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ORIGINAL ARTICLE

Background factors of molar-incisor hypomineralization in a group of Finnish children

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Abstract

Objective. Molar-Incisor Hypomineralization (MIH) is a common developmental enamel defect characterized by demarcated opacities in permanent molars and incisors. Its etiology still remains unclear. The aim of this retrospective cohort study was to assess if the socioeconomic environment of the child is associated with MIH. ***Materials and methods.*** The study was located in two rural towns and three urban cities in Finland. A total of 818 children, between 7–13 years old, were examined for MIH using the evaluation criteria in line with those of the European Academy of Paediatric Dentistry, but excluding opacities smaller than 2 mm in diameter. The mothers filled in a questionnaire which included questions related to the family's way of living (e.g. area of residency, farming, day care attendance) and socioeconomic status (family income, number of mother's school years, level of maternal education). ***Results.*** The prevalence of MIH in the study population was 17.1%. Family income, urban residency and day care attendance were associated with MIH in the univariate analysis. In the multivariate analysis using binary logistic regression, only urban residency during a child's first 2 years of life remained associated with MIH. The prevalence of MIH in urban areas was 21.3% and in rural areas 11.5% (OR = 2.18, CI = 1.35–3.53, $p = 0.001$). ***Conclusions.*** The prevalence of MIH was related to urban residency and could not be explained by any other factor included in the study.

Key Words: *aetiology, developmental enamel defects, hypomineralization, urban living, socioeconomic status*

Introduction

Developing teeth are sensitive to environmental disturbances. Since dental hard tissues do not recover, problems during their development can cause permanent defects. A qualitative defect in the permanent first molars and often also in incisors, called Molar-Incisor Hypomineralization (MIH), is a common enamel aberration [1]. The visual appearance varies from a white to yellow or brown demarcated opacity. In a severe form, the enamel is broken.

The enamel development consists of two major stages: the secretory stage, when the enamel matrix is produced, and the maturation stage, when the mineralization dominates. Between these two stages is a short transitional stage. A disturbance to ameloblasts may influence the cells at any stage, but it has been suggested that ameloblasts are most vulnerable at the transitional and early maturation stages [2,3]. In the first permanent molars (FPM), mineralization of enamel starts just before birth. Enamel formation in the tooth cusps is completed around the age of 1 year and throughout the crown at ~3 years [4]. Thereafter, the enamel is further matured until the tooth erupts into the oral cavity. Based on the development schedule of FPM, the first years of the child's life is the target time period in many etiological studies, including the present study [5–8].

A number of studies have been made trying to shed more light on the cause of MIH. Still, the etiology remains unclear and results are controversial [9,10]. Proposed etiological factors are related to different medical conditions, such as problems during pre- and perinatal periods, frequent childhood diseases and the use of antibiotics [5–8,11,12]. In some studies, greater prevalence of MIH has been associated with longer breastfeeding [13,14] and exposure to environmental toxicants [15]. The prevalence of MIH

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varies between the studies made and diagnostic criteria used, but in northern Europe the percentage of affected children in studied populations has mostly been 15–20% [5,13,16]. Taking into account the high prevalence of MIH in these areas, there is a need to know more about the etiology of the defect.

From the clinical experience, it seemed to us that the children with MIH are not equally divided between families from different backgrounds. The results from a few other studies support this point [17,18]. Our hypothesis was that children from higher socioeconomic backgrounds present a higher prevalence of MIH than children from lower socioeconomic backgrounds. Our aim was to test the hypothesis and also to evaluate the factor/factors explaining such a difference if it existed. The information would be useful when considering the perspectives of future research.

Materials and methods

Participants

The study was located in two rural towns, Lammi and Jalasjärvi, and in three cities, Helsinki, Oulu and Lappeenranta. These regions are located in different parts of Finland. The study population was gathered from two sources. From Lammi, Jalasjärvi and Lappeenranta, a total of 994 children attending public school in the 2nd to 5th grades were invited to participate in the study. From the Oulu and Helsinki districts, a total of 167 children had participated in a previous study, which focused on the possible role of environmental toxicants on MIH [19]. Alongside that study, a similar questionnaire with only minor modifications was collected and the clinical examination was conducted in the same manner as in Lammi, Jalasjärvi and Lappeenranta.

Parents (usually the mother) of 676/994 children (68%) from Lammi, Jalasjärvi and Lappeenranta gave informed consent for the participation of the child in the clinical examination and filled out a questionnaire which consisted of questions related to socioeconomic status, health and the way of living of the family and the child. Parents from the Oulu and Helsinki districts had already given consent for the previous study. Thus, altogether 843 children were eligible. A total of 25 children were excluded because their MIH status could not be determined due to unclear records or fixed orthodontic appliances preventing complete view or they had one or more unerupted FPMs. The same dentist (SL) performed all examinations.

The final number of participants was, thus, 818. The children were 7–13 years old and born between 1990–1999. The Ethics Committee at South Karelia Hospital District, in Lappeenranta, Finland, approved the study.

Questionnaire

Among 72 questions included in the questionnaire, the ones which attempt to explain possible differences in MIH prevalence between children from different socioeconomic backgrounds were selected (a mother–child research questionnaire by the National Public Health Institute). The questionnaire was originally designed for the purpose of studying allergies and lifestyle and it was slightly modified to suit this study. Most of the questions used in this study were either a multiple choice or yes/no style, except for the questions such as place of residency and questions about duration of breastfeeding, which were open-ended.

Questions related to the socioeconomic environment of the child were the following: area of residency, farming, family income, mother's school years, level of maternal education, day care attendance of the child and questions about mother's smoking (Tables I and II).

- *Area of residency*: Mothers were asked to name the area/areas where the family had lived and the periods of residence in those areas. For further analysis, the area where the family lived during a child's first 2 years was categorized into urban or rural area according to the classification made by Statistics Finland [20]. 'Rural areas' are municipalities where less than 60% live in suburbs and where the biggest suburb has less than 15 000 residents. 'Rural areas' also include municipalities where more than 60% but less than 90% live in suburbs and where the biggest suburb has less than 4000 residents. Areas which did not fit into either of the above classifications were classified as urban areas. Table I shows how the participants were distributed according to the place of residency in early childhood as well as the fluoride content in the communal pipe lines and in the wells in the study locations. If the family had changed their residency into a different category during the 2-year period or they left the question unanswered, the data was omitted from the statistical analysis.
- *Farming*: It was also asked whether the family had a farm.
- *Family income*: The annual family gross income was classified into six classes, from the lowest, less than 13 500€, to the greatest, more than 50 400€.
- *Mother's school years*: It was asked how many years the mother had attended school.
- *Education of the mother*: The question about mother's education had four classes: primary and secondary school, vocational school or equivalent, high school or higher vocational school and college/university graduate. The first level also included former forms of Finnish basic education, which were a 4–6 year-long compulsory school and a 5 year-long voluntary school.

Table I. Number of children and prevalence of MIH according to the areas where the children lived during the first 2 years of life.

Residence area		Non-MIH, *n* (%)	MIH, *n* (%)	*F* (mg/L)
Rural areas	Lammi	123 (84)	23 (16)	< 0.1
	Jalasjärvi	156 (92)	13 (8)	0.7–1.0
	Other rural area	22 (92)	2 (8)	Vary
Urban areas	Lappeenranta	186 (75)	62 (25)	0.25
	Oulu district	13 (76)	4 (23)	< 0.2
	Helsinki district	98 (83)	20 (17)	< 0.2
	Other urban area	53 (85)	9 (14)	Vary
Not defined (data omitted from statistical analysis)	Category changed during the first 2 years	4 (50)	4 (50)	Vary
	Abroad	2 (100)	0 (0)	Unknown
	Unknown	21 (87)	3 (12)	Unknown
Total		678 (83)	140 (17)	

Table II. Background factors of the children with Molar-Incisor Hypomineralization (MIH) or without (non-MIH).

Characteristic	Non-MIH	MIH	*p*	Total
Number of children	678 (83)	140 (17)		818 (100)
Gender, male	343 (51)	74 (53)	0.625	417 (51)
Age, years	10.0 ± 1.5	10.1 ± 1.6	0.499	10.0 ± 1.5
Residence area, urban	351 (54)	95 (71)	< 0.001**	446 (57)
Farm	92 (14)	12 (9)	0.125	104 (13)
Mother's education			0.872	
Primary & Secondary school	88 (13)	22 (16)		110 (14)
Vocational school	166 (25)	33 (24)		199 (25)
High school/higher vocational school	310 (47)	60 (43)		370 (46)
College/University graduate	102 (15)	24 (17)		126 (16)
Mother's school years	13.9 ± 2.9	13.9 ± 2.9	0.835	13.9 ± 2.9
Family income			0.006**	
<13 500€	16 (3)	3 (3)		19 (3)
13 500–16 800	52 (9)	7 (6)		59 (9)
16 800–25 200	70 (12)	9 (8)		79 (12)
25 200–33 600	111 (20)	16 (13)		127 (19)
33 600–50 400	153 (27)	38 (32)		191 (28)
>50 400€	165 (29)	46 (39)		211 (31)
Mother ever smoked regularly	261 (39)	57 (41)	0.651	318 (39)
Exposure to tobacco smoke <1 year old (from the mother smoking)	98 (15)	21 (15)	0.897	119 (15)
Exposure to tobacco smoke <1 year old (from someone smoking in the family)	273 (41)	60 (44)	0.590	333 (42)
Breastfeeding, months	7.5 ± 5.4	6.5 ± 4.3	0.092	7.3 ± 5.2
Breastfeeding only, months	3.1 ± 2.0	3.2 ± 2.0	0.881	3.1 ± 2.0
Day care attendance				
The 1st year	18 (3)	10 (7)	0.017*	28 (4)
The 2nd year	95 (14)	31 (23)	0.020*	126 (16)

Data are presented as the mean ± SD or number of cases (percentages). Percentages are calculated according to the total number of cases in a category of characteristic, which may not be equivalent to the total number of participants because some data was not obtained from all participants. *p*-values were obtained by using Pearson/Fisher's exact or Mann-Whitney U-test. $^{*}p < 0.05$, $^{**}p < 0.01$.

- *Smoking habit of the mother*: Questions about smoking were whether the mother had ever smoked regularly and whether the mother or someone in the household had smoked during the child's first year of life.
- *Day care*: It was asked at what age the child attended day care and whether it was in a day care center or home environment (nanny, other family). For the analysis it was assessed if the child had attended day care during his/her first and second year of life in a day care center.
- *Duration of breastfeeding*: Mothers were asked to report the duration of mother's milk as the only source of nutrition and total duration of breastfeeding. The questions about breastfeeding were selected based on the assumption that the variables might act as confounding factors between SES and MIH (Table II).

When answering the questions, the mothers were asked to utilize a notebook distributed by maternity clinics. In that notebook, information of the child's well-being and development is recorded by the medical staff on each regular check-up at the health care center.

Dental examination

The dental examinations were performed in the dental clinic under standard dental lighting. Examinations were part of the check-ups that are offered free of charge to every child in Finland at certain ages. According to the study protocol, all examinations were done by one calibrated dentist (SL) using a mirror and a periodontal probe. The questionnaire was sent home by post or brought home by the child from school in advance. The questionnaire was returned at the examination. The examiner had no knowledge of the questionnaire information. The teeth were not cleaned or dried before the examination. The probe was used for removing plaque when necessary. The teeth were examined for MIH-characteristic hypomineralization such as demarcated opacities, post-eruptive enamel loss and atypical restorations replacing the affected dental hard tissue, in line with the judgement criteria for MIH set by the European Academy of Paediatric Dentistry [21]. In addition to these criteria, lesions smaller than 2 mm in diameter were not recorded. The diagnosis of MIH was set when a lesion was present in at least one FPM. Diffuse opacities indicating fluorosis were recorded but not included in the analyses. Children with hereditary defects of dental hard tissues were not seen. If the patient had orthodontic molar bands or partially erupted molars, only the visible teeth surfaces were examined. The participating dentist was trained and calibrated for the screening of MIH, diffuse opacities and hypoplasia by examining part of the children twice at an interval of a few weeks. The training included inter-examiner calibration by another author (SA). The inter-examiner kappa coefficient for teeth with developmental defects of enamel (≥2 mm) was 0.96 and for classified defects (MIH, diffuse opacity and hypoplasia) it was 0.81 between SL and SA. The intra-examiner kappa coefficients were 0.91 and 0.90, respectively.

Statistics

The results of the dental examinations and the data gathered with the questionnaire were collected in a Microsoft Excel database. Statistical analysis was performed with PASW® Statistics version 18.0 (SPSS Inc., Chicago, IL). Associations between MIH and non-parametric variables were analyzed using the Mann-Whitney U-test. The Pearson Chi-Square test was used for proportion comparison. Multivariate analysis between MIH and associated factors ($p < 0.05$) was performed with binary logistic regression. The variables that had strong correlation (correlation coefficient >0.5) were not used together in a logistic regression model. The statistical significance level was 0.05.

Results

The study sample consisted of 401 (49%) girls and 417 (51%) boys. The mean age of the examined children was 10.0 years (SD = 1.52). A total of 140 children (17.1%) had MIH. Of these, 56% ($n = 78$) had demarcated defects in at least two FPMs. Age or the year of birth did not differ between the children with and without MIH ($p = 0.499$ and 0.336). Prevalence of MIH in different study locations is seen in Table I.

Background characteristics of the study population in regard to the diagnosis of MIH are shown in Tables I and II. Factors associated with MIH in the univariate analyses were the following: urban residency, greater family income and day care attendance.

In the binary logistic regression analysis, which consisted of the variables associated with MIH in the univariate analyses, living in an urban area for the first 2 years of life was the only factor to remain

Table III. Analysis of Molar-Incisor Hypomineralization as a dependent variable and background factors as independent variables in a binary logistic regression ($n = 639$).

	B	p	OR	95% CI
Residence area, urban	0.78	0.001**	2.18	1.35–3.53
Family income	0.15	0.078	1.16	0.98–1.37
Day care during the 1st year	0.59	0.213	1.80	0.71–5.54
Day care during the 2nd year	0.30	0.262	1.34	0.80–2.25

**$p < 0.01$.

significantly associated with MIH (Table III). The prevalence of MIH in urban areas was 21.3% and in rural areas 11.5% (OR = 2.18, CI = 1.35–3.53, $p = 0.001$).

A total of 657 mothers (80%) had used a notebook containing information of the child's well-being and development when answering the questions.

Discussion

The prevalence of MIH in the whole study population was 17.1%. It ranged from 8% in Jalasjärvi to 25% in Lappeenranta. Many studies in Europe have found similar prevalence rates [5,17,22]. However, a very wide variation of prevalence has been reported, from 2.4% in Germany [23] to 37.3% in Denmark [24]. Part of the differences in the reported prevalence of MIH can be explained by the different diagnostic criteria used. Some studies included even the smallest opacities, whereas others, such as this study, excluded opacities smaller than 2 mm. Here all children were examined by one calibrated dentist, which increases the reliability of the results and suggests that the differences found were real.

The principal finding in our study was the following: when studied individually, greater family income, urban residency and day care attendance were associated with MIH. The association between urban residency and MIH remained significant in the multivariate analysis. Other SES-related factors became non-significant in the multivariate analysis.

Recently there have been a few other studies examining the relationship between higher SES and the presence of MIH. An Argentinian study found that, among patients with better access to healthcare, the prevalence and degree of severity of MIH was greater [18]. In a British report, an association was found between prevalence of MIH and deprivation quintiles so that the MIH rate rose when moving from the most deprived categories to the least deprived categories, up to the second highest category [17]. In New Zealand, researchers did not find any statistically significant associations between MIH and SES, which was measured by school decile [25].

In the current study, MIH was more common among children who had lived in urban areas than among those who had lived in rural areas their first 2 years of life, which is the approximate time when enamel mineralizes in permanent incisors and first molars. The prevalence of MIH in children living in urban areas (21.8%) was approximately at the same level as in two earlier Finnish studies (19.3% and 24.7%) conducted on children living in urban areas [13,16]. The result appears to be the reverse of the common understanding of prevalence of developmental defects of enamel (DDE): they are more common in rural areas [26]. These earlier results have been explained by malnutrition in poorer rural areas, since a low supply of calcium, vitamin D and other nutrients does not allow enamel to develop normally [27]. Only few studies have been made evaluating the residence area of the MIH patients particularly. Da Costa-Silva et al. [28] from Brazil found results opposite to ours: higher MIH prevalence was found in rural areas. The authors state that Brazil has significant socioeconomic discrepancies, with poorer individuals concentrated in rural areas. In Finland wealth is not divided equally either, with lower levels of education and income in rural areas, but the differences are fairly small. There is no real difference in health or diet in sociodemographic characteristics [29]. Quality-of-life is experienced equally regardless of the area of residency [30]. The great differences in countries' wealth, economy and healthcare systems may explain the difference in results between this study and the one done in Brazil.

Other studies have proposed different childhood infections as etiologic factors of MIH [5–8,31]. The retrospective nature of this study did not make it possible to reliably assess the number or types of infections the children may have suffered. However, the prevalence of MIH was higher among the children who had attended day care centers during the first and second year of life. Children who attend day care centers are known to have higher rates of infections than those not in day care [32,33]. In the present study, 8% of the children attended day care during the second year of life in rural areas, whereas in urban areas the proportion was 22%. The difference was statistically significant, but in the multivariate analysis, day care attendance did not explain why there were more children with MIH in urban areas. There were also fewer children with MIH among the families who lived on a farm (12% vs 18% in non-farming families), but the difference was not statistically significant.

Some studies have found an association between MIH and the use of antibiotics, especially amoxicillin [7,8,11], although the evidence is still too weak to draw any definite conclusions. In experimental studies, amoxicillin has disrupted the development of enamel [11,34]. One speculation for the increased prevalence of MIH in urban areas is that there is a difference in the rate of antibiotic use between rural and urban areas. This could be explained by the different habits of taking a child to a doctor between families from different socioeconomic backgrounds. Indeed there is some proof for this speculation [35]. The Finnish healthcare system consists of publicly funded healthcare and a much smaller private healthcare sector. In many rural towns, like those where this study was conducted, there is no private healthcare available and, if there is, they serve only on weekdays during working hours. People who decide to pay for private insurance prefer the faster access to a doctor and possibility for better service. Private insurance usually covers all the medication in excess of a deductible. It is possible that children from the families with private insurance would get more antibiotics or just that in rural areas children receive less antibiotics in general. The role of the antibiotics in developmental defects of the enamel needs to be researched more precisely to make any conclusions.

In Australia, scientists assessed risk factors for DDE and found that exposure to cigarette smoke increased the risk of enamel hypoplasia and opacities [36]. We did not find any correlation between the prevalence of MIH and the exposure to cigarette smoke during the first year of life. We also analyzed duration of breastfeeding as a confounding factor between MIH and SES, because long breastfeeding has been mentioned as an etiologic factor of MIH and the duration of breastfeeding is known to be related to SES [37]. In a Swedish study it was proposed that long breastfeeding (>6 months), together with late introduction to gruels and infant formula, is related to MIH [14]. The authors were of the opinion that mother's milk lacks essential nutrients for the complete development of enamel. In the present study, there was no association between MIH and duration of mother's milk as the only source of nutrition, or the total duration of breastfeeding. Again, it is possible that this information is not reliable due to the retrospective study design, but most of the mothers had used a notebook where the duration of breastfeeding had been marked earlier. Long breastfeeding has also been proposed to increase the risk of MIH through environmental toxicants that are secreted in the milk [13]. In a Finnish study, MIH defects were clearly associated with the total exposure to toxic dioxins and furans via mother's milk [38]. However, in a later study, when the levels of toxicants in mother's milk had already decreased [39], such an association was not found [19].

The areas differed in respect to local industry and traffic. In Lappeenranta and Oulu, where the prevalence of MIH was high, there is a heavy pulp and paper industry. Moreover, in urban cities, traffic causes air pollution. In the rural locations, Lammi and Jalasjärvi, only little industry and traffic exists. As air pollutants are known to increase respiratory diseases and possibly affect the immune system [40,41], it could be speculated that they have an indirect role in MIH. However, further research on this is needed.

Another aspect related to different prevalence of MIH between localities in this study is fluoride content in drinking water. The aforementioned study in England found that there were fewer children with MIH in the fluoridated area [17]. The authors state that fluoride could be a somewhat protective factor for developing MIH or that the remineralization effect could reduce the severity of the defect after eruption. In the current study, there were considerably fewer children with MIH in Jalasjärvi, where the fluoride level in drinking water was naturally higher. Our hypothesis is that the higher fluoride content in drinking water after eruption might mineralize especially small MIH defects and, thus, decrease the prevalence of MIH. That would partially explain the lower prevalence of MIH in those rural areas, where the fluoride content in communal pipelines or in wells can be ~1 mg/L. Moreover, the Brazilians found lower prevalence of MIH in an urban area where the level of fluoride in drinking water was 0.7 mg/L [28]. In a rural area where higher prevalence of MIH was found, the fluoride content in drinking water was 0.1 mg/L [28].

In conclusion, we found that urban living was associated with the prevalence of MIH. This is a new finding. However, as in other studies, no single cause of MIH was found. According to the literature, the etiology of MIH is multifactorial. The putative etiologic factors could occur in one's life simultaneously or one after another, promoting the development of MIH. This study indicates that those factors are more frequent in urban areas. The different lifestyle or morbidity/use of medications in urban and rural areas can probably explain part of the prevalence differences found in this study. Also, the role of the environmental toxicants should be taken into account. Those aspects could be used as a basis for future studies. In addition, the result of this study raises the question of the positive effect of fluoride in drinking water, which should be further studied.

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