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LITERATURE REVIEW

FLUORIDE PENETRATION DEPTH AND ITS IMPACT ON WHITE SPOT LESIONS AND MOLAR INCISOR HYPO-MINERALIZATION: A LITERATURE REVIEW

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ABSTRACT

Background: Fluoride (F) is an effective anticaries agent and can be delivered through various mediums at different concentrations. A pivotal aspect of fluoride's effectiveness is its ability to penetrate enamel, impacting its remineralizing potential but limited comparative data exists on their effects on lesion depth.
Objective: To evaluate the efficacy of topical fluoride on lesion depth specifically by comparing its effects on white spot lesions and Molar Incisor Hypo-mineralization (MIH).
Material and Methods: Literature review included 16 references dated from 2021 to 2024. The articles were divided into 6 clinical studies analyzing the Fluoride effect on enamel lesions and 4 articles treating its effect on MIH lesions. In addition, 4 studies revealing depth of enamel lesions and a reviewing of EAPD and ICDAS international guidelines.
Results: In healthy enamel and early carious lesions such as white spot lesions (WSLs), fluoride primarily acts on the superficial layers, typically within the outer 30-50 μm, promoting remineralization and inhibiting demineralization. However, deeper penetration is often limited, making fluoride less effective in reversing more advanced subsurface demineralization. In contrast, molar incisor hypo-mineralization (MIH) affected enamel is structurally compromised, with porosities extending much deeper (often beyond 300 μm), making it less receptive to conventional fluoride treatments.
Conclusion: Although Fluoride is frequently recommended, its remineralization effect on MIH lesions is limited, whereas it has been proven effective on white spot lesions.

Keywords: Lesion depth, remineralization, demineralization, fluoride, white spot lesion, MIH.

INTRODUCTION

Enamel demineralization is a critical issue in modern dentistry, leading to aesthetic and structural damage to teeth. Two common enamel conditions are white spot lesions (WSLs) and molar-incisor hypo-mineralization (MIH**)**. While both conditions weaken the enamel, their structural differences impact how well they respond to topical fluoride treatments.

White Spot Lesions

WSLs are the initial stage of dental caries, and their prevalence has been rising in recent years, ranging from 10% to 49%. They are commonly observed in patients undergoing orthodontic treatment, primarily due to the accumulation of bacterial plaque in the cervical region of the tooth (Fig1).[1] Clinically, the lesion appears as an opaque white area due to an optical phenomenon resulting from mineral loss and the difference in the refractive index of water and air filling the spaces within the enamel. As a result, the lesion exhibits a whitish color with reduced translucency due to increased enamel porosity.[2]

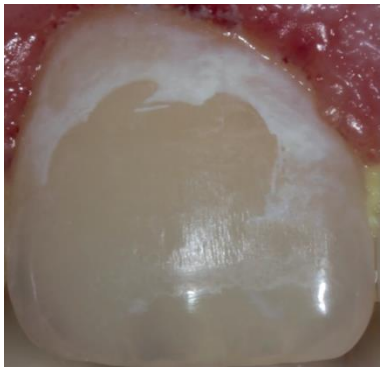


Figure 1. A clinical photo of WSL

According to the International Caries Detection and Assessment System (ICDAS), WSLs are classified as follows.[3]

Code 1	Code 2
Visible only on dry surfaces	visible on wet surfaces

Histologically, WSLs display four zones: (A) The demineralized translucent zone is characterized by the loss of the enamel structure by a 1% pore volume from the initial mineral loss.
(B) The dark zone is characterized by a 2 - 4% pore volume filled with air.
(C) The demineralization core zone is situated approximately 15 - 30 µm beneath the overlying intact enamel surface. It is characterized by a structureless enamel, with the highest pore volume 5-25%.
(D) The remineralization surface zone forms the outermost intact surface overlying the lesion, with < 5% pore volume (10 to100µm).[4]
In this context, accurate diagnostic tools are essential for measuring enamel demineralization depth. Silvabraga et al. evaluated OCT and TMR for measuring enamel caries depth in demineralized bovine enamel. OCT ranged from 24.0–174.0 µm, TMR from 59.2–198.0 µm, showing a strong correlation (rho = 0.75, $p < 0.001$), supporting OCT's reliability.[5]

Molar Incisor Hypo-mineralization

The term molar-incisor hypo-mineralization (MIH) was initially introduced by Weerheijm et al. in 2001, where it was defined as "hypo-mineralization of systemic origin, characterized by demarcated, qualitative defects in the enamel of one to four first permanent molars (FPMs), often associated with affected incisors.
The histopathological data relating to MIH reveals that, unlike other types of enamel defects, *hypo-mineralization* in MIH begins at the amelodentinal junction (ADJ) and not at the surface of the enamel." For example, Incisor enamel thickness ETH ranged between 0.60 and 0.84 mm (600 and 840 µm), so it's expected that lesion will fall within this range.

Figure 2. MIH figure representation (6)

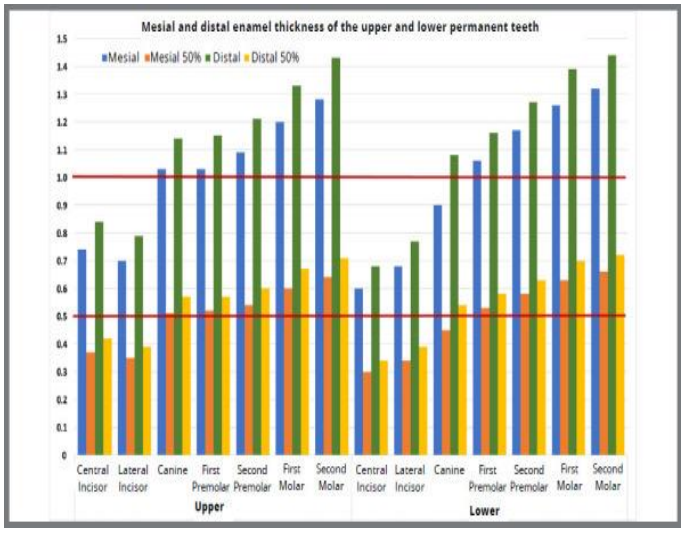


Figure 3. Enamel thickness on the mesial and distal surfaces of the upper and lower permanent teeth. Lower horizontal line indicates value limits up to 0.5 mm and upper horizontal line indicates value limits up to 1 mm. [7]

The European Academy of Pediatric Dentistry (EAPD) has established diagnostic criteria for assessing dental defects. These criteria are based on the description of the defect, including the affected teeth, presence of demarcated opacities, sensitivity, atypical restorations, and severity classification. The severity is categorized into two levels: mild and severe lesions.
Meanwhile, the EAPD outlines treatment options involving fluoride and their effects, as detailed in the table below.

Table 1. Grade Ratings for Remineralization Management in MIH

Interventions for remineralization	No. of studies	No. of teeth	GRADE of evidence quality	Strength of Recommendation
Topical CPP-ACP can be used to remineralize affected teeth	3	61	Moderate	Conditional
Topical CPP-ACFP/NaF 4–5% with and without tricalcium phosphate can be used to remineralize affected teeth	3	88	Very low	Conditional

Given the limited capacity for enamel recovery, the EAPD guidelines do not recommend fluoride-based treatments as a primary approach for MIH management, as shown in table 2.[8]

Table 2. Diagrammatic Management Summary for MIH-Affected Incisors

Severity	Clinical examination	Problems	Therapeutic approach
Severe ↑ Mild	Opacities + Loss of enamel structure	Risk of tooth fracture + Aesthetic concerns	Localised macro-abrasion/micro-abrasion + Resin infiltration + Composite restoration
	Opacities on the incisal edge	Aesthetic concerns ± Risk of tooth fracture	Localised macro-abrasion/micro-abrasion + Resin infiltration + Composite restoration
	Brown/yellow opacities	Aesthetic concerns	Localised macro-abrasion/micro-abrasion + Resin infiltration + Composite restoration
	White/creamy opacities	Aesthetic concerns	Regional whitening +/- Micro-abrasion +/- Resin infiltration OR don't do anything

Therefore, distinguishing between the two lesions is crucial for selecting the appropriate treatment. Table 3 presents a comparative analysis of WSL and MIH.

Table 3. Comparative analysis of WSL and MIH

WSL	MIH
Initial stage of dental caries	Hypo-mineralization begins at the amelodentinal junction,(lesions> 1 mm)
Lesion appears opaque white	White-creamy to yellow-brown opacities
Cervical region of the tooth (Fig1)	Incisal edge of the incisors (lesions do not involve the cervical third of affected teeth) (Fig2)
Due to the accumulation of bacterial plaque	Hypo-mineralization of systemic origin
Lesion depth varied from 24.0 to 198.0 µm	Lesion depth ranged between 600 and 840 µm
All teeth can be affected	Permanent molars, often associated with affected incisors

This study comprehensively evaluates the efficacy of fluoride treatment on enamel lesions by examining lesion structure, clinical results, and advancements in treatment approaches. The comparison of fluoride treatments based on their depth of penetration provides practical guidance for clinical decision-making. Moreover, the findings establish a crucial baseline for future research and the formulation of evidence-based guidelines for enamel lesion management.

MATERIALS AND METHODS

This literature review covered the field of WSL, MIH and remineralization by using varnish fluoride. It was reported per the PRISMA guidelines and outlined the research question, objectives, inclusion and exclusion criteria, and the methodological approach. The review included articles from Google Scholar, Medline, Scopus, Web of Sciences, and PubMed. Two review authors screened the results of the searches against inclusion criteria, extracted data and assessed the risk of bias independently and in duplicate.

This review presents a comparative overview of remineralization studies between WSL and MIH focusing on NaF (5%) as an active ingredient.

- The literature search included sixteen articles from the period 2021 to 29 December 2024.
- Scientific articles published in the English language.
- Role of caries in lesion formation.
- Six Clinical studies that mention the effect of fluoride varnish on Enamel lesions.
- Four studies mention the effect of fluoride varnish on MIH lesions
- EAPD and ICDAS Guidelines.

Experience revealing the depth of enamel lesions:

- Radiographic evaluation of enamel thickness

- Enamel caries lesion depth (Aline Silva Braga).

- Findings from Chris Ivanoff's study about fluoride penetration into enamel.

RESULTS

The results are divided into WSL-remineralization studies and MIH remineralization using in both studies FV 5%NaF. Although fluorides are frequently recommended for MIH patients, the clinical evidence for using fluoride for remineralization of MIH is very low (table1).

Six studies were found analyzing the WSL remineralization effect using 5% sodium FV (table 4), And four studies evaluating the effect of same FV on MIH patients (table5).

Table 4. Overview of studies analyzing the WSL remineralization effect using 5% sodium FV

Articles	Age	Patients	Applications range	Duration	Diagnosis method	Results
Effectiveness of Fluoride Varnishes for White Spot Lesion Prevention and Remineralization during Orthodontic Treatment: A Randomized Controlled Trial. [9]	Adolescents	65	Weekly for the first 4 weeks and then after 6 and 12 months	12 months	-ICDAS -Quantitative light-induced fluorescence -ANOVA -Kruskall-Wallis tests	Decline of WSL at 12 months
Fluoride varnish, ozone and octenidine reduce the incidence of white spot lesions and caries during orthodontic treatment.[10]	16 - 50	30	5 % NaF Every 4 weeks	12 months	WSL index	Reduce the incidence of WSLs comparing to control group
White spot lesions: diagnosis and treatment – a systematic review. [2]	12 - 22	110	Every month	6 months	Diagnodent	WSLs decreased at 3-month and more at 6-month
Systematic review of preventive and treatment measures regarding orthodontically induced white spot lesions.[11]	12 - 25	240	2 app at 3 months and 6 months	6 months	Quantitative light-induced fluorescence	Treatment can induce the greatest amount of remineralization in comparison with control group
Systematic review of preventive and treatment measures regarding orthodontically induced white spot lesions. [12]	13 - 20	12	2 app at 1 week interval 1 week 1 month 2 months 3 months	3 months	Diagnodent	Capable of controlling the WSLs adjacent to bracket
Analyzing Effectiveness of Different Delivery Methods for Remineralization Agents in Pediatric Dental Health: A Systematic Review. [12]	6 - 7	12	Applied at baseline, 1 month, and 3 months	3 months	Diagnodent	showed significant remineralization at 3 and 6 months
Analyzing the Effectiveness of Different Delivery Methods for Remineralization Agents in Pediatric Dental Health: A Systematic Review.[12]	8 - 15	21	5 treatments (weeks 1-4 and week 12	12 weeks	Visual assessment Diagnodent	Visual appearance Laser fluorescence showed significant remineralization in all treatment groups (p <

						0.001).
Analyzing the Effectiveness of Different Delivery Methods for Remineralization Agents in Pediatric Dental Health: A Systematic Review.[12]	12-20 years	240	No specific duration mentioned, treatment was applied during monthly visits	Once a month	QLF imaging, assessing DF (%), area (mm^2), and DQ (mm^2 × %)	significant improvements in demineralization metrics (DQ,DF, area) after 3 and 6 months
Methods for Remineralization Agents in Pediatric Dental Health: A Systematic Review.[12]	12-36 Months	140	Fluoride varnish is applied every 4 months: 1minute per session	12 months	Visual inspection of WSL area. DMFT index	Significant reduction in WSL after 12 months 51% decrease in WSL
Evaluation of the preventive effect of two concentrations of xylitol varnish versus fluoride varnish on enamel demineralization around orthodontic brackets: a randomized controlled trial.[13]	Orthodontic patients	30	App at T1(before ortho treatment) T2 at 3 months T3 at 6 months T4 after treatment	Not mentioned	Diagnodent	lower mineral loss than the placebo group at T2 and T3

Table 5. Overview of studies analyzing the MIH-remineralization effect of 5% sodium fluoride.

Article (year of publication)	Age	Patients	Applications range	Duration	Diagnosis method	Results
Remineralization Strategies for Teeth with Molar Incisor Hypomineralization (MIH): A Literature Review.[6]	6-17	29	3 app of 5% sodium fluoride varnish (Colgate Duraphat®) for 1 minute; T0 T1= day15 T2= day30	45days	Diagnodent	Effective in moderate lesions
Treatment Approaches to Molar Incisor Hypomineralization: A Systematic Review.[14]	9-12y	51	4 app of 5% NaF (Duraphat) varnish, with a 1-week interval	4 Weeks	Quantitative Light- Induced Fluorescence QLF. The data were analyzed by repeated measures ANOVA and Tukey's	No significant changes

Structural integrity of MIH-affected teeth after treatment with fluoride varnish or resin infiltration: An 18-Month randomized clinical trial. [15]	6-12	51 (86 teeth)	FV Duraphat	18 months	Fisher's Exact was used to test the association of treatments with PEB, the Kaplan-Meyer and Cox DMFT	loss of integrity due to post-eruptive enamel breakdown (PEB)
Effects of different remineralization agents on MIH defects: a randomized clinical study.[16]	6-9	49	FV no clarification	24 months	Diagnodent	No statistically significant difference

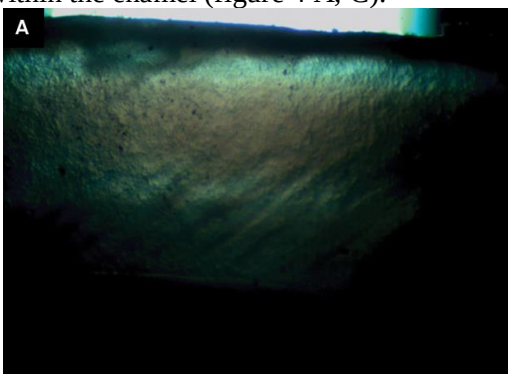
DISCUSSION

Recently, non-invasive approaches to managing early carious lesions for preserving healthy tooth substance and preventing lesion progression have become important. In this regard, fluoride has been shown to increase remineralization and fluoride varnishes have gained importance.

In this regard, this literature review represents a comparative analysis of the remineralization effects of sodium fluoride (NaF) varnishes on white spot lesions and molar incisor hypo-mineralization (MIH). It examines the efficacy of NaF varnishes in promoting enamel remineralization in both conditions, providing insights into their clinical implications and potential benefits.

NaF Varnish (5%) is a commonly used fluoride varnish that has been evaluated by similar studies, and it increases the fluoride content of the enamel by releasing sufficiently high levels of fluoride ions. In the present study, Duraphat, the gold standard fluoride varnish, containing NaF alone, was used. White spot lesions (WSL) and molar incisor hypo-mineralization (MIH) differ in their response to remineralization with sodium fluoride (NaF) varnishes due to variations in their etiology, enamel structure and depth of the lesion inside.

An image with polarized light microscope demonstrates the effectiveness of fluoride penetration within the enamel (figure 4 A, C).



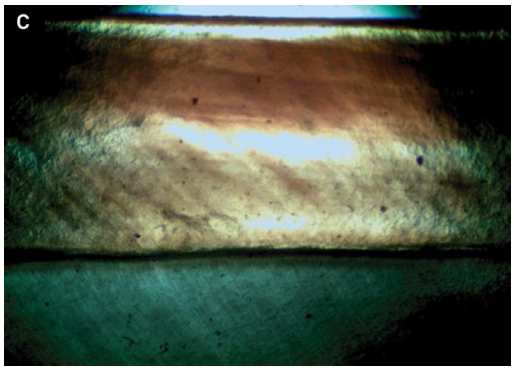


Figure 4. Polarized light microscopy images showing the subsurface caries lesion, as well as the region of the most mineralized surface, resulting from varnish application. A) dark color in the subsurface area (the most demineralized); C) Duraphat group.[17]

The distinct contrast observed in the treated areas highlights the mineral deposition facilitated by fluoride, reinforcing its role in enamel remineralization. The image provides visual evidence of fluoride's ability to integrate into demineralized regions, enhancing enamel structure and reducing lesion porosity. Such microscopic analysis is crucial for understanding the depth and extent of fluoride uptake, particularly in different enamel conditions like white spot lesions and molar incisor hypo-mineralization.

In the present study, to monitor mineralization changes in both cases, laser fluorescence scanning method with a Diagnodent device was used in most studies.

In most clinical cases of white spot lesion (WSL), sodium fluoride (NaF) Varnish has shown a significant reduction in lesion size and severity at both 3- and 6-month follow-up visits (Table 4).

The effectiveness of NaF in WSL is attributed to its ability to enhance remineralization by depositing fluoride ions, as deep as possible, which integrate into the enamel and strengthen its structure.

However, in cases of molar incisor hypo-mineralization. (MIH), clinical studies have reported minimal or no significant improvements following NaF varnish application (Table5).

This lack of response, along with experimental studies analyzing the depth of fluoride penetration into enamel, inspired me to undertake this article.

Dr Chris Ivanoff has conducted significant research on enhancing fluoride penetration into dental enamel to improve the treatment of lesions and reduce their depth. Traditional methods of fluoride application often result in limited penetration, typically not exceeding 50 micrometers (μm) into the enamel. To address this limitation, Dr Ivanoff explored the use of Di electrophoresis (DEP) and alternating current electroosmosis (ACEO) as techniques to facilitate deeper fluoride delivery.

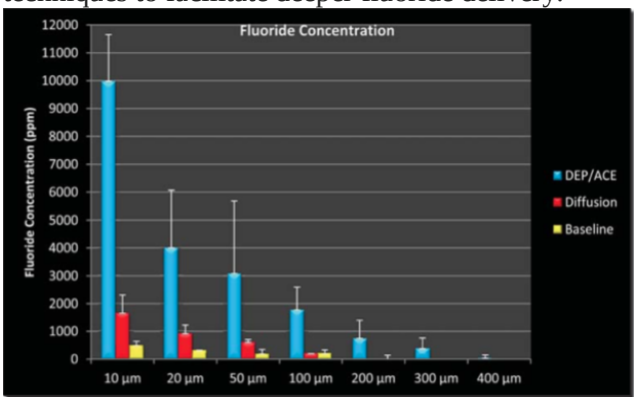


Figure 5. Chart showing how fluoride concentrations vary at different depths within tooth enamel[18]

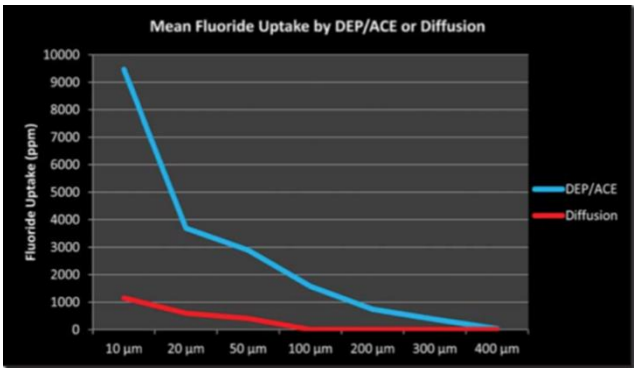


Figure 6. Chart showing Mean fluoride Uptake by DEP/ACE or diffusion (18)

CONCLUSION

In summary, the comparison of enamel conditions such as white spot lesions (WSLs) and molar-incisor hypo-mineralization. (MIH) reveals significant differences in their structural characteristics and treatment responses, particularly concerning fluoride varnish applications. WSLs, being an initial stage of dental caries, demonstrate a robust capacity for remineralization through topical fluoride treatment, leading to a marked reduction in lesion size and severity. In contrast, MIH, characterized by a systemic origin of hypo-mineralization and significant structural deficits beginning at the amelodentinal junction, shows a limited response to fluoride varnish treatments.

This literature review highlights that while sodium fluoride (5% NaF) varnishes have proven effective in the management of WSLs, their clinical efficacy in MIH presents minimal improvement or no significant change. The findings underscore the necessity for tailored management strategies for these enamel conditions, focusing on the inherent differences in lesion depth, structural integrity, and underlying pathology. Moreover, advancements in fluoride delivery methods, such as those explored by Dr. Chris Ivanoff, offer promising avenues for enhancing fluoride penetration and efficacy in treating deeper enamel lesions. The potential application of these innovative techniques may improve the clinical outcomes for MIH patients, warranting further exploration and research.

As evidence-based guidelines continue to evolve, it is crucial for practitioners to be informed about the comparative effectiveness of fluoride treatments in managing enamel defects. Future studies should aim to establish standardized protocols for addressing MIH while assessing new technologies that may augment treatment efficacy. Overall, this review provides foundational insights into enamel remineralization strategies, reinforcing the importance of individualizing treatment approaches to optimize patient outcomes in modern dental practice.

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