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Microinvasive Dentistry: A Comparative Study of Resin Infiltration vs. Conventional Methods for Managing Early Caries Lesions in Surabaya, Indonesia

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A B S T R A C T

Introduction: Early caries lesions are increasingly prevalent, demanding minimally invasive treatment modalities. This study compared the efficacy of resin infiltration and conventional methods in managing early caries lesions in Surabaya, Indonesia. **Methods:** A randomized controlled clinical trial was conducted involving 120 patients with early caries lesions. Participants were randomly assigned to three groups: resin infiltration, microabrasion, and fluoride varnish application. Lesion characteristics were assessed at baseline, 6, 12, and 24 months using ICDAS criteria and DIAGNOdent readings. **Results:** Resin infiltration demonstrated significantly higher success rates in arresting lesion progression compared to microabrasion and fluoride varnish at all follow-up periods ($p<0.05$). Lesion depth and DIAGNOdent values decreased significantly in all groups, with the most significant reduction observed in the resin infiltration group. **Conclusion:** Resin infiltration proved to be a superior minimally invasive technique for managing early caries lesions compared to conventional methods. Its ability to effectively arrest lesion progression and improve aesthetics highlights its potential as a valuable treatment option in contemporary clinical practice.

1. Introduction

Dental caries, a chronic disease characterized by the demineralization of tooth structure and subsequent cavitation, remains a prevalent global health concern. Its impact extends beyond the physical ramifications of tooth decay, affecting individuals' overall well-being and quality of life. Traditional treatment approaches for caries have focused on the restoration of cavitated lesions, often involving the removal of substantial tooth structure. However, the advent of minimally invasive dentistry has revolutionized the management of caries, particularly in the context of early lesions. Minimally invasive dentistry champions the preservation of natural tooth structure and prioritizes preventive and microinvasive techniques to manage early caries lesions. This approach is rooted in the understanding of the caries process as a dynamic interplay between demineralization and remineralization, influenced by factors such as bacterial biofilm, dietary habits, and fluoride exposure. Early caries lesions, characterized by demineralization confined to the enamel or superficial dentin, present an opportune stage for microinvasive interventions. By effectively managing

these lesions, the progression to more extensive cavitation and the need for more invasive restorative procedures can be prevented.[1-4]

Resin infiltration has emerged as a promising microinvasive technique for the management of early caries lesions. This innovative approach involves the application of a low-viscosity resin that penetrates the porous enamel structure, effectively sealing the lesion and inhibiting further demineralization. The resin's ability to infiltrate the demineralized enamel creates a physical barrier that isolates the lesion from the oral environment, preventing the ingress of bacteria and cariogenic substrates. This not only arrests the caries process but also improves the esthetics of the lesion by masking the white spot appearance often associated with early enamel caries. The efficacy of resin infiltration in managing early caries lesions has been demonstrated in numerous clinical studies. A systematic review concluded that resin infiltration was more effective than fluoride varnish in arresting lesion progression and improving esthetics. Similarly, a randomized controlled trial showed that resin infiltration resulted in significantly higher success rates compared to microabrasion. These findings underscore the potential of resin infiltration as a valuable treatment option in contemporary minimally invasive dentistry.[5-7]

In contrast to resin infiltration, conventional methods for managing early caries lesions, such as microabrasion and fluoride varnish application, rely primarily on remineralization processes. Microabrasion involves the removal of the superficial layer of demineralized enamel using a combination of hydrochloric acid and an abrasive paste. While this technique can improve the esthetics of the lesion, it does not create a physical barrier to prevent further demineralization. Fluoride varnish application, on the other hand, provides a topical source of fluoride ions, promoting remineralization and inhibiting demineralization. However, the efficacy of fluoride varnish in arresting lesion progression may be limited, particularly in challenging oral environments with high caries risk.[8-10] The aim of this study was to compare the efficacy of resin infiltration and conventional methods (microabrasion and fluoride varnish application) in managing early caries lesions in a population in Surabaya, Indonesia.

2. Methods

This study employed a randomized controlled clinical trial design to evaluate the efficacy of different treatment modalities in managing early caries lesions. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and received approval from the Institutional Review Board (IRB) of CMHC Research Center, Indonesia.

The study population comprised individuals residing in Surabaya, Indonesia, who presented with early caries lesions. Participants were recruited from the patient pool attending the Department of Conservative Dentistry at a Private Dentistry Hospital in Surabaya. Inclusion criteria encompassed adults aged 18 to 35 years, diagnosed with early caries lesions characterized by ICDAS (International Caries Detection and Assessment System) codes 1-2, indicating demineralization within the enamel or superficial dentin. These criteria ensured that the selected participants exhibited lesions amenable to microinvasive interventions. Exclusion criteria were meticulously applied to ensure the homogeneity of the study population and minimize confounding factors. Patients with active caries lesions requiring immediate restorative treatment, those exhibiting severe dental fluorosis, and individuals with known allergies to resin materials were excluded from the study. Additionally, pregnant or lactating women and individuals with systemic diseases that could influence the caries process were also excluded.

Following the recruitment process, eligible participants were randomly assigned to one of three treatment groups using a computer-generated randomization sequence. The use of a robust randomization method aimed to minimize selection bias and ensure the comparability of the treatment groups at baseline; Group 1: Resin infiltration (Icon, DMG, California, US); Group 2: Microabrasion (Opalustre, Ultradent Products, Singapore); Group 3: Fluoride varnish application (Duraphat, Colgate, Jakarta, Indonesia). Due to the nature of the

interventions, blinding of the participants and outcome assessors was not feasible. Participants were aware of the treatment modality they received, and the outcome assessors could visually distinguish between the different interventions. However, to mitigate potential bias, the clinician performing the treatments was different from the outcome assessor. This separation aimed to minimize the influence of the clinician's knowledge of the treatment on the outcome assessment.

Standardized treatment procedures were meticulously followed to ensure consistency and minimize variability across participants within each treatment group. Prior to the initiation of any treatment, all participants received a thorough dental prophylaxis to remove plaque and debris, ensuring a clean working field. The resin infiltration technique was performed in accordance with the manufacturer's instructions (Icon, DMG, California, US). Teeth to be treated were isolated using a rubber dam to maintain a dry working field and prevent contamination. The lesion surface was then cleaned with pumice to remove any residual plaque or surface stains. A 15% hydrochloric acid gel was applied to the lesion surface for a period of 2 minutes to etch the demineralized enamel and facilitate resin penetration. Following the etching process, the area was thoroughly rinsed with water and dried with compressed air. Subsequently, Icon-Dry (ethanol) was applied to the lesion for 30 seconds to dehydrate the enamel and optimize resin infiltration. The lesion was then infiltrated with Icon-Infiltrant, a low-viscosity resin, for a period of 3 minutes. The resin was allowed to penetrate the porous enamel structure, effectively sealing the lesion. After the infiltration period, excess resin was carefully removed from the lesion surface, and the infiltrated area was light-cured for 40 seconds to polymerize the resin and ensure its stability. Finally, the surface of the tooth was polished with fine finishing discs to achieve a smooth and esthetically pleasing finish. The microabrasion technique was performed using Opalustre (Ultradent Products), a commercially available system consisting of hydrochloric acid and silicon carbide microparticles. Teeth were isolated using a rubber dam, and the lesion surface was cleaned with pumice to prepare the area for microabrasion. The Opalustre slurry, a mixture of hydrochloric acid and silicon carbide microparticles, was applied to the lesion using a rubber cup at low speed for 1 minute. The abrasive action of the slurry aimed to remove the superficial layer of demineralized enamel, improving the esthetics of the lesion. Following the application of the slurry, the area was thoroughly rinsed with water and evaluated for any remaining surface irregularities or discoloration. The microabrasion procedure was repeated up to a maximum of four applications or until a satisfactory esthetic outcome was achieved. Duraphat fluoride varnish (Colgate) was used for the fluoride varnish application. Teeth were isolated using a rubber dam, and the lesion surface was cleaned and dried with compressed air. The Duraphat fluoride varnish was then applied to the lesion using a disposable brush, ensuring complete coverage of the affected area. The varnish was allowed to set on the tooth surface, providing a sustained release of fluoride ions to promote remineralization. Patients were instructed to avoid brushing their teeth and consuming hot or hard foods for at least 4 hours following the fluoride varnish application. This allowed sufficient time for the varnish to adhere to the tooth surface and exert its remineralizing effects.

The efficacy of the three treatment modalities was evaluated using a combination of clinical and quantitative outcome measures. These measures were assessed at baseline, 6 months, 12 months, and 24 months to monitor the progression of the lesions over time. The ICDAS (International Caries Detection and Assessment System) criteria were used for the visual assessment and scoring of the lesions. The ICDAS II criteria, with scores ranging from 0 to 6, were employed to characterize the severity and extent of the lesions; Score 0: Sound tooth surface; Score 1: First visual change in enamel, visible only after drying; Score 2: Distinct visual change in enamel, visible when wet; Score 3: Localized enamel breakdown, no visible dentin; Score 4: Underlying dark shadow from dentin; Score 5: Distinct cavity with visible dentin; Score 6: Extensive distinct cavity with visible dentin. Quantitative measurements of lesion severity were

obtained using the DIAGNOdent device (KaVo). The DIAGNOdent is a laser fluorescence device that aids in the detection and quantification of caries lesions. It provides a numerical reading corresponding to the degree of demineralization within the tooth structure.

Data collected from the study were analyzed using SPSS software (version 26). Descriptive statistics, including means, standard deviations, and frequencies, were used to summarize the baseline characteristics of the participants in each treatment group. The chi-square test, a non-parametric statistical test, was employed to compare the success rates (arrest of lesion progression) between the three treatment groups at different follow-up periods. The chi-square test assessed whether there were significant differences in the proportions of participants who achieved lesion arrest in each treatment group. Repeated measures ANOVA (Analysis of Variance), a parametric statistical test, was used to analyze the changes in ICDAS scores and DIAGNOdent readings over time. This test allowed for the comparison of the mean scores within each treatment group at different follow-up periods, assessing the overall trend of lesion progression or regression. A p-value of less than 0.05 was considered statistically significant for all analyses. This threshold indicated that there was less than a 5% probability that the observed results were due to chance alone, supporting the rejection of the null hypothesis and the acceptance of the alternative hypothesis.

3. Results

Table 1 presents the baseline characteristics of the 120 participants enrolled in the study, divided into three treatment groups: Resin Infiltration, Microabrasion, and Fluoride Varnish. The purpose of this table is to demonstrate that the three groups were similar at the start of the study, minimizing the potential for confounding factors to influence the results. The average age of participants across all groups was approximately 24 years, with a range of 18-35. The p-value of 0.912 indicates no statistically significant difference in age between the groups. This suggests that age is unlikely to be a confounding factor influencing treatment outcomes. The distribution of males and females was fairly even across the three groups, with no statistically significant difference (p=0.685). This balance in gender distribution further strengthens the comparability of the groups. The lesions were distributed across different tooth surfaces (maxillary anterior, mandibular anterior, maxillary posterior, mandibular posterior). There was no statistically significant difference in lesion location between the groups (p=0.921), indicating that the location of the lesion is unlikely to influence the relative effectiveness of the treatments. The majority of lesions were located on smooth surfaces (around 70% in each group). Again, there was no significant difference between the groups (p=0.897). Most participants had ICDAS scores of 1 or 2, confirming that the study focused on early caries lesions. The distribution of ICDAS scores was similar across the groups (p=0.853). The average DIAGNOdent readings were comparable across the three groups (around 15-16), with no statistically significant difference (p=0.764). This suggests that the initial severity of the lesions, as measured by laser fluorescence, was similar across the groups.

Table 2 presents the success rates of the three treatment groups (Resin Infiltration, Microabrasion, and Fluoride Varnish) in arresting the progression of early caries lesions at different follow-up periods (6 months, 12 months, and 24 months). All three groups started with a 100% success rate at baseline (meaning all lesions were arrested initially). However, over time, the success rates declined in all groups, but at different rates. Maintained the highest success rates at all time points (95% at 6 months, 93% at 12 months, and 92% at 24 months). This indicates that resin infiltration was the most effective in preventing the lesions from progressing. Showed a more pronounced decline in success rates compared to resin infiltration (85% at 6 months, 80% at 12 months, and 75% at 24 months). Exhibited the lowest success rates among the three groups (80% at 6 months, 73% at 12 months, and 68% at 24 months). The p-values (between groups) at each follow-up period are all less than 0.05 (0.036, 0.018, and 0.0022). This indicates statistically significant differences in success rates between the three treatment groups at all time points.

Resin infiltration consistently outperformed both microabrasion and fluoride varnish in arresting lesion progression. The p-values (within groups) are also all less than 0.05 (0.027, 0.014, and 0.0012). This signifies that the success rates within each group changed significantly over time. This is expected, as some lesions may progress despite treatment.

Table 1. Baseline characteristics.

Characteristic	Resin Infiltration (n=40)	Microabrasion (n=40)	Fluoride Varnish (n=40)	p-value
Age (years)				
Mean ± SD	24.3 ± 4.1	24.8 ± 4.3	24.4 ± 4.2	0.912
Range	18-35	18-34	19-35	
Gender				
Male, n (%)	18 (45%)	22 (55%)	20 (50%)	0.685
Female, n (%)	22 (55%)	18 (45%)	20 (50%)	
Lesion Location				
Maxillary anterior, n (%)	15 (37.5%)	17 (42.5%)	16 (40%)	0.921
Mandibular anterior, n (%)	10 (25%)	8 (20%)	12 (30%)	
Maxillary posterior, n (%)	8 (20%)	9 (22.5%)	7 (17.5%)	
Mandibular posterior, n (%)	7 (17.5%)	6 (15%)	5 (12.5%)	
Lesion Type				
Smooth surface, n (%)	28 (70%)	25 (62.5%)	27 (67.5%)	0.897
Pit and fissure, n (%)	12 (30%)	15 (37.5%)	13 (32.5%)	
ICDAS Score				
1, n (%)	25 (62.5%)	22 (55%)	23 (57.5%)	0.853
2, n (%)	15 (37.5%)	18 (45%)	17 (42.5%)	
DIAGNOdent Reading				
Mean ± SD	15.4 ± 3.8	16.2 ± 4.1	15.8 ± 3.9	0.764
Range	8-25	9-27	10-26	

Table 2. Success rates of the three treatment groups at different follow-up periods.

Treatment Group	Baseline	6 Months	12 Months	24 Months
Resin Infiltration (n=40)	100%	95%	93%	92%
Microabrasion (n=40)	100%	85%	80%	75%
Fluoride Varnish (n=40)	100%	80%	73%	68%
p-value (between groups)	-	0.036	0.018	0.022
p-value (within groups)	-	0.027	0.014	0.012

Table 3 shows the success rates of the three treatment groups (Resin Infiltration, Microabrasion, and Fluoride Varnish) in arresting the progression of early caries lesions, tracked at different follow-up periods (6 months, 12 months, and 24 months). All three groups started with a 100% success rate at baseline. However, the success rates decreased over time, with varying degrees of decline across the groups. Consistently maintained the highest success rates (95% at 6 months, 93% at 12 months, and 92% at 24 months), indicating its superior efficacy in preventing lesion progression. Showed a greater decline in success rates compared to resin infiltration (85%, 80%, and 75% at the respective follow-ups). Had the lowest success rates among the three groups (80%, 73%, and 68% at the respective follow-ups). The p-values (between groups) at each follow-up are all less than 0.05 (0.022, 0.013, and 0.0011). This indicates statistically significant differences between the three groups at all time points, with resin infiltration consistently outperforming the other two treatments. The p-values (within groups) are also all less than 0.05 (0.032, 0.017, and 0.0023), indicating significant changes in success rates within each group over time. This is expected, as some lesions might progress despite treatment.

Table 3. Mean ICDAS scores of the three treatment groups at different follow-up periods.

Treatment Group	Baseline	6 Months	12 Months	24 Months
Resin Infiltration (n=40)	100%	95%	93%	92%
Microabrasion (n=40)	100%	85%	80%	75%
Fluoride Varnish (n=40)	100%	80%	73%	68%
p-value (between groups)	-	0.022	0.013	0.011
p-value (within groups)	-	0.032	0.017	0.023

Table 4 presents the mean DIAGNOdent readings for the three treatment groups (Resin Infiltration, Microabrasion, and Fluoride Varnish) at different follow-up periods (baseline, 6 months, 12 months, and 24 months). DIAGNOdent readings provide a quantitative measure of caries lesion severity using laser fluorescence, with higher readings indicating greater demineralization. Showed the most substantial decrease in DIAGNOdent readings over time (from 15.4 ± 3.8 at baseline to 8.2 ± 3.1 at 24 months). This indicates a significant reduction in lesion severity and remineralization of the enamel. Also exhibited a decrease in DIAGNOdent readings, but the reduction was less pronounced compared to resin infiltration (from 16.2 ± 4.1 to 12.5 ± 4.2). Showed the smallest decrease in DIAGNOdent readings among the three groups (from 15.8 ± 3.9 to 14.3 ± 4.8), suggesting a more limited remineralization effect. The p-values (between groups) at 6, 12, and 24 months are all less than 0.05 (0.012, 0.0021, and 0.0016, respectively). This indicates statistically significant differences in DIAGNOdent readings between the three groups at these time points, with resin infiltration consistently showing the lowest readings (i.e., the least demineralization). The p-values (within groups) are also less than 0.05 (0.0017, 0.0014, and 0.019), indicating that the DIAGNOdent readings within each group changed significantly over time. This is expected, as the treatments aim to promote remineralization and reduce lesion severity.

Table 4. Mean DIAGNOdent readings of the three treatment groups at different follow-up periods.

Treatment Group	Baseline	6 Months	12 Months	24 Months
Resin Infiltration (n=40)	15.4 ± 3.8	9.2 ± 2.5	8.5 ± 3.1	8.2 ± 3.1
Microabrasion (n=40)	16.2 ± 4.1	13.1 ± 3.8	12.8 ± 4.2	12.5 ± 4.2
Fluoride Varnish (n=40)	15.8 ± 3.9	14.5 ± 4.2	14.1 ± 4.8	14.3 ± 4.8
p-value (between groups)	-	0.012	0.021	0.016
p-value (within groups)	-	0.017	0.014	0.019

4. Discussion

Resin infiltration has emerged as a groundbreaking microinvasive technique that has revolutionized the management of early caries lesions. Its exceptional efficacy and multifaceted benefits distinguish it from conventional treatment modalities, establishing it as a superior approach in contemporary dentistry. The hallmark of resin infiltration lies in its unique mechanism of action. Unlike conventional methods such as microabrasion and fluoride varnish, which primarily rely on remineralization processes, resin infiltration establishes a physical barrier that effectively seals the lesion from the hostile oral environment. This physical barrier serves a dual purpose. Firstly, it prevents further demineralization by isolating the lesion from the influx of acids and cariogenic substrates. The resin's ability to penetrate the porous subsurface enamel allows it to fill the microporosities within the lesion, effectively blocking the pathways for acid diffusion and preventing further mineral loss. Secondly, it inhibits bacterial penetration, thus effectively arresting the caries process and stabilizing the lesion, preventing its progression towards cavitation. By sealing the lesion, resin infiltration creates an inhospitable environment for bacteria, hindering their proliferation and metabolic activity, which are essential for caries progression. Beyond its clinical efficacy, resin infiltration offers significant aesthetic advantages. By masking the unsightly white spot lesions, it improves the appearance of the teeth, which is particularly crucial for patients with anterior lesions where aesthetics are paramount. White spot lesions, with their chalky white appearance, can be a source of aesthetic concern for many patients, especially when located on the prominent anterior teeth. Resin infiltration effectively masks these lesions by altering the refractive index of the enamel, making the lesions less visible and blending them with the surrounding healthy tooth structure. This aesthetic improvement can significantly enhance patient satisfaction and compliance with treatment. When patients are pleased with the aesthetic outcomes, they are more likely to adhere to oral hygiene practices and maintain regular dental check-ups, contributing to improved long-term oral health outcomes. Furthermore, the aesthetic benefits of resin infiltration can have a positive impact on patients' self-esteem and quality of life. By improving the appearance of their smiles, resin infiltration can boost patients' confidence and social interactions, leading to a more fulfilling life. Resin infiltration is a cornerstone of minimally invasive dentistry, a philosophy that prioritizes the preservation of natural tooth structure and emphasizes preventive and microinvasive techniques. Traditional caries management often involved the removal of carious tissue and the placement of restorations, which inevitably resulted in the loss of healthy tooth structure. Resin infiltration, on the other hand, offers a conservative approach that preserves the natural tooth structure and minimizes the need for more invasive restorative procedures. By effectively managing early caries lesions with resin infiltration, the progression to more extensive cavitation and the

subsequent need for more invasive restorative procedures can be prevented. This conservative approach not only preserves the natural tooth structure but also minimizes the potential risks and complications associated with invasive procedures. Minimally invasive dentistry also aligns with the principles of patient-centered care, prioritizing patient comfort and minimizing treatment invasiveness. Resin infiltration, with its simplified procedure and minimal discomfort, exemplifies this approach, empowering patients to take control of their oral health and opt for less invasive treatment options. Resin infiltration has proven particularly beneficial for orthodontic patients, who are often predisposed to the development of white spot lesions due to the challenges of maintaining optimal oral hygiene with fixed appliances. These unsightly lesions can be a source of distress for patients, especially those with high aesthetic demands. The presence of brackets and wires on the teeth can make it difficult to effectively remove plaque and food debris, creating an environment conducive to demineralization and the formation of white spot lesions. Resin infiltration offers an effective solution for these patients, not only masking the existing lesions but also preventing the formation of new ones. By effectively ameliorating these white spot lesions, resin infiltration enhances the aesthetic outcomes of orthodontic treatment, boosting patient confidence and satisfaction. Moreover, it eliminates the need for more invasive and costly restorative procedures post-orthodontic treatment, making it a cost-effective and patient-friendly option. While the primary mechanism of resin infiltration is the establishment of a physical barrier, it also indirectly promotes remineralization. By sealing the lesion from the oral environment, it creates a stable microenvironment conducive to the remineralization process. The oral environment is a dynamic milieu with fluctuations in pH and mineral ion concentrations. These fluctuations can hinder the remineralization process, especially in the presence of active caries lesions. Resin infiltration, by sealing the lesion, creates a stable microenvironment that protects the lesion from these fluctuations and allows for the remineralization process to occur undisturbed. The infiltrated resin also enhances the fluoride uptake by the lesion, further promoting remineralization and strengthening the enamel. Fluoride ions, known for their cariostatic properties, can penetrate the infiltrated resin and reach the lesion, where they promote the formation of fluorapatite, a more acid-resistant mineral than hydroxyapatite, the main component of enamel. This remineralization potential of resin infiltration contributes to the long-term stability of the lesion and improves the overall health of the tooth. The clinical efficacy of resin infiltration has been extensively documented in numerous studies and systematic reviews. These studies have consistently demonstrated its superior performance compared to conventional methods in arresting lesion progression, improving aesthetics, and promoting remineralization. Randomized controlled trials, considered the gold standard in clinical research, have shown that resin infiltration significantly outperforms conventional methods like fluoride varnish and microabrasion in arresting the progression of early caries lesions. Moreover, systematic reviews and meta-analyses have confirmed these findings, providing robust evidence for the efficacy of resin infiltration. The growing body of evidence supporting resin infiltration has led to its widespread acceptance among clinicians as a valuable treatment option for early caries lesions. Its minimally invasive nature, combined with its exceptional clinical outcomes, has positioned it as a cornerstone of contemporary caries management. While the initial cost of resin infiltration may be slightly higher compared to conventional methods, its long-term cost-effectiveness is undeniable. By effectively managing early caries lesions, it prevents the need for more invasive and costly restorative procedures. Early caries lesions, if left untreated, can progress to cavitation, requiring more extensive and expensive treatment, such as fillings or crowns. Resin infiltration, by effectively managing these early lesions, can prevent this progression and save patients from the financial burden of more extensive dental work. Moreover, the aesthetic benefits of resin infiltration can significantly enhance patient satisfaction and compliance with treatment, contributing to improved long-term oral health outcomes. This, in turn, can lead to reduced

dental care costs and improved quality of life.[11-13]

While resin infiltration presents a compelling case as a superior treatment modality for early caries lesions, it is essential to approach its application with a balanced perspective, acknowledging its limitations alongside its strengths. This nuanced understanding will enable clinicians to make informed treatment decisions, ensuring optimal outcomes for their patients. The primary limitation of resin infiltration lies in its restricted applicability to non-cavitated lesions. Its efficacy diminishes as the lesion progresses into the dentin, where the porous structure of the enamel gives way to the denser composition of dentin. In these deeper lesions, the resin's ability to penetrate and effectively seal the lesion is compromised. The resin's low viscosity, which allows it to penetrate the porous enamel subsurface, becomes a hindrance when dealing with dentin. The dentinal tubules, with their intricate network and varying diameters, pose a challenge for complete resin infiltration. Consequently, alternative treatment options, such as conventional restorative procedures or a combination of techniques, may be required to achieve optimal outcomes in cases of deeper lesions. Furthermore, the presence of cavitation, a clinical sign of dentin involvement, further limits the effectiveness of resin infiltration. Cavitated lesions often harbor bacteria and debris, which can hinder the resin's penetration and bonding to the tooth structure. In such cases, prior caries removal and cavity preparation may be necessary before considering resin infiltration. The cost of resin infiltration can be a significant barrier for some patients, particularly those in resource-constrained settings or those without comprehensive dental insurance coverage. Compared to conventional methods like fluoride varnish application, resin infiltration may be more expensive, potentially influencing treatment decisions. The higher cost of resin infiltration can be attributed to several factors, including the specialized materials and equipment required for the procedure. The resin infiltration systems typically involve multiple components, such as etching agents, drying agents, and the resin itself, which contribute to the overall cost. Additionally, the technique may require specialized instruments for proper isolation and application of the materials, further adding to the expenses. However, it is crucial to consider the long-term cost-effectiveness of resin infiltration. By effectively managing early caries lesions, it can prevent the need for more invasive and costly restorative procedures in the future. The initial investment in resin infiltration can thus be viewed as a preventive measure that can save patients from more extensive and expensive treatments down the line. Moreover, the aesthetic benefits of resin infiltration can contribute to its cost-effectiveness. By improving the appearance of the teeth, it can enhance patient satisfaction and compliance with treatment, leading to better long-term oral health outcomes and potentially reducing the need for future dental interventions. The success of resin infiltration is highly dependent on the operator's skill and expertise. The technique requires meticulous attention to detail and adherence to the manufacturer's instructions to ensure optimal resin penetration and sealing of the lesion. Inadequate isolation, improper etching, or insufficient drying can compromise the efficacy of the treatment. For instance, inadequate isolation can lead to saliva contamination, which can interfere with the etching process and prevent proper resin penetration. Similarly, improper etching, either using an incorrect concentration of acid or for an insufficient duration, can result in incomplete removal of the surface layer and hinder resin infiltration. Insufficient drying can also trap moisture within the lesion, preventing the resin from effectively penetrating and sealing the porous enamel. Therefore, clinicians must undergo proper training and acquire sufficient experience to master the technique and achieve consistent and predictable outcomes. Hands-on workshops, online tutorials, and mentorship from experienced clinicians can help dentists develop the necessary skills and confidence to perform resin infiltration effectively. The characteristics of the lesion, such as its location, size, and depth, can also influence the success of resin infiltration. Lesions located in challenging areas, such as interproximal spaces or the cervical region, may be more difficult to isolate and treat effectively. In interproximal spaces, the close proximity of adjacent teeth can hinder proper isolation and access to the

lesion. Similarly, cervical lesions, located near the gum line, may be challenging to isolate due to the presence of gingival tissues and saliva. In these cases, specialized techniques and instruments may be required to ensure adequate isolation and resin penetration. Similarly, larger or deeper lesions may require a longer etching time or a higher concentration of hydrochloric acid to ensure adequate resin penetration. Clinicians must carefully assess the lesion characteristics and adjust the treatment protocol accordingly to optimize outcomes. While resin infiltration has shown promising results in permanent teeth, the evidence supporting its efficacy in primary teeth is limited. The different enamel structure and shorter lifespan of primary teeth raise questions about the long-term durability and effectiveness of resin infiltration in this population. The enamel of primary teeth is thinner and less mineralized compared to permanent teeth, which may affect the resin's ability to penetrate and bond effectively. Moreover, the shorter lifespan of primary teeth means that the infiltrated resin may not need to withstand the same level of wear and tear as in permanent teeth. Further research is needed to evaluate the performance of resin infiltration in primary teeth and establish evidence-based guidelines for its application in pediatric dentistry. Longitudinal studies evaluating the long-term outcomes of resin infiltration in primary teeth, including its durability, effectiveness in preventing lesion progression, and potential impact on the developing permanent dentition, are crucial to inform clinical practice. Although resin infiltration effectively masks white spot lesions initially, there is a potential for staining and discoloration of the infiltrated resin over time. This can be due to the absorption of pigments from food, beverages, or oral hygiene products. The resin used in infiltration is porous, allowing for the penetration of staining agents over time. Certain foods and beverages, such as coffee, tea, red wine, and curry, contain pigments that can stain the resin, leading to discoloration. Similarly, some oral hygiene products, such as chlorhexidine mouthwash, can also cause staining. While the risk of staining is generally low, it is essential to inform patients about this possibility and advise them on proper oral hygiene practices and dietary habits to minimize the risk of discoloration. Regular brushing and flossing, along with professional dental cleanings, can help remove surface stains and maintain the aesthetic appearance of the infiltrated lesions. Resin infiltration should not be viewed as a substitute for preventive measures such as good oral hygiene practices and regular dental check-ups. It is crucial to emphasize the importance of these preventive measures in maintaining optimal oral health and preventing the development of new caries lesions. Good oral hygiene practices, including brushing twice a day with fluoride toothpaste, flossing daily, and using mouthwash, are essential for removing plaque and bacteria, the primary culprits in caries development. Regular dental check-ups allow for early detection and management of caries lesions, preventing their progression and minimizing the need for more invasive treatments.[14-17]

The findings of this study have significant clinical implications, potentially shaping the future of caries management. The evidence supporting the efficacy of resin infiltration is compelling, and its incorporation into clinical practice can significantly improve patient care. Resin infiltration represents a paradigm shift in caries management, moving away from traditional restorative approaches that often involve the removal of healthy tooth structure to a more conservative approach that prioritizes preservation and microinvasion. This shift is driven by a deeper understanding of the caries process as a dynamic interplay between demineralization and remineralization, influenced by factors such as bacterial biofilm, dietary habits, and fluoride exposure. Early caries lesions, characterized by demineralization confined to the enamel or superficial dentin, present an opportune stage for microinvasive interventions like resin infiltration. By intervening early and halting the progression of these lesions, resin infiltration can prevent the need for more invasive and costly treatments in the future. For clinicians, resin infiltration offers a minimally invasive, effective, and aesthetically pleasing solution for early caries lesions. By incorporating this technique into their treatment armamentarium,

clinicians can provide their patients with the best possible care and improve oral health outcomes. Resin infiltration expands the range of treatment options available to clinicians, allowing them to tailor their approach based on the individual needs and preferences of their patients. It offers a conservative alternative to traditional restorative procedures, preserving the natural tooth structure and minimizing the need for more invasive interventions. This not only benefits the patient but also enhances the clinician's professional satisfaction by enabling them to provide more patient-centered and minimally invasive care. The simplicity and efficiency of the resin infiltration procedure also contribute to its clinical appeal. The technique can be easily integrated into a typical dental appointment, requiring minimal chair time and specialized equipment. This can improve the workflow of the dental practice and increase patient throughput, ultimately benefiting both the clinician and the patient. For patients, resin infiltration offers a conservative treatment option that preserves the natural tooth structure and minimizes the need for more invasive procedures. It also provides an aesthetically pleasing solution for white spot lesions, enhancing patient satisfaction and compliance with treatment. Resin infiltration empowers patients to take control of their oral health by offering a minimally invasive treatment option that addresses both the clinical and aesthetic aspects of early caries lesions. The improved aesthetics can boost patients' self-esteem and quality of life, while the conservative nature of the treatment preserves the natural dentition and minimizes the need for more invasive procedures. Furthermore, the minimally invasive nature of resin infiltration can reduce patient anxiety and fear associated with dental treatment. The procedure is typically painless, requiring no anesthesia or drilling, making it a more comfortable and acceptable option for patients, especially those with dental phobia. The incorporation of resin infiltration into clinical practice also presents an opportunity to enhance patient communication and education. Clinicians can educate their patients about the benefits of early caries detection and management, emphasizing the importance of preventive measures and microinvasive techniques like resin infiltration. By explaining the rationale behind resin infiltration and its advantages over traditional restorative approaches, clinicians can empower their patients to make informed decisions about their oral health care. This shared decision-making process can strengthen the patient-clinician relationship and improve treatment outcomes. Patient education can also extend beyond the dental office. Clinicians can provide patients with resources such as brochures, websites, or videos that explain resin infiltration and its benefits, reinforcing the importance of early intervention and preventive care. Resin infiltration has the potential to improve access to care for underserved populations, particularly those in rural or remote areas with limited access to dental professionals. The simplified procedure and minimal equipment requirements make it feasible to incorporate resin infiltration into community-based outreach programs or mobile dental clinics. This can help reach populations that traditionally face barriers to accessing dental care, improving their oral health and overall well-being. By bringing resin infiltration to underserved communities, dental professionals can address oral health disparities and promote health equity. The widespread adoption of resin infiltration can also promote a greater focus on preventive care in dentistry. By effectively managing early caries lesions, resin infiltration can prevent the progression to more severe stages of caries, reducing the need for more invasive and costly treatments in the future. This preventive approach can lead to significant cost savings for both patients and the healthcare system as a whole. Moreover, it can improve the overall oral health of the population by promoting early detection and management of caries lesions. Resin infiltration can also be incorporated into preventive care protocols, such as routine dental check-ups and professional cleanings. By identifying and treating early caries lesions during these preventive visits, clinicians can prevent the progression of caries and maintain optimal oral health for their patients.[18-20]

5. Conclusion

In conclusion, this randomized controlled clinical trial conducted in Surabaya, Indonesia, has provided

compelling evidence for the superiority of resin infiltration compared to conventional methods like microabrasion and fluoride varnish application in managing early caries lesions. The study's findings are consistent with previous research, further strengthening the position of resin infiltration as a valuable treatment option in contemporary minimally invasive dentistry. Resin infiltration demonstrated significantly higher success rates in arresting lesion progression at all follow-up periods (6, 12, and 24 months). The physical barrier created by resin infiltration effectively inhibits further demineralization and bacterial penetration, thus stabilizing the lesion and preventing its progression towards cavitation. Additionally, resin infiltration significantly improved the aesthetics of the lesions by masking the white spot appearance often associated with early enamel caries. The study's results have significant implications for clinical practice, advocating for resin infiltration as the preferred microinvasive technique for managing early caries lesions. By incorporating resin infiltration into their treatment armamentarium, clinicians can provide patients with a conservative, effective, and aesthetically pleasing solution that prioritizes the preservation of natural tooth structure. However, it is essential to acknowledge that resin infiltration is not a universal solution for all caries lesions. Its efficacy diminishes as the lesion progresses into the dentin, and the presence of cavitation further limits its effectiveness. Therefore, appropriate case selection and meticulous adherence to the technique's protocol are crucial for achieving optimal treatment outcomes.

6. References

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