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Optimizing Resin Infiltration Treatment of Post-Orthodontic White Spot Lesions by Increasing Infiltrant Penetration Duration — In Vitro Study

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OPTIMIZING RESIN INFILTRATION TREATMENT OF POST-ORTHODONTIC WHITE SPOT LESIONS BY INCREASING INFILTRANT PENETRATION DURATION —IN VITRO STUDY

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Abstract

OPTIMIZING RESIN INFILTRATION TREATMENT

OF POST-ORTHODONTIC WHITE SPOT LESIONS

BY INCREASING INFILTRANT

PENETRATION DURATION

—IN VITRO STUDY

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ABSTRACT

Background: This study focuses on evaluating the effect of increasing duration allowed for resin infiltrant penetration in improving the aesthetic outcome of resin infiltration treatment. Additional investigations into repeat treatment and long-term stability were also conducted. Artifically created white spot lesions were induced on one hundred extracted teeth made up of either incisors or canines. Teeth were divided into enamel and dentin groups depending on the extent of the lesion and then further subdivided into varying treatment protocol groups: 3-minute, 6-minute, and 9-minute penetration time. Teeth were thermocycled for one clinical year and then

divided into a repeat treatment and no additional treatment group. Teeth were thermocycled for an additional clinical year. Spectrophotometric analysis was measured at all timepoints for all groups.

Results: Mean ΔE values, for the enamel group, were slightly above or significantly below the critical value and, for the dentin group, were significantly above the critical value of 3.7. Mean ΔE values within the enamel and dein groups both demonstrated a downward trend with increasing time allowed for resin infiltrant penetration. A single treatment for a white spot lesion resulted in a significant difference compared to no treatment. No significant difference was found between groups that received a single or repeat treatment. There was significant difference in ΔE values for the D3 group following thermocycling after a single treatment. There was significant difference in ΔE values for all groups except the enamel group that received a single treatment following thermocycling after a single or repeat treatment.

Conclusions: Resin infiltration is an effective treatment modality to improve the appearance of white spot lesions. The aesthetic benefit of resin infiltration works best for shallow enamel lesions. Increasing the resin infiltrant penetration time to at least nine minutes is advised as the most optimized treatment protocol. Resin infiltration treatment is recommended only once per a tooth's lifetime. At least 1-year color stability can be reasonably expected. An additional year of color stability can be expected following a single and optimized infiltration treatment of shallow lesions.

Keywords: resin infiltration, post-orthodontic white spot lesions, long-term stability, repeat treatment, thermocycling

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Chapter 1: Introduction

Dr. G. V. Black (1908), the father of operative dentistry, defined white spot lesions (WSLs) as "occasional white or ashy gray spots that were small and covered with the ordinary glazed surface of the enamel, so that an exploring tine will glide over them the same as over the perfect enamel." Typically, the first clinically visible stage of caries presents as enamel demineralization without cavitation (Sadyrin et al., 2020). After a certain degree of demineralization, the enamel demineralization takes on a whitish opaque appearance. Applebaum later confirmed in 1932 and Silverstone in 1973, through polarized microscopy and/or microradiography, that these enamel defects present with a relatively intact surface layer. However, this presentation is misleading as beneath this pseudo-surface is a porous demineralized area described as the body of the lesion (Silverstone, 1973). The extent of these noncavitated lesions typically occupies an area of 15-30 μm beneath the intact enamel surface and may extend further into dentin. Sadyrin's (2020) investigation into the effects of a WSL on enamel and dentin describes a weakening of the surface enamel despite its sound appearance and a decrease in mineral density of the WSL area and bordering dentin. In orthodontics, white spot lesions are a common problem that orthodontists face while treating patients with fixed appliances.

For orthodontic patients, fixed appliances render the maintenance of oral hygiene difficult. In a normal and healthy oral environment, enamel regularly undergoes both demineralization and remineralization in dynamic equilibrium; the synergy between the two keep enamel intact (Shan 2021). When a change in the environment occurs such as the bonding of orthodontic brackets, this balanced microenvironment becomes disrupted, tipping the balance towards demineralization.

Numerous studies have reported the association between orthodontic treatment and WSL formation. Mizrahi (1982) observed an 11.7% increase in WSLs following orthodontic treatment. Gorelick (1982) found that nearly half of the orthodontic patients resulted in at least one WSL after treatment. Lovrov (2007) observed that, of all teeth, 24.9% developed new WSLs. Richter et al. (2011) reported a high incidence of 72.9% for early enamel lesions and a small incidence of 2.3% for new cavitated lesions following orthodontic treatment. A correlation was found between the number of lesions and the length of treatment. "As the duration of fixed appliances increased by one month, 0.08 new WSLs developed" so that treatment of less than 22 months developed an average of 3.01 WSLs, and treatment of 33 months or greater developed an average of 5.28 WSLs. As lesions that still present for 6 months are likely to remain for life without any changes in size or appearance, it appears that both the prevention and treatment of white spot lesions should be an imperative part of comprehensive orthodontic treatment (Perdigão, 2020).

The formation of white spot lesions can be prevented through a combination of influential professional and home care oral hygiene. It is strongly supported in the literature that there is a significant association between poor oral hygiene and the formation of white spot lesions (Geiger et al., 1988). Professional oral hygiene instruction and cleaning may effectively reduce the risk of decalcification (Geiger et al., 1988). In addition to professional help, home care is a pivotal part of effective oral hygiene. The AAO recommends that patients brush for two minutes after every meal or snack and before bed and floss for a minimum of once a day (AAOinfo.org). For patients with poor home care oral hygiene, periodic reinforcement by the clinician may help to remotivate the patient. However, in a systematic review investigating the effectiveness of motivational interviewing, randomized controlled trials showed varied success

of MI in improving oral health (Gao et al., 2014). Although prevention should continue to be a mainstay for orthodontic providers throughout treatment, despite professional efforts, patients, especially those with poor oral hygiene and resistance to changing behavior, still run the risk of forming white spot lesions.

After completion of orthodontic treatment, various treatment modalities can be administered to help in either reducing the carious progression or the WSLs unaesthetic appearance. The more popular and commonly known treatments include the application of remineralizing agents-fluoride and/or casein phosphopeptide-amorphous calcium phosphate(CPP-ACP)-,microabrasion, and resin infiltration.

Fluoride administration is a highly recommended minimally invasive technique to arrest the carious process of white spot lesions. Fluoride has a caries-preventive effect through its ability to be integrated into the crystalline lattice of dental enamel. Doing so results in a fluorapatite structure that is more resistant to the onset of dissolution (ten Cate, 1999). There are many ways to administer fluoride to teeth: toothpaste, mouth rinse, gel, or varnish. To add, fluoride products can be used during orthodontic treatment as a bonding agent or a fluoride-releasing auxiliary (e.g. elastomeric module). Although there are definite benefits to the use of fluoride, in the case of white spot lesions, precaution should be taken as to the type of fluoride used. High concentration fluoride agents should be avoided when treating visible white lesions on labial surfaces as such treatment results in surface hypermineralization (Ogaard et al., 1988). Although hypermineralization arrests the lesion, it also causes both demineralization and remineralization diffusion pathways of enamel to become blocked; in this way, complete repair can no longer be achieved. Such a situation may be recommended for posterior carious lesions but for visible lesions that pose a cosmetic challenge, the appearance of the arrested lesion stays

the same and runs the chance of becoming less aesthetic if stained with organic debris (Willmot, 2004). Instead, it is recommended to allow for natural remineralization or treat with low dose fluoride preparations.

Remineralization of WSLs may occur predominantly in the first 6 months after removal of orthodontic appliances, the original WSL size being reduced to up to 50% (Willmot, 2004). However, evidence to the contrary has been shown that WSLs, if left untreated, experience limited natural remineralization and regression (Beerens, 2015). Shan et al. (2021) observed that both the size and quality of WSLs decreased very slightly after 6 months in the natural remineralization group. Moreover, not all patients experienced this regression. On the other hand, Linton (1996) observed that fluoride solutions of 50 ppm fluoride had a higher efficacy for remineralization than a higher dose solution of 225 ppm fluoride. Thus, low-dose fluoride may be preferable to natural remineralization as a white spot lesion treatment modality especially if the regression of the lesion is the therapeutic goal.

Casein phosphopeptide-amorphous calcium phosphate complex (CPP-ACP) is a milk product recognized for its compatibility with fluoride and its anticariogenic effects. Previous studies on animal and human *in situ* demonstrated CPP-ACP's potential to promote remineralization and inhibit demineralization (Yamaguchi et al., 2007; Cai et al., 2007). The mechanism behind CPP-ACP's anticariogenicity can be explained by APP's ability to bind and stabilize calcium and phosphate in solution.to form ACP clusters (Roopa 2015). In this way, CPP localizes ACP in dental plaque and onto the tooth surface acting as a calcium and phosphate reservoir (Reynolds 1997). The localized CPP-ACP nanocomplexes act as buffers to free calcium and phosphate ions, which in turn maintains a state of supersaturation of ACP with respect to tooth enamel. As a result, enamel demineralization is depressed and remineralization is

enhanced. Iijima and colleagues (2004) observed that enamel remineralization via CPP-ACP results in increased acid-resistance when compared to normal tooth enamel. Unlike high fluoride concentrations, CPP-ACP does not run the risk for hypermineralization; in fact, it has been observed that CPP-ACP usually performs slightly poorer than fluoride in terms of remineralization of smooth-surface WSLs (Llenna et al., 2015). However, the combination of CPP-ACP with fluoride varnish enhances the caries preventive potential of fluoride and antibacterial activity against *Streptococcus mutans* (Attiguppe et al.., 2019). CPP's enhance fluoride's remineralizing efficacy due to its ability to keep fluoride ions in solution (Reynolds 2008). Thus, for post-orthodontic WSLs, it may be advisable to combine CPP-ACP with low dose fluoride to maximize a lesion's potential for remineralization.

However, remineralization reagents while great for prevention and their anticariogenic effects are not very effective at reducing the size and appearance of postorthodontic WSLs (Nascimento et al., 2016). This can be attributed to the fact that fluorides cannot reach the underlying porous demineralized zone through the highly-mineralized surface layer. While remineralization agents are highly recommended for the prevention and arresting of WSLs, for treatment, methods such as microabrasion and resin infiltration have been developed to help with the aesthetic improvement of WSLs.

Microabrasion is a minimally invasive procedure with great potential for managing white spot lesions. In contrast to remineralizing agents, microabrasion aims to remove the highly-mineralized surface layer and expose the underlying poorly-mineralized layer for remineralization (Pini et al., 215; Shan 2021). This is achieved through repeated strong acid application with subsequent polishing; enamel microabrasion involves the use of acidic and abrasive agents to form a semiliquid microabrasive reagent applied with mechanical pressure from a rubber cup

mounted on a rotary handpiece. Reagent combinations include 37% phosphoric acid or 6-18% hydrochloric acid and pumice. If necessary, this treatment can be safely combined with bleaching for improved esthetic results. Microabrasion has been demonstrated to markedly improve the appearance of WSLs and has been regularly reported to be a safe and minimally invasive procedure. In a split-mouth study, that compared two microabrasion techniques with 37% phosphoric acid or 18% hydrochloric acid, it was concluded that both showed successful esthetic results with great patient satisfaction (Sheoran et al., 2014).

However, as the procedure essentially results in removing enamel structure, care should be taken to prevent excessive results. In a study that examined the microscopic effects of microabrasion, it was found that 18% hydrochloric acid applied in a pumice slurry resulted in removal of up to 360 μm of enamel and was time-dependent (Tong et al., 1993). Another study reports that "although it was not the intent of our study to measure the amount of tooth loss, the examination of the photomicrographs gave clear evidence that substantial tooth loss does occur" (Train et al., 1996). In addition, if the technique is to be performed in the cervical region of a tooth, where the thickness of enamel is relatively thin, it is likely that there will be post-treatment sensitivity (Tong et al., 1993). Microabrasion also faces another challenge in that there is no consensus on the ideal treatment time. Some report at most 5-second treatments repeated fifteen times for a total of 1 minute and 15 seconds while others recommend only five treatments with no specifics regarding the time (Croll & Cavanaugh, 1986; Adams, 1987; Berg & Donly 1991). To sum, microabrasion has great potential for white spot lesion aesthetic improvement but must be used clinically with caution.

The resin infiltration technique aims to not only improve the appearance of white spot lesions but also increase resistance to cariogenic attack. Similar to microabrasion, resin

infiltration uses acid to expose the underlying porous layer; however, the acid step is applied alone without additional mechanical stimulation. Following surface exposure, the infiltrant resin is applied with the aim for the resin to "fill the porous space and render the refractive index of WSL similar to normal enamel, thereby masquerading and mitigating" the WSL (Shan 2021). Sound enamel has a refractive index of 1.62 (Kim et al., 2011). Enamel becomes porous when demineralized and thus, experiences varying refractive indexes depending on its environment. When wet, a white spot lesion has a refractive index of 1.33 and clinically appears opaque. When dry, air replaces water in the pores of a WSL, thus lowering the refractive index to 1.0 and clinically appearing more obvious. The difference in refractive indices causes light scattering, which gives the WSL its characteristic white, chalky appearance (Kidd & Fejerskov, 2004). When infiltrant resin fills the pores, the WSLs refractive index increases to 1.52. The difference between an infiltrated lesion and enamel is negligible and, thus, the lesion clinically appears similar to the surrounding sound enamel.

Studies have confirmed the effectiveness of the technique clinically and, in vitro, not only as an esthetic treatment but also as a microinvasive cariostatic procedure (Paris & Meyer-Lueckel, 2010). The infiltrant resin is specially designed to be a low-viscosity curing resin optimized for rapid penetration into the porous enamel. The resin penetrates into the lesion body driven by capillary forces creating a diffusion barrier inside the lesion, not on the lesion surface. Because the infiltrant resin fills the exposed porosities, resin infiltration is able to reinforce the unsupported enamel crystallites in the body of the WSL. This leads to an increase in mechanical strength and, thus, a higher resistance to acid dissolution. (Kielbassa et al., 2009). In this way, resin infiltration makes for an alternative therapeutic approach to prevent further progression of enamel lesions.

Compared to remineralizing agents and microabrasion, resin infiltration may be a superior white spot lesion treatment modality. Although remineralizing agents and resin infiltration both have great potential in arresting the carious progress of WSLs, resin infiltration has been shown to be more effective than fluoride or CPP-ACP in improving the esthetic appearance of WSL (Yuan et al., 2014; Kim et al., 2011). A systematic review and meta-analysis reports that resin infiltration has a significantly higher masking effect than natural remineralization or regular application of fluoride varnishes (Bourouni, 2021). In studies comparing microabrasion to resin infiltration, a handful report that although both techniques improve the esthetic appearance of WSLs, resin infiltration demonstrated better effects when compared to microabrasion (Gu et al., 2019; Shan 2021). In addition, resin infiltration is much less invasive than microabrasion. When the benefits of these two techniques are combined, it has been observed that resin infiltration preceded by microabrasion showed significant esthetic improvement immediately and for six months (Alrebdi & Alyahya, 2022).

At this time, numerous studies have investigated the benefits of resin infiltration, and so several systematic reviews and meta-analyses have been conducted. Interestingly, a handful of reviews share the conclusion that the clinical benefits of resin infiltration is yet inconclusive (Borget, 2017; Bourouni, 2021; Sonesson et al., 2017; Paula et al., 2017) Instead, the recommendation is for additional well-designed and performed controlled clinical trials with long-term follow up to be conducted. Yet, reviews also exist that do support the efficacy of resin infiltration in not only the prevention of caries progression but also the esthetic improvement of WSLs (Doméjean et al., 2015; Lin, et al., 2022; Faghihigan et al., 2019).These reviews although differ in conclusion with the former reviews, agree that further studies should be pursued to establish the best clinical practice.

Chapter 2: Methodology

A sample size of 100 human teeth with at least ten teeth per group was selected to adequately estimate clinical average change of color. Each group's sample size of at least ten was four more than the sample size (n=6) of the reference study on which this research followed up (Abbas et al., 2018). A hundred human teeth of either incisors or canines were collected from patients treated in the Department of Oral Surgery at the University of Nevada, Las Vegas.

Criteria for selection included

1. Healthy, sound teeth free from caries or restorations
2. Intact enamel surface
3. No gross visible cracks and/or stains
4. No white spot lesions

The teeth were divided into two control groups and a treatment group.

A. Ten teeth were set aside for the positive control group in which enamel was not demineralized or treated. The positive control group is expected to give consistent findings with minimal changes throughout the experiment at all timepoints.
B. Ten teeth were also set aside for the negative control group in which enamel was demineralized but was given no treatment It is expected that the negative control group will, at first, confirm the experimental intervention, resin infiltration treatment, and, then, give consistent findings with minimal changes.
C. The remaining 80 teeth were divided into two groups according to the depth of the induced WSL: enamel (E) and dentin (D). Each of the two groups were subdivided into three groups of ten (or 20) teeth each according to the resin infiltration protocol applied. The different infiltration protocols used were: 3-

minute penetration duration (E3 and D3), 6-minute penetration duration (E6 and D6), and 9-minute penetration duration (E9 and D9). 20 teeth, instead of ten, were placed into the E3 and D3 groups as these groups were planned to be further subdivided in a later part of the study.

a. Later, the 20 teeth in each of the E3 and D3 groups were randomly subdivided to make two groups of ten teeth each. One group was randomly assigned as a control, while the other group was designated as the experimental group. The E6, D6, E9, and D9 groups were discarded.

Teeth preparation

1. After extraction, teeth were cleaned with water and fluoridated toothpaste and, then, stored in a diluted solution of water and 2% chlorhexidine gluconate.
2. Tooth roots were removed at the cemento-enamel junction.
3. Tooth crowns were embedded into a silicone mold with self-curing acrylic resin with the lingual surfaces facing inwards and incisal edges facing a 12 o' clock position. Buccal enamel surfaces were left exposed and level with the raised edges of the silicone mold. Resin and teeth were painted over with a black acid-resistant nail varnish leaving a 4x4mm window of enamel.
4. Prior to color measurement, all teeth were polished by a rubber prophylaxis cup loaded on a low-speed rotary handpiece with a pumice and water mixture and then rinsed with water.
5. Resin blocks were labeled clearly on the bottom right corner of the six o' clock face with a black permanent marker.

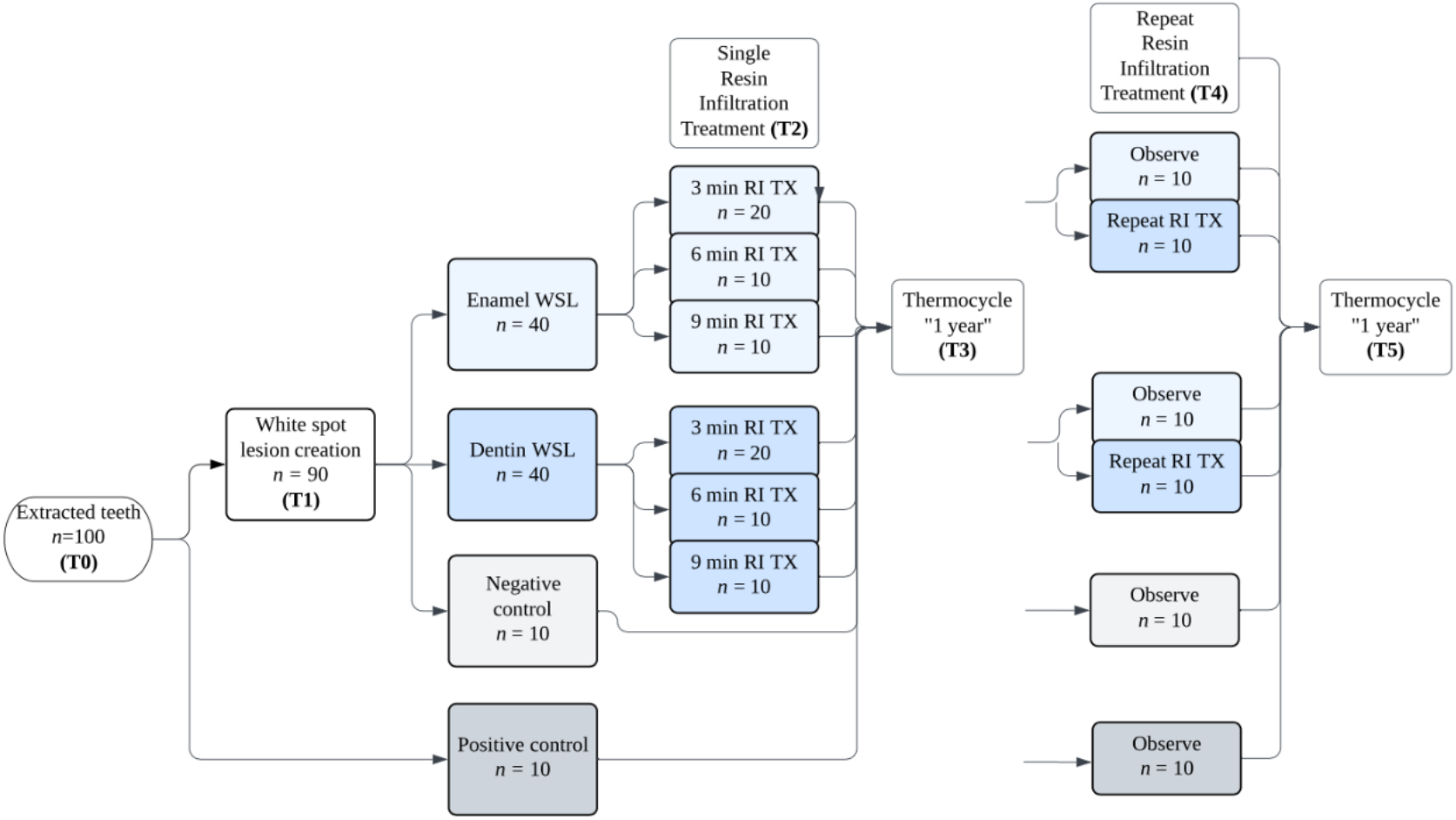
6. Baseline (T0) colorimetric analysis was carried out on all teeth using a spectrophotometer (VITA EasyShade V, VITA North America, CA).
7. Ten teeth were randomly selected for the positive control group.
8. The remaining 90 teeth were immersed in a demineralization solution of 0.1M lactate buffer maintained at pH4.2 and incubated at 37 degrees Celsius for at most three weeks. The solution was checked daily for changes in pH and adjusted to maintain a constant acidic pH of 4.4.
9. The extent of the white spot lesion was evaluated with a DIAGNOdent every day. Lesions that extended into dentin were removed from the demineralization solution and placed into artificial saliva at pH 7. Teeth were immersed again in the demineralization solution if lesion's extent was insufficient. Once 45 teeth with dentin lesions were set aside, the remaining teeth were confirmed as enamel lesions and also set aside and placed into artificial saliva at pH7.
    i. Readings of induced white spot lesions ranging from 14-20 were placed into the enamel group (Appendix A, **Table 1**).
    ii. Readings of induced white spot lesions greater than 20 were placed into the dentin group (Appendix A, **Table 1**).
10. Five teeth in both the dentin and enamel pools of teeth were randomly selected for the negative control group. The remaining 40 teeth in each group were then randomly assigned to 3-minute (n=20), 6-minute (n=10), and 9-minute groups (n=10).
11. Induced white spot lesion (T1) spectrophotometer readings were recorded on all teeth except for the positive control group.

12. Icon® resin infiltration (DMG America, Englewood, NJ, USA) was applied on the lesions of the treatment groups (E3, E6, E9, D3, D6, D9) according to the manufacturer's kit instructions (Appendix B) but with the following adustments:
    i. ICON-Etch was repeated three times for two minutes each.
    ii. ICON-Infiltrant penetration time was determined according to the group assigned.
    iii. Final treatment surfaces were polished using polishing points.
13. Lesions following resin infiltration treatment (T2) spectrophotometer readings were recorded on all teeth including untreated control groups.
14. All teeth were thermocycled for 10,000 cycles (equivalent to one clinical year).
15. Spectrophotometer readings were recorded on all teeth following thermocycling (T3).
16. The 20 teeth in the E3 and D3 groups were then randomly assigned to one of two groups of ten. One group acted as the control group; the other group acted as the treatment group. The 6-minute (E6 and D6) and 9-minute (E9 and D9) groups were discarded.
17. Icon® resin infiltration was applied on the previously treated lesions of the treatment group according to the manufacturer's kit instructions but with the following adjustments.
    i. ICON-Etch was repeated three times for two minutes each.
    ii. An ICON-Infiltrant penetration time of 3 minutes was used on all treatment teeth.
    iii. Final treatment surfaces were polished using polishing points.

18. Spectrophotometer readings were recorded on treatment teeth and all control groups following repeat resin infiltration treatment (T4).
19. All teeth were again thermocycled for 10,000 cycles (equivalent to one clinical year).
20. Final spectrophotometer readings were recorded on all teeth following the second thermocycling (T5).

Figure 1 Study flowchart can be found on next page.

Figure 1 Study flowchart



Statistical analysis

Two spectrophotometer readings per tooth were taken for each time point to reduce measuring error. The color difference between the two readings was verified when the difference did not exceed the threshold of 1 ΔE unit. When the difference of ΔE did exceed 1unit, readings were rejected and new readings were taken.

A ΔE was calculated using the following formula for T2-T0, T3-T0, T4-T0, and T5-T0. Most studies set the proposed acceptance for color matching to be 3.7 units, above which the differences are clinically visible.

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

In order to compare the threshold of clinical detection and the mean ΔE at T2-T0 for multiple groups, a one-way analysis of variance (ANOVA) was performed,-followed by a post hoc test.

In order to compare the mean ΔE values at T2-T0 between the groups that received no resin infiltration treatment and a single resin infiltration treatment, an independent samples t test was performed. An independent samples t-test was also performed to compare mean ΔE values at T4-T0 between the groups that received a single resin infiltration treatment and a repeat resin infiltration treatment.

In order to determine the significance when comparing the mean ΔE values at T3-T0 within groups before and after thermocycling, a paired-sample t-test was performed. A paired-sample t-test was also performed to determine the significance when comparing the mean ΔE values at T5-T0 within groups before and after the second round of thermocycling.

Chapter 3: Results

WSL formation

Following immersion in the demineralization solution, white spot lesions were clinically detectable in all groups excluding the positive control group in which WSLs were not induced. The white spot lesion formation was further confirmed by a DIAGNOdent measurement exceeding 14 and by a ΔE difference from baseline (T0) to after WSL formation (T1) that exceeded the threshold of clinical detection of 3.7.

Table 1 Comparison between the threshold of clinical detection and the mean ΔE (T2-T0) following different resin infiltration protocols of the WSLs in enamel and dentin

		Mean ΔE	SD	Critical value ΔE	*t*	*P* value
Enamel (*n*=40)	3 min (*n*=20)	3.7	0.97	3.7	0.032	0.975
	6 min (*n*=10)	3.2	0.68		-2.512	0.033*
	9 min (*n*=10)	2.3	0.86		-5.127	0.001*
Dentin (*n*=40)	3 min (*n*=20)	15	12		4.089	0.001*
	6 min (*n*=10)	7.4	2.5		4.623	0.001*
	9 min (*n*=10)	5.8	1.7		3.747	0.005*
(-) Control	No RI TX (*n*=10)	29	9.0		9.101	0.000*
(+) Control	No WSL, No RI TX (*n*=10)	1.0	0.42		-20.005	0.000*

*significant at *P* value <0.05; *n* meaning sample size; RI TX meaning resin infiltration treatment; WSL meaning white spot lesion

Color change comparisons following different resin infiltration protocols

Table 1, above, displays the mean color difference ΔE between the baseline (T0) and following different resin infiltration protocols (T2). The positive control gave the least mean value 1.0 ±

0.42 of all groups as was expected. E9 observed the next least mean value 2.3 ± 0.86, which was the least of all experimental groups. Within each enamel and dentin group, both of the 9 minute groups gave the least mean values compared to different resin infiltration protocols: E9 with 2.3 ± 0.86 and D9 with 5.8 ± 1.7. Within each enamel and dentin group, mean ΔE values increased with decreasing time for the resin infiltration protocol. E6 with 3.2 ± 0.68 was greater than E9, while E3 was the greatest of all enamel groups with 3.7 ± 0.97; D6 with 7.4 ± 2.5 was greater than D9, while D3 was the greatest of all dentin groups with 15 ± 12. The negative control gave the greatest mean value 29 ± 9.0 of all groups as was expected.

When comparing the same resin infiltration protocol between the enamel and dentin groups, the enamel group's mean ΔE was always less than the dentin group's mean ΔE value: E9 with 2.3 ± 0.86 was less than D9 with 5.8 ± 1.7; E6 with 3.2 ± 0.68 was less than D6 with 7.4 ± 2.5; and E3 with 3.7 ± 0.97 was less than D3 with 15 ± 12.

Only the positive control, E9, and E6 groups were clinically not detectable as their values did not exceed the threshold of clinical detection, 3.7. The positive control group demonstrated high significant difference ($P<0.001$) while the E9 and E6 groups demonstrated significant difference ($P<0.05$) when compared with the critical value. The negative control and all dentin groups-D3, D6, D9-were clinically detectable as their values exceeded the threshold of clinical detection, 3.7. The negative control group demonstrated high significant difference ($P<0.001$) while the dentin groups demonstrated significant difference ($P<0.05$) when compared with the critical value in the reverse direction.

A high standard deviation above 1 was observed for all dentin groups and the negative control group, increasing with decreasing time for resin infiltration: D9 with ±1.7, D6 with ±2.5, D3 with ±12, and the negative control with ±9.0.

Figure 2, found below, represents the previously explained results in box and whisper plot form. Note the downward trend in mean ΔE values within the enamel and dentin groups with increasing time for resin infiltration protocol. For the enamel group, mean ΔE values were slightly above or significantly below the critical value of 3.7. For the dentin group, mean ΔE values were significantly above the critical value of 3.7. The positive control and negative control groups were highly significantly below and above the critical value of 3.7, respectively.

Figure 2 Mean ΔE (T2-T0)

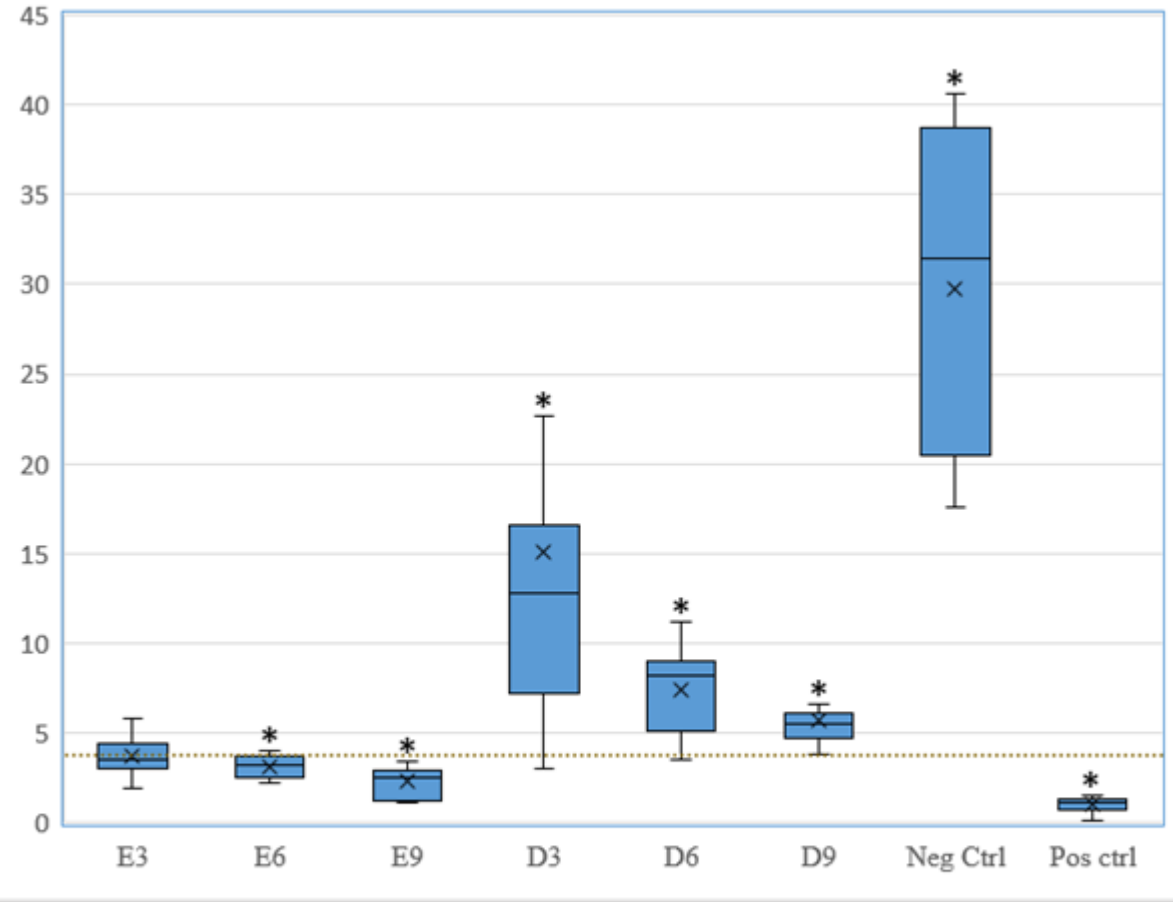


Fig 2. Box and whisker plot displaying the mean ΔE (T2-T0) values following different resin infiltration protocols compared to the threshold of clinical detection at 3.7
*significant at *P* value <0.05

Table 2 Multiple comparisons for the mean ΔE (T2-T0) between the different resin infiltration protocols in the enamel and dentin groups

Enamel (*n*=40)		E6	E9	Neg Control	Pos Control
	E3	0.257	0.001*	0.000*	0.962
	E6		0.093	0.000*	0.996
	E9			0.000*	1.000
Dentin (*n*=40)		D6	D9	Neg Control	Pos Control
	D3	0.084	0.030*	0.000*	0.000*
	D6		0.915	0.000*	0.361
	D9			0.000*	0.728
*significant at *P* value <0.05					

Table 2, above, shows multiple comparisons of the mean color difference ΔE between the baseline (T0) and following different resin infiltration protocols (T2). It was found that negative control mean ΔE values differ significantly at *P* value <0.001 compared to all other experimental groups. Within the enamel and dentin groups, the mean ΔE values of the E3 and D3 groups differed significantly from those of the E9 and D9 groups, respectively (*P* value<0.05). The D3 group's mean ΔE also differed significantly from that of the positive control group at *P* value <0.001. It should also be noted that the *P* value between the mean ΔE values of the E9 and positive control groups was found to be 1.000. A *P* value close to 1 suggests no difference between the groups other than due to chance.

Figure 3, on the next page, displays the visual changes observed for all groups at various timepoints and resin infiltration treatment steps. The E3, E9, D9, and positive control groups at T2 following resin infiltration treatment were comparable to pre-WSL baseline presentation of

enamel at T0; the before and after treatment comparisons within each of these groups is highlighted by yellow boxes. The D3 group at T2 following resin infiltration treatment was only moderately comparable to pre-WSL baseline presentation of enamel at T0; the before and after treatment comparisons for D3 is highlighted by orange boxes. The negative control group at T2 following resin infiltration treatment was not comparable to pre-WSL baseline presentation of enamel; the before and after treatment comparison for this group is highlighted by red boxes.

Figure 3 Groups at various timepoints

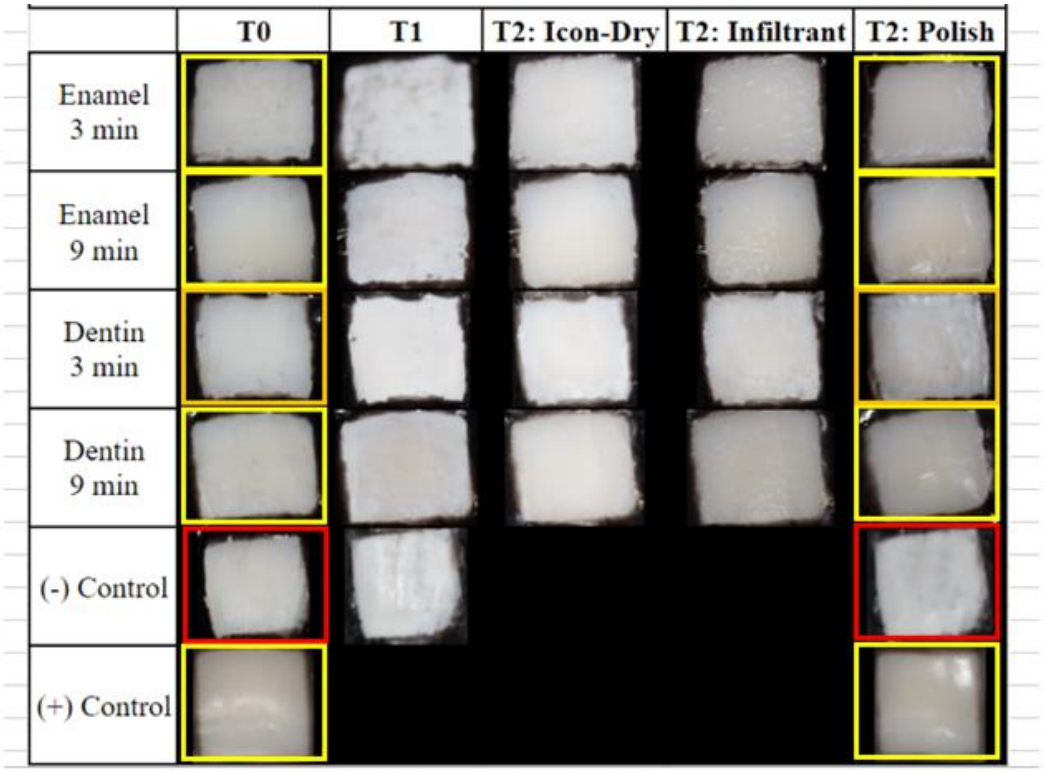


Fig. 3 Visual changes observed within each group at different timepoints and resin infiltration treatment steps. Yellow highlighted groups following resin infiltration treatment were comparable to pre-WSL baseline presentation of enamel. Orange highlighted group following resin infiltration treatment was only moderately comparable to pre-WSL baseline presentation of enamel. Red highlighted group following resin infiltration treatment was not comparable to pre-WSL baseline presentation of enamel.

Note the chalky and white appearance of the enamel at T1, acting as a visual confirmation of the formation of white spot lesions. Also, note the appearance of the enamel at T2: ICON-Dry does not look similar to that of T2: Polish.

Color change comparisons between groups that received different numbers of treatment

Table 3 and **Table 4** compare the mean ΔE values following the first resin infiltration treatment at T2 between the no and the single resin infiltration treatment group and following the second resin infiltration treatment at T4 between the single and repeat resin infiltration treatment group, respectively. These tables give the numerical breakdown of **Figure 4** and **Figure 5** shown on page 23. **Figure 4** and **Figure 5** display, as a box and whisper plot, the comparison of the mean ΔE of the groups in **Table 3** and **Table 4**, respectively.

Table 3 Comparison of the mean ΔE (T2-T0) between WSL groups that received no resin infiltration treatment and a single resin infiltration treatment

	Mean ΔE	Standard deviation	Standard error mean	Mean difference	Standard error difference	t	*P* value
No TX (*n*=10)	29	9.0	2.9	19	3.6	5.608	0.000*
Single RI TX (*n*=40)	9.4	11	1.7				
	*significant at *P* value <0.05; *n* meaning sample size; RI TX meaning resin infiltration treatment						

Table 4 Comparison of the mean ΔE (T4-T0) between WSL groups that received a single resin infiltration treatment and a repeat resin infiltration treatment

	Mean ΔE	Standard deviation	Standard error mean	Mean difference	Standard error difference	t	*P* value
Single RI TX (*n*=10)	9.3	8.7	1.9	1.7	2.6	0.633	0.530
Repeat RI TX (*n*=40)	7.6	8.0	1.8				
	*significant at *P* value <0.05; *n* meaning sample size; RI TX meaning resin infiltration treatment						

In **Table 3,** the mean ΔE for the no treatment group was higher at 29 ± 9.0 compared to that of the single treatment group at 9.3 ± 11. This mean difference of 19 ± 3.6 was found to be highly significant (*P* value <0.001). **Figure 4** displays the differences between the no and single treatment groups as two box and whisker plots with a line connecting the mean ΔE of the two groups. The slope of the line is quite steep, suggesting a notable difference between the two means. Note the two outliers in the single resin infiltration treatment group.

In **Table 4,** the mean ΔE for the single treatment group was higher at 9.3 ± 8.7 compared to that of the repeat treatment group at 7.6 ± 8.0. This mean difference of 1.7 ± 2.6 was found to be not significant with a *P* value of 0.530 (*P* value is not <0.05). **Figure 5** displays the differences between the single and repeat treatment groups as two box and whisker plots with a line connecting the mean ΔE of the two groups. The slope of the line is not steep and relatively flat, suggesting no notable difference between the two means. Note the total of two outliers, one in both the single and repeat treatment groups.

Figure 4 ΔE (T2-T0): No TX vs. single RI TX

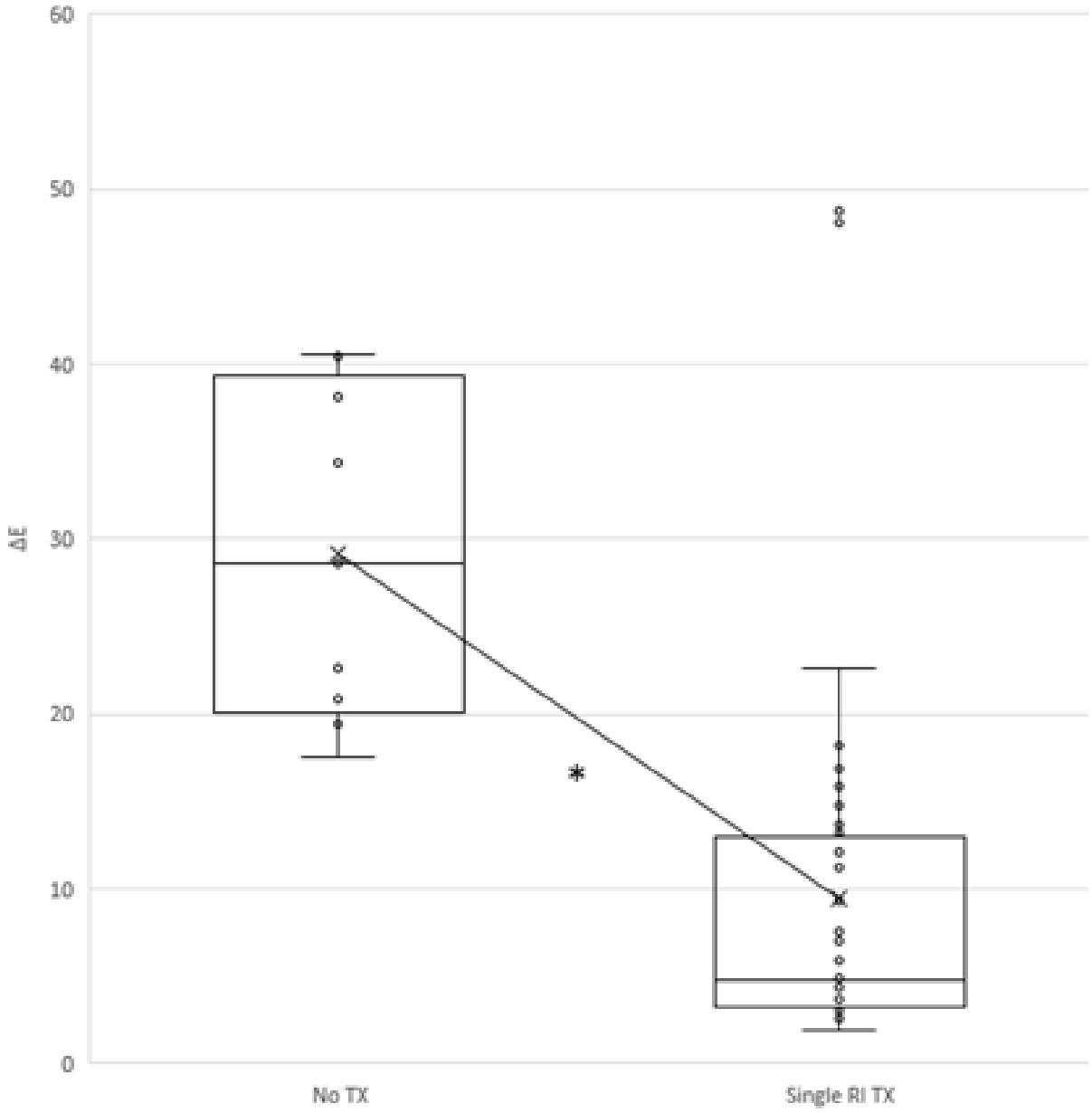


Fig. 4 Box and whisker plot comparing the diference in mean ΔE values (T2-T0) between the WSL group that received no resin infiltration treatment and the WSL group that received a single resin infltration treatment. *significant at *P* value <0.05

Figure 5 ΔE (T4-T0): Single RI TX vs. repeat RI TX

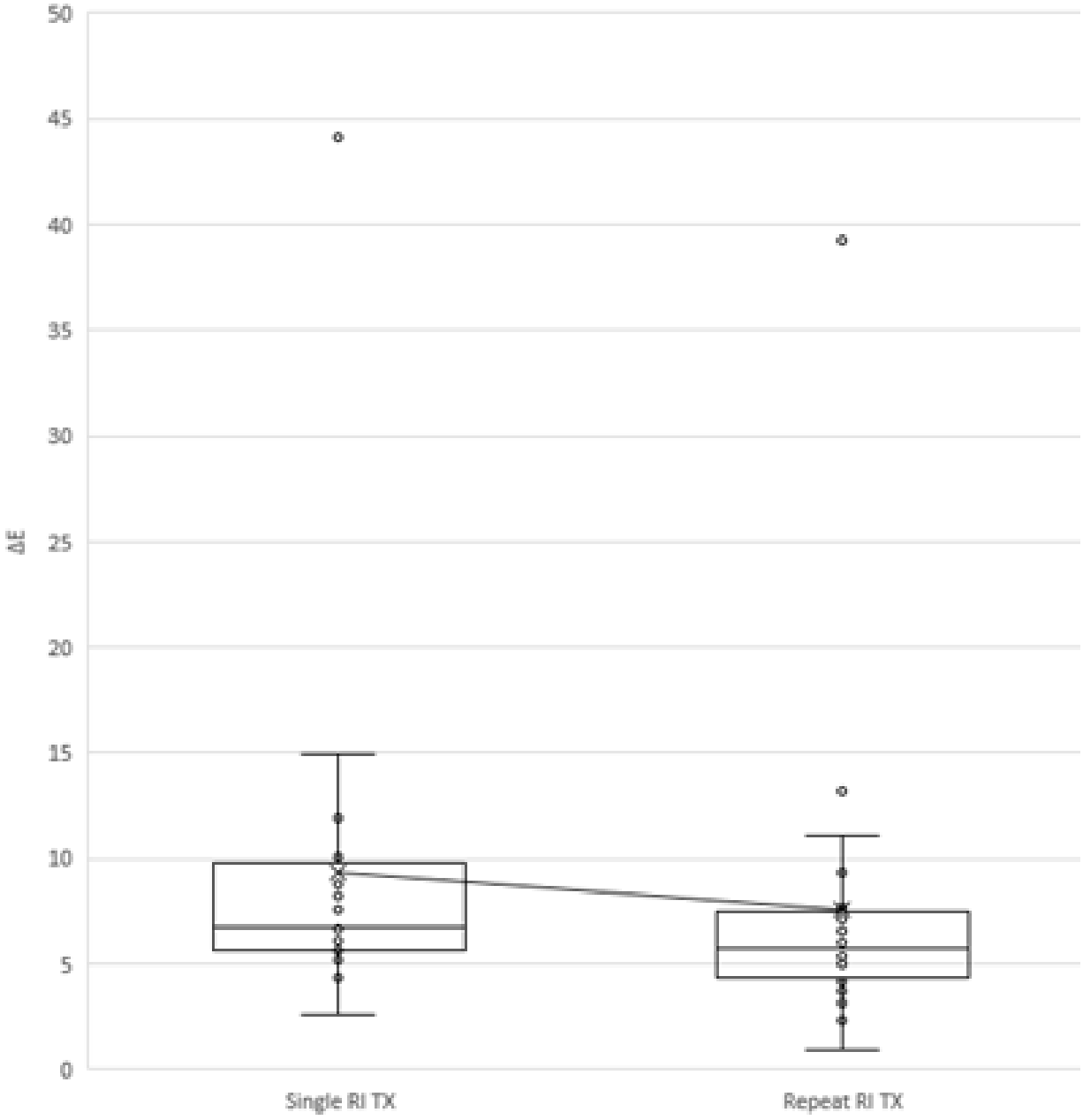


Fig. 5 Box and whisker plot comparing the diference in mean ΔE values (T4-T0) between the WSL group that received a single resin infiltration treatment and the WSL group that received repeat resin infltration treatment.
*significant at *P* value <0.05

Significance of thermocycling following different treatment protocols

Table 5 and **Table 6**, found on the following page, display the *P* values when comparing the mean ΔE within each group at two different timepoints: before and after thermocycling.

Table 5 observes thermocycling effects after no treatment or a single resin infiltration treatment with varying protocols. A highly significant difference was found in the negative control group and the D3 resin infiltration group due to thermocycling.(*P* value <0.001). The positive control group and the E9 resin infiltration group observed high values at 0.846 and 0.723, respectively.

Table 6 observes thermocycling effects after a single or repeat resin infiltration treatment. A highly significant difference was found in the negative control group, both dentin groups-dentin group that received a single treatment and dentin group that received a repeat treatment-, and the enamel group that received a repeat treatment due to thermocycling. (*P* value <0.001). The positive control group and the enamel group that received a single treatment had positive *P* values at 0.653 and 0.054, respectively.

Table 5 Significance when comparing mean ΔE values (T3-T0) within groups before and after thermocycling following no or a single resin infiltration treatment with varying treatment protocols

		P value
Enamel (*n*=40)	3 min (*n*=20)	0.322
	6 min (*n*=10)	0.433
	9 min (*n*=10)	0.723
Dentin (*n*=40)	3 min (*n*=20)	0.000*
	6 min (*n*=10)	0.401
	9 min (*n*=10)	0.194
(-) Control	No RI TX (*n*=10)	0.000*
(+) Control	No WSL, No RI TX (*n*=10)	0.846

*significant at *P* value <0.05; *n* meaning sample size; RI TX meaning resin infiltration treatment; WSL meaning white spot lesion

Table 6 Significance when comparing mean ΔE values (T5-T0) within groups before and after thermocycling following a single or repeat resin infiltration treatment of the WSLs in enamel or dentin

		P value
Enamel (*n*=20)	Single RI TX (*n*=10)	0.054
	Repeat RI TX (*n*=10)	0.000*
Dentin (*n*=20)	Single RI TX (*n*=10)	0.000*
	Repeat RI TX (*n*=10)	0.000*
(-) Control (*n*=20)	No RI TX (*n*=10)	0.000*
(+) Control (*n*=20)	No WSL, No RI TX (*n*=10)	0.653

*significant at *P* value <0.05; *n* meaning sample size; RI TX meaning resin infiltration treatment; WSL meaning white spot lesion

Chapter 4: Discussion

Infiltration by a low-viscosity resin has great potential in not only treating early enamel lesions noninvasively but also providing other benefits. Resin infiltration treatment at an earlier stage of lesion development precludes the need to remove porous carious tissue at a relatively late stage in the disease process. Its ability to fill the microporosities of lesions inhibits further microbial attack by reducing the porosity, and thus, "the access of acid and egress of dissolved material" (Robinson et al., 2001). In addition, WSL treatment with infiltrating resins has been likened to an enamel hybridization process with the formation of resin extensions into the hollow spaces inside the demineralized enamel (Meyer-Lueckel & Paris, 2008). This hybridization makes the resin-embedded enamel more resistant to acid attack than sound enamel (Perdigão, 2020). Robinson et al. also report that the resin matrix can also strengthen the enamel structure by providing mechanical support.

> Meyer-Lueckel (2008) summarizes the resin infiltration process well in three steps: "both enamel structural reinforcement and cariostatic properties have been accomplished by infiltrating enamel WSLs using 15% HCl etching to make the mineralized surface layer more porous, followed by a drying step with ethanol to remove excess water, and application of a low-viscosity light-cured resin."

Resin penetration depth and quality is the hallmark for a successful resin infiltration treatment. Each of the three steps can be further explored in order to better understand how to maximize the final benefit of resin infiltration-aesthetic improvement.

DMG America, a manufacturer of the resin infiltration product, Icon®, states in their instructions that the lesion's appearance following the application of ethanol should be a good representation of the final treatment results. Thus, ethanol can act as a visible check. Perdigao

(2020) explains that if a white spot lesion is still fully visible on a hydrated tooth surface or on a tooth that has been wet with ethanol, the lesion has likely extended through the enamel and possibly into the dentin. A noncavitated white spot lesion that extends into dentin may be unable to be completely infiltrated and, thus, results in a poor resin infiltration treatment outcome. Icon can be used for lesions up to the first third of the dentin (DMG America). However, due to Icon-Infiltrant being hydrophilic whereas dentin is hydrophobic, Icon cannot fully infiltrate the dentin.

The purpose of Icon-dry as the second step of the Icon treatment is much more significant than as a visual check. 99% ethanol is used to remove the water stored inside the microporosity of the lesion body (Meyer-Lueckel et al., 2006). A study by Paris et al. in 2007 confirms how the addition of ethanol decreased viscosities, surface tensions, and contact angles leading to an increased penetration coefficient for all monomer combinations. Ethanol thus allows the resin to freely penetrate into the lesion body by capillary forces. In this study, Icon-Dry was always applied prior to Icon-Infiltration penetration to maximize the drying effects of ethanol alcohol.

Prior to the drying step is the etching step by 15% HCl. Bertacci et al's study in 2014 observed the differences between phosphoric acid and HCl gel etching on the structural arrangement of outer enamel. Phosphoric acid gel resulted in a reduction of channels and pores and, thus, enamel permeability, as opposed to HCl treatment, which maintained enamel porous structure. As a result, phosphoric acid gel was better recommended for adhesive procedures. However, because penetration of resin is the therapeutic goal of resin infiltration treatment, based off these study results, it can be surmised that HCl acid treatment would allow for a higher quality of penetration than phosphoric acid. This may explain as to why Icon uses 15% HCl for their Icon-Etch step as opposed to phosphoric acid gel.

Acid treatment produces an enamel surface erosion that demonstrates a strong relationship between loss of enamel and etching duration (Bertacci et al., 2014). Meyer-Lueckel et al. in 2007 demonstrated that there is a significantly increased surface layer reduction with the use of HCl 15% compared to 37% phosphoric acid gel (Meyer 2007). Paris et al. observed that HCl 15% gel for 90 and 120 seconds resulted in a more effective reduction in the surface layer of natural enamel caries than 37% phosphoric acid gel for 30-120 seconds. Thus, they recommended 120 seconds of HCl 15% as the etching protocol prior to resin infiltration. However, in the same study, they found that the surface layer could not be eroded completely in 67% of lesions in the HCl group. It is difficult to create enough porosities on thick surface layers with just one application of 15% HCl, resulting in poor capillary infiltration of the resin into the body of the lesion. However, although the authors recommended longer application times to achieve complete surface layer erosion, whether the study results implicated longer application times or repeat etching rounds is unclear. A study by Grey & Shellis observed that while longer etching time resulted in increased enamel loss and a partial breakdown of the lesion surface, no increase in penetration depths was observed (Grey & Shellis, 2002). As a result, this may explain as to why Icon recommends only up to 120 seconds for each round of etch.

Perhaps rather than increasing etching time, multiple sessions of etch could result in a more effective etch. In a 2018 study, Abbas et al. explored the effect of the number of etchings in preparation for resin infiltration on the treatment outcome. While a single etching was observed to be adequate in opening lesion pores without weakening the tooth structure, a double etching was found to result in exfoliation of the enamel surface. In addition, the double etching resin infiltration outcomes were found to be above the clinically detectable threshold as opposed to samples that received a single etching that generally observed results below the threshold.

Although 15% HCl is able to remove the hypermineralized surface layer, this effect can also additionally weaken the lesion structure (Hammad et al., 2012). Thus, multiple studies share the observation that detrimental effects to the enamel mechanical structure can occur by either increasing the duration of the etch or the number of etches. Icon recommends up to three rounds of etching under certain conditions; however, this may not be advised as the benefits may be slim to none.

The risks of etch can also be observed during orthodontic treatment. During orthodontic treatment, enamel facial surfaces are exposed at least once to the etching process in order to bond brackets, attachments, or an appliance. Multiple factors such as a lost bracket or a bracket repositioning may result in additional exposure to etching. Several studies delineate the risks that come with excessive surplus orthodontic etching. Kuhar (1997) concluded that both acid etching and grinding of the enamel surface increases enamel permeability, thus increasing the probability of demineralization and tooth decay. Knösel (2012) recommends avoiding orthodontic etching of the complete labial enamel surface and only etching the bracket base area in order to prevent iatrogenic white spot lesions. The risk is especially severe in etched surfaces that are subsequently incompletely covered by bonding material or sealers. “The iatrogenic damage that appears with surplus etching should be viewed as initial demineralization amplified by exposure to an acidic environment, as is typical for interbracket sites during stages of insufficient oral hygiene.” As a result, the authors recommend a more diligent application and shorter intervals of etching.

Whether etch is used during orthodontic treatment or afterwards as a part of resin infiltration treatment, there are a number of variables that can be changed to increase the effect

of the etch, but just as many risks are involved. As a result, this study chose a different resin infiltration step as the focus of the study-the resin infiltrant step.

A commonly used brand for resin infiltration is made by DMG America called Icon® resin infiltration. On their kit, instructions are illustrated and described in a step-by-step fashion (Appendix B). However, these instructions are less informative and detailed compared to those found on the manufacturer's website (Appendix C). The website instructions differ by making further suggestions to increase the efficacy of the resin infiltration treatment. In terms of etching, the online instructions include to "activate the effect by moving the tip occasionally." For the infiltrant step, the online instructions suggest "extending the exposure time…in case of deeper and larger defects [to improve] the esthetic result." Compared to increasing the resin infitrant time, changing variables in the etch step can result in as many drawbacks as it does benefits. As a result, this study focused on maximizing the effects of the resin infiltrant step as changing variables in this step does not have known detrimental effects.

Following etching and drying, the penetration of infiltrant resin is the last step in the resin infiltration process. In order to increase the penetration depth of the infiltrant resin, "extending the exposure time" as recommended by DMG America may result in improved treatment outcomes. A study conducted by Meyer-Lueckel et al. in 2006 tested the penetration depths of five different adhesives and a single sealant. The different resins were allowed to penetrate for either 15 or 30 seconds. It was observed that an application time of 30 seconds resulted in a significantly deeper penetration for all of the materials. Similarly, in this study, Icon-Infiltrant was allowed to penetrate for a total uninterrupted time of either 3 minutes, 6 minutes, or 9 minutes. Although measuring penetration depth of the resin was not a part of this study, the improved color resolution observed with longer penetration times agrees with the previous

study's results-increasing penetration duration allows for a more complete resin penetration. A deeper look into all of the findings of the study will follow.

According to the manufacturer instructions, a second application of the resin for 1 minute follows the first application. The second application is due to the polymerization shrinkage that occurs after curing the first application (Robinson, Brookes, Kirkham, Wood, & Shore, 2001). This final coat of resin aims to occlude the generation of space as a result of the shrinkage of materials. In fact, because resin infiltration treatment aims to construct a diffusion barrier inside the lesion and rather than on top, a resin layer on the lesion surface is not required if the lesion body is infiltrated homogeneously with the resin (Mueller et al., 2006).

This study has observed several findings in regards to the use of Icon resin infiltration as a treatment for post-orthodontic white spot lesions. This study's results support that resin infiltration treatment has consistent ability in improving the aesthetics of white spot lesions. However, it does not have the ability to completely resolve the appearance of all white spot lesions. Shallow lesions that extended only into enamel fared a better chance at complete resolution compared to deeper white spot lesions that extended into dentin. This finding agrees with previously mentioned studies' results and DMG America. Overall, resin infiltrant as a hydrophilic medium cannot infiltrate completely into the permanent moisture in the dentinal tubules. As a result, although resin infiltration of deeper lesions can be attempted to arrest the lesion, deep dentinal lesions may require more invasive restorative procedures.

No matter the depth of the lesion, results demonstrated that extending the penetration duration to at least nine minutes gave the best mean ΔE improvement. It is surmised that the extended time allows for the resin infiltrant to achieve a higher quality of enamel hybridization. The capillary action of the resin to form extensions into the hollow spaces may be resisted by

negative pressure. The increased time and constant wetting of the surface possibly allows the infiltrant to better overcome resisting forces and barriers and further extend into the exposed lesion. Thus, it can be concluded that extending the time for resin infiltrant penetration is the most optimal treatment protocol.

Although this study did not focus on the drying step, it was observed that the Icon-Dry step did not act as a reliable visual check as to the treatment outcome. This may be a faulty recommendation. A future study investigating the reliability of Icon-Dry is advised.

In cases in which resin infiltration does not completely resolve the lesion, it may be tempting to attempt another round of treatment. However, this study observed that a repeat treatment does not result in a significant change in mean ΔE. In fact, when looking at the effects of thermocycling on the various groups at T4 vs. T5, all groups except the enamel group that received a single resin infiltration treatment experienced poor long-term color stability. It was expected that a repeat treatment would result in stable mean ΔE outcomes as the extra layer of resin could act as another protective layer for the previous resin infiltration. However, the repeat treatment appears to have had a detrimental effect on the color stability. This outcome may be explained by the repeated exposure to possible sources of iatrogenic effects: excess etching, poor sealing, and excess polishing. In addition, the finding supports that a repeat treatment cannot re-expose the demineralized zone as well as a first treatment does for a virgin lesion. Thus, a repeat treatment is ineffective and only results in an additional surface layer of low-viscosity resin that is prone to wear. Overall, the findings imply that it is advised against repeating resin infiltration treatment as not only are the results expected to be marginal but also the tooth may experience less color stability after one clinical year.

The effects of thermocycling after a single resin infiltration treatment was found to have good color stability. Only the D3 treatment group observed poor color stability. This could be explained by the deep extent of the initial lesion and the poor treatment protocol applied (3 minute infiltrant penetration). In addition, it was previously noted that the enamel group that received a single treatment experienced stable mean ΔE following the second thermocycling. In a sense, shallow lesions with a single and optimized resin infiltration treatment may experience color stability after two clinical years. Overall, the findings of this study support that resin infiltration observes good color stability for at least one clinical year and an additional clinical year when treatment is optimized and applied to shallow lesions.

This study suffered from high standard deviations. This was noted in the dentin groups and groups that were given the least time allowed for infiltrant penetration (E3 and D3). For the dentin group, no further distinction was made within the group regarding the extent of the depth of the lesion. As a result, DIAGNOdent readings in this group ranged from 21 to 47. It is advised that a future study limit the range of the dentin lesion readings in order to lessen the effect of this variable. For the 3-minute treatment groups-in another sense, the group with the poorest treatment outcomes-it can be surmised that the little time allowed for infiltrant penetration resulted in a poor quality of enamel hybridization. Thus, it is assumed that these poorly treated samples experienced greater enamel permeability and, in turn, less color stability. It is only more imperative then to increase time allowed for infiltrant penetration in order to achieve a greater quality of resin infiltration.

Chapter 5: Conclusion

It can be concluded that

1. Resin infiltration is an effective treatment modality to improve the appearance of white spot lesions.
2. The aesthetic benefit of resin infiltration works best for shallow enamel lesions. Although deeper dentinal lesions may improve in aesthetics following resin infiltration treatment, these lesions may require more invasive restorative procedures.
3. Increasing the resin infiltrant penetration time to at least nine minutes is advised as the most optimized treatment protocol.
4. Resin infiltration treatment is recommended only once per a tooth's lifetime. Thus, treatment technique is critical as results cannot be further improved with additional treatments. In fact, additional treatment may result in reduced initial color stability.
5. At least 1-year color stability can be reasonably expected. An additional year of color stability can be expected following a single and optimized infiltration treatment of shallow lesions.

Appendix A

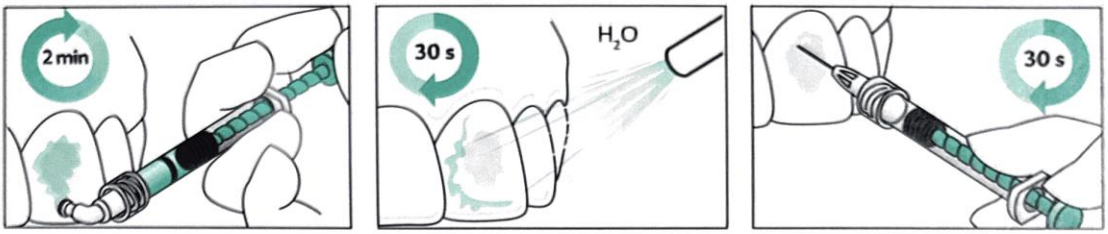
Table 7 Scale of DIAGNOdent threshold values correlating with depth of caries

DIAGNOdent pen Values	Diagnosis - Treatment
0 to ~13	Healthy tooth
~14 to ~20	Enamel caries
~21 to ~29	Deep enamel caries
>~30	Dentine caries

Appendix B

Figure 6 Icon® resin infiltration Kit Instructions

Quick guide for the application of Icon®



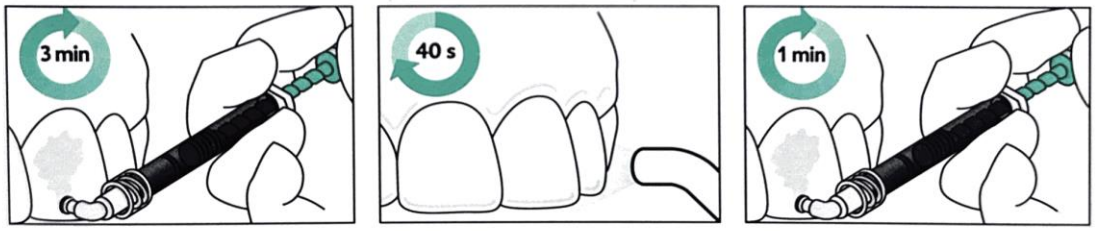
1. Clean tooth. Apply rubber dam.

2. Apply Icon-Etch. Let sit for 2 min.

3. Rinse off with water for 30 s. Dry with oil- and water-free air.

4. Apply Icon-Dry. Let sit for 30 s and thereby carry out visual inspection*. Dry with oil- and water-free air.

* Unless white spots are being treated shortly (1–2 months) after bracket removal, it is recommended that the etching process is performed two times. If a white spot has not diminished significantly after the Icon-Dry has been applied, then a third etching process is recommended.



5. Switch off operatory light. Apply Icon-Infiltrant. Let sit for 3 mins. Maintain wet lesion surface with occasional twist of syringe.

6. Disperse with air, and floss. Light-cure for 40 s.

7. Replace applicator tip. Apply Icon-Infiltrant. Let sit for 1 min.

8. Remove excess and floss. Light-cure for 40 s. Polish.

Consult instructions for use.

Figure 7 Icon® resin infiltration Online Instructions

Application of Icon Smooth Surface Etch:

- Screw the Vestibular Tip onto the Icon Smooth Surface Etch syringe.
- Apply an ample amount of Icon Smooth Surface Etch onto the lesion site by turning the syringe shaft carefully, let it take effect for 02:00 minutes and activate the effect by moving the Tip occasionally. Remove excess material with cotton roll (Fig. 1).
- Aspirate off Icon Smooth Surface Etch and rinse with water for at least 30 seconds. Then dry using oil-free and water-free air.

4. Infiltration

Do not apply Icon Infiltrant under direct operating light as this may cause the material to set prematurely.

Application of Icon Infiltrant

- Screw a new Vestibular Tip onto the Icon Infiltrant syringe.
- Apply an ample amount of Icon Infiltrant by turning the shaft.
- Allow Icon Infiltrant to infiltrate for 3:00 minutes, occasionally activate the infiltration by moving the syringe and top up if necessary (Fig. 3).

In case of deeper and larger defects the esthetic result can be improved by extending the exposure time.

- Remove excess material with a cotton roll and, if necessary, dental floss.
- Light-cure Icon Infiltrant for a minimum of 40 seconds from all sides.
- Repeat the application with Icon Infiltrant as previously described but with a contact time of 1:00 minute
- Remove the rubber dam.
- Use polishing cups, or similar, for the surface finish.

References

Abbas, B. A., Marzouk, E. S., & Zaher, A. R. (2018). Treatment of various degrees of white spot lesions using resin infiltration-in vitro study. *Progress in orthodontics*, *19*(1), 27.

Adams T. C. (1987). Enamel color modifications by controlled hydrochloric acid pumice abrasion: a review with case summaries. *Journal (Indiana Dental Association)*, *66*(5), 23–26.

Alrebdi, A. B., & Alyahya, Y. (2022). Microabrasion plus resin infiltration in masking white spot lesions. *European review for medical and pharmacological sciences*, *26*(2), 456–461.

Applebaum, E. (1932). Incipient dental caries. *J Dent Res.*, 2, 619-627.

Attiguppe, P., Malik, N., Ballal, S., & Naik, S. V. (2019). CPP-ACP and Fluoride: A Synergism to Combat Caries. *International journal of clinical pediatric dentistry*, *12*(2), 120–125.

Beerens, M. W., Boekitwetan, F., van der Veen, M. H., & ten Cate, J. M. (2015). White spot lesions after orthodontic treatment assessed by clinical photographs and by quantitative light-induced fluorescence imaging; a retrospective study. *Acta odontologica Scandinavica*, *73*(6), 441–446.

Berg J. H., Donly K.J. (1991). The enamel surface and enamel microabrasion. Chapter 7. In: Enamel Microabrasion. TP Croll, Ed. Lombard, IL: Quintessence Publishing Co.

Bertacci, A., Lucchese, A., Taddei, P., Gherlone, E. F., & Chersoni, S. (2014). Enamel structural changes induced by hydrochloric and phosphoric acid treatment. *Journal of applied biomaterials & functional materials*, *12*(3), 240–247.

Black, G. V. (1908). Operative Dentistry: The Pathology of the Hard Tissues of the Teeth. Chicago, IL: Medico-Dental Publishing.

Cai, F., Manton, D. J., Shen, P., Walker, G. D., Cross, K. J., Yuan, Y., Reynolds, C., & Reynolds, E. C. (2007). Effect of addition of citric acid and casein phosphopeptide-amorphous calcium phosphate to a sugar-free chewing gum on enamel remineralization in situ. *Caries research*, *41*(5), 377–383.

Croll, T. P., & Cavanaugh, R. R. (1986). Enamel color modification by controlled hydrochloric acid-pumice abrasion. I. technique and examples. *Quintessence international (Berlin, Germany : 1985)*, *17*(2), 81–87.

DMG America. https://www.dmg-america.com/fileadmin/DMG_ygvgvAmerica/user_upload/IFU_Icon-Etch_092103_us_LAY.PDF

Doméjean, S., Ducamp, R., Léger, S., & Holmgren, C. (2015). Resin infiltration of non-cavitated caries lesions: a systematic review. *Medical principles and practice : international journal of the Kuwait University, Health Science Centre*, *24*(3), 216–221.

Faghihian, R., Shirani, M., Tarrahi, M. J., & Zakizade, M. (2019). Efficacy of the Resin Infiltration Technique in Preventing Initial Caries Progression: A Systematic Review and Meta-Analysis. *Pediatric dentistry*, *41*(2), 88–94.

Gao, X., Lo, E. C., Kot, S. C., & Chan, K. C. (2014). Motivational interviewing in improving oral health: a systematic review of randomized controlled trials. *Journal of periodontology*, *85*(3), 426–437.

Geiger, A. M., Gorelick, L., Gwinnett, A. J., & Griswold, P. G. (1988). The effect of a fluoride program on white spot formation during orthodontic treatment. *American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics*, *93*(1), 29–37.

Gray, G. B., & Shellis, P. (2002). Infiltration of resin into white spot caries-like lesions of enamel: an in vitro study. *The European journal of prosthodontics and restorative dentistry*, *10*(1), 27–32.

Gu, X., Yang, L., Yang, D., Gao, Y., Duan, X., Zhu, X., Yuan, H., & Li, J. (2019). Esthetic improvements of postorthodontic white-spot lesions treated with resin infiltration and microabrasion: *A split-mouth, randomized clinical trial*. *The Angle orthodontist*, *89*(3), 372–377.

Hammad, S. M., El Banna, M., El Zayat, I., & Mohsen, M. A. (2012). Effect of resin infiltration on white spot lesions after debonding orthodontic brackets. *American journal of dentistry*, *25*(1), 3–8.

Iijima, Y., Cai, F., Shen, P., Walker, G., Reynolds, C., & Reynolds, E. C. (2004). Acid resistance of enamel subsurface lesions remineralized by a sugar-free chewing gum containing casein phosphopeptide-amorphous calcium phosphate. *Caries research*, *38*(6), 551–556.

Kidd, E. A., & Fejerskov, O. (2004). What constitutes dental caries? Histopathology of carious enamel and dentin related to the action of cariogenic biofilms. *Journal of dental research*, *83 Spec No C*, C35–C38.

Kielbassa, A. M., Muller, J., & Gernhardt, C. R. (2009). Closing the gap between oral hygiene and minimally invasive dentistry: a review on the resin infiltration technique of incipient (proximal) enamel lesions. *Quintessence international (Berlin, Germany : 1985)*, *40*(8), 663–681.

Kim, S., Kim, E. Y., Jeong, T. S., & Kim, J. W. (2011). The evaluation of resin infiltration for masking labial enamel white spot lesions. *International journal of paediatric dentistry*, *21*(4), 241–248.

Knösel, M., Bojes, M., Jung, K., & Ziebolz, D. (2012). Increased susceptibility for white spot lesions by surplus orthodontic etching exceeding bracket base area. *American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics*, *141*(5), 574–582.

Kuhar, M., Cevc, P., Schara, M., & Funduk, N. (1997). Enhanced permeability of acid-etched or ground dental enamel. *The Journal of prosthetic dentistry*, *77*(6), 578–582.

Lin, G. S. S., Chan, D. Z. K., Lee, H. Y., Low, T. T., Laer, T. S., Pillai, M. P. M., Yew, Y. Q., & Wafa, S. W. W. S. S. T. (2022). EFFECTIVENESS OF RESIN INFILTRATION IN CARIES INHIBITION AND AESTHETIC APPEARANCE IMPROVEMENT OF WHITE-SPOT LESIONS: AN UMBRELLA REVIEW. *The journal of evidence-based dental practice*, *22*(3).

Linton J. L. (1996). Quantitative measurements of remineralization of incipient caries. *American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics*, *110*(6), 590–597.

Llena, C., Leyda, A. M., & Forner, L. (2015). CPP-ACP and CPP-ACFP versus fluoride varnish in remineralisation of early caries lesions. A prospective study. *European journal of paediatric dentistry*, *16*(3), 181–186.

Lovrov, S., Hertrich, K., & Hirschfelder, U. (2007). Enamel Demineralization during Fixed Orthodontic Treatment - Incidence and Correlation to Various Oral-hygiene Parameters. *Journal of orofacial orthopedics = Fortschritte der Kieferorthopadie : Organ/official journal Deutsche Gesellschaft fur Kieferorthopadie*, *68*(5), 353–363.

Meyer-Lueckel, H., & Paris, S. (2008). Progression of artificial enamel caries lesions after infiltration with experimental light curing resins. *Caries research*, *42*(2), 117–124.

Meyer-Lueckel, H., Paris, S., & Kielbassa, A. M. (2007). Surface layer erosion of natural caries lesions with phosphoric and hydrochloric acid gels in preparation for resin infiltration. *Caries research*, *41*(3), 223–230.

Meyer-Lueckel, H., Paris, S., Mueller, J., Cölfen, H., & Kielbassa, A. M. (2006). Influence of the application time on the penetration of different dental adhesives and a fissure sealant into artificial subsurface lesions in bovine enamel. *Dental materials : official publication of the Academy of Dental Materials*, *22*(1), 22–28.

Mizrahi E. (1982). Enamel demineralization following orthodontic treatment. *American journal of orthodontics*, *82*(1), 62–67.

Mueller, J., Meyer-Lueckel, H., Paris, S., Hopfenmuller, W., & Kielbassa, A. M. (2006). Inhibition of lesion progression by the penetration of resins in vitro: influence of the application procedure. *Operative dentistry*, *31*(3), 338–345.

Nascimento, P. L., Fernandes, M. T., Figueiredo, F. E., & Faria-E-Silva, A. L. (2016). Fluoride-Releasing Materials to Prevent White Spot Lesions around Orthodontic Brackets: A Systematic Review. *Brazilian dental journal*, *27*(1), 101–107.

Ogaard, B., Rølla, G., & Arends, J. (1988). Orthodontic appliances and enamel demineralization. Part 1. Lesion development. *American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics*, *94*(1), 68–73.

Ogaard, B., Rølla, G., Arends, J., & ten Cate, J. M. (1988). Orthodontic appliances and enamel demineralization. Part 2. Prevention and treatment of lesions. *American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics*, *94*(2), 123–128.

O'Reilly, M. M., & Featherstone, J. D. (1987). Demineralization and remineralization around orthodontic appliances: an in vivo study. *American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics*, *92*(1), 33–40.

Paris, S., & Meyer-Lueckel, H. (2010). Infiltrants inhibit progression of natural caries lesions in vitro. *Journal of dental research*, *89*(11), 1276–1280.

Paris, S., Meyer-Lueckel, H., Cölfen, H., & Kielbassa, A. M. (2007). Penetration coefficients of commercially available and experimental composites intended to infiltrate enamel carious lesions. *Dental materials : official publication of the Academy of Dental Materials*, *23*(6), 742–748.

Paris, S., Meyer-Lueckel, H., & Kielbassa, A. M. (2007). Resin infiltration of natural caries lesions. *Journal of dental research*, *86*(7), 662–666.

Paula, A. B., Fernandes, A. R., Coelho, A. S., Marto, C. M., Ferreira, M. M., Caramelo, F., do Vale, F., & Carrilho, E. (2017). Therapies for White Spot Lesions-A Systematic Review. *The journal of evidence-based dental practice*, *17*(1), 23–38.

Perdigão J. (2020). Resin infiltration of enamel white spot lesions: An ultramorphological analysis. *Journal of esthetic and restorative dentistry : official publication of the American Academy of Esthetic Dentistry ... [et al.]*, *32*(3), 317–324.

Reynolds E. C. (1997). Remineralization of enamel subsurface lesions by casein phosphopeptide-stabilized calcium phosphate solutions. *Journal of dental research*, *76*(9), 1587–1595.

Reynolds E. C. (2008). Calcium phosphate-based remineralization systems: scientific evidence?. *Australian dental journal*, *53*(3), 268–273.

Richter, A. E., Arruda, A. O., Peters, M. C., & Sohn, W. (2011). Incidence of caries lesions among patients treated with comprehensive orthodontics. *American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics*, *139*(5), 657–664.

Robinson, C., Brookes, S. J., Kirkham, J., Wood, S. R., & Shore, R. C. (2001). In vitro studies of the penetration of adhesive resins into artificial caries-like lesions. *Caries research*, *35*(2), 136–141.

Roopa, K. B., Pathak S., Poornima, P., Neena, I. E. (2015). White spot lesions: A literature review. *Journal of Pediatric Dentistry*., 3(1), 1-7.

Sadyrin, E., Swain, M., Mitrin, B., Rzhepakovsky, I., Nikolaev, A., Irkha, V., Yogina, D., Lyanguzov, N., Maksyukov, S., & Aizikovich, S. (2020). Characterization of Enamel and Dentine about a White Spot Lesion: Mechanical Properties, Mineral Density, Microstructure and Molecular Composition. *Nanomaterials (Basel, Switzerland)*, *10*(9), 1889.

Shan, D., He, Y., Gao, M., Liu, H., Zhu, Y., Liao, L., Hadaegh, F., Long, H., & Lai, W. (2021). A comparison of resin infiltration and microabrasion for postorthodontic white spot lesion. *American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics*, *160*(4), 516–522.

Sheoran, N., Garg, S., Damle, S. G., Dhindsa, A., Opal, S., & Gupta, S. (2014). Esthetic management of developmental enamel opacities in young permanent maxillary incisors with two microabrasion techniques--a split mouth study. *Journal of esthetic and restorative dentistry : official publication of the American Academy of Esthetic Dentistry ... [et al.]*, *26*(5), 345–352.
Silverstone, L. M. (1973). Structure of carious enamel, including the early lesion. *Oral Sci Rev*. 3, 100-160.

Sonesson, M., Bergstrans, F., Gizani, S., & Twetman, S. (2017). Management of post-orthodontic white spot lesions: an updated systematic review. *European journal of orthodontics, 39(*2), 116-121.

ten Cate J. M. (1999). Current concepts on the theories of the mechanism of action of fluoride. *Acta odontologica Scandinavica*, *57*(6), 325–329.

Tong, L. S., Pang, M. K., Mok, N. Y., King, N. M., & Wei, S. H. (1993). The effects of etching, micro-abrasion, and bleaching on surface enamel. *Journal of dental research*, *72*(1), 67–71.

Train, T. E., McWhorter, A. G., Seale, N. S., Wilson, C. F., & Guo, I. Y. (1996). Examination of esthetic improvement and surface alteration following microabrasion in fluorotic human incisors in vivo. *Pediatric dentistry*, *18*(5), 353–362.

Willmot D. R. (2004). White lesions after orthodontic treatment: does low fluoride make a difference?. *Journal of orthodontics*, *31*(3), 235–202.

Yamaguchi, K., Miyazaki, M., Takamizawa, T., Inage, H., & Kurokawa, H. (2007). Ultrasonic determination of the effect of casein phosphopeptide-amorphous calcium phosphate paste on the demineralization of bovine dentin. *Caries research*, *41*(3), 204–207.

Yuan, H., Li, J., Chen, L., Cheng, L., Cannon, R. D., & Mei, L. (2014). Esthetic comparison of white-spot lesion treatment modalities using spectrometry and fluorescence. *The Angle orthodontist*, *84*(2), 343–349.

Zimmer, B. W., & Rottwinkel, Y. (2004). Assessing patient-specific decalcification risk in fixed orthodontic treatment and its impact on prophylactic procedures. *American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics*, *126*(3), 318–324.

Curriculum Vitae

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Integrative Biology and Physiological Science B.S., June 2012

University of the Pacific, Arthur A. Dugoni School of Dentistry
Doctor of Dental Surgery, June 2020

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Certificate in Orthodontics and Dentofacial Orthopedics
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Research Experience

Optimizing Resin Infiltration Treatment of Post-orthodontic White Spot Lesions by Increasing Infiltrant Penetration Duration--in vitro study
Masters Project
UNLV Advanced Education Program in Orthodontics, 2022
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Investigate the clinical application of Icon as a treatment for post-orthodontic white spot lesions to obtain the best treatment outcome.

Hard Tissue Evaluation after Microimplant Assisted Rapid Palatal Expansion
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