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In vivo comparison of resin infiltration outcomes under different light conditions: A randomized controlled clinical trial

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ABSTRACT

Objective: Success of resin infiltration for the masking of MIH-lesions remains difficult to predict, prompting suggestions to adjust the treatment protocol. This exploratory in vivo study aims to evaluate whether monitoring the resin infiltration process using transmitted light, compared to ambient light, enables a better estimation of when the infiltration process is completed, and to assess how the treatment success, i.e. masking effect and infiltration proportion, is influenced accordingly.
Methods: 15 patients with 19 MIH-lesions, diagnosed according to EAPD diagnostic criteria, were enrolled. MIH-lesions were randomly assigned to two treatment groups. In one group resin infiltration progression was monitored under transmitted light, whereas in the second group ambient light was used, representing the standard procedure. Pictures were taken before infiltration and when progression became evident until infiltration was judged to be completed. Infiltration proportion and color difference between the opacity and surrounding sound enamel were calculated and analyzed using the independent-sample *t*-test with a level of significance of $p < 0.05$.
Results: Compared to the ambient light group, the transmitted light group showed a significantly higher infiltration time (17.7 ± 8.2 min vs. 9.3 ± 1.6 min); a significantly higher mean infiltration proportion (97.6 ± 2.8% vs. 83.9 ± 9.7%) and a significantly better masking effect (i.e. lower mean color difference (ΔE) between effected and sound enamel: 4.5 ± 2.4 vs. 7.5 ± 3.3).
Conclusion: Transillumination-guided resin infiltration required prolonged infiltration time but led to an increased infiltration proportion and improved masking effects.
Clinical significance: Transillumination guided resin infiltration enables a more accurate judgement as to when the infiltration process has been completed, which leads, through extension of the infiltration time, to a significantly higher mean infiltration proportion and provides favorable esthetic outcomes.

1. Introduction

Molar incisor hypomineralisation (MIH) is a qualitative developmental demarcated defect of enamel with a reported mean global prevalence of around 12.9–14.2% [1,2] affecting at least one first permanent molar, commonly involving the permanent incisors [3]. MIH-lesions have decreased mineral density, and a higher protein content compared to sound enamel, which is associated with decreased hardness and fracture resistance as well as an altered opaque appearance. In the case of affected anterior teeth, lesions are in the middle and incisal third of teeth, with a sharp demarcation between affected and sound enamel. MIH-lesions vary greatly in terms of location, size and shape, with a wide variation in color ranging from white to yellow/-brown [4,5]. The appearance of anterior MIH-lesions has esthetic and functional implications, negatively affecting their smile and self-perception, and thus their social interactions and oral health related

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quality of life (OHRQoL). Children who have MIH-affected teeth, for example, are 17–25 times more likely to have negative repercussions for OHRQoL compared to children without MIH [6–8]. Esthetic management of MIH-lesions has been reported to result in good clinical outcomes and significant improvement in OHRQoL.

Managing anterior MIH-lesions (i.e. to mask, remove, or cover the lesions) is typically challenging due to biological, mechanical and aesthetic aspects. Generally, the most conservative approach is recommended, i.e. as minimally invasive as possible, to preserve tooth structure, to minimize structural damage and for future restorative or reparative options. This is particularly relevant in children, due to the presence of large pulp chambers and elongated pulp horns [9].

Suggested management options include bleaching, micro-abrasion and resin composite restorations, as well as the resin infiltration technique, which has recently been proposed as an ultraconservative option to improve the esthetics of anterior MIH-lesions [10,11]. Resin infiltration was initially developed to arrest the progression of non-cavitated carious lesions and has been used for esthetic treatment of vestibular caries, fluorotic, idiopathic and traumatic enamel lesions [10,12,13]. The esthetic improvement is achieved by infiltrating the porous body of lesions with a low-viscosity resin (Icon Infiltrant; DMG, Hamburg, Germany) after they have been made accessible by removing the relatively hypermineralised surface layer. The resin infiltrant has a refractive index like enamel, and therefore the infiltrated lesion changes to a translucence and color like the surrounding sound enamel, thus effectively masking it.

While there are many successful cases of masking MIH-lesions using resin infiltration, success of this technique remains difficult to predict compared to masking carious or fluorotic vestibular lesions. This may be attributed to variations in the physical structure of MIH-lesions including porosity, mineral density and geometry/ thickness of the hypermineralised surface layer [4,14–16]. MIH-lesions also have a 3-to-15-fold higher protein content, which negatively affects the infiltration of the resin [15,16]. To account for these variables, the approach for treating MIH-lesions should be adapted accordingly [14,17]. As such, several modified protocols have been investigated including bleaching of affected teeth prior to resin infiltration [11,18,19], modifying surface layer removal techniques [20], mechanical removal of the surface layer with or without transillumination assistance [10,21], deproteinization of the affected enamel using sodium hypochlorite before resin infiltration [22], combining resin infiltration with remineralization agents [23], and increasing the infiltration time of the resin infiltrant before light curing [24,25]. The latter approach, in particular, i.e. increasing the infiltration time, has been reported to significantly improve the outcome by achieving a more complete and more cohesive infiltration, which has also been shown to be the case for carious and fluorotic lesions [19,24,26–28]. However, the question remains: How long is enough? More specifically, recent studies on anterior MIH lesions have indicated that a longer infiltration time of the resin offers better esthetic outcomes [7,28]. There are currently no specific recommended infiltration times for deep and large hypomineralised defects, posing the risk that the infiltration process may be stopped prematurely before optimal infiltration has been achieved. This may limit potential esthetic improvements.

To estimate the optimal infiltration time for such cases it has been suggested to visually monitor the infiltration progress under ambient light until either the esthetic improvement is clinically apparent, i.e. opacity of the lesion is similar to the surrounding sound enamel, or until no further improvement is evident [25]. However, under ambient light, the optical contrast between the lesion that is being infiltrated and the surrounding sound enamel is suboptimal, making it difficult to judge visually if the process is complete or still ongoing. To improve this method, the use of transillumination has been suggested. Transillumination offers better optical contrast and therefore has the potential to be more reliable, providing a better assessment of when the infiltration process is finished [21,25,29].

The aim of this exploratory clinical pilot study is to evaluate whether monitoring the resin infiltration process using transmitted light, in comparison to monitoring under ambient light, enables a better estimation as to when the infiltration process is completed, and to assess how the treatment success, i.e. masking effect and infiltration proportion, is affected accordingly.

2. Materials and methods

Ethical approval for the study was given by the local institutional board of Farhat Hached Hospital, Sousse, Tunisia (12/2019, IRB:8931). Recruitment was initiated in April 2021 and completed in April 2024. Participants were informed and understood that the success of the treatment is difficult to predict, potentially varying between complete visual disappearance of the lesions to partial aesthetic improvement.

2.1. Subjects

Patients diagnosed with MIH-related opacities on the incisal and middle thirds of the buccal surface of their permanent incisors, according to EAPD diagnostic criteria of MIH [30], were invited to participate in the study. Permanent canines, although outside the MIH classification, were also included. To avoid more than one lesion per buccal surface and to ensure consistency in the sample, only isolated lesions presenting a heterogeneous, demarcated opacity of the lesion body, defined as Type 2 lesions [31], were selected for this study. (Fig. 1) Type 2 lesions are characterized by a non-homogeneous opacity in the lesion body, often accompanied by extensions that are less opaque than the primary defect. This distinguishes them from Type 1 lesions, which have homogeneous opacity, and from Type 3 lesions, which are multiple isolated opacities separated by sound enamel [32]. Initial lesion assessment and selection was based on the appearance of the opacity of the lesion body observed in transmitted light. The light was transmitted perpendicularly from the lingual/palatal surface using a handheld LED transilluminator with a 3 mm glass light guide (Microlux Transilluminator, AdDent, CT, USA).

2.2. Exclusion criteria

Teeth with resin composite restorations as well as teeth previously treated with micro-abrasion, supervised professional remineralization (fluoride varnish or calcium-based products such as CPP-ACP) or resin-infiltration were excluded.

2.3. Pre-infiltration protocol

The pre-infiltration protocol of the transillumination-aided infiltration concept was followed in this study [21]. Guided by the appearance of the lesion in transmitted light, the hypermineralised surface layer was removed gently via micro-abrasion using 6.6% hydrochloric acid paste with fine silicon carbide particles (Opalustre; Ultradent, South Jordan, UT, USA). The micro-abrasion paste was applied to the affected tooth surface with a specially designed rubber cup (OpalCups Bristle; Ultradent, South Jordan, UT, USA) in a low-speed handpiece (500 rpm according to the manufacturer's instructions) under light pressure for approximately 60 s. The remnant paste was removed with a suction tip, then teeth were thoroughly rinsed, and the procedure was repeated as necessary until well defined margins at the sound enamel-lesion interface were clearly observed in transmitted light. According to the manufacturer's instructions, the remaining hypomineralised enamel was etched using 15% hydrochloric acid (Icon Etch; DMG, Hamburg, Germany) for 120 s and thoroughly washed for 30 s using triplex water spray; ethanol (Icon Dry; DMG, Hamburg, Germany) was then applied for 30 s to desiccate the lesion

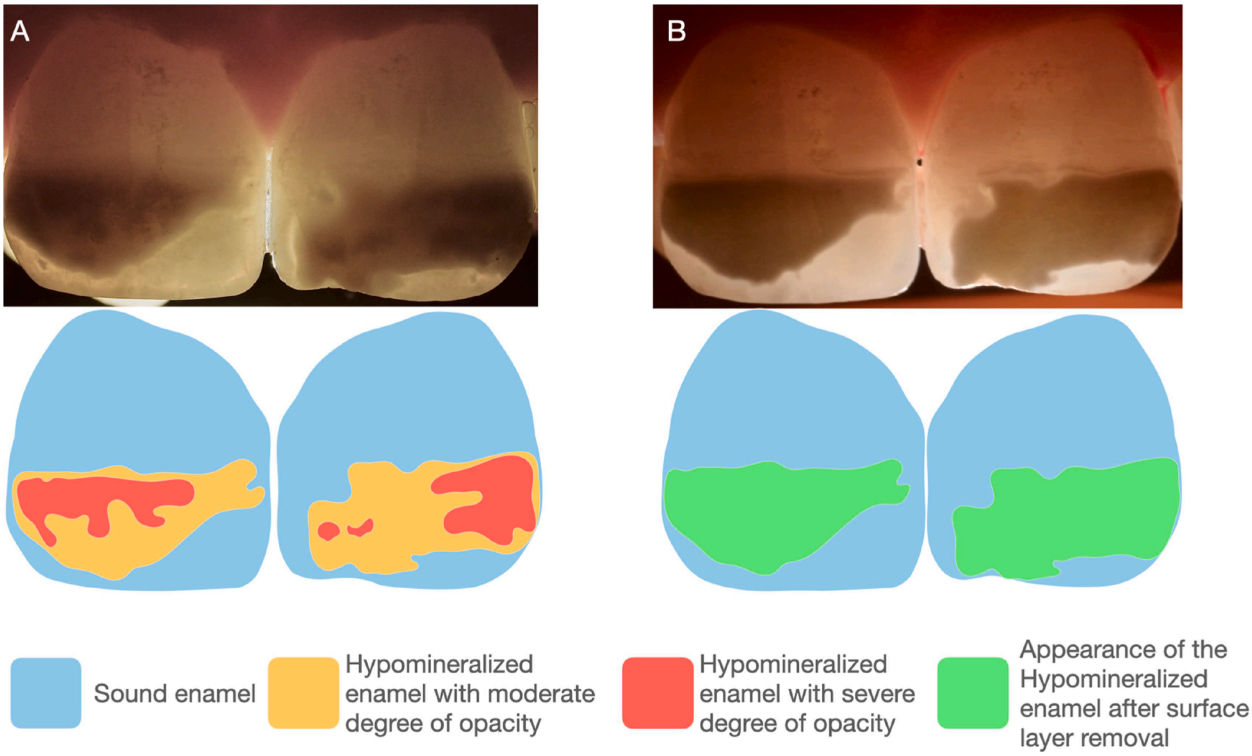

Fig. 1. Clinical image and schematic drawing showing the pre-operative (A) appearance of Type 2 lesions affecting the central incisors, with a non-homogeneous lesion body, and their appearance after the removal of the surface layer (B). Note how the appearance of the lesion margins has been transformed from diffuse to well-defined.

2.4. Infiltration protocol

Lesions were infiltrated using a low-viscosity resin (Icon Infiltrant; DMG, Hamburg, Germany) for at least 3 min, as recommended by the manufacturer, continuing until it was visually evident that either infiltration had ceased progressing or until it was apparent the lesion opacity had disappeared clinically (t_{max}). At t_{max}, the resin was light-cured (MiniLED active; ACTEON, Bordeaux, France) for 40 s. Following the manufacturer's recommendation, the resin was applied a second time for 60 s and then light-cured for an additional 40 s.

2.5. Lesion infiltration monitoring under transmitted and ambient light conditions

Using block randomization, lesions were assigned into two groups depending on the method by which the infiltration progress was to be monitored. To record the progress of infiltration and for data analysis, standardized clinical images were taken at baseline, i.e. before applying the resin infiltrant (t_0), as well as when the infiltration was ongoing (t_x) until it was judged to be completed (t_{max}) as outlined (Fig. 2). The endpoint of the infiltration process was decided on a visual impression of completion using either transmitted or ambient light conditions depending on the group.

2.5.1. Transmitted light group

The monitoring of the infiltration progress was assessed in a darkened room with minimal ambient light, utilizing transillumination whereby the light emitted from the transilluminator was transmitted through an orange filter to protect the affected teeth from any blue light and to prevent any unwanted polymerization of the resin infiltrant. Clinical images were taken at a standardized distance using a digital single lens reflex camera (D7200; Nikon, Tokyo, Japan), and 90 mm macro lens (SP AF90 mm F⁄2.8; Tamron, Saitama, Japan) at 1:1 magnification. Camera settings were F/22 aperture at 1/200 s shutter speed and ISO 800, and no flash.

2.5.2. Ambient light group

The monitoring of the infiltration progress was assessed under ambient light. Clinical images were taken using the same methods as above apart from using ISO 100, using flash illumination (R1C1 Macro flash; Nikon, Tokyo, Japan) with auto white balance.

Independently of the assigned group, ambient light and transmitted light images were taken for all lesions at t_0 and t_{max} before light curing.

2.6. Standardizing transmitted and ambient light images

Using an image analysis software (Keynote 8.2; Apple, CA, USA) one examiner (OM) identified the region of interest containing the enamel opacity and the surrounding sound tissue. After selecting this region, images belonging to one lesion, i.e. images taken at t_0 and t_{max} with transmitted and ambient light, were superimposed by changing height and width attributes so that the enamel opacities would overlap as closely as possible.

2.7. Evaluation of infiltration proportion

From standardized t_{max} and t_0 transilluminated images, the same examiner (OM) manually outlined the outer border between the lesion and sound enamel (entire opacity area (O)) as well as the border between the infiltrated area and the area that was not infiltrated (infiltrated opacity area (IO)). The segmented areas were then colored in black and white, respectively, and the new resulting images were converted into TIFF format and scaled to 1920 × 1080-pixel resolution. Then the image surface-areas ($inch^2$) of the opacity and infiltrated areas were calculated using image analysis software (ImageJ; National Institutes of Health, MD, USA). The infiltration proportion (IP) at t_{max} of the estimated infiltrated opacity surface area (IO) at t_{max} to the entire opacity (O) area at t_0 in % was then calculated using the following

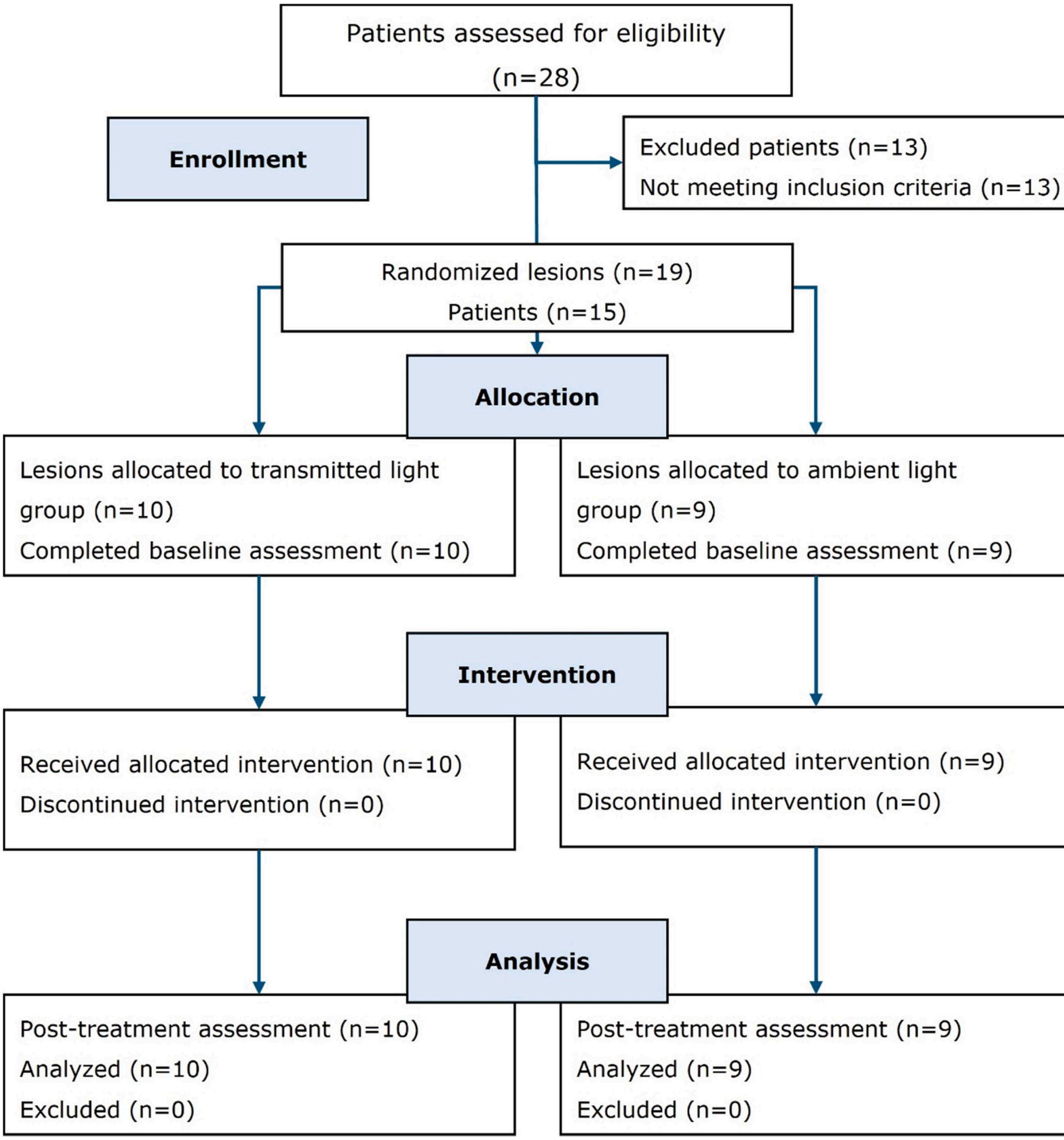

Fig. 2. Flowchart of the study.

formula: IP = (IO*100)/O.

2.8. Evaluation of masking efficacy

Regions of interest containing either the lesion area (infiltrated area at t_{max} and the same area before infiltration at t_0) or surrounding sound enamel were selected and isolated by the same examiner (OM) using the selection tool of the image software (Keynote 8.2; Apple, CA, USA). Color parameters (L*a*b* values) of these areas were then determined using colorimetry software (Digital Color Meter 5.22; Apple). To ensure that the same area for a particular lesion was analyzed, the selected window was copied and matched for size, orientation, and location for the lesion and sound enamel areas in both lighting conditions. Areas with flash reflection or non-infiltrated lesion areas (in t_{max} images) were excluded from the evaluation of color difference. Additionally, when possible, the lesion and sound enamel areas were preferentially chosen within the same horizontal plane to ensure consistent dental tissue thickness (Fig. 3).

Color differences (ΔE) between the lesion (either after or before infiltration) and the corresponding sound enamel were calculated from L*a*b* values (Numbers 10.3; Apple, CA, USA) using the following formula: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ for transmitted (ΔET) and ambient (ΔEA) light images. A greater ΔE value corresponds to a larger color difference and thus to a more perceptible defect to the human eye. This color difference is often clinically interpreted using thresholds, i.e. ΔE values where 50% of the observers can either perceive a difference or find this difference acceptable. Typically, a threshold value of 3.7 is considered to indicate a clinically meaningful color difference for teeth [33].

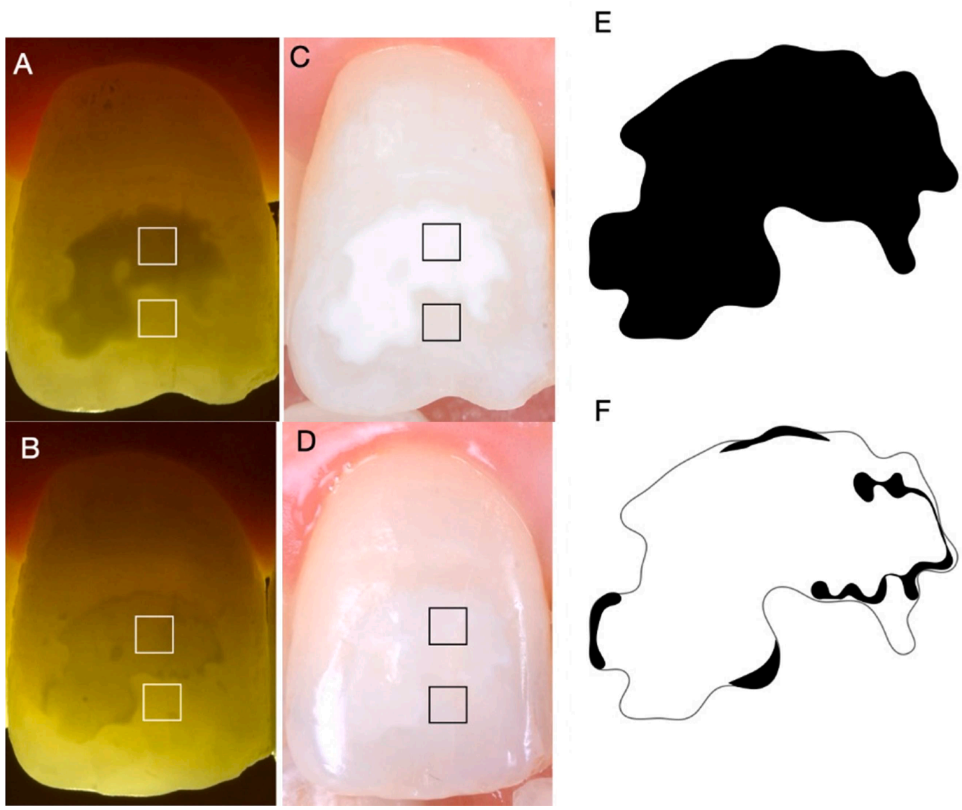

Fig. 3. Comparison of infiltration proportion in lesions infiltrated under different light conditions. Transmitted light images (A, B) and ambient light images (C, D) representing the opacity after the pre-infiltration protocol and just before the infiltration at t_0 (A, C) as well as after the infiltration is judged to be completed at t_{max} (B, D). The black and white squares represent the areas where the color measurement was recorded. E, F are schematic drawings representing the surface area opacity at t_0 (E) and at t_{max} (F) the white area represents the non-infiltrated surface area at t_{max}.

2.9. Sample size and statistical analysis

As this was an exploratory pilot study, a convenience sample was used, and no sample size calculation was performed. Given this being an exploratory trial and the magnitude of clustering limited, we did not adjust for clustering but considered each lesion an independent statistical unit. The large variation present between lesions on different teeth in an individual is a justification for the approach chosen. Statistical analyses were performed using a dedicated software package (SPSS Statistics, V. 20; IBM, NY, USA). Data were checked for normal distribution using the Kolmogorov-Smirnov test and ΔET_{t0} values were compared in both groups to check the similarity of the sample. The data were analyzed using the independent-sample *t*-test with a level of statistical significance of $p < 0.05$.

3. Results

3.1. Distribution

Of 28 patients screened, 15 were included with a total of 19 MIH-affected anterior teeth. The CONSORT flowchart is shown in Fig. 1, with the characteristics of all participants summarized in Table 1. Both groups were comparable in terms of gender, age and number of lesions.

Table 1
Patient characteristics.

Parameter	Transmitted light group ($n = 7$ patients & 10 teeth)	Ambient light group ($n = 8$ patients & 9 teeth)
Age / median (range)	27 (14–37)	29 (17–35)
Sex		
Female / count (%)	3 (43%)	1 (12.5%)
Male / count (%)	4 (57%)	7 (87.5%)
Affected anterior teeth		
Maxillary incisors	7	8
Mandibular incisors	2	0
Maxillary Canine	0	1
Mandibular Canines	1	0

3.2. Infiltration time and proportion

Lesions monitored under transmitted light required a statistically significant longer infiltration time, approximately twice as long, compared to lesions monitored under ambient light either until it was visually evident that infiltration had ceased progressing or until masking of the lesion was clinically apparent. Associated with the longer infiltration time, lesions also displayed a significantly higher infiltration proportion in the transmitted light group, however, the difference was not proportional to the infiltration time (Table 2).

3.3. Evaluation of masking efficacy

Color difference between both groups was similar at baseline as indicated by the ΔET_{t0} and ΔEA_{t0} values, i.e. the color difference between lesion and sound enamel under ambient and transmitted light (Table 2). However, ΔET_{t0} values were approximately twice as large as

Table 2
Infiltration time and treatment results.

	t_{max} /min mean (SD)	IP /% mean (SD)	ΔET_{t0} mean (SD)	ΔET_{tmax} mean (SD)	*p*-value	ΔEA_{t0} mean (SD)	ΔEA_{tmax} mean (SD)	*p*-value
Transmitted light group	17.7 (8.2)	97.6 (2.8)	22.7 (9.2)	5.9 (3.7)	<0.05	11.0 (3.9)	4.5 (2.4)	<0.05
Ambient light group	9.3 (1.6)	83.9 (9.7)	23.2 (5.8)	9.2 (3.3)	<0.05	12.7 (4.3)	7.5 (3.3)	<0.05
p-value	<0.05	<0.05	>0.05	<0.05		>0.05	<0.05	

t_0 & t_{max}: Infiltration time (baseline and after infiltration).
ΔET_{t0} & ΔET_{tmax}: Color difference based on transmitted light images at baseline and after infiltration.
ΔEA_{t0} & ΔEA_{tmax}: Color difference based on ambient light images at baseline and after infiltration.
p-value: independent-sample *t*-test, $\alpha = 5\%$.
SD, standard deviation; IP, infiltration proportion.

ΔEA_{t0} values in both groups, confirming that transmitted light offers greater optical contrast compared to ambient light.

After the infiltration process was completed, the opacity of lesions improved significantly irrespective of the group. Nonetheless, the masking efficacy was statistically significantly greater in the transmitted light group ($\Delta EA_{tmax} = 4.5 \pm 2.4$) compared to the ambient light group ($\Delta EA_{tmax} = 7.5 \pm 3.3$).

4. Discussion

In this in vivo pilot study on resin infiltration of anterior MIH-lesions the impact of monitoring the infiltration process using either ambient light or transmitted light has been investigated in terms of infiltration time, infiltration proportion and masking efficacy (i.e. color difference between lesion and sound enamel). For infiltration proportion and masking efficacy, the two esthetic endpoints, statistically significant differences were determined between lesions monitored under ambient light and those monitored under transmitted light, with lesions monitored under transmitted light showing significantly better outcomes. The better esthetic outcome in the transmitted light group is attributed to a significantly longer infiltration time of 17.7 (SD 8.2) min in comparison with 9.3 (SD 1.6) min in the ambient light group (Table 2).

Interestingly, the current results indicated that the differences in terms of masking efficacy and infiltration proportion were not proportional to the infiltration time (Table 2). The infiltration proportion in the transmitted group is only a little greater (97% compared to 84%) despite the infiltration time being twice as long. Indeed, this non-linear correlation has also been reported recently [29,34]. The infiltration proportion increases greatly at first and then slows down considerably over time, putatively explaining the difference of infiltration time between ambient light and transmitted light group. It was apparent that transillumination offers significantly larger optical contrast between healthy/infiltrated and hypomineralised enamel compared to ambient light [24,29], as indicated in the present study by a significantly higher color difference between lesion and sound enamel at baseline (approximately twice) under transmitted light compared to ambient light (Table 2). Clinically, as shown in Figs. 4 and 5, the increased contrast provided by transillumination allows for a more accurate assessment of the progression of resin infiltration and the point at which it stabilizes or saturates; in contrast to monitoring infiltration under ambient light, which makes it difficult to determine whether the infiltration is still progressing or not. This enhanced visualization explains why the transmitted light group showed better a better infiltration proportion and masking efficacy compared to the ambient light group, as it allows for better-adapted infiltration timing based on the lesion's true infiltration status.

In the present study, the empirical observation/evaluation of the progression of the infiltration status was used to determine whether to cease (light cure) or continue the infiltration process. It allows for the infiltration time to be adapted optimally to each lesion, as the variability is significant, particularly in the transmitted light group. This contrasts with other studies where arbitrary infiltration times of up to 30 min were used to assess aesthetic improvement, which may be overestimated for some lesions [35].

It is important to emphasize that in the present study, the evaluation of color differences, as well as the infiltration proportion calculation, were performed before light curing. This approach may lead to an underestimated result, as the aesthetic outcome improves after a few days, once the tooth has rehydrated [24]. Additionally, the photo-initiator camphor quinone (present in the resin infiltrant) may impart a yellowish hue to the final infiltrated area, which should be considered in color difference calculations. Therefore, for more accurate

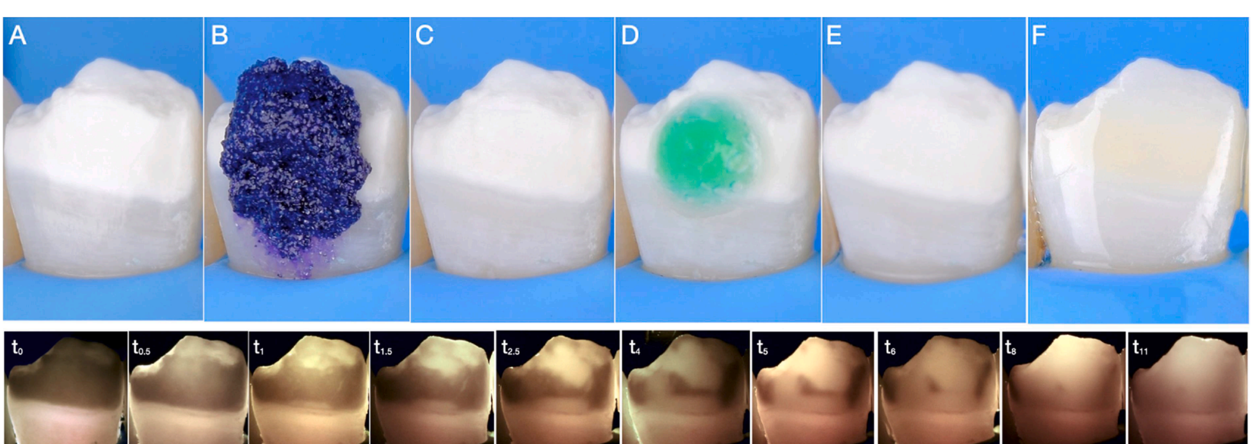

Fig. 4. Transmitted light group. Clinical workflow of the resin infiltration for MIH-lesions and recording of the infiltration progress under transmitted light conditions. A) Baseline. B) Surface erosion using microabrasion. C) Surface condition after microabrasion. D) Surface erosion using HCl gel. E) Surface condition after acid erosion. F) Infiltrated lesion prior to light curing (t_{max}). Lower panel images display progression of resin infiltration recorded under transmitted light conditions from baseline (t_0; left) until full lesion infiltration is observed (t_{11} (t_{max} at 11 min); right).

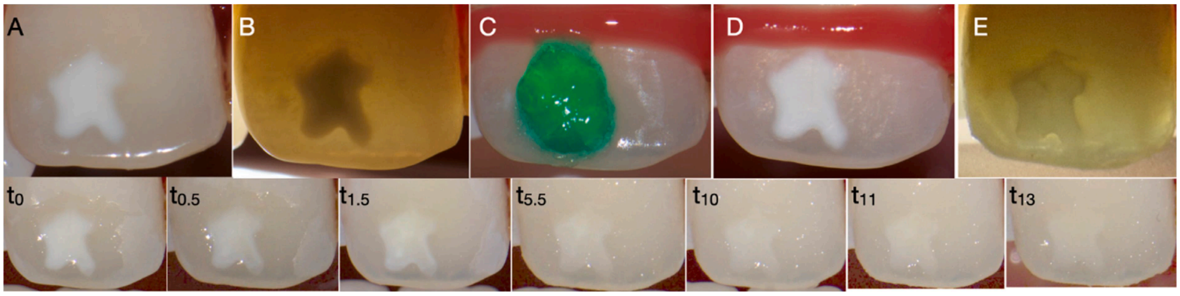

Fig. 5. Ambient light Group. Clinical workflow of the resin infiltration for MIH-lesions and recording of the infiltration progress under ambient light conditions. A) Baseline under ambient light. B) Baseline under transmitted light. C) Surface erosion using HCl gel. E) Surface condition after acid erosion. F) Infiltrated lesion prior to light curing (t_{max}) under transmitted light. Lower panel images display progression of resin infiltration recorded under ambient light conditions from baseline (t_0; left) until full lesion infiltration is observed (t_{13} (t_{max} at 13 min); right).

evaluation in future studies, it is crucial to assess the outcome after light curing and allow sufficient time for rehydration [36,37].

In the present study, ambient and transmitted light were used to monitor the progression of resin infiltration into anterior MIH-lesions. It is acknowledged that white ambient light may induce premature curing of the infiltrant, therefore it has been recommended to reduce ambient light exposure during the infiltration procedure [19]. However, this reduction might prevent accurate evaluation of the infiltration's progression and lead to premature light curing. In the transmitted light group, the infiltration process was monitored through an orange ambient light protecting filter, to avoid premature polymerization of the infiltrant. The orange filter blocks out the blue light wavelength (typically around 450–490 nm) necessary for activating camphor quinone [37]. This method allows the monitoring of the infiltration progression without the risk of prematurely curing the resin infiltrant.

Defining what constitutes a successful treatment for MIH-affected incisors is challenging due to several nuanced and complex factors. The primary goal of this technique is commonly aesthetic improvement. However, perceptions of aesthetic acceptability vary among patients, parents, and dental professionals, leading to differences in expectations between clinicians and patients. Dentists may focus on clinical indicators such as the quality of the infiltration, optical alignment of the affected areas with the surrounding sound tooth substance, lesion coverage, and structural integrity. In contrast, patients tend to prioritize subjective outcomes, such as the overall appearance of the treated teeth and overall satisfaction with the treatment. Several methods have been used to assess the clinical success of infiltration, including questionnaires such as the Child's and Parent's Questionnaire about Tooth Appearance after Treatment [38], as well as variables such as the proportion of infiltration or the masking efficacy, which is determined by

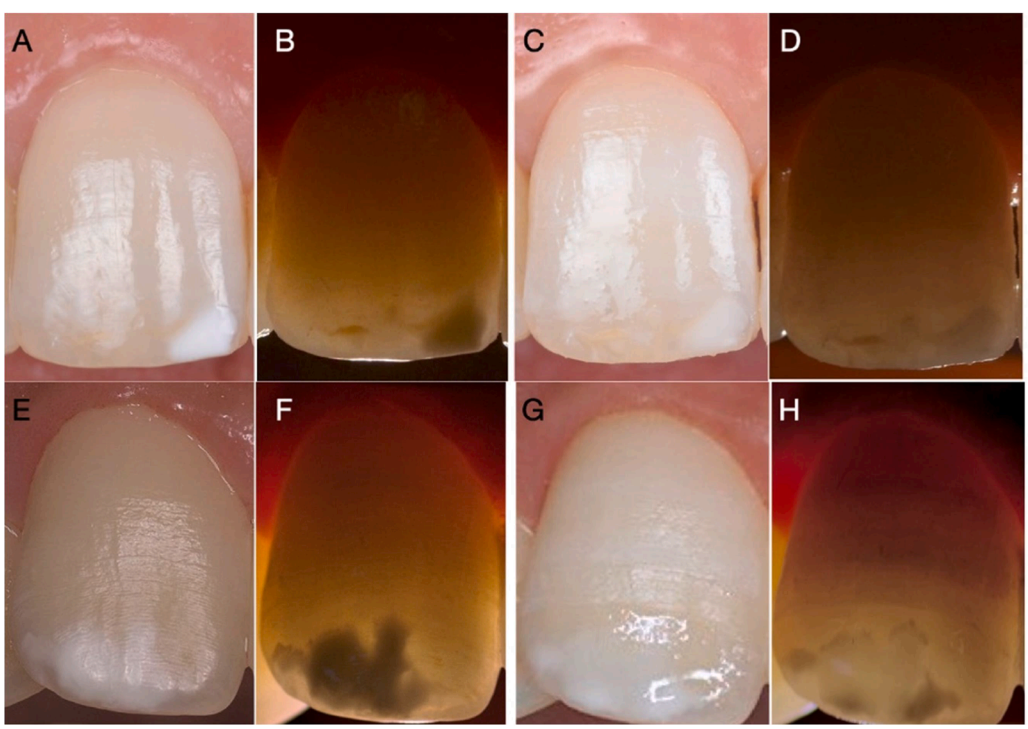

Fig. 6. Illustration of two clinical cases (ABCD) and (EFGH) demonstrating different types of failures encountered during the resin infiltration procedure. Case 1: Showing a MIH-lesion where the masking effect was insufficient, despite complete infiltration. The resin successfully penetrated the lesion, but the aesthetic outcome remains unsatisfactory, as the opacity of the lesion is still visible in both transmitted light (D) and ambient light (C). This suggests that while the lesion was infiltrated, the optical properties were not fully corrected, likely due to insufficient depth or uniformity of resin distribution. Case 2: Showing a MIH-lesion with partial masking. In this instance, the infiltrant only partially penetrated the lesion, resulting in incomplete masking of the opacity (G). The transillumination image (H) reveals areas where the resin failed to reach certain portions of the lesion, potentially due to premature light curing or insufficient infiltration time, leading to incomplete coverage and uneven results.

calculating the color difference between infiltrated and sound enamel [19,29].

In the present study, infiltration proportion and masking efficacy, which are objective and quantifiable criteria, have been used to evaluate the success of the resin infiltration procedure. As strange as it may seem, these two parameters are different and can be explained separately. For instance, a lesion that shows a good masking effect may be incompletely infiltrated, whereas a completely infiltrated lesion may have a limited masking effect. Thus, two kinds of failure can be described. On the one hand, the infiltrated area might be complete, but the masking effect remains insufficient (Fig. 6, case 1). Putatively, deeper, more complete penetration would lead to better aesthetic outcomes. Complete and homogenous infiltration is crucial for the successful application and coverage of the lesions, as the optical and dynamic properties of the infiltrated lesions are heavily dependent on the amount of the porous lesion body being filled with resin. Deeper and homogenous infiltration ensures that the resin can penetrate uniformly. We can assume that incomplete masking of the opacity is likely related to the infiltration not reaching the base of the lesion which can be explained and imaged (Fig. 6, case 1) by premature light curing and not adapted infiltration time. On the other hand, premature light curing may also result in incomplete infiltration (Fig. 6, case 2). The failure also depends on the infiltration pattern, whether homogeneous or heterogeneous [25]. The outcome prediction of the success of resin infiltration for MIH-affected incisors presents a clinical challenge. Several complex and interrelated factors play important roles. MIH-lesions can vary greatly in size, depth, color, extension inside the enamel and mineral density/porosity. Variability in the discoloration and opacity of the enamel can affect the esthetic result, thus potentially affecting patient satisfaction.

Accurate prediction of the clinical esthetic result of resin infiltration is critically important for young patients due to their unique developmental, psychosocial and behavioral needs. There is a limited choice of suitable treatment options for children and adolescents with anterior MIH-lesions. Ensuring the efficacy of the outlined micro-invasive approach enhances the esthetic outcomes and oral health related quality of life for these patients [38]. In summary, the difficulty in predicting treatment outcomes and success in MIH-affected incisors stems from the heterogenous nature of the underlying condition. Properties, such as structural alterations, patient compliance and ability to cooperate during the procedure, esthetic demands and the necessity of individual clinical protocols play an important role. These factors combined make each case unique and complicate the possibility to forecast the outcome of any given treatment option reliably.

5. Conclusion

Monitoring the resin infiltration process using transmitted light enables a better estimation as to when the infiltration process is completed compared to monitoring using ambient light, leading to significantly better esthetic outcomes, i.e. a higher masking efficacy and infiltration proportion. Infiltration under transmitted light provides reliable assistance, a valuable monitoring and communication tool for the successful clinical management of MIH-affected incisors.

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CRediT authorship contribution statement

Omar Marouane: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Conceptualization. **David John Manton:** Writing – review & editing, Supervision, Conceptualization. **Marcus Cebula:** Writing – original draft, Visualization, Validation, Formal analysis, Data curation. **Falk Schwendicke:** Writing – review & editing, Supervision. **Susanne Effenberger:** Writing – original draft, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: SE reports a relationship with Dental-Material Gesellschaft mbH that includes: employment. MC reports a relationship with Dental-Material Gesellschaft mbH that includes employment. FS reports a relationship with Dental-Material Gesellschaft mbH that includes consulting or advisory and speaking and lecture fees. DJM reports a relationship with Dental-Material Gesellschaft mbH that includes consulting or advisory and speaking and lecture fees.OM reports a relationship with Dental-Material Gesellschaft mbH that includes: consulting or advisory and speaking and lecture fees.

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