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Review Article

Resin infiltrants- A new era in minimal intervention dentistry

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ABSTRACT

Aim: The aim of this review article was to assess the technique of resin infiltration, its scientific basis and different applications in clinical situations.
Data sources: Scientific papers published between 2014 and 2019 in English were searched using Pubmed data source.
Conclusion: Resin infiltration can be a promising technique in the minimum intervention concept. It helps in masking the initial enamel lesions and also inhibits their progression into deeper areas. Eventhough more studies and clinical trials are required to confirm its effects, it can significantly reduce long term restorative needs and costs when combined with other caries remineralization programs.

1. Introduction

Dental caries management had changed dramatically in recent years, evolving from the traditional restorative treatment approach to a preventive approach, non-invasion or minimal invasion. Minimal intervention is a necessary element of modern dentistry focusing on preventive or non-surgical actions to preserve dental hard tissues, thus avoiding any unwanted sacrifice of tooth structure, and ensuring a prolonged tooth survival. Several approaches have been proposed for the noninvasive management of non-cavitated caries lesions like fluoride, casein phosphopeptide-amorphous calcium phosphate or the use of therapeutic sealants for occlusal lesions.

In recent decades, a much more tissue conserving approach to arrest and control the initial carious lesions has been studied extensively, namely resin infiltration. This concept aims at occluding the highly porous structures of incipient enamel lesion by means of low-viscosity resins. In contrast to the sealing of caries lesions that depends upon the external occlusion of the lesion with the sealant material, the potential caries-inhibiting effect of resin infiltrant acts by occlusion of the pores within the body of the lesion.

This ultraconservative approach effectively builds a covalently bound three-dimensional polymer framework thus (partially) replacing the lost minerals, encapsulating the hydroxyapatite crystals, micromechanically interlocking the remaining enamel prisms, and acting as an effective barrier for hydrogen ions to inhibit further demineralization and to arrest subsurface lesion progress.[1,2] Other indications for resin infiltrant include amelogenesis imperfecta, molar incisor hypomineralization, fluorosis and white spots.[3,4]

Many materials have been tried for infiltration in the past. Resin infiltrant—Icon was introduced in Germany in 2009. Manufacturers claim that this is an innovative product for the microinvasive treatment of early carious lesions in the proximal and vestibular regions. It can be used to treat caries in a timely manner without drilling. So the aim of this review was to assess the scientific basis, principles and clinical applications of resin infiltrants.

2. Materials and Methods

The Pubmed database was searched for scientific articles on resin infiltration. The search was limited to articles published in English between 2014 and 2019. The keywords

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used for the search were 'resin infiltration', 'incipient caries,' 'minimal intervention dentistry" and 'white spot lesions'.

3. Results

3.1. Resin Infiltration Concept

Resin infiltration technique is a novel technology that bridges the gap between prevention and restoration of carious lesions. It is marketed under the trade name Icon® (DMG America Company, Englewood, NJ) in two different forms: proximal surface and vestibular surface kits. Resin infiltration works on the principle of perfusion of the porous enamel with resin by capillary action and thus it helps in arresting progression of lesion by occluding the microporosities which may act as diffusion pathways for the acids and dissolved materials. This technique aims to create a diffusion barrier inside the lesion and not on the lesion surface.[5] Robinson et al.[6] reported that about 60 $\pm$ 10% of the lesion's pore volume had been occupied by resin. According to Kielbassa et al.[7] resin infiltrates into subsurface lesions and produces resin infiltrated parts of the lesion and the depth of resin infiltration was over 100 μm.

3.2. Resin Infiltration Technique

A preparation phase is required (since surface enamel is less porous) where the surface of the teeth is cleaned and prepared with 15% hydrochloric acid (icon etch) for 2 minutes and stirring the gel from time to time during application with a microbrush. 15% hydrochloric acid gel has been demonstrated to be superior to 37% phosphoric acid gel in removing the mineralized surface layer of natural teeth.[8]

Ethanol wet bonding technique is used to desiccate the surface by applying 99% ethanol (Icon Dry) for 30 seconds followed by air drying. It is based on the assumption that it will coax hydrophobic monomers to infiltrate into demineralized wet enamel or dentine, and improve the efficacy of penetration of the hydrophobic infiltrate to get a well-defined, resin-infiltrated layer.

Icon resin, composed of TEGDMA, is applied on the lesion surface using a microbrush and allowed to penetrate for three minutes. Material is light cured after removing excess using a cotton ball. Repeated application for another one minute is performed and then the resin is light cured again. Two applications are preferred one after the other, because single application can result in spaces which can be occluded by the second application. The excess resin is then removed and the surface is polished.[9,10]

3.3. Resin Infiltration in Primary Teeth

The management of non-cavitated caries lesions using the resin infiltration technique in primary teeth differs from that in permanent teeth. Firstly, primary enamel is less mineralized, more porous and aprismatic when compared to permanent enamel. So primary enamel has a greater diffusion co-efficient than permanent. Secondly, the proximal surface layer is less mineralized and thinner in primary molars compared to the permanent ones and thus, the rate of progression of proximal caries in primary molars is significantly higher than that in the permanent ones.[11]

In an in vitro study by Paris S et al.,[12] primary teeth exhibited better infiltrant penetration than permanent teeth, after 1 minute application of resin.[1] On the other hand, 3–5 minutes are required to almost completely infiltrate a natural lesion in permanent teeth with a lesion extended to the inner half of enamel, whereas, one-minute application resulted in only superficial infiltration.

4. Clinical Applications

4.1. White spot lesions

Enamel carious lesions are characterized by mineral loss beneath an apparently intact surface layer. Increased porosity within lesion causes characteristic whitish appearance. Thus, these lesions are often called white spot lesions (WSLs). Refractive index(RI) of sound enamel is 1.62, whereas that of porous enamel is 1.33 when it is filled with watery medium and 1.0 when filled by air. This significant difference in refractive indices, which causes changes in the scattering of light leading to the formation of white spot lesion.[13]

Icon infiltrant has a low viscosity, low contact angle, high surface tension and high penetration coefficient with RI of1.47. The resultant RI is 1.52, which is close to that of healthy enamel. This makes the difference in refractive indices between porosities and enamel to be negligible and lesions appear similar to the surrounding sound enamel. It has a chameleon effect and requires no shade matching. Lesions lose their whitish opaque colour and blend reasonably well with surrounding natural tooth structure.[13] Hence an immediate improvement in the esthetic appearance was observed. The mineralized surface interferes with the resin penetration and to overcome this, the surface of the lesion is conditioned with 15% hydrochloric acid gel.

In the 70s, Robinson et al.[14] investigated the concept of infiltrating a carious lesion with resorcinol-formaldehyde resin. According to Abbas et al.[15] for shallow enamel lesions, the best treatment option is to perform one etching step with one application of resin infiltrant while for deep enamel and shallow dentine, the best treatment modality is one etching step and two applications of the resin infiltrant. Arora et al.[16] concluded that resin infiltrant showed minimum surface roughness, maximum microhardness and penetration depth as compared to conventional pit and fissure sealants. Subrahmanian et al.[17] found that the resin

Table 1: Research studies on resin infiltration

Authors	Type of study	Teeth selected	Condition	Follow up period	Results
Subrahmanian P et al. 2014	In vitro	Extracted premolars	Artificial caries lesion	_	Maximum depth of penetration of resin is $6.06 \pm 3.32\mu$m
Arnold WH et al. 2014	In vitro	Extracted premolars and molars	Artificial demineralization	_	Artificial caries lesions were completely penetrated by the resin.
Tostes MA et al. 2014	In vitro	Bovine incisors	Artificial demineralization	_	Resin infiltrant was efficient in preventing the progression of demineralization
Altarabulsi MP et al. 2014	In vivo	Deciduous and permanent teeth	Proximal lesions	12 months	Resin infiltrant hamper progression of caries in proximal lesions
Paris S et al. 2014	In vitro	Extracted human teeth	Fissure caries	_	Penetration of resin infiltrant was superior when etched with HCl when compared to fissure sealant
Yim HK et al. 2014	In vitro	Extracted premolars and molars	White spot lesions	_	For resin infiltration 37% phosphoric acid with brush applicator preserve the protective surface layer of WSL
Arslan S et al. 2015	In vitro	Sound incisors	Hypomineralization	_	Resin infiltration shows increase in microhardness an decrease in surface roughness of demineralized enamel with low bacterial count
Eckstein A et al. 2015	In vivo	Permanent teeth	Postorthodontic white spot lesions	1 year	Colour and lightness of resin infiltrant were not altered significantly after 1 year
Askar H et al. 2015	In vitro	Enamel specimen	Artificial caries lesion	_	Microfilled resin(organic filler of 42μm size) showed similar penetration depth of unfilled resin
Lausch J et al 2015	In vitro	Extracted premolars and molars	Noncavitated white lesion	_	Use of abrasive HCl with modified brush as pretreatment showed enhanced penetration depth
Liu Y et al. 2015	In vitro	Bovine enamel	Artificial caries lesion	_	Resin infiltration can effectively strengthen microhardness of enamel surface and cross-section of different depth of artificial caries.
Arnold WH et al. 2016	In vitro	Extracted premolars	Noncavitated white lesion	_	After thermocycling, resin-infiltrated enamel surfaces become smoother and had no additional risk for plaque accumulation.
Elhiny OA et al. 2016	In vitro	Extracted premolars	Sound enamel surface	_	Resin infiltrant surface pretreatment for prevention of white spot lesions can be done clinically under orthodontic brackets without affecting the shear bond strength significantly.

Zankalouny S et al. 2016	In vitro	Extracted premolars	Artificial caries lesions	_	Resin infiltration significantly has the highest penetration depth and increased microhardnes in comparison to Cpp-acp and Exite fluoride varnish
Zhao X et al. 2016	In vitro	Extracted third molars	Artificial demineralization	_	Surface hardness of enamel lesions increased significantly after resin infiltration and remained stable following thermocycling. Surface roughness and color stability of resin-infiltrated enamel lesions were less than ideal and might further deteriorate after aging in the oral environment.
Tawakoli PN et al. 2016	In vitro	Enamel specimen	Artificial demineralization	_	Freshly resin-infiltrated enamel surfaces show a biofilm reducing effect, while monomer leakage was not affected by bacterial presence.
Kielbassa M et al. 2017	Ex vivo	Extracted premolars and molars	Artificial demineralization	_	Resin infiltration increased the initial quality of fissure sealing an control occlusal caries
Lausch J et al. 2017	In vitro	Extracted molars	Hypomineralization		Microfilled resin infiltrant has same penetration as conventional
Prajapati D et al. 2017	In vitro	Extracted premolars	Artificial demineralization	_	Significant increase in microhardness was observed postinfiltration
Kumar H et al. 2017	In vitro	Extracted human teeth	MIH	_	There was marked variation in the surface layer thickness of MIH lesions and resin infiltration did not increase microhardness significantly.
Gugnani N et al. 2017	RCT	Maxillary anteriors	Fluorosis stains	_	Resin infiltration procedure with tailored etching times and increased infiltration time exhibited best results in terms of change in esthetics and improvement in stains.
Bhandari R et al. 2018	In vivo	Permanent incisors	MIH	6 months	Resin infiltrant conceal white opaque lesion of MIH and reduce lesion whiteness with time
Askar H et al. 2018	In vitro	Extracted human teeth	Proximal lesions	_	Microfilled resin has same penetration of conventional but fill cavitated areas more effectively
Abbas BA at al. 2018	In vitro	Extracted premolars	Hypomineralization		Shallow lesions require one etching and one resin application whereas deep lesions need one etching and two applications of resin for better esthetics

Yazkan B et al. 2018	In vitro	Extracted human teeth	Artificial caries lesions	_	Resin infiltration and microabrasion technique appeared to be effective for improving microhardness. and reducing surface roughness,
Prasada KR et al. 2018	In vitro	Extracted maxillary central incisors	Artificial demineralization	_	Resin infiltrant has got better ability to mask WSL when compared to sodium fluoride and bioactive glass
Arora TC et al. 2019	In vitro	Extracted premolars	Fissure caries	_	Resin infiltrant has maximum penetration and microhardness when compared to sealants
Kannan A et al. 2019	RCT	Molar teeth	Postorthodontic hypomineralization	6 months	Clinpro varnish has better ability to mask the color and opaqueness of lesions after 3 and 6 months follow up
Knosel M et al. 2019	In vivo	Molar teeth	Postorthodontic white spot lesions	2 years	Resin infiltrant is efficient in improving the esthetics of the WSL for long time after orthodontic treatment
Schnab D et al. 2019	In vitro	Extracted molars	Developmental enamel hypomineralization	_	Resin infiltrant filled the depth upto 2mm
Perdigao J et al. 2019	In vitro	Extracted teeth	White spot lesions	_	Resin infiltrant filled the space between enamel crystals and formed a hybrid layer which makes it more resistant to acid attack

can penetrate upto a depth of 6.06+_3.32micrometre.

Arnold et al.[18] concluded that the depth of etched surface can be increased by conditioning with 15% hydrochloric acid repeatedly. Nevertheless, the total erosion depth is rather shallow and hence negligible. Paris et al.[1] showed that resin penetrate superiorly after etching with HCl whereas sealant penetrate only superficially. According to Lausch et al.[19] use of abrasive HCl gel with modified brush enhanced infiltration into fissures. The acid reistance of resin infiltrated teeth due to formation of a hybrid layer with enamel crytals was proved by Perdigao et al.[20]

Resin infiltrants can also used for treating incipient proximal caries. From the ex vivo investigation by Kielbassa et al.[21] the ability of the infiltrant resin to infiltrate into non- and micro-cavitated proximal enamel caries was proved. Also resin infiltrants have been tried in treating postorthodontic enamel scars. Study by Kannan et al.[22] studied the effect of resin infiltrants in masking postorthodontic lesions. Knosel et al.[23] proved that resin infiltrant can bring about long term aesthetic improvement of lesions after orthodontic therapy.

4.2. Developmental defects of enamel (DDE)

Development of ameloblasts are highly affected by even minor changes in their surrounding environment. The resulting enamel defects vary depending on the nature and severity of the insult as well as the stage of tooth development. [24] It is believed that the whitish opaque appearance of DDE may be caused by subsurface porosities in the enamel below a well-mineralized surface layer. It has been demonstrated that hypomineralized enamel is resistant to conventional acid etching.[24] This, in turn, may contribute to poor micro-tag formation at the interface between hyopmineralized enamel and adhesives leading to bonding failure and microleakage.[25]It was noticed that lesions infiltrated by resin took on the appearance of the surrounding enamel. Opaqueness of enamel lesions can be reduced by filling the microporosities with resin and they will look similar to the sound enamel. The masking effect of resin infiltration on DDE was studied by Kim et al.[26] who showed that the masking effect was dramatic in some cases, but not in others and that only 60% of teeth with DDE were completely masked. However, aesthetic improvement was still observed in teeth with incomplete penetration.Schnab et al.[27] showed that resin infiltrant can penetrate a defect upto 2.

The practitioner should select the cases carefully. Teeth with brown discoloration may not be good candidates for resin infiltration, since the later will not mask the brown color and, in fact, it may saturate the color and make it look worse clinically. Microabrasion or conventional resin restorations may be better options for treating teeth with brown discoloration. Patients treated with resin infiltration should be monitored closely.

4.3. Molar-incisor hypomineralisation

Resin infiltration is a treatment option which is minimally invasive, yet not patient compliance based. It is made possible by eroding the hypermineralized surface layer and then infiltrating resin through capillary action into the hypocalcified void of enamel. Meyer-Lueckel et al.[28] revealed that the infiltrant was able to penetrate 600 μm into enamel lesions clinically. The infiltration of the resin owing to its low viscosity into the voids of enamel has been shown in many in vitro studies. Eckstein et al.[29] in their study showed that infiltrant material's concealment effect on WSL had no statistically significant or clinically relevant additional color or lightness alterations between 6 and 12 months after infiltration.In the study by Bhandari et al.[30] a 6-month follow-up was done and a reduction in the whiteness of white spot and also change in total color were noted only after treatment and 6 months after treatment, following resin infiltration. This study shows that resin infiltration shows immediate results and also it shows further improvement overtime.Similar results were observed by Cohen-Carneiro et al.[31] who showed that lesions infiltrated with icon had good colour matching.

5. Discussion

An innovative way in minimal intervention dentistry concept is to treat initial caries lesions with resin infiltration. Infiltration of carious lesions represents a new approach to the treatment of non-cavitated lesions of proximal and smooth surfaces of deciduous and permanent teeth up to the first third of dentin. From the foregoing review, it seems clear that the resin infiltration technique bears several advantages as follows:[32,33]

1. Good patient acceptance
2. Single visit treatment
3. Preserves tooth structure and noninvasive
4. No postop sensitivity and pulpitis
5. Lesion progression arrested/retarded
6. Low risk of gingivitis and periodontitis
7. High esthetic result
8. Low risk of secondary caries
9. More penetration into demineralized areas

Resin infiltration has been tried in cases of white spot lesions, developmental enamel defects and also for molar incisor hypomineralization.

5.1. Aesthetic Outcome of Resin Infiltration Therapy

Cosmetics and esthetics are current trends of dental industry. As more and more patients are demanding for minimally invasive cosmetic enhancement without anesthesia and drilling, the technique of resin infiltration may be considered as one that allows for the recovery of natural tooth appearance. The porosity created by the initial demineralization of a caries process changes the refractive index of enamel, resulting in a white coloration in the incipient lesion. The resin infiltration technique has an additional positive effect on esthetics in which the penetration and polymerization of the low viscous resin inside the lesion body allows a change of the lesion's whitish appearance to the natural enamel appearance.[34–36]

Highest number of studies were conducted in white spot lesions, both in vitro and in vivo. Lueckel and Paris[37,38] demonstrated that the application of resin infiltrants had caused an inhibition of caries progression. Knosel et al.[39] in a clinical trial with patients having white spot lesions, treated after the removal of braces in orthodontically treated teeth reported that there were no statistically significant differences in the color of the infiltrated resin during a 6 month follow-up, confirming theaesthetic effect of this minimal intervention treatment procedure.

After resin infiltration the microhardness of enamel lesions showed an improvement, but not upto predecalcification levels, so this technique may not be able to bring back the original levels. However, according to Kim et al.[26] it was observed that the microhardness of carious lesions increased with the infiltration of resin which is obviously due to a uniform complex composed of triethylene glycol dimethacrylate and hydroxyapatite,[40–42] and this interaction with crystals results in improved mechanical strengths and aesthetic appearance.[43–45] Ekstrand et al.[46] evaluated the effectiveness of the treatment of proximal lesions of temporary molars with resin infiltration but the reported rate of failure after one year was higher than that reported in other studies after the same period of follow up.

The resin infiltrate penetrated the affected enamel in the developmental enamel opacities.[26] Few studies have evaluated in vivo conditions despite promising short-term reports. Study by Ciftci et al.[47] concluded that the resin infiltrate enabled a significant decrease in opaque lesions and it was not high as in WSLs, which received resin infiltrate and the colour difference was partially masked.The researchers stated that developmental opacities cannot be totally corrected through resin infiltration systems because they have a thicker surface, similar to inactive decay lesions.

The infiltration of the resin and it's color masking effects has been shown in many in vitro studies.[8,37]Nonetheless, there is a paucity of clinical confirmation about the efficacy of the resin infiltration treatment for masking

enamel whitish discolorations in MIH patients. Eckstein et al.[48] evaluated the color improvement of hypomineralized areas after resin infiltration treatment, and its stability after discoloration insults. In his study, conclusion was made that resin infiltration treated lesions were stable after discoloration challenges.[48] Furthermore, Senestraro et al.[49,50] concluded that resin infiltration shows stable results up to 8 weeks after treatment.[4] It can be recommended that mild MIH lesions can betreated with minimally invasive treatment such as resininfiltration before trying any invasive approach such asveneering.

The masking effect of infiltration therapy on fluorosis and hypoplasia stains has been described in some case reports and case series and also has been evaluated in nonrandomized studies or randomized clinical trials.[9,25,26] However, little research has been published with regard to resin infiltration depth in these conditions, and results were considered unpredictable in respect of infiltration depth and change in microhardness. Since just a few articles mention more than the immediate aesthetic outcome, there is an evident need for more clinical studies demonstrating long-term aesthetic results of resin infiltration therapy.

6. Limitations of Resin Infiltration

Even though the resin infiltration technique has opened up a new range of options for minimal invasive treatment of white spots, there is the need to mention few reasons that may affect the success of the treatment.[32]

1. Inefficient isolation;
2. Incomplete resin polymerization;
3. Depth of the lesion

ICON works on the principle of infiltration and requires a very dry field. Apart from keeping the environment moisture-free, additional steps must be taken to dry the lesion. This is accomplished by treating the lesion area with alcohol, which evaporates the water within the porosities, which can inhibit the process of infiltration.

The greater the depth of the carious lesion, the lower will be the probability of achieving a complete infiltration. Extensive lesions are also associated with a higher polymerization shrinkage and the consequent appearance of porosities and cracks.[22] The infiltration of cavitated lesions does not produce satisfactory results, taking into account the weak capillary action of the resin into these lesions.[15]

7. Conclusion

Caries resin infiltration represents a new concept in dentistry and therefore needs to be better investigated. Based on the available laboratory and clinical studies, it seems convincing that the resin infiltration of enamel lesions should reduce or even stop the progress of white spot lesions. While this therapy can rightly be categorized as minimum intervention dentistry, clinical experience is limited and further controlled clinical trials are required to assess its long-term results.

8. Source of Funding

None.

9. Conflict of Interest

None.

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