Journal of
Lasers
in Medical Sciences

J Lasers Med Sci. 2025;16:e60

Original Article

http://journals.sbmu.ac.ir/jlms

doi 10.34172/jlms.2025.60

The Efficacy of Various Conditioning Methods in Restoring the Color of White Spot Lesions Through Resin Infiltration

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Received: October 7, 2024
Accepted: October 12, 2025
ePublished: December 6, 2025

Abstract

Introduction: This study aimed to assess the effects of supplemental conditioning methods, including extended etching time, Er,Cr:YSGG laser radiation, and sandblasting, on enhancing the recovery of white spot lesions (WSLs) through resin infiltration.

Methods: Seventy premolars were subjected to a cariogenic solution to induce WSLs. Subsequently, the teeth were divided into 5 groups of 14, based on the enamel conditioning protocol applied, as follows: Group 1: Icon-Etch (Control), Group 2: Double Icon-Etch, Group 3: Sandblasting + Icon-Etch, Group 4: Er,Cr:YSGG laser + Icon-Etch, and Group 5: Icon-Etch + Er,Cr:YSGG laser + Icon-Etch. The Er,Cr:YSGG laser (2780 nm) was applied at 0.75 W and 20 Hz. Tooth color was measured initially (T0), after WSL induction (T1), and following resin infiltration (T2). Color changes between treatment stages were compared among the groups.

Results: One-way analysis of variance (ANOVA) displayed no significant differences in ΔET0-T1 or ΔET1-T2 between the groups ($P>0.05$). However, a significant difference was found between the groups in the color change from baseline to post-resin infiltration (ΔET0-T2) ($P=0.004$). The ΔET0-T2 was significantly lower in groups 4 and 5 compared to the control group and group 3. Group 2 did not demonstrate a significant difference from the other groups ($P>0.05$).

Conclusion: The combination of laser etching and acid etching was effective in enhancing the recovery of WSLs through resin infiltration. The ΔET0-T2 in groups subjected to laser plus acid etching fell below the critical threshold of 3.7 units, indicating that the post-treatment tooth color was not clinically distinguishable from the original tooth color.

Keywords: Color, Dental caries, Enamel demineralization, Erbium, Icon infiltrant, Laser, Resin infiltration, Sandblast, White spot lesions

Introduction

Fixed orthodontic therapy has gained increasing popularity for improving esthetics, correcting dentoskeletal discrepancies, and restoring proper dental function. Despite the advancements in orthodontic treatment procedures, the issue of enamel decalcification adjacent to bonded brackets remains a considerable concern. White spot lesions (WSL) are subsurface enamel porosities resulting from carious demineralization. The lesions may compromise the aesthetic outcome of orthodontic treatment by appearing as chalky, white discolorations[1,2] and may even progress to form caries cavities.

In cases of good oral hygiene, approximately half of the post-orthodontic WSLs tend to naturally undergo remineralization through saliva within six months following the removal of orthodontic appliances. However, a notable portion of WSLs does not exhibit spontaneous improvement. Enaia et al[3] demonstrated that 26% of WSLs remained unchanged, while 16.7% worsened within a one-year follow-up period, despite adherence to standard prophylactic instructions.

To counteract WSLs, the use of fluoride or casein-phosphopeptide amorphous calcium phosphate (CPP-ACP) products is considered an effective preventive and therapeutic strategy.[4,5] However, sufficient cooperation in using remineralizing products may not be attained in all patients. Additionally, some arrested lesions persist as opaque spots even after remineralizing treatments. This phenomenon occurs when minerals precipitate on the enamel surface and block the superficial porosities, restricting the remineralization process within the subsurface lesion body.[6] In cases where WSLs do not show spontaneous improvement, techniques such as vital bleaching, microabrasion, or resin infiltration have been recommended for concealing enamel opacities before considering more invasive restorative procedures.[7,8]

Resin infiltration stands as a minimally invasive technique for the treatment of post-orthodontic WSLs. This

Please cite this article as follows: Boruziniat A, Ahrari F, Shafaee H, Faravani F, Rangrazi A, Akbari Kamrani F, et al. The efficacy of various conditioning methods in restoring the color of white spot lesions through resin infiltration. *J Lasers Med Sci*. 2025;16:e60. doi:10.34172/jlms.2025.60.

therapeutic approach works by blocking the micropores within the lesions through the infiltration of low-viscosity light-curing resin, which quickly penetrates the porous enamel.[9] The opaque white appearance of enamel lesions is assumed to result primarily from differences in the refractive indices of enamel, air, and water. The resin employed in the resin infiltration technique possesses a refractive index close to that of enamel, thereby reducing light scattering. This process leads to the restoration of translucency and the improvement of esthetic qualities in the lesions.[10,11] Furthermore, the resin fills the inter-crystalline spaces within the subsurface enamel. In this way, the resin infiltration technique impedes the progression of caries and reinforces the mechanical support and structural properties of enamel.[9,12-15]

A predominant challenge in achieving optimal aesthetics through the resin infiltration technique is the relatively limited infiltration capacity of the resin infiltrant, leading to partial enhancement in the appearance of advanced lesions. Previous studies have demonstrated a significant correlation between lesion depth and the degree of shade improvement in enamel opacities. It may not be feasible to completely conceal lesions that extend beyond the infiltration capacity of the resin infiltrant.[16, 17] A 15% hydrochloric acid solution has traditionally been employed to eliminate the hypermineralized enamel layer before applying the resin infiltrant.[18] Supplementary conditioning approaches, such as extending the etching duration and using abrasives in the etchant, have been proposed to facilitate resin penetration into the lesion structure and improve the masking of enamel opacities.[19-21]

The introduction of laser technology has significantly expanded its applications in dentistry.[22] The erbium laser family, including erbium: yttrium-aluminum-garnet (Er:YAG) and erbium, chromium: yttrium-scandium-gallium-garnet (Er,Cr:YSGG), exhibits strong absorption in water and hydroxyapatite. Erbium lasers have been applied for conditioning enamel, dentin, and various dental materials.[23-28] They can produce irregular, roughened surfaces that may improve resin penetration into caries lesions.[29,30]

There remains a paucity of evidence regarding the effectiveness of different conditioning techniques in improving the aesthetic appearance of WSLs. Therefore, this study was conducted to investigate the effects of supplemental conditioning methods, including prolonged etching time, Er,Cr:YSGG laser irradiation, and sandblasting, on the color enhancement of white spot lesions through resin infiltration.

Materials and Methods

The study protocol was approved by the ethics committee of Mashhad University of Medical Sciences (Approval ID: IR.MUMS.DENTISTRY.REC.1399.009).

Study Design and Sample Size Calculation

This was an in vitro experimental study. The sample size was calculated based on the data obtained from a previous study,[17] using the significance level of 5% and power of 80%. The sample size was calculated as n = 14 per group.

Specimen Preparation

The study involved 70 human premolars, all of which had been extracted for orthodontic reasons. The teeth were carefully examined at x 20 magnification to discard those with decalcification, cracks, and discoloration on the buccal and lingual surfaces.

The selected teeth underwent debridement and disinfection procedures, followed by storage in a normal saline solution at room temperature. To facilitate the examination of the buccal surface, each tooth was embedded in self-curing acrylic resin up to the cementoenamel junction. The embedding was meticulously done to ensure that the buccal enamel surface was aligned perpendicularly to the horizontal plane.

The enamel surface was polished with a rubber prophylaxis cup and a mixture of pumice and water, followed by rinsing and drying. Subsequently, a 4 mm x 4 mm area was demarcated on the buccal surface using acid-resistant nail varnish to define the area for color assessment. Tooth color was then measured, and color values were recorded at the baseline examination (T0).

Induction of White Spot Lesions

To induce WSLs, the teeth were immersed in a 400 ml demineralizing solution consisting of 2.2 mmol/L KH_2PO_4, 2.2 mmol/L $CaCl_2$, and 50 mmol/L acetic acid at pH 4.6 for 12 hours. Subsequently, the teeth were immersed in a remineralization solution at pH 6.8 for another 12 hours. This demineralization-remineralization cycle was repeated over 14 days, with a fresh solution utilized for each cycle. Following this process, a frosty white appearance was observed on all the specimens. Then, tooth color was measured to obtain color values after lesion induction (T1).

Grouping and Surface Conditioning Procedures

The teeth were divided into five groups of 14, based on the specific enamel conditioning protocol applied before the application of the resin infiltrant:

Group 1 (Control): In this group, a 15% hydrochloric acid (Icon-Etch; DMG, Hamburg, Germany) was applied to the lesions for 2 minutes. The acid was then rinsed off with a water spray for 30 seconds, and the teeth were dried with an air spray.

Group 2 (Double Icon-Etch): In this group, the Icon-Etch process was performed twice.

Group 3 (Sandblasting + Icon-Etch): The specimens in group 3 underwent a sandblasting procedure before the application of Icon-Etch. Sandblasting was carried out using 50-micron aluminum oxide particles at a pressure of 50 psi. The particles were directed perpendicularly at a distance of 5 mm from the tooth surface for 10 seconds.

Group 4 (Er,Cr:YSGG laser etching + Icon-Etch): Specimens in group 4 were first etched with an Er,Cr:YSGG laser (Waterlase, Biolase, San Clemente, CA, USA) and then treated with a 15% hydrochloric acid (Icon-Etch). The laser operated at a wavelength of 2780 nm, with a power output of 0.75 W, a pulse duration of 140 µs, and a pulse repetition rate of 20 Hz, using 55% water and 65% air spray. The handpiece was positioned approximately 1 mm from the tooth and scanned the surface perpendicularly for 10 seconds using an MZ6 sapphire tip (600 µm diameter, 6 mm length).

Group 5 (Icon-Etch + laser etching + Icon-Etch): The specimens in group 5 were initially treated with Icon-Etch, followed by laser etching as described in group 4, and finally exposed to a second application of Icon-Etch.

Application of Resin Infiltrant

After surface preparation, ethanol (Icon-Dry; DMG) was applied to the lesion for 30 seconds and then air-dried. Icon-Infiltrant (DMG) was subsequently applied and left on the surface for 3 minutes, with care taken to avoid light exposure during the procedure. Excess resin was removed with a cotton roll, and the surface was light-cured for 40 seconds using an LED device (Woodpecker, China) at 1200 mW/cm². The resin infiltrant was then reapplied for one minute, followed by another 40-second light-curing cycle. Finally, the roughened enamel surface was polished with discs and cups. The final color measurement was recorded after resin infiltration (T2).

Colorimetric Assessment

Tooth color was measured at three time points: baseline (T0), after the formation of WSLs (T1), and following resin infiltration (T2). Measurements were performed using a Vita Easyshade spectrophotometer (Vita Zahnfabrik, Bad Säckingen, Germany) based on the Commission Internationale de L'Eclairage L*a*b* (CIELAB) color space system. This system quantifies color with three coordinates: L* indicates lightness (0 = black, 100 = white), a* represents the green–red axis (-a = green, + a = red), and b* represents the blue–yellow axis (-b = blue, + b = yellow).

The spectrophotometer measurements were conducted between 11 AM and 12 PM on sunny days at the Laser Center of Mashhad Dental School to provide consistent lighting conditions. To minimize potential errors, color measurements were taken twice per specimen, and the mean values of the L, a, and b components were employed in the statistical analysis. Color changes between different treatment stages were computed through the following formula:

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

The color alterations between the treatment stages were defined as follows:

ΔET0-T1: The color change between the baseline and post-lesion induction stages

ΔET1-T2: The color change between the post-lesion induction and post-resin infiltration stages

ΔET0-T12: The color change between the baseline and post-resin infiltration stages

Statistical Analysis

The normal distribution of the data was confirmed using the Shapiro-Wilk test ($P > 0.05$). A one-way analysis of variance (ANOVA) was employed to compare the mean ΔE values between the experimental groups. When a significant difference was noted, pairwise comparisons were made with the Duncan post hoc test. The analysis was carried out using SPSS software (version 16.00 for Windows, Chicago, IL, USA), and a *P* value less than 0.05 was considered statistically significant.

Results

Table 1 presents the mean and standard deviation (SD) of color change (ΔE) across various treatment stages in the study groups. ANOVA revealed no significant difference in the color change between baseline and post-lesion formation (ΔET0-T1) or between post-lesion formation and post-resin infiltration (ΔET1-T2) among the experimental groups ($P = 0.825$ and $P = 0.141$, respectively; Table 1). However, a statistically significant difference was observed between the study groups when considering the color change between baseline and post-resin infiltration (ΔET0-T2) ($P = 0.004$; Table 1).

The highest ΔET0-T2 value was observed in the control group (7.67 ± 4.68), whereas the lowest values were observed when laser etching was combined with Icon-Etch application, as seen in group 4 (3.42 ± 1.73) and group 5 (3.28 ± 0.82). A pairwise comparison using the Duncan test indicated that the color change between the baseline and post-resin infiltration (ΔET0-T2) was significantly lower in groups 4 and 5, compared to both the control group and group 3 (sandblasting + Icon-Etch). Notably, group 2, which underwent double Icon-Etch treatment, did not exhibit any significant difference from the other groups ($P > 0.05$; Table 1). No significant difference was found in ΔET0-T2 between groups 1 and 3, nor between groups 4 and 5 ($P > 0.05$).

Discussion

This study investigated the impact of different conditioning methods applied before resin infiltration on the color change of white spot lesions (WSLs). In all specimens, a two-step infiltration method was employed, with the first step lasting three minutes and the second step lasting one minute. This dual application of the infiltrant was designed to reduce the pore volume within the lesions and

Table 1. Comparison of the mean color change (ΔE) between different treatment stages in the experimental groups

Group	Definition	ΔET0-T1		ΔET1-T2		ΔET0-T2	
		Mean	SD	Mean	SD	Mean*	SD
1	Icon-Etch (15% HCl for 2 minutes)	11.22	4.58	13.21	5.32	7.67[b]	4.68
2	Double Icon-Etch	11.02	4.25	13.07	5.08	5.36[a,b]	5.17
3	Sandblasting + Icon-Etch	11.93	3.03	15.46	3.72	6.98[b]	3.51
4	Laser etching + Icon-Etch	11.45	5.93	10.81	5.49	3.42[a]	1.73
5	Icon-Etch + laser etching + Icon-Etch	12.82	3.63	13.55	2.92	3.28[a]	0.82
Significance		$P = 0.825$		$P = 0.141$		$P = 0.004$	

*The groups that have been defined by different letters indicate statistically significant differences at $P < 0.05$.
ΔET0-T1: Color change between baseline and post-lesion induction
ΔET1-T2: Color change between post-lesion induction and post-resin infiltration
ΔET0-T2: Color change between baseline and post-resin infiltration

compensate for material shrinkage following the initial resin infiltration.[17]

Colorimetric assessments were conducted at three stages: baseline (T0), post-induction of WSLs (T1), and post-resin infiltration (T2). These measurements were taken using a Vita Easy Shade spectrophotometer. This device is easy to use and can provide accurate and consistent results, making it a preferred instrument for tooth color evaluations.[25] The outcome variable in this research was the degree of color change (ΔE) between the various treatment stages. It is crucial to highlight that color changes exceeding 3.7 units typically become perceptible to the naked eye, whereas changes below this threshold are considered acceptable.

The results of the present study indicated no significant difference in color change between baseline (T0) and post-lesion induction (T1) among the groups. This suggests that the development of WSLs was consistent across all groups. The ΔET0-T1 ranged from 11.02 to 12.82 units, indicating that the induced lesions were observable. Following resin infiltration (T2), a noticeable shift in the color of WSLs was observed in all groups. Still, the variations in ΔET1-T2 between the groups did not reach statistical significance. However, when comparing the color change between the baseline and post-resin infiltration (ΔET0-T2), a statistically significant difference emerged between the groups.

In the control group, the surface was subjected to a 15% HCl treatment for 2 minutes before the resin infiltrant application. In this group, ΔET0-T12 amounted to 7.67, exceeding the clinical visibility threshold of 3.7 units for WSLs. In group 2, the surface was etched twice with 15% HCl, as some studies suggested that an etching duration exceeding 120 seconds may enhance the effectiveness of resin infiltration.[19,31] Some improvement in the masking of WSLs was observed in group 2 (ΔET0-T2 = 5.36). However, pairwise comparisons showed that there was not a statistically significant difference between Group 2 and either the control group or any of the other study groups. This finding aligns with the conclusions of Abbas et al[17] who suggested that single etching is adequate for opening the lesion pores without weakening the tooth structure. They noted that double etching may not offer any additional benefits in terms of improving the color of WSLs with various depths.[17] There is some concern regarding the impact of prolonged etching time on tooth health. Arnold et al[19] exhibited a median enamel loss of 34.02 µm after two minutes of exposure to 15% HCl. In their study, increasing the number of etching cycles up to four times led to a significant increase in erosion, ranging from 13.28 to 15.16 µm depth at each etching cycle and culminating in a mean total surface loss of 77 µm. The authors concluded that repeated conditioning with 15% HCl increased the depth of surface erosion, although the overall erosion depth remained relatively shallow.

In group 3, sandblasting followed by acid etching was applied for surface preparation. The ΔET0-T2 was determined to be 6.98, indicating that this approach did not demonstrate a superiority over the control or the double etching groups in concealing WSLs. There is limited research on the use of sandblasting before resin infiltration. The current recommendations propose that sandblasting should not be utilized as a standalone method for enamel etching, but rather in conjunction with acid treatment.[32,33] Patcas et al[32] evaluated the effect of sandblasting, acid etching, or sandblasting followed by acid etching before orthodontic adhesive bonding on the characteristics of enamel and enamel-adhesive interfaces. Consistent with the present findings, they reported no difference in the extent of resin infiltration between the acid-etched and sandblasted-plus-acid-etched groups, although the latter exhibited an improved infiltration quality.[32]

In Groups 4 and 5, an Er,Cr:YSGG laser was applied on enamel lesions at a setting of 0.75 W, 20 Hz, and a pulse duration of 140 µs. These parameters were chosen to achieve surface modification while avoiding deep ablation. It is believed that a power output around 1.0 W is adequate for etching enamel without excessive removal of tooth structure.[34] Given that the specimens in this study had hypomineralized enamel, the lower power of 0.75 W was judged to be more suitable. The use of 55% water and 65% air spray helped to control thermal buildup and facilitated debris removal during irradiation.

In group 4, laser etching was followed by acid etching, whereas group 5 underwent a double acid etching, with one application before and another after laser treatment. Both groups yielded ΔET0-T2 values below the threshold of 3.7 units, signifying that the post-treatment tooth color was clinically indistinguishable from the original tooth color. Therefore, the combination of Er,Cr:YSGG laser irradiation and acid etching proved highly effective as a tooth conditioning method before applying the resin infiltrant, showing considerable potential for concealing opaque lesions. The statistical analysis revealed that the specimens prepared by the combination of Er,Cr:YSGG laser and acid etching (groups 4 and 5) exhibited significantly lower ΔET0-T2 values compared to those of the control group (group 1) and the combined sandblasting and acid etching group (group 3).

The aesthetic improvements observed in the groups utilizing combined laser etching and acid etching may be attributed to surface irregularities and microcavities created during laser etching of the enamel. These irregularities allow for better penetration of the resin infiltrant, resulting in improved restoration of enamel opacities. The degree of color change between the baseline and post-resin infiltration was comparable between the two laser groups, implying that extending the etching time when employing the Er,Cr:YSGG laser does not yield any additional benefits in terms of restoring enamel lesion aesthetics.

The findings of this study align with those of previous studies that reported the effectiveness of resin infiltration in concealing non-cavitated enamel lesions.[31,35,36] A recent systematic review underscored the superiority of resin infiltration over fluoride varnish for the management of WSLs.[37] Wierichs et al[7] indicated that resin infiltration effectively masks carious lesions, and this optical improvement remains stable for at least six years. Vijayan et al[38] evaluated resin tag depth following various enamel surface conditioning and bracket bonding methods, using confocal microscopy. They found that combining acid etching with Er,Cr:YSGG laser irradiation produced significantly longer resin tags than using acid etching or laser etching alone. However, this combined method required more operator time and resulted in the least conservative etch depth patterns.[38]

One limitation of this study was the relatively small sample size. Furthermore, the study did not account for the potential influence of daily activities such as eating, drinking, and brushing, which could impact the effectiveness and durability of resin infiltration. Future research should aim to replicate this study with a larger tooth sample, and examine the color stability of treated lesions prepared using diverse conditioning methods under the conditions experienced in real-life situations. Further clinical trials are also recommended to validate the results obtained in this study.

Conclusion

Within the limitations of this study, it may be concluded that:

1. There was a significant difference in the color change between baseline and post-resin infiltration (ΔET0-T2) among the study groups. The control group exhibited the highest ΔET0-T2 value (7.67).
2. Some improvement in the recovery of WSLs was observed in samples subjected to double acid etching (group 2) with a ΔET0-T2 value of 5.36. However, the results showed that there was not a statistically significant difference between Group 2 and the control group or any other groups.
3. The application of sandblasting followed by acid etching (group 3) did not demonstrate superiority in concealing WSLs compared to either the control or the double etching groups. The ΔET0-T2 value for this group was recorded as 6.98.
4. The groups conditioned using the Er,Cr:YSGG laser and once (group 4) or twice (group 5) acid application exhibited ΔET0-T2 values of 3.42 and 3.28, respectively, which were significantly lower than the control group and the combined sandblasting and acid etching group. These values fell below the threshold of 3.7 units, indicating that post-treatment tooth color was indistinguishable from the original tooth color in clinical terms.

Authors' Contribution

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Competing Interests

The authors declare that they have no conflict of interest

Ethical Approval

The study protocol was approved by the ethics committee of Mashhad University of Medical Sciences (Approval ID: IR.MUMS.DENTISTRY.REC.1399.009).

Funding

This study was funded by the Mashhad University of Medical

Sciences, Mashhad, Iran (Grant number: 980599).

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