Original Article

Aesthetic efficacy of resin infiltration on post-orthodontic white spot lesions using different conditioning methods: 24-month randomized control follow-up

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ABSTRACT

Objectives: To assess color and fluorescence changes in post-orthodontic white spot lesions (WSLs) using different surface conditioning methods from prior to resin infiltration to a 24-month follow-up.

Materials and Methods: Thirty patients, each with a minimum of four WSLs with ICDAS (International Caries Detection and Assessment System) II code 1 and 2 after bracket debonding were included. After baseline (T0), the lesions were randomly divided into four groups: regular brushing, 15% HCl (hydrogen chloride) gel, 37% H_3PO_4 (phosphoric acid) gel, and Er:YAG (erbium-doped yttrium aluminium garnet) laser. Icon resin infiltration was applied. In the treatment groups, color and fluorescence were reexamined just after the resin infiltration treatment (T1), and after 6 (T2) and 24 months (T3).

Results: There were no significant fluorescence or color changes between the treatment groups for the different time intervals. The control group showed a significantly lower color change from T0 to T2 and T0 to T3 than all the treatment groups whereas, at T2–T3, the control group showed the greatest improvement.

Conclusions: Resin infiltration caused greater esthetic improvement and more revival of the lost fluorescence than daily brushing. HCl gel, H_3PO_4 gel, and Er:YAG laser are adequate conditioning methods for resin infiltration of post-orthodontic WSLs with ICDAS II code 1 and 2. (*Angle Orthod*. 2026;96:311–317.)

KEY WORDS: Color stability; Fluorescence; Resin infiltration; White spot lesion

INTRODUCTION

White spot lesions (WSLs) are one of the most common side effects of fixed orthodontic treatment. The prevalence of WSLs during fixed orthodontic treatment has been reported to range widely due to the increased difficulty of maintaining oral hygiene around the brackets, and microbial adhesion.[1] These lesions are characterized by an intact surface layer and a porous demineralized subsurface beneath an external intact layer.[2]

For WSLs, noninvasive remineralization treatments such as topical fluoride and casein phosphopeptide-amorphous calcium phosphate are recommended.[3] Although these treatments arrest progression of the lesion, the opaque appearance may remain because superficial remineralization occurs and the body of the lesion remains porous.[4] Microabrasion and minimal composite restorations can be used to treat WSLs, but these treatments require enamel reduction and loss of healthy tooth structure.[5] In recent years, resin infiltration has emerged as an alternative for managing WSLs that is faster than traditional remineralization techniques and less invasive. This technique consists of using hydrochloric acid (HCl) for erosion of the surface layer and exposing the lesion body, and a low-viscosity TEGDMA (triethyleneglycol-dimethacrylate)-based resin for filling the subsurface porous structure.[6] Resin infiltration is a

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minimally invasive approach to post-orthodontic enamel decalcification that is well accepted and highly satisfactory.[7] Studies revealed significant and clinically meaningful reduction in color and clarity of infiltrated WSLs, whereas there was no significant change in untreated WSLs over time.[8,9] Therefore, resin infiltration is regarded as a reliable and conservative option for managing enamel decalcification after orthodontic therapy.

For complete infiltration of resin into the lesion body and, thus, successful treatment, removal or perforation of the surface layer is critical. The use of 15% HCl for 120s has been recommended.[10] However, a single application of HCl has been reported to be insufficient in the presence of arrested lesions, and repeated etching steps have been attempted as pre-treatment,[11] resulting in increased chairside time. In addition, HCl requires cautious application, especially to WSLs at facial surfaces close to the gingiva, since it is an extremely aggressive acid and may cause gingival damage.[12]

Phosphoric acid (H_3PO_4) etching removes the smear layer, creates microscopic roughness, and enhances enamel surface energy by removing prismatic and interprismatic mineral crystals. Similar to acid etching, the erbium-doped:yttrium aluminum garnet (Er:YAG) laser has been introduced as a good alternative technique to remove the smear layer and create a microscopically rough surface.[13] Although several in vitro studies have investigated the effects of resin infiltration on masking WSLs and restoring lost fluorescence,[5,14] as well as short-term clinical studies,[15–17] there remains a significant gap in the literature regarding the comparative effectiveness of different surface conditioning techniques on WSLs. Despite the clinical promise of resin infiltration, there has not been a comprehensive and long-term clinical investigation comparing the effects of alternative surface preparation methods, such as phosphoric acid etching or Er:YAG laser conditioning, to traditional HCl etching in terms of their impact on lesion masking, color stability, and fluorescence recovery.

The present study aimed to assess whether alternative surface conditioning methods, applied prior to resin infiltration instead of HCl gel, affected the extent and durability of color and fluorescence changes in post-orthodontic WSLs after 24 months, and compare them with a control group.

MATERIALS AND METHODS

This study was approved by the Republic of Turkey Ministry of Health Ethics Committee (No: 1700213) and the study was registered on the ClinicalTrials.gov database (NCT06259214). The study design was randomized and double blinded, according to the Consolidated Standards of Reporting Trials (CONSORT). Both participants and assessors were blinded, and treatments were performed by independent operators.

Table 1. Distribution of Lesions According to ICDAS II Codes and Baseline DIAGNOdent Pen Values[a]

	ICDAS II Code (n)	DIAGNOdent Pen Values Mean (SD)
Control	Code 1 (10)	13.40 (0.516)
	Code 2 (20)	15.80 (1.321)
HCl gel	Code 1 (10)	12.40 (1.173)
	Code 2 (20)	17.05 (1.276)
H_3PO_4 gel	Code 1 (8)	13.50 (0.534)
	Code 2 (22)	16.22 (1.066)
Er:YAG laser	Code 1 (9)	13.11 (0.333)
	Code 2 (21)	15.80 (0.980)

[a] Er:YAG indicates erbium-doped yttrium aluminium garnet; HCl, hydrogen chloride; H_3PO_4, phosphoric acid; ICDAS, International Caries Detection and Assessment System.

Sample size calculations were based on considering a type I error risk of 5% and 90% power. Thirty teeth per group would give more than 90% power to detect significant differences with a 0.13 effect size between groups at a significance level of $P = .05$.

For the visual severity evaluation, International Caries Detection and Assessment System (ICDAS) II free smooth-surface criteria were used.[18] Lesions with code 1 (first visual change after prolonged air drying) and code 2 (distinct visual changes without air drying) were included.

DIAGNOdent Pen 2190 (Kavo, Biberach, Germany) was used to score each lesion. The teeth were rinsed and air dried before registration and a type B probe tip was positioned on the buccal surface of the tooth. All measurements were taken three times and the average fluorescence value was recorded. Distribution of lesions according to ICDAS II codes and baseline DIAGNOdent values are shown in Table 1.

A spectrophotometer (SpectroShade; Medical High Technologies, Verona, Italy) was used to measure color parameters. The mouthpiece attached to the intraoral camera of the spectrophotometer was placed at 90° on the alveolar process. The results from each tooth obtained by spectrophotometer were recorded, with the mean values of L^*, a^*, and b^* automatically calculated. Three consecutive readings were taken using the spectrophotometer and the mean values were recorded.

The lesions of each patient were randomly assigned into four groups according to surface conditioning methods:

G1: The control group received no treatment except regular brushing.

G2: 15% HCl gel (Icon Etch, DMG, Hamburg, Germany) was applied for 2 minutes, followed by water rinsing and drying.

G3: 37% H_3PO_4 gel (Scotchbond Etchant, 3M ESPE, St. Paul, MN, USA) was applied for 30 seconds, followed by water rinsing and drying.

Figure 1. Representative images of a 15 year old patient at baseline (top), and after 24 months (bottom). Tooth #12 belongs to Group 2, Tooth #11 to Group 3, Tooth #21 to Group 4, and Tooth #22 to Group 1.

G4: Er:YAG laser with a wavelength 2.94μm, (Fotona AT Fidelis III, Ljubljana, Slovenia) was applied for 10 seconds, energy 300 mJ, frequency 10Hz, pulse duration of 180 μs, water spray cooling 80%. The distance was kept at 1 mm away from the lesion.

The lesions were desiccated with ethanol (Icon Dry, DMG, Hamburg, Germany) and dried for 30 seconds. Then, resin infiltrant (Icon Infiltrant, DMG, Hamburg, Germany) was applied and allowed to penetrate for 3 min. The material was light cured for 40s with an LED device (Elipar S10; 3M ESPE, St. Paul, MN, USA) with 1200 mW/cm^2 intensity. Then, polishing was conducted with abrasive disks (Sof-Lex, 3M ESPE, St. Paul, MN, USA). All restorative procedures were performed under rubber dam isolation by the same clinician.

Oral hygiene instructions and kits containing a toothbrush (Oral B, P&G Oral Health Care, Mason, OH, USA), fluoride toothpaste (Pro-Expert Professional Protection, Ipana, Gross-Gerau, Germany), and dental floss (Oral B Essential floss, P&G Oral Health Care) were given to all patients.

In the treatment groups, examinations were performed at baseline (T_0), just after the resin infiltration treatment (T_1), and after 6 (T_2) and 24 months (T_3). In the control group, examinations were performed at T_0, T_2, and T_3 (Figure 1).

*L**, *a**, and *b** were measured each time, and the changes in them (ΔL, Δa, Δb) were calculated. The color change $\Delta E < 3.7$ is considered a clinically acceptable color difference and ΔE for each tooth was calculated as: $\Delta E = ((\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2)^{1/2}$

Statistical Analysis

The data were analyzed using IBM SPSS version 23. The normality of the data distribution was assessed with the Shapiro-Wilk test. Since the data included repeated measurements over time, a generalized estimating equations (GEE) analysis was performed to evaluate the effects of group and time. Although the distributions of the continuous ΔE and DIAGNOdent measurements did not fully meet the assumption of normality, they did not exhibit severe kurtosis or skewness. Therefore, to reduce the sensitivity of the model to the normality assumption of error distribution in the GEE analysis, the "Robust estimator" option was used. A significance level of $P < .05$ was considered for all statistical tests.

RESULTS

The flowchart of the study is shown in Figure 2. A total of 120 noncavitated, unrestored WSLs after orthodontic treatment on the buccal surfaces of the anterior and premolar teeth in the upper and lower jaws of 30 patients were included. Table 1 shows the distribution of lesions according to ICDAS II codes and baseline DIAGNOdent Pen values.

Table 2 shows the ΔE values across different intervention groups and time points. At T1, no significant differences were observed among the treatment groups; all showed moderate ΔE values ranging between 5.77 ± 2.74 and 6.58 ± 3.25. At T2, HCl gel showed the highest color change, followed by H_3PO_4 gel and Laser, whereas the control group exhibited a notably lower ΔE. The differences between groups were statistically significant ($P < .001$). At T3, HCl gel remained the highest, with Laser and Acid following, and control still significantly lower. Overall, the HCl gel group exhibited the greatest total color change, significantly higher than the control group. No significant difference was found between Laser, HCl, and H_3PO_4 gel groups overall.

Table 3 presents the DIAGNOdent measurements, assessing demineralization status across groups and times. At T0, all groups had comparable values with no significant differences. The differences in DIAGNOdent values between the different time intervals reflected the improvement of WSLs. At T1, there was a substantial decrease in values across all intervention groups indicating effective initial treatment. At T2, control showed a higher DIAGNOdent value (8.10 ± 1.24) compared to the other groups. Statistically significant differences were observed, especially between control and the intervention groups. At T3, all groups had low and comparable values, indicating maintenance of low demineralization levels over time. Accordint to total values, the control group had the highest overall mean (9.90 ± 3.92), whereas intervention groups remained lower,

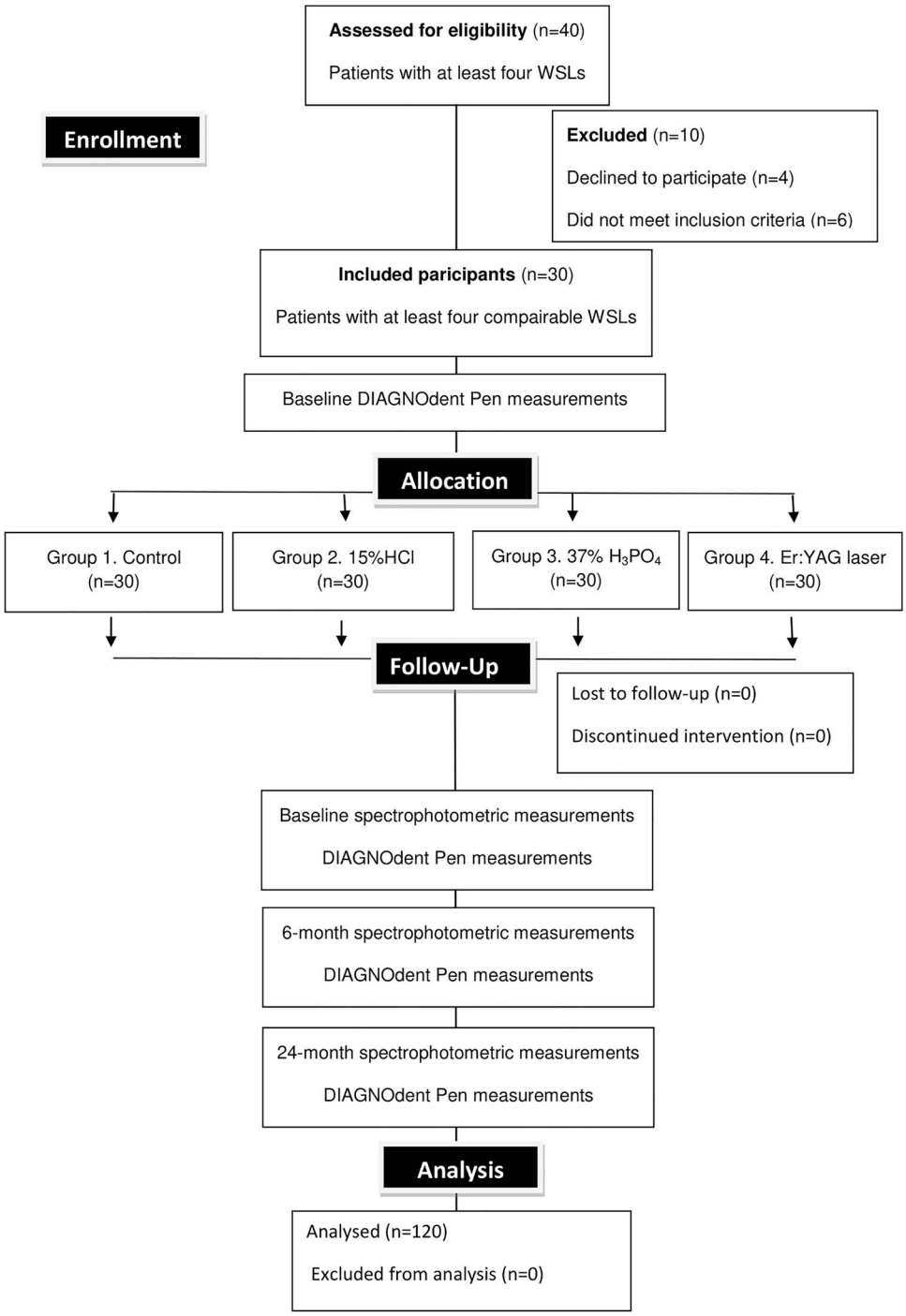

Figure 2. Flowchart of the study design.

with a significant difference between the control and other groups.

DISCUSSION

Resin infiltration is a minimally invasive technique that arrests early enamel carious lesions by sealing microporosities within demineralized enamel. Widely validated with systems like ICON, it offers caries control and esthetic improvement, particularly for white spot lesions in orthodontic and nonorthodontic patients. In the current study, the ΔE values following the application of resin infiltration were higher than 3.7, indicating that resin infiltration considerably improved the color of WSLs and the infiltrated lesions had a clinically acceptable color recovery. This finding supported the outcomes

Table 2. Comparison of ΔE Values According to Group and Time[a]

Time	Group				Total		Test Statistics	df	P
	Laser	H_3PO_4	HCl	Control					
T1	5.77 ± 2.74BC	6.01 ± 2.98BC	6.58 ± 3.25B	—	6.12 ± 2.99	Group	127.758	3	**<0.001**
T2	6.63 ± 3.15BC	6.79 ± 3.16BC	7.85 ± 3.60C	2.58 ± 0.87A	5.96 ± 3.50	Time	32.919	2	**<0.001**
T3	6.50 ± 3.16BC	6.70 ± 3.12BC	7.82 ± 3.75C	3.23 ± 0.9D	6.06 ± 3.38	Group* Time	13.692	5	**0.018**
Total	6.30 ± 3.02a	6.50 ± 3.07a	7.42 ± 3.55a	2.91 ± 0.96b	6.04 ± 3.31				

[a] HCl indicates hydrogen chloride; H_3PO_4, phosphoric acid.

* Generalized estimating equations (GEE), mean ± standard deviation, a–b: No significant difference between groups sharing the same letter; A–D: No significant difference between interactions sharing the same letter; df indicates degrees of freedom.

of previous in vivo studies.[15,16] For ΔE value changes over time, no significant changes were observed at the recall time points, indicating that the effect of resin infiltration on returning enamel to a natural color was stable over 24 months. This result corresponded with previous clinical trials that showed that the color and lightness characteristics of resin infiltrant were not altered significantly after 1 or 2 years.[9,15,16] The statistically similar ΔE values of all treatment groups showed the durable nature of the material regardless of the conditioning method.

Although both fluoridated toothpaste and resin infiltration application resulted in improvement in the esthetics of the WSLs in the current study, fluoridated toothpaste did not alter the color as much as the resin infiltration did. From a previous study, it appeared that resin infiltration improved the appearance of WSLs over 12 months better than daily brushing with fluoride toothpaste.[19] Similar to the current results, it has also been reported that resin infiltration performed better in diminishing the opaque WSL appearance compared with fluoride treatment.[20] After bracket removal, WSLs have been reported to be visible after 6 months or are likely to persist and might be visually compromising, even when fluorides are utilized.[21] In contrast with these findings, although fluoridated toothpaste did not significantly change the ΔE values over 6 months, the ΔE values of the control group significantly increased from baseline to 24 months. This finding may have been related to the increased exposure to fluoride over time. Zero et al[22] concluded that fluoride concentrations of saliva increased with longer brushing times, showing that increased contact time caused more fluoride retention in the oral cavity.

In the current study, the different surface conditioning methods did not affect the success of resin infiltration treatment. In the ICON technique, microporosities formed within the enamel structure as a result of demineralization are filled by a low-viscosity resin that penetrates the lesion through capillary forces, eliminating the white spot appearance caused by altered light scattering.[23] Previous studies demonstrated that the application of HCl gel effectively removed the hypermineralized superficial layer, which otherwise hinders resin infiltration.[24,25] Although in previous studies it was reported that the lesions treated with resin infiltration pretreated with HCl were resistant to lesion progression, there was concern about the possibility of degradation of the resin infiltrant over time.[26] Although in some in vitro studies it was reported that H_3PO_4 gel application was not adequate for pretreatment of resin infiltration because it did not completely remove the surface layers,[25,27] in agreement with the current findings, Yim et.al[28] reported similar penetration depths and areas with H_3PO_4 and HCl gel and absolute removal of the protective surface layer but also successfully masking the WSLs at the same time with H_3PO_4. The Er-YAG laser etched enamel subsurface has been reported to show a small reduction in mineral concentration, suggesting an increase in porosity that allows greater penetration.[29] The results of the current study showed that phosphoric acid, which is available in every clinic, can be used as an alternative to HCl acid for surface preparation before ICON treatment.

Table 3. Comparison of DIAGNOdent Values According to Group and Time

Time	Group				Total		Test Statistics	df	*P*
	Laser	H_3PO_4	HCl	Control					
T0	15.00 ± 1.51 a, C	15.50 ± 1.55 a, D	15.50 ± 2.54 a, C	15.00 ± 1.60 a, C	15.25 ± 1.84 a	Group	12.425	3	**0.006**
T1	6.20 ± 2.11 a, B	6.50 ± 1.91 a, C	6.97 ± 2.24 a, B	—	6.56 ± 2.09 b	Time	4183.873	3	**<0.001**
T2	5.87 ± 1.85 a, AB	5.93 ± 1.64 a, B	6.23 ± 1.96 ab, A	8.10 ± 1.24 b, B	6.53 ± 1.91 b	Group* Time	192.948	8	**<0.001**
T3	5.70 ± 1.80 a, A	5.63 ± 1.65 a, A	6.00 ± 1.84 a, A	6.60 ± 1.28 a, A	5.98 ± 1.68 c				
Total	8.19 ± 4.34 a	8.39 ± 4.46 a	8.68 ± 4.51a	9.90 ± 3.92 b	8.72 ± 4.37				

* Generalized estimating equations (GEE); mean ± standard deviation; a–c: No difference between groups/time points sharing the same letter; A–D: No difference between time points within each group sharing the same letter; a–b: No difference between groups within each time point sharing the same letter; df indicates degrees of freedom.

This is an advantage for cases in which it is impossible to completely isolate the gingiva because of fixed retainers or if a rubber dam is contraindicated due to the patient having a latex allergy.

In the current study, only patients who had just completed fixed orthodontic treatment and had lesions with ICDAS II code 1 and code 2 were included, and this was a limitation. It has been stated that the masking effect might be better for lesions in a more active and younger state rather than old ones with thicker surface layers, and when the lesion is not so deep and the surface layer is relatively thin.[30] Another limitation of the study may have been the inclusion of premolars, which could have made a difference in terms of cleaning, but all research groups were designed in the oral environment of the same patient to eliminate patient-related factors. Therefore, it would be interesting to compare the results of the same treatments in WSLs of different activity and severities in long-term clinical studies.

CONCLUSIONS

Within the limitations of this clinical study, the following conclusions can be drawn:

- Surface conditioning with 37% H_3PO_4 gel and Er:YAG laser treatment prior to resin infiltration resulted in similar clinical outcomes to those achieved with 15% HCl gel and may be an alternative for WSL treatment,
- Regardless of the conditioning method, resin infiltration treatment improved the color of lesions and showed greater recovery of lost fluorescence than daily brushing with fluoride toothpaste,

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