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Resin Infiltration: Color Restorability and Stability

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Resin infiltration is a minimally invasive technique that has emerged almost 10 years ago. One of its major applications is the masking of initial carious lesions also known as white spot lesions (WSL). Resin infiltration has also shown considerable success in masking of WSL of developmental origin such as fluorosis and molar-incisor hypomineralization. Due its immediate action and superior esthetic results, resin infiltration has become an alternative to other treatment options for WSL such as remineralization and micro-abrasion. However, color restorability of resin infiltration is affected by a number of factors including lesion depth, number of etching cycles and infiltrant duration and application time. Therefore, for successful masking of WSL, these factors must be known and considered before application of resin infiltrant. In addition, due to the infiltrant composition, resin-infiltrated teeth are prone to discoloration if subjected to colored foods and drinks. Long-term color stability is essential for superior esthetic outcome and patient satisfaction. Therefore, to achieve the best possible results, the technique of resin infiltration and factors affecting the esthetic outcome will be discussed.

Keywords: resin infiltration, white spot lesions, demineralization, discoloration.

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Introduction

Minimally invasive approaches are becoming an essential element of modern dentistry. This approach is based on maximal conservation of tooth structure in the treatment of carious lesions.[1] Minimally invasive dentistry includes several techniques especially in the management of non-cavitated carious lesions also known as white spot lesions (WSL). These include remineralization, microabrasion and more recently resin infiltration.[2,3]

Resin infiltration is a technique based on filling the spaces present in initial carious lesions or WSL with low viscosity resins. Resin infiltration was initially introduced to cease the progression of non-cavitated proximal carious lesions.[4] Subsequently, its applications expanded including the masking of WSL, fluorotic defects and hypomineralized enamel defects.[5,6] Since resin has a closer refractive index (1.475) to enamel (1.65) than demineralized enamel lesions filled with air (1.00-1.33), filling the pores of the lesions with resin will lead to masking of the white spot lesion.[7] Therefore, not only is resin infiltration capable of halting the progression of the carious lesion by blocking the diffusion of acids, but it also has a successful esthetic effect in concealing WSLs.[8]

Resin infiltrant is formed of pure resin which is prone to discoloration. Therefore, increased consumption of food and beverages with coloring pigments may lead to color change and staining of resin infiltrated enamel.[9,10] As this may lead to patient frustration due to poor esthetics, color stability is an essential property that must be studied in any esthetic treatment. Therefore, this review will emphasize on the color restorability and stability of resin infiltration.

1. Resin infiltration:

1.1 Concept and technique:

The concept of resin infiltration was first developed by Croll in 1976.[11] This concept was based on filling the pores present in the WSLs with low viscosity light curing resins rather than removing them. The resin will occlude these pores leading to hampering the progression of carious lesions.[12] However, most WSLs contain a surface hyper-mineralized layer overlying the body of the lesion. The presence of this surface layer may hinder resin penetration due to its minimal porosity, therefore it must be removed.[13] The removal of the hypermineralized surface layer depends on the type of acid used and duration of application.[14] The application of 15% HCl for 2 minutes was found to remove up to 36.70 ±7.62µm of the surface layer. Even though phosphoric acid has a higher penetration ability than HCl, the latter removed more of the hypermineralized layer. This can be attributed to the less caustic effects of phosphoric acid leading to less removal of mineralized layer.[15] In addition, phosphoric acid causes selective dissolution of enamel structure leading to variations in the patterns of the etched enamel surface.[14,16] Therefore, according to manufacturer's instructions, etching of surface layer must be performed prior to infiltration by applying 15% hydrochloric acid (HCL) for two minutes.

After etching, ethanol is applied to the lesion and left to set for 30 seconds.Ethanol is applied to desiccate the lesion and remove any internal moisture thus facilitating infiltration of resin. After ethanol application, WSL is expected to disappear temporarily.[7] If that doesn't occur, manufacturers recommended repeating etching step one or two times for two minutes each. Failure of resolving of WSL may be due to having a surface layer thickness larger than 50 µm or the increased depth of the

lesion where it penetrates the full thickness of enamel and extends into dentin. Therefore, in these cases additional etching step is essential to create larger porosities for effective and deeper resin infiltration into the lesion.[17]

Following application of HCl and ethanol, resin infiltrant is applied to the WSL. The infiltrant is mainly formed of low viscosity TEGDMA which has many desirable properties for infiltration. TEGDMA has low viscosity, high degree of conversion and high penetration coefficient compared to other monomers such as UDMA and HEMA which are key constituents in many adhesives, fissure sealants and composites.[14,18] However, UDMA and HEMA are multifunctional molecules with high molecular weight and leading to lower penetration capability.[14] Timing of application of resin infiltrant is an important factor for more efficient penetration. Studies showed that 3 and 5 minutes application is necessary for penetration and filling pores of demineralized lesion.[14] Therefore, manufacturers recommend 3 minutes application time for infiltrant followed by a one minute application for higher efficacy of resin infiltration. Not only does this compensate for polymerization shrinkage of resin infiltrant, but it also compensates for the resin that may have been dissolved in ethanol in the first application.[19]

Studies have shown that penetration of resin infiltrant was found to reach 177 µm which is higher than fissure sealants, adhesives and flowable composites.[14,20] Ultra-morphological analysis using scanning electron microscope of resin infiltrated WSLs revealed that resin tags are formed, and at the bottom side of the resin tag a 'hybrid layer' is formed of resin reinforced tissue which is part resin and part enamel.[13,21] Despite its adequate penetration, the resin does not occupy the whole body of the lesion. According to Soveral[22] approximately 65.35% of the lesion is filled with resin. Prolonging the application time improves the penetration depth.

An important factor affecting the outcome of resin infiltration is lesion depth and activity. Deeper lesions that may extend into full enamel thickness are more difficult to fully penetrate by the resin infiltrant which may lead to lower esthetic outcome.[17,23] Infiltration may be more difficult in deeper lesions due to the smaller and tighter pores. In addition, saliva, air, and organic material may fill these pores making infiltration more challenging.[19] Despite reports on improvement of penetration of resin infiltrant when increasing number of etching cycles by HCL, deeper lesions especially those extending into dentin may not be fully masked.[24,25] Failure of esthetic improvements in deeper lesions even with additional etching steps may indicate that these lesions might require more invasive treatments.[22] Therefore, in these cases resin infiltration is not recommended. On the other hand, Ou et al[26] studied the masking effect of resin infiltration on demineralized enamel lesions with different depths. Results showed that both depths showed comparable masking effects.

1.2 Color restorability of Resin infiltration:

Clinically, resin infiltration has shown positive esthetic outcomes and masking of WSLs. [6,25,27–29]A common etiology of WSLs in which resin infiltration has been repeatedly tested is post-orthodontic WSLs.[25,27,28] WSLs are common in orthodontic more than non-orthodontic patients especially in those with poor oral hygiene and highly cariogenic diets. The higher susceptibility to caries is mainly due to plaque retention and difficulty of plaque removal around bands and bracket especially in presence of poor oral hygiene.[30] The incidence of WSL in these

cases has been reported to be 46-73%.[31] Resin infiltration has shown positive esthetic outcomes and masking of post-orthodontic WSL. According to a systematic review by Baptista-S et al[28] resin infiltration has been capable of improving color and brightness of post-orthodontic WSLs and results remained stable for 6 months. In addition, Bourouni et al[29] also concluded that resin infiltration had a significantly higher masking effect than fluoride varnishes or natural remineralization in post-orthodontic WSLs. However, many factors such as lesion depth and the timing between debonding and resin infiltration were found to influence the treatment outcome. It was reported that the sooner the infiltration after debonding the more superior the results.[19,25,29] This may be attributed to surface changes caused by tooth brushing or further progression of the lesion which may lead to surface integrity loss.[19,25]

Resin infiltration has been reported to give positive outcomes in developmental enamel lesions such as fluorosis and molar-incisor hypomineralization (MIH). However, color restorability was more superior in post-orthodontic white spot lesion.[6,29] According to Borges et al[6] resin infiltration showed promising results in developmental enamel lesions despite lower masking effects than post-orthodontic white spot lesions. The lower efficacy in developmental enamel lesions may be attributed to the different histopathology of these lesions. In addition, Bourouni et al[29] also reported that resin infiltration has a significantly higher masking effect than natural or fluoride remineralization in case of WSLs and mild or moderate fluorosis.

Nevertheless, several studies have reported satisfying results for resin infiltration in mild fluorosis cases. According to a systematic review by Di Giovanni T et al[32], resin infiltration resulted in superior esthetic results than micro-abrasion and bleaching in mild and moderate fluorosis especially with increased number of application. In addition, resin infiltration combined with bleaching resulted in better masking effect than bleaching alone. Similar conclusions have been reached by another systematic review by Shahroom et al[33] who also concluded that resin infiltration alone, resin infiltration with increased application time and resin infiltration combined with bleaching provides higher esthetic improvement than bleaching or microabrasion. They also mentioned that increasing etching times was necessary to ensure efficient infiltration of resin into the depth of the fluorotic lesions. However, both systematic reviews mentioned that their results must be interpreted with caution since the studies included were small with limited sample size and moderate to high risk of bias.

Several recent clinical studies evaluated the effect of combining resin infiltration with other minimally invasive modalities such as bleaching and/or microabrasion on the color change of fluorotic teeth.[34–36] Ghanem et al[34] compared the effect of bleaching alone, microabrasion and bleaching, bleaching and resin infiltration and finally microabrasion, bleaching and resin infiltration on the color change in mild fluorosis cases. Bleaching alone achieved adequate results by increasing overall brightness of the tooth thus reducing the contrast between white spots and the rest of the tooth. However, when resin infiltration was combined with the other treatments, the results were further enhanced than with the other treatments alone. Singhania et al[35] compared between microabrasion combined with resin infiltration and microabrasion combined with remineralization in mild-moderate fluorosis cases. Results indicated that microabrasion combined with resin infiltration performed significantly better. Another study by

Sherwood et al[36] evaluated the combination of microabrasion followed by bleaching and resin infiltration. Color changes were recorded after each procedure and compared. They reported that after each treatment procedure, significant color change occurred with the highest color change achieved after resin infiltration was performed. Therefore, according to the results from the previous studies combining resin infiltration with other treatments such as bleaching and/or microabrasion achieves satisfying results and enhances the esthetic outcome than with each treatment alone.

As for traumatic hypomineralization, results using resin infiltration are usually difficult to predict due to the high variety existing in these lesions. According to Denis et al[37] sometimes when these lesions are resin infiltrated, the margins might not be properly penetrated by the resin leading to visual appearance of the margin and hence an unsightly appearance. This is known as the 'edge effect'. This effect occurs when the defect takes a circular shape leading to an acute angle forming at the margins with the enamel surface. Therefore, the margins in this case are covered with sound enamel. Hence, during application of HCL the surface layer is removed at the center of the lesion but does not reach the margins as they are surrounded by sound enamel. Consequently, the resin penetrates the center of the lesion and not the margins.[37] Nevertheless, several case reports of traumatic hypomineralization reported satisfactory results of resin infiltration alone or in combination of microabrasion and bleaching[38–40]. However, a clinical study by Brescia A.V et al[41] evaluated the effect of resin infiltration on mild-moderate fluorosis, MIH and traumatic hypomineralization cases. Based on qualitative visual assessment using digital photography they found that traumatic hypomineralization resulted in the least satisfactory results. This was attributed to the acute angle of the lesion and 'edge effect' that was mentioned formerly. The authors also mentioned that combination of bleaching and microabrasion with resin infiltration may enhance the esthetic outcome. Therefore, we can presume that results from resin infiltration of traumatic hypomineralization can sometimes be unpredictable. Hence, more clinical studies with long follow up periods are needed to substantiate the use of resin infiltration and combination techniques in traumatic hypomineralization cases.

Concerning MIH, a systematic review by Bulanda et al[42] concluded that the results of application of resin infiltration in MIH- affected teeth was found to be encouraging. According to the 11 cited studies included in the review, resin infiltration significantly improved esthetics and patients' well-being. However, the authors did mention that the treatment carried a risk of failure due to the different histopathologic features of MIH affected teeth compared to other WSL lesions. In these teeth, lesions usually initiate from the dentino-enamel junction (DEJ) towards the enamel surface and acquire a different shape where the lesions are wider at the subsurface and narrower at the surface layer is. Therefore, these lesions, particularly the edges may be situated under sound enamel.[37] Hence, to improve the esthetic outcomes, authors suggested different protocols such as prolonging etching time, repeated etching, prolonging application time and enamel preparation prior to infiltration.[43] An additional obstacle to efficient penetration of resin infiltrant in MIH affected teeth is the presence of high levels of protein in these lesions. The application of NaOCl and H2O2 were effective in the removal of proteins and peptides.[44] Furthermore, a recent invitro study published this year compared the impact of different pretreatment methods

such as NaOCl, microabrasion, air-abrasion, and air-abrasion combined with NaOCl on penetration depth of resin infiltration on MIH- affected teeth using confocal laser scanning microscopy (CLSM) and scanning electron microscope(SEM).[45] Results revealed that NaOCl and air abrasion improved penetration depth even though results could not be statistically verified. NaOCl has been known for its unspecific proteolytic actions, antimicrobial properties, and its ability to deproteinize the proteins present in MIH-affected teeth which assists in more efficient infiltration.[46] Air abrasion might have improved penetration depth due to more effective removal of surface layer. However, authors from this study stated that results must be interpreted with caution due to limited sample size which probably prevented differences between groups from being statistically significant.

Several in-vitro and in-vivo studies compared the esthetic outcome of resin infiltration to other techniques such as remineralization and microbrasion for management of WSLs.[29,30,47–53] Torres et al[49] studied the effect of resin infiltration and fluoride remineralization on the color masking of artificial (WSLs) in bovine enamel. Resin infiltration showed better improvement in color than remineralization by fluoride. Groups treated with fluoride showed minimal color changes not significant from control groups immersed in artificial saliva which was probably the result of surface only remineralization which usually occurs when the surface is exposed to high concentration fluoride. This leads to minimal mineral gain in the subsurface lesion and consequently minimal color change. Yuan et al[50] also compared color changes of white spot lesions created on human enamel after treatment by resin infiltration and remineralization by fluoride and CPP-ACP. Results showed that resin infiltration yielded the best results compared to remineralization. Remineralization showed color improvement after four weeks. However, this was probably attributed due to the single application time for NaF and CPP-ACP that were used in the study. Yetkiner et al[51] also concluded that resin infiltration improved color masking of artificial white spot lesions induced in bovine teeth more than remineralization by fluoride and was comparable to microabrasion. In addition, Obead et al[53] compared the immediate masking effects of artificial WSLs induced in human premolars treated with resin infiltration and remineralization using fluoride varnish. Results also showed superior results for resin infiltration.

As for in-vivo studies, a systematic review by Bourouni et al[29] in which 11 clinical studies were included stated that resin infiltration showed a significantly higher masking effect than remineralization by fluoride or natural remineralization regardless of the outcome used. Only one study mentioned comparable results between fluoride remineralization and resin infiltration. However, the esthetic improvement with fluoride appeared after 6 months whilst immediate results are seen with resin infiltration.[54] A more recent systematic review by Ibrahim et al[19] also confirmed the superiority of resin infiltration over remineralization and microabrasion. Furthermore, a recent RCT conducted by Wang et al[48] compared the esthetic outcome of resin infiltration, 5% sodium fluoride varnish, CPP-ACP and fluoride toothpaste alone in post-orthodontic WSLs. The fluoride varnish and CPP-ACP were applied every 6 months, and the outcome of the treatments were measured after 12 months. Results showed the percentage of lesion reduction was significantly higher for resin infiltration (46.64%) than fluoride varnish (26.57%), CPP-ACP (28.64%) and control group (29.75%). Therefore,

authors concluded that resin infiltration combined with oral hygiene measures is the preferred technique for post-orthodontic WSLs.

1.3 **Color stability of Resin infiltration:**

The color stability of resin infiltration has been questioned in several studies. Due to its resin nature, concerns are present regarding its susceptibility to discoloration.[55] The main component of resin infiltrant is triethylene glycol dimethacrylate (TEGDMA). TEGDMA is a highly hydrophilic monomer which is susceptible to hydrolytic degradation and high pigmentation tendency due to transportation of pigments deep into resin.[19,56] Moreover, the oxygen inhibited surface layer and polymerization shrinkage of the resin infiltrant may result in non-homogenous areas which could contribute to the increased susceptibility to staining.[57] Other factors may affect color stability such as duration of exposure to pigmented drinks, type of colored drinks, patient oral hygiene, and technical errors such as improper handling of resin.[56,58]

Several clinical studies have evaluated the persistence of the masking effect of resin infiltration through different follow-up periods.[6,27,59–62] The follow up periods in most studies ranged from one week to two years which is a relatively short period compared to the recommended 3-year follow up period for direct restorations. However, two studies have been published recently evaluating infiltrated lesions after six years.[60,61] Wierichs et al[60] evaluated esthetic outcome qualitatively and quantitively for post-orthodontic WSLs after 6 years. A significant decline in colorimetric values, ICDAS scores and visual impairment were found after treatment and results remained persistent after six years suggesting satisfactory color stability of resin infiltration. Furthermore, Mazur et al[61] assessed the color stability of hypomineralized enamel lesions treated with resin infiltration on 74 permanent teeth in 14 adults. Results showed that the mean color difference between 1st year follow up and after 6 years was 1.261+0.637 which indicates a satisfactory long term color stability considering that the thresholds of 1.1 for perceptibility threshold (PT) and 3.3 for acceptability threshold (AT). In addition, quantitative esthetic outcome was evaluated by patients and more than 92% gave an FDI score of 1 or 2 conforming to a clinically very satisfactory result. However, more clinical studies with long term evaluation are needed to confirm the longevity and durability of resin infiltration.

Consumption of colored foods and drinks can significantly affect color change in resin infiltration based on several in-vitro studies despite the different methodologies, immersion periods and conditions implemented in these studies.[9,10,51,57,63–67] Several colored drinks have been investigated in various studies. Most common of these drinks are coffee and red wine considering their common consumption and their strong staining potential. Leland et al[10] studied the effect of various solutions (coffee, orange juice and red wine) on resin and non-resin infiltrated human enamel. They found that red wine caused the highest staining effect of all solutions tested. They also found that both resin infiltrated, and normal enamel showed color changes after immersion in solutions more than the clinically acceptable range. However, resin infiltrated enamel had a higher staining susceptibility. Interestingly, polishing after retrieval from solutions significantly reduced color changes in both surfaces. Likewise, Borges et al[57] investigated the color stability of resin infiltrated and remineralized enamel with fluoride after exposure to coffee and red wine for 10 minutes daily for 8 days. Results showed that color change was significant in all specimens immersed in coffee and wine

showing decreased ΔL values despite the treatment applied to the WSLs. Cohein-Carneiro et al[67] also studied the color stability of resin infiltrated enamel after immersion in red wine and coffee for 4 and 8 weeks. Results showed significant color changes for resin infiltrated enamel and unsatisfactory ΔE values with the largest color changes for the samples immersed in wine. Staining by wine that occurred in all previous studies mentioned is probably due to presence of tannins in its composition which is a strong discoloring agent. In addition, wine also contains alcohol which can lead to softening of polymers and intensify staining accordingly.[57,63] As for coffee, color changes are probably due to compatibility and high affinity between polymers and colorants present in coffee which led to absorption and adsorption of stains.[7,57,65]

The staining effect of tea on resin infiltration has also been investigated by several studies. S.Alqahtani et al[65] studied the discoloration effect of red tea, arabic coffee, and black coffee on resin infiltrated WSLs after 1,3 and 7 day intervals. Results revealed color changes in all resin infiltrated specimens after immersion in solutions especially after 3 days. Red tea showed the highest color change compared to arabic coffee and black coffee. In addition, Arjomand et al[68] investigated the color stability of resin infiltrated human enamel after immersion in tea for 15 minutes 3 times a day for 2 weeks. Results revealed that the resin infiltration group compared to demineralized and sound enamel showed the highest ΔE values. Tea like coffee was also reported to contain yellow colorants. However, in tea the colorants are usually adsorbed only on the surface.[63,65] The staining potential of resin infiltration in relation to other drinks such as cola and different juices have also been studied to a lesser extent and showed also different degrees of color staining.[10,69,70] Therefore, patients must be informed that frequent consumption of colored drinks especially red wine, coffee and tea might lead to staining of resin infiltrated teeth.

Nevertheless, polishing of the surface of infiltrated lesions reduces staining effects. Polishing leads to removal of oxygen inhibited layer and reduces surface porosities which consequently reduces dye penetration into resin and limits their adsorption to the surface only.[7,55] Not to mention that a rough surface promotes plaque retention and colonization by biofilm which will enhance enamel demineralization and resin dissolution.[19] Therefore, polishing of resin infiltrated surfaces is crucial to maintain color stability.

In addition, some studies resorted to polishing of resin infiltrated samples after retrieval from staining solutions to reduce the resultant discoloration. Leland et al[10] and Borges et al[57] reported that polishing of stained resin infiltrated samples reduced color changes. However, after polishing the infiltrant will still remain in the enamel which implies that staining could occur again, and the polishing procedure will need to be repeated. Repetitive polishing may not be preferred as it could lead to wear and loss of enamel.[71] Therefore, bleaching of stained resin infiltrated lesions was suggested as an alternative to polishing. Araújo et al[71] and Yeslam and AlZehrani[72] both reported that bleaching significantly cause color changes and leads to increased lightness in discolored infiltrated lesions counteracting the effects of staining.

Conclusions:

Resin infiltration is a minimally invasive technique that has shown considerable success in the management of WSL. However, several factors such as number of etching cycles, time of application of infiltrant, lesion activity and depth affect the treatment outcome. Regarding color restorability, in-vitro

and in vivo studies have shown significant success in the esthetic outcome in masking of WSLs whether of carious origin such as post-orthodontic WSLs or of developmental origin such as fluorosis or MIH although lower in the latter. In addition, compared to other minimally invasive techniques such remineralization and microabrasion, resin infiltration has also shown better results. Regarding color stability, most clinical studies showed stable long-term effects of resin infiltration up to 2 years with only a few studies reporting a follow-up period of 6 years. In-vitro studies revealed susceptibility to staining when exposed to colored drinks. Polishing of resin infiltrated surfaces and bleaching after staining may reduce discoloration. More clinical studies with longer follow up periods are needed to confirm color stability of resin infiltration.

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