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A COMPARATIVE STUDY IN PENETRATION DEPTH OF RESIN-BASED MATERIALS INTO WHITE SPOT LESION

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Abstract

Purpose: This study conducts an in vitro comparison of the depth of penetration of a resin infiltrant material (Icon), a two-step self-etch resin-based material (OptiBond™ XTR), and a solvent-free self-etch resin-based material (Bond-1SF) into white spot lesions (WSLs).

Methodology: Through an in vitro clinical trial, a total of 60 human posterior teeth, free from caries, were collected. The buccal and lingual surfaces of each tooth were marked, resulting in a total of 120 samples of surfaces, which represented the operational sample size. The samples were randomly divided into four equal main groups (n = 30) according to the materials used. Group 1 (M1) was the control group. Group 2 (M2) was restored using Icon, Group 3 (M3) using OptiBond™ XTR, and Group 4 (M4) using Bond-1SF. Each group was divided into two equal groups (n = 15) according to the surface treatment, and the first group (W1) was subjected to surface treatment but the second group (W2) was not. The resin penetration depth was observed using confocal laser scanning microscopy.

Findings: The highest penetration depth was recorded for Group 2 with surface treatment (M2W1), and the lowest was recorded for Group 4 without surface treatment (M4W2). An analysis of variance test revealed a statistically significant difference in the penetration depth of tested materials ($p < 0.05$).

Conclusion: Icon shows the best penetration depth value in relation to WSLs, whereas Bond-1SF shows the worst. Surface treatment has a positive effect on the penetration depth of the resin-based materials.

Keywords: *Penetration Depth, Average Penetration Value, Resin Infiltrant Material, White Spot Lesion*

INTRODUCTION

White spot lesions (WSLs) are early signs of demineralization under intact enamel, which could lead to the development of caries, owing to the leaching out of a certain amount of calcium and phosphate ions that may or may not be replaced naturally through a remineralization process. The likely causes of WSLs include plaque accumulation—particularly along the cervical margins of the teeth—inadequate home oral care, and consumption of diets rich in sugar, which frequently lower the intraoral pH. In addition, WSLs may occur after orthodontic bands and brackets are removed (Shivanna and Shivakumar 2011). A recently introduced alternative therapy is the use of resin-based materials over the dental tissue, which completely fills the pores within the tooth, replacing lost tooth structure and stopping caries progression. The resin infiltration system Icon is a new approach developed to counteract incipient enamel caries lesions. In contrast to conventional sealants, in which the material adheres to the enamel surface, resin infiltration penetrates into the porous lesion body of the enamel's initial carious lesions using a special low-viscosity resin that blocks the diffusion of acids into the lesion, and thus, it blocks the demineralizing effects of cariogenic acids, thereby slowing or arresting the progression of caries (Gugnani et al. 2012). Self-etch adhesives contain a high concentration of solvents that must be eliminated after completing their function because the residual solvent leads to the deterioration of the adhesive interface between the tooth structure and the composite resin by interfering with resin polymerization. Complete solvent elimination by air-drying is difficult to achieve, and consequently, some residual solvent remains trapped in the adhesive (Itthagarun et al. 2004). Solvent-free adhesives are hydrophobic and dense and have less water sorption and solubility than solvated resin blends materials; thus, these enhance the tooth adhesion because these are free from the solvent residue (Werle et al. 2015).

In addition, the pretreatment of the WSL surface with phosphoric acid etch may show a higher result for the penetration coefficient because it allows a larger surface area to be coated by the resin-based material. This most suite the two-step self-etch adhesive system. Since the main idea behind a self-adhesive system is to reduce dentine sensitivity—and as long as WSLs are confined to the enamel—surface treatment may increase the depth of the penetration into WSLs without causing postoperative sensitivity (Oliveira et al. 2015). Confocal laser scanning microscopy (CLSM) was used to determine the amount of resin-based material that had penetrated into the WSLs. Thus, the success of the infiltration technique depends on the efficacy of this low-viscosity resin to penetrate up to the depth of the WSL and not just mask the lesions (Jonkman and Brown 2015). In this regard, clinical studies have thus far focused mainly on the clinical success and outcome of the resin. However, the depth of resin penetration could be a key determining factor in creating a diffusion barrier and in the success of infiltration. Hence, to fill this gap in the related literature, the present study compares the depth of penetration in WSLs of a commercially available resin infiltrate system and two bonding agents (Paris et al. 2007). Accordingly, the current study evaluates the effects of the application of resin-based materials, as well as resin infiltration, on enamel subjected to WSLs, and the effects of enamel surface conditioning prior to material application.

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MATERIAL AND METHODS

Study design: In vitro clinical trial.

Materials:

The composition of the materials used in this study, their manufacturer details and website, and the batch number are listed in Table 1.

Table 1: Materials used in the study

	Brand Name	Composition
1	**Scotchbond™ Universal Etchant**	32% phosphoric acid by weight; pH of approximately 0.1. Fumed silica and a water-soluble polymer.
2	**Icon**	Icon-Etch: Hydrochloric acid, pyrogenic silicic acid, surface-active substances. Icon-Dry: 99% ethanol. Icon-Infiltrant: Methacrylate-based resin matrix, initiators, additives.
3	**OptiBond™ XTR two-component. Self-etch universal Adhesive.**	**Primer:** • Monomers: Glycerol phosphate dimethacrylate (GPDM) self-etching adhesive monomer and Hydrophilic co-monomers, including mono- and di-functional methacrylate monomers. • Solvents: Water, acetone, ethyl alcohol. • Photo initiator: Camphor quinine (CQ)-based. **Adhesive:** • Monomers: Hydrophobic, structural, and cross-linking monomers. • Solvents: Ethyl alcohol Photo initiator Camphor quinine (CQ)-based. • Fillers: 0.4-micron barium glass nano-silica Fluoride: Sodium hexafluorosilicate.
4	**Bond-1®SF** **Solvent-Free** **SE Adhesive**	7,7,9 (or 7,9,9)-trimethyl-4, 13 dioxo-3,14-dioxa-5, 12 diazahexadecane-1, 16-diyl bismethacrylate 2-hydroxyethyl methacrylate 2,2'-ethylenedioxydiethyl dimethacrylate diphenyl(2,4,6-trimethylbenzoyl) phosphine oxide

Preparation of Samples

A total of 60 human posterior teeth, free from caries, were collected. The buccal and lingual surfaces of each collected tooth were marked for differentiation, resulting in a total of 120 samples of surfaces, which represented the operational sample size. The crowns of all teeth were separated from the roots using a diamond-coated band saw under continuous water cooling and then stored in a saline solution until required.

1. **Grouping of samples for measuring thickness and depth of penetration of the resin-based materials**: The 120 samples were randomly divided into four equal main groups (n = 30) according to the resin-based materials (M) used. Group 1 (M1) was the control group. Group 2 (M2) was restored using Icon. Group 3 (M3) was restored using a two-step self-etch adhesive system (OptiBond^{TM} XTR). Group 4 (M4) was restored using a solvent-free self-etch adhesive system (Bond-1SF). Each group was divided into two equal groups (n = 15) according to the surface treatment (W), and the first group (W1) was subjected to surface treatment, whereas the second group (W2) was without surface treatment.
2. **Fabricating the molds:** A specially fabricated circular plastic mold of internal diameter 10 mm and height 20 mm was fabricated. A separating medium was used to coat its internal surface. The mold was filled with self-curing acrylic resin, and the base of the mold was placed on a glass slap to obtain a flat, smooth surface base. The buccal and lingual surfaces of the teeth were embedded horizontally in the mold while the acrylic resin was still in the dough stage to be flush with the level of the mold.
3. **Creating enamel white spot lesions**: The buccal and lingual surfaces of all samples were subjected to short-term acidic exposure by applying 37% phosphoric acid (H_3PO_4) to the surfaces for one minute to create artificial WSLs.
4. **Conducting surface treatment:**

- **Subgroup (W1)**: The surfaces of 15 samples were treated with 37% H_3PO_4 for 30 seconds, rinsed with water for two seconds and air-dried with an oil-free air spray. Next, the resin-based material was applied, according to the manufacturer's instructions, and the samples were then immersed in artificial saliva, which was changed daily.
- **Subgroup (W2):** Without performing prior surface treatment, the resin-based material was applied, according to the manufacturer's instructions, on 15 samples and these were then immersed in artificial saliva, which was changed daily.

5. **Application of the resin-based materials:** Each resin-based material was applied according to the manufacturer instructions as follows:

- **Icon application procedure:** Icon-Etch (hydrochloric acid) was applied and allowed to sit for two minutes, and then rinsed off with an air–water spray for at least 30 seconds; next, the samples were dried gently with an oil-free air spray. Icon-Dry was applied to the lesion site and left for 30 seconds; next, the samples were gently air-dried. Icon-Infiltrant was applied to the etched surface and allowed

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to sit for three minutes, and then light-cured for 40 seconds using the Elipar Light cure unit.

- **OptiBond™ XTR application procedure:** OptiBond™ XTR Primer was applied to the enamel surface using the disposable applicator brush. The surface was scrubbed using brushing motions for 20 seconds. Then, it was air-thinned for five seconds under medium air pressure. A light brushing motion was used to shake it for 15 seconds, and it was again air-thinned for five seconds. Next, it was light-cured for 10 seconds using the Elipar Light cure unit.
- **Bond-1 SF application procedure**: Bond-1 SF was applied with the flocked tip and rubbed for 20 seconds. The bonding agent was light-cured for 10 seconds using the Elipar Light cure unit[*].

Measurement of the Depth of Penetration of Resin-Based Materials into WSLs

- **Preparation of resin material for CLSM Analysis:** A 0.05 mg/ml ethanolic solution of tetramethyl Rhodamine-isothiocyanate (Sigma-Aldrich, Steinheim, Germany), was used to label the resin-based materials under study by adding 0.02 ml of this solution in 0.5 ml. Resin penetration was observed using CLSM (Leica Microsystems CMS, Mannheim, Germany); the microscope was equipped with four solid state lasers, ranging from 488 nm to 635 nm. The samples were observed using a 403 objective in fluorescence (wavelength k = 532 nm) and a reflection (wavelength k = 488 nm) mode.
- **Resin penetration depth measurement using CLSM:** Two teeth were selected randomly from each set of W1 and W2 groups. Then, the images of the samples captured through CLSM were assessed for measuring the penetration depth of the resin-based materials and for comparing each result with those of the other groups.

RESULTS

After storage for one month, as shown in Figure 1, the Icon group without conditioning recorded the highest average thickness, followed by OptiBondTM XTR group, while the Bond-1 SF group with pervious conditioning recorded the lowest average thickness; however, these differences are statistically not significant (P>0.05).

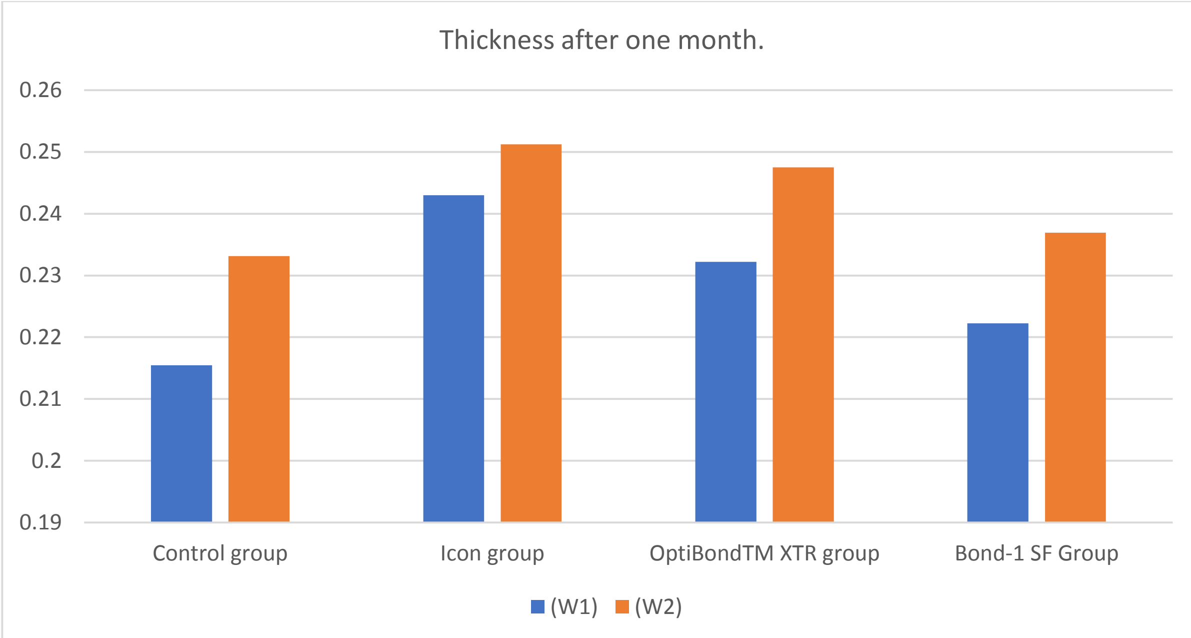

Figure (1)**:** Average thickness of resin-based materials with (W1) and without (W2) surface treatment after storage for one month.

Table (2) demonstrate the average penetration depth of the resin-based materials into (WSLs). The highest penetration depth (mean±SD; 7.15±3.551) was recorded in groups treated with Icon (M2) after being subjected to surface treatment, and the lowest penetration (mean±SD; 1.65±0.709) was observed in groups treated with Bond-1 SF without surface treatment; the ANOVA test revealed that these differences in the penetration depth of tested materials are statistically significant difference *($p<0.05$)*. The Post hoc test revealed that the penetration depth of Icon group (M2) with surface treatment was statistically significant when compared with all other resin-based materials either with or without surface treatment ($p < 0.05$).

Table 2: Penetration depth of the resin-based materials according to previous conditioning.

Material	Penetration depth	
	With previous conditioning Mean(SD) in nm	Without previous conditioning Mean(SD) in nm
Icon group (M2)	7.15(3.551)	3.53(1.547)
OptiBond™ XTR group (M3)	3.63(1.415)	1.65(0.709)
Bond-1 SF group (M4)	1.90(1.064)	0.90(0.588)

P=0.000 based on ANOVA test.

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DISCUSSION

WSLs are early signs of demineralization under intact enamel, which could lead to the development of caries. WSLs occur when the pathogenic bacteria have breached the enamel layer and the organic acids produced by the bacteria have leached out a certain amount of calcium and phosphate ions that may or may not be replaced naturally through a remineralization process (Bishara and Ostby 2008). The progression of WSLs can be slowed, or even arrested, through nonoperative measures that influence etiologic factors, such as maintaining oral hygiene and using remineralizing agents, including topical fluorides and casein phosphor peptide–amorphous calcium phosphate (Hammad et al. 2012). An alternative therapy is the use of resin-based materials over the dental tissue, which completely fills the pores within the tooth, replacing the lost tooth structure and stopping caries progression (Wiegand et al. 2011). Icon was developed to counteract incipient enamel caries lesions. In contrast to conventional sealants, in which the material adheres to the enamel surface, resin infiltration penetrates into the porous lesion body of the initial carious lesions using a special low-viscosity resin that blocks the diffusion of acids into the lesion, thus blocking the demineralizing effects of cariogenic acids and slowing or arresting the progression of caries (Ceci et al. 2017). Since solvent-free adhesives are hydrophobic and dense and have less water sorption and solubility than solvated resin blends materials, these enhance the tooth adhesion, given the lack of solvent residue (Werle et al. 2015).

Moreover, pretreatment of the WSL surface with an H_3PO_4 etch may show a higher result of penetration coefficient because it allows a larger surface area to be coated with the resin-based material. This most suite the two-step self-etch adhesive system. Since the main idea behind the self-adhesive system is to reduce dentine sensitivity, and as long as the WSLs are confined to the enamel, surface treatment increases the depth of penetration into WSLs without causing postoperative sensitivity. Determining the penetration depth of the resin-based materials sheds light on their efficacy in penetrating the enamel structure and in establishing a successful adhesion bond with it. In this respect, the recently introduced CLSM and the electron scanning microscope allow exploring the microscopic structure of the sample and distinguishing the different layers within it, respectively. The use of CLSM has become popular among life sciences researchers, primarily because of its ability to remove blur from outside the focal plane of the image (Jonkman and Brown 2015).

The current study's results are as follows. The highest penetration depth was recorded for the Icon group with surface treatment and the lowest for the Bond-1 SF group without surface treatment; the difference in the penetration depth was statistically significant ($P < 0.05$). This difference may occur for the following reasons. The Icon is basically composed of the triethylene glycol dimethacrylate (TEGDMA) monomer, and the resinous sealant consists of the TEGDMA and bisphenol glycidyl methacrylate (BisGMA) monomers. In this regard, TEGDMA-based materials show greater penetration because of their low viscosity, high degree of conversion, and high penetration coefficient. This finding is in line with that of Onta et al. (2016), who stated that the Icon showed greater depth and homogeneity of penetration than the other materials they examined, followed by the resinous sealant (Bishara and Ostby 2008).

However, the OptiBond^{TM} XTR group recorded a lower mean value for the depth of penetration than the Icon group, but it was higher than that of the solvent-free adhesive group. This may be due to the presence of hydroxyethyl methacrylate (HEMA), which has less penetration ability in comparison with that of the Icon. Further, the solvent-free adhesive group recorded the lowest mean value for the penetration depth and this result may mainly be attributable to the absence of a solvent, which causes a significant drop in the penetration coefficient. This finding agrees with that of Koumpia et al. (2014), who found that eliminating solvents from self-etch adhesive systems may decrease the penetration depth and cause adhesive failures with partial cohesive failures (Koliniotou-Koumpia et al. 2014).

Thus, the current study revealed that the highest mean value of penetration was recorded for all groups that have been treated with surface conditioning. This result may be obtained owing to the larger surface area and the complete filling of the pores within the teeth post surface treatment as well as the dissolution of the prismatic layer of the enamel. This finding is similar to that of Bishara and Ostby (2008) who found that etching with H_3PO_4 improves the mechanical retention of dental materials by promoting the dissolution of prismatic and inter-prismatic enamel and creating irregularities in the enamel "prisms" in which the resin-based material can flow (Bishara and Ostby 2008). It is also in agreement with Pashley et al.'s (2011) finding that etch-and-rinse adhesives produce higher resin–dentin bonds that are more durable than most one- and two-step adhesives (Pashley et al. 2011).

CONCLUSION AND RECOMMENDATIONS

Icon has the best penetration depth value in relation to WSLs, whereas Bond-1SF has the worst value. Surface treatment has a positive effect on the penetration depth of resin-based materials. To confirm the promising findings of our study, further researches are needed to clearly determine retention and durability of the tested resin-based materials, in terms of prolonged erosive and abrasive changes. Moreover, before testing the resin infiltration clinically, it is essential to clarify the effects of the material on the dentin erosion inhibition, since erosive lesions are usually diagnosed in late stage when the dentin is compromised.

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