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ORIGINAL ARTICLE

Making white spots disappear! Do minimally invasive treatments improve incisor opacities in children with molar-incisor hypomineralisation?

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Abstract

Background: Children with molar-incisor hypomineralisation (MIH) frequently seek aesthetic treatment for incisor opacities. Surprisingly, few studies have evaluated the clinical success of such interventions.

Aim: To quantify the effectiveness of minimally invasive treatments in reducing enamel opacity visibility in children with MIH.

Design: This in vitro study used digital clinical images of 23 children aged 8–16 years with MIH who underwent microabrasion and/or resin infiltration for the management of incisor opacities. Standard images were taken pre-treatment and 6 months post-treatment. Image software (Image-Pro Plus® V7) was employed to convert 24-bit RGB images to 16-bit greyscale and 145× magnification. Measurement repeatability was assessed using intra-class correlation coefficients (ICCs). Post-treatment changes in visible opacity area (mm^2) and brightness (greyscale value) were tested using the Wilcoxon signed-rank test for related samples.

Results: The mean total opacity surface area significantly reduced from 14.3 mm^2 (SD = 7.5) to 9.4 mm^2 (SD = 9.0) post-treatment. The proportion of tooth surface affected by the opacity also significantly reduced from 22.5% (SD = 10.5) to 14.7% (SD = 12.7). The mean maximum opacity brightness significantly reduced from 53 066 greyscale value (SD = 4740) to 49 040 (SD = 3796). ICC was good/excellent (0.75–1.0).

Conclusion: Minimally invasive treatment is effective in reducing the size and brightness of discrete incisor opacities. Future research should compare objective findings with patient-reported outcomes.

KEYWORDS
children, enamel opacity, image analysis, molar-incisor hypomineralisation, treatment

1 | INTRODUCTION

The negative psychosocial effects of having molar-incisor hypomineralisation (MIH) are well-reported and acknowledge both the functional burden of having hypersensitive molars and the more socially related impacts of having visible anterior enamel opacities.[1] It is, however, only relatively recently that investigators have explored the effect of dental treatment in addressing some of these impacts.[2-4] Notably, Hasmun and colleagues[3] used a theoretical model and a validated measure of oral health–related quality of life (OHRQoL) to evaluate child-reported outcomes following the minimally invasive aesthetic management of enamel opacities in 86 individuals with MIH, aged 7–16 years. They found a significant improvement in OHRQoL 6 months after treatment. In conjunction with patient-reported outcome measures, such as OHRQoL, it is also important to develop clinical outcome measures against which treatment 'success' can be objectively measured, thereby informing the evaluation of new materials and techniques.

Variation in the clinical presentation of hypomineralised permanent anterior teeth may account for the broad spectrum of treatment regimens offered to children with MIH, which essentially aim to mask, remove, or cover the affected enamel.[5] Management options include the topical use of remineralisation agents such as fluoride varnish or casein phosphopeptide-amorphous calcium phosphate; minimally invasive techniques such as microabrasion, resin infiltration, and tooth whitening; and more conventional techniques such as composite resin restorations.[1,6,7] An understanding of the optical properties of enamel opacities is fundamental to inform treatment strategies; in particular, hypomineralised enamel has a different refractive index (RI) to normal enamel, which, in turn, affects colour perception. The RI of a substance is the amount of light that is refracted or scattered through a medium and is unique for different materials.[8] Enamel opacities have a highly mineralised surface, but the subsurface is porous, meaning it can fill with water or air.[9] The differences between the RI of sound enamel (1.62) and the subsurface porosities, if filled with water (1.33) or air (1.0), cause increased visibility of the lesion at the interface with surrounding normal tissue.[9-12] Enamel opacities therefore scatter light differently to sound enamel leading to the opaque appearance of the lesion, which can become even more pronounced with drying.[10,11,13]

To date, few studies have adopted an objective methodology to measure the change in the appearance of incisor enamel opacities following simple interventions to improve aesthetics.[12] The evaluation of tooth colour is acknowledged to be complex. Furthermore, attempts to measure tooth colour by the human eye are highly susceptible to bias.[14] Investigators have therefore sought to employ image analysis techniques to provide more objective and reproducible measurements of enamel colour/characteristics. Notably, Kim and co-workers[9] appear to have been the first to use image analysis software to evaluate the effectiveness of treatment in improving the aesthetics of both anterior enamel opacities and post-orthodontic decalcification lesions in young patients.

The overall aim of this study was to further explore the use of objective computerised assessment to determine the effectiveness of minimally invasive treatments in reducing the visibility of discrete enamel opacities on maxillary central permanent incisors in children with MIH. Specific objectives were to quantify treatment-related changes in opacity size and brightness.

Why this paper is important to paediatric dentists

- Around a third of MIH-affected maxillary incisors in this study had opacities which involved the incisal edge, which has aesthetic relevance.
- Minimally invasive treatments (resin infiltration alone or in conjunction with microabrasion) significantly reduce the size and maximum brightness of discrete anterior white/cream enamel opacities in children with MIH, quantifiable by image analysis software.
- Further research is needed to explore the relevance of reduction in opacity size and brightness in the context of patient experience and expectations.

2 | MATERIALS AND METHODS

2.1 | Study design overview

This laboratory-based investigation was carried out in conjunction with a large-scale clinical study, which sought to explore the change in OHRQoL in children with MIH following the aesthetic management of their incisor opacities.[2,3] Ethical approval was obtained from the local NHS Research Ethics Committee, and written parental and child consent was required for study inclusion (Ref. 17/WA/0096).

In the primary study, two investigators (NH and JL) treated children aged 8–16 years, who attended the Paediatric Dentistry Clinic, Charles Clifford Dental Hospital, Sheffield, UK, following a referral for the management of their incisor opacities. Children were clinically diagnosed with MIH, confirmed by a consultant paediatric dentist, according to established criteria.[15] A variety of treatments were provided pragmatically, depending on opacity characteristics and child/parent preferences. Treatment options, which could be provided, alone or in combination, included the following: microabrasion; resin infiltration; tooth whitening; or composite resin restoration. Standard intra-oral anterior RGB (red, green and blue) clinical images were taken for each child pre-treatment and 6 months post-treatment, using a digital SLR camera (Nikon D3400; Nikon UK Ltd.) equipped with a Sigma EM 140DG macro ring flash (Sigma Imaging [UK] Ltd.) and Tamron 90-mm macro lens (TAMRON Europe GmbH). To ensure image capture standardisation, a modified method described by Murphy and colleagues was adopted.[16] Clinical images were taken in the same surgery using standardised camera settings (ISO 100, 1/160 speed, and F/22 aperture). The natural and room illumination conditions were kept the same, and the images were taken at the same distance of 20 cm from the patient's mouth to the camera lens.

The clinical digital images, recording the appearance of the patients' affected teeth before and after treatment, were anonymised and stored securely. The images provided the experimental material for the purposes of the present study as described below.

2.2 | Participants

Inclusion criteria were as follows:

- Children enrolled in the primary study[2,3] who had at least one discrete, visible white/cream enamel opacity present on at least one fully erupted maxillary permanent central incisor.
- Treatment received was microbarasion (Opalustre™; Optident Ltd.) and/or resin infiltration (ICONTM; DMG) in any combination.
- Availability of good-quality pre-treatment and 6-month post-treatment images for quantitative analysis.

2.3 | Image analysis

Forty-six clinical images were analysed on a 27-inch, 4K, HDR-enabled monitor using the commercially available image analysis software (Image-Pro Plus® V7; Media Cybernetics, Inc). An example image is shown in Figure 1, which illustrates participants were asked to bite on a disposable wooden lollipop stick, including their ID number and five standard coloured stickers, for linear calibration and to ensure standardisation of the image colour. The

FIGURE 1 Clinical colour image showing a participant (ID-58) biting on the linear calibration wooden stick with five standard coloured stickers. The image was taken prior to treatment to reduce the visibility of the white opacity affecting the maxillary left central incisor

images were converted from 24-bit RGB to 16-bit greyscale with the selection of the best pixel fit value option. This rendered a range of greyscale pixels from black (zero value) to white (maximum 65 535 value). The images were also magnified by 145% to facilitate the use of interactive (and semi-automated) drawing tools to quantify image features.

2.3.1 | Opacity area

Interactive drawing tools were used to determine the total incisor labial tooth surface area and the opacity surface area in both pre- and post-treatment images. Total tooth surface area and total enamel opacity surface area(s) were automatically calculated (in mm^2) after linear calibration of each image, using the known diameter of a coloured circle attached to the bite stick (which was included in all images). The percentage area of the tooth affected by the opacity was then calculated. A record was also made of where the opacity was located on the incisal edge (by splitting the surface into thirds) and whether or not the opacity involved the incisal edge of the treated tooth.

2.3.2 | Opacity brightness

Pixel intensity was used to measure opacity brightness in relation to adjacent surrounding normal enamel, using a line profile tool. In both pre- and post-treatment images, a line profile was drawn through the middle of the enamel opacity in a mesial-distal (horizontal) direction from and to normal enamel through the lesion (Figure 2A). A reference point was marked at the junction between normal adjacent and opacity enamel, and pixel intensity was measured every 0.009 mm along with the line profile, with maximum and minimum values used for analysis. If

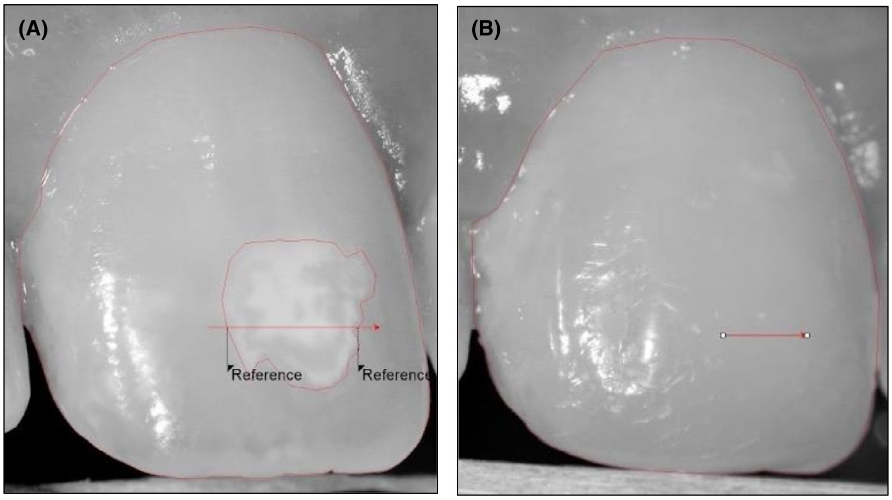

FIGURE 2 (A) Monochrome image demonstrating the placement of a horizontal line profile through the outlined opacity following image conversion to greyscale format. Reference markers are also shown at the opacity edges along the profile line, and the entire labial tooth surface area is also outlined in red. (B) Corresponding post-treatment monochrome image of participant ID-17′s maxillary right central incisor after the placement of profile line (the opacity is now no longer readily visible)

an opacity was not visible in post-treatment images, a line profile was placed in the corresponding position identified from the saved corresponding pre-treatment image (Figure 2B).

2.4 | Intra-operator repeatability

All image analysis was undertaken by one investigator (CW), and intra-operator repeatability was determined by repeating the quantification process with a 1- to 8-week interval on 20% ($n = 9$) of the images. Intra-class correlation coefficients (ICC) were calculated to determine the level of agreement between the first and repeat tooth labial surface area and opacity size (mm^2) as well as the line profile values.

2.5 | Statistical analysis

Data were entered using the Statistical Package for the Social Sciences (SPSS) v26.0 (IBM Corp.). A descriptive analysis was used for participant gender, age, treatment undertaken, labial tooth surface area, opacity lesion area, percentage tooth area affected by the opacity, and the opacity location. Line profile data were analysed using the descriptive analysis of pixel intensity (mean, standard deviation, range) for both pre- and post-treatment images. The percentage of pixel intensity change after treatment was also calculated. Line profile data distribution was assessed for normality (the Shapiro-Wilk test) and was found not to be normally distributed. The Wilcoxon signed-rank test for related samples was therefore used to determine any significant differences between pre- and post-treatment data (opacity area and greyscale values). The significance level was set at 5% ($p \leq .05$).

3 | RESULTS

3.1 | Participants and affected teeth

A total of 23 participants received minimally invasive treatment for a discrete anterior white/cream opacity. Seventeen children received treatment on one maxillary central incisor, and six children underwent treatment on both central incisors providing a total of 29 teeth for analysis (and 35 discrete opacities). There was a nearly equal number of maxillary left and right incisors ($n = 15$ and $n = 14$ respectively). The majority ($n = 23$; 79%) of teeth were managed using a combination of microabrasion followed immediately by resin infiltration, and the remaining six cases (21%) underwent resin infiltration alone.

The mean age of participants was 10 years, with a range of 7–15 years, and there were almost twice as many female patients as male patients ($n = 15$ and $n = 8$ respectively).

3.2 | Opacity characteristic quantification

Figures 3 and 4 show an example of the image analysis performed; in this case, a maxillary left central incisor

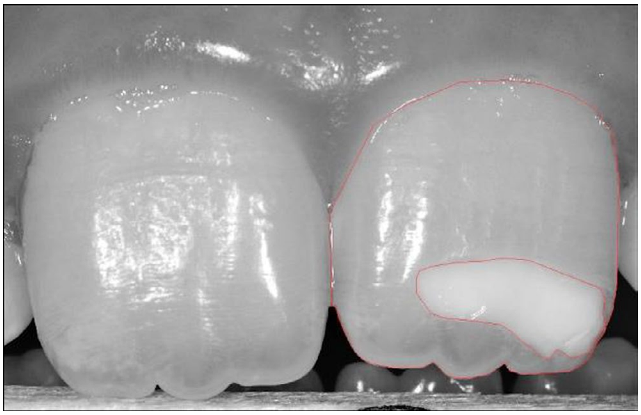

FIGURE 3 Monochrome image showing the labial tooth surface area and enamel opacity surface area outlined in red after image conversion to greyscale format. Participant ID-58, pre-treatment image, and maxillary left central incisor enamel opacity (see corresponding colour image in Figure 1)

pre- and post-treatment involving microabrasion and resin infiltration. The tooth surface and the opacity are outlined. The total labial surface area (mm^2) of the 29 incisors and the area of all 35 opacities, pre- and post-treatment, are shown in Table 1. Pre-treatment, the mean labial surface area of the whole tooth was 62.9 mm^2 (SD 9.3; range = 41.1–80.8 mm^2) and the mean opacity surface area was 14.3 mm^2 (SD 7.5; range = 3.9–38.3 mm^2). All opacities were located in the incisal third of the tooth, with around a third (n = 10) involving the incisal edge. There was a significant reduction in the mean total opacity surface area from 14.3 mm^2 (SD 7.5; range = 3.9–38.3 mm^2) to 9.4 mm^2 (SD 9.0; range = 0–39 mm^2) following treatment ($p < .001$, the Wilcoxon signed-rank test for related samples). The proportion of visible opacity covering the tooth was also significantly reduced from 22.5% (SD 10.5; range = 6.8%–53.2%) to 14.7% (SD 12.7; range = 0%–49.4%) ($p < .000$, the Wilcoxon signed-rank test for related samples).

Pre- and post-treatment data for the greyscale pixel intensity are shown in Table 2. A significant reduction in mean maximum greyscale pixel value following treatment was observed, indicative of a reduction in the brightness/whiteness of the opacity: the mean maximum opacity brightness after treatment significantly reduced from 53 065.9 (SD 4740.0; range = 43 813.0–65 535.0) to 49 039.7 (SD 3795.9; range = 42 093–54 323) ($p < .001$, the Wilcoxon signed-rank test for related samples). No significant change, however, was observed in the minimum greyscale pixel values, which reflect the 'normal' adjacent enamel appearance, which remained unchanged following the treatment of the opacity.

3.3 | Intra-examiner repeatability

Intra-class correlation coefficients (ICC) for initial and repeat measurements of tooth and opacity area and line profile data were calculated, with 95% confidence intervals. Intra-examiner repeatability of measurements was good-to-excellent for all parameters, ranging from 0.75 to 1.00.[17]

4 | DISCUSSION

Using computerised image analysis, this study aimed to objectively assess the effectiveness of minimally invasive treatments in reducing the visibility of discrete enamel opacities in children with MIH. The two parameters that defined this clinical outcome are considered thoroughly: a reduction in opacity size and a reduction in the maximum pixel intensity (whiteness/brightness) of the treated area.

A key finding was that, following treatment, the proportion of tooth surface that appeared visibly different (ie, representative of a discrete enamel opacity) was reduced by almost half of its original size. This certainly suggests an 'improvement' following the intervention, but whether this is a meaningful change, from the patient perspective, is considered later in the discussion. In addition to overall size, the location of an enamel opacity may also have a bearing on its overall visibility. Opacities located on the more translucent incisal third of the tooth are more noticeable, by virtue of their opaque nature.[14] If the patient has a short upper lip length, incompetent oral seal and/or proclined incisors, the opacity may also be subject to drying and may be even more visible. In this study, all opacities were located in the incisal third of affected incisors, although the details about the patient's lip line were not recorded. A third of all opacities involved the incisal edge itself, in keeping with findings in other studies.[18] Yet, no teeth showed any post-eruptive breakdown, a feature that has been commonly observed in teeth with yellow/brown opacities.[18]

An optimal treatment outcome would render the opacity 'invisible' next to adjacent sound enamel. Yet, the disappearance of opacity margins makes measurement of the post-treatment opacity area difficult. Indeed, some opacities in this study completely 'disappeared'; thus, no measurement could be made of the post-treatment lesion area, as it essentially no longer existed. Further work is needed to identify whether the change in opacity size per se is an appropriate parameter to determine the treatment success, and how (if at all) opacity size correlates with patient perceptions and OHRQoL outcomes.

The greyscale pixel intensity of normal and hypomineralised (area of opacity) enamel was used to objectively determine opacity visibility. This approach has been previously well described in studies exploring interventions to improve the aesthetics of post-orthodontic demineralised lesions and developmental enamel defects.[19,20] The maximum pixel intensity within the enamel opacity was significantly lower following treatment, which correlated with the investigator's observation of a reduction in opacity brightness ('whiteness') and visibility, as the opacity's optical properties became closer to that of sound enamel. It may be argued that this change could have been due to variations in other factors, such as ambient lighting. Yet, as the greyscale pixel intensity found in adjacent sound enamel did not significantly differ between visits, one can be more confident that the changes in pixel intensity within the opacity were directly due to the treatment performed.

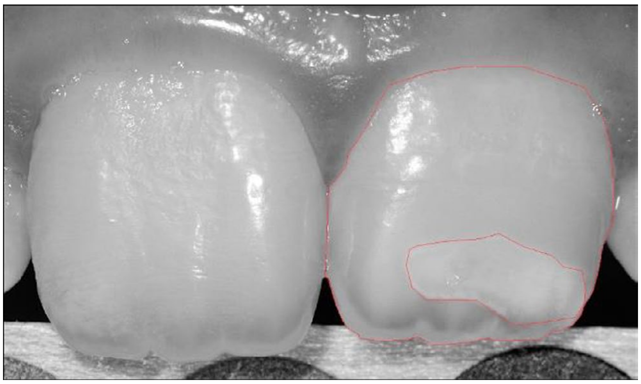

FIGURE 4 Corresponding post-treatment monochrome image of participant ID-58′s maxillary left central incisor, showing labial tooth surface area and enamel opacity surface area outlined in red after image conversion to greyscale format

The main strength of the present study was that it provided objective, albeit preliminary, outcome data for the management of a common clinical condition. To date, there appear to be no standard clinical outcome measures against which to appraise the effectiveness of minimally invasive treatments in reducing the visibility of enamel opacities in children with MIH. The present study has explored the use of image analysis to objectively measure size and brightness characteristics of enamel opacities in this population. The methodology was shown to be repeatable, and the techniques used were non-invasive and relatively straightforward. Furthermore, this approach did not necessitate the purchase of expensive equipment and would be accessible to clinical researchers in this field. A further strength of the study is that post-treatment images were taken 6 months after the initial intervention. This afforded the opportunity to determine the stability of the treatment outcome on a more longitudinal basis. A further review at 2 years would provide an invaluable insight, but this is more difficult to arrange in secondary care settings when patients are discharged after the completion of a course of specialist treatment.

A limitation of the present study was that a single investigator conducted all the image analysis, albeit with training and calibration from the supervisory team. Although intra-examiner repeatability was found to be good-to-excellent, a more robust approach would have involved two investigators, thereby reporting on inter-examiner reliability and providing additional evidence for the standardisation of methodology. Indeed, on initial inspection, intra-examiner repeatability may be questioned in view of the slight variation seen in the overall tooth size pre- and post-treatment. This was, however, likely due to the continuing maturation of the gingival margin in this

TABLE 1 Image analysis data: Clinical characteristics (tooth and opacity surface area [mm^2] and proportion of tooth surface area affected by opacity [%]), pre- and post-treatment

Clinical characteristics	Pre-treatment Mean (SD, range)	Post-treatment Mean (SD, range)
Surface area (mm^2)		
Tooth ($n = 29$) labial surface area	62.9 (9.3, 41.1–80.8)	64.3 (9.8, 45.1–81.1)
Opacity ($n = 35$) surface area	14.3 (7.5, 3.9—38.3)	9.4 (9.0, 0–39.8)*
% area of tooth affected by opacity	22.5 (10.5, 6.8–53.2)	14.7 (12.7, 0–49.4)*

Note: *Significant difference between pre- and post-treatment measurements ($p < .05$, the Wilcoxon signed-rank test for related samples).

TABLE 2 Greyscale pixel intensity data of enamel opacities ($n = 35$) pre- and post-treatment (±the Wilcoxon signed-rank test for related samples; *$p < .05$)

Pixel Intensity	Pre-treatment	Post-treatment	*p* Value±
Maximum mean (SD, range)	53 066 (4740, 43 813–65 535)	49 040 (3796, 42 093–54 323)	<.001*
Minimum mean (SD, range)	39 565 (4361, 29 317–47 862)	40 416 (4534, 32 228–50 060)	.534

young population, which would account for a slightly increased tooth surface area after 6 months.[21,22] Another acknowledged weakness with the study design was that the placement of the line profile on the images relied on operator selection (thus subjectivity) and could not be fully automated. Colour analysis could offer future possibilities for more detailed analysis, but this approach is recognised to be complex and not without limitations (including the use of some invasive methods and data that are not readily accessible to direct clinical interpretation). In the present study, a manageable quantity of relatable data was produced by converting the images to work in greyscale. This method would need to be tested but may not be as applicable to coloured MIH lesions or those with diffuse margins. In some cases, reflections were seen on the tooth surface images, partly due to the shape of the tooth surface. These were minimised as much as possible, but post-treatment the teeth needed time to rehydrate and could not be imaged dry (air-dried) due to dehydration effects that would have an adverse impact on lesion appearance; the reflections were minimised as much as possible, and no measurements were made including these small artefacts. Finally, it was not appropriate to compare outcomes according to treatment regimen due to the widely different sample numbers in the two groups (resin infiltration, $n = 6$; combined microabrasion and resin infiltration, $n = 23$). The initial aim of the study was not to compare the effectiveness of different treatments as such, as this would have required an intervention study design with proper sample size calculation, as well as randomisation of participants to one of the two treatment options. The study, however, does provide invaluable outcome data for each regimen, which could be used to inform sample size calculations for future randomised controlled studies. This remains a priority research area as, currently, clinicians have limited evidence to support one treatment regimen over another when providing aesthetic treatment for children with white/cream or indeed yellow/brown incisor opacities.

It is helpful, however, to review the findings from previous studies that have provided some clinical evidence for the success of various interventions in reducing the visibility of enamel defects. Recent attention has turned to the effectiveness of resin infiltration in reducing opacity visibility by virtue of its ability to change the refractive index of hypomineralised enamel to correlate more closely with that of sound enamel.[9,23] In a study of children with enamel opacities (and post-orthodontic decalcified lesions), Kim and colleagues[9] applied resin infiltration to reduce the visibility of these white lesions. They compared RGB characteristics of enamel defects, using spectrophotometry, before and 1 week after resin infiltration and found that this approach completely masked developmental enamel opacities in 25% of cases, partially masked 35% of cases, and had no effect in 40% of cases. Another study, which also quantified a treatment-related change in enamel opacity appearance, using spectrophotometry, was conducted by Mazur and colleagues,[23] although MIH cases were excluded. The spectrophotometric colour difference between the affected and sound enamel in each tooth was calculated before and after resin infiltration, and the aesthetic outcomes were found to be excellent. More recently, investigators have compared resin infiltration, microabrasion, or fluoride varnish/Tooth Mousse® in reducing the visibility of hypomineralised and fluorotic enamel lesions, again using spectrophotometric analysis of colour change.[24] Clinically observable improvements were reportedly achieved in all three regimens, but resin infiltration was quantifiably more effective in normalising enamel colour. To date, there appear to be no published objective outcomes for the effectiveness of resin infiltration preceded by microabrasion in reducing opacity visibility, although clinical impressions suggest this is successful.[2]

The two main areas for future inquiry may follow on from this study, which relate to patients' perspectives and to the technologies used to measure enamel opacities. Although the present study's focus was biomedical, it must be pointed out that the original research programme was entirely patient-centred and incorporated several patient-reported outcome measures following aesthetic treatment of enamel opacities.[2,3] The next step, therefore, would be to explore how the clinical outcome data, derived from the present study, correlate with patient-reported outcomes, within a theoretical model of health. Put more simply, does a reduction in opacity size or brightness actually predict an improvement in child-reported OHRQoL? Previous research suggests that patient-related factors such as perception of self-worth and family support are, in fact, more predictive of the psychosocial impact of enamel opacities on children rather than the 'severity' of the appearance of the enamel defect itself.[25-27] Nonetheless, qualitative enquiry, with a small group of these patients, would provide invaluable insights into what 'clinical' factors are viewed by children and their families to be a measure of treatment success. The second priority for future research relates to an evaluation of the techniques available to objectively measure enamel opacities, pre- and post-treatment. The methodology used in the present study was admittedly unidimensional, and other approaches such as spectrophotometric or other analytical image measures may have a role in future work. The application of optical coherence tomography has also received attention with respect to quantification of hypomineralised enamel but only within a research setting.[5] Clinicians need a meaningful evidence base to select the most efficacious materials and techniques to improve incisor aesthetics of children with MIH.

This study found that current minimally invasive treatment approaches used to manage MIH were effective in reducing the clinical characteristics (size and brightness) of visible incisor enamel opacities in children. The study has demonstrated that clinical images and computerised image analysis can be used to objectively measure such characteristics in a non-invasive way with good intra-operator repeatability. Future research should seek to correlate these objective findings with patient-reported outcomes.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest with respect to the authorship and/or publication of this article.

AUTHOR CONTRIBUTIONS

HDR, MVV, NNH, and C.E conceived the idea; CW collected and analysed the data; NNH and JAL provided clinical images; and C.W, HDR, and C.E led the writing.

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