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RESEARCH ARTICLE

RESIN INFILTRATION IN NON-SURGICAL CARIES MANAGEMENT: A CONTEMPORARY REVIEW

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Abstract

Dental caries remains one of the most prevalent chronic diseases world wide, with early enamel lesions representing a critical intervention window before irreversible structural breakdown occurs. Resin infiltration on has emerged as an innovative micro-invasive technique that bridges the gap between preventive and restorative dentistry by penetrating low-viscosity light-curable resin into the microporosities of non-cavitated enamel lesions. This contemporary review comprehensively evaluates the biological basis, mechanism of action, clinical protocol, indications, comparative effectiveness, limitations, safety considerations, and future perspectives of resin infiltration in the non-surgical management of dental caries. Current evidence from randomized clinical trials, systematic reviews, and meta-analyses supports resin infiltration as a predictable and safe treatment for carefully selected non-cavitated enamel and early proximal lesions, demonstrating superior lesion arrest compared with conventional non-invasive therapies. The technique also provides significant esthetic improvement through the masking of white spot lesions, making it particularly valuable in post-orthodontic patients. However, successful outcomes remain highly dependent on accurate diagnosis, appropriate case selection, meticulous clinical technique, and integration with comprehensive caries-risk management. Future advances in bioactive infiltrant materials, antimicrobial resin formulations, artificial intelligence-assisted lesion detection, and combination remineralization therapies may further enhance the effectiveness and longevity of this approach.

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Introduction:-

Dental caries remains one of the most prevalent chronic diseases worldwide and continues to represent a significant public health burden despite substantial advances in preventive dentistry. The disease is characterized by a dynamic process of demineralization and remineralization driven by biofilm-mediated acid production, resulting in the gradual destruction of dental hard tissues. Early carious lesions are initially confined to enamel and present clinically as non-cavitated white spot lesions, which remain amenable to non-invasive or micro-invasive interventions before irreversible structural breakdown occurs. Contemporary caries management therefore emphasizes early detection, risk assessment, and minimally invasive treatment strategies aimed at preserving natural tooth structure while preventing disease progression rather than relying solely on conventional restorative approaches.^{9, 25, 29}

Traditional management of early enamel lesions has primarily relied on preventive measures such as fluoride therapy, dietary modification, oral hygiene reinforcement, and casein phosphopeptide-amorphous calcium phosphate (CPP-ACP). Although these approaches promote remineralization, their clinical success depends heavily on patient compliance and may be insufficient for lesions exhibiting established subsurface demineralization. Conversely, conventional restorative treatment often requires unnecessary removal of sound enamel for lesions that have not yet cavitated, contradicting the principles of minimally invasive dentistry. These limitations have created a need for treatment modalities that effectively arrest lesion progression while conserving healthy tooth structure.^{12, 25}

Resin infiltration has emerged as an innovative micro-invasive technique that bridges the gap between preventive and restorative dentistry. The procedure involves penetration of a low-viscosity light-curable resin into the microporosities of non-cavitated enamel lesions following controlled surface conditioning. After polymerization, the infiltrated resin occludes diffusion pathways within the lesion body, restricting the movement of acids and dissolved minerals and thereby arresting lesion progression. In addition to its therapeutic benefits, resin infiltration improves the optical properties of demineralized enamel by reducing the refractive index difference between healthy and affected tissues, effectively masking white spot lesions and enhancing esthetics.^{25, 11}

Over the past decade, increasing evidence from randomized clinical trials, systematic reviews, and meta-analyses has demonstrated the effectiveness of resin infiltration in reducing the progression of proximal caries lesions, improving esthetic outcomes of post-orthodontic white spot lesions, and preserving tooth structure. Nevertheless, important considerations remain regarding appropriate case selection, long-term durability, technique sensitivity, and future developments involving bioactive infiltrants and artificial intelligence-assisted diagnosis.^{9, 26-29}

Therefore, this contemporary review aims to comprehensively evaluate the biological basis, mechanism of action, clinical protocol, indications, comparative effectiveness, limitations, safety considerations, and future perspectives of resin infiltration in the non-surgical management of dental caries, highlighting its role within modern minimally invasive dentistry.

Biological Rationale:-

The rationale for this technique is based on the structural characteristics and demineralization process of early enamel lesions. Under acidic conditions, mineral loss from the enamel results in the formation of microporosities within the lesion body. These porosities act as diffusion pathways, facilitating the movement of acids and dissolved minerals through the enamel. Resin infiltration targets these porous areas by penetrating and occluding the lesion body, thereby sealing the lesion internally rather than merely covering the surface. This occlusion restricts the diffusion of cariogenic acids which may arrest lesion progression and reduce the risk of further demineralization. Furthermore, resin infiltration has been reported to improve the mechanical properties of demineralized enamel, potentially enhancing its resistance to future acid challenges.¹³

The effectiveness of this approach is largely dependent on the properties of the infiltrate material. Resin infiltrates are primarily composed of triethylene glycol dimethacrylate (TEGDMA), a low-viscosity monomer that enables effective infiltration of porous enamel lesions. Furthermore, infiltration of the lesion body alters its optical properties, contributing to the masking of non-surgical carious lesions and improved aesthetic outcomes.³⁴

Mechanism of Action:-

The mechanism of resin infiltration is based on the penetration of a low-viscosity resin into the porous enamel lesion. The infiltrate diffuses into the microporosities created during the demineralization process and subsequently polymerizes within the lesion body. By filling and occluding these pores, the resin restricts lesion progression and promotes lesion arrest.³

Chemical Alteration:-

Etching:-

Enamel etching is a critical step in resin infiltration, as the hyper-mineralized surface layer can impede resin penetration into the lesion body. The application of 15% hydrochloric acid for 90–120 seconds effectively removes this surface barrier, exposing the underlying porous enamel and facilitating penetration of the infiltrate. Compared with mechanical surface removal, acid etching provides more controlled surface erosion and avoids smear layer formation which may obstruct lesion pores and compromise resin infiltration.¹³

Ethanol:-

Ethanol is used as a drying agent prior to resin infiltration to displace residual water within the lesion and enhance resin penetration. By reducing the viscosity of the infiltrate and improving its diffusion into the porous enamel, ethanol facilitates more effective infiltration of the lesion body.¹³

Physical Penetration:-

Capillary Action:-

Resin infiltration relies on capillary action as the primary mechanism for penetration into porous enamel lesions. According to the Washburn equation, the movement of resin through the lesion is driven by capillary forces and is influenced by factors such as pore volume, capillary radius, surface tension and resin viscosity. The low viscosity and high penetration coefficient of the infiltrate enable it to flow into the microporosities of demineralized enamel allowing deep penetration throughout the lesion body. This capillary-driven infiltration facilitates the effective filling of enamel pores and subsequent lesion sealing.¹³ This approach bridges the gap between non-invasive preventive measures and conventional restorative treatment for non-cavitated lesions extending into the outer third of dentin. The formation of an internal resin barrier further contributes to the stabilization of weakened enamel and preservation of tooth structure.³

TEGDMA Chemistry:-

TEGDMA-based resin infiltrates possess physicochemical properties that facilitate penetration into porous enamel lesions. Their low viscosity, low contact angle and high penetration coefficient enable effective infiltration of demineralized enamel through capillary forces. However, the extent of penetration is influenced by lesion characteristics as highly mineralized surface layers and deeper enamel defects may reduce lesion permeability and limit infiltrate penetration.⁷

Dual Biological Result:-

Mechanical Arrest:-

Mechanical arrest is achieved following infiltration and polymerization of the resin within the lesion body. The formation of an internal resin network reinforces the demineralized enamel increasing its mechanical stability and resistance to subsequent cariogenic challenges. As a result, the structural integrity of the affected enamel is preserved and further lesion progression may be arrested.³⁴

Optical Masking:-

The optical masking effect of resin infiltration is primarily dependent on the refractive index of the infiltrate. The refractive index of the resin infiltrate (1.52) closely approximates that of sound enamel (1.62) in contrast to the lower refractive indices of water (1.33) and air (1.00) present within enamel porosities. Following infiltration, the resin replaces the air and water within the lesion, thereby reducing the refractive index mismatch between the porous lesion and the surrounding enamel. This reduction in refractive index disparity decreases light scattering and enhances its transmission through the enamel, resulting in a masking effect that renders non-surgical carious lesions and enamel opacities less perceptible. Consequently, the infiltrated lesion exhibits optical properties that more closely resemble those of healthy enamel and improves its aesthetic appearance.¹

Clinical Protocol and Technique:-

The clinical success of resin infiltration depends largely on appropriate case selection and strict adherence to the treatment protocol. Resin infiltration is a minimally invasive technique designed to arrest the progression of non-cavitated enamel lesions by occluding the microporosities within the lesion body. The procedure preserves sound tooth structure and offers both therapeutic and esthetic benefits, particularly in the management of early enamel lesions and post-orthodontic white spot lesions.^{28, 25}

Case Selection and Diagnosis:-

Accurate diagnosis is essential before performing resin infiltration. The technique is primarily indicated for non-cavitated enamel lesions, proximal caries extending into the outer third of dentin, and white spot lesions associated with orthodontic treatment. Clinical examination, bitewing radiographs, and assessment of lesion activity should be performed to determine the suitability of treatment. Lesions exhibiting cavitation or extensive dentinal involvement generally require conventional restorative procedures rather than infiltration therapy.^{24,3} Proper isolation of the operative field is equally important. Rubber dam isolation is considered the gold standard because it minimizes contamination from saliva and moisture, thereby improving resin penetration and clinical outcomes. Interproximal wedges may be used to provide better access to proximal lesions.²⁷

Clinical Procedure and Resin Application:-

The outer surface of early enamel lesions often contains a hypermineralized layer that limits resin penetration. Therefore, 15% hydrochloric acid gel is applied for approximately 120 seconds to remove this superficial barrier and increase lesion porosity. The etched surface is then thoroughly rinsed and dried. Ethanol is subsequently applied to eliminate residual moisture and improve visualization of the lesion.^{25,16}

A low-viscosity light-curable resin infiltrant is applied to the lesion surface and allowed to penetrate through capillary action. The infiltrant typically remains on the lesion for approximately three minutes to maximize penetration depth. Excess material is carefully removed using cotton pellets and dental floss before light polymerization. Following curing, a second application of the infiltrant may be performed to compensate for polymerization shrinkage and enhance lesion sealing.^{24,20}

Finishing Procedures and Clinical Outcomes:-

After polymerization, finishing and polishing procedures are performed to remove excess resin and improve surface smoothness. Polished surfaces reduce plaque retention and contribute to improved esthetic outcomes. This is particularly important when treating anterior white spot lesions, where patient satisfaction largely depends on the final esthetic appearance.¹⁶

Several clinical studies have demonstrated that resin infiltration effectively arrests lesion progression and improves the appearance of white spot lesions. The technique represents an important component of minimally invasive dentistry because it preserves healthy tooth structure while reducing the need for restorative intervention. Consequently, resin infiltration has become an increasingly accepted approach in contemporary non-surgical caries management.^{28,20}

Clinical Applications:-

Resin infiltration has come forward as a vital micro-invasive treatment option for the management of non-cavitated proximal caries lesions.^{9,11} Resin infiltration is notably indicated for proximal lesions limited to enamel or extending into the outer third of dentin (D1) without cavitation.³³ By infiltrating the porosities of demineralized enamel with a low-viscosity resin, the technique results in a diffusion barrier that prevents the penetration of acids and dissolved minerals, thereby inhibiting lesion progression.²⁴ Evidence from systematic reviews and meta-analyses has reproducibly indicated significantly lower rates of lesion progression in infiltrated lesions compared with non-invasive methods such as fluoride therapy, oral hygiene measures, or placebo treatment.¹¹ As a result, resin infiltration has become an effective modality for delaying and preventing restorative treatment, preserving healthy tooth structure.⁹

Moreover, resin infiltration has gained substantial attention for the management of white spot lesions, notably orthodontic treatment-associated lesions.⁹ By infiltrating enamel microporosities, the resin alters the lesion's optical properties, reducing the refractive index disparity between healthy and demineralized enamel and consequently diminishing light scattering and lesion opacity.²¹ The ability of resin infiltration to improve esthetics has extended its clinical use beyond caries management to encompass post-orthodontic enamel demineralization, fluorosis-associated lesions, and developmental enamel defects. Furthermore, the minimally invasive nature of resin infiltration, combined with the absence of drilling and the limited requirement for local anesthesia, makes it particularly well suited for pediatric patients and individuals seeking conservative treatment options.²¹

Indications for Resin Infiltration:-

Resin infiltration is recommended for the treatment of initial caries lesions involving enamel and the outer third of dentin, provided that no cavitation or surface breakdown is present.⁹ These lesions represent a transitional stage at

which preventive measures alone may be insufficient to arrest disease progression, whereas conventional restorative treatment may result in unnecessary removal of healthy tooth structure. By penetrating the lesion body and sealing diffusion pathways, resin infiltration offers a micro-invasive approach that bridges the gap between preventive and restorative care.²⁴ Current evidence particularly supports its use in proximal lesions, where access for oral hygiene procedures and topical remineralization therapies is limited, increasing the risk of lesion progression.⁹

A further important indication for resin infiltration is the treatment of white spot lesions, particularly those arising as a consequence of orthodontic therapy.²⁴ The opaque appearance of white spot lesions results from subsurface enamel porosity and altered light scattering. By penetrating and filling these microporosities, resin infiltration reduces optical differences between sound and demineralized enamel, making it an effective treatment when both caries control and esthetic improvement are desired.²¹ Furthermore, resin infiltration has been suggested as a treatment option for selected developmental enamel defects, including fluorosis, molar-incisor hypomineralization, and amelogenesis imperfecta, where increased enamel porosity contributes to both structural and esthetic concerns.⁸ Furthermore, resin infiltration may be particularly beneficial for patients at increased risk of caries progression or those with limited adherence to long-term remineralization regimens, as its clinical effectiveness is less reliant on sustained patient compliance than conventional preventive approaches.⁹ However, the technique is contraindicated in cavitated lesions, lesions extending deeply into dentin, or situations where adequate isolation and moisture control cannot be achieved.³³

Comparative Effectiveness of Resin Infiltration in Non-Surgical Caries Management:- Resin Infiltration versus Topical Fluoride:-

Resin infiltration acts as a physical, internal diffusion barrier to halt lesion progression.^{14,34} Unlike topical fluoride varnish, which relies entirely on biochemical surface remineralization and continuous patient compliance, the low-viscosity resin monomer penetrates deeply into the enamel pore volume via capillary forces.³⁴ A landmark systematic review and meta-analysis established that resin infiltration significantly reduces the risk of initial proximal caries progression compared to topical fluoride or placebo alone, yielding a combined risk ratio (RR) of 0.37 (95% CI: 0.29–0.48).¹⁴ Furthermore, regarding cosmetic performance, a randomized controlled trial demonstrated that resin infiltration achieves superior visual results, showing a significantly smaller residual color difference when masking post-orthodontic white-spot lesions compared to traditional fluoride varnish, with high visual stability tracked up to 24 months.¹⁹

Resin Infiltration versus Pit and Fissure Sealants:-

While conventional pit and fissure sealants place a thick, protective resin or glass ionomer cap over the external enamel surface, resin infiltration shifts the primary diffusion barrier directly into the subsurface lesion body itself.^{10,15} Both micro-invasive approaches exhibit high success rates in arresting initial, non-cavitated lesions over long-term follow-ups.¹⁰ However, a network meta-analysis revealed that resin infiltration offers a distinct clinical advantage in patients with high caries risk, reporting significantly lower odds ratios (OR = 0.14 to 0.20) for lesion progression compared to alternative surface sealing methods.¹⁰ Supporting this finding, clinical evidence highlights that because the infiltrant eliminates excessive external material before light-curing, the internal infiltration mechanism makes the final treatment far less vulnerable to the complete retention loss or marginal microleakage that frequently compromises conventional surface sealants.¹⁵

Resin Infiltration versus Silver Diamine Fluoride (SDF):-

Resin infiltration and Silver Diamine Fluoride (SDF) represent contrasting therapeutic strategies for non-surgical caries control.^{14,10,4} SDF relies on silver ions for antimicrobial action and heavy fluoride saturation for chemical arrest, but its primary clinical drawback is the dark, permanent black staining of the treated tooth structure.⁴ A comprehensive systematic review confirmed that while SDF demonstrates high arrest rates (25–99%) in active lesions, its severe aesthetic limitations drastically reduce parental and patient acceptance in the anterior zone.⁴ In contrast, resin infiltration offers an optimal aesthetic alternative because its refractive index matches that of healthy hydroxyapatite, allowing it to blend seamlessly without discoloration.^{34,15} However, syntheses emphasize that resin infiltration remains a highly technique-sensitive procedure requiring 15% hydrochloric acid etching and strict rubber dam isolation, whereas SDF remains a rapid, moisture-tolerant application ideal for uncooperative pediatric patients where aesthetics are secondary.^{14,4}

Limitations:-**Restricted Indications:-**

The main drawback of resin infiltration is the lack of clinical applications. The technique is mainly recommended for the management of non-cavitated enamel lesions and early proximal carious lesions which are not extensive in dentin. The effectiveness relies on the underlying lesion body being porous and the infiltrant resin reaching the porous body and occluding it. Resin infiltration is less reliable and lesion progression may not be halted if significant dentinal involvement is present after the cavitation has occurred.⁹ Moreover, there is a high rate of success in proximal lesions, but limited evidence exists for the use of this technique in occlusal, root surface or advanced dentinal caries. Hence appropriate case selection is crucial and if the cavity is too deep or cavitated, the infiltration may not be adequate, leading to residual caries activity. Therefore, resin infiltration is recommended for certain cases, and stages of the caries process, and should not be used to replace traditional restorative methods.³³

Technique Sensitivity:-

The clinical success of resin infiltration is very technique dependent and depends on careful execution of many of the steps in the procedure such as isolation, surface conditioning, drying of the lesion, resin application and light polymerization. To achieve successful infiltration, the hypermineralized surface layer needs to be removed by etching with 15% hydrochloric acid; these "channels" provide pathways for the infiltration of the lesion body by resin. In reality, if the etching is improper, the penetration depth can be reduced by leaving unetched parts of the surface barrier, and preventing the penetration of the subsurface porosities, as was shown by Meyer-Lueckel and Paris.²⁵ Likewise, incomplete drying after ethanol application can also affect the ability to get the low viscosity resin to penetrate the capillary of the lesion; the moisture in the lesion will limit uptake of the low viscosity resin, and will also make proper sealing of the lesion difficult. Clinical isolation is also a vital element because contamination from saliva, crevicular fluid or moisture from the infiltration process can have a negative impact on resin penetration and polymerization. The resin infiltration is a multi-step procedure, requiring a specific sequence of the steps and accuracy of the procedure in order to achieve optimal results, unlike the conventional fluoride-based preventive therapies. Another limitation of the systematic review presented by Dorri et al. was the differences in treatment protocols and operators' technique in the clinical studies, which is one possible explanation for the discrepancy in clinical success rates. In addition, the depth, size and mineralization of lesions may affect the infiltration effectiveness, which requires careful case selection and the operator's experience to achieve successful treatment. Resin infiltration, therefore, though considered to be a minimally invasive technique, relies heavily upon the exactness of clinical procedures and may not be as widely accepted in clinical use as it might be, leading to a degree of variability in long-term outcome.¹²

Limited Penetration Depth:-

The major drawback of resin infiltration is the lack of complete infiltration in deeper carious lesions. The method of resin infiltration is based on capillary forces to infiltrate a low viscosity resin into the micro-porosities caused by enamel demineralization. A number of investigations have shown that penetration depth is affected by lesion depth, pore volume, lesion activity and the presence of areas with high mineralization on the surface. Paris, and later Meyer-Lueckel, showed that resin infiltrants can be used to penetrate a large part of non-cavitated lesions, but it is not always possible to completely infiltrate lesions that have progressed into the inner enamel or the outer dentin.²⁵ Un-infiltrated residual porosities can remain under the infiltrated surface layer, providing a potential pathway for diffusion of acids, bacteria and dissolved minerals to continue. This is a growing issue with more severe proximal lesions where the depth of the lesion could exceed the ability of the infiltrant to penetrate. In addition, systematic reviews have indicated that resin infiltration is most successful in early enamel lesions and evidence for its success in deeper lesions is less definitive. Partial penetration of infiltrant may therefore not be sufficient to completely halt lesion progression and therefore early diagnosis and intervention are highly significant. Potential modifications of infiltrant components, infiltrant penetration and delivery systems could improve infiltration of deeper lesion bodies and the clinical use of this micro-invasive treatment option.¹²

Long-Term Durability Concerns:-

Although resin infiltration is clinically successful in the short and medium term, its durability has yet to be determined. The follow-up periods of most clinical trials that have assessed lesion arrest, esthetic masking and color stability have been from 6-months to 3-years with a few studies exceeding 5 years. Systematic review studies have consistently shown that resin infiltration is an effective method in reducing the progression of non-cavitated proximal lesions up to 2-3 years and achieved satisfactory esthetic results in short and intermediate-term follow-up. But solid evidence of the long-term effects is limited. Many of the studies included in the recent systematic review which compared outcomes of resin infiltration over varying time periods had small sample sizes, showed

methodological variability, and had a relatively short follow-up time, so it was hard to make any clear conclusions about long term clinical results.³² Likewise, systematic reviews have shown that there is a requirement for good studies with RCTs and a good follow up period to see if the beneficial effects of resin infiltration persist over decades. Another issue is the possibility of aging, change of colors, hydrolytic degradation and wear with time, which might affect esthetic and clinical results. Recent studies have shown that esthetic improvements may be maintained for up to 6 years in most instances, but there is little data available beyond 5-10 years. Thus, although there are current indications of the efficacy of resin infiltration in the short and medium term, there is a certain level of doubt about its durability over time, which would require longer-term clinical studies to confirm.³²

Esthetic Limitations:-

While resin infiltration has proved to be very successful at concealing white spot lesions and enhancing enamel esthetic appearance, concerns about esthetic long-term stability of infiltrated enamel still exist. The infiltrant resin changes the refractive index of demineralized enamel which decreases the visual difference between the lesion and normal enamel. But there are a few studies that indicate that the colour stability of infiltrated lesions might be affected by the physicochemical properties of the resin materials and the presence of staining agents like coffee, tea, red wine and tobacco. Ibrahim et al. performed a systematic review and found good esthetic results and color stability for up to 24 months, but noted a lack of long-term clinical studies and suggested additional longitudinal studies to determine long-term esthetic performance.¹⁷ Likewise, Borges et al. found that there is a limited number of high-quality clinical trials and follow-up periods that provide support for long-term color maintenance of resin infiltration, and that it can be used successfully to mask enamel opacities.⁶ Laboratory testing has also shown that infiltrant resins containing a high percentage of TEGDMA have the ability to absorb water and easily take up pigments, which may lead to discoloration in the long term. Thus, although resin infiltration is a very good means of immediate and short-term restorative esthetic improvement, there are still some doubts about its long-term color stability and resistance to extrinsic staining.⁷

Failure to Address the Causes:-

A major drawback of resin infiltration is treating the lesion and not the causes underneath the caries process. The technique works by blocking the microporosities in a demineralized lesion which decreases the diffusion of acids and dissolved minerals and stops the progression of the lesion. It does not directly affect biological and behavior risk factors for caries: diet (sugar), plaque formation, oral hygiene, reduced saliva flow, and changes in the oral microbiome. Thus, the treated lesion may not progress, but if the patient continues to have risk factors associated with caries, then other areas of the dentition may develop lesions. Modern caries management philosophies focus on a risk-based management strategy which involves minimal intervention as well as preventive treatment like dietary counselling, fluoride treatment, oral hygiene counselling, and regular monitoring. This is why a few reviews on the management of micro-invasive caries have recommended to consider resin infiltration as a complement to comprehensive preventive care. Successful infiltration of lesions is the most important aspect of long term success, however, there must be control of the etiological factors which started the disease process. A lack of management of these factors could jeopardize the overall caries management even if there is success in the management of the lesions.²²

Learning Curve and Cost:-

Although resin infiltration is a very simple technique, the widespread use of this technique might be restricted because of economic and operator factors. Special materials are needed for the procedure, such as proprietary infiltration systems, hydrochloric acid etchants, ethanol drying agents and dedicated application protocols, which can add to the expense of treatment as opposed to traditional preventive treatments like the use of fluoride varnishes. In addition, there are several procedural steps, such as isolation, etching, drying, resin application and polymerization, that are crucial for successful treatment, and require a lot of experience from the clinician. The sensitivity of the technique employed with these steps develops a learning curve, especially for those clinicians who are not familiar with micro-invasive techniques. Discrepancies in clinical results between studies could be due to variations in operator skill. Furthermore, since resin infiltration is a relatively new technique compared to traditional restorative methods, the policies and practices of reimbursement and insurance vary from healthcare systems, making it less accessible for certain patients. The process, although it could eventually lead to fewer restorative treatments that rely on more complex procedures, still presents some challenges in terms of the materials, and the training that is needed for widespread use. The use of resin infiltration in routine clinical practice may become more accessible and adopted in the future if clinical protocols can be further simplified, material expenses can be decreased, and more clinicians can be trained.²³

Safety and Clinical Considerations:-

Recent clinical research shows that resin infiltration (RI) is highly effective in slowing down the progression of early carious lesions when compared to traditional non-invasive methods. Studies, including randomized clinical trials, have consistently found that lesions treated with RI are much less likely to progress. In fact, long-term data suggest that this treatment can successfully arrest caries for up to seven years.^{30,26} Further support comes from systematic reviews, which confirm that resin infiltration is both a safe and effective micro-invasive procedure. When performed correctly, it carries minimal risk of adverse effects, making it a reliable choice in clinical practice.¹¹ The way RI works is by allowing a low-viscosity resin to penetrate the tiny pores within demineralized enamel. Once these pores are sealed, acids can no longer diffuse easily into the lesion, thereby stopping further demineralization and disease progression.²⁵

Apart from preventing caries progression, RI also provides clear aesthetic benefits. It is especially useful in treating early white-spot lesions, as it reduces their chalky appearance and helps restore the natural translucency of enamel. This is particularly important for anterior teeth, where appearance plays a major role in patient satisfaction.²⁹ The clinical procedure for resin infiltration is relatively simple and minimally invasive. First, the tooth is isolated to maintain a dry field. The enamel surface is then treated with approximately 15% hydrochloric acid to open up the surface pores. After rinsing and drying, an ethanol-based drying agent is applied to remove any remaining moisture. A low-viscosity resin is then placed on the lesion and allowed to penetrate for a few minutes, often with gentle agitation to enhance infiltration. Excess material is removed, followed by light curing. Finally, polishing may be done to achieve a smooth surface. Following each step carefully is essential to ensure the best possible outcome.^{29,25} RI is mainly indicated for non-cavitated lesions, such as proximal caries, smooth-surface lesions, and white-spot lesions that commonly occur after orthodontic treatment. It works best when the lesion is limited to enamel or the outer third of dentin and the tooth surface is still intact. However, in cases where the lesion is cavitated or extends deeper into dentin, resin infiltration becomes less effective and conventional restorative treatment may be required.¹¹ In summary, resin infiltration is a scientifically supported, patient-friendly approach for managing early carious lesions. It helps preserve natural tooth structure, prevents further progression of decay, and improves aesthetics, making it an important tool in modern minimally invasive dentistry.³⁰⁻²⁹

Future Directions:-**Bioactive Resin Infiltrants:-**

Chemically modified resin infiltrant materials that can prevent lesion progression along with producing antimicrobial activity and remineralization seem to be the most promising future direction of resin infiltration. The traditional infiltrants drain away cavity fluid from the enamel, and serve as passive barriers to the diffusion of acids and dissolved minerals through the enamel. However, they do not actively participate in tissue regeneration and don't help control bacteria. Recently, a number of studies have explored the incorporation of fluoride-containing compounds as well as nanoparticles of calcium phosphate, amorphous calcium phosphate (ACP), nano hydroxyapatite and bioactive glass particles in the infiltrant formulation. In these materials, the release of calcium, phosphate and fluoride ions has been demonstrated that results in the deposition of minerals in the demineralized enamel and makes it more resistant to future acid attacks. In vitro tests of these bioactive glass-containing infiltrants have also been conducted and they have been shown to be more microhard on the surface and remineralizing than traditional resin-based systems. Besides, the research of antimicrobial modification using quaternary ammonium methacrylates, silver nanoparticles and chlorhexidine has been centered on prevention of the bacterial colonization and biofilm formation. All these enhancements suggest that future infiltrants may evolve into multifunctional therapeutic systems that may inhibit caries, induce remineralization, and inhibit microbial activity.^{5,2}

AI-Guided Lesion Selection:-

Patient selection for resin infiltration therapy will become increasingly critical and rely on more and more Artificial Intelligence (AI) and machine learning (ML) technologies. A major reason for the success of infiltration is the identification of lesions at an advanced stage but not yet cavitated which can be treated using micro-invasive techniques. Near-infrared transillumination, digital imaging, optical coherence tomography and new deep-learning algorithms for analysing bitewing radiographs are found to be as accurate or more accurate, and more accurate in classification, than a clinician in detecting and classifying early carious lesions. Diagnostic consistency and efficiency can be enhanced in the future with AI-powered systems that minimize inter-examiner variability and deliver objective measurements of the depth, activity, and risk of progression of a lesion. In addition, the application of predictive models that consider individual patient risk factors such as oral hygiene, dietary habits, salivary properties and previous caries experience may help select the lesions most amenable to resin infiltration. Digital

caries management processes combined with the implementation of AI could then help render earlier interventions, improved treatment options and improved long-term outcomes, without unnecessary treatment.³¹

Combination Therapies:-

The future paradigm of non-surgical caries management may be the resin infiltration, not singly as a method of remineralization treatment, but rather in combination with other remineralizing methods. Resin infiltration can slow down lesion progression by blocking the microporosities and reduce the permeability of the lesion, but it does not provide as much biological regeneration of the demineralized tooth structure. As a result, combinations of self-assembling peptides (P11-4), casein phosphopeptide-amorphous calcium phosphate (CPP-ACP), fluoride varnishes and nano-hydroxyapatite-containing materials have been investigated. Self-assembling peptides have been successfully used to create a biomimetic scaffold for the de novo hydroxyapatite formation in early carious lesions, while CPP-ACP is a source of calcium and phosphate ions. In several clinical and laboratory studies, it has been demonstrated that resin infiltration combined with remineralizing agents gave better remineralized and better esthetic effect as compared with using remineralizing agents alone. Such a combined therapy may be able to deliver a more comprehensive therapy in that it hinders the development of the lesion, promotes demineralization of the enamel and stabilises the lesion over time. Randomised controlled trials to establish optimal treatment regimens and to evaluate the softness of these co-numerous effects are warranted.¹⁸

Improved Resin Formulations:-

The next generation of infiltrant resin is being developed based on material science advances, such as enhanced physical, biological and esthetic properties of the resin. The majority of the commercially available infiltrants currently available are prepared using the low viscosity monomer, triethylene glycol dimethacrylate (TEGDMA), which is well suited for the ability to penetrate the microporosities of the enamel structure, but also has a relatively high water sorption and staining potential. The next step in the formulations is to develop improved penetration coefficients, while simultaneously reducing the polymerization shrinkage and hydrolytic degradation. The use of nanofillers in order to increase the mechanical strength and anti-discolor properties has been studied, as well as the use of new monomer systems and bioactive additives. Moreover, antimicrobial modification using quaternary ammonium and bioactive ion releasing silver nanoparticles has been found to be effective in reducing bacterial adhesion and biofilm formation. Colour stability is one of the major esthetic issues with the materials currently available, and such efforts are being taken to develop more colour stable materials that can be infiltrated. The innovations that are developing may well substantially improve the usefulness and durability of resin infiltration therapy, as well as its effectiveness.⁵

Long-Term Clinical Trials:-

A number of clinical studies and systematic reviews have demonstrated that there is benefit using resin infiltration for arresting non-cavitated lesions, but the longevity of this treatment remains uncertain. Most of the available clinical studies have short follow up periods of 1-3 years, but a few are longer (5 years or more). Long-term stability of lesion arrest, susceptibility to discoloration, material ageing and cost-effectiveness are significant issues to be addressed. Reports have been numerous about systematic reviews that have pointed to the need for additional multicenter randomized controlled trials with longer follow-up time (more than 5-10 years) and consistent outcome measures. Data from such research will be helpful to decide this treatment option in various clinical and patient risk situations. Long term data would also need to be analyzed to assess whether resin infiltration provides economic benefit over a patient's lifetime compared to preventative/restorative treatment and will result in a major reduction of the need for restorative treatment. Additionally, substantial evidence with long-term follow-up will be essential in advancing clinical guidelines and the expanding role resin infiltration has in minimally invasive dentistry.³²

Conclusion:-

Resin infiltration has established itself as an important micro-invasive treatment modality for the management of non-cavitated enamel lesions and early proximal caries. By penetrating and sealing subsurface enamel porosities, the technique arrests lesion progression while preserving healthy tooth structure, effectively bridging the gap between preventive and restorative dentistry. In addition to its caries-arresting potential, resin infiltration provides significant esthetic improvement through masking of white spot lesions, making it particularly valuable in post-orthodontic patients and other developmental enamel defects. Current clinical evidence supports resin infiltration as a predictable and safe treatment for carefully selected lesions, with systematic reviews and randomized clinical trials demonstrating superior lesion arrest compared with conventional non-invasive therapies. However, successful outcomes remain highly dependent on accurate diagnosis, appropriate case selection, meticulous clinical technique, and integration with comprehensive caries-risk management. Limitations such as technique sensitivity, incomplete

penetration in deeper lesions, uncertain long-term durability, and higher treatment costs continue to warrant consideration.

Future advances in bioactive infiltrant materials, antimicrobial resin formulations, artificial intelligence-assisted lesion detection, and combination remineralization therapies may further enhance the effectiveness and longevity of this approach. Well-designed multicenter randomized clinical trials with extended follow-up periods are still needed to establish long-term clinical performance and cost-effectiveness. Overall, resin infiltration represents a significant advancement in contemporary minimally invasive dentistry and is expected to play an increasingly important role in preserving natural tooth structure while improving both functional and esthetic patient outcomes.

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