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ORIGINAL SCIENTIFIC ARTICLE

Penetration depth and enamel hardness effects of resin infiltrate and fissure sealant in MIH-affected molars: An in-vitro comparison

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Abstract

Purpose To measure and compare the penetration depth of two treatment materials, a resin infiltrate (RI) and a fissure sealant (FS), into the enamel of MIH-affected molars without post-eruptive breakdown, and the materials' effect on the hardness of the hypomineralised enamel.

Methods Two groups of sixteen mildly affected MIH-molar specimens were treated with either RI or FS. Two additional groups of untreated MIH specimens and healthy specimens served as a positive and a negative control, respectively. Specimens were treated and thereafter analysed using scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (SEM–EDX), and hardness testing machine. Penetration depth of treatment material, surface element analysis and hardness values were measured.

Results There was a statistically significant difference in penetration depth between the tested materials ($p < 0.05$). RI penetrated deeper and more evenly into the affected enamel of MIH-lesions, compared to FS. EDX analysis showed statistically significant differences in mineral contents between the study groups ($p < 0.05$), and presence of fluoride was detected only in the FS group. In the RI-treated enamel, the hardness reached values twice as high as compared to that in the untreated MIH-group but remained below the hardness of healthy enamel. Mean hardness values in FS samples were not significantly different from those of untreated MIH-samples ($p > 0.05$).

Conclusion The low-viscosity RI penetrated more deeply into porous hypomineralised enamel of MIH-affected molars compared to the FS. RI increased enamel hardness and altered mineral content. These findings encourage clinical use of RI as minimally invasive treatment of mildly MIH-affected molars to prevent post-eruptive breakdown.

Keywords Tooth enamel · Molar-incisor-hypomineralisation · Resin infiltrate · Fissure sealant · Minimally invasive treatment

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Introduction

Enamel of the teeth diagnosed with molar-incisor-hypomineralisation (MIH) is characterized by less distinct and disorganized prism borders and crystals, as well as by more marked inter-prismatic space in contrast to the unaffected enamel. In addition, the affected enamel has lower mineral density (Fagrell et al. 2010) and higher protein content (Magnum et al. 2010), leading to increased porosity. The highest permeability in enamel is in the prismatic boundaries—rod sheaths, which can be broader than in unaffected enamel.

Clinical signs of hypomineralised areas typical in MIH-affected teeth, are asymmetric demarcated opacities, which vary widely in severity, size and color that can be from creamy white to yellowish up to brown. Clinical symptoms

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of MIH-affected teeth are frequently sensitivity, ranging from mild response to external stimuli to spontaneous hypersensitivity. The MIH-affected posterior teeth tend to suffer post-eruptive breakdown (PEB), occurring soon after tooth eruption, due to masticatory forces (Lygidakis et al. 2022). PEB in turn facilitates bacterial and plaque accumulation and increases tooth sensitivity. These may be reasons for insufficient daily brushing, facilitating the onset of carious lesions under caries-promoting oral circumstances (Fragelli et al. 2015; Oreano et al. 2023). According to clinical follow-up studies, the yellow and brown opacities seem to be in a greater risk of PEB or any failure of treatment than lighter opacities (Da Costa-Silva et al. 2011).

Due to subjective symptoms and aesthetic issues caused by enamel opacities as well as PEB, oral health-related quality of life of children and adolescents with MIH diagnosis is compromised with subsequent psychological consequences and functional burden (Jälevik et al. 2022). Moreover, children with MIH require more frequently dental preventive and restorative treatments than their healthy counterparts (Jälevik & Klingberg 2012).

Consensus recommendations of the International Association of Paediatric Dentistry (IAPD 2020) and the European Association of Paediatric Dentistry (EAPD) (Lygidakis et al., 2022) emphasize early diagnosis and provision of preventive strategies as key to the management of MIH-affected molars to avoid progressive breakdown and possible pulpal inflammation and hypersensitivity of MIH-affected teeth. Main preventive strategies recommended are fluoride varnishes, remineralization agents and minimally invasive techniques, such as resin-based fissure sealants (Lygidakis et al. 2022).

Being the early preventive and noninvasive treatment modality, topical fluoride varnishes and remineralization agents such as casein phosphopeptide–amorphous calcium phosphate (CPP-ACP) may slow demineralization by enhancing fluoride uptake and promoting deposition of calcium and phosphate ions on the lesion surface (Inchingolo et al. 2023). Such treatments may not, however, always give a satisfying result and other, minimally invasive approach are required.

Fissure sealants (FS) have been used in MIH-affected molars as the highly recommended preventive approach at present (Lygidakis et al. 2022; Zöllner et al. 2024), especially when in need for control of PEB and caries occlusally. In turn, resin-infiltrates (RI), low-viscosity resins, have been used in treatment of active caries lesions of approximal surfaces and white spot lesions of smooth surfaces, as well as in demarcated opacities of aesthetic areas (Hoan et al. 2024). Mechanisms of action of RI is characterized by penetrating deep into the enamel tissue, reinforcing and stabilizing demineralized areas without sacrificing healthy tooth tissue. Hypomineralised enamel due to MIH-affection could benefit from the mechanism of action of RI.

Despite an increase in the number of studies addressing the management of MIH-affected teeth with RI (Meyer-Lueckel et al. 2007; Paris et al. 2013; Crombie et al. 2014; Kumar et al. 2017; Hoan et al. 2024) the evidence of comparison of minimally invasive treatment modalities is still limited, especially in MIH-affected molars, with conventional restorative options remaining the most common approach. Therefore, in line with EAPD address for future research, the purpose of the present study was to assess and compare novel minimally invasive technique, in this case RI, with the current preventive treatment modality, FS, for MIH-affected molar teeth without PEB, in vitro.

Aim

The aim was to measure and compare the penetration depth of two minimally invasive preventive treatment materials, a resin infiltrate (RI) and a fissure sealant (FS), into hypomineralised MIH-affected enamel of molars without PEB. In addition, the post-treatment hardness and mineral content of treated enamel were measured and compared with those of both non-treated hypomineralised enamel and healthy enamel.

The null hypothesis was that there will be no difference in materials' penetration depth, enamel hardness and mineral content of the porous, hypomineralised enamel of MIH-affected molars treated with either RI or FS, and that these values will not differ from the values for non-treated hypomineralised and healthy enamel.

Material and methods

Sample teeth

MIH-affected first permanent molars ($n = 38$ in total) of young patients (7–12 years of age) were collected at the at the Helsinki University Hospital, Finland. . The extraction procedure was carried out by a pediatric dentist, as part of the patient's individual comprehensive care for management of the MIH condition. The extracted teeth were immediately cleaned under tap water and sealed in container with water and transported to the Nordic Institute of Dental Materials, Oslo, Norway , to be kept in refrigerator (at 4 °C). The teeth were collected between 2018 and 2022. Permission for collection of extracted teeth was obtained from the the City of Helsinki (HEL 2018-003492 T130201) and Vantaa (VD/4714/13.00.00/2018), where referral patients came from. An informed consent of the study was provided and permission for further use of extracted tooth or teeth for research purpose was asked from patients and parents/

caregiver. As negative controls, healthy caries-free molars, mostly extracted wisdom teeth, were used in this study. Oslo local authorities of Public Health services (Biobank: 2013/413, NIOM tooth bank) guaranteed the use of the control teeth for this study.

Classification of MIH teeth

All collected MIH-affected molars were placed in a colour light box (VisionView, VeriVide, Leicester, UK), photographed with a digital camera (Canon EOS 60D, Canon 105 mm; Sigma EM-140 DG, Canon Inc, Tokyo, Japan) at the point of view angle and visually examined by three researchers (BT, AM and AT) to be classified according to the severity of the occlusal lesions. For this purpose, the researchers were previously calibrated on MIH severity level (Lygidakis et al. 2022), with an inter-examiner agreement [κw] of 0.8. Accordingly, all teeth were classified either as A) mild: demarcated enamel opacities without PEB; or B) severe: demarcated enamel opacities with breakdown and caries. Subsequently, opacities were subgrouped into two by colour: 1) white, creamy, yellow; or 2) brown. For this study, teeth from group A (Fig. 1), with enamel opacities without PEB, of white, creamy, or yellowish colour (subgroup 1) were selected to compare minimally invasive materials as an early treatment option for prevention of PEB and further caries development.

Sample preparation

MIH-teeth ($n=6$) were randomly distributed into two groups: treatment group ($n=4$), and group that did not receive any treatment ($n=2$), serving as positive control. Additionally, healthy teeth with sound enamel ($n=2$) served as negative control.

The teeth were cleaned with a brush under running tap water and glued in a round Teflon mold (Ø 25 mm) in an upright position. A fast-curing clear acrylic mounting system (ClaroCit, Struers ApS, Ballerup, Denmark) was poured into the mold covering the root segment only. Curing time was approximately 20 min at controlled room temperature (21 °C ± 1 °C). To preserve the surface moist while curing, the teeth were covered with a paper towel soaked in artificial saliva solution, pH 7.0, made locally following the protocol of Eisenburger et al. (2001). The samples were then fixed in a holder of a precise cutting machine with a 0.8 mm cut-off water-cooled diamond wheel (Struers Secotom 60, Struers ApS, Ballerup, Denmark) and cut in the middle in buccolingual direction, perpendicular to the occlusal surface, separating each tooth in a mesial and a distal half.

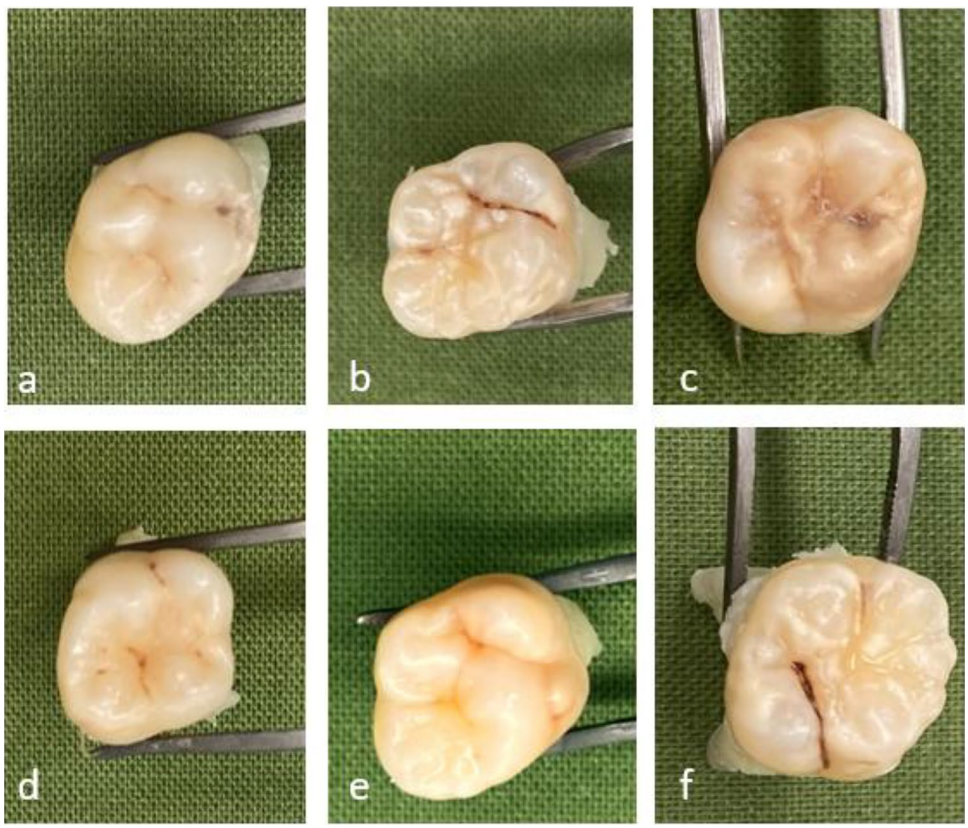

Fig. 1 The six MIH-affected teeth selected for the study. Teeth in **a**, **d** were left untreated and served as positive controls. Teeth in **b**, **c**, **e**, **f** were treated with Icon Vestibular and Helioseal F Plus

In the treatment-group teeth, mesial halves ($n=4$) received resin infiltration (RI)(Icon Vestibular, DMG, Hamburg, Germany) treatment, while distal halves ($n=4$) received fissure sealant (FS) (Helioseal F Plus, Ivoclar Vivadent GmbH, Schaan, Germany) treatment. Treatments were applied only occlusally by a single researcher (BT). Treatment procedure is described in Table 1.

Each tooth half was then cut three times in the same manner giving four samples approximately 1.0 mm in thickness. In total, there were sixteen specimens per each group (Fig. 2). Specimens were left in an artificial saliva solution in a desiccator at 37 °C for 14 days.

Next, the crown and root part were separated. Each specimen was placed in a round Teflon mold (Ø 18 mm) and embedded in clear resin. Grinding of the samples was performed in a semi-automatic polishing machine using subsequent US # grits 500, 800, 1200 and 2000-grit grinding papers (SiC paper, 3 M, St. Paul, MN, USA) at 150 rpm for 30 s each under constant water cooling. Samples were then polished for 30 s by a circular hand movement against the backside of the 3M waterproof silicon carbide paper with

Table 1 Content of materials and application procedure

	Icon vestibular	Helioseal F plus
Pre-treatment	Icon Etch, a hydrochloric acid-based etching gel (etching 120 s, water rinse 30 s, compressed air drying 5 s) Icon Dry, a 99% ethanol-based drying agent (application 30 s, compressed air drying 5 s) (procedures repeated two times prior to the next step)	3M Scotchbond Universal Etchant, a 37% phosphoric acid gel (etching 30 s, water rinse 30 s, compressed air drying 5 s)
Agent application	Icon Infiltrant, a methacrylate-based resin (1st application 180 s, air dispersing, light curing 40 s, 2nd application 60 s, air dispersing, light curing 40 s)	Helioseal F Plus (application 15 s, air dispersing, light curing 20 s)

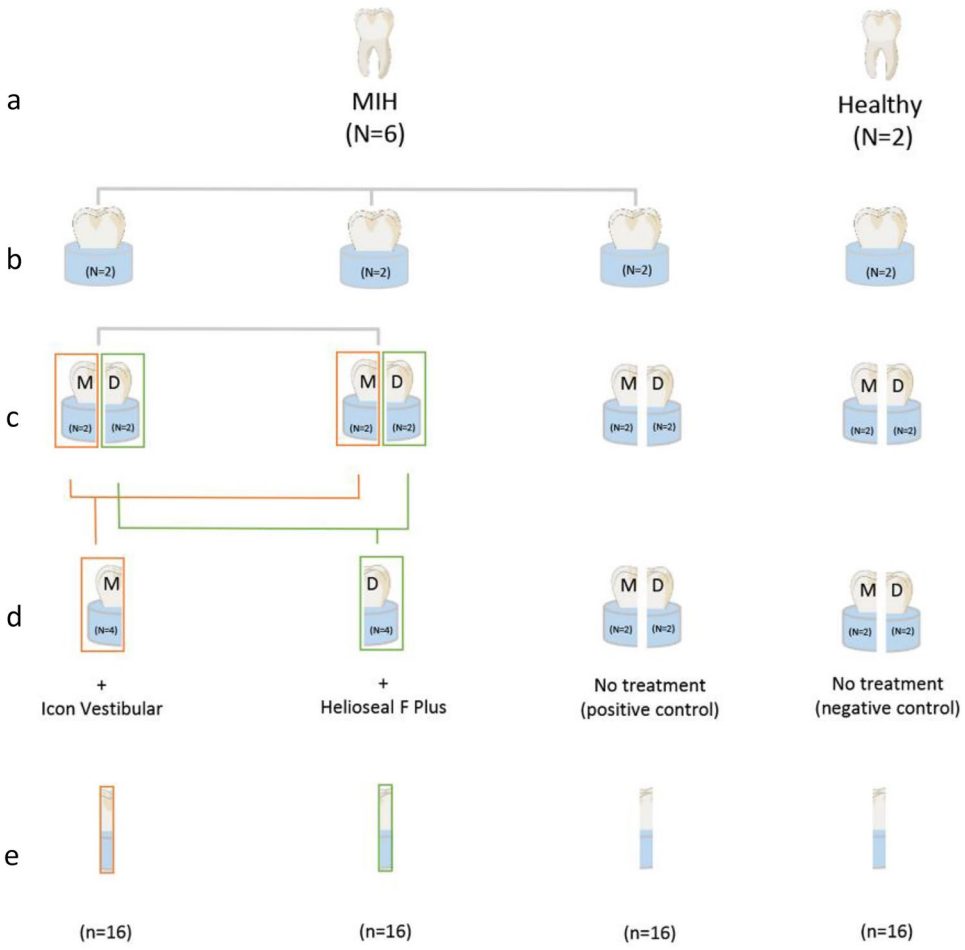

Fig. 2 Schematic representation of sample distribution

0.05 µm particle-size alumina powder (Buehler Micropolish, Buehler, Lake Bluff, IL, USA) mixed with water. Any powder remnants were then brushed away with a soft brush under water. Specimens were stored in artificial saliva in a desiccator at 37 °C. Samples were taken out of the saliva 24 h prior to analysis and left for air-drying at room temperature (21 °C ± 1 °C).

Analyses

Scanning electron microscopy (SEM), penetration depth, and energy dispersive X-ray spectroscopy (SEM–EDX)

All specimens were analysed using SEM (Tabletop Microscope TM4000Plus, Hitachi, Tokyo, Japan) operated at 15 kV, the area of interest being the occlusal enamel covering the buccal and lingual cusps and the fissure between. In the SEM images, presence of treatment materials was assessed visually, and structure of the enamel was analysed and compared between the groups.

The treatment infiltration depth was measured perpendicularly to enamel surface using 3D visualization software (Hitachi map 3D standard V8, Hitachi Ltd, Tokyo, Japan) powered by surface analysis software (Mountains 8, Digital Surf's Mountains Technology, Besancon, France), both linked to the SEM facility. The thickness of the anticipated occlusal treatment, at the area of interest, was marked between the arrows with a flattened tip. The distance (µm) between the upper and the corresponding lower arrow was read at five equally distributed location, and the mean value was thereafter calculated. In addition, quantitative elemental analysis was done using EDX (QUANTAX 75/80, Bruker, Ettlingen, Germany) coupled to the SEM facility. A rectangular area of 30 × 10 µm below the enamel surface was selected. EDX analysis was performed immediately after the image was obtained in SEM (Fig. 3).

Hardness measurements

Hardness testing machine (Duramin 40 A1, Struers Aps, Ballerup, Denmark) with a loading mass of 0.5 kg and a 15 s dwell-time was used to perform the transversal Vickers micro hardness measurements. A diamond-shaped indenter with a square base was pressed vertically onto the plan-parallelised and polished enamel at 0.5 µm below the occlusal enamel surface, where it was anticipated the treatment might have an effect. This was repeated at five different locations along the occlusal enamel starting from the lingual aspect of the mesiobuccal/distobuccal cusp and proceeding to the buccal aspect of the mesiolingual/distolingual cusp and following the cross-section curvature (Fig. 4).

Statistical analyses

Based on Cohen's effect sample size guidelines, to have at least 80% power and 5% significance level, a minimum of thirteen samples per group was needed. Considering that there were sixteen samples per group this suggests that the study herein has sufficient test power. All numerical data were tabulated and analysed with the Statistical Package for Social Sciences (SPSS) version 22.0 for Windows (SPSS Inc., Chicago, IL, USA). Mean values and standard deviation for infiltration depth and chemical elements present were calculated. The influence of each of the two different treatments on enamel hardness was assessed and inter-sample difference was analysed. One-way ANOVA and Tukey's multiple comparisons tests were used to compare the difference between the different groups.

Results

SEM

The teeth visually classified as MIH teeth, all exhibited a less uniform enamel structure with porosities than the healthy teeth serving as negative controls and displayed more distinct interprismatic areas (Fig. 3). The treated samples were visually different from the two control groups at magnification 30×, with RI samples exhibiting a thin superficial zone darker in shade from the rest of the enamel, and non-observable in the control samples. FS samples, on the other hand, were covered with a layer of the material applied. No change in shade or structure of the underlying enamel was observed at this point (Fig. 3a–d). When a section of a cusp incline area was analysed at magnification 800× in the RI samples, a distinct layer was visible even clearer while presence of any material was not detected above the enamel surface (Fig. 3g). At this magnification, the outermost enamel of the FS samples evidently bordered with the material layer with no change in shade or structure of enamel (Fig. 3h).

At magnification 1200× of the same sections, presence of material could be identified dispersed at some depth within the enamel of RI samples (arrows in Fig. 3k), smoothing out the prismatic pattern. In FS samples, no such phenomenon was visible, with a rather distinct border between the material and the enamel surface (arrows in Fig. 3l).

Penetration depth

Infiltration was quantified for the thickness of the continuous darker-shade layer observed in the RI samples, with a mean depth of 25.53 ± 7.01 µm. FS samples were covered with a material layer penetrating sporadically and unevenly, with

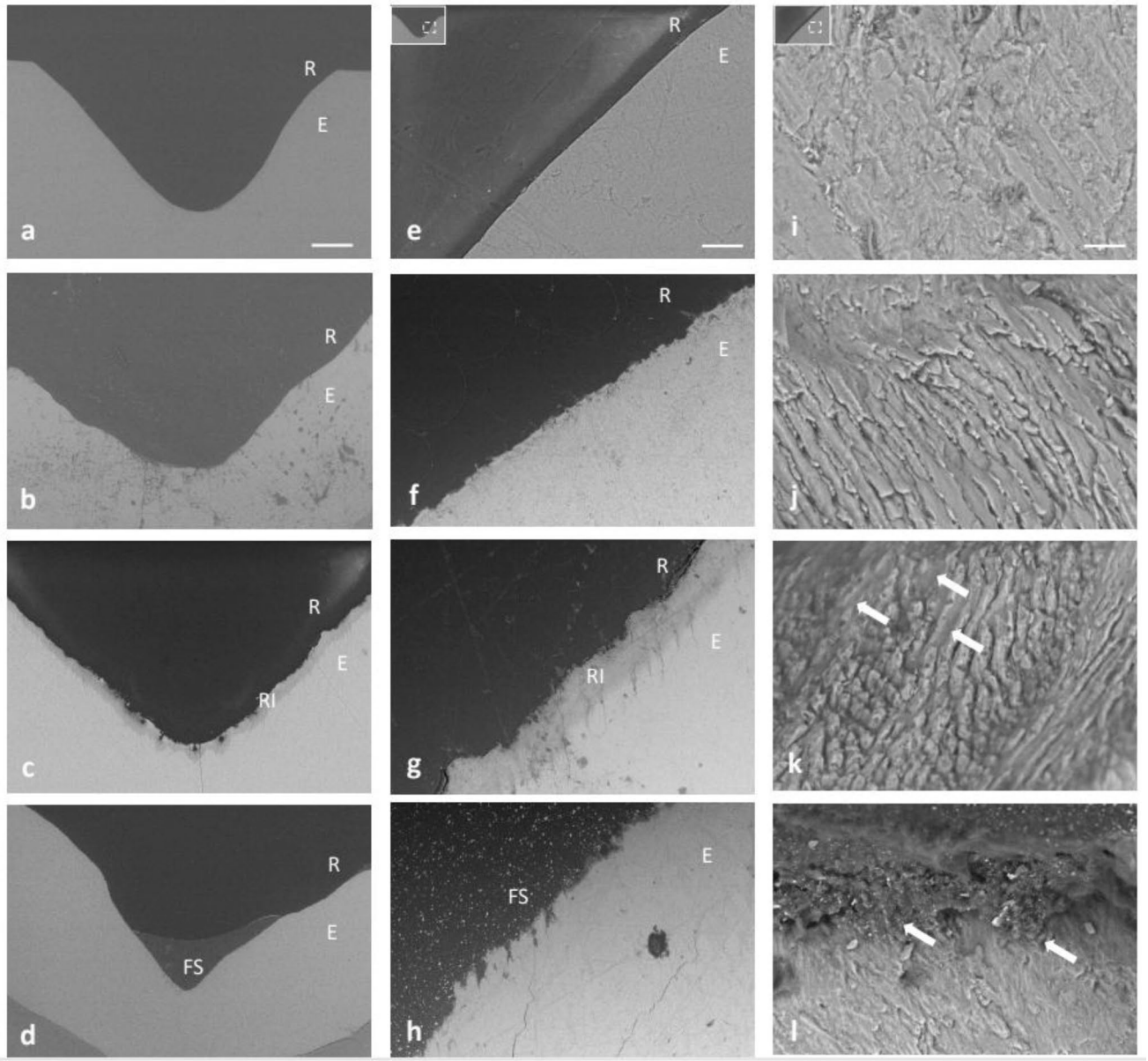

Fig. 3 SEM images of a representative tooth from the two control groups and treated teeth. Cross-section of the fissure area of the tooth at magnification 30× from negative control (**a**); positive control (**b**); RI treatment (**c**) and FS treatment (**d**). Panels **e**–**h** represent magnification 800× from one side of the fissure in these groups, respectively. Panels **i**–**l** Represent magnification 1200× from a segment of the panels **e**–**h**, respectively. White arrows in panels **k** and **l** point at the areas with the treatment material, RI and FS, respectively. Bar represents 100 µm in panels **a**–**d**, 50 µm in panels **e**–**h** and 5 µm in panels **i**-**l**. *R* resin, *E* enamel, *RI* resin infiltrant, *FS* fissure sealant

statistically significantly lower mean depth of 3.1 ± 0.74 µm (two-sample *t* test, $p < 0.05$) (Table 2).

SEM–EDX

Statistically significant differences between the groups were found for several elements (Table 3). Among the groups, the MIH untreated group had the lowest calcium and sodium contents. RI group had the lowest carbon and the highest phosphorous content. In RI and FS treatment groups, magnesium content showed similar values, in RI group with no significant difference from the healthy negative controls, while the magnesium content was lowest in the untreated MIH-samples. In both treatment groups silicon component was detected, while presence of fluorine was detected in samples treated with FS.

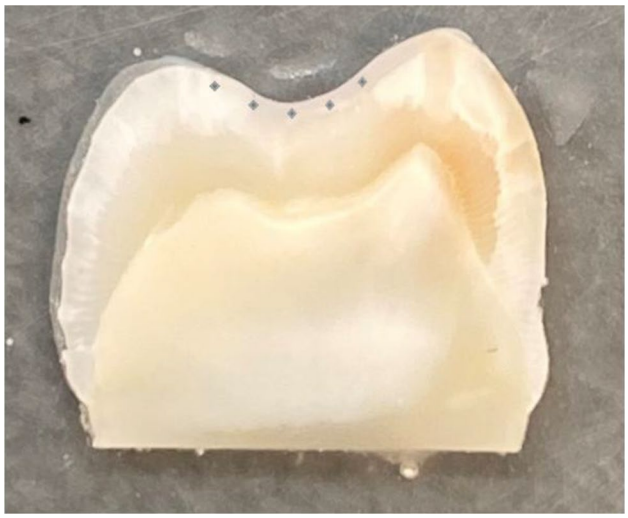

Fig. 4 Representation of the sites where hardness measurements were performed

Table 2 Mean infiltration depth (µm) ± standard deviation, minimum depth, and maximum depth in the two treated groups

Group	Mean ± SD	Min. depth	Max. depth
Icon vestibular ($n=16$)	25.53 ± 7.01*	16.20	41.30
Helioseal F plus ($n=16$)	3.10 ± 0.74	1.94	4.91

*Significant difference, $p<0.05$

Vickers hardness

Mean hardness of the RI-treated samples was significantly higher compared to the FS-treated and untreated MIH-samples; indeed, the mean hardness of RI samples was twice as high as that in untreated MIH samples (Table 4). However, the values did not reach the level of hardness measured in healthy samples. Mean hardness values in FS treatment group showed no significant difference compared to untreated MIH group (p˃0.05).

Table 4 Mean Vickers hardness (0.5 kg load) ± standard deviation, minimum and maximum values for different groups

Group	Mean ± SD	Min. hardness	Max. hardness
Icon vestibular ($n=16$)	203.7* ± 19.0	174.0	240.0
Helioseal F plus ($n=16$)	129.8 ± 38.2	89.3	204.0
MIH untreated ($n=16$)	111.8 ± 27.9	63.0	164.0
Healthy ($n=16$)	261.9 ± 15.6*	235.0	296.0

*Significant difference, $p<0.05$

Discussion

This in vitro study was carried out as a contribution to research of minimally invasive alternative treatment modalities, resin infiltration (RI) and application of resin-based fissure sealant (FS), for management of MIH-affected molars with opacities in occlusal surfaces without PEB.

The obtained mean values for material penetration depth, enamel hardness and mineral content of the porous, hypomineralised enamel of MIH-affected molars treated with either RI or with FS showed a significant difference. In addition, these were significantly different when compared to the non-treated hypomineralised or healthy enamel values. Therefore, the null hypothesis was rejected.

As confirmed in this study, RI and FS are clearly two distinct treatment modalities. RI treatment did not result in a discernable material build-up on top of the enamel but instead formed a continuous layer where the material had infiltrated the outermost enamel to the mean depth of 26 µm, increasing significantly its hardness. FS, on the other hand, remained as a covering protective layer over the enamel surface, with a low, sporadic and uneven penetration.

A successful penetration of RI has also been reported in previous study (Schnabl et al. 2019), suggesting RI to be considered a routine treatment procedure in the management of hypomineralised teeth. According to the current

Table 3 Chemical quantification (atomic concentration %) of elements identified (mean value ± standard deviation) by SEM–EDX analysis

Group	Calcium	Carbon	Oxygen	Phosphorus	Sodium	Magnesium	Silicon	Fluorine
Icon vestibular ($n=16$)	38.87 ± 2.73	14.56 ± 1.72*	30.40 ± 2.33	15.70 ± 1.75*	0.43 ± 0.07	0.72 ± 0.13	3.27 ± 0.30	-
Helioseal F plus ($n=16$)	27.20 ± 3.03	26.84 ± 2.87	32.29 ± 2.05	11.47 ± 1.09	0.57 ± 0.05	0.70 ± 0.07	3.52 ± 0.25	1.49 ± 0.16
MIH untreated ($n=16$)	20.42 ± 1.25*	26.53 ± 1.55	40.67 ± 2.00*	11.70 ± 0.90	0.25 ± 0.02*	0.45 ± 0.06*	–	–
Healthy ($n=16$)	38.48 ± 2.02	21.32 ± 1.41	36.70 ± 2.09	12.01 ± 0.75	0.73 ± 0.08	0.88 ± 0.10	–	–

*Significant difference from other groups, $p<0.05$

literature, low-density RIs penetrate deeper into enamel than low-viscosity FSs (Ibrahim et al. 2023). There are three likely explanations to this difference; 1) etching agent, 15% hydrochloric acid (HCl) in RI *vs* typically 37% phosphoric acid in FS-treatment, 2) efficient drying of enamel by removing water with the aid of ethanol in RI, thereby creating actual spaces for the material to penetrate, and 3) a higher filler content in FS compared to RI.

In this study, RI penetration depth was somewhat lesser but more uniform, with mean value of 25.53 ± 7.01 µm, than those reported for MIH teeth in earlier studies, 58 ± 37 µm (Meyer-Lueckel et al. 2007). This may be because the collected teeth in the present study were likely previously treated with common treatment approaches for MIH teeth, such as remineralization agents, that may have altered the solubility of enamel. On the other hand, for interpretation of the results, one must consider the inherent variability of MIH lesions in terms of size, location and shape and of porosity and protein content. Variations in enamel porosity make the penetration of the infiltrate unpredictable.

In line with this study, results of several earlier in vitro studies have shown that RI penetrates MIH-affected enamel with variation in pattern and extent (Crombie et al. 2014; Paris et al. 2013; Kumar et al. 2017). Raman spectroscopic investigation of RI penetration in MIH-affected enamel after various pretreatment methods have shown that infiltration depth is inconsistent and varies, partly depending on pretreatment protocols with combinations of hydrochloric acid (HCI), sodium hypochlorite (NaOCI) and hydrogen peroxide (H2O2) (Natarajan et al. 2015). In the present study, the protocol did not include a pretreatment agent, calling for further studies with different pretreatment options, for instance the previously mentioned ones.

Concerning the chemical composition of enamel after treatment, element fluorine was detected in FS-treated teeth. This is in concordance with Helioseal F Plus formula, which contains fluoride, the ionic form of fluorine. A significantly lower carbon content in RI-treated samples in comparison with MIH samples untreated or FS-treated might be compatible with replacement of organic components, in particularly albumin, present in hypomineralised enamel, by the infiltrated material in the porosities and even in the interprismatic spaces.

Our results showed greater hardness of the treated samples compared to the untreated MIH group. This is supported by a randomized clinical trial among children aged 6–12 years where it was shown that RI positively influenced the structural integrity of MIH-affected teeth by decreasing the risk of PEB after 18 months follow-up (Nogueira et al. 2021). In addition, the same study revealed that children's caries risk (DMFT index > 3), color of opacities (brown) and location of the opacities (cusp involvement) and age (between 6–8 years) predicted the PEB of MIH-affected teeth. However, another investigation studying the effect of RI on micromechanical properties of hypomineralised enamel did not show significant increase in enamel microhardness after RI (Kumar et al. 2017).

Findings of the present study suggest that of these two minimally invasive materials as options for treatment approaches in clinical situations, RI seems to be more effective than FS, at least in MIH-affected molar teeth with mild opacities without PEB. Results should not be generalized to smooth surface lesions of anterior teeth with vestibular or lingual opacities. In further studies, penetration of both materials needs to be assessed in severe opacities of brown color to reveal whether the penetration pattern is dependent of porosity variation or protein content or use of a pretreatment agent. However, one also must take into account the child's cooperation and experience from the treatment in a clinical situation, since RI application technique requires excellent isolation and use of relatively aggressive agents and thorough drying. This may preclude or complicate its use where isolation cannot be achieved due to patient cooperation or when the teeth are already extremely sensitive (Crombie et al. 2014). The goal of pediatric dentists is to keep treatment methods as simple as possible to avoid technical sensitivity issues of the procedures.

The study has several methodological strengths. The sample teeth were all permanent first molars chosen to represent similar clinical severity of MIH. The teeth were cut into two halves for the comparison of two treatments instead of treating different teeth with different treatments, and controls included both MIH-molars left untreated as well as teeth with healthy enamel. The teeth were carefully stored and handled throughout the study to avoid drying and cracking of the enamel, and all procedures were standardized to the reasonable optimum. As limitations of the study, one can list the relatively small sample size, even if it fulfilled the power calculation. Moreover, the study serves as a comparative study of the two minimally invasive preventive treatment methods in mild MIH instead of covering a larger spectrum of MIH severities and associated PEB and caries, limiting the generalization of the findings and comparison with other studies. A limitation inherent to this type of an *in vitro* study is that factors such as moisture control or patient cooperation did not influence the treatment results, hampering their translation into clinical situations with notable patient-related variability. In addition, neither simulation of oral conditions, like demineralisation-remineralisation cycle, nor toothbrushing were carried out. Finally, the extracted teeth had erupted and from children who likely underwent preventive dental care for MIH-affected teeth previously. Therefore, the presence of remnants of fissure sealants cannot be completely ruled out, similar to role of remineralization agents and topical fluoride applications on the pattern of enamel erosion at etching and consequent penetration

of test materials into the enamel. Therefore, real penetration capacity of the materials may be underestimated in the present study, even though a clear trend of tested materials was observed. One can also pose as a limitation the visual identification method of materials presence. However, all samples were observed in the SEM and the same distinct effect was visible in the samples of a single treatment group while it was absent in the both control groups.

Clinical relevance: statistically significantly higher hardness values of hypomineralised enamel were measured after treatment with low-viscosity resin infiltration material compared to a resin-based fissure sealant. Thus, this minimally invasive approach could be used as alternative treatment modality in clinical situations, where early intervention is warranted and addressed to prevent PEB. In vivo, clinical controlled studies on comparison of the minimally invasive preventive materials would be challenged for future research, specially to investigate the effects of such treatment on hypersensitivity and caries development.

Conclusion

The low-viscosity resin-infiltration (RI) material penetrated more deeply into porous hypomineralised enamel of mildly affected MIH-teeth compared to the fissure sealant. Areas where RI penetrated were found to be higher in enamel hardness compared to untreated or FS-treated hypomineralised enamel. Some changes in element contents between the groups were also recorded. These preliminary findings should be taken into consideration when selecting the optimal minimally invasive treatment of mildly MIH-affected molars to prevent post-eruptive breakdown and further increase of hypersensitivity. To the best of our knowledge, the treatment effect of these materials in more severe cases with opacities of a different grade is still not clearly documented. Such studies are warranted in the future.

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Author contribution Conceived and designed the study: BT, AM and AT. Performed the laboratory procedures: BT and AT. Analysed the data: BT, AM and AT. Wrote the paper: BT, AM, JW-S, AT. All authors critically reviewed and edited the paper.

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Data availability The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author.

Declarations

Conflict of Interest The authors declare no competing interests.

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