furthermore, it is not well known to what extent rebleaching is possible. Both HB and IB effectively contributed to the whitening of resin-infiltrated WSLs and resulted in comparable whitening, highlighting their suitability for clinical use. These findings are consistent with those of previous researchers, who have also found that IB is an effective method for tooth whitening.[12,23] In addition, researchers have confirmed that carbamide peroxide can be used successfully for whitening.[13,27]

After application of the bleaching agents, the teeth showed higher L* values (indicating an increase in brightness) and a decrease in a* and b* values (signifying a reduction in color intensity). These changes led to a whiter appearance, aligning with the findings of previous researchers who documented similar color value changes in bleached bovine and human teeth.[14] A shift in the a* and b* values toward 0 suggests that the colors were moving toward neutral tones (white, gray) according to the CIE L*a*b* color coordinate system.[22] This phenomenon was also observed after rebleaching the stains.

Both control and resin-infiltrated WSLs showed comparable ΔE values after rebleaching compared with their respective baseline values. A possible explanation could be the silorane-based resin matrix of TEGDMA, which may be more susceptible to bleaching agents than other dimethacrylate-based composites.[28] In addition, it is easier to normalize substantially stained teeth with a high ΔE value than to treat slightly stained teeth. This suggests that resin-infiltrated WSLs are more sensitive to bleaching than untreated stained enamel areas.

Overall, our results indicated that bleaching can be a viable option for the esthetic improvement of stains in both infiltrated and untreated WSLs. However, this effect is not universally observed, as researchers reported limited effectiveness of bleaching agents on WSLs, which appeared darker after infiltration.[29] The bleaching effect of agents, particularly those based on carbamide or hydrogen peroxide, depends on their diffusion capability (the permeability of free radicals through the enamel). After penetrating the enamel, these radicals reach the underlying dentin and infiltrate deeper areas, depending on the specific properties of the substrate.[29,30] Sealing the enamel surface may influence the penetration of bleaching agents and thereby their effectiveness, particularly in the case of intrinsic stains.[29] In their study, the entire enamel surface was infiltrated.[29] However, in clinical situations, only the buccal enamel of WSLs is typically infiltrated, allowing the bleaching agent to act on other tooth structures. To our knowledge, no clinical researchers specifically have investigated the barrier effect of RI. In our study, RI was limited to the buccal and circumferential oral enamel areas, which correspond to the typical clinical manifestation of WSLs. The adjacent occlusal or incisal noninfiltrated enamel seems to allow the penetration of bleaching solutions, influencing the color of the entire tooth surface, including the infiltrated WSLs. Furthermore, we speculated that thermocycling and the water absorption of TEGDMA may have led to microporosities between the RI and the enamel, potentially enhancing the penetration of oxygen radicals during the bleaching process. This increased penetration could explain why the color measurements indicated a continued improvement in the optical appearance of the teeth over the 14 days after bleaching. This gradual improvement is consistent with the findings of previous researchers who observed a convergence of CIE L*a*b* values toward those of healthy enamel within the first week

after bleaching.[22,31] Although the CIE L*a*b* color space has been the benchmark in dentistry for evaluating color differences,[22,32,33] the ΔEab metric, which assumes that perceptually equal color differences are represented by equal Euclidean distances (ΔEab), has faced criticism in the literature. Advancements have led to the CIEDE2000 formula, which offers enhanced sensitivity for detecting subtle color variations,[34] but in a high-precision colorimetric study, researchers reported that the ΔEab formula aligned more closely with visually assessed color data than the CIEDE2000 formula, reaffirming its relevance in dental applications.[34] For this reason, we opted to use the traditional ΔEab metric. Spectrophotometers are highly effective and precise in dental color analysis,[35,36] but their performance can be limited on curved tooth surfaces. To address this limitation, we used standardized digital photography combined with image analysis for a more precise evaluation of the entire tooth surface, particularly in areas with complex morphology. This approach ensures consistent and reproducible color assessments across different time points, enhancing reliability in clinical and research settings.[34,37,38]

As we observed, previous researchers have also reported that HB can successfully reverse coffee-induced stains.[39] The staining and color changes of teeth treated with RI are considerable esthetic challenges, particularly with the regular consumption of certain staining foods, which has clinical implications.[40] The TEGDMA in Icon is characterized by its hydrophilic properties, leading to a substantially increased rate of water absorption.[10,40] Water acts as a medium for pigment transport within the resin matrix. TEGDMA-based resins exhibit a higher tendency for water absorption and subsequent staining compared with other resins, such as bisphenol A glycidyl methacrylate and urethane dimethacrylate.[11,12] We used coffee as the staining agent to simulate dye absorption,[41] specifically espresso capsules that represent a globally popular choice.[42] Several researchers examining the effects of staining beverages on restorative materials and tooth structures have successfully used this immersion model.[43] However, there are conflicting findings regarding the extent of staining in restored tooth structures and resin-infiltrated WSL.[12] Our study results suggested that with increased exposure time, infiltrated enamel is more susceptible to extrinsic coffee staining than natural enamel. This was consistent across all infiltrated groups, with no significant differences between the groups. These findings align with those of others who have reported that resin-infiltrated tooth surfaces exhibited greater color changes than untreated healthy teeth.[12] The increased susceptibility of resin-infiltrated WSLs when exposed to red wine has also been confirmed.[44] In our study, stained teeth exhibited a reduction in L* values and an increase in a* and b* values, indicating darkening and a shift in color toward reddish-yellow tones.[12]

Our demineralization protocol, based on that of Hu and colleagues,[17] resulted in the artificial creation of WSLs; similar to those in Akküc and colleagues,[45] the WSLs extended to a depth from 50 through 200 μm. As observed in a previous study, our demineralization process also led to a significant increase in L* values and a decrease in a* and b* values.[9] These changes resulted in a corresponding increase in ΔE values in the DRI, IB, and HB groups compared with the control group, without significant differences between the demineralized groups. Our color results are consistent with those from a previous investigation.[46] This also applies to the effectiveness of the RI therapy in masking WSLs.[7] The infiltrated groups showed a clear masking performance with a reduction in ΔE values below the threshold of 3.7, with no significant differences between groups.

Our findings highlight the clinical significance of bleaching treatments for resin-infiltrated WSLs, particularly in terms of esthetic improvement. WSLs commonly result from caries or orthodontic treatments, and the combination of RI and bleaching offers an effective approach to enhance the appearance of affected teeth. The comparable whitening achieved by both bleaching methods (IB, HB) in vitro suggests that clinicians may flexibly choose between these techniques on the basis of patient preferences and material availability. However, the full clinical applicability of these findings will only be confirmed once sufficient clinical studies are available. Further in vivo research is essential to validate the effectiveness and safety of these treatments for all ages under real-world conditions, ensuring their reliability in everyday dental practice.

Our study has some limitations. Our findings are based on an in vitro model; although well-controlled, it cannot fully replicate the complex biological and environmental conditions present in the oral cavity. Clinical factors, such as saliva composition, fluoride exposure, and oral hygiene practices, may influence both the formation of WSLs and the effectiveness of treatments like RI or bleaching. As such, further in vivo studies are necessary to validate the clinical relevance of these findings. Given the in vitro nature of our study, these findings should be interpreted cautiously, and

further clinical research is needed to confirm their relevance. We also used extracted human teeth. The natural tooth color and composition vary both among people and among different teeth within the oral cavity and are influenced by factors such as genetic predispositions and differences in calcification rates, which can affect outcomes.[47] In addition, only 2 different products were tested for the bleaching procedures. Given regulatory restrictions in the European Union on the use of high-concentration hydrogen peroxide products for IB, it is expected that these products will gradually be phased out. As a result, future research should focus on products with lower concentrations of carbamide peroxide. Furthermore, we decided to forgo polishing the infiltrated enamel areas to study the natural staining potential of RI areas without additional polishing influences. This represents the worst-case staining scenario, as polishing would likely reduce the staining potential and improve the effectiveness of bleaching treatments.[13,48] Moreover, other variables may influence the results, such as the thickness of the RI layer, the extent of the application area, the degree of preexisting tooth discoloration, and aging after RI, which could potentially lead to the formation of porosities.

CONCLUSIONS

RI combined with either IB or HB effectively managed the esthetic challenges of WSLs by means of restoring color after staining, with no significant differences observed between the 2 methods. However, limited color stability under staining conditions underscores the importance of additional strategies for long-term maintenance. Our findings support the clinical integration of RI and bleaching protocols, while emphasizing the need for further research. ■

DISCLOSURE

Dr. Wicht reports a relationship with DMG Chemisch-Pharmazeutische Fabrik GmbH that includes speaking and lecture fees. None of the other authors reported any disclosures.

SUPPLEMENTAL DATA

Supplemental data related to this article can be found at: https://doi.org/10.1016/j.adaj.2025.04.009.

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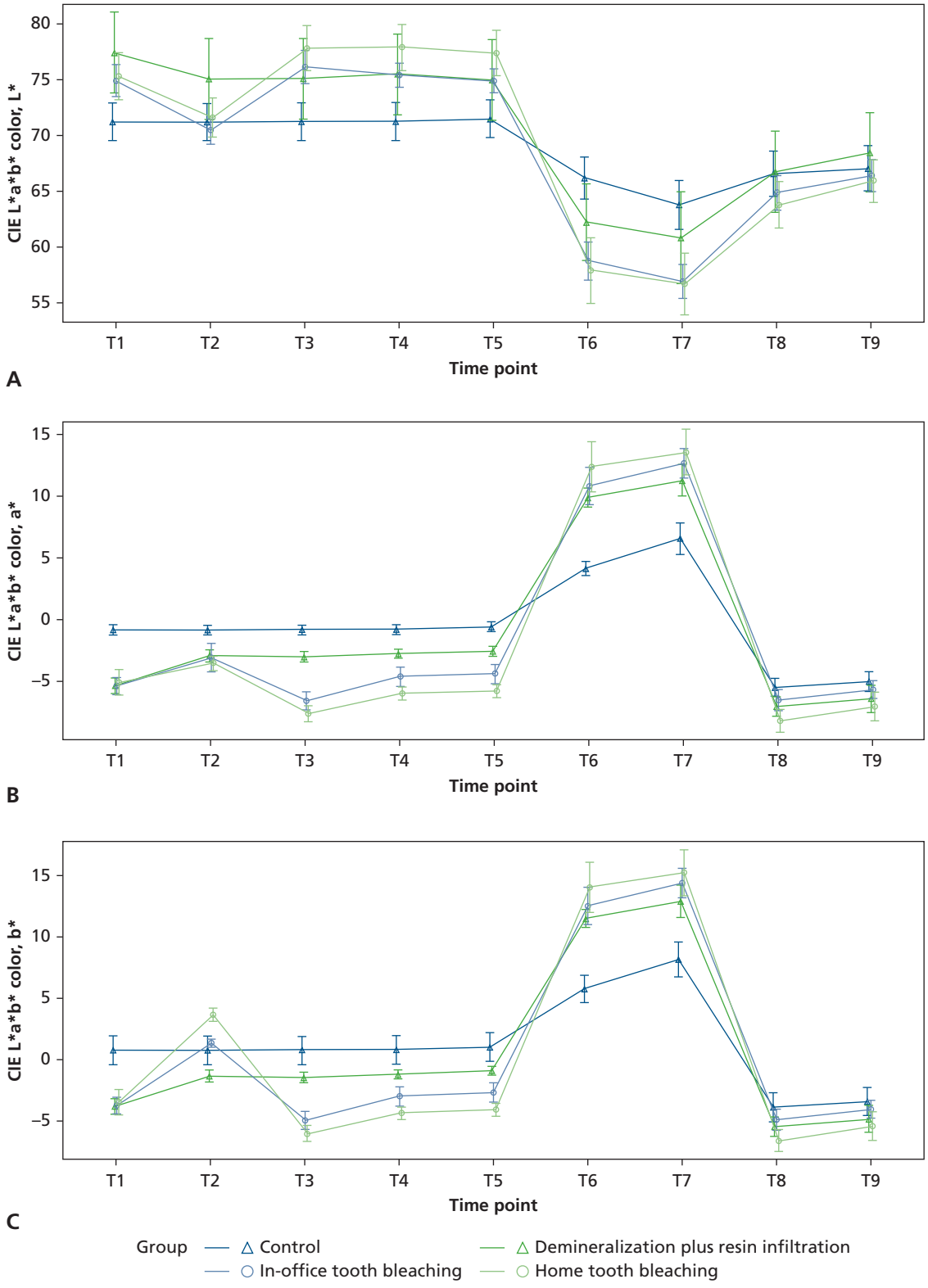

eFigure. Group by time point effect plot. Commission Internationale de l'Eclairage L*a*b* (lightness, red-green axis, and yellow-blue axis) color values (mean [SD]) for the 4 treatment groups at the various time points (T1-T9) throughout the experimental setup. **A.** L* indicates the brightness or darkness of the color on a scale from 0 (black) through 100 (white). **B.** a* indicates the color's position between green (negative values) and red (positive values). **C.** b* indicates the color's position between blue (negative values) and yellow (positive values). T1: After white-spot lesion creation. T2: After resin infiltration. T3: After tooth bleaching in the in-office bleaching and home tooth bleaching groups. T4: After a waiting period of 14 days. T5: After thermocycling, T6: After artificial coffee staining at 6 days. T7: After artificial coffee staining at 12 days. T8: Immediately after poststaining bleaching of all groups. T9: After a further waiting period of 2 weeks.

eTable. Mean total color difference values for the 4 treatment groups at time points from T1 through T9 throughout the experimental setup.

IDENTIFICATION NO.	TIME POINTS, TOTAL COLOR DIFFERENCE, MEAN								
	T1*	T2†	T3‡	T4§	T5¶	T6#	T7**	T8††	T9‡‡
Control Group									
1	0.10	0.03	0.05	0.70	0.50	11.61	11.71	8.32	6.86
2	0.17	0.04	0.09	0.12	0.61	8.60	15.70	5.91	4.19
3	0.06	0.12	0.09	0.11	0.73	8.49	14.98	11.54	10.86
4	0.02	0.01	0.14	0.06	0.48	6.55	16.55	5.21	3.00
5	0.06	0.01	0.09	0.05	0.32	12.40	13.39	8.53	7.60
6	0.02	0.04	0.02	0.10	0.71	9.04	11.22	6.18	5.36
7	0.12	0.07	0.03	0.08	0.49	7.91	9.16	10.02	9.58
8	0.10	0.04	0.11	0.07	0.63	8.32	12.09	7.13	6.62
9	0.13	0.03	0.07	0.09	0.38	7.15	8.61	4.62	4.41
10	0.06	0.03	0.05	0.02	0.53	9.52	19.9	8.85	8.21
11	0.04	0.01	0.08	0.06	0.61	9.52	7.83	7.02	7.17
12	0.14	0.09	0.06	0.07	0.55	8.32	17.86	10.35	9.71
13	0.03	0.02	0.11	0.08	0.44	6.55	6.57	8.65	8.53
14	0.02	0.03	0.08	0.09	0.57	8.60	11.63	9.52	9.29
15	0.12	0.08	0.05	0.13	0.59	7.91	16.14	8.74	6.21
Demineralization Plus Resin Infiltration Group									
16	9.59	4.74	4.85	4.83	4.95	21.69	28.45	8.96	8.21
17	5.86	3.79	3.67	3.99	4.20	17.77	21.13	10.76	9.33
18	5.25	3.64	3.60	3.55	4.12	19.43	23.21	9.23	7.70
19	12.35	4.97	4.90	4.88	5.56	23.06	14.93	5.98	4.39
20	8.10	3.65	3.5	3.55	4.71	21.99	21.24	12.43	11.29
21	8.60	6.36	6.28	6.11	7.15	13.81	14.02	10.04	9.19
22	5.66	5.51	5.45	5.68	7.09	19.35	18.18	6.66	4.74
23	10.03	3.29	3.29	3.15	4.21	16.19	15.86	13.12	12.32
24	6.65	4.81	4.83	4.66	5.42	16.33	20.31	9.51	7.36
25	9.02	3.30	3.33	3.16	3.71	17.80	19.23	13.54	10.84
26	7.27	3.37	3.25	3.37	4.28	17.04	22.77	14.78	13.29
27	8.25	4.36	4.21	4.18	5.50	20.80	27.52	10.12	11.12
28	6.21	1.13	1.19	1.07	1.88	18.81	21.20	13.23	14.78
29	10.07	1.41	1.29	1.33	2.10	16.97	27.76	8.75	6.17
30	4.83	2.81	2.85	2.73	3.01	17.90	20.25	13.75	12.10
In-Office Tooth Bleaching Group									
31	9.35	2.66	7.27	9.88	10.54	20.93	19.18	7.22	6.14
32	4.44	1.89	14.09	7.52	8.01	25.70	25.49	10.82	9.46
33	10.39	4.15	12.84	8.66	8.51	18.72	24.67	9.24	8.38
34	5.73	2.07	10.82	4.62	5.14	20.84	28.91	7.02	5.53
35	11.86	1.21	8.18	3.10	3.30	16.05	28.0	8.90	8.67
36	5.94	6.11	11.05	5.40	5.89	9.07	20.5	9.85	8.77
37	7.84	3.23	5.68	8.83	8.51	22.24	20.51	9.12	7.47
38	6.46	3.73	13.55	9.14	9.72	23.11	27.01	14.80	12.44

* T1: After white-spot lesions creation. † T2: After resin infiltration. ‡ T3: After tooth bleaching in the in-office bleaching and home bleaching groups. § T4: After a waiting period of 14 days. ¶ T5: After thermocycling. # T6: After artificial coffee staining at 6 days. ** T7: After artificial coffee staining at 12 days. †† T8: Immediately after poststaining bleaching of all groups. ‡‡ T9: After a further waiting period of 2 weeks.

eTable. Continued

IDENTIFICATION NO.	TIME POINTS, TOTAL COLOR DIFFERENCE, MEAN								
	T1*	T2†	T3‡	T4§	T5¶	T6#	T7**	T8††	T9‡‡
39	6.18	1.19	8.46	9.48	10.54	16.51	27.21	6.12	4.92
40	9.08	2.69	9.70	3.61	4.58	28.88	21.52	14.51	11.13
41	11.49	3.80	7.96	8.63	8.88	13.59	27.2	8.42	7.79
42	5.00	1.66	10.4	7.21	7.70	19.75	16.66	14.74	12.15
43	7.40	4.25	10.66	13.84	14.51	18.79	27.30	8.10	7.59
44	8.65	2.59	10.01	3.73	4.98	25.85	21.87	10.30	8.70
45	6.05	3.12	6.82	4.64	5.21	25.59	17.66	6.78	5.22
Home Tooth Bleaching Group									
46	3.53	3.62	7.82	6.32	6.81	26.37	27.18	12.34	10.93
47	14.8	6.78	12.26	11.57	10.32	27.96	32.38	17.23	15.00
48	4.50	4.38	9.00	8.02	8.23	18.94	23.35	11.21	9.05
49	11.95	3.03	11.07	9.73	10.03	11.16	14.25	13.45	10.86
50	4.71	5.46	11.35	10.24	12.1	22.79	33.05	9.31	6.77
51	6.09	2.82	14.08	12.81	13.56	26.38	35.52	14.77	12.06
52	8.92	4.66	14.38	12.00	12.81	34.03	30.32	14.23	12.80
53	6.67	1.87	10.67	8.45	9.17	33.83	25.84	10.42	7.16
54	5.62	2.68	10.74	8.08	8.54	22.51	23.64	16.32	14.72
55	6.05	4.65	10.88	7.92	7.99	23.11	25.74	7.98	4.66
56	12.96	5.35	16.32	12.10	12.99	17.80	20.03	13.42	9.93
57	6.56	4.62	10.68	9.95	10.97	15.15	16.16	10.23	9.10
58	5.11	4.01	11.94	10.78	11.11	13.11	18.01	8.21	7.16
59	8.73	2.49	13.46	11.43	12.17	30.19	29.19	16.45	15.15
60	3.04	4.40	10.69	9.74	9.79	21.64	21.59	15.03	14.91