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ORIGINAL RESEARCH

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The effect of molar incisor hypomineralization on the stomatognathic system in children: a comparative cross-sectional study

Humeyra Tercanli[1], Ozge Erken Gungor[2,*], Busra Karaca[3], Zeliha Merve Semerci[1], Burcu Yagmur[2]

[1]Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, University of Akdeniz, 07058 Antalya, Turkey
[2]Department of Pedodontics, Faculty of Dentistry, University of Akdeniz, 07058 Antalya, Turkey
[3]Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, University of Burdur Mehmet Akif Ersoy, 15100 Burdur, Turkey

***Correspondence**
ozgegungor@akdeniz.edu.tr
(Ozge Erken Gungor)

Abstract

Background: Molar Incisor Hypomineralization (MIH) is a developmental enamel defect of systemic origin, characterized by demarcated hypomineralization affecting at least one permanent first molar, often with incisor involvement, and distinct from other enamel defects. Hypomineralized enamel in MIH has reduced hardness and elastic modulus. This study aims to assess the impact of MIH on the stomatognathic system and investigate its potential clinical association with temporomandibular dysfunctions (TMD). **Methods**: In order to evaluate temporomandibular joint (TMJ) sounds, headaches, deviation/deflection, muscle sensitivity, and jaw motions, 84 patients underwent clinical examinations. The Fonseca Anamnestic Index was used to assess TMD. The masseter (MM), temporalis (TM), sternocleidomastoid (SCM), and articular disc (AD) were evaluated bilaterally (n = 168) for muscle thickness and elasticity (E) using ultrasound. **Results**: TMD was present in 60.5% of the MIH group and 19.5% of the control group ($p < 0.001$). Headaches, joint noises, deviation/deflection, and limited mouth opening were also substantially more common in the MIH group ($p < 0.001$). There was a significant difference between MIH group and control group according to thickness of TM (right), thickness of TM (left), mean thickness of TM, ($p < 0.001$ for all). There was a significant difference between MIH group and control group according to right TME, left TME, mean TME, right MME, left MME, mean MME, right SCME, left SCME, and mean SCME ($p \leq 0.001$ for all except left TME and right SCME; $p = 0.006$ and $p = 0.004$ for these parameters respectively). The suggested revisions have been made. **Conclusions**: The frequency of TMD differs in the MIH group, and this affects the masticatory muscle thickness and elasticity. These results emphasize that MIH affects the entire stomatognathic system in addition to the teeth. **Clinical Trial Registration**: ClinicalTrials.gov ID: NCT06951139.

Keywords

Elasticity; Masticatory muscle; Molar incisor hypomineralization; Temporomandibular disorders; Ultrasound

1. Introduction

Molar Incisor Hypomineralization (MIH) is a developmental enamel defect of systemic origin, characterized by demarcated hypomineralization affecting one to four permanent first molars, often with incisor involvement, and distinct from other enamel defects such as fluorosis or amelogenesis imperfecta [1, 2]. MIH is highly prevalent and affects around 878 million individuals globally, with 17.5 million new cases reported annually and highlighting a significant public health concern [3]. This condition not only affects individuals' oral health but also impacts their quality of life and social interactional processes during childhood, making it a significant public health [4, 5].

Clinically, teeth exhibit demarcated opacities on the occlusal and buccal surfaces of the crowns, with color and size changes, appearing as well-defined opacities with distinct edges that can be differentiated from healthy enamel [3, 6]. Affected teeth may be more sensitive to thermal stimuli. Hypomineralized enamel has lower hardness and elastic modulus compared to normal enamel [7]. The presence of MIH, through post-eruptive enamel breakdown and heightened tooth sensitivity, can negatively impact masticatory function and food choice, compromise oral hygiene maintenance, influence salivary mineral balance, and pose challenges for restorative and preventive dental procedures [8].

While studies on temporomandibular dysfunctions (TMD) and stomatognathic disorders are well-documented in adults

[9, 10], limited research exists in children, highlighting a critical gap in the literature.

Ultrasound (USG) is a non-ionizing imaging technique that provides real-time and dynamic images used in various areas such as TMD, salivary glands, thyroid gland, lymph nodes, and masticatory muscles [11]. In recent years, ultrasonographic elastography, which has become widespread, takes advantage of the changing elasticity of soft tissues resulting from certain pathological or physiological processes [12]. Share wave elastography (SWE) offers non-invasive assessment of soft tissue stiffness, expressed in kilopascals (kPa). This method provides advantages such as low operator dependency, high reproducibility, and quantitative evaluation of masticatory muscles and the temporomandibular joint [13].

This study aims to assess the impact of MIH on the stomatognathic system and investigate its potential clinical association with TMD. The null hypothesis of this study is that there is no significant increase in the prevalence of TMD and no significant differences in ultrasonographic results between children with MIH and those without MIH.

2. Material and methods

2.1 Study design

This study was registered on ClinicalTrials.gov (NCT06951139) during the planning stage as a prospective study. However, no intervention, randomization, or allocation to treatment groups was performed, and the study was ultimately conducted as an observational comparative cross-sectional design. This study was carried out between March 2025 and June 2025.

Based on the study conducted by Strini *et al.* [14], the sample size for this study was calculated using the G*Power 3.1.9.2 program (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, NRW, Germany), with a power of 90%, an error margin of 0.05, and an effect size of 0.66. The minimum required sample size was determined to be a minimum of 41 participants per group. Accordingly, 43 patients with MIH and 41 healthy volunteers for the control group were included in the study. The study was initiated with patients who met the inclusion criteria, and it was concluded upon the completion of clinical and radiological evaluations of all participants.

The study included a total of 84 participants who visited the Department of Pediatric Dentistry, Faculty of Dentistry, Akdeniz University, for routine clinical examinations. Intraoral examinations were performed using reflector light, a dental mirror, and a probe. MIH was diagnosed by two pediatric dentists (ÖEG and BY) with at least 15 years of experience in their field. The diagnosis of MIH was based on the criteria described by [15, 16]. Only children with severe MIH—defect codes 3 (post-eruptive breakdown, PEB) and/or 22 (yellow/brown demarcated opacity)—affecting $\geq$1/3 and $<$2/3 of the tooth surface (extent code II) were included. All included teeth were fully erupted, and classification was performed according to the Lygidakis *et al.* [16] 2022 and Ghanim *et al.* [15] 2017 criteria (example coding: B, 3(22), II). Lesion severity, extent, and classification followed the EAPD/Ghanim 2017 criteria [1, 15, 16].

The study included participants who met the following criteria: (1) aged between 9 and 14 years, (2) healthy without any ongoing medication use, (3) a score of 3 or 4 on the Frankl Behavior Scale [17], (4) have no parafunctional oral habits, such as bruxism, (5) no skeletal orthodontic abnormalities, (6) no missing teeth, (7) no requiring pulpal treatment (excluding teeth with MIH). Patients with deep carious lesions involving the pulp, those with systemic diseases, those requiring orthodontic treatment, and uncooperative patients with a Frankl behavior scale rating of 1 and/or 2 were excluded from the study.

The age range of 9–14 years was selected for methodological and clinical reasons. By approximately nine years of age, the permanent first molars and incisors affected by MIH are typically fully erupted, enabling accurate diagnosis and reliable intergroup comparisons. Additionally, children within this age range demonstrate greater cooperation during both clinical and ultrasonographic assessments compared with younger patients, thereby enhancing measurement accuracy and reproducibility. Furthermore, functional parameters of the temporomandibular joint (TMJ)—including condylar path length and maximum mouth-opening capacity—have been shown to increase with age and approach adult values around the age of ten [18]. This developmental maturity supports the appropriateness of the 9–14-year age range for meaningful evaluation of TMJ and masticatory muscle function while still representing a pediatric population. Individuals with advanced periodontal disease leading to tooth mobility or those with a history of jaw or facial fractures or accidents that could adversely affect the temporomandibular joint (TMJ) were excluded from the study. For the MIH group, participants had to have a confirmed diagnosis of MIH in at least one permanent first molar. For the control group, participants were required to not have a diagnosis of MIH. In the control group, patients with anterior dental crowding or malocclusion were also excluded to minimize potential occlusal interferences in TMJ assessment. In the MIH group, while skeletal orthodontic abnormalities were excluded, mild dental crowding was permitted to reflect the typical clinical presentation of MIH. None of the MIH-affected teeth had full-coverage crowns; when restored, they were treated only with composite resin fillings.

2.2 Extraoral and intraoral examination

The TMJ examination was conducted by an oral and maxillofacial radiologist (MS) and an oral and maxillofacial surgeon who has minimum three years of experience in their field. For interobserver calibration, both researchers assessed first 10 patients together. The remaining patients were evaluated independently, with each examiner assessing an equal number of cases (n = 37).

During extraoral examinations, the lateral aspect of the TMJ was palpated in the resting position and during function by applying gentle pressure to the preauricular area. For intra-auricular palpation, the examiner placed the ear finger on the external acoustic meatus while asking the patient to open and close their mouth. Simultaneously, gentle forward pressure was applied. During mandibular manipulation, mild force was applied to the symphyseal area to palpate the posterior

movement of the mandible.

TMJ sounds, headache and deviation/deflection were classified as “presence” and “absence”. Additionally, the sensitivity of the masseter and temporalis muscles was evaluated during rest and function. This sensitivity was also classified as “presence” and “absence”. No formal pain scale was used; the classification of sensitivity as “presence” or “absence” was based solely on the patient’s report of pain during palpation.

The mandibular movement during opening and closing was observed by standing in front of the patient and requesting the patient to open and close their mouth. Maximum mouth opening, lateral, and protrusive movements were measured using a digital caliper and recorded in millimeters (mm).

The presence of TMJ problems were evaluated using the Fonseca Anamnestic Index [19]. While some variables detected in TMJ evaluation such as headache, pain are based on patient-reported variables such as TMJ sounds, mouth opening, lateral and protrusive movement are based on objective evaluation.

2.3 Ultrasonographic evaluation

Ultrasound imaging was performed on participants using the GE HealthCare Logiq P9 Ultrasound System (General Electric Medical Systems, Milwaukee, WI, USA). A linear transducer operating at 3–12 MHz was utilized to assess the masseter, anterior temporalis, sternocleidomastoid muscles, and TMJ. For consistency, the probe was held transversely, and the scanning depth for all measurements was set to 4.0 mm. In total, evaluations were performed for 168 masseter muscles (MM), 168 temporalis muscles (TM), 168 sternocleidomastoid muscles (SCM), and 168 TMJs. Measurements included muscle thickness and elastography for the MM, TM, SCM and all measurements recorded as “right”, “left”, and “mean”. “mean” was the arithmetic average of the left and right measurements.

During the examination, participants were instructed to sit upright and avoid swallowing to maintain stable conditions. A water-based ultrasound gel was applied to the transducer to ensure optimal acoustic coupling, and the operator did not apply excessive pressure to the tissues. The ultrasound examinations were performed by an experienced radiologist specializing in maxillofacial imaging, with over 15 years of clinical experience and advanced certification in TMJ ultrasonography.

For the MM, thickness and elasticity measurements were performed on both the right and left sides. For thickness assessment, a linear probe was positioned in the transverse plane at the most voluminous portion of the muscle, aligned with the occlusal plane, parallel to the mandibular corpus, and approximately at the midpoint of the mediolateral region of the mandibular ramus. The probe was oriented perpendicularly to the muscle fibers, and the maximum distance between the inner and outer fascia of the muscle was recorded in millimeters. While maintaining the same probe position, SWE measurements were obtained for both the right and left masseter muscles.

Anterior TM evaluation was performed by placing a linear probe between the upper margin of the zygomatic arch and the hairline, in a region parallel to the posterior aspect of the zygomatic arch, at a slightly oblique angle extending from the lateral canthus toward the hairline. The thickness of the right and left anterior temporalis muscles was measured, similar to the MM, as the maximum distance between the inner and outer fascia. SWE measurements of the anterior TM were also obtained separately for the right and left sides, following the same procedure as for the MM.

For the SCM, the probe was placed adjacent to the jugular vein between the dorsal and ventral fascia, halfway along the line from the mastoid bone to the clavicular margin, and the maximum thickness between the inner and outer fascia was recorded in millimeters [14]. During SCM assessment, participants were seated in a resting position with their heads slightly turned toward the opposite side of the muscle being evaluated. The thickness of the right and left SCM was measured, similar to the MM and anterior TM, as the maximum distance between the inner and outer fascia. SWE measurements were also obtained separately for the right and left sides, following the same procedure other muscles.

For the TMJ, the intermediate zone of the articular disc (AD) was examined in the closed-mouth position, capturing joint space and elastography data (Fig. 1). During the measurement, the distance between the most inferior point of the articular fossa and the most superior point of the mandibular condyle head was recorded in millimeters. Ultrasonographic imaging of the TMJ disc was performed in a plane parallel to Camper’s plane.

SWE measurements were recorded for elasticity (kPa). Six suitable circular regions of interest each with a diameter of 4 mm, from the elastography images were selected for the masseter (MME), anterior temporalis (TE), and sternocleidomastoid muscles (SCME) bilaterally. The ultrasound device automatically calculated the average values for these measurements in terms of elasticity. SWE values for the intermediate part of the disc (ADE) were measured using a 1 mm diameter area in the closed-mouth position (Fig. 2). All variables (thickness measurements and elastography measurements) detected in ultrasonographic evaluation are based on objective evaluation.

After 4 weeks, all ultrasonographic measurements were repeated for 30 randomly selected patients and intra-observer agreement was assessed.

2.4 Statistical analysis

Data was statistically analyzed using an SPSS software package (version 23.0, IBM Corp., Armonk, NY, USA). Descriptive statistics were presented with frequency, and percentage, mean ± standard deviation and median (minimum–maximum) values. The normality assumption was evaluated using the Shapiro-Wilk method. The Pearson chi-square test and Fisher’s exact test were used to analyze the difference between categorical variables. Quantitative variables among the two groups were compared using the student’s *t*-test for the normal distribution and the Mann-Whitney U test was utilized for data that did not display a normal distribution. Multivariate logistic regression analysis was performed to determine whether the MIH parameter is an independent predictor for TMD and to control for possible confounding variables. Intra-observer reliability was

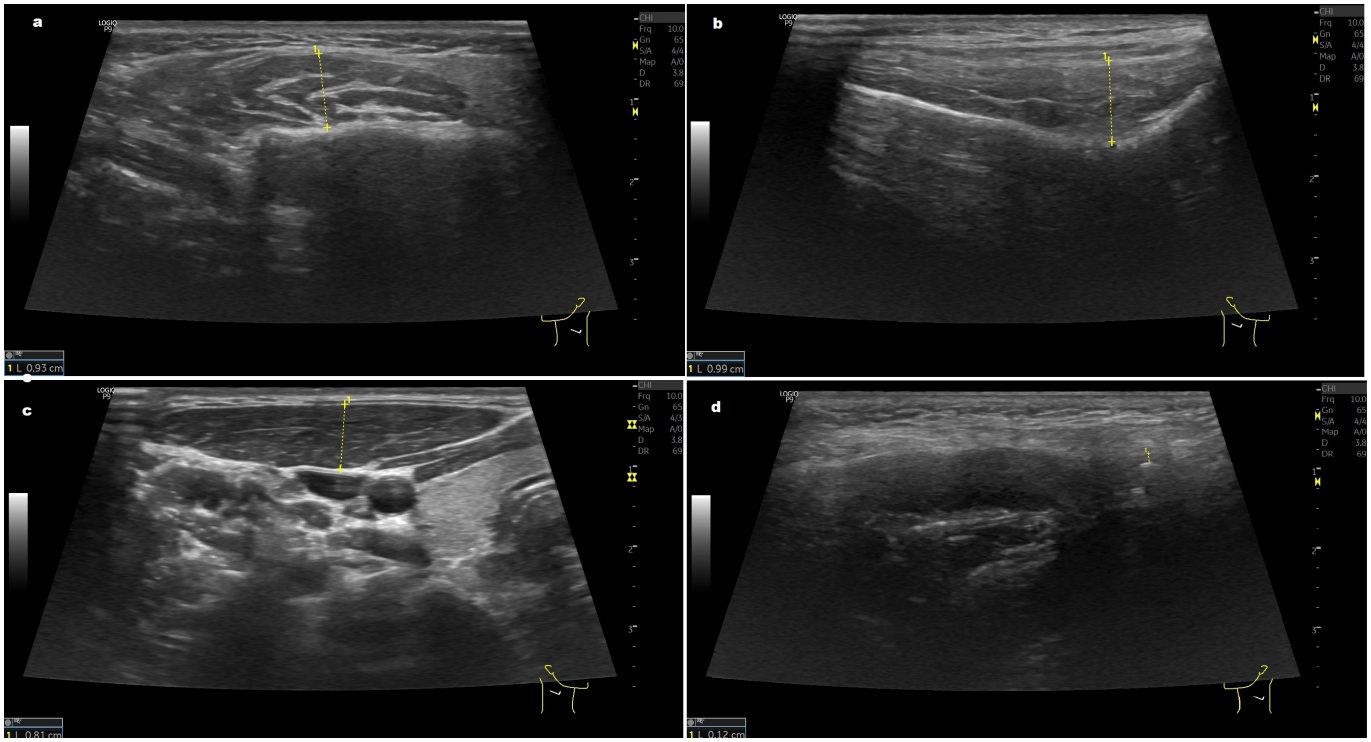

FIGURE 1. Evaluation of the TMJ in the closed-mouth position showing the intermediate zone of the articular disc, joint space, and elastography data. (a) masseter muscle; (b) temporal muscle; (c) sternocleidomastoid muscle; (d) the intermediate zone of the articular disc.

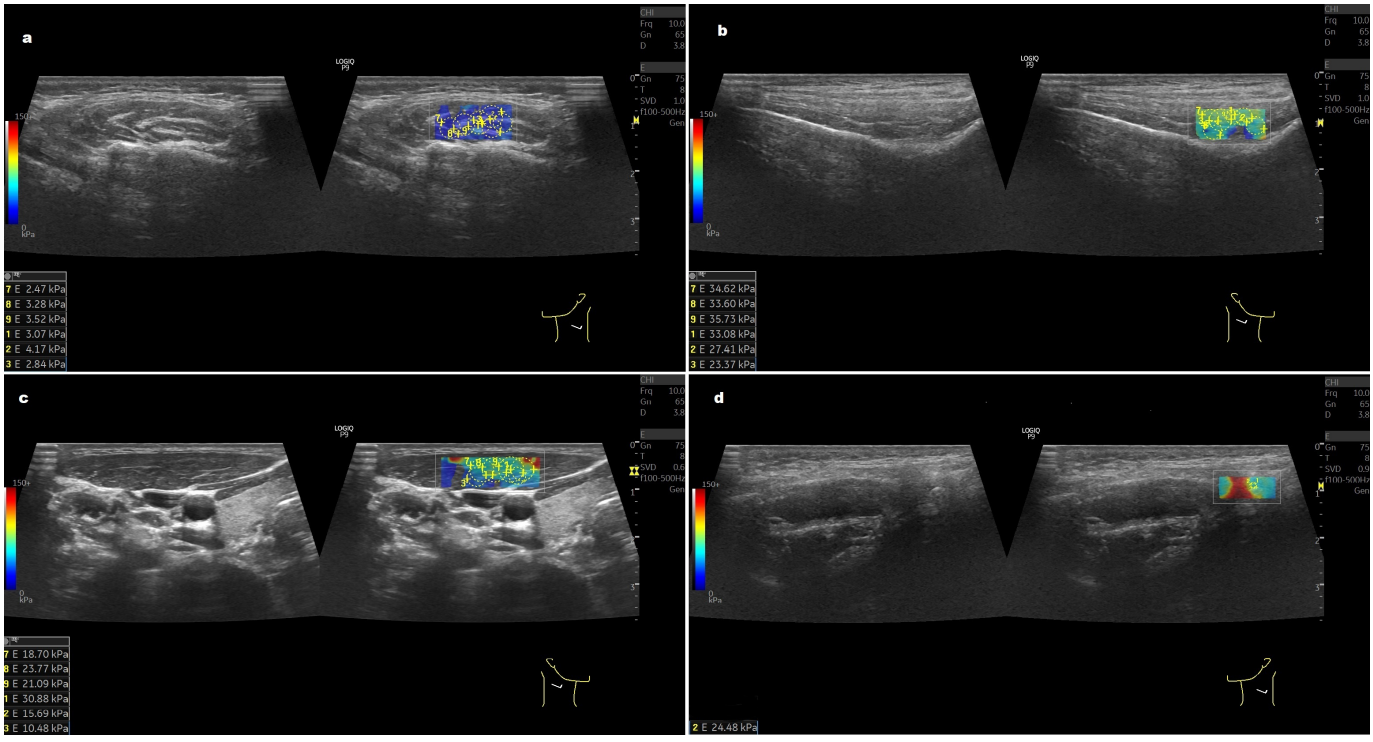

FIGURE 2. SWE values for the intermediate part of the disc (ADE) were measured using a 1 mm diameter area in the closed-mouth position. (a) masseter muscle; (b) temporal muscle; (c) sternocleidomastoid muscle; (d) the intermediate zone of the articular disc.

assessed by the interclass correlation coefficient. Statistical significance was accepted at $p < 0.05$.

3. Results

The inter-class correlation coefficient (ICC) was found to be greater than 90% in all parameters.

A total of 84 patients were included in the study (n = 43 for MIH group, n = 41 for control group). There were 34 (40.5%) boys and 50 (59.5%) girl patients, there was no difference between the presence of MIH and gender ($p = 0.791$). The mean age of the patients was 11.73 ± 1.34 years and there was no significant difference between age and both groups ($p = 0.860$) and age and gender ($p = 0.850$).

There were 18 (41.9%) boys and 25 (58.1%) girl patients in the MIH group, and the mean age of the patients was 11.79 ± 1.1 years. There were 16 (39%) boys and 25 (61%) girl patients in the control group, and the mean age of the patients was 11.66 ± 1.6 years.

A total of 43 patients with MIH were examined, and 148 teeth were found to be affected. Among these, 33 were tooth #16, 34 were tooth #26, 34 were tooth #36, 33 were tooth #46, 3 were tooth #11, 3 were tooth #21, 2 were tooth #41, 1 was tooth #22, 3 were tooth #32, and 2 were tooth #42. With respect to the number of affected teeth per patient, 4 patients had 1 affected tooth, 7 patients had 2 affected teeth, 12 patients had 3 affected teeth, 16 patients had 4 affected teeth, 1 patient had 5 affected teeth, 3 patients had 6 affected teeth, and 1 patient had 7 affected teeth.

Post-eruptive breakdown in molars was observed in 41 of the 43 patients.

3.1 Temporomandibular joint examination

The prevalence of TMD in this study was 40.5% in the whole group. The frequency of TMD was 60.5% (n = 26) in the MIH group, while this frequency was 19.5% (n = 8) in the control group. There was a significant difference between MIH group and control group according to TMD ($p < 0.001$). Table 1 shows the results of temporomandibular joint examination. In the clinical examination of the masseter and temporal muscles, although more pain was observed in the MIH group compared to the control group during rest and function, for both muscles, this did not result in a statistically significant difference (p values were 0.055 and 0.257) for pain in masseter muscle at rest and in function respectively; p values 0.434 and 0.058 for pain in temporal muscle at rest and in function respectively. On the other hand, the presence of headache, joint sound, and deviation/deflection was significantly higher in the MIH group compared to the control group ($p < 0.001$, $p = 0.014$, and $p < 0.001$, respectively). Table 2 shows the limits of opening, lateral, and protrusive movements according to groups. Mouth opening (both inactive and active positions) was significantly higher in MIH group than controls ($p < 0.001$ for both).

3.2 Ultrasound examination

While left thickness of SCM was significantly higher in girls than boys ($p = 0.03$), right, left, and mean muscle thickness of all other muscle groups and AD thickness did not differ according to gender. In addition, there was a significant difference between the presence of TMD and absence of TMD left thickness of TM, mean thickness of TM, left thickness of SCM and mean thickness of SCM ($p = 0.001$, 0.004, 0.004, and 0.006 respectively). All measurements were higher in absence of TMD than presence of TMD.

Table 3 shows the results of muscle thickness in study groups. There was a significant difference between MIH group and control group according to thickness of TM (right), thickness of TM (left), mean thickness of TM, ($p < 0.001$ for all). Control group measurements for these parameters are higher than MIH group.

Table 4 shows the results of elastography measurements. There was a significant difference between MIH group and control group according to right TME, left TME, mean TME, right MME, left MME, mean MME, right SCME, left SCME, and mean SCME ($p \leq 0.001$ for all except left TME and right SCME. $p = 0.004$ and $p = 0.006$ for these parameters respectively). Although there was no significant difference between genders in any elastography measurements, mean TME, left MME, mean MME was significantly higher in presence of TMD ($p = 0.048$, 0.004 and 0.017, respectively).

Multivariate logistic regression analysis demonstrated that MIH was an independent predictor of TMD (OR = 40.646, 95% CI: 5.106–323.546, $p < 0.001$), even after adjusting for age, gender, muscle thickness measurements, and muscle elastography measurements. Among the covariates, gender ($p = 0.029$), mean SCM thickness ($p < 0.001$) and mean SCME ($p = 0.026$) also remain significant predictors, while age, mean TM thickness, mean AD thickness, mean MM thickness, mean TME, mean ADE, mean MME were not associated with TMD ($p > 0.05$). In summary, MIH can be regarded as an independent predictor. The presence of MIH has been demonstrated to increase the risk of TMD by 40.646 times, when controlling for age, gender, muscle thickness measurements, and muscle elastography measurements. Table 5 shows the results of the multivariate logistic regression analysis.

4. Discussion

In this study, authors aimed to evaluate the condition of the TMJ and associate muscles in children with MIH using ultrasound and elastography methods, and to investigate the relationship between MIH and TMD in this population. The null hypothesis of this study was that there is no significant increase in the prevalence of TMD and no significant differences in ultrasonographic results between children with MIH and those without MIH. The current study demonstrated that the prevalence of TMD was significantly higher in the MIH group compared to the control group. In addition, significant differences in ultrasonographic parameters in the MIH group compared to the control group does not support the null hypothesis. The higher frequency of TMD in individuals with MIH indicates an association with potential clinical and functional impacts on the stomatognathic system in these individuals.

MIH is characterized by demarcated qualitative defects in the enamel, where the hypomineralized tissue contains a higher organic content and reduced mineral density, leading to altered mechanical properties [20]. Affected teeth may be more sen-

TABLE 1. Temporomandibular joint examination results.

Parameter	Group	Presence (n/%)	Absence (n/%)	*p* value
TMD				
	MIH	26/60.5	17/39.5	<0.001*
	Control	8/19.5	33/80.5	
Pain in masseter muscle (at rest)				
	MIH	5/11.6	38/88.4	0.055
	Control	0/0	41/100	
Pain in masseter muscle (in function)				
	MIH	13/30.2	30/69.8	0.257
	Control	8/19.5	33/80.5	
Pain in temporal muscle (at rest)				
	MIH	5/11.6	38/88.4	0.434
	Control	2/4.9	39/95.1	
Pain in temporal muscle (in function)				
	MIH	7/16.3	36/83.7	0.058
	Control	1/2.4	40/97.6	
Headache				
	MIH	31/72.1	12/27.9	<0.001*
	Control	8/19.5	33/80.5	
TMJ sound				
	MIH	12/27.9	31/72.1	0.014*
	Control	3/7.3	38/92.7	
Deviation/deflection				
	MIH	25/58.1	18/41.9	<0.001*
	Control	5/12.2	36/87.8	

*Pearson chi square, Fisher's exact test; n: number of patients; %: percentages; TMD: temporomandibular joint disorder; TMJ: temporomandibular joint; MIH: Molar Incisor Hypomineralization. *: $p < 0.05$.*

TABLE 2. The minimum, maximum, mean, standard deviation, median and *p* values of joint movements in study groups.

Parameter	Group	n	min	max	Mean	SD	Median	*p* value
Mouth opening (inactive)								
	MIH	43	40	61	43.84	3.92	43.0	<0.001*
	Control	41	25	47	39.02	5.13	39.5	
Mouth opening (active)								
	MIH	43	42	65	49.60	4.35	50.0	<0.001*
	Control	41	26	52	41.08	5.77	41.0	
Lateral movement (right)								
	MIH	43	4	12	7.56	1.88	8.0	0.693
	Control	41	5	15	7.57	1.55	7.5	

TABLE 2. Continued.

Parameter	Group	n	min	max	Mean	SD	Median	*p* value
Lateral movement (left)								
	MIH	43	4	11	7.70	1.57	8.0	0.147
	Control	41	4	15	7.35	1.68	7.0	
Protrusive movement								
	MIH	43	2	11	6.26	1.85	8.0	0.629
	Control	41	2	8	5.91	1.57	6.0	

*Student's t-test; Mann-Whitney U; n: number of patients; min: minimum; max: maximum; SD: standard deviation; MIH: Molar Incisor Hypomineralization. *: $p < 0.05$.*

TABLE 3. The minimum, maximum, mean, standard deviation, median and *p* values of ultrasonic examination in study groups.

Parameter	Group	n	min	max	Mean	SD	Median	*p* value
Thickness of TM (right)								
	MIH	43	0.43	0.90	0.68	0.11	0.67	<0.001*
	Control	41	0.52	10.23	0.87	0.15	0.86	
Thickness of TM (left)								
	MIH	43	0.48	10.04	0.71	0.11	0.71	<0.001*
	Control	41	0.56	10.28	0.88	0.14	0.86	
Mean thickness of TM								
	MIH	43	0.51	0.89	0.70	0.09	0.70	<0.001*
	Control	41	0.62	10.26	0.88	0.13	0.88	
Thickness of AD (right)								
	MIH	43	0.06	0.16	0.11	0.03	0.11	0.331
	Control	41	0.06	0.16	0.11	0.03	0.11	
Thickness of AD (left)								
	MIH	43	0.06	0.18	0.11	0.03	0.11	0.727
	Control	41	0.05	0.18	0.11	0.03	0.11	
Mean thickness of AD								
	MIH	43	0.08	0.17	0.11	0.02	0.11	0.381
	Control	41	0.07	0.15	0.11	0.02	0.12	
Thickness of MM (right)								
	MIH	43	0.65	10.29	0.86	0.11	0.86	0.378
	Control	41	0.65	10.20	0.89	0.14	0.86	
Thickness of MM (left)								
	MIH	43	0.55	10.08	0.80	0.12	0.77	0.860
	Control	41	0.51	10.19	0.85	0.16	0.84	
Mean thickness of MM								
	MIH	43	0.66	10.19	0.83	0.10	0.83	0.230
	Control	41	0.63	10.20	0.87	0.13	0.83	

TABLE 3. Continued.

Parameter	Group	n	min	max	Mean	SD	Median	*p* value
Thickness of SCM (right)								
	MIH	43	0.52	0.98	0.72	0.11	0.70	0.334
	Control	41	0.43	1.0	0.70	0.14	0.67	
Thickness of SCM (left)								
	MIH	43	0.53	10.07	0.73	0.13	0.73	0.632
	Control	41	0.44	30.03	0.77	0.39	0.67	
Mean thickness of SCM								
	MIH	43	0.54	10.02	0.73	0.11	0.72	0.480
	Control	41	0.44	10.80	0.73	0.22	0.68	

*Student's t-test; Mann-Whitney U; TM: temporal muscle; AD: articular disc; MM: masseter muscle; SCM: sternocleidomastoid muscle; n: number of patients; min: minimum; max: maximum; SD: standard deviation; MIH: Molar Incisor Hypomineralization. *: $p < 0.05$.*

TABLE 4. The minimum, maximum, mean, standard deviation, median and *p* values of elastography measurements in study groups.

Parameter	Group	n	min	max	Mean	SD	Median	*p* value
Right TME								
	MIH	43	18.05	49.08	32.06	7.16	33.10	<0.001*
	Control	41	2.48	43.31	20.78	10.21	17.77	
Left TME								
	MIH	43	16.28	46.95	31.71	7.18	32.13	0.006*
	Control	41	4.27	51.68	26.00	10.97	26.61	
Mean TME								
	MIH	43	21.08	48.02	31.89	5.52	33.34	<0.001*
	Control	41	3.86	44.56	23.39	9.14	22.65	
Right ADE								
	MIH	43	5.20	54.24	28.75	11.05	29.00	0.880
	Control	41	5.29	68.58	28.29	16.24	26.14	
Left ADE								
	MIH	43	7.41	45.08	28.91	8.44	30.41	0.640
	Control	41	5.13	66.73	34.03	15.31	33.57	
Mean ADE								
	MIH	43	12.21	49.45	28.83	7.54	28.53	0.328
	Control	41	8.71	60.08	31.16	13.21	29.16	
Right MME								
	MIH	43	7.96	40.28	27.57	7.60	27.40	<0.001*
	Control	41	2.78	36.71	12.67	9.46	8.82	
Left MME								
	MIH	43	14.76	41.74	28.68	7.03	29.26	<0.001*
	Control	41	1.92	47.76	14.44	11.21	10.51	
Mean MME								
	MIH	43	14.91	38.42	28.13	5.66	29.15	<0.001*
	Control	41	3.26	35.72	13.55	9.33	10.17	

TABLE 4. Continued.

Parameter	Group	n	min	max	Mean	SD	Median	*p* value
Right SCME								
	MIH	43	12.82	61.34	33.82	9.70	33.20	0.004*
	Control	41	0.68	70.66	26.22	13.46	26.45	
Left SCME								
	MIH	43	12.70	73.34	33.14	10.85	30.69	<0.001*
	Control	41	3.57	77.51	24.89	15.54	23.39	
Mean SCME								
	MIH	43	16.15	56.35	33.48	8.63	31.14	<0.001*
	Control	41	8.56	60.61	25.55	11.86	24.01	

*Student's t-test; Mann-Whitney U; TME: temporal muscle elastography; ADE: articular disc elastography; MME: masseter muscle elastography; SCME: sternocleidomastoid muscle elastography; n: number of patients; min: minimum; max: maximum; SD: standard deviation; MIH: Molar Incisor Hypomineralization. *: $p < 0.05$.*

TABLE 5. The results of multivariate logistic regression analysis.

	β	SE	Wald	p^L	OR	95% CI	
MIH presence	3.705	1.058	12.253	<0.001*	40.646	5.106	323.546
Age	0.192	0.261	0.540	0.463	1.211	0.726	2.021
Gender (male)	−1.575	0.723	4.739	0.029*	0.207	0.050	0.855
Mean TM thickness	1.434	3.053	0.221	0.639	4.194	0.011	1663.750
Mean AD thickness	−4.343	14.415	0.091	0.763	0.013	0.000	24,213,967,063.799
Mean MM thickness	6.164	3.360	3.366	0.067	475.355	0.657	344,127.676
Mean SCM thickness	−16.261	4.261	14.561	<0.001*	0.000	0.000	0.000
Mean TME	−0.016	0.045	0.120	0.729	0.984	0.900	1.076
Mean ADE	−0.020	0.034	0.338	0.561	0.981	0.918	1.048
Mean MME	−0.048	0.050	0.915	0.339	0.953	0.864	1.052
Mean SCME	0.094	0.042	4.975	0.026*	1.099	1.011	1.193
Constant	0.772	4.883	0.025	0.874	2.163		

*^{L}Multivariate Logistic Regression Analysis. SE: standard error; OR: odds ratio; CI: confidence interval; TM: temporal muscle; AD: articular disc; MM: masseter muscle; SCM: sternocleidomastoid muscle; TME: temporal muscle elastography; ADE: articular disc elastography; MME: masseter muscle elastography; SCME: sternocleidomastoid muscle elastography; MIH: Molar Incisor Hypomineralization. *: $p < 0.05$.*

sitive to thermal stimuli. The global prevalence rate of MIH being 13.5% indicates that this situation is a significant public health issue. Therefore, understanding not only its prevalence but also the consequences of this enamel developmental defect is critically important and vital for the effective planning and implementation of oral health programs [3]. In individuals with MIH, the asymmetric distribution of affected teeth disrupts the balance of the stomatognathic system, as one molar or incisor may be severely affected while the opposing tooth remains intact or shows minor defects [21, 22]. Furthermore, the loss of tooth structure caused by post-eruptive enamel breakdown may lead to a reduction in the occlusal vertical dimension. This reduction, combined with the asymmetrical distribution, could further disrupt the functional balance of the stomatognathic system, and contribute to the development of TMD. The authors believe that this situation may affect TMJ. In the current study, the prevalence of TMD in the MIH group, at a notably high rate of 60.5%, is remarkable. Additionally, the increased active mouth opening, symptoms such as headache, joint sounds, and deviation/deflection were observed more frequently in the MIH group compared to the control group, suggesting that MIH may be associated with TMD, possibly due to functional imbalances, although the cross-sectional design of this study precludes establishing a causal relationship.

These results suggest that MIH might induce an adaptive process within the TMJ and masticatory muscle systems. However, the absence of statistically significant findings for pain indicates the need for a broader biomechanical assessment of MIH's impact on TMD [23, 24].

It has been stated that factors such as emotional state, stress, and bruxism play a significant role in the development of TMD symptoms [25]. Dental sensitivity and treatment need in patients with MIH are likely to negatively impact on their qual-

ity of life, potentially leading to increased stress levels [26]. Considering that further studies are needed to directly evaluate the stress levels in patients with MIH, and given the established link between stress and TMD, it can be hypothesized that these patients may also have a predisposition to developing TMD. In this study, authors excluded patients with bruxism; however, the study does not have a parameter to measure to what extent MIH affects the stress levels of patients.

In the study by Macrì M *et al.* [27], some associations were found between TMD and occlusal factors; however, it was suggested that this might be due to individual morphology or other external factors rather than a causal relationship and it was emphasized that occlusion is not the primary cause of TMD but rather a secondary factor or a consequence of individual skeletal morphology. On the other hand, it has generally been shown that in some research's occlusal factors such as deep bite, increased overjet, and posterior crossbite may be associated with TMD [28, 29]. In the presented study, class I patients were included in both groups to ensure standardization and to minimize the effect of occlusal factors on TMD. However, this classification of occlusion was made only dentally, and this is considered a limitation of the study.

USG is a real-time, cost effective, non-ionizing and non-invasive method that allows for the dynamic evaluation of the TMJ and masticatory muscles [23]. The efficiency of the masticatory system is fundamentally dependent on the chewing forces produced by the masseter and temporal muscles, and it has been noted that the muscle's function is related to the muscle thickness and volume values. The ability of ultrasound to examine superficial muscles such as the masseter and temporal muscles is a reason for its preference among clinicians [30, 31].

In the literature, some studies have measured the thickness of the masseter and/or temporal muscles using ultrasound in the pediatric patient/adolescent's population, and the relationship of this thickness with malocclusions, bruxism, or TMD has been examined [30, 32, 33]. It has been reported that MM thickness in children varies between 7.3 and 10.3 mm [30, 34]. In the present study the mean MM thickness was 8.5 mm, compatible with the literature.

Pereira *et al.* [32] did not find a significant difference in muscle thickness values (masseter and anterior temporalis) between the TMD group and the control group in their studies conducted on adolescents. On the other hand, in the same study, according to gender, only the anterior temporalis of the boy children in the control group was found to be significantly thicker than that of the girl children in the same group. Tatlı *et al.* [30], in their study on bruxism in children, found that the thickness of the right and left masseter muscles was significantly higher in the study group compared to the control group, both in the resting and contracted positions. In our analysis, the right, left, and mean MM thickness did not differ in the presence of TMD, whereas the left TM and mean TM thickness were found to be higher in the absence of TMD. When considering MM thickness, the results of the present study are consistent with the studies of Pereira *et al.* [32] but contradict those of Tatlı *et al.* [30] This situation can be explained by the inclusion of children without bruxism in the presented study. When considering TM thickness, the results of the present study contradict those of Pereira *et al.* [32]. It is thought that this situation may be due to the different positioning of the probe when evaluating this muscle in the two studies. The reduced masseter and temporal muscle thickness observed in the MIH group compared to the control group may reflect an association with weakened or insufficient muscle development. Similarly, Arıkan *et al.* [23] study in patients with TMJ osteoarthritis, the thickness of the masseter muscle during rest and maximum bite found to be lower than that of healthy controls and this reduction was attributed to decreased chewing function and muscle atrophy. To our knowledge, there is no study in literature that measures SCM thickness in pediatric patients. In the current study, the left SCM thickness and mean SCM thickness were found to be higher in the absence of TMD.

In the present study, the right, left, and mean TM and MM thicknesses were slightly higher in girls, but no statistical difference was observed. However, only the left SCM thickness was found to be significantly higher in girls compared to boys. The literature indicates that boys have greater muscle mass than girls [34–36]. It has been emphasized that this difference is first observed during puberty due to the effects of androgenic steroids [34, 37]. In light of this information, based on the age range of the participants in our study, it is reasonable to accept that our findings may contradict the literature.

Elastography measurements, like muscle thickness measurements, are also important indicators of muscle activity and strength. Therefore, muscle elasticity measurements are crucial for detecting pathological conditions of the muscle, evaluating muscular TMD, diagnosing and treating systemic diseases affecting the muscles, and assessing muscle performance. The change in elastography values indicates a deterioration in the joint and muscle dynamics in the individuals [24].

In the study by Öztürk *et al.* [38], normative elastographic stiffness values for the TMJ disc and masseter muscle and in the study by Olchowy *et al.* [13] normative elastographic stiffness values for MM in healthy children were provided. Öztürk *et al.* [38] indicating that posterior TMJ disc exhibited significantly lower stiffness compared to the anterior and middle regions in healthy children. This situation may explain due to the rich blood vessels and connective tissue in the posterior segment of the disc [39]. In the presented study, due to the very small joint space in the age group examined, elasticity was evaluated only in the intermediate part of the disc.

While Öztürk *et al.* [38] found a significant difference in stiffness of MM in the opened mouth compared to closed mouth according to age, Olchowy *et al.* [13] found a significant difference between boys' and girls' stiffness of MM. In this study, although the control group was not grouped according to age or gender as in the above studies, the stiffness values for the intermediate part of the disc determined in the control group were consistent with Öztürk *et al.* [38], and the mean MME was found to be lower than in both studies.

Current study results indicate that the elastographic values of all the examined parameters were higher in the MIH group compared to the control group, but this difference was not statistically significant for the right, left, and mean ADE values, whereas significant differences were observed in the right, left, and mean elastographic values of the muscles. Based on these

results, there appears to be an association between MIH and adaptive changes in the muscles, but this has not yet been reflected in the disc complex. If these changes are detected and treated early, the joint complex may be preserved.

To the best of our knowledge, there are no elastography studies conducted in pediatric patients with TMD in the literature. According to the results of the present study, although elastographic values increase in the presence of TMD, this is only statistically significant in the MME. Despite differences in the age groups of the conducted studies, several studies in the literature on adult patients have also reported higher MME values compared to the control group [23, 40, 41].

While quantitative elasticity values measured in kPa and m/s have been shown to provide good diagnostic performance in musculoskeletal ultrasound examinations, the evaluation of muscles with ultrasound elastography has some potential limitations regarding repeatability. When conducting the assessment, standardizing the muscle's contraction/relaxation state and considering the muscle's condition according to the exercise/rest position are also important. Although SWE has largely eliminated such problems, the muscle's contraction/relaxation state should be determined during ultrasound examinations and recorded by a standardized practitioner if possible [42]. In the present study, both the practitioner was standardized, and the ICC values demonstrated consistency in the measurements. The fact that only the resting states of the muscles were recorded represents a significant limitation of the study, given the dynamic nature of the masticatory system. The authors preferred to record measurements only in the resting state due to the study groups being a pediatric population and the participants' compliance deteriorating as the examination period increased. This study has several other limitations including the exclusion of variables such as facial morphology or body mass index and the lack of evaluation of psychological factors such as stress and anxiety, as well as parafunctional behaviors other than bruxism. A relatively smaller sample size in the control group is another limitation of this study, which may have affected the statistical power of the comparisons. While this study has certain limitations, study result' highlight that MIH is not merely a dental issue but is associated with parameters of the musculoskeletal system. It is also recommended that in future studies, Decayed, Missing, and Filled Teeth (DMFT) index and Pulpal involvement, Ulceration, Fistula, and Abscess (PUFA) index indices be included in the study data to investigate the effect of these indices on the stomatognathic system in patients with MIH. A limitation of our study is that the subgroup sizes were insufficient to statistically assess the relationship between the number and location of MIH teeth and the prevalence of TMJ or ultrasonographic findings. Further studies with larger sample sizes are needed to demonstrate this relationship more clearly.

5. Conclusions

The frequency of TMD differs in the MIH group, and this affects the masticatory muscle thickness and elasticity. MIH is not only a dental problem but should also be associated with a broader imbalance affecting the entire stomatognathic system in children.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the corresponding author.

AUTHOR CONTRIBUTIONS

OEG and HT—designed the research study, reviewed and edited the paper. BK and ZMS—conducted the literature review and collected the data. HT—analyzed the data. BY and HT—wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was conducted at Akdeniz University, Faculty of Dentistry, Antalya, Turkey, and was approved by the Clinical Research Ethics Committee of Akdeniz University with protocol number TBAEK-75. The parents or guardians of all participants agreed to participate in the study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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