Available online at www.sciencedirect.com

Pediatric Dental Journal

journal homepage: www.elsevier.com/locate/pdj

FISEVIER

Review

Is molar incisor hypomineralisation (MIH) a new disease of the 21st century?



Chelsea Cook^{*}, Rosa Moreno Lopez

Institute of Dentistry, University of Aberdeen, AB25 2ZR, Aberdeen, United Kingdom

ARTICLE INFO

Article history: Received 23 February 2022 Received in revised form 24 March 2022 Accepted 11 April 2022 Available online 28 April 2022

Keywords: Molar incisor hypomineralisation MIH Cheese molars MIH timeline Archaeological dental studies

ABSTRACT

Introduction: The term molar incisor hypomineralisation (MIH) was used by Weerheijm, Jälevik and Alaluusa in 2001 to describe hypomineralisation of systemic origin of 1–4 permanent first molars, frequently associated with affected incisors. MIH had previously been described by various terms such as, mottling of enamel and cheese molars. Assessment of MIH between studies is confounded by different terminology, resulting in difficulty in being able to ascertain when this disorder initially presented. Asking whether MIH is a new disease of the 21st century, or whether it existed previously, may help to establish if aetiological factors are liked to contemporary lifestyle.

Materials and methods: Cochrane Library, Embase, Medline and Web of Science were the databases used to conduct an extensive literature search. Specific search terms and inclusion/ exclusion criteria were used to identify relevant publications. After the screening process, 13 articles were included in this review, 5 investigated archaeological specimens, whilst the remaining 8 were clinical studies, where participants were born before the 21st century.

Results: Four common themes identified on review of the selected publications were: suggested rates of MIH between archaeological studies vastly differ, clinical studies carried out before 2001 suggest similar rates of MIH to present day, despite use of different terminology. Both archaeologic and clinical studies suggest MIH existed before the 21st century and publications using clinical assessment either focus on children or adolescents. *Conclusion:* Analysis of the selected publications suggests that MIH was present before the 21st century. This is demonstrated in both clinical and archaeological studies.

© 2022 The Authors. Published by Elsevier Ltd on behalf of Japanese Society of Pediatric Dentistry. This is an open access article under the CC BY license (http://creativecommons. org/licenses/by/4.0/).

1. Introduction

The term molar incisor hypomineralisation (MIH) was used by Weerheijm, Jälevik and Alaluusua (2001) [1], to describe hypomineralisation of systemic origin of 1–4 permanent first molars (FPMs), frequently associated with affected incisors. The authors of this study recognised the need for standardisation of terminology when discussing these specific enamel defects. Multiple descriptions of MIH had been used previously including: mottling of enamel, opaque spots; idiopathic enamel opacities; demarcated enamel opacities;

* Corresponding author.



E-mail addresses: c.cook.18@abdn.ac.uk (C. Cook), r.m.lopez@abdn.ac.uk (R. Moreno Lopez). https://doi.org/10.1016/j.pdj.2022.04.001

^{0917-2394/© 2022} The Authors. Published by Elsevier Ltd on behalf of Japanese Society of Pediatric Dentistry. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

cheese molars; chalky enamel; non-fluoride hypomineralisation in the first molar and idiopathic enamel hypomineralisation in permanent first molars [2–6] In addition to this, MIH had often been confused with - and misdiagnosed - as other developmental enamel defects such as fluorosis and enamel hypoplasia [7].

Assessment of MIH between studies is confounded by different terminology. This results in difficulty in being able to ascertain when this disorder initially presented.

Recently, there has been recommendation that the nomenclature 'MIH' should be replaced with Molar Hypomineralisation ('MH') [5,8]. This change in terminology is to signify that a currently accepted phenotype of this disorder is a demarcated opacity in any molar \pm any other teeth, of primary or permanent dentition [9,10]. Hypomineralisation of the Second Primary Molar (HSPM) is often a predictive sign of MIH in the permanent dentition [11,12]. Hubbard et al. (2017) [8] and Hubbard, Perez and Ganss (2021) [5], suggest 'MH' is used collectively, instead of using the terms - 'MIH' and 'HSPM' - to describe hypomineralisation of the primary and secondary molars as separate entities. Using the term MH simplifies the language used to describe this disorder, which is important for standardisation of common terminology [5]. However, most publications from 2001 to present, have used the term MIH, therefore this is the nomenclature used throughout this article.

For decades it has been known that systemic interference could result in developmental defects of enamel [13]. Kronfeld and Schour stated in 1939 [14], that a systemic disturbance could result in either 'hypocalcification' (a form of hypomineralisation) or hypoplasia of enamel depending on the severity of the disturbance, with a more severe systemic insult resulting in hypoplasia.

The differences between enamel hypoplasia and enamel hypomineralisation have also been well documented within the dental literature for many years [4]. Developmental *quantitative* deficiencies of enamel often resulting in pits, grooves and thin enamel are known as enamel hypoplasia. *Qualitative* enamel defects - some of which are known today as MIH - often exhibit altered mineralisation and are more likely to cause changes in the translucency of enamel, resulting in white, yellow or brown demarcated opacities [15]. Research investigating the aetiology of enamel hypoplasia has successfully resulted in a significant decrease in current paediatric cases of the disorder [8]. An understanding of the causes and subsequent prevention of MIH has been less successful, with an unclear aetiology and current childhood rates ranging from 2.8 to 21% [16].

The challenges caused by MIH, both to the patient and dentist, as well as to public health, are considerable [5]. At a patient level, children with hypomineralised enamel are at an increased risk of caries, posteruptive enamel breakdown and hypersensitivity [6]. These teeth are often avoided when brushing, due to the discomfort [17,18], which further exacerbates risk of dental caries. The demarcated enamel opacities may cause significant aesthetic concerns, particularly when the anterior dentition is affected [10]. From a dentist's perspective, MIH can be difficult to diagnose and manage [19].

Hypomineralisation can make teeth difficult to anaesthetise [6], this is attributed to the porous enamel, resulting in inflammation of the pulp [20]. These teeth generally require a greater amount of dental treatment which can be further complicated by increased risk of restoration failure [21] and potential behavioural issues from the paediatric patient [22]. In severe cases, extraction of hypomineralised FPMs may be needed [6,12], this can lead to a general anaesthetic procedure for young patients, putting the child at further risk of health complications [23]. In addition, extractions can further impact and complicate future orthodontic treatment [10,24].

The high costs to society, combined with the likelihood that MIH may be preventable, calls for further research and understanding within this field [5]. Increased knowledge regarding the causative factors will be a step towards understanding the prevention. It is largely accepted that the aetiology is multifactorial [25] and many causes have been hypothesised such as environmental toxins, prolonged breastfeeding, infantile respiratory illness and low pre-term birth weight [6,25-28]. However, a common aetiology is still poorly accepted globally. It has been suggested that rates of MIH are increasing and causative factors may be linked to modern-day life [12]. The question whether MIH is a new disease of the 21st century, or whether it existed previously in past populations may help to ascertain if aetiological factors are liked to contemporary lifestyle [12]. This literature review shall investigate whether MIH was evident before the 21st century.

2. Methods

2.1. Study identification strategy

The following online databases were used to conduct an extensive search of the literature: The Cochrane Library (Ovid), Embase (Ovid), Medline (Ovid) and Web of Science. The search terms used were as follows: (molar incisor hypomineralisation OR hypomineralisation OR chalky enamel OR cheese molars OR opaque spot OR enamel opacities) and were combined using AND with both of the following: (adults OR elderly OR older) or (century OR past OR archaeological). Depending on the database, free text-terms were used to account for differences in US and UK spelling, to include singular and plural versions of words, for example, 'cheese molar' and 'cheese molars' and to restrict the search to the title and abstract fields. Additionally, any relevant studies that were referenced in the screened publications and adhered to the inclusion/exclusion criteria, were added to a list of 'grey literature'.

2.2. Inclusion and exclusion criteria

For inclusion within this review, the specific criteria which selected publications had to meet were as follows: (1) molar incisor hypomineralisation had to be specified or an alternative term/earlier term listed within the search terms; (2) the study should investigate adults born before the 21st century. If participants aged 21 or under were included, the study must have commenced before 21st century or could be an archaeological/historical study; (3) the examination of the dentition must involve at least one permanent first molar \pm other teeth; (4) the publications must be written in English language.

The exclusion criteria were: (1) studies carried out in animals and not humans; (2) data involving enamel defects caused by fluorosis, enamel hypoplasia, white spot lesions, caries, amelogenesis imperfecta or hypophosphatasia; (3) paediatric studies where the participants were born after the year 2000; (4) studies which focussed on the deciduous dentition only; (5) review articles with no primary data.

2.3. Data extraction strategy

Title and abstract screening for relevancy was carried out by two of the authors separately (CC and RML). Full text screening was performed for any publication which passed the initial title and abstract screening, this was completed by the same two authors, independently. For the data analysis, descriptive data was extracted regarding: study design; sample size; age of participants; term used to describe MIH; methods and criteria used to assess MIH; teeth examined and the percentage of participants suggested to display characteristic signs of MIH.

The findings from the publications were summarised using two main themes which were converted on a two-by-two table: (1) Archaeological studies and (2) Clinical Studies. These two themes were then subdivided into two results options (3) Similar rates of MIH to present day and (4) Different rates of MIH to present day (Table 1).

3. Results

3.1. Results from database search

385 citations were found using the database search and 5 additional studies were found from the reference lists of key publications (grey literature). Out of these 390 citations, 48 duplicate records were excluded. A further 315 articles were excluded at the abstract screening stage. The reasons for these exclusions were: irrelevance; the study investigating fluorosis, enamel hypoplasia or the dental effects of hypophosphatasia and not MIH; paediatric study with children born after the year 2000; article not available in English language and examination of the primary dentition only. Full text screening was then carried out of the remaining 27 publications and a further 14 were excluded. Reasons for exclusion at this stage were: no examination of molars and/or lack of reference to which teeth were examined; enamel defect not specifically MIH; study investigating fluorosis and article being a literature review.

13 articles remained which were included for this literature review: 5 case series; 4 cross-sectional studies; 3 cohort studies (longitudinal) and 1 case report. Characteristics of these 13 articles are shown in Table 3. The full search strategy is shown within the Prisma Flow Diagram (Fig. 1).

3.2. Reviewing the selected publications

5 of the studies used archaeological specimens, these ranged from 7 to 11th century to 20th century in age. 8 clinical studies were reviewed, all participants were born before the 21st century. Sample sizes ranged from 1 (archaeological study) to 2226 (clinical study).

The aims of the studies varied. The 5 archaeological studies were investigating the presence of MIH in past populations. The aims of the clinical studies ranged from investigating 'enamel opacities', 'idiopathic enamel hypomineralization', 'cheese molars', the dental health of certain populations, development of teeth in low-birth-weight children, developmental tooth defects in children exposed to breast milk dioxins and treatment outcomes and dental anxiety in 18yr olds with MIH. Some of the studies did not share common aims with this review article, however, it was still possible to use data from these articles to support our research question.

The varied terminology used to describe enamel hypomineralisation within the clinical studies is presented in Table 2. The reasons why these enamel defects were accepted as MIH for the purposes of this literature review are also included.

The criteria used to assess and grade MIH was not homogenous between studies. Some of the score criteria used were: European Academy of Paediatric Dentistry (EAPD) 2003; developmental defects of enamel (DDE) index; modified DDE

Table 1 – Common themes identified from the articles included within the literature review. The prevalence rates from Refs. [2,34,35] are not displayed because not all of their cases can be regarded as having MIH, as individuals may have demonstrated enamel opacities without any involvement of a FPM.

Study type	Similar rates of MIH to present day (2.8–21%)	Different rates of MIH to present day (2.8–21%)
Clinical study	3.6–15.4%, n = 2226, 8–13yrs [3] 17%, n = 102, 6–7yrs [26] 15%, normal birth-weight group, n = 55, 4–12yrs [29] 10%, n = 497, 11yrs [6] 18.4%, n = 516, 8yrs and 18yrs [22]	n/a
Archaeological study	3.1%, n = 323, adults [30]	93.2%, n = 45, children/adolescents [31] 100%, n = 1, adult [32] 100%, n = 3, 2 children and 1 adolescent [12] 27%, n = 22, all under 18yrs [33]



Fig. 1 – PRISMA flow diagram outlining search strategy.

index; modified Curzon and Spector (1977) system; X-ray fluorescence analysis and other novel methods.

4. Discussion

This literature review included 13 publications; 3825 individuals were examined in the 8 clinical studies and 394 dentitions were studied in the 5 archaeological studies. It is important to differentiate clinical and archaeological studies, mainly due to the major differences in reliability of MIH diagnosis.

4.1. Suggested rates of MIH between archaeological studies vastly differ

Rates of MIH varied vastly between the 5 archaeological publications (Table 1), including results from Ogden, Pinhasi and White (2008) (MIH diagnosis 93.2%) [31]and Garot et al. (2019) (MIH differential diagnosis 27%) [33]; two studies which examined 22 of the same archaeological specimens.

MIH diagnosis can be subject to bias when examining teeth from archaeological dentitions due to taphonomic processes (actions related to how specimens' decay and become

Table 2 – Terminology use	ed to describe suspected MIH in each clinical study inclu	ded within the literature review.
Clinical Study	Terminology	Reasons to suspect MIH
[2]	'White spots, opaque enamel, demarcated enamel'	 The lesions were demarcated and not diffuse First permanent molars affected the most and more extensively than other teeth Lesions described as chalky and susceptible to increased erosion in acid Authors clearly distinguish between hypoplasia and these onacities
[34]	'Enamel opacities'	 The lesions considered were discrete areas of white opaque enamel, including a line or a patch Teeth with highest prevalence of enamel opacities were the mandibular and maxillary first permanent molars, followed by the maxillary incisors
[3]	'Idiopathic enamel hypomineralization'	 Restricted to first permanent molars and incisors
[35]	'Demarcated enamel opacity'	 Opacities were demarcated and either white or coloured Upper incisors and lower first permanent molars examined
[26]	'Hypomineralization'	 Mineralisation changes examined in the first permanent molars only
[29]	'Enamel opacity, mineralisation defects'	 Opacities defined as a change in enamel translucency, without a break in enamel continuity Only the first permanent molars and incisors assessed
[6]	'Cheese molars'	 Demineralised defects described as soft and porous enamel with the appearance of discoloured chalk First permanent molars and maxillary central incisors avanined only.
[22]	'Molar incisor hypomineralisation'	 Classed as MIH by the authors First permanent molars had to be involved

preserved). Teeth can be affected by certain chemical elements, such as iron and manganese within the burial soil [33,36]. This can cause discolouration resembling hypomineralised enamel [33,37].

Garot, Couture-Veschambre, Manton, Rodriguez, et al. (2017) [38], advised to avoid MIH misdiagnosis due to taphonomic staining, X-ray fluorescence and microtomographic analyses should be used to confirm post-mortem contamination and enamel hypomineralisation respectively. Garot, Couture-Veschambre, Manton, Beauval, et al. (2017) [12], reinforced this, by comparing clinical examination of historical teeth by 19 MIH specialists, with non-subjective enamel microanalysis testing. 3 archaeological dentitions were examined, the Fleiss kappa test performed for each specimen demonstrated a poor agreement between expert responses regarding clinical diagnosis of MIH. Again, this was seen in Garot et al. (2019) [33], where 3 examiners obtained an almost perfect agreement when diagnosing MIH in a current population (Fleiss Kappa = 0.9), this contrasted with poor reliability when they assessed an archaeological collection (Fleiss Kappa = 0.3). The authors concluded that low reliability of MIH diagnosis in historical dentitions could explain the varying prevalence values between archaeological studies [30].- [32] used clinical assessment or 'macroscopic methods' to determine MIH diagnosis, perhaps contributing to the variable rates of MIH suggested.

Numbers of archaeological series with dental remains and information regarding health and lifestyle are limited [30]. Low sample sizes in many of the archaeological studies could also contribute to the variability in results. The case report by Curzon et al. (2015) [32], examined 1 single adult dentition, similarly, Garot, Couture-Veschambre, Manton, Beauval, et al. (2017) [12], investigated 3 historical dentitions. The authors from either study did not mention why these specimens were selected specifically. As all 4 dentitions were reported as displaying signs of MIH, it can be assumed that they were not selected at random. Therefore, although these studies were not investigating MIH rates, assumptions regarding historical prevalence of MIH may be overestimated.

Archaeological studies Garot et al. (2019) [33], and Ogden, Pinhasi and White (2008) [31], also studied relatively small sample sizes of 22 and 45 respectively. Interestingly [33], reassessed the archaeological collection used in Ref. [31], to examine the reliability of MIH diagnosis in past populations.

Table 3 – Characteris	tics of the studies include	ed in the literature i	eview.				
Type of study	Study name	Author(s)	Year of publication	Journal published in	Sample size	Age of participants	Host Country
Case series	DEVELOPMENTAL OPACITIES OF TEETH IN A NEW ENGLAND COMMUNITY Their Relation to Fluorine Toxicosis	V. O. Hurme and D. M. D. Boston	1949	American Journal of Diseases of Children	170	Range of 13–30 yrs old with a mean of 17 yrs old	USA
Cross sectional study	Enamel opacities in primary and high school pupils	E. Mizrahi	1982	Journal of Dentistry	204 primary school and 222 high school	Children, mean ages 12 yrs and 17 yrs for both groups	South Africa
Cross sectional study	Epidemiologic study of idiopathic enamel hypomineralization in permanent teeth of Swedish children	G. Koch et al.	1987	Oral Epidemiology	2226	Children born in 1966, 1969, 1970 and 1971 were examined in 1979, children born in 1972, in 1980 and children born in 1974, in 1983, (ages 8 -13 yrs)	Sweden
Cross sectional study	The dental health of adults in an integrated urban development in Addis Ababa, Ethiopia	J. H. Nunn, R. R. Welbury, and P. H. Gordon	1993	International Dental Journal	243 adults	All over 18 yrs, mean age = 32 yrs	Ethiopia and UK
Cohort study - longitudinal	Polychlorinated dibenzo-p- dioxins and dibenzofurans via mother' s milk may cause developmental defects in the child' s teeth	S. Alaluusua, PL. Lukinmaa, T. Vartiainen, M. Partanen, J. Torppa, and J. Tuomisto	1996	Environmental Toxicology and Pharmacology	102 children	6–7 yrs old	Finland
Cohort study — longitudinal	A study of the development of the permanent dentition in very low birthweight children	W. K. Seow	1996	Paediatric Dentistry	55 very low birthweight vs 55 matched controls	4–12 yrs	Australia
Cross sectional study	Prevalence of cheese molars in eleven-year-old Dutch children	K. L. Weerheijm, H. J. Groen, V. E. V. M. Beentjes, and J. H. G. Poorterman	2001	Journal of Dentistry for Children	497	11 yr olds	The Netherlands
Archaeological case series	Nothing new under the heavens: MIH in the past?	A. R. Ogden, R. Pinhasi, and W. J. White	2008	European Archives of Paediatric Dentistry	45 archaeological 'subadults'	Range but all 'subadults' therefore children or adolescents	Republic of Ireland and UK
Cohort study -longitudinal (original study in 2001 where MIH patients were selected from was a cross sectional study)	Treatment outcomes and dental anxiety in 18-year- olds with MIH, comparisons with healthy controls – a longitudinal study	B. Jälevik and G. Klingberg	2012	International Journal of Paediatric Dentistry	32 children with MIH and 41 controls revisited	8 yrs old in 1998 (baseline study) and followed up at 18 yrs again	Sweden
Archaeological case report	Case report: A medieval case of molar-incisor- hypomineralisation	M. E. J. Curzon, A. R. Ogden, M. Williams- Ward, and P. E. Cleaton-Jones	2015	British Dental Journal	1 adult female skull	Thought to be between 25 and 44 yrs old from the mid 15th century	UK and South Africa

PEDIATRIC DENTAL JOURNAL 32 (2022) 67-76

Archaeological case series	Was molar incisor hypomineralisation (MIH) present in archaeological case series?	J. Kühnisch et al.	2016	Clinical Oral Investigations	323 historical adult dentitions	323 adults (3891 permanent teeth). Archaeological specimens taken from three different time periods, 12th-16th century, 16th-18th century and 19th-20th century.	Germany
Archaeological case series Archaeological case series	Analytical evidence of enamel hypomineralisation on permanent and primary molars amongst past populations Differential diagnoses of enamel hypomineralisation in an archaeological context: A postmedieval	E. Carot, C. Couture- Veschambre, D. Manton, C. Beauval, and P. Rouas E. Garot, C. Couture- Veschambre, D. J. Manton, J. Bekvalac, and P. Rouas	2017 2019 1	Scientific Reports Scientific Reports International Journal of Osteoarchaeology	3 archaeological specimens chosen from a large group 22 individuals	3-6yrs (7th-11th century), 3-6 yrs (12th- 16th century) and approx. 14 yrs (15th-18th century) 47 'subadults' (under 18 yrs) - many excluded due to no FPMs	France and Australia France, Australia and JK
	skeletal collection reassessment						

The striking differences in MIH diagnosis – 93.2% [31], and 27% [33], led the latter to conclude that macroscopic analysis of historical dentition is not reliable for MIH diagnosis, mainly due to reasons outlined previously regarding taphonomic staining. Garot et al. (2019) [33], could only use 22 out of the 45 subadult dentitions examined by Ogden, Pinhasi and White (2008) [31], due to the requirement for at least one FPM to be present. This raises the question of how MIH was diagnosed in 23 historical dentitions lacking any FPMs [31].

Kühnisch et al. (2016) [30], examined a relatively large sample size of 323 historical adult dentitions, taken from 3 different time periods (12th-16th, 16th-18th and 19th-20th century). This larger study was the only archaeological research paper to suggest similar prevalence rates of MIH to present day (Table 1). However, the authors did mention that MIH opacities may have changed in appearance due to the high level of attrition noted, meaning that numbers may have been underestimated.

In addition to taphonomic staining and low sample size numbers, significant dental pathology can also contribute to complications when diagnosing MIH in historical dentitions. Dental disease such as caries, abscesses and periodontitis were not as well prevented nor treated as they are at present day. The single specimen examined in Curzon et al. (2015) [32], was reported as displaying signs of two 'Turner Teeth', periodontal disease and a dental abscess. Complications such as these can lead to discolouration as well as tooth loss, making any post-mortem diagnosis of MIH challenging.

Other developmental defects of enamel can also cause problems, not only with MIH diagnosis but also with author terminology and nomenclature. In Ogden, Pinhasi and White (2008) [31], the authors used the terms enamel developmental dysplasia and MIH interchangeably. Even more confusingly, in an earlier publication, the authors described the 93.2% of MIH specimens from the 2008 study, as having enamel hypoplasia [39]. This highlights the importance of a globally recognised terminology and definition when describing MIH. The differences between enamel hypoplasia and enamel hypomineralisation have been documented for many years. Despite this, many dental professionals continue to use these terms as one, complicating the understanding of MIH by both the general public and other members of the dental team.

4.2. Clinical studies carried out before 2001, suggest similar rates of MIH to present day (2.8–21%), despite use of different terminology

Regarding the 8 clinical studies, suspected rates of MIH also seemed diverse initially. However, in 3 of the studies, a subject counted towards the overall rates, if any 1 of their teeth were affected by an enamel opacity [2,34,35]. These 3 studies did not count towards the clinical study prevalence rates shown in Table 1. The reasons outlined in Table 2 state why these 3 studies remained within this literature review and still regarded as demonstrating MIH prevalence.

It is important to highlight that both Hurme and Boston (1949) [2], and Mizrahi (1982) [34], stated that FPMs were the most affected teeth regarding enamel opacities. Therefore, it is probable that many of these participants were displaying MIH, due to the clinical description of the opacities and the

strong involvement of FPMs. However, not all of the cases can be regarded as having MIH as many individuals may have demonstrated enamel opacities without any involvement of a FPM – a requirement for MIH diagnosis today.

The five remaining clinical studies either restricted their examination to FPMs, FPMs and incisors or specified that FPMs had to be involved. The overall figures from these studies were therefore classed as rates of MIH. These rates lie within the prevalence range for MIH today.

Despite the reasons for suspecting MIH outlined in Table 2, there is no certainty that all these cases displayed definite examples of MIH. Many confounding factors may bias the rates significantly, even with comparatively modern-day clinical studies. Examples include, teeth being restored, tooth loss and confusion with other developmental enamel defects such as fluorosis. The clinical studies were predominantly carried out in children and/or adolescents which partly mitigates extensive restoration and tooth loss potential. Additionally, there has been an understanding for many years that fluorosis presents with more diffuse enamel opacities, therefore studies only describing demarcated enamel opacities were accepted.

The fact that the term MIH was devised in 2001, potentially presents the greatest challenge for accurate assessment of past rates of the disorder. Without access to clinical photographs of the participants entire dentition and a detailed history, there is no certainty to a MIH diagnosis. Again, this emphasizes the importance of a widely used and accepted nomenclature.

4.3. Both archaeologic and clinical studies suggest MIH existed before the 21st century

Some of the many differences between the 13 publications reviewed included: variations in the terminology used; sample sizes and whether the teeth were assessed clinically in the 20th century or taken from archaeological skeletal material. Prevalence data for suggested rates of MIH varied, especially amongst the archaeological studies. Despite this, a common theme linking all 13 of these studies together, is that MIH seems to have been present before the 21st century. 7 out of the 13 studies reviewed did not use the term MIH. However, every individual study could identify at least one mouth displaying a demarcated opacity on a FPM which aligned with today's description of MIH (Table 1).

Kühnisch et al. (2016) [30], reported the lowest rates of MIH out of the 5 archaeological publications. The authors concluded that MIH was 'rarely present' in the investigated archaeological case series which included specimens from the 12th up until the 20th century (10 individuals out of 323 remains with MIH, 3.1%). However, for the purposes of our research question, this suggests that MIH exists in archaeological samples. Although higher rates are quoted today compared to the rates quoted in Kühnisch et al. (2016) [30,] this study suggests that MIH did exist historically.

4.4. Publications using clinical assessment either focus on children, adolescents or young adults

The aim of this literature review was to investigate whether MIH was evident before the 21st century. Because the term MIH was only described in 2001 [1], the literature search was initially focused on finding studies which examined present day adults (>21-year-olds) for MIH, this was to avoid complication regarding different terminology. However, no studies identified from the literature search investigated this. Publications identified were either archaeological studies, which investigated historical dentitions for MIH, or clinical studies using participants born before the 21st century. Table 1 shows that most of these clinical studies were either carried out in children or adolescents. Table 2 demonstrates that 7 out of 8 of these clinical studies were published before 2001 and therefore, used different terminology to describe these hypomineralised areas of enamel.

There is therefore a gap in the literature. Current studies investigating adults for evidence of MIH would minimise issues regarding different terminology use. Up to date definitions of MIH would be used to aid diagnosis, this would prevent confusion with other enamel disorders. Use of current studies would also avoid the problems that archaeological studies encounter, such as potential for taphonomic staining in historical remains.

There could potentially be issues regarding FPM examination in older adults. FPMs may already have been extracted, lost, exhibit extensive caries or have undergone heavy restoration. However, strict criteria to follow when diagnosing and grading MIH would perhaps mitigate any issues with standardisation and reproducibility.

5. Conclusion

Analysis of the 13 selected publications suggests that MIH was present before the 21st century. This is demonstrated in both clinical studies and archaeological studies. The clinical studies, (carried out on participants born before the 21st century), suggest similar rates of MIH (2.8-21%) to present day. The rates of MIH determined from archaeological studies varies vastly between publications. Studies using clinical assessment focussed on children, adolescents or young adults. No current articles could be found which focussed on present day older adults and evidence of MIH, this has identified a significant gap in the literature. Clinical studies examining present day adults (>21-year-olds) for MIH would minimise problems with terminology, as current nomenclature and definitions would be used. Such studies would also mitigate issues which the archaeological studies encountered, such as difficulty differentiating taphonomic staining from enamel hypomineralisation and small sample sizes.

Declaration of competing interest

The authors declare no conflicts of interest.

Acknowledgements

This literature review was made possible through the scholarship funding from The Institute of Dentistry via The INSPIRE Scheme, Academy of Medical Sciences. We thank Dr Malcolm Stewart (Aberdeen Dental Institute, University of Aberdeen) for his help and valuable insight.

REFERENCES

- Weerheijm KL, Jälevik B, Alaluusua S. Molar-incisor hypomineralisation. Caries Res 2001;35(5):390–1 [Online]. Available: www.karger.com/journals/cre.
- [2] Hurme VO, Boston DMD. Developmental opacities of teeth in a New England community; their relation to fluorine toxicosis. Am J Dis Child 1949;77(1):61–75 [Online]. Available: http://archpedi.jamanetwork.com/.
- [3] Koch G, et al. Epidemiologic study of idiopathic enamel hypomineralization in permanent teeth of Swedish children. Community Dent Oral Epidemiol 1987;15:279–85.
- [4] Suckling GW. Developmental defects of enamel historical and present-day perspectives of their pathogenesis. Adv Dent Res 1989;3(2):87–94. https://doi.org/10.1177/ 08959374890030022901.
- [5] Hubbard MJ, Perez VA, Ganss B. 100 Years of chalky teeth research: from pioneering histopathology to social good. Frontiers in Dental Medicine Jan. 2021;1:1–8. https://doi.org/ 10.3389/fdmed.2020.632534.
- [6] Weerheijm KL, Groen HJ, Beentjes VEVM, Poorterman JHG. Prevalence of cheese molars in eleven-year-old Dutch children. J Dent Child 2001;68(4):259–62.
- [7] Garg N, Jain AK, Saha S, Singh J. Essentiality of early diagnosis of molar incisor hypomineralization in children and review of its clinical presentation, etiology and management. International Journal of Clinical Pediatric Dentistry Dec. 2012;5(3):190–6. https://doi.org/10.5005/jp-journals-10005-1164.
- [8] Hubbard MJ, Mangum JE, Perez VA, Nervo GJ, Hall RK. Molar hypomineralisation: a call to arms for enamel researchers. Front Physiol Aug. 2017;8:1–6. https://doi.org/10.3389/ fphys.2017.00546.
- [9] Steffen R, van Waes H. Therapy of MolarIncisorHypomineralisation under difficult circumstances. A concept for therapy. Quintessenz 2011;62:1613–23.
- [10] Almuallem Z, Busuttil-Naudi A. Molar incisor hypomineralisation (MIH) – an overview. Br Dent J Oct. 2018;225(7):601–9. https://doi.org/10.1038/sj.bdj.2018.814.
- [11] Elfrink MEC, ten Cate JM, Jaddoe VWV, Hofman A, Moll HA, Veerkamp JSJ. Deciduous molar hypomineralization and molar incisor hypomineralization. J Dent Res Jun. 2012;91(6):551–5. https://doi.org/10.1177/0022034512440450.
- [12] Garot E, Couture-Veschambre C, Manton D, Beauval C, Rouas P. Analytical evidence of enamel hypomineralisation on permanent and primary molars amongst past populations. Sci Rep Dec. 2017;7(1):1–10. https://doi.org/ 10.1038/s41598-017-01745-w.
- [13] Gottlieb B. Rachitis and enamel hypoplasia. Dental Cosmos 1920;62(11):1316–26.
- [14] Kronfeld R, Schour I. Neonatal dental hypoplasia. J Am Dent Assoc Jan. 1939;26(1):18–32. https://doi.org/10.14219/ jada.archive.1939.0041.
- [15] Clarkson J, O'Mullane D. A modified DDE index for use in epidemiological studies of enamel defects. J Dent Res 1989;68(3):445–50. https://doi.org/10.1177/ 00220345890680030201.
- [16] Saitoh M, Shintani S. Molar incisor hypomineralization: a review and prevalence in Japan," Japanese Dental. Sci Rev Nov. 2021;57:71–7. https://doi.org/10.1016/j.jdsr.2021.05.001.
- [17] Parikh DR, Ganesh M, Bhaskar V. Prevalence and characteristics of molar Incisor Hypomineralisation (mIH) in

the child population residing in Gandhinagar, Gujarat, India. Eur Arch Paediatr Dent Feb. 2012;13(1):21–6. https://doi.org/ 10.1007/BF03262836.

- [18] Zhao D, Dong B, Yu D, Ren Q, Sun Y. The prevalence of molar incisor hypomineralization: evidence from 70 studies. Int J Paediatr Dent Mar. 2017;28(2):170–9. https://doi.org/10.1111/ ipd.12323.
- [19] Hussein AS, Ghanim AM, Abu-Hassan MI, Manton DJ. Knowledge, management and perceived barriers to treatment of molar-incisor hypomineralisation in general dental practitioners and dental nurses in Malaysia. Eur Arch Paediatr Dent Oct. 2014;15(5):301–7. https://doi.org/10.1007/ s40368-014-0115-2.
- [20] Rodd HD, Boissonade FM, Day PF. Pulpal status of hypomineralized permanent molars. Pediatr Dent 2007;29(6):514–20.
- [21] Mejare I, Bergman E, Grindefjord M. Hypomineralized molars and incisors of unknown origin: treatment outcome at age 18 years. Int J Paediatr Dent Jan. 2005;15(1):20–8. https://doi.org/ 10.1111/j.1365-263X.2005.00599.x.
- [22] Jälevik B, Klingberg G. Treatment outcomes and dental anxiety in 18-year-olds with MIH, comparisons with healthy controls - a longitudinal study. Int J Paediatr Dent Mar. 2012;22(2):85–91. https://doi.org/10.1111/j.1365-263X.2011.01161.x.
- [23] Knapp R, Marshman Z, Rodd H. Treatment of dental caries under general anaesthetic in children. BDJ Team 2017;4(7):17116–undefined. https://doi.org/10.4317/jced.51906.
- [24] Cobourne MT, Williams A, Harrison M. National clinical guidelines for the extraction of first permanent molars in children. British Dental Jounral 2014;217(11):643–8.
- [25] Lygidakis NA, Dimou G, Marinou D. Molar-Incisor-Hypomineralisation (MIH). A retrospective clinical study in Greek children. II. Possible medical aetiological factors. Eur Arch Paediatr Dent Dec. 2008;9(4):207–17. https://doi.org/ 10.1007/BF03262637.
- [26] Alaluusua S, Lukinmaa P-L, Vartiainen T, Partanen M, Torppa J, Tuomisto J. Polychlorinated dibenzo-p-dioxins and dibenzofurans via mother's milk may cause developmental defects in the child's teeth. Environ Toxicol Pharmacol 1996;1(3):193–7.
- [27] Jälevik B, Noren JG, Klingberg G, Barregard L. Etiologic factors influencing the prevalence of demarcated opacities in permanent first molars in a group of Swedish children. European Jounral of Oral Science 2001;109(4):230–4.
- [28] Prokocimer T, Amir E, Blumer S, Peretz B. Birth-weight, pregnancy term, pre-natal and natal complications related to child's dental anomalies. J Clin Pediatr Dent 2015;39(4):371–6.
- [29] Seow WK. A study of the development of the permanent dentition in very low birthweight children. Paediatric Dentistry 1996;18(5):379–84.
- [30] Kühnisch J, et al. Was molar incisor hypomineralisation (MIH) present in archaeological case series? Clin Oral Invest Dec. 2016;20(9):2387–93. https://doi.org/10.1007/s00784-016-1717-3.
- [31] Ogden AR, Pinhasi R, White WJ. Nothing new under the heavens: MIH in the past? Eur Arch Paediatr Dent 2008;9(4):166–71.
- [32] Curzon MEJ, Ogden AR, Williams-Ward M, Cleaton-Jones PE. Case report: a medieval case of molar-incisorhypomineralisation. Br Dent J Dec. 2015;219(12):583–7. https://doi.org/10.1038/sj.bdj.2015.957.
- [33] Garot E, Couture-Veschambre C, Manton DJ, Bekvalac J, Rouas P. Differential diagnoses of enamel hypomineralisation in an archaeological context: a postmedieval skeletal collection reassessment. Int J Osteoarchaeol Sep. 2019;29(5):747–59. https://doi.org/10.1002/oa.2785.

- [34] Mizrahi E. Enamel opacities in primary and high school pupils. J Dent 1982;10(1):28–38.
- [35] Nunn JH, Welbury RR, Gordon PH. The dental health of adults in an integrated urban development in Addis Ababa, Ethiopia. Int Dent J 1993;43(3):202–6.
- [36] Turner-Walker G. The chemical and microbial degradation of bones and teeth. In: Advances in human palaeopathology. Chichester, UK: John Wiley & Sons; 2007. p. 11–5.
- [37] McKay S, Farah R, Broadbent JM, Tayles N, Halcrow SE. Is it health or the burial environment: differentiating between hypomineralised and post-mortem stained enamel in an archaeological context. PLoS One May

2013;8(5):e64573-undefined. https://doi.org/10.1371/journal.pone.0064573.

- [38] Garot E, Couture-Veschambre C, Manton D, Rodriguez V, Lefrais Y, Rouas P. Diagnostic guide enabling distinction between taphonomic stains and enamel hypomineralisation in an archaeological context. Arch Oral Biol Feb. 2017;74:28–36. https://doi.org/10.1016/j.archoralbio.2016.11.008.
- [39] Ogden AR, Pinhasi R, White WJ. Gross enamel hypoplasia in molars from subadults in a 16th-18th century London graveyard. Am J Phys Anthropol Jul. 2007;133(3):957–66. https://doi.org/10.1002/ajpa.20608.