Pain Research and Management

Pain of Temporomandibular Disorders: from Etiology to Management 2020

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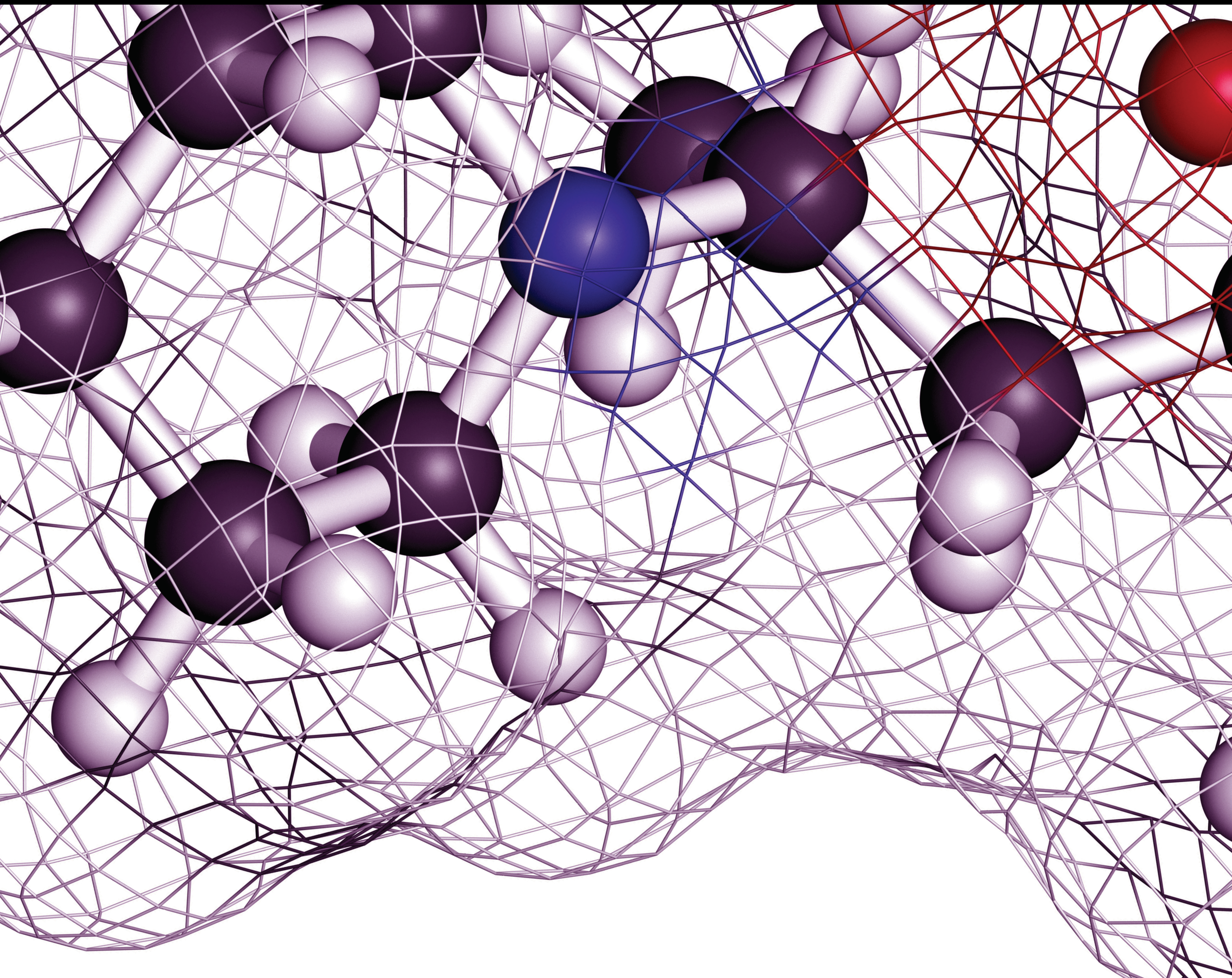

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Research Article

The Prevalence of Temporomandibular Disorders and Dental Attrition Levels in Patients with Posterior Crossbite and/or Deep Bite: A Preliminary Prospective Study

Naser Khayat,[1] **Efraim Winocur**,[2] **Ron Kedem**,[3] **Orit Winocur Arias**,[4] **Ayman Zaghal**,[5] **and Nir Shpack**[6]

[1]*Maurice and Gabriela Goldschleger School of Dental Medicine, Tel Aviv University, Tel Aviv-Yafo, Israel*
[2]*Department of Oral Rehabilitation, Maurice and Gabriela School of Dental Medicine, Tel Aviv University, Tel Aviv-Yafo, Israel*
[3]*Academic Branch of the IDF Medical Corps, Tel Hashomer, Israel*
[4]*Department of Oral Pathology and Oral Medicine, Maurice and Gabriela Goldschleger School of Dental Medicine, Tel Aviv University, Tel Aviv-Yafo, Israel*
[5]*Department of Oral and Maxillofacial Surgery, Al Quds University, Jerusalem, Israel*
[6]*Department of Orthodontics, Maurice and Gabriela Goldschleger School of Dental Medicine, Tel Aviv University, Tel Aviv-Yafo, Israel*

Correspondence should be addressed to Efraim Winocur; winocur@tauex.tau.ac.il

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Background. The prevalence of various temporomandibular disorders (TMD) and the severity of attrition in patients with either bilateral or unilateral deep bite and/or posterior crossbite has not been established, nor has the effect of one year of orthodontic treatment on TMD. *Methods*. Of 310 patients presenting with suspected TMD, 160 were diagnosed with various TMD and 150 were TMD-free. Diagnosis was according to the Axis I of the Diagnostic Criteria for TMD. All participants underwent a dental examination, and 100 patients were reevaluated after one year of orthodontic treatment. Fisher's exact test and the proportion test with Bonferroni's correction were used for the categorical univariate analysis. *Results*. There was a significant association ($P < 0.001$) between deep bite and dental attrition (wear), but not between crossbite and/or deep bite in patients diagnosed with either painful TMD or disc displacement. The risk of sustaining painful TMD when crossbite presented simultaneously on the anterior and the posterior dentition was 2.625-fold greater than when it presented with a normal bite, although this difference was not significant ($P = 0.286$) due to the lack of statistical power. There was no significant sex-related association between the occurrence of either painful TMD or disc displacement. A reduction in TMD findings was demonstrated after one year of treatment, but no statistical power was reached due to the small sample size. *Conclusions*. Deep bite may be related to dental wear but not to pain from TMD and/or disc displacement. Only crossbite that presents simultaneously on the anterior and the posterior dentition (mixed X-bite) may have some effect on the level of pain in TMD, but not on in the prevalence of disc displacement. Confirmation of these conclusions by well-designed studies on larger patient groups is warranted. There was a clinically significant improvement in TMD findings after one year of treatment.

1. Introduction

The term "temporomandibular disorders" (TMDs) refers to a set of clinical problems that involve the masticatory musculature, the temporomandibular joint (TMJ), and associated structures or both [1]. It has been identified as the leading cause of nondental pain in the orofacial region and is considered a subclass of musculoskeletal disorders [2]. Several investigations on the relationship between occlusal factors and TMDs have been carried out. List et al.'s [3] case control study found that psychosocial factors, somatic complaints, and emotional problems seem to play a more prominent role than dental factors in adolescents with TMDs. Although occlusion has been hypothesized as an etiological or perpetuating cofactor, the degree to which it plays a role has not been definitively delineated [4]. Pullinger and Seligman [5] identified some occlusal features as being potentially related to TMDs, including unilateral lingual crossbite and deep bite. In Magnusson et al.'s study which extended over a 20-year period, a unilateral posterior crossbite was considered as being a possible local risk factor for the development of TMDs [4]. Others [6], however, rejected this latter hypothesis, showing that TMDs are either weakly or not at all associated with posterior crossbite.

Extreme deep bite values have shown an association with TMDs, which is a necessary but not a sufficient sole criterion for a causal relationship [7]. In addition, some researchers are of the opinion that occlusion may be an important factor in causing TMDs [8], while most reviews concluded that malocclusion does not cause TMDs [9].

Tooth wear is a multifactorial condition leading to the progressive loss of dental hard tissue through three processes: attrition (loss of substance on opposing occlusal units caused by tooth-to-tooth contact), abrasion (wear produced by interaction between teeth and artificial materials), and erosion (dissolution of teeth by acidic substances) [10]. Attrition is the most frequently mentioned sign of bruxism [11], although there is considerable controversy about the correlation between bruxism and tooth wear. Some investigators suggest that bruxism causes attrition [12], but others have not found the tooth wear status to be predictive of ongoing bruxism levels [13]. Lavigne et al. are of the opinion that tooth wear should not be considered a specific marker of bruxism since the cause (bruxism) and the effect (tooth wear) could have occurred long before the dental wear had been diagnosed [14].

Given all of these dissenting opinions and claims taken together, the aims of this study were twofold: to assess the occurrence of different TMDs and the presence and severity of attrition in patients with posterior crossbite and/or deep bite and to assess the effect of 1-year orthodontic treatment on TMDs. The null hypotheses of the study were as follows. (1) The prevalence of posterior crossbite and/or deep bite will be significantly greater among patients with TMDs. (2) The prevalence and severity of dental attrition will be significantly greater among patients with posterior crossbite and/or deep bite. (3) The incidence of TMDs will remain unchanged after one year of orthodontic treatment.

2. Materials and Methods

2.1. Study Population. The study population was composed of two cohorts that included a total of 310 patients with an age range of 11–49 years. There were 153 males (49.4%) with a mean age of 16.8 years (95% confidence interval (CI): 16.1, 17.5) and 157 females (50.6%) with a mean age of 19.4 years (95% CI: 18.2, 20.6). The sample was taken from two sources in 2018: patients who were referred to the Postgraduate Orthodontic Clinic, Department of Orthodontics, The Maurice and Gabriela Goldschleger School of Dental Medicine, Tel Aviv University, Tel Aviv, Israel (71 patients), and those referred to a private orthodontic clinic located in East Jerusalem (89 patients). All of the participants (Table 1) were diagnosed according to the DC/TMD (AXIS I) (http://rdc-tmdinternational.org) [15].

The TMD group consisted of 160 patients. It was further divided into (1) the painful TMD group (TMD pain: 53 patients; 17%) defined by the presence of at least one of the following: myalgia, myofascial pain, headache attributed to TMD, or arthralgia; (2) the disc displacement (DD) group (54 patients; 18%): defined by the presence of at least one of the following: DD with reduction, DD with reduction with intermitting locking, and DD without reduction; (3) the mixed group (mixed TMD: 53 patients; 17%) defined as patients that present with at least one diagnosis belonging to the TMD pain group, and at least one diagnosis belonging to the DD group. The TMD-free group (FREE TMD) consisted of 150 orthodontic patients that were found not to have any TMDs.

2.2. Initial Clinical Examination

2.2.1. Temporomandibular Clinical Examination and Diagnosis. All patients were examined by the examining investigator (NK), who had been previously calibrated according to the training practice session of the International Consortium for TMD (http://rdc-tmdinternational.org) [15].

2.2.2. Dental Clinical Examination and Diagnosis. The examining investigator (NK), an orthodontic specialist, examined all patients. A posterior crossbite (X-bite) was defined when one or more of the teeth of the posterior dental group (from canine to second molar) were found to present at least one cusp wide buccolingual or buccopalatal relationship, with one or more opposing teeth in intercuspal position [16]. An anterior crossbite was defined when one or more maxillary anterior teeth are palatally positioned relative to the mandibular anterior teeth [17].

The patients' final diagnosis was no X-bite (NoXB), anterior X-bite (AntXB) only, posterior X-bite (PostXB), which included an X-bite unilaterally or bilaterally, and mixed X-bite (MIXXB), which included AntXB and PostXB.

An overbite was defined by the vertical overlap of lower incisors by the upper incisors. An overbite was considered normal when 1/3 of the lower incisor was covered by the upper incisor (grade 0). A vertical overlap ranging from 1/3 to less than 2/3 was considered a mild deep bite (grade 1), a vertical overlap from 2/3 to less than full length of the lower incisor was considered a moderate deep bite (grade 2), and a vertical overlap equal to or more than the full length of a lower incisor was considered a severe deep bite (grade 3) [18]. A negative overbite was considered an open bite. Patients were finally categorized as having a normal-to-mild = grade 0–1 = NorMil or a moderate-to-severe = grade 2–3 = ModSev.

Tooth attrition was assessed on a tooth-by-tooth basis according to Lobbezo and Naeije [19] and rated according to a 5-point ordinal scale (0–4), where grade 0 = no wear, grade

Table 1: Age group by sex type.

Testing group	Age group (years)	Male	Female	Fisher's exact test exact sig. (2-sided)	Odds ratio
Sex	11.0–16.9	57.1% 198	42.9% 85	$P < 0.001$	1.598 95% CI [1.212–2.106]
	17.5–50.0	35.7% 112	64.3% 72		

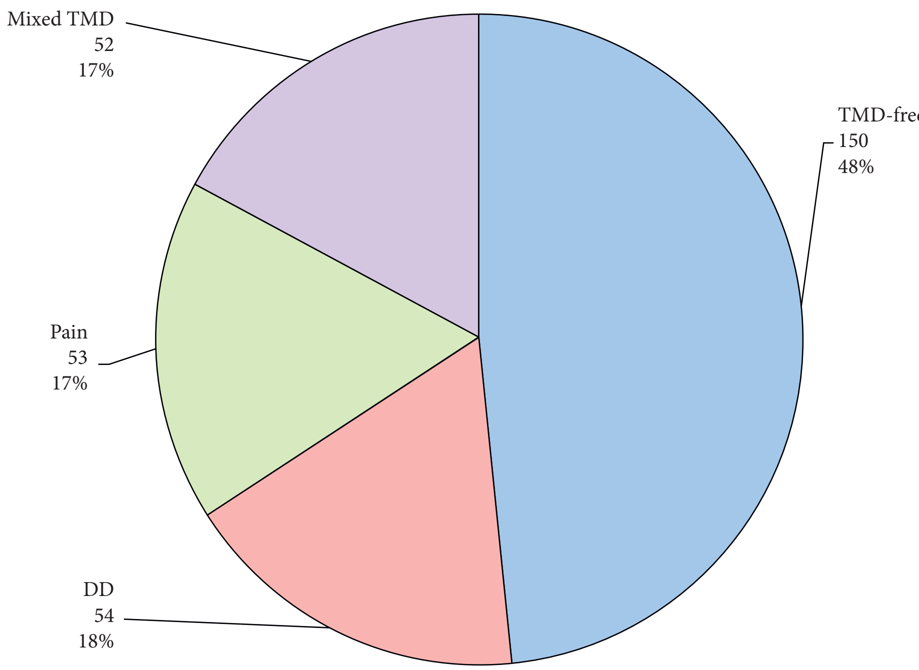

Figure 1: Distribution of the temporomandibular disorders (TMD) groups. DD = disc displacement; pain = painful TMD; mixed TMD = DD + Pain.

1 = visible wear within the enamel only, grade 2 = visible wear with dentin exposure and mild-to-moderate loss of clinical crown height (≤1/3), grade 3 = significant loss of crown height >1/3 but <2/3, and grade 4 = loss of crown height (≥2/3). All of the teeth, including the anterior ones, were included in the analysis. Wear was calculated for each subject as an average score [20]. Teeth affected by erosion were excluded. The final analysis was performed according to the European Consensus Statement (2017) [21] as low wear = grades 0–2, and high wear = grades 3-4.

2.3. Repeat Clinical Examination. The first 1/3 of the study patients to be enrolled were reevaluated during a routine orthodontic appointment one year from the initial examination. Each was fully examined and a diagnosis was again arrived at according to the DC/TMD and by the same clinician. The examiner was blind to the initial diagnosis in order to prevent bias.

2.4. Ethical Concerns. Approval to conduct this study was obtained from the Tel Aviv University Institutional Ethical Committee (no.: 20170529 12272191) on May 29, 2017. Written and oral informed consent was provided by all of the participants or the legal guardian. The study was self-funded by the authors.

2.5. Statistical Methods. A univariate analysis followed by Fishers' exact test was used for the descriptive data. A proportion test with Bonferroni correction was applied as appropriate for categorical variables. ANOVA with Tukey's post hoc test was employed for comparing the patient's age and sex of the X-bite and the overbite groups (without the Tukey's post hoc test). The variously diagnosed groups were analyzed for each category variable: "TMD pain," "DD," and "mixed TMD were compared to the reference group "FREE TMD" by using Fisher's exact test and the proportion test with Bonferroni's correction. The significance level of the result was $\alpha = 0.05$. The data were analyzed using IBM SPSS statistics version 23.0. (SPSS, Inc., Chicago, IL USA).

3. Results

3.1. Sampling. Around one-half (49.4%) of the 310 patients included in this study were men. The FREE TMD group comprised about one-half (48%) of the study participants. In the TMD group, 18% were diagnosed with DD alone (the DD group), 17% had temporomandibular pain alone (the TMD pain group), and 17% of the patients had both DD and

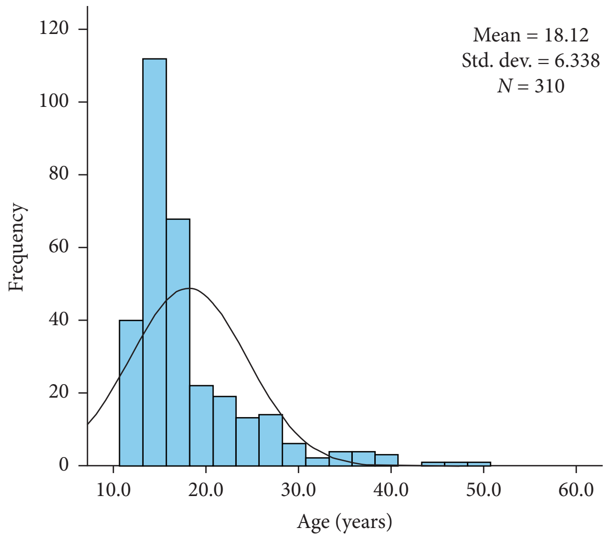

Figure 2: Age distribution of the participants.

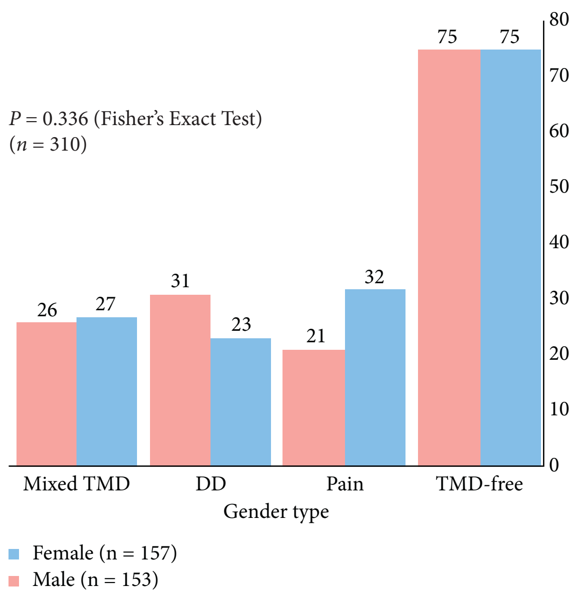

Figure 3: Distribution of TMD groups by sex. DD = disc displacement; TMD = temporomandibular disorders.

temporomandibular pain (the mixed TMD group) (Figure 1).

The average age of the study participants was 18.1 years (range 11–49 years; Figure 2), but since the age demonstrates a right skewed distribution ($P < 0.001$ in Kolmogorov–Smirnov with Lilliefors Significance Correction), which invalidates the use of a parametric test, the median 16.0 years denotes better the center of the sample group. To allow analysis on the age variable, it was coded into two age groups with a cut-point using ROC analysis with dental wear.

The sampling of sex type did not differ among the TMD groups ($P = 0.336$; Figure 3), but the young age group comprised significantly more males (57.1%; $P < 0.001$) than the elder group (17.5–50.0), as expected in an orthodontic clinic (Table 1).

The prevalence of TMD pain in the patients with mixed XB was 21%, while it was only 16% in those with NoXB (a relative risk of 1.3125) (Table 2). The prevalence of DD was 11% in patients that exhibited mixed XB, while it was 22% in those with NoXB (a relative risk of 0.50). This meant that the risk of belonging to the TMD pain group compared to the DD group in the mixed XB group was 2.625-fold greater than for the NoXB. Nevertheless, due to the lack of power, this difference was not found to be significant ($P = 0.286$) (only three patients had both mixed XB and DD). The prevalence of mixed TMD in patients with mixed XB was 21% compared to 13% among those with NoXB (a relative risk of 1.6154). The risk of belonging to the mixed TMD group compared to the DD group in those with mixed XB was 3.231-fold greater than in patients with NoXB, but again the difference was not found to be significant ($P = 0.146$).

There was a significant ($P < 0.001$) dependency between deep bite and wear (Table 3): 46 (17%) of the 275 participants were found to have had a ModSev bite. Of them, 38% exhibited extensive wear, and only 13% patients had low levels of wear. The odds ratio according to the Mantel–Haenszel common estimate analysis was 4.21 (95% CI: 2.05, 8.62).

3.2. Age, TMD, and Dental Wear. Due to the sample size, the lack of power was prevented from this study to assess the influence of age on patients with crossbite or deep bite in the occurrence of TMD, and it was not the aim of the study. It was found that 57.1% of the male are in the range of 11.0–16.9 age group which is significantly higher than the 17.5–50.0 age group (35.7%). The age cut-point when wear sensitivity and specificity is minimal is 17.5 years (the area under the curve is 0.699, 95% CI [0.617–0.780]; asymptotic significance when null hypothesis, true area = 0.5, is <0.001) (Figure 4). When computing dichotomously the two-age group (<17.5; and ≥17.5), and cross-check it with each TMD group, it was found that age is not an influence factor of any of the TMD groups (Table 4), but it is a significant factor in the developing of dental wear ($P < 0.001$, Table 5). In other words, it can be concluded that age is not an influence factor to the research variables.

3.3. TMD Diagnoses at Reevaluation. The interval between the initial diagnosis and the reevaluation was 12.21 ± 0.51 months (range of 12–14). Comparison of the results of the initial diagnosis with the results of the reevaluation revealed a clear-cut improvement after one year of orthodontic treatment. By the time of the follow-up evaluation at one year, the TMD-free group increased from 32% to 73%, while the distribution of the TMD diagnoses decreased as follows: the DD group decreased from 21% to 16%, the TMD pain group decreased from 28% to 7%, while the mixed TMD group decreased from 19% to 4%. The McNemar–Bowker Test of Symmetry was used for testing correlated proportions of the initial diagnosis and of the reevaluation ($P < 0.0001$). In addition, proportion tests with Bonferroni correction were calculated for each cell and the results are displayed in

Table 2: Dental diagnoses at initial evaluation (according to TMD groups).

		Initial diagnosis groups				Total	P
		TMD-free (control)	Pain	DD	Mixed TMD		
	Total	150 (48%)	53 (17%)	54 (17%)	53 (17%)	310 (100%)	
X-bite, n	No X-bite	$88_{a, b}$ (49%)	$29_{a, b}$ (16%)	39_b (22%)	23_a (13%)	179 (100%)	0.294
	Anterior X-bite	9 (43%)	3 (14%)	4 (19%)	5 (24%)	21 (100%)	
	Posterior X-bite	40 (49%)	15 (18%)	8 (10%)	19 (23%)	82 (100%)	
	Mixed X-bite	13 (46%)	6 (21%)	3 (11%)	6 (21%)	28 (100%)	
Open bite, n	No open bite	117 (48%)	42 (17%)	41 (17%)	42 (17%)	242 (100%)	0.713
	Anterior open bite	20 (49%)	6 (15%)	8 (20%)	7 (17%)	41 (100%)	
	Posterior open bite	6 (46%)	3 (23%)	4 (31%)	0 (0%)	13 (100%)	
	Mixed open B	7 (50%)	2 (14%)	1 (7%)	4 (29%)	14 (100%)	
Overbite, n	Normal or mild	110 (48%)	42 (18%)	42 (18%)	35 (15%)	229 (100%)	0.547
	Deep bite	24 (52%)	6 (13%)	8 (17%)	8 (17%)	46 (100%)	
Wear, n (erosion excluded)	Low	127 (49%)	45 (17%)	46 (18%)	41 (16%)	259 (100%)	0.856
	High	23 (45%)	8 (16%)	8 (16%)	12 (24%)	51 (100%)	

TMD = temporomandibular disorders; pain = pain = painful TMD; DD = disc displacement; mixed TMD = DD + PAIN. $_{a, b}$Each subscript letter denotes a subset at reevaluation categories whose column proportions do not differ significantly from each other at the 0.05 level with Bonferroni correction. So, $_a$ is a significantly different proportion comparing to $_b$ proportion with Bonferroni correction. $_{a, b}$Proportions are overlapped. The proportion of normal bite is compared to not-normal bites.

Table 3: Low wear compared to high wear (erosion excluded) versus deep bite.

		Deep bite			P
		Normal or mild	Moderate or severe	Total	
Total, n		229 (83%)	46 (17%)	275 (100%)	
Dental wear*	Low	201 (**87%**)	29 (13%)	230 (100%)	<0.001
	High	28 (62%)	17 (**38%**)	45 (100%)	

*35 patients with eroded dentition were excluded. Bold indicates no conflicted result.

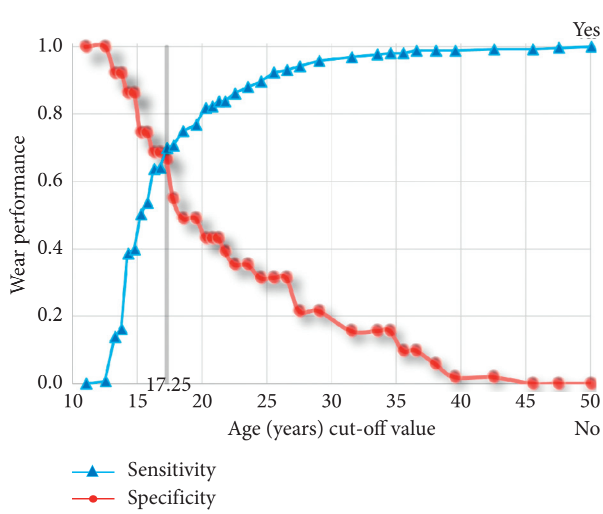

Figure 4: ROC analysis for age cutpoint via dental wear.

Table 6. Achieving statistical power for assessing the results required a sample size of 300.

4. Discussion

We had hypothesized that the prevalence of posterior crossbite and/or deep bite will be greater among patients with TMDs, that the prevalence and severity of dental attrition will be significantly greater among patients with posterior crossbite and/or deep bite, and that the incidence of TMDs will remain unchanged after 1 year of orthodontic treatment. These null hypotheses were only partially rejected by the findings of this study.

There was no significant sex-related association ($P = 0.336$) between the occurrence of TMDs. These findings are in contrast to those of Rushdi Khayat et al. [22] who studied the prevalence of TMDs, occlusal diagnosis, and bruxism in the general population and found that there was a significant sex difference (more among females) in the prevalence of painful TMDs. They also oppose those of Bagis et al. [23] who found that females had TMD signs and symptoms more frequently than males in their study population. The present findings are, however, in accordance with Khayat et al. [24] who reported that there is no significant association between the sex of the patient and the occurrence of either pain TMDs or DD. It was also found that age has no influence to the research TMD variables, but it is a significant factor in the developing of dental wear. This finding has to be cautiously considered due to the lack of power in the present sample.

Thilander et al. [25] found that TMDs were significantly associated with posterior crossbite, and those authors recommended that such malocclusions should be treated orthodontically at an early age to eliminate the traits of the anomaly. Additionally, Sonnesen et al. [26] observed that signs and symptoms of TMDs were significantly associated with malocclusions, such as unilateral posterior crossbite.

Table 4: Age group by TMD groups and male sex type.

Testing group	Age group (years)	Yes (%)	N	Fisher's exact test exact sig. (2-sided)	Odds ratio comparing to TMD-free
Pain	11.0–16.9 17.5–50.0	26.4 26.4	125 78	0.520	1.0296 95% CI [0.638–1.661]
DD	11.0–16.9 17.5–50.0	29.8 20.5	131 73	0.102	1.449 95% CI [0.860–2.442]
Mixed TMD	11.0–16.9 17.5–50.0	27.0 24.7	126 77	0.424	1.094 95% CI [0.674–1.775]

TMD = temporomandibular disorders; pain = pain = painful TMD; DD = disc displacement; mixed TMD = DD + pain.

Table 5: Age group by dental wear.

Testing group	Age group (years)	Severe	Not severe (erosion excluded)	Fisher's exact test exact sig. (2-sided)	Odds ratio
Dental wear	11.0–16.9	8.6% 17	91.4% 181	$P < 0.001$	4.641 95% CI [2.448–8.800]
	17.5–50.0	30.4% 51	69.6% 78		

Table 6: Comparison of initial diagnoses with reevaluation.

			Diagnoses at reevaluation				Initial diagnosis
			TMD-free	TMD pain	DD	Mixed group	
Initial diagnoses	TMD-free	Count	$25_{a, b}$	0_{b}	$4_{a, b}$	3_{a}	32
		% within initial diagnosis	78.1%	0.0%	12.5%	9.4%	100.0%
	TMD pain	Count	$22_{a, b}$	5_{b}	1_{a}	$0_{a, b}$	28
		% within initial diagnosis	78.6%	17.9%	3.6%	0.0%	100.0%
	DD**	Count	15_{a}	0_{a}	6_{a}	0_{a}	21
		% within initial diagnosis	71.4%	0.0%	28.6%	0.0%	100.0%
	Mixed group	Count	11_{a}	2_{a}	5_{a}	1_{a}	19
		% within initial diagnosis	57.9%	10.5%	26.3%	5.3%	100.0%
Total		Count	73	7	16	4	100
		% within initial diagnosis	73.0%	7.0%	16.0%	4.0%	100.0%

TMD = temporomandibular disorders; pain = pain = painful TMD; DD = disc displacement; mixed TMD = DD + pain. $_{a,\ b}$Each subscript letter denotes a subset at reevaluation categories whose column proportions do not differ significantly from each other at the 0.05 level with Bonferroni correction. So, $_{a}$ is a significantly different proportion comparing to $_{b}$ proportion with Bonferroni correction. $_{a,\ b}$Proportions are overlapped.

Alarcon et al. [27] suggested that the altered morphological/occlusal relationship between the upper and lower dentition may result in right-to-left-side differences in the masticatory muscles and the condyle–fossa relationship and that the asymmetric activity of the masticatory muscles could therefore be the source of their tenderness. In contrast, Al-Ani [28] and Špalj et al. [29] reported that signs and symptoms of TMDs seemed to be poorly related to malocclusions. The present study found that a painful TMD diagnosis was prevalent only among those patients who exhibited both anterior and posterior crossbite (the mixed XB group) compared to patients with a normal bite (the NoXBite group). As far as we know, this is the first time this population of patients had been analyzed since the reports in the literature deal with cases of either anterior or posterior crossbite but not with both appearing concomitantly. In other words, in the current work, only severe cases of full mouth crossbite (anterior and posterior) may be a risk factor for the development of temporomandibular pain. This difference was not found to be significant ($P = 0.286$) due to lack of power (only three of the study patients had both mixed XB and DD), so these figures should be interpreted with caution until well-designed studies with larger samples confirm them.

The present study demonstrated a significant dependency between deep bite and dental wear. These findings are in accordance with Richard et al. [30] who found that the attrition score tends to increase with the bite depth. They also agree with Grzegocka et al. [31], who concluded that deep bite in association with "tight incisal occlusion" represents an additional risk factor for dental wear, advising that orthodontic treatment is aimed at modification of the occlusion. These findings, however, are in opposition to the results of Seligman et al. [12] who reported that dental attrition in a nonpatient population was not associated with either signs or symptoms of TMDs or with occlusal factors.

We observed a remarkable reduction in TMDs when comparing the initial TMD diagnoses with the results of the reevaluation after one year of orthodontic treatment. Unfortunately, sample size precluded achieving statistical power and a study on a larger sample study is warranted to address this issue. These findings are in accordance with Tecco et al. [32] who observed a significant improvement in myofascial pain syndrome (muscular pain) after treating the malocclusion by means of a fixed orthodontic appliance. Those authors hypothesized that orthodontic therapy could allow the improvement of the maxillomandibular relationship, thus improving the function of the related muscles. Also, Henrikson et al. [33] found that the prevalence of pain upon mandibular movement and of tenderness to palpation of the masticatory muscles was significantly less common during and after orthodontic treatment than before. In contrast, Nielsen et al. [34] evaluated the effect of orthodontic treatment on the functional status of the masticatory system and found that tenderness on palpation of the musculature and the TMJ capsule were generally more prevalent among orthodontically treated subjects. The improvement that we observed in the 1-year reevaluation can be due to the fact that the teeth are sensitive during the active phase of the orthodontic treatment, especially during loading [35]. That would explain why patients report some reduction of bruxism during the period of orthodontic treatment [36]. This reduction in the muscular hyperactivity and in the bruxist's grinding and clenching of the teeth might have a favorable effect on painful TMD and even on the occurrence of clicks, as discussed below.

The reduction in the occurrence of DD may be due the fact that the sensitivity of a DD diagnosis without magnetic resonance imaging is only 0.34, which raises some doubt about the accuracy of the diagnosis. It must be kept in mind that clicks may be caused by factors other than disc position [37]. Moreover, awake clenching can cause temporary disc adhesion [38] which is released when moving the mandible (opening or contralateral movement). The energy invested is expressed as a click [39]. In other words, the reduction in the DD group at reevaluation may express a reduction in awake bruxism. Further study that includes orthodontic patients definitively diagnosed as having awake bruxism is warranted to clarify this possibility.

5. Conclusions

(1) Deep bite and age may be related to dental wear but not to pain associated with TMDs and/or DD.

(2) Only crossbite presenting concomitantly on both the anterior and the posterior dentition (the Mixed X-bite group) may have some effect on the pain associated with TMDs, but not on the prevalence of DD. Confirmation of these conclusions by well-designed studies on larger patient groups is warranted.

(3) A clinically significant improvement of TMD findings was found after one year of orthodontic treatment.

Data Availability

The data are available upon reasonable request from the corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding this paper.

Acknowledgments

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Review Article

Local Vibratory Stimulation for Temporomandibular Disorder Myofascial Pain Treatment: A Randomised, Double-Blind, Placebo-Controlled Preliminary Study

Emanuela Serritella, Giordano Scialanca, Paola Di Giacomo, and Carlo Di Paolo

Clinical Gnathology Unit, Department of Oral and Maxillofacial Sciences, "Sapienza" University of Rome, Rome, Italy

Correspondence should be addressed to Emanuela Serritella; emanuela.serritella@uniroma1.it

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Several methods are currently used to manage pain related to temporomandibular disorder (TMD). Vibratory stimulation is applied as a pain treatment for several musculoskeletal disorders, but it has not yet been studied in-depth for TMD symptoms. The aim of this study is to analyse the effectiveness of at-home local vibration therapy (LVT) for the management of TMDs-related myofascial pain. *Methods*. Fifty-four TMD patients (43 F, 11 M) with an average age of 40.7 (age range: 29–54 yr.) were randomly subdivided into two groups. The study group (AG) received 1 week of at-home LVT treatment with the NOVAFON Pro Sk2/2 : 50/100 Hz, bilaterally applied to the pain area for 16 minutes daily. The placebo group (IG) followed the same protocol using inactive devices. Temporomandibular joint pain (TMJ), muscular pain (MM), and headache (HA) were assessed. Pain was evaluated using the visual analogue scale (VAS) before (T0) and after therapy (T1). Statistical analysis and Student's t-tests were applied (statistical significance for $P < 0.05$). *Results*. AG patients reported decreased average values for all types of pain considered between T0 and T1, with a statistically significant difference for TMJ pain ($P < 0.05$), MM pain, and HA ($P < 0.001$). IG patients reported a no statistically significant decrease in the average values of MM pain and an increase in the average values of TMJ pain and HA. *Conclusion*. The study supports the use of local vibration therapy in the control of TMD-related TMJ pain, local muscular pain, and headache.

1. Introduction

Temporomandibular disorders (TMD) comprise a large number of pathologies related to the masticatory muscles and/or temporomandibular joint (TMJ) and constitute a part of the musculoskeletal disorder group [1]. Current indications for treatment of these conditions follow a conservative approach that includes information, reassurance, control of functional excesses, physiotherapy rehabilitation, application of physical therapies, administration of drugs, and intraoral devices [1–3]. Like other musculoskeletal disorders, TMD has been treated in recent years with various physical therapy methods, in cases with different types of TMD pain (pain-related, intraarticular, degenerative groups). TENS (transcutaneous nerve electrical stimulation) and low-level laser therapy (LLLT) are among the most utilized treatment procedures [4–6].

One of the most recently proposed physical therapy treatments is local vibration therapy. Local vibration therapy produces vibrations that reach up to 6 centimetres of tissue depth; it is used to regulate muscle tone, relieve localized pain, and stimulate an increase in blood and lymphatic circulation [7–9]. This therapy is most frequently applied in the treatment of chronic pathologies affecting the muscles, tendons, and joints. Several studies evaluating the impact of local vibration therapy on skeletal muscles and joints have highlighted its effectiveness for increasing joint mobility and decreasing pain [10, 11], but analysis of its potential for the temporomandibular region is still lacking. Only two studies have addressed the application of this therapy to TMD and both demonstrate its effectiveness for muscle pain relief [12, 13].

The aim of this study is to evaluate the effectiveness and efficiency of local vibration therapy in the treatment of craniomandibular pain by comparing the application of an active vibratory device with the application of an inactive placebo device on two samples of dysfunctional patients.

2. Materials and Methods

A randomized, double-blind, placebo-controlled clinical study was conducted at the Clinical Gnathology Unit of the Department of Oral and Maxillofacial Sciences at the "Sapienza" University of Rome. The study was approved by the Institutional Ethics Committee (N. 93/2017-0001385); all patients signed an informed consent document before participating in the study.

2.1. Participants. The patient enrollment process followed the CONSORT (Consolidated Standards of Reporting Trials) criteria (Figure 1).

During the period of February 2018–July 2019, 317 subjects under observation in our department were assessed for eligibility. All patients were screened for temporomandibular disorders (TMD) by specialists in the field using the DC/TMD diagnostic criteria [14]. Criteria for inclusion in the study were as follows: (1) diagnosis of chronic local myalgia (ICD-9 729.1) with average reported pain greater than or equal to 3 on the numeric verbal scale (NVS); (2) availability to participate in the study; and (3) current residence in Rome or the surrounding province. Patients meeting the following exclusion criteria were excluded from the study: (1) diagnosed with widespread pain; (2) diagnosis of joint disorders (ICD-9 524.63; ICD-9 715.18; and ICD-9 830.0); and (3) receiving ongoing gnathological treatment. Following manufacturer indications for the therapeutic device, additional exclusion criteria were also applied: (1) presence of open wounds/eczema on the skin or the skin membranes involved in the treatment; (2) diagnosis of arteriosclerosis, thrombosis, cardiac arrhythmias, or use of a pacemaker; (3) diagnosis of epilepsy; (4) use of brain stimulators or presence of metal implants; (5) presence of tumour lesions; and (6) pregnant women.

256 patients were excluded according to these criteria. The resulting study sample consisted of 61 patients, 16 male (26.2%) and 45 female (73.8%), with an average age of 38.39 years (range 29–54 years).

2.2. Interventions. The study involved the administration to all patients of a local vibration device (NOVAFON Pro (Sk2)) for professional/home mixed use. Patients were treated with both active, functioning devices and placebo devices identical to the functioning ones but therapeutically inactive. The therapeutic protocol involved 7 applications of vibration therapy: the first and last applications were performed by a specially trained operator (G.S.) at the clinical gnathology department; the remaining 5 were carried out at home by the patient.

A single operator (G.S.), blinded to the diagnosis and symptoms of patients, carried out the distribution of the devices and provided patient instruction on correct methods of use; all patients were given the same instructions for home use following the indications provided by the manufacturer. Patients used the active or placebo device for 5 days for 16 minutes a day.

The symptoms evaluated for all patients were joint pain, muscular pain (masticatory muscle pain), and headache (attributed to TMD). Each type of pain was measured at the following times:

(i) T0 : before treatment

(ii) T1 : after the last application (7 days after T0)

The 0–100 visual analogue scale (VAS) was used to measure pain self-assessment, with 0 indicating "no pain" and 100 "the worst imaginable pain."

At the end of treatment (T1), all patients were given a questionnaire regarding their impression of the treatment's effectiveness: Patients' Global Impression of Improvement (PGI-I) Scale (Figure 2).

In order to perform a comparative data analysis of the active and inactive devices, all participants were subsequently divided into two groups: a study group (AG) that received active devices and a placebo group (IG) that received inactive devices.

The primary outcome of the study was to evaluate the change in perceived pain levels after one week of local vibration therapy in the group that received active devices (AG) and in the group that received placebo devices (IG).

2.3. Local Vibration Device and Application Procedure. The device used was the NOVAFON Pro Sk2/2 (NOVAFON GmbH, Weinstadt).

This direct current electromedical device consists of a switch with two levels to adjust the intensity of the vibration produced (50/100 Hz); a handpiece to modify the power of the vibration; spherical and disc-shaped extra oral heads (means of stimulating the skin and mucous membranes); and an extension clamp (Figure 3(a)).

Two different application modalities were applied on both sides of the face to the masseter (deep and superficial) and temporal (anterior, middle, and posterior) muscles and to the TMJ [1], for a total of 16 minutes per day (Figures 3(b) and 3(c)):

(1) Use of the disc head on button 2 (50 Hz) for 4 minutes/side. The device was used with moderate pressure and rotational movements along the masseter and temporal muscles. The disc surface allows for greater dispersion of vibratory stimulation, with the aim of relaxing the musculature.

(2) Use of the spherical head on button 1 (100 Hz) for 4 minutes/side. The device was used with moderate pressure and punctual movements localized on patients' most painful areas along the masseter and temporal muscles and temporomandibular joint. The spherical surface concentrates vibratory stimulation

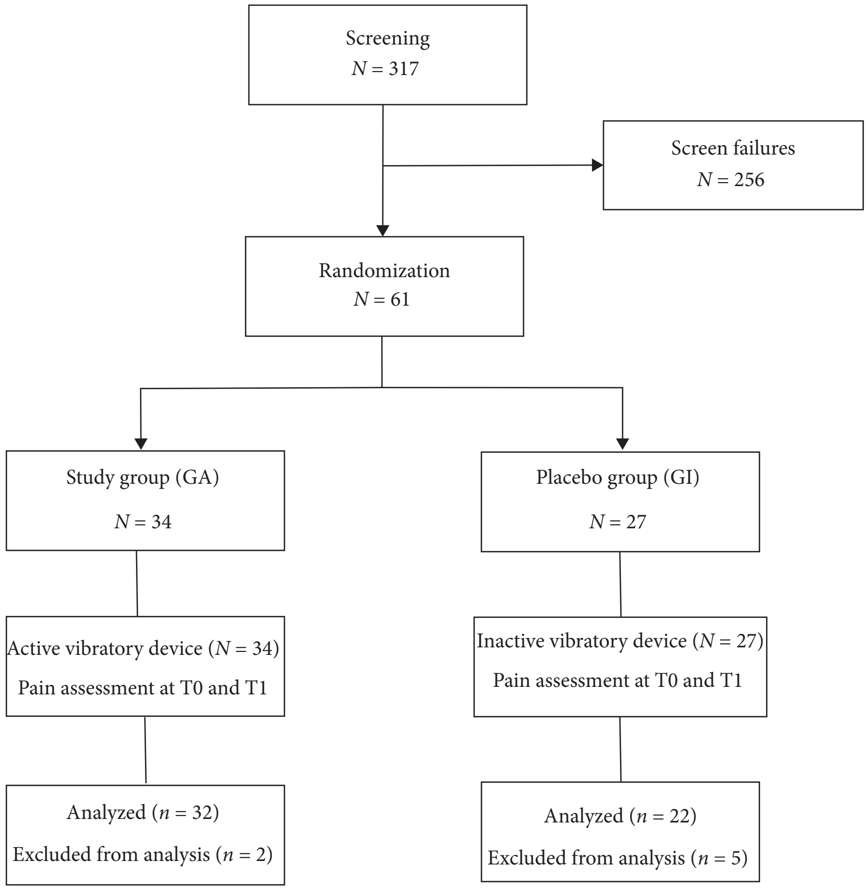

Figure 1: CONSORT flow diagram of patient enrollment and interventions.

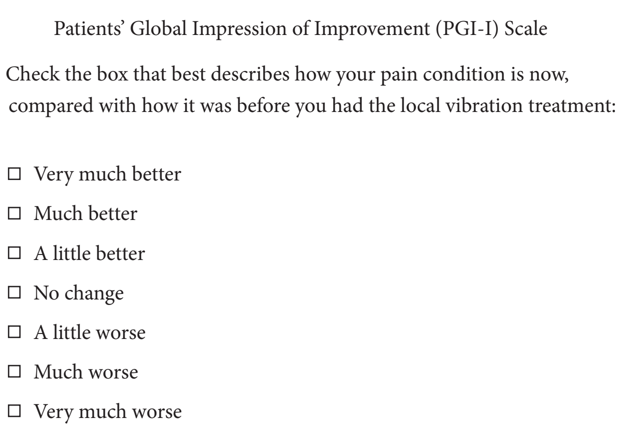

Figure 2: PGI-I Scale used to evaluate patients' impression of improvement.

on a smaller surface, with the aim of resolving muscle contractures and reducing myalgia.

2.4. Sample Size Estimation and Randomization. Since there were no data available from other clinical studies about the application of this kind of vibratory stimulation for TMD-related pain, patients were recruited using convenience sampling.

All local vibration devices (active and inactive) were randomly assigned to the study population using a random number generator (Research Randomizer©).

We used a total of 10 devices received from the manufacturer, 5 active and 5 inactive. These devices were delivered to patients by a single operator (G.S.); 34 active and 27 inactive devices were assigned over the course of the study. The devices showed the same exterior and functional characteristics. Neither the patients nor the operator knew which devices were active.

2.5. Statistical Analysis. Data analysis was performed with SPSS (version 23) statistical processing software. To assess whether there were significant differences in the pain levels (joint pain, muscular pain, and headache) of AG and IG patients at T0 and T1, a paired samples t-test was performed (statistical significance for $P < 0.05$).

3. Results

From the expected sample of 61 suitable patients, 7 were excluded for not carrying out the therapy according to the planned treatment modalities (Figure 1).

The resulting study sample therefore consisted of 54 patients; the characteristics of all study subjects are shown in Table 1.

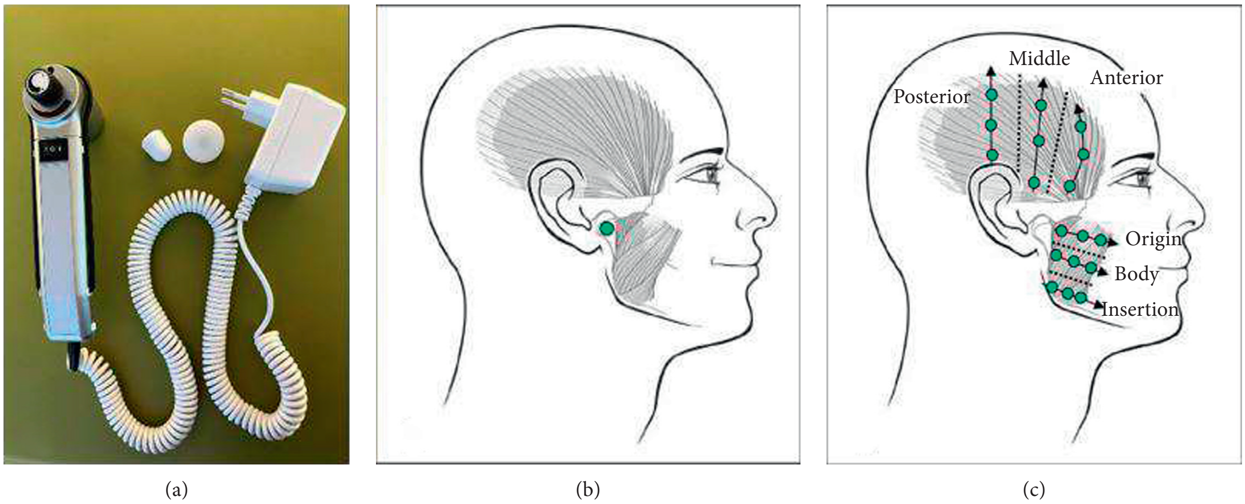

Figure 3: NOVAFON Pro Sk2/2 (a); application points used at the (b) temporomandibular joint; (c) masseter muscle and temporalis muscle.

Table 1: Characteristics of the study population.

Variable	Study group (AG), $N = 32$	Placebo group (IG), $N = 22$	Total, $N = 54$
Gender, no. (%)			
Female	24 (75.0)	19 (86.4)	43 (79.6)
Male	8 (25.0)	3 (13.6)	11 (20.4)
Age, mean (SD)	39.8 (9.9)	41.1 (9.9)	40.7 (9.9)

We found no significant differences comparing male and female subjects. Results for the group that carried out the therapy with active devices (AG) show a decrease between T0 and T1 in average values of all types of pain considered, with a statistically significant difference for TMJ pain, muscle pain, and headache. Results for the group that performed the therapy with inactive devices (IG) show a decrease in average values of muscular pain and an increase in the average values of TMJ pain and headache. In comparing data between the start (T0) and end of therapy (T1), Student's *t*-test was not significant for TMJ pain and muscular pain (Table 2 and Figure 4).

3.1. Device-Placebo Comparison. The Student's *t*-test analysis of the decrease in relative average pain values between patients who performed active and inactive therapy at T1 did not show significant results for TMJ pain, muscular pain, or headache ($P > 0.05$).

3.2. Treatment Effectiveness (PGI-I). The results of patients' self-evaluations of treatment effectiveness using the PGI-I Scale are shown in Figure 5.

4. Discussion

This is the first study involving application of a local vibration device directly at the level of the joint area and masticatory muscles (masseter and temporalis) in order to evaluate the effectiveness of local vibration therapy for reducing TMD-related joint/muscular pain and headache.

The subjects of the group who underwent active local vibration therapy (AG) reported a significant decrease in average values of TMJ pain, muscular pain, and headache. Furthermore, there were no significant decreases in average pain values for patients in the study group that received placebo therapy with inactive devices (IG); these patients reported an increase in TMJ pain and headache that was statistically significant for the latter with respect to the initial pain level.

The choice to use vibratory stimulation in dysfunctional patients was based on evidence from previous studies showing the effectiveness of local vibration therapy in reducing chronic musculoskeletal pain and in delaying the onset of muscular pain [10, 11]. Several studies have shown that vibratory stimulus is capable of exciting afferents in both the Pacinian corpuscles and in the receptors of the skin, periodontium, muscle spindles, and tendon organs [15–17]. Moreover, from the gate control theory, we know that these sensory afferents can interact with the pain transmission pathways at the spinal level, causing modulation in response to the pain sensation [15, 18, 19]. All these mechanisms may contribute to the symptoms decrease observed in dysfunctional patients undergoing vibratory therapy in this study.

The pain symptomatology afflicting temporomandibular disorder patients is very complex and often invalidating, and it demonstrates a tendency to become chronic when there is no timely therapeutic intervention. There are several therapeutic strategies for relieving TMD-related pain, but only two studies evaluated the possible application of vibratory

Table 2: Average values of perceived pain in AG and IG.

	Study group-AG mean (SD)			Placebo group-IG mean (SD)		
Pain (VAS)	T0	T1	P value	T0	T1	P value
TMJ	53.33 (6.17)	44.33 (7.37)	0.0053*	54.54 (21.15)	55.45 (20.18)	(NS)
Muscular	52.00 (26.70)	31.00 (21.75)	7.0223E–06**	41.82 (22.28)	40.00 (19.49)	(NS)
Headache	45.33 (29.88)	22.33 (24.31)	1.3521E–05**	8.18 (14.01)	10.91 (18.68)	0.0407*

*$P < 0.05$ and **$P < 0.001$ in the difference T0–T1.

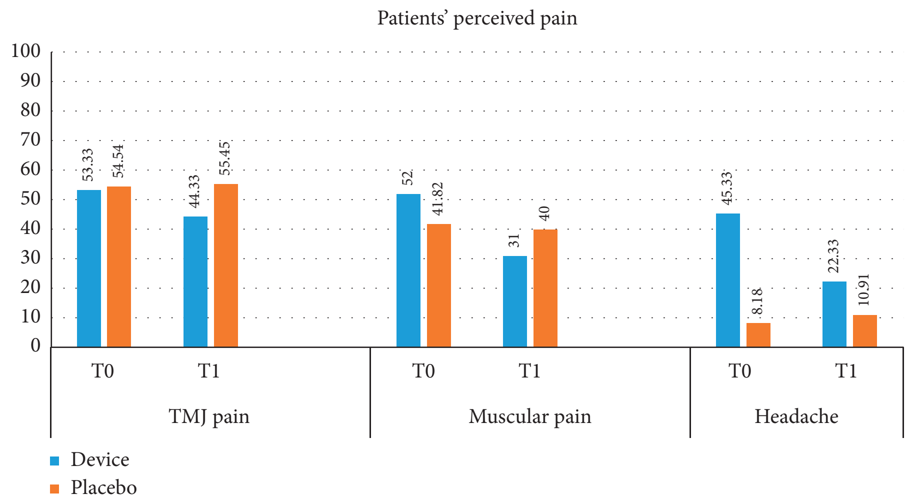

Figure 4: Average values of perceived pain in AG and IG at T0 and T1, according to VAS.

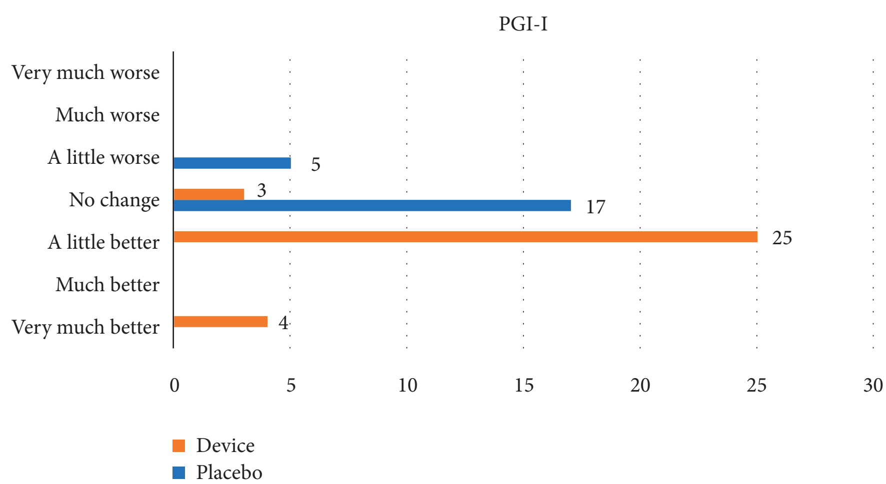

Figure 5: Patients' impression of the effectiveness of treatment according to the PGI-I Scale.

stimulation, and both report results in line with those obtained by our research.

Roy et al. [12] investigated the effect of vibrotactile therapy on resolution of chronic temporomandibular pain for a sample of 17 patients through the use of a stimulator that emitted vibrations of 20 Hz and 100 Hz. The results show the validity of this therapy in relieving TMD-associated pain, with a greater effectiveness at 100 Hz than 20 Hz for reducing muscular pain. Hara et al. [13] examined the analgesic efficacy of vibratory stimulation of an occlusal splint for a sample of 10 patients. The results highlighted significant variations in pain values on the VAS scale and on palpation, indicating the efficacy of the device in resolving TMD-related muscular pain.

In light of this evidence, the type of the device we used is particularly versatile, since it allows for daily home use for short periods and the possibility of extraoral application near the location of the pain. Patients who underwent therapy with an active device mostly reported an improvement in their pain condition and had no notable difficulty in following the home prescription. The extraoral application of the therapy also presents the additional advantage of being able to be applied in concomitance with the conventional therapy of occlusal splints, for patients needing mechanical support. Our study results reinforce the evidence that local vibration therapy is most effective for muscular and tension pain, such as local myalgia and headache. Our results regarding decrease in TMJ pain, however, also suggest that this therapy is able to resolve strictly articular problems. From this perspective, local vibration therapy could be a valuable addition to complement other conservative therapies.

This study also presents several limitations. First, despite the positive results obtained, the patient sample examined is still too limited to represent reliable and significant results regarding the efficacy of NOVAFON Pro Sk2/2 in reducing TMD-related symptoms. We see evidence of this limitation in the statistical nonsignificance, despite the encouraging clinical decrease of symptoms, of the compared average pain values between AG and IG at the end of therapy (T1) (with significance threshold set at 5%). Having noticed values close to the aforementioned significance threshold and in light of the limited sample size, the same test was carried out with an increased significance threshold of 10%. The results obtained from the second test show a significant difference regarding TMJ pain and headache with a P value of 0.08 and 0.06, respectively. To address this limitation and obtain more reliable results, the study sample is currently being expanded.

Second, the results obtained correspond to a single week of therapy, while prolonged evaluation, extending beyond the completion of therapy (follow-up), is necessary. Finally, pain assessment in this study was limited to patient self-assessment, but the importance of using multiple methods of pain assessment, given the complexity of changes this symptom can undergo during experimental procedures, has been well documented [20, 21].

5. Conclusion

Local vibration therapy is a valid support tool in the control of TMD-related familiar muscular pain. The extraoral application method is versatile, easy to apply, and integrates well with other conservative therapies; it is also useful for increasing patient compliance with other rehabilitation treatments. Moreover, this therapy offers the advantage of being performed at home by the patient, in different therapeutic moments, allowing the clinician greater possibility for treatment individualization.

Further studies are needed, however, to confirm the results obtained with larger samples and to include the short/long-term follow-up.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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Review Article

Diagnosis of Temporomandibular Disorders Using Thermovision Imaging

Monika Machoy,[1] Liliana Szyszka-Sommerfeld,[1] Mansur Rahnama,[2] Robert Koprowski,[3] Sławomir Wilczyński,[4] and Krzysztof Woźniak[1]

[1]*Division of Orthodontics, Pomeranian Medical University in Szczecin, Powstańców Wielkopolskich Street 72, Szczecin 70-111, Poland*
[2]*Department of Oral Surgery, Medical University of Lublin, Karmelicka Street 7, Lublin 20-081, Poland*
[3]*Institute of Biomedical Engineering, Faculty of Science and Technology, University of Silesia in Katowice, Bedzińska 39, 41-200 Sosnowiec, Poland*
[4]*Department of Basic Biomedical Science, Faculty of Pharmaceutical Sciences in Sosnowiec, Medical University of Silesia, Będzińska Street 39, Sosnowiec 41-200, Poland*

Correspondence should be addressed to Monika Machoy; m.machoy@gmail.com

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Temporomandibular joint dysfunction (TMD) is a chronic disease of various etiologies. Correct TMD diagnosis enables to apply effective treatment and significantly improves the quality of patients' lives. One of the diagnostic methods subjected to evaluation in recent years is thermography, which enables safe, noninvasive, and quick imaging of the temperature distribution of temporomandibular joint-associated tissues. This paper, based on Medline, Dentistry & Oral Sciences Source, Academic Search Ultimate, Medline Complete databases, presents basic information related to thermovision imaging and outlines the direction of research conducted in recent years which fight with difficulties in the interpretation of thermograms that require specialized, dedicated analysis and processing of the obtained images. The problem concerns also no standardized protocol for measuring masticatory muscle temperature.

1. Introduction

Temperature is one of the basic state parameters, determining in thermodynamics the mean kinetic energy of the molecules making up a given system. Temperature can be strictly defined only for thermodynamic equilibrium distates, i.e., stable body temperature or its equalization between two bodies. In medicine, a temperature increase (*calor*) is one of the basic, in addition to redness (*rubor*), swelling (*tumor*), and pain (*dolor*), signs of tissue inflammation, defined by Aulus Cornelius Celsus before 50 AD. Since the beginning of the development of medical diagnostics, *calor*, as the most basic and noticeable feature of an ongoing disease process, has been subjected to analysis and the results of interpretation have been objectified according to the possibilities of contemporary science. The first thermometers created around 200 BC in the ancient cradles of culture and science, namely, Byzantium and Alexandria used the phenomenon of thermal expansion of gases to measure temperature. Galileo also used this phenomenon to create his thermoscope around 1600 [1].

During the centuries that followed, there arose new concepts for thermometers and their construction as well as measurement methods, differing in terms of the type of physical phenomena and sensors used. The measurement of the electrical voltage at the contact of two metals by assessing the changing thermoelement resistance was used (thermocouple method). Moreover, diode, liquid, magnetic, resistance, pyrometric, and other thermometers were created [2]. Electronic thermometers, including those based on the detection of invisible energy of the electromagnetic waves of the wavelength ranging from 7 to 14 μm, were developed after mechanical thermometers. The human eye receives only a small part of the electromagnetic spectrum [3]. In addition to visible rays, the spectrum of electromagnetic radiation includes gamma rays, X-rays, ultraviolet rays, infrared rays, microwaves, and radio waves. Infrared radiation (IR) is produced by all objects with temperatures above absolute zero, including warm-blooded living organisms. The rapid development of technology in the field of infrared radiation measurement and its conversion into a visible image led to the emergence of a new technique called thermography [4]. IR emitted or reflected from warm objects is registered by a detector (thermal or photonic). The thermal imaging camera lens focuses infrared radiation on the surface of a matrix consisting of infrared sensors. The matrix sensors react to the absorption of IR radiation by changing one of the system parameters, e.g., pressure, polarization, resistance, and temperature, and then they are transformed into an image. As a result, thermovision provides images reflecting the physiological processes of living organisms by observing the temperature distribution on the external surface of the examined system without the need for any contact [4, 5]. The use of the term "observation of the temperature distribution on the external surface" not only narrows the area of research to the properties of that surface but also has deeper implications, especially if the observed system is a living organism [6]. Thermal heterogeneity, e.g., on the surface of the skin of the face, largely depends on the blood flow and the type of tissue directly underneath it. Thus, the skin surface above the muscle tissue, which is characterized by high metabolic activity, emits more heat radiation than the skin covering the bone or connective tissue. Therefore, thermography visualizes the thermal properties of tissues in a similar way as radiology illustrates their anatomy [4–7].

The advantages of thermography are noninvasiveness, asepsis, which is extremely important in medicine, the lack of ionizing radiation, and the relatively low cost of testing [8], and many specialties were used in medical diagnostics, mainly dermatology—through the possible analysis of changes in skin temperature [9], obstetrics and gynecology [10], neurology [11], oncology [12, 13], pediatrics [14], ophthalmology [15], orthopedics [16], forensic medicine [17], acupuncture medicine [18], cardiology [19], transplantology [20], and dentistry [21]. The advantages of the thermovision have also contributed to the introduction of this method into the diagnosis of temporomandibular dysfunction [4, 22–33].

Temporomandibular disorders (TMDs) are a collective term covering a number of clinical issues affecting the masticatory structures (muscles), the temporomandibular joint (TMJ), and associated tissues. Different types of TMD can be distinguished. Pain-related temporomandibular disorders (TMD-P) are the most prevalent conditions among TMD. The primary manifestations of TMD-P are pain of a chronic nature in the masticatory muscles and temporomandibular joint and pain projection in adjacent structures such as skin and fascia. The other characteristic symptoms include limitations in the range of mandibular motion and crackling joint noises [34, 35]. The pain frequently radiates to the dental arches, molar teeth, ears, temples, forehead, occiput, cervical region of the spine, or shoulder girdle. TMD causes a reduction in mouth opening as well as discomfort and pain during chewing. Among the chronic diseases that cause facial pain, this dysfunction occurs in different decades of life, but mainly in adulthood [36, 37]. The etiology of TMD is multifactorial—occlusal, anatomical, emotional, and behavioral causes are distinguished [38–45]. One of the most frequent symptoms in multifactorial TMD is orofacial pain. Orofacial pain is defined as a pain manifested in the face or oral cavity, including such disorders as TMD, which are a major cause of nonodontogenic orofacial pain [37]. Such pain can affect ears, eyes, and/or throat, producing neck pain, facial pain, and headaches [46]. Pain is an exclusive, complex experience for each person. The nociception depends on factors such as cultural differences, previous pain experience, knowledge, learned behavior, and expectations that may contribute to the individual response to pain [47]. The International Association for the Study of Pain provides the following definition of pain: "an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage" [48].

The first attempts of imaging with the TMD thermal imaging camera were made in the mid-90s of the last century. Attempts have been made to analyse and compare the temperature of the temporomandibular joint area with the clinical symptoms of patients [27], thermographic characterization of internal derangement of the temporomandibular joint [49], diagnostic tool for arthralgia of TMJ [50], asymptomatic TMJ [32, 33], and degenerative joint disease [51]. Due to hardware and procedural limitations, these tests can be described as recognizing the topic and possible applications. With the current technological progress and the development of biomedical imaging, it was justified to analyse the latest research evaluating the possibilities of using the latest thermal imaging cameras in the routine diagnosis of a temporomandibular joint.

2. Materials and Methods

The article analyses English-language research from the PubMed/Medline, Dentistry & Oral Sciences Source, Academic Search Ultimate, Medline Complete databases. Since the authors wanted to present the latest achievements and the possibility of using thermography in the diagnosis of the temporomandibular joint, articles were selected that were published within no earlier than 5 years. Only the PubMed database gave satisfactory searching results. The inclusion criteria were research and review articles not older than 5 years, focusing on temporomandibular disorders diagnosed with help of thermovision. Exclusion criteria were articles out of date. There are few articles concerning the topic, so the authors could not use strict exclusion criteria. The search phrases were "TMD and thermovision," "temporomandibular disorders and thermovision," "TMD symptoms and thermovision," "TMD and thermal diagnosis," "temporomandibular disorders and thermal diagnosis," and "TMD and thermo".

The end date of the search was June 2020. 18 articles meeting the above criteria were found; they were research articles, carried out on adult patients of both sexes.

2.1. Thermovision as a Diagnostic Tool in TMD. In the years 2014–2019, only a few papers were published examining the possibilities of using a thermal imaging camera in the effective diagnosis of temporomandibular joint dysfunction. In the paper by Woźniak et al. [35], sensitivity, specificity, and accuracy of thermography in identifying the degree of dysfunction in patients were assessed. Both facial and neck thermograms were taken using the right and left side projections under constant test conditions. Automatic calibration tools were used during the tests, which enabled to optimize both the level and range of displayed temperatures, and the color palette and the highest contrast in all image areas. Quantitative analysis of thermograms was carried out in selected areas of the face and neck, which were marked with tools in a 1 cm diameter circular area. Due to the possibility of displacement of individual thermograms of the examined subjects, each image was analysed individually and corrections were made if necessary. Despite such a thoroughly conducted methodology and a large study group, based on imaging, it was possible to identify patients only without joint dysfunction in 95.5% of cases. The rest of the results did not allow for precise diagnosis. Thermographic scans from the carried out tests are provided in Figures 1–3 with the consent of the authors.

However, it should be noted that skin surface temperature changes are not a TMD-specific symptom. Also, other diseases including skin diseases can cause a local temperature increase. In the present case, a significant element indicating TMD was the symmetrical occurrence of changes on both sides of the face as well as the specific location of local temperature changes. Nevertheless, thermography alone cannot be treated in this case as a diagnostic tool with high sensitivity and specificity, and thermographic examination should be supplemented with subjective and physical examinations. An additional prognostic factor which was not included in the publication of Woźniak et al. [35] could be the use of dynamic thermovision analysis. In this case, a factor provoking inflammation and/or pain in the temporomandibular joint should be used, and then, the temperature rise should be recorded. Such a factor could be, for example, chewing food.

Also, the research by Barbosa et al. [52] defined the infrared thermography as a rather difficult tool to differentiate TMD because of no significant association between the presence of temperature and pain asymmetry. The main conclusion of the research was that the use of infrared thermography in a day-by-day clinical environment may not be as easy as it seems. The standardization of all protocols needs to ensure that all possible thermal changes related to the image acquisition room and patient's habits do not interfere with the image data acquisition. It is very hard to replicate it in a dental clinic. The image acquisition room must have a perfectly controlled room temperature, and a limited number of staff members should be allowed in the room. The surface temperature of the skin can also be affected by, among others, the day of the menstrual cycle for women, taking hot or spicy dishes, and emotional state. The patient must follow meticulously the professional's instructions for image acquisition, avoiding hot beverages, hot baths, exercises, and other activities or substances that can affect their microcirculation before infrared thermography image acquisition [52].

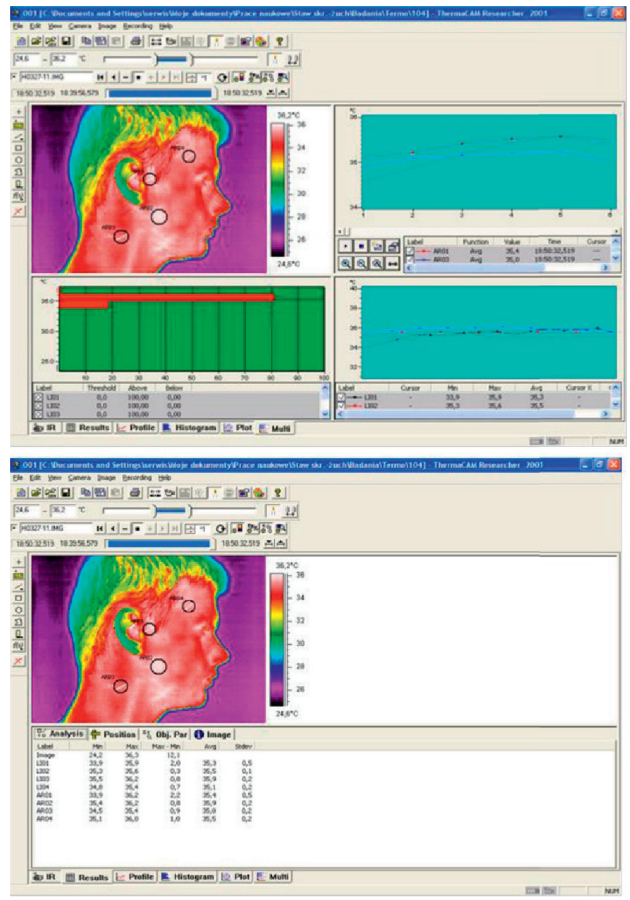
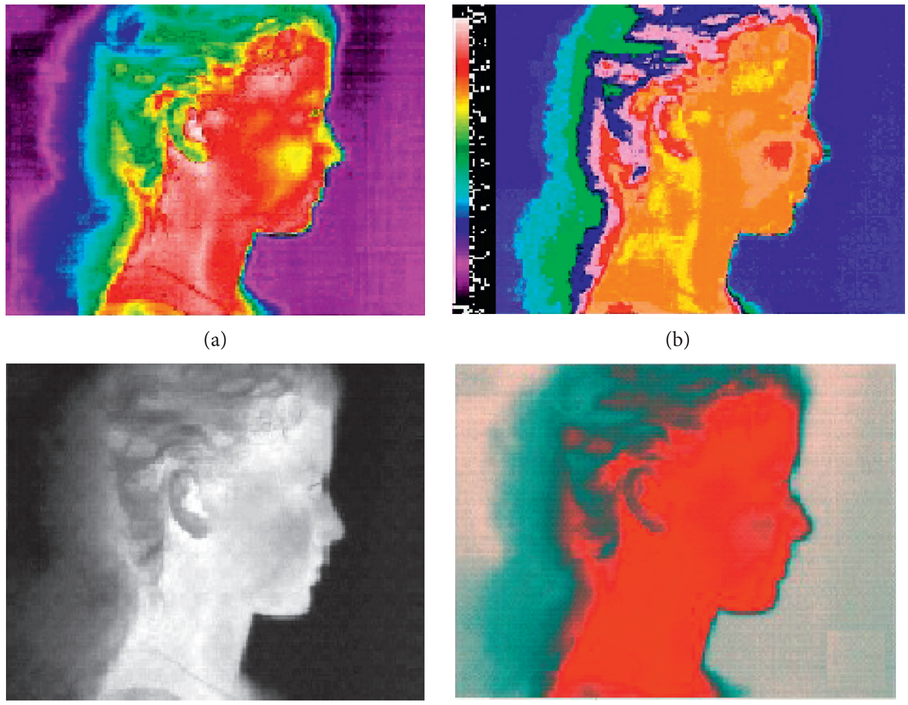


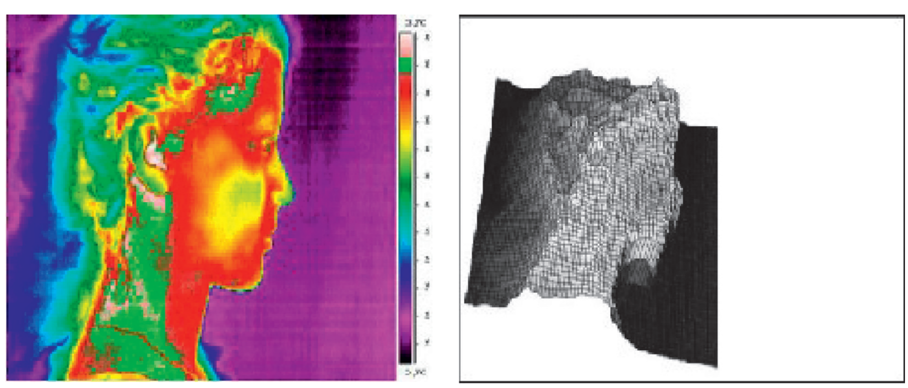
Figure 1: Location of the analysed areas of thermograms in the ThermaCAM Researcher program with measuring window and measured temperature of the exact points.

The thermal imaging camera was also used to visualize TMD in two professional musicians—a violinist and a clarinettist—in whom it was possible to assess temperature changes in various parts of temporomandibular joint-associated muscles, under the influence of occlusal splint therapy [53, 54]. A clinical trial showed internal disorders of both joints, osteoarthritis with prior displacement of the articular disc. The analysed thermograms confirmed the existence of a temperature difference at the level of the front part of the temporal muscle, the joint itself, and the masseter muscle. Thermography also confirmed the effectiveness of occlusive splint therapy by visualizing the temperature drop of given anatomical sites, which indicates a reduction in inflammation that was reported by patients as reduced discomfort. One of the conclusions of the publication was



(a) (b) (c) (d)

Figure 2: The use of different color scales in the evaluation of thermograms. (a) The "rain" scale enables an accurate analysis of the temperature distribution due to the large range of colors. (b) "Iron" scale enables the blurring of isotherms due to a smaller color range. (c) "Medical" scale enables contrasting color separation in qualitative analysis of thermograms. (d) "Gray" scale enables accurate analysis of temperature distribution based on intensity luminance.



(a) (b)

Figure 3: The use of tools: (a) isotherms enabling the determination of areas with the same temperature and (b) 3D visualization algorithm for three-dimensional analysis of the presentation of thermographic results.

the need to use thermovision techniques in dentistry, which would enable to prevent overloading of certain anatomical structures owing to the early diagnosis of degeneration and its proper monitoring. Therefore, thermographic imaging may not only be a relatively effective diagnostic element, but nevertheless require supplementation with subjective and physical examinations, but may also be used to assess the effectiveness of treatment. Temporomandibular dysfunction therapy should lead to a reduction of inflammation which will result in a change in temperature on the skin surface. However, it should be taken into account that also other drugs not used in TMD may affect the result of such examination. These are, e.g., nonsteroidal anti-inflammatory drugs and glucocorticosteroids. These drugs, used by the patient in other indications, can disturb the temporomandibular joint disorder thermovision image by temporarily reducing inflammation and thus affecting local tissue temperature increase.

In the study by de Melo et al. [55], the possibility of TMD therapy using occlusal splints or low-frequency lasers was compared and evaluated. The clinical results of the treatment were analysed using thermography. Based on them, it was found that both methods were effective in reducing myofascial pain syndrome. Taking into consideration the thermographic data, it was found that the use of lasers can provide more favourable results because lower temperatures within the masseter muscles were visualized in the described study group. The result of the experiment shows the possibility of using a thermal imaging camera as a tool to refine the results of treatment effects already observed clinically. In addition, in the case of nonpharmacological therapies that use physical methods such as laser therapy, thermovision can be useful not only to assess the effectiveness of treatment but also to assess the extent of inflammatory changes. Therefore, it is possible to thermographically precisely mark the inflamed place and to irradiate the laser with that exact place.

The topic of treatment of temporomandibular joint diseases with the help of occlusal splints and evaluation of their effectiveness using thermographic techniques was also discussed in an older, but worth mentioning article by Valentim Adelino Ricardo Bara ẽt al. published in 2010. It was aimed to evaluate the effect of occlusal splint treatment on the temperature of the whole group of muscles that are part of the masticatory system such as masseter (inferior, intermediate, and superior), anterior temporal, digastric, and trapezius muscles in patients with temporomandibular disorder. The patients were diagnosed with muscular TMD by clinical examination, and occlusal splints were inserted in all patients with a weekly follow-up. The superficial thermography on both sides of the muscles was performed using a digital thermometer in a controlled temperature room. This procedure was performed before occlusal splint insertion and after the completion of the treatment. After occlusal splint treatment, a significant increase in temperature was observed in each muscle, both on the right and left sides. When the muscles were compared in the same period of treatment, there was no significant difference among them which shows that the use of occlusal splint promoted a significant increase in the muscles temperature and that there was symmetry in the temperature of muscles on the right and left sides both before and after the treatment. The authors concluded that the results of the research are useful from the clinical point of view, and they show that thermographic visualization is beneficial not only in determining both activity and progress of the disease, which is a very similar conclusion as in previously mentioned articles [53, 54], but also in monitoring the progress of the treatment [31]. Barão VA et al. tested patients being treated for TMD by occlusal splints. Each patient was examined before treatment, and each temperature analysis was performed twice in each measurement time, two times before occlusal splint treatment and two times after treatment. A mean value of the two measurements was calculated. In all temperature measurements, the thermometer was positioned at 10 mm from each muscle surface. Thermography was performed before and after occlusal splint treatment. The follow-up of patients was 3.2 ± 1.01 months. Thermography was a sufficient tool to state a conclusion that occlusal splint therapy statistically increased the temperature of three parts of the masseter muscle (inferior, intermediate, and superior), anterior temporal, digastric, and trapezius muscles in patients with muscular temporomandibular disorder and also that there was a symmetry in the temperature of muscles on the right and left sides both before and after the treatment. The possibility of monitoring the progress of the treatment by using thermovision confirmed the research of de Melo et al. after years of research. Importantly, with the help of thermography, it can be visualized which muscles have an elevated temperature in the course of TMD, which can be used, among others, for treatment planning, including orthodontic treatment. The specific jaw setting through orthodontic treatment will affect selected muscles and muscle groups, and thus, the therapy method can be optimized based on imaging data so as to most effectively affect those muscles or their fragments whose temperature is the highest [55].

The study by Dibai-Filho et al. [56] aimed at assessing the correlation between TMD severity and the skin temperature above the temporomandibular joint (TMJ), masseter muscles, and anterior temporal muscle fibers. Cross-sectional studies were performed on a large group of patients, 60 women aged 18–40 years. The patients were assigned to groups based on the Fonseca Anamnestic Index (FAI): no TMD, mild TMD, moderate TMD, and severe TMD ($n = 15$ each). For each patient, the skin temperatures in the joint area, the masseter muscle, and the anterior temporal muscle were identified. It was found that the temperatures within the joint were statistically significantly higher within the group of patients with severe TMD symptoms. A similar group of patients consisting also only of women was examined by Haddad et al. [57]. The study conducted measurement of the cutaneous temperature of selected masticatory muscle regions of volunteers with and without myogenous temporomandibular disorder (TMD), using infrared thermography. The temperature levels measured at the masseter and anterior temporalis muscle regions in myogenous TMD volunteers were surprisingly significantly lower than those measured in controls, which is quite the opposite of all other presented research. The sensitivity and specificity of the thermographic assessment for the masseter region were 70% and 73%, respectively, and for the anterior temporalis region were 80% and 62%, respectively, but the study group was very small, the research was treated as a small-scale preliminary study, and therefore, to confirm these puzzling conclusions, it would be necessary to carry out the same research methodology on a much larger group of respondents, thus enabling the drawing of reliable, statistically significant conclusions.

A study of Magalhães et al. [58] noticed that joints and muscle disorders assessment and diagnosis methods require palpation or the application of certain forces on the skin, which affects the structures beneath which can be a possible influence on skin temperature. The aim of the experiment was to determine the ideal time for performing thermographic examination after palpation based on the assessment of skin temperature evolution. They concluded that infrared thermography can be used after assessment or diagnosis methods focused on the application of forces on tendons and muscles, provided the procedure is performed 15 minutes after contact with the skin. Regarding the myofascial trigger point, the thermographic examination can be performed within 60 minutes after the contact with the skin.

3. Conclusions

In the last 5 years, only a few studies using a thermal imaging camera in the diagnosis of temporomandibular joint dysfunction have been published. This is probably due to the difficulties in the interpretation of thermograms, which require specialized, dedicated analysis and processing of the obtained images. There is no standardized protocol for measuring masticatory muscle temperature using infrared imaging. This causes difficulties in implementing thermovision analysis as a standard diagnostic clinical procedure. To date, there are no objectified computer analytical tools, which would enable doctors to draw conclusions from the obtained images. Among the presented papers, only a few included sufficiently large study groups [34, 56], which made it possible to obtain statistically significant results. In the next two papers [41, 42], the authors studied individual cases, so they can be treated only as an indication of the problem for other researchers.

Importance should be accorded also regarding the choice of the selected software, in order to delimit an accurate, representative area of the region in question. Rodrigues-Bigaton et al. [30] used linear tools and a square area positioned along the masseter and anterior temporal muscles in order to check the mean temperature and correlation with regard to the diagnosis of myogenic TMD; however, none of the analytical methods was consistent and satisfactory [56].

Regardless of the analytical difficulties encountered, the described diagnostic method is worth further development. As a noninvasive technique, it does not pose any danger during in vivo tests and requires mainly patience and time from the person performing the test and the examined subject. It may result in minimizing the costs of measuring equipment, introducing it to dental offices and orienting it towards a standard screening tool for the occurrence of temporomandibular joint dysfunction [30, 57–65].

Further interest in thermography should be expected, primarily due to its zero invasiveness, speed of testing, and continuous development of thermal imaging cameras. Not only a sharp increase in the spatial resolution of cameras is observed which enables the possibility of imaging even with a resolution of 1080p but also a thermal resolution of even 0.001 K. In addition, more and more cameras allow for hybridization of the image in visible and infrared light, which allows precise identification of anatomical structures affected by inflammation. Hyperspectral thermal imaging cameras can be mentioned as a very interesting direction of thermal imaging cameras development. Hyperspectral cameras recording the spectrum in a wide wave range can be used to identify very narrow spectral ranges for individuals, perhaps not only to assess the skin temperature on its surface but also by using appropriate algorithms for analysis and processing of temperature assessment images in 3D of inflamed tissues [21, 66, 67].

However, attention should also be paid to the limitations of the thermovision method. These are primarily the need to control the measurement conditions, difficulties with complete objectification of the results—the impact of factors such as the patient's emotional state on the results obtained, and the lack of analytical tools that would allow for repetitive, fast, and objective analysis of data by a doctor in a dental office environment.

Nevertheless, despite these limitations, thermographic imaging can be a very interesting and useful tool in the diagnosis and assessment of the progress of TMD therapy.

Disclosure

The research was performed as part of the employment of the authors mentioned in Pomeranian Medical University, Medical University of Lublin, Silesia Medical University, and Silesia University.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Catastrophizing Has a Better Prediction for TMD Than Other Psychometric and Experimental Pain Variables

Lisa Willassen,[1] **Anders Arne Johansson**,[1,2] **Siv Kvinnsland**,[1] **Kordian Staniszewski**,[1] **Trond Berge**,[1,2] **and Annika Rosén**[1,2]

[1]*Department of Clinical Dentistry, University of Bergen, Bergen, Norway*
[2]*Department of Oral and Maxillofacial Surgery, Haukeland University Hospital, Bergen, Norway*

Correspondence should be addressed to Annika Rosén; annika.rosen@uib.no

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Temporomandibular disorders (TMDs) are characterized by moderate to severe pain in the masticatory muscles and/or the temporomandibular joint (TMJ). The present study is a part of a multidisciplinary project, initiated by the Norwegian Ministry of Health. The main purpose of this study is to compare a cohort of TMD patients to healthy individuals regarding experimental pain, the degree of disability caused by living with pain and psychometric variables, and to investigate which of these variables is the best predictor for TMD patients. We hypothesised that TMD patients have more disability when living with pain and lower pain thresholds than healthy controls, and those psychometric variables are stronger predictors than pain thresholds provoked by experimental pain. Sixty TMD patients were matched by sex and age to sixty healthy individuals without TMD symptoms or other musculoskeletal symptoms in the head and neck region. All subjects completed a questionnaire that included psychometric characteristics, that is, a one- and two-item version of the Pain Catastrophizing Scale, the Hospital Anxiety and Depression Scale (HADS), and the Roland Morris Scale (RMS), which measures disability when living with pain. They also underwent a clinical examination including the measurement of pain thresholds with electrical and pressure stimuli. The TMD patients had lower pain thresholds for experimental electrical and pressure stimuli compared with the controls ($P < 0.05$ and <0.001, respectively). They also scored higher than healthy individuals with disability living with pain ($P < 0.001$), anxiety ($P < 0.001$), depression ($P < 0.001$), and catastrophizing ($P < 0.001$). The results for anxiety, depression, and catastrophizing have been published earlier, and the reused data in this study are compared with RMS and pain thresholds. The conditional logistic regression model identified catastrophizing (OR = 2.42, CI 1.22–4.79) as a significant predictor of TMD patients. The results support this hypothesis and indicate that TMD patients have lower pain thresholds and more disability when living with pain compared to healthy individuals, where the strongest prediction for TMD was catastrophizing. Awareness of psychometric disabilities in TMD patients is of importance when considering the choice of treatment.

1. Introduction

The conditions that cause pain and/or dysfunction of the temporomandibular joint (TMJ) and muscles that regulate jaw movements are collectively known as temporomandibular disorder (TMD). In a TMD population, the disorder is assumed to be at least three times as common in women as in men [1], while in the general population, TMD is assumed to be two times as common [2]. The overall prevalence in the general population is around 3% to 12% among 30- to 50-year-old individuals [3, 4]. According to a prospective study of adults in the United States, the annual incidence of TMD onset is 4% [5]. TMD-related pain usually occurs periodically over time and can be mild, moderate, or severe. In most cases of TMD, symptoms can usually be managed with simple reversible conservative treatment [6]. However, some patients with painful TMD experience prolonged chronic pain and reduced function of the masticatory system, both of which can be treatment-resistant. Prolonged and intense TMD symptoms may have severe consequences for patients, including psychological, physical, behavioural, and psychosocial problems [1]. Patients with TMD often have impaired mandibular function, with difficulties in jaw movement such as chewing, yawning, speaking, and even kissing as the dominant problems. Comorbidities often occur, particularly general pain conditions, such as other systemic joint diseases, headaches, and ear and eye pain [1, 7, 8].

Understanding the source of pain is important for making a diagnosis and for choosing the appropriate treatment, which may be conservative, psychological, and/or surgical [9]. The pathophysiology of TMD is currently unknown, but pain amplification (abnormal pain sensitivity), central sensitisation, and changes in immune activity have been associated with TMD [10]. A prospective genetic-based study found that individuals who are more sensitive to pain have a significantly higher probability of developing painful TMD than patients who are less sensitive [11].

Sensitivity of tissues can be assessed by measuring pressure pain thresholds (PPTs) with algometry. It is a valid and reliable method used to measure the PPT in craniocervical muscles [12]. In tension-type headaches, decreased pressure pain thresholds over the craniocervical area have shown to reflect signs of the sensitisation of the trigeminocervical nucleus caudalis [13]. In the orofacial area, experimental pain, induced by pressure [14–16] or electricity [17], determines individual pain thresholds or objective pain. Pressure is used to activate mechanosensitive receptors and quantify deep muscle pain. Electricity activates non-nociceptive and nociceptive afferents, affecting tissue that is more superficial [18]. An electrical stimulus can gradually be increased, and subjects have to report when the stimulus changes from a feeling of sensation to a feeling of pain. This neurophysiological model of sensitisation of the trigeminocervical nucleus caudalis is generally presumed to play an important role in the onset and maintenance of migraine and chronic tension-type headaches [19]. Chronic headaches are common in TMD, a well-known comorbidity [7]. Previous studies have shown low pain thresholds in TMD patients in response to noxious stimuli [20–22].

Questionnaires are often used to assess self-reported symptoms such as pain (subjective pain) and psychometric status. Psychosocial factors are suggested as linked to pain-related disability and duration of pain [23]. Pain is found to be strongly associated with specific anxiety and depressive disorders [24], and the presence of anxiety and depression is found to be associated with higher muscle tenderness in patients with different types of facial pain [25]. High scores for anxiety/depression and pain catastrophizing are commonly reported in TMD patients [26–28]. Comorbid anxiety and depressive disorders are associated with disability, impairment, decreased quality of life, increased health care utilisations, and substance use in individuals with pain disorders and symptoms [24].

Patients with TMD, who will undergo TMJ surgery, may have a high risk of ultimately experiencing postoperative pain. Among the patients included in this study, seven patients underwent TMJ surgery, and only one of them was pain-free at the follow-up [29]. According to the guidelines from the International Association for the Study of Pain (IASP), patients with psychological disorders should receive treatment for such disorders prior to surgery to prevent the development of persistent postoperative pain. Such pain is more likely when preoperative pain, fear of pain, expected pain, and catastrophizing are present [30]. An earlier study assessed if preoperative psychological testing could predict the outcome after arthroscopy, and a weak statistically insignificant association was found between chronic anxiety and pain in TMD patients after surgery. However, the authors addressed the need for further studies in order to clarify the role of chronic anxiety for the outcome of TMJ surgery [31]. Currently, there exist several studies suggesting the relationship between experimental pain, psychometric variables, and TMD [5, 32, 33], but to our knowledge, few studies explore the combined significance of experimental pain thresholds/psychometric variables regarding TMD. An earlier study on the same cohort as presented in this study found higher scorings for anxiety, depression, and catastrophizing in TMD patients compared to healthy controls [34]. These psychometric data are reused in the present study in order to perform inferential analyses with new findings and execute more advanced statistical analysis.

The main purpose of this study is to compare a cohort of TMD patients to healthy controls regarding experimental pain, disability when living with pain and psychometric variables, and to investigate which of these variables was the best predictor for TMD patients. We hypothesised that TMD patients have more disability when living with pain and lower pain thresholds than healthy subjects. We further hypothesised that psychometric variables are stronger predictors for TMD than pain thresholds provoked by experimental pain.

2. Materials and Methods

Under direction from the Norwegian Directorate of Health, the Oral and Maxillofacial Surgery Department and the Clinic for Pain Treatment and Palliation at Haukeland University Hospital in Bergen, Norway, developed a multidisciplinary investigation programme for patients with severe TMD [9].

2.1. Participants. The participants in this study consisted of sixty consecutively referred patients with severe TMD and sixty age- and gender-matched healthy controls. The study groups to be characterized were set at sixty patients by the directive from the health directorate. The sixty TMD patients included in the study were referred from their general medical practitioner during 2013 to 2015 for severe TMD with long-lasting pain. The consecutively included patients were assessed for TMD with a modified DC/TMD, without using the mandatory command, which has previously been shown not to impair diagnostic reliability [35]. Inclusion criteria for admission to the programme included TMD-related pain in the orofacial area, decreased function of the jaw, and general disability because of pain. Exclusion criteria included current substance abuse or severe psychiatric diagnoses. Subjective symptoms and clinical signs were assessed by a multidisciplinary team consisting of specialists in oral and maxillofacial surgery, specialists in orofacial pain, a pain physician, a psychologist, a physiotherapist, and a radiologist. The mean duration of pain for the patients was 11 years. TMD main diagnoses comprised myalgia ($n = 22$), arthralgia ($n = 1$), disc derangement ($n = 2$), and combinations thereof ($n = 35$).

Sixty healthy age- and sex-matched subjects without symptoms of TMD were recruited to serve as a control group. The inclusion criteria for the controls were that they were age- and gender-matched to each of the participants in the patient group. The exclusion criteria included TMD symptoms and pain symptoms in the head and neck. The participants in the control group were a convenience sample selected from the Department of Clinical Dentistry at the University in Bergen. All included patients and controls signed a consent form for participating in the study before the investigations. Two different examiners assessed the groups, one for the control group and one for the TMD group. Both examiners underwent specific correlation/synchronisation training before the clinical assessments.

Recorded details for all patients were stored in their hospital medical records (DIPS). Data were collected in an anonymised form. The project was approved by the Regional Committee for Medical and Health Professional Research Ethics (2015/930/REK sør-øst).

2.2. Measurements

2.2.1. Subjective Self-Reported Measurement. All study participants completed a questionnaire, the Roland Morris Scale (RMS), and an additional questionnaire assessing general disability when living with pain [36]. RMS consists of 24 questions/claims as a measure of disability when living with chronic pain. The participants marked claims that were correct with an X (1 point for each claim; maximum score = 24 points and cut-off = 7 points).

The psychometric data from the already published study [34] included the two-item version of Coping Strategies Questionnaire (CSQ) regarding catastrophizing [37] and the Hospital Anxiety and Depression scale (HADS) [38]. The CSQ included two questions which ranged from 0 to 6 points, where 0 was the lowest score and 6 the highest score (a total of 6 + 6 points, cut-off >1 for each question). The HADS included 7 questions regarding anxiety and 7 questions regarding depression. Each question could be answered in 4 different ways, ranging from 0 to 3 points (a total of 21 points and cut-off ≥8 for each condition).

2.2.2. Experimental Pain: Assessment of Sensitivity and Pain Thresholds. To assess pain sensitivity and hyperalgesia, pressure and electrical stimuli were used. An algometer assessed pressure pain thresholds (PPTs) on the TMJ, the masseter muscle, and the finger [39, 40]. The algometer (Somedic, Hörby, Sweden) had a probe with a surface area of $1.0\ \text{cm}^2$ and a slope of 30 kPa/s. The algometer was equipped with a warning signal to prevent overload and a green light to indicate correct pressure. The assessment was performed on the TMJ and the most prominent part of the masseter muscle, representing local pain. The patients were asked to occlude their teeth and then relax their jaw to enable the examiner to find the most prominent part of the masseter muscle prior to the algometer measurement. Algometry was also performed on the tip of the pointing finger, representing global pain. The examiner placed the probe on the area being tested, and as soon as the subject perceived pain (PPT), they pushed a button to register the exact value of the weight used. A computer registered and displayed the pressure value. All tests were performed three times bilaterally, and the mean of the measured values was recorded.

The electrical stimuli pain test was performed on the fingers, as for the algometer, representing global pain. We included two measurements, specifically electrical sensibility thresholds (ESTs) and electrical pain thresholds (EPTs), using the PainMatcher (PainMatcher AB, Lund, Sweden). The PainMatcher is a microprocessor, which delivers a constant current of 15 mA with monophasic pulses of 10 Hz to the electrodes. Finger press on the electrode ensures an electrically closed circuit and increased intensity of the pulse, which is sustained for 4 μs to a maximum of 396 μs [39]. In the first test, subjects were asked to release the electrode as soon as the stimulus was felt. In the second test, subjects were asked to release the electrode as soon as they felt the first feeling of pain from the stimulus. A number corresponding to the intensity of the electric stimulus was displayed on the apparatus (score 0–99). The tests were repeated three times, and the mean value was calculated.

2.3. Statistical Analyses. Descriptive data were analysed, and the Wilcoxon signed-rank test was used for bivariate analyses between TMD cases and controls. The results from HADS and catastrophizing have been published earlier as single independent variables, but the present results are novel with respect to the adjusted conditional logistic regression [34]. Multivariate conditional logistic regression using an unadjusted Wald test, and an adjusted one with a stepwise forward procedure including five variables (PPT in the masseter muscle/finger and scores from catastrophizing, depression, and anxiety scales), was performed. Selection criteria for the independent experimental pain and psychometric variables were of theoretical relevance among the variables showing significant associations in bivariate comparisons between TMD cases and controls (Wilcoxon signed-rank test).

The data analysis was performed in IBM SPSS Statistics for Macintosh, version 25.0 (IBM Corp., Armonk, N.Y., USA), and Stata Statistical Software: release 14, College Station, TX: StataCorp LLC. $P < 0.05$ was considered a statistically significant difference.

3. Results

3.1. Descriptive Data

3.1.1. Study Population. The TMD group had a mean age of 45 years (SD 12.6) and included 51 women and 9 men. The mean age of the age- and sex-matched control group was 46

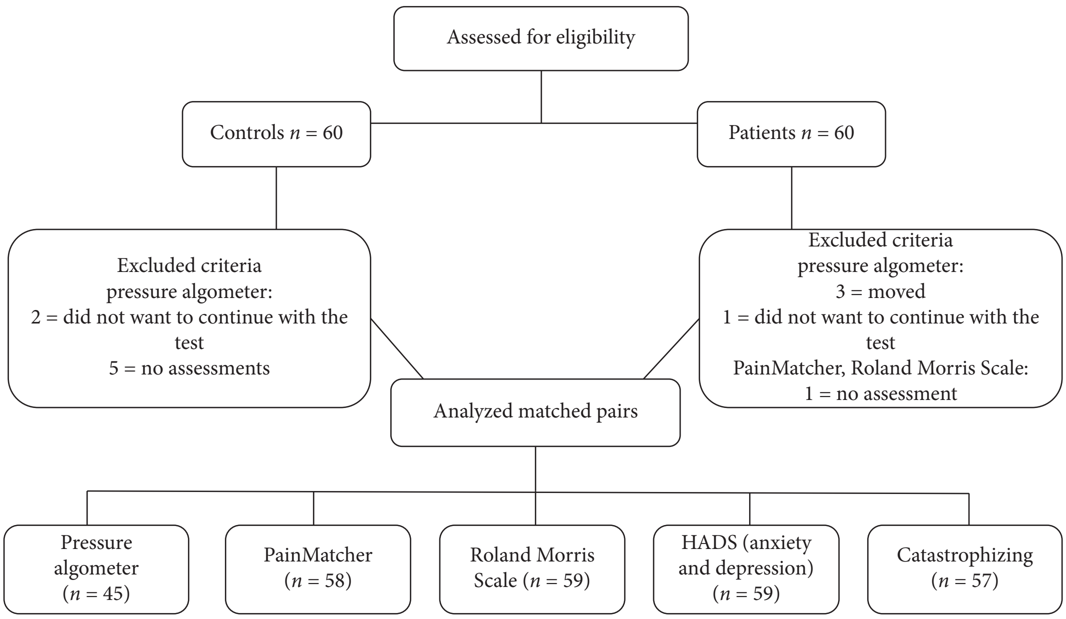

Figure 1: Flowchart of the study sample.

Table 1: Experimental induced sensitivity or pain thresholds and scores for disability when living with pain and psychometric variables in TMD patients compared to healthy controls.

Measure	Controls Mean (SD)	Controls Median	Patients Mean (SD)	Patients Median	P value
PPT finger	553 (235.6)	516.05	402 (178.1)	375.3	0.001
PPT masseter	246 (106.3)	211.72	168 (81.4)	167.7	0.001
PPT TMJ	225 (112.9)	202.20	157 (69.6)	156.3	0.003
EPT finger	12.94 (6.29)	11.50	11.10 (6.27)	10	0.014
EST finger	4.66 (1.42)	4.00	4.36 (1.15)	4.00	0.185
RMS	0.86 (2.15)	0.00	7.25 (4.11)	7.00	0.001
HADS anxiety∗	3.22 (2.98)	2.00	7.12 (4.83)	6.00	0.001
HADS depression∗	1.36 (1.99)	1.00	5.83 (4.67)	5.00	0.001
Catastrophizing∗	1.33 (2.44)	2.44	7.16 (2.47)	8.00	0.001

Notes: the Wilcoxon signed-rank test was used for group comparison. Abbreviations: PPT = pressure pain threshold; TMJ = temporomandibular joint; EPT = electrical pain threshold; EST = electrical sensibility threshold; RMS = Roland Morris Disability Questionnaire (0–24p); HADS = Hospital Anxiety and Depressions Scale. Units: PPT = kPa; EPT/EST = 0–99; RMS = 0–24p; HADS anxiety = 0–21p; HADS depression = 0–21p; catastrophizing = 0–12p. ∗These results have been published before by Staniszewski et al. in 2018.

years (SD 12.6), and it consisted of 51 women and 9 men. Because some patients dropped out or moved during the study, we ultimately had a smaller number of participants and matched pairs (Figure 1): pressure algometer ($n = 45$), PainMatcher ($n = 58$), Roland Morris Scale ($n = 59$), HADS ($n = 59$), and catastrophizing ($n = 57$).

3.2. Experimental: Assessment of Sensitivity and Pain Thresholds. The results show that the TMD patients had a lower PPT than the controls (P = 0.001 for the finger and masseter muscle and P = 0.003 for the TMJ).

Results from the analysis of the EPT measurements indicate significant differences between the two groups, with the TMD patients scoring lower than the controls (P = 0.014). However, the EST measurements did not differ significantly between the TMD group and the controls (Table 1).

3.3. Self-Reported Measurements. The results from the RMS showed increased disability for TMD patients compared to controls (P = 0.001, positive score $n = 33$ for the patients and $n = 2$ for the controls; cut-off $P < 0.001$). Furthermore, the TMD patients had more anxiety (P = 0.001, positive score $n = 22$ for the patients and $n = 5$ for the controls; cut-off $P < 0.001$), depression (P = 0.001, positive score $n = 16$ for the patients and $n = 1$ for the controls; cut-off $P < 0.001$) and catastrophizing (P = 0.001, positive score $n = 52$ for the patients and $n = 11$ for the controls; cut-off $P < 0.001$) compared to the controls. Descriptive data are shown in Table 1. The results regarding anxiety, depression, and catastrophizing have previously been published [34]. In this study, those results were used to perform inferential analyses with data from the RMS, HADS, and experimental pain in order to execute more appropriate statistical analyses, i.e., conditional regression.

Table 2: Unadjusted and adjusted regression analysis of TMD patients.

Independent variables	Unadjusted			Adjusted		
	OR	95% CI for OR	P value	OR	95% CI for OR	P value
PPT finger ($n = 45$)	0.99	0.99–0.99	0.004	—	—	—
PPT masseter ($n = 47$)	0.10	0.01–0.98	0.001	—	—	—
HADS anxiety ($n = 60$)	1.23	1.10–1.38	0.001	—	—	—
HADS depression ($n = 59$)	1.63	1.27–2.08	0.001	—	—	—
Catastrophizing ($n = 57$)	1.90	1.34–2.72	0.001	2.42	1.22–4.79	0.01

Notes: conditional logistic regression including both unadjusted analysis (Wald test) and adjusted (stepwise forward) analysis with temporomandibular disorders (TMDs) and matched control as dependent variables and with two experimental pain measurements and three self-reported psychometric variables as independent variables. Nagelkerke $R^2 = 0.917$. Abbreviations: PPT = pressure pain threshold; HADS = Hospital Anxiety and Depression Scale; n = number of individuals included in the analysis; SD = standard deviation; OR = odds ratio; units: PPT = kPa; HADS anxiety = 0–21p; HADS depression = 0–21p; catastrophizing = 0–12p.

3.4. Conditional Logistic Regression Analysis. Multivariate conditional logistic regression using an unadjusted Wald test and an adjusted model using stepwise forward procedure included five independent variables: PPT in the masseter muscle and finger as well as scores from catastrophizing, depression, and anxiety scales. Unadjusted and adjusted models are shown in Table 2. Adjusted conditional logistic regression identified catastrophizing (OR = 2.42, CI 1.22–4.79, Table 2) to be the only significant predictor. The Nagelkerke was 0.917. The results from the Wald test and stepwise forward test regarding catastrophizing did not appear identical. This can be explained by a reduced number of matched pairs in the adjusted analysis due to missing values in the included independent variables.

4. Discussion

Decreased PPT and higher scorings for psychological factors in TMD patients compared to healthy controls are well known in the literature [5, 14, 15, 21, 27, 32, 41, 42], but the relationship of different factors with predicting TMD patients is yet to be described. To our knowledge, this study is the first to analyse the interrelationship between experimental pain thresholds and psychometric variables in relation to TMD by using a multivariate regression model. Thus, our study demonstrates that the catastrophizing has the best prediction of TMD compared to other psychometric variables (anxiety and depression) and experimental pain thresholds (EPT and PPT). In this regard, a previous study found that high levels of pain catastrophizing increased the risk of pain and disability in chronic back pain patients [43]. A study by Sorbi et al. using electronic EMS diaries suggests that both pain intensity and psychological variables explain disability in chronic pain disorders (CPDs), as well as substantiate the relevance of psychological functioning for disability in CPD. They found that the prediction of disability by avoidance behaviour, pain-related fear, and catastrophizing was better compared to pain intensity and stronger in pain of longer duration than pain of shorter duration [44]. Another study found that high-pain catastrophizing TMD patients were similar to patients with other chronic pain conditions and supported the decision to add scoring for pain catastrophizing to the DC/TMD in order to identify TMD patients who are at the risk of developing chronic pain [41]. The present study supports the aforementioned reports and indicates that catastrophizing might be of causal importance in the development and persistence of pain related to TMD. Moreover, it highlights the importance of assessing catastrophizing in the diagnosis and addressing it in the treatment of TMD.

In addition to the interesting findings in the multivariable analysis, the bivariate analyses showed significant differences between the TMD group and controls regarding not only catastrophizing but also anxiety, depression, and disability when living with pain and experimental sensitivity/pain thresholds. In this regard, it has previously been suggested that psychological factors are associated with the development of painful TMD [21], and enhanced pain sensitivity for experimental pain has been registered in TMD patients [20]. The OPPERA study recently published a community-based cohort study regarding risk factors and enduring characteristics in TMD patients. They studied risk factors using questionnaires and clinical measures, which included clinical, health, psychological, behavioural, and neurosensory domains. Risk factors from the psychological domain were, among others, anxiety, depression, and catastrophizing. The results indicate that nearly all risk factors from all domains increased in patients who developed TMD, while remaining in patients with persistent TMD and declining in those with transient TMD. This suggests that TMD pain onset is determined by enduring characteristics and changes in biopsychosocial functioning across time [45]. These results corroborate our study, which found high psychological scorings in patients with severe TMD and long-lasting pain. All of these findings could indicate that the intensity and duration of TMD are related to the severity and type of psychological impact and that fluctuations of TMD symptoms are dependent on psychological mechanisms. To further evaluate this speculation, future studies should have a longitudinal design, including a higher number of patients with different severity and duration of pain and robust measures of psychological impacts in order to evaluate its impact on painful TMD.

Previously published data, in the same cohort of patients as presented in this study, show higher scoring on HADS and CSQ compared to healthy individuals, as well as higher levels of cortisol in the saliva, showing an upregulated HPA axis indicating higher levels of stress [34]. These findings are also supported by others who have found that stress is a strong predictor of TMD pain [46]. Canales et al. found high to moderate levels of depression and somatisation in patients with TMD [47], and it has been established that concurrent depression and pain have a greater impact on chronic pain disorder than pain disorders alone [42]. Greater pain intensity, longer duration of pain, persistent pain, impaired social functioning, and the likelihood of poor treatment outcome are seen when depression and pain coexist [48]. A similar study assessing the potential role of biological, psychological, and social factors in order to predict the presence of painful TMD using multivariate analysis found a relationship between TMD pain and depression, which supports the need of considering both psychological factors in relation to TMD signs and symptoms [27].

An association between psychological distress, a lower threshold in experimentally induced pain, and painful TMD has been found [5] in analogy with the present study.

Not unexpectedly, the TMD patients in the present study had more tenderness measured by the PPT, and previous studies have reported greater sensitivity to experimental pain because of alterations in endocrine, sensory, and psychological processes, as well as central sensitisation [49, 50]. In tension-type headaches and migraines, decreased PPT in the trapezius muscle and suboccipital sites reflect altered pain perception and support the pathophysiological model of sensitisation [51]. On the contrary, Stuginski-Barbosa et al. [33] found a statistically weak correlation between pain intensity (shown on a visual analogue scale) and PPT (measured by an algometer) in TMD patients with arthralgia, suggesting that other factors, such as nociceptive processes in the central nervous system and additional psychological factors, are important in explaining pain in TMD patients. The difference in PPT between the TMD patients and controls in our study might have an association with the high psychological impact in the TMD group.

The surgically treated patients in this cohort, published in 2017, had high scoring of catastrophizing and postoperative pain [29], possibly due to surgical fear, expected pain, and preoperative pain [30, 52]. The suggestion that catastrophizing might be a predictive factor for persistent postoperative pain [30] may be supported by our study, which shows that the same cohort of patients who had poor surgical outcomes [29] also scored high on catastrophizing. If so, screening the patient's psychological status and preoperative treatment of such disorders may be necessary to avoid persistent postoperative pain.

Our study had several limitations. First, most of the participants in the control group were selected from the Department of Clinical Dentistry at the University of Bergen and were acquainted with the examiner who evaluated them. The acquaintance between the subjects and the examiner may have affected measurements and given rise to bias. A second limitation was that the exclusion criteria did not include other chronic pain disorders and neurological disorders that might have affected the pain perception or medications such as paracetamol, NSAID's, opioids, and antidepressants that might have affected the pain threshold as well as anxiety and depressive symptoms. Since the patients were recruited consecutively by referrals to the National TMD project at Haukeland University Hospital, other chronic pain disorders, neurological disorders, or medications used by the patients were not considered during the recruitment process but were scrutinized during the thorough multidisciplinary investigation by six different specialists. If there was a need of additional specialist investigation, the patients were further referred before the summation of the investigation was presented for the patient. A third major limitation was that there were two different examiners, one examiner for the control group and one for the TMD patient group. The examiners were trained prior to the examination of participants to minimise variabilities and achieve acceptable interexaminer reliability. Nevertheless, there may still have been interexaminer differences that could have affected the results. A fourth limitation was the drop-out of participants in the algometer test due to either no assessments or healthy individuals not wanting to be exposed to the algometer. A final limitation is that the RMS is originally a questionnaire for low-back pain patients, but since it shows disability when living with pain, and because the questions can apply to any type of body pain, it should not affect the validity. An additional shortcoming is that part of the results was published earlier, the psychometric data, but at this time using single independent variables [34]. This can affect the results to be not that relevant or less novel. But after using more advanced statistical analysis which strengthened the results, we found it motivated to let the results be disseminated via a research publication.

5. Conclusions

To conclude, the TMD patients have lower pain thresholds and a higher disability of pain compared to healthy individuals. The strongest prediction for TMD was catastrophizing. These results are important to be considered when managing TMD patients. Awareness of psychometric disabilities in TMD patients is of importance and should be addressed in the treatment plan.

Data Availability

The data used to support the findings in the present study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Potential of Using Shear Wave Elastography in the Clinical Evaluation and Monitoring of Changes in Masseter Muscle Stiffness

Cyprian Olchowy,[1] **Mieszko Więckiewicz**,[2] **Luca Maria Sconfienza**,[3,4] **Mateusz Łasecki**,[5] **Piotr Seweryn**,[2] **Joanna Smardz**,[2] **Sylwia Hnitecka**,[1] **Marzena Dominiak**,[1] **and Anna Olchowy**[2]

[1]*Department of Oral Surgery, Wroclaw Medical University, Wroclaw, Poland*
[2]*Department of Experimental Dentistry, Wroclaw Medical University, Wroclaw, Poland*
[3]*IRCCS Istituto Ortopedico Galeazzi, Milano, Italy*
[4]*Dipartimento di Scienze Biomediche per la Salute, Università degli Studi di Milano, Milano, Italy*
[5]*Department of Radiology, Wroclaw Medical University, Wroclaw, Poland*

Correspondence should be addressed to Cyprian Olchowy; cyprian.olchowy@gmail.com

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The study aimed to evaluate masseter muscle stiffness in adult healthy volunteers referred to a massage treatment and also to investigate whether shear-wave elastography can be used to monitor the effect of massage on the masseter muscle. The study included 21 healthy volunteers, who were subjected to a 30-minute massage of the masseter muscle. Muscle stiffness was measured by shear-wave elastography before and directly after the massage. Pain during the massage was assessed using the visual analogue scale (VAS). The data of 20 patients (one excluded due to severe pain) with a median age of 34.5 years were analysed. The stiffness values were 11.46 ± 1.55 kPa before and 8.97 ± 0.96 kPa after the massage ($p < 0.0001$). The mean drop was 2.49 ± 1.09 kPa. The greatest decrease was observed in people with higher elasticity values before the massage ($r = 0.79$; $p < 0.0001$). The median intensity of pain was 7.2 (range: 6–9.5). We concluded that shear-wave elastography is a sensitive tool to monitor changes in the stiffness of the masseter muscle.

1. Introduction

The masseter muscle constitutes a part of the stomatognathic system. Inappropriate functioning and stiffness of the masseter muscle may lead to many pathologies, including myalgia, myofascial pain, and disordered function [1]. Furthermore, it can also be an aesthetic defect associated with a change of the contours of the face [2]. Increased stiffness of the masseter muscle is observed in many pathologies. Patients with temporomandibular disorders (TMD) often complain about pain in the masseter muscle, as well as its hypertrophy, which clinically manifests with increased stiffness and tension [3, 4]. In patients with fibromyalgia and also those with myofascial pain syndrome, specific biochemical pathways may be responsible for the increased stiffness and tenderness of affected muscles [5]. Moreover, exposure to emotional stress contributes to increased muscle tension [6, 7]. Clinicians highlight the role of addressing increased stiffness and tonus of the masseter muscle as part of the conservative treatment of TMD [6].

Several methods of assessing muscle stiffness have been developed. However, none of them have been introduced into routine clinical practice. Myotonometry has been found to be reliable for measuring muscle stiffness in both larger muscles and smaller muscles, but it is not common for the assessment of dysarthria and TMD [8]. Electromyographic evaluation was also reported to be useful in monitoring the treatment of TMD [9]. Moreover, a portable muscle hardness meter has been used in clinical research [10], and shear-wave elastography can be seen to be a very promising method. Elastography has been validated in studies using phantoms of known hardness and has also been compared to other methods [11, 12]. Results of studies on other organs show that agreement between radiologists is statistically significant [13]. However, despite promising results obtained in studies on healthy volunteers [14, 15], this method still needs to be tested on patients with increased muscle tonus (e.g. suffering from TMD) and those undergoing interventions aimed at reducing muscle stiffness [16].

The aim of this study was to evaluate masseter muscle stiffness in adult healthy volunteers subjected to massage treatment and also to investigate whether shear-wave elastography can be used to monitor the effect of massage on the masseter muscle.

2. Materials and Methods

The study included 21 adult healthy volunteers. All of the participants underwent a 30-minute massage session applied to both masseters. Patients who had any neuromuscular disorders, malignancy, local and/or general contraindications for massage, symptoms of TMD, were pregnant, had reported a history of TMD or neuromuscular disorders, or were on muscle relaxants and/or other drugs affecting the muscles (and/or pain killers) were excluded from the study. Generally healthy, adult patients who gave informed written consent were included in the study. The study was approved by the Bioethical Committee at the Wroclaw Medical University (KB, 592/2018).

During the therapy of deep muscle tissue, massage using the following techniques was performed: transverse friction movements of muscle fibers and release techniques of trigger points. The muscle trigger points therapy was conducted by exerting increasing pressure using the tip of the index finger and the thumb until relaxation of the muscle or a significant reduction in pain was perceived by the patient. Next, the pressure was increased to the next pain threshold. This was repeated until the patient perceived no pain. The transverse friction of muscle fibers was conducted for about 2 minutes or until the pain subsided. Similar massage techniques were reported in the literature [17, 18]. The massage was conducted by a physiotherapist with a 5-year experience in physiotherapy of the masticatory muscles.

Masseter muscle stiffness was measured with shear-wave elastography before and immediately after the massage using the Aixplorer Ultimate device (SuperSonic Imagine, Aix-en-Provence, France) with a high-frequency linear probe SL 18–5 (5–18 MHz). On each examination, elastic Young's modulus was recorded, named in this study as an elasticity value and expressed in kPa [16, 19–21]. The patients were examined in a supine, relaxed, and comfortable position.

Table 1: Elasticity values before and after massage (data are shown in kPa).

	Before massage	After massage	p-value
Left masseter	11.55 ± 1.48	9.07 ± 1.00	<0.001
Right masseter	11.37 ± 1.66	8.87 ± 0.94	<0.001
p-value	0.7115	0.5291	

They were advised to relax, not to bite down, and refrain from swallowing during the examination. A small amount of ultrasound gel was used to eliminate the air between the patient's skin and the probe. Scanning was carried out without compressing the examined tissues. The ultrasound probe was placed parallel to the long-axis of the masseter muscle in the middle of the muscle belly where the volume of the fibers is the highest. The authors used a Region of Interest (ROI) of 4 mm diameter for all measurements on all the patients. Three measurements were taken from each muscle, and means of those measurements were analysed. Elastography examinations were performed by a radiologist with seven years of experience. Additionally, all the participants were asked to grade their perceived intensity of pain during the massage and also their perceived relaxation of the masseter muscles directly after the massage. For this purpose, the visual analogue scale (VAS) was used. The VAS scale has been evaluated for orofacial pathologies [22]. In the present study, participants used the scale twice. First they rated their perceived pain, where 10 denoted the maximal pain and 0 denoted no pain, and next, they rated their perceived relaxation, where 10 denoted the maximal relaxation and 0 denoted no relaxation.

The data were statistically analysed and presented as means with standard deviations and medians with range. The Shapiro–Wilk test was used to test for normal distribution. Paired Student's t-test was used to compare the measurements before and after the massage. Unpaired Student's t-test was used to compare the measurements of the left and right masseters. Pearson's correlation coefficient was used to measure the strength of the association between elasticity values and the change in elasticity before and after the massage. Differences were considered statistically significant at $p\ 0 < 0.05$. Statistical analysis was carried out with the *R* Project for Statistical Computing v. 3.4.1.

3. Results

Overall, 21 subjects were enrolled in the study, but the data of 20 subjects (10 men and 10 women) were analysed. One participant withdrew written consent due to acute pain during the massage. The median age of the studied subjects was 34.5 years (range 18–60 years). The distributions of elasticity measurements were normal. The mean elasticity for both sides before the massage was 11.46 ± 1.55 kPa, and after the massage, it was 8.97 ± 0.96 kPa. The difference between the measurements was statistically significant ($p < 0.0001$). The mean difference before and after the massage was 2.49 ± 1.09 kPa. The drop in elasticity was observed in every patient. There was a strong positive correlation between the elasticity values before the massage

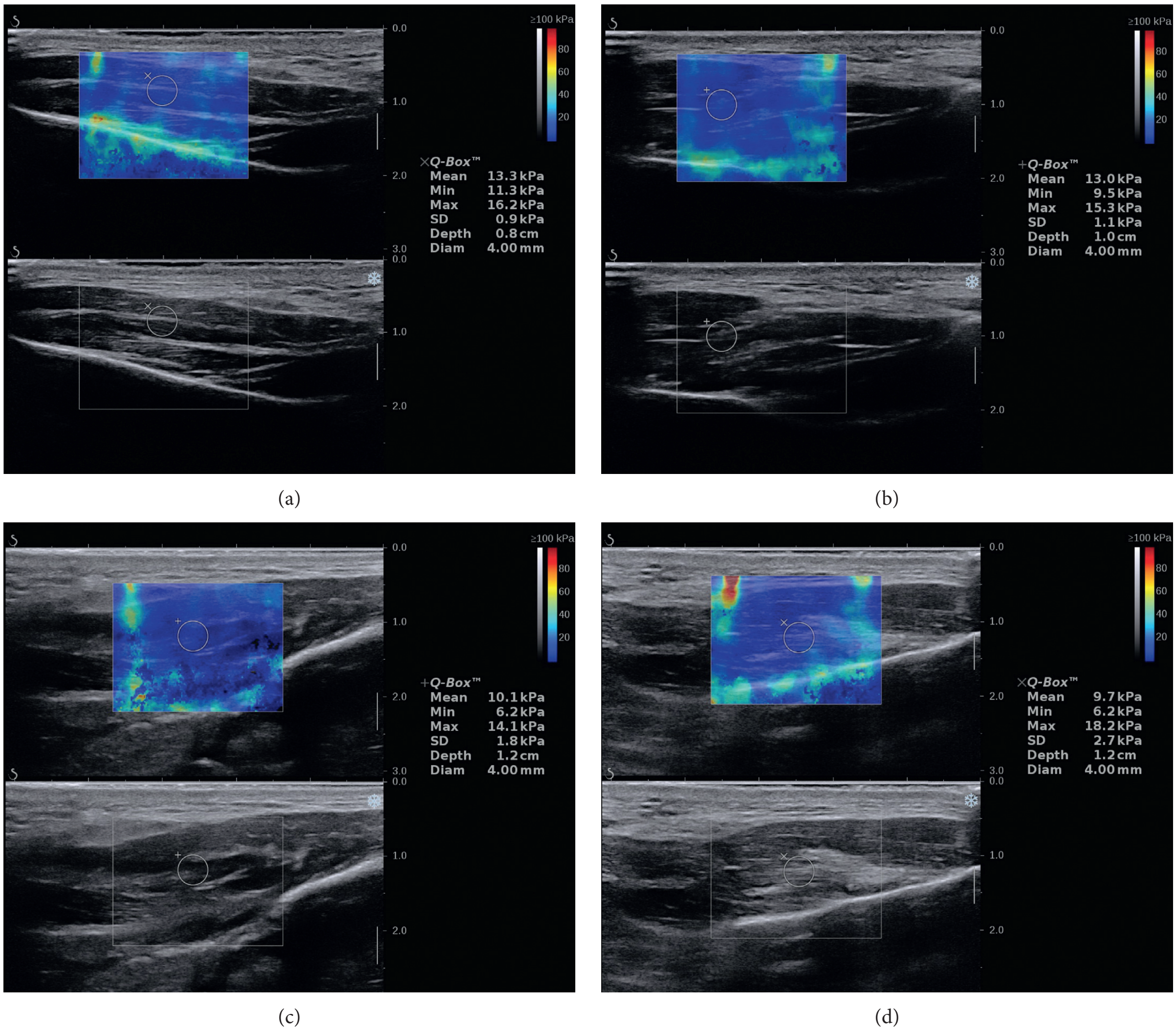

Figure 1: Measurements of elasticity in a 27-year-old female: (a) left masseter before massage; (b) right masseter before massage; (c) left masseter after massage; and (d) right masseter after massage.

and the difference between the two measurements ($r = 0.79$; $p < 0.0001$), which indicates that the drop in elasticity was greater in people with greater tonus. Such a correlation was not observed between after-massage measurements and the change in elasticity ($r = 0.14$; $p = 0.3888$). The detailed results are shown in Table 1. The intensity of pain reported by the studied subjects ranged between 6 and 9.5, with a median of 7.2 (men experienced a higher level of pain). All the subjects reported a sensation of relaxation directly after the massage, which was reflected on the VAS scale (median before massage 5.5 vs. median after massage 8.3). Also, elasticity values correlated significantly positively with the VAS score for relaxation after massage ($r = 0.38$; $p = 0.0127$).

Figure 1 shows the measurements performed on a 27-year-old female, a participant of the study group. The figure shows measurements of the elasticity of the left and right masseter muscle before and directly after the massage therapy. The images reveal a significant drop in stiffness values directly after the massage for all measurements. It corresponds to the sensation of relaxation of the muscle reported by the patient.

None of the subjects reported side effects or any unpleasant experience associated with the shear-wave elastography examination.

4. Discussion

Our study showed that shear-wave elastography reflects the changes in masseter muscle stiffness achieved by muscle massage. The elasticity of the masseter muscle dropped significantly from 11.46 ± 1.55 kPa before the massage to 8.97 ± 0.96 kPa after the massage. A decrease in elasticity was associated with an increase in the feeling of muscle relaxation reported by the subjects after the procedure. The shear-wave elastography examination was tolerated very well by all the participants of the study. To the best of our knowledge, this is the first study that investigates the response of the masseter muscle to massage that is measured with shear-wave elastography. The strength of this study lies in the fact that it proves that the subjective feeling of relaxation of the masticatory muscles after massage corresponds with the drop in stiffness observed using the objective shear-wave elastography method.

Massage applied to muscle tissue provides beneficial effects. It has been shown that massage reduces muscle stiffness, pain, and swelling; increases blood flow and the temperature of treated tissues; and exerts a general relaxation effect on the treated patient [23, 24]. However, the biomechanisms of the action of massage have not been fully elucidated. Despite these limitations, massage is a common form of physiotherapy used in a wide range of disorders [25]. Massage is also recommended for patients with TMD. In those patients, massage aims to revert the proper length flexibility of masticatory muscles. For this purpose, techniques such as effleurage, kneading, friction, and petrissage are widely used [17]. The present study evaluated 2 perceived feelings: (1) sensation of pain assessed using the VAS for pain during the massage and (2) sensation of relaxation after massage. The level of pain during the massage was high (median score of 7.2 out of 10), indicating that effective therapeutic massage requires application of pressure on trigger points. At the same time, this massage relieves tension. The subjects reported an increase in perceived relaxation of the masseter muscle (an increase from 5.5 to 8.3 scores).

Currently, no standards for the assessment of masseter muscle stiffness exist. Attempts to use shear-wave elastography to evaluate the effect of massage were reported in the literature. Eriksson Crommert et al. investigated the effect of a 7-minute massage of leg muscles in 18 healthy volunteers [26]. For the measurements, researchers used the Supersonic Aixplorer ultrasound scanner. A significant drop in elasticity was observed directly after massage in comparison to before massage, but the effect was no longer visible after 3 minutes, which suggested a short-term change. Moreover, there was no correlation between the rated pain level and a reduction in stiffness. Although elasticity values of leg muscles cannot be compared to those of the masseters, due to the fact that the values vary among different muscles [14], the study of Eriksson Crommert et al. brings valuable input into the assessment of the effect of massage on muscles using shear-wave elastography. Ariji et al. also carried out a series of studies on masseter muscle stiffness. In their study from 2009, different methods were used to those from our study [27]. First, the authors used strain elastography to evaluate stiffness, and therefore, the elasticity values cannot be compared due to the use of a different technique. Second, an oral rehabilitation robot was used for the massage. Finally, each person under study received five sessions of 1-minute robotic massage with various massage pressures. However, Ariji et al. came to an interesting conclusion that the masseter stiffness index correlated with the most comfortable massage pressure in healthy people. In another study by Ariji et al. from 2016, 37 patients with TMD suffering from myofascial pain were subjected to a 9.5-week massage therapy (five 16-minute sessions every 2 weeks) [11]. The researchers reported that only some of the patients responded to the treatment. This could be determined by the sonographic features of the masseter muscles. In massage participants, the median elasticity index ratios were decreasing gradually during the treatment, yet such a drop was not detected in those who did not participate.

The protocol of the shear-wave elastography of the masseter muscle still needs to be developed. In this study, we found that the most homogenous elasticity colour map was observed in the middle of the probe and cube box (colour-filled square, Figure 1). For this reason, we recommend taking measurements (round ROI) in the most homogenous field, which is in the middle of the square in almost all cases. We also recommend taking 3 separate measurements from 3 different images rather than, as was conducted in the present study, multiple measurements from 1 image. The method of measurement was modelled on previously published studies [16].

Despite the promising results, our study also has some limitations. We only evaluated the short-term response to massage. Long-term studies are needed, especially on patients with different types of masticatory muscle disorders, who could potentially benefit the most from the massage treatment. Furthermore, this study is a pre- and postmassage study showing the effectiveness of a single diagnostic technique, but in the future, comparative studies to evaluate shear-wave elastography in relation to other modalities are needed. In the present study, a 30-minute massage was conducted by a physiotherapist, while other researchers studied different forms of massage and much shorter session durations. The optimal massage protocol has not been established. Further research should focus on the selection of the most effective protocol. Shear-wave elastography, providing objective measurements, seems to be an important and valid tool for such an assessment. Moreover, we did not perform any reproducibility and interobserver variability, which requires further study. Finally, it may be valuable to extend the observation to other masticatory muscles (e.g., temporal) in order to investigate the impact of stiffness on patients suffering from TMD.

5. Conclusions

Our study showed that shear-wave elastography is a sensitive tool for monitoring changes in the stiffness of the masseter muscle after a single massage session. The objectivity and noninvasive character of this method and the provision of numerical values of stiffness seem to offer superiority with regards to previous methods and patient-reported effects. The potential of shear-wave elastography for use in clinical practice to monitor the condition of the masseter muscle should be further investigated in larger controlled studies.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Comparative Analysis of the Influence of Selected Physical Factors on the Level of Pain in the Course of Temporomandibular Joint Disorders

Łukasz Kopacz,[1] Żaneta Ciosek ,[2] Helena Gronwald ,[1] Piotr Skomro,[1] Roman Ardan,[3] and Danuta Lietz-Kijak [1]

[1]*Department of Propaedeutic, Physical Diagnostics and Dental Physiotherapy, Faculty of Medicine and Dentistry, Pomeranian Medical University, Szczecin, Poland*
[2]*Department of Medical Rehabilitation and Clinical Physiotherapy, Pomeranian Medical University, Szczecin, Poland*
[3]*Department of Econometrics, Faculty of Economic Sciences, Koszalin University of Technology, Koszalin, Poland*

Correspondence should be addressed to Danuta Lietz-Kijak; danuta.lietzkijak@gmail.com

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Introduction. Temporomandibular joints (TMJs) play a very significant function in the activity of the locomotor system of the masticatory system. But they are often a source of pain, myopathy, myoarthropathy, and malfunction of their surrounding or internal structures. The treatment of a patient's discomfort associated with masticatory system dysfunctions strongly depends on their cause. *Aim of the Study*. The objective of the study was to evaluate the impact of selected physical factors: LED light therapy with electromagnetic field and cryotherapy for the level of pain, in the treatment of patients suffering from temporomandibular disorders (TMDs). *Materials and Methods*. The study included 60 patients of both genders with diagnosed TMD in a clinical trial. The participants were randomly divided into two groups. Each group consisted of 30 people and was subjected to separate therapies in which LED light therapy with electromagnetic field (MLT) and cryotherapy (CT) were applied. *Results*. Having assessed the results of the author's own research in terms of analgesic activity, determined on the VAS scale during the daily routine activity of the mandible and its individual movements, in general, each of the studied groups demonstrated a considerable decrease in the level of the patients' perception of pain (<0.001). Having compared both the therapeutic methods used, a greater reduction in the level of perceived pain was achieved with MLT ($p = 0.002$). The type of therapy used turned out to be the only significant factor for the magnitude of this reduction. *Conclusions*. Conclusions based on the results of our own research indicate that the selected methods of treatment demonstrate an analgesic effect in terms of the overall discomfort in the course of TMD, and that they may be an alternative pain relief thereby reducing the patient's intake of painkillers.

1. Introduction

One of the main symptoms of a dysfunction within the masticatory system, in addition to functional disorders, is pain, and it is one of the most common reasons for patients to seek help from specialists. This discomfort may be caused by the dysfunction of the masticatory muscles, tendons, or temporomandibular joints (TMJs). In addition, it may occur not only at rest but also during the movement of the mandible [1]. Increased muscle strain on components of the masticatory system can lead to a compensatory rise in tension in adjacent muscle groups. As a result, pain also occurs in the area of the head, neck, neck muscles, spine, and shoulder girdle, even including the lower parts of the musculoskeletal system [2]. Additional symptoms accompanying temporomandibular dysfunctions (TMDs) are pathological tooth wear following bruxism, tinnitus, and a change in psychological profile [3]. Women are more often affected than men [4]. Further signs of dysfunction within the stomatognathic system are restrictions and disorders of mandible mobility, often associated with disabilities and pain while chewing, yawning, or biting hard foods [5]. In addition, we should pay attention to muscular tenderness on palpation and touch, as their hypertrophy is characterised by a "square" facial appearance and migraine headaches [6].

The application of various forms of physiotherapy procedures in dentistry significantly complement the process of treating patients with the abovementioned symptoms, with postoperative complications, as well as those with severe disorders within the locomotor system of the masticatory system. It is primarily aimed at relieving pain, reducing muscle tension within the stomatognathic system, inducing regenerative processes in soft tissue, and restoring the positive psychophysical effect of the patient. The basis of this treatment is the application of the same physiotherapeutic factors during applicable periods, which facilitates the mechanisms of homeostasis equalisation and thus contributes to the stimulation of self-healing reactions of the body. The above-described influence on the human body and its potent development contributed to the fact that dental physiotherapy has become a separate branch of medicine that includes physiotherapy and kinesitherapy, as well as massage [7]. Any physical stimulus may affect tissue, systems, and the entire human body, leading to reduced inflammation, improved circulation, enhanced immunity, and decreased or increased excitability of nerves. Such an action improves the effects of treatment and accelerates the regeneration of the affected tissue and its recovery to physiological efficiency. Moreover, analgesic effects in the area under treatment, as well as the degenerative effects of pathological tissue, are incredibly significant [8, 9]. Frequently, among patients with TMD, specific healing treatments are used, such as electrotherapy, thermotherapy, or phototherapy. However, it should be noted that each type of treatment is a supportive therapy and should not be performed individually, although, in the case of stomatognathic disorders in combination with splint therapy, various methods of physiotherapy or pharmacotherapy are possible [7].

In TMD, the most commonly used physical factors are ozone, a laser with a suitable wavelength, and a slowly alternating electromagnetic field. Studies conducted in the last twenty years prove that combined therapy in the form of LED light therapy (MLT), which is a fusion of the action of the light emitted from high-energy LEDs and a slow alternating extremely low-frequency magnetic field (ELF-MF), produces synergistic therapeutic effects [10]. An electromagnetic field is characterised by its permeability through any structure of the body, and its action may be profound and equal. The appropriate length of light applied simultaneously penetrates deeper than would otherwise be the case with an independent agent. Such an impact of the magnetic field and light is a characteristic of this procedure as other physical factors reach only superficial depth of the tissue. The definition of the treatment with the use of ELF-MF depends on its parameters, and its range allows for the division of procedures into magnetotherapy and magnetostimulation [11]. The emission of electromagnetic radiation through LEDs takes place in the range of red (R, red), infrared (IR, infrared), and mixed light (RIR). The optical radiation energy, in the visible and infrared spectra produced by LEDs, ultimately causes tissue regeneration [12, 13].

The application of another healing stimulus, through low temperatures, is also used in TMD therapies. The influence of cryotherapy on the human body is based primarily on analgesic processes, which promote the treatment of symptom disorders within the stomatognathic system. These effects are caused by lowering the speed of nerve fibre conduction, slowing down the nociceptive conductivity located in the skin tissue and reducing the release of pain mediators. A further impact of cryotherapy beneficially affecting the human body is the inhibition of inflammatory processes, by reducing the level of the metabolism of cells involved in inflammation, as well as decreasing the frequency of enzymatic reactions. The result is a drop in the amount of inflammatory mediators and improved blood supply to the tissues in the affected area [14]. Cryotherapy, in addition to the analgesic effect, has a positive influence on enhanced muscle tension, decreasing it.

Another desirable effect of this procedure is the anti-oedematous function, as well as inhibiting haemorrhage tendencies. However, during the selection of a cold treatment, and determining the purpose of its action, it should be noted that there is a two-phase vascular reaction to extremely low temperatures [15, 16]. It is also essential that by the consensual reflexes, vascular reactions caused by the cold factor, occurring in the target may also arise in spaces distant from the area of the performed surgery [17, 18].

The local cryotherapy procedure is based on the application of cold within the area subjected to the treatment. The temperature value depends on the agent used during the treatment. The cryogen may be liquid nitrogen, carbon dioxide, or cooled air [19, 20]. Due to the fact that the body's reaction to the stimulus generated during the procedure depends on many factors (e.g., area undergoing the treatment, physiology and type of tissue, gender, age, patient's condition, and type of disease), the therapy should be planned individually. The temperature and the amount of refrigerant required for the treatment, the duration of the procedure, as well as the area undergoing therapy must be taken into account. Despite the existing guidelines for the parameters used in individual diseases, it has been scientifically proved that there is a correlation between changes in the body and the number of treatments performed in a particular series [21].

The main purpose of applying physical stimuli in the course of TMD is primarily to eliminate pain, regulate the metabolism, and improve circulation in overloaded muscles by relaxing them. Although there are a large number of methods used in the course of the described condition, there is no specific and effective one that would present an advantage over other types of therapy. This statement encourages the maintenance of the continuity of research on developing an appropriate method. There are also many trials in which individual therapies are combined to improve the effectiveness of the conducted treatment. The interest in applying cold for therapeutic purposes is still increasing, and the research related to this subject should be constantly developed [22].

2. Objective

The study was aimed at examining the effects of selected physical factors, such as cryotherapy (CT) and LED light therapy with electromagnetic field (MLT), on the level of pain experienced by the patient in the course of TMD and comparing their analgesic effects.

3. Materials and Methods

The research was conducted at the Department of Propaedeutic, Physical Diagnostics and Dental Physiotherapy of the Pomeranian Medical University in Szczecin. All patients were informed about the aim and course of the study and expressed their written consent for participation. The criteria for inclusion in the study group were the studies based on the diagnostic criteria for temporomandibular disorders —DC/TMD. The research was approved by the Bioethics Committee of the Pomeranian Medical University (Resolution No. KB-0012/36/15 of 23.03.2015 and Annex No. KB-0012/47/17 of 27.02.2017). Participation in the study was voluntary, and during the performance of the research, the anonymity of patients was maintained in accordance with the Act on Personal Data Protection of 29.08.1997 (Journal of Laws No. 133, item 883).

The study group consisted of 60 patients with TMD disorders of a myofascial nature. They were observed and diagnosed in the clinical examination. The examination was performed by a dentist and a physiotherapist. The examined patients were randomly divided into two groups, each represented by 30 patients. The first group treated with LED light therapy accompanied by electromagnetic field (MLT) consisted of 23 women and 7 men, while the other group, undergoing cryotherapy (CT), consisted of 16 women and 14 men. All therapeutic series were carried out in line with the valid and standard procedure in this field. The complete duration of treatment with both physical agents was three weeks with weekend breaks, during which 15 physical therapy treatments were performed. All the patients had a painful form of dysfunction of the masticatory system that manifested itself during daily routine activities. In the clinical trial, from both the groups, those patients were additionally selected who reported pain during specific movements of the mandible: abduction, laterotrusion to the right and left, and protrusion. In the studied patients, pain was assessed before the start of a series of treatments and immediately after the end of the last treatment. For this purpose, the Visual Analogue Scale (VAS) was used, in which the patient determined the degree of discomfort intensity on a 10 cm point scale, where “0” would indicate no pain and “10” would indicate the sharpest pain they can imagine. Values in the VAS 0–3 range indicate correct results of the therapy and a feeling of improvement. However, VAS above 7 means a very severe pain and the necessity for further diagnosis and consultation with a doctor. The study assessed pain during the daily activities of the jaw such as biting, chewing, and yawning. Pain was also assessed during specific movements. The pain level experienced by each patient was assessed before the therapy and immediately after the last treatment from a series of all the procedures undertaken. Nominal measurements (pain/no pain) were made before and after the therapy.

For the purpose of carrying out MLT, a Viofor JPS (Med & Life) device was used, which emits an alternating low-frequency electromagnetic field and light in the visible and invisible range through high-energy LEDs (red light 640 nm and infrared light 830 nm). During therapy, the patient was situated in a comfortable lying position, and the two panels of the device, each containing 280 diodes, were placed parallel to the treated surface at the height of the TMJ area, in direct contact (Figure 1). Out of concern for the patients’ safety and with reference to the methodology of the procedure, the patients were asked to clean their face prior to the start of the therapy. The physiotherapist verified the absence of skin lesions in the treated area and provided the patients with safety glasses used at the time of the procedure. The therapy lasted 10 minutes, during which the participant was advised to relax and have a rest. The MLT physical therapy was carried out using an electromagnetic field generated by the system using the M1 method, P3 programme, at an intensity of 6, which ensures the constant application of the selected intensity and applies the highest values of ionic cyclotron resonance generated in cells. Therefore, the frequency of basic pulses was in the range 180–195 Hz, the frequency of pulse packets was in the range 12.5–29 Hz, the groups of packets were in the range of 2.8–7.6 Hz, and the series were in the range of 0.08–0.3 Hz.

The local cryotherapy procedure for the TMJ region was performed once a day, using a cryostimulator (CryoFlex, Poland, Cryo-T), operating on the CO_2 system. The process involves the application of cold air on the area of joints on the right side and left side at a temperature of approximately −70°C at the nozzle’s exit. Here, it only triggers a local effect. The type of coolant used for the treatment was carbon dioxide. TMJ was cooled down by a special nozzle directed to the treatment site. The affected space was completely dry, and there were no skin lesions in this particular area. The respiratory tract, lymph nodes, as well as the eyes and ears located within the TMJ, were covered by the patient’s face mask, a special band for the eyes, ears, and neck, and the application of earplugs (Figure 2). The nozzle’s exit was held at an appropriate distance from the patient’s body (at least 10 cm), and the movement of the cryoapplicator nozzle was adjusted in cooperation with the participant to prevent the cold stream from constantly falling on one area of the treatment site. The duration of the procedure was 2 minutes.

Descriptive statistics for quantitative characteristics are presented in terms of mean, standard deviation, and maximum and minimum values. The assumption of the normal distribution of quantitative traits was checked with the Shapiro–Wilk test. In the case of no normal distribution, the Wilcoxon test was applied to compare mean pain intensity

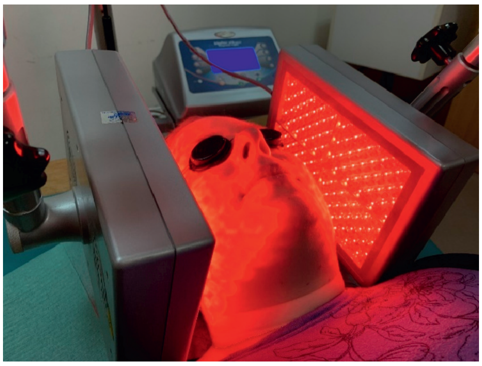

Figure 1: MLT treatment using LED panels (author's photo).

Figure 2: Local cryotherapy procedure in the TMJ area (author's photo).

values before and after the therapy. In addition, McNemar's chi-square test was used to analyse the nominal data. The results were considered statistically significant at $p < 0.05$. For calculations, *R* package was selected.

4. Results

Following the treatment in each group, a decrease in the level of pain during the daily activity of the mandible, such as biting, chewing, and yawning, was observed. The measurements displayed significant deviations from normal distribution; the Wilcoxon test was implemented. The differences before and after therapy were statistically significant (Table 1).

The efficacy of the abovementioned methods was compared using the Mann–Whitney *U* test, which demonstrated a statistically significant difference between methods tested ($p = 0.002^*$). A plot in Figure 3, presenting a change in mean values in the VAS scale, suggests a greater reduction in the level of pain using MLT.

Since the groups were not identical in terms of sex and age, a linear regression model with three independent variables was elaborated: type of therapy, sex (women-0 and men-1), and age (years). Only the type of therapy turned out to be a significant variable (Table 2).

The results of measuring the level of pain during specific movements of the mandible were obtained. A decreasing tendency of pain during the exercise of particular mandibular movements was observed. Upon using the chi-square McNemar test, all the cases yielded statistically significant differences in the number of patients feeling pain.

Our findings demonstrate a large decrease in complaints during the abduction movement in the CT group where pain before and after the treatment was observed in 21 and 7 subjects, respectively. Likewise, after MLT, the number of patients with pain decreased from 18 to 6 ($p < 0.01$ for both the treatments).

Pain during right side laterotrusive movement decreased after applying selected physical factors in the studied groups. Before CT procedures, pain was reported by 14 patients, while after the therapy, by only 4 patients. In the case of MLT, 10 patients reported pain before the procedures and only 3 after treatment ($p < 0.01$ for both the treatments).

Table 1: Comparison of pain parameters on the VAS scale during the daily activity of the mandible before and after the therapy in each group ($n = 30$).

Therapy	Parameter	Mean	SD	Min	Max	p
MLT	Pain before	3.57	1.85	1.00	7.00	<0.001*
	Pain after	5.83	1.72	2.00	9.00	
CT	Pain after	4.03	1.50	1.00	7.00	0.001*
	Pain before	4.97	1.59	2.00	8.00	

*n, number of patients; SD, standard deviation; Min, minimum; Max, maximum. *Parameter statistically significant (Wilcoxon test).

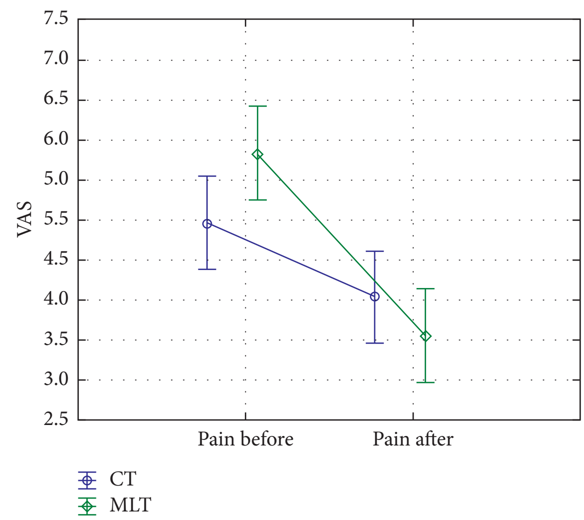

Figure 3: Changes in mean values in the VAS scale before and after the therapy (95% confidence interval for the mean value). *MLT, LED light therapy with electromagnetic field; CT, cryotherapy.

Table 2: Results of the regression model estimation

	Estimate	Std. Error	t value	p
Intercept	−1.684	0.665	−2.534	0.014
MLT group	−1.306	0.272	−4.801	<0.001*
Sex	0.219	0.284	0.772	0.443
Age	0.024	0.023	1.032	0.307

Note. A negative value means a greater pain reduction.

Comparing the effect of the applied therapeutic methods in terms of the change of parameters determining the occurrence of pain during the left side laterotrusive movement, a decreasing trend was also observed. Pain was experienced by 15 subjects before the cryotherapy, and 5 subjects after the cryotherapy. In the case of MLT, 8 subjects felt pain discomfort before the treatment, after which this changed to 4 patients ($p < 0.01$ for CT and $p = 0.046$ for MLT).

After the therapy in both groups, a reduction in pain during protrusion movement was also observed. In the group covered by CT, 14 patients felt pain during movement before the procedures and only 4 after the procedures. In the case of MLT, 9 patients reported pain discomfort before treatment and 3 after the procedures ($p < 0.01$ for CT and $p = 0.014$ for MLT).

5. Discussion

The authors' study confirmed the analgesic effect of the selected physical therapy methods. They focused on the analysis of results obtained for each group, in which the influence of individual methods on the level of pain (measured on the VAS scale) during active chewing movements were compared. After the therapy, a decrease in the level of pain during active mandibular movement was noted in each of the studied groups, whereas in general comparison, the differences between both therapies were statistically significant in favour of MLT. There are many publications related to the anti-inflammatory and analgesic effects of the slow alternating low-frequency electromagnetic field. Thomas used this field in his research to treat chronic musculoskeletal pain, providing an analgesic effect. The result obtained in the group of 17 patients was similar to the statistical significance ($p = 0.06$) [23]. Calderhead confirmed in his studies that the light radiation energy derived from LEDs, which is mainly used in aesthetic medicine, depending on the radiated wavelength and angle of incidence, exerts an effect on tissues locally and has an ability to penetrate into their interior [24]. The abovementioned process of action confirms the results achieved in the authors' own research, which are undoubtedly influenced by the factor in question at the site of pain and an adequate penetration into painful tissue, which certainly leads to an analgesic effect. Simpson observed that near-infrared LEDs cause the deepest tissue penetration of visible wavelengths and are therefore used for targeted therapy in subcutaneous structures and fibroblasts [25]. There are many studies on the use of red LEDs in various diseases, including wound healing, precancerous treatment, warts, and prevention of oral mucositis. It has been observed that IR LED infrared light therapy is able to penetrate the skin and provide a therapeutic stimulus between 5 and 10 mm [26]. The authors' research and observations inferred a confirmation of the beneficial effect of the discussed method on the human body. At the same time, they proved an improvement in the analgesic effect after its use. Arneja, in contrast, used an electromagnetic field in the treatment of chronic spinal pain in patients with degenerative disease. These studies indicate the safety and effectiveness of the method and its high relevance in clinical trials [27]. Iannitti, in his clinical studies with the use of pulsed electromagnetic field among elderly people, obtained a beneficial effect of the therapy conducted in the form of reduction of pain and stiffness of joints, as well as improvement of physical fitness of the examined population [28]. These studies show how important the therapeutic factor is in the use of electromagnetic fields in therapy. The author's research also obtained an analgesic effect at the same level of significance. Nelson, on the other hand, found that noninvasive electromagnetic field therapy leads to a rapid and significant reduction of pain in the early stages of osteoarthritis of the knee joint. An analgesic effect was achieved in the study group composed of 34 patients at the level of $p < 0.001$ [29]. The analgesic effect of slow alternating electromagnetic fields with low frequency and magnetic induction is particularly important in the treatment of patients with pain. According to Wheeler, discomfort in musculoskeletal and fascial structures affects approximately 85% of people who are struggling with posttraumatic pain. Additionally, more than 90% of people are reporting to their doctor regarding pain in the course of other diseases. Components of these ailments may also be found in 55% of patients suffering from head and neck pain [30].

Cryotherapy, as one of the physical treatments with a wide range of applications, also reached an enormous interest among researchers and authors of many publications. It confirms the author's results and the beneficial effects of this type of treatment in the analgesic direction. Lateef et al., in their research, focused on the assessment of the effectiveness of the Hilotherm cooling system in reducing pain and postoperative oedema in patients after maxillofacial trauma and orthognathic surgeries. The study was conducted in 34 patients with these described symptoms. After the examination, analgesic ($p < 0,01$) and antioedematous ($p < 0,01$) effects were significantly better in the study group with the use of a cooling agent than in the control group not covered by the therapy. Additionally, patient satisfaction with the results of the postoperative treatment was noted [31]. The author's research in the group of patients covered by the local cryotherapy treatment also presented an analgesic effect, although, in the author's comparison, MLT yielded better results than CT. This may be due to a deeper local effect and the simultaneous use of both factors in a single treatment. The light of an adjusted length used concomitantly with electromagnetic field penetrates deeper than if used independently. Such a synergy of both the discussed factors is more beneficial from a therapeutic point of view. Chou and Liu, on the other hand, in their research, compared the efficacy between cold compresses (towel) and ice pack in postoperative care. The analysis included the temperature of the skin in the treated area, pain, and swelling. Both wet cryotherapy and dry cryotherapy effectively reduced postoperative discomfort. Cryotherapy, in the form of a cold compress, was more effective in reducing the subjective discomfort caused by surgery. However, cryotherapy with ice packs was more successful in reducing the local temperature in some areas after surgery [32]. Both the subjective feelings of a patient and the temperature drop of the skin layers in the area undergoing treatment are particularly important in the treatment of the patient, especially when oedema and pain are reported in a given case. The abovementioned studies are in line with the author's findings. Filho et al. reported that, among 14 patients after the extraction of defective third mandibular molars, cryotherapy was performed only on one side, while on the other side, the patient did not receive a cooling stimulus. The authors conducted clinical trials to determine the analgesic effect of the procedure, as well as to measure swelling before surgery, directly after the procedure and 24 and 48 hours after surgery. Cryotherapy was effective in reducing both the swelling and the level of pain experienced by the patients [33]. In our studies, among patients from the cryotherapy group, no oedema was observed. Moreover, taking into account the level of pain, a statistically significant decrease of values was revealed after the treatment. Similar results have been obtained by other authors conducting research in this area. Hirvonen et al. examined 60 patients with active seropositive arthritis by treating them with systemic cryotherapy, local cryotherapy, and cold compresses. After the application of these therapeutic factors, the pain was reduced in all groups, but with the best effect in a systemic cryotherapy group. It is also significant that no severe or persistent adverse effects were detected in the studied population [34]. The authors' comparative analysis demonstrate that the approximate values of temperature at the level of −110°C used in other experiments brought better results than the temperature conditions used in the authors' own study, i.e., −60°C. Higher values of the CT temperature used in the author's study stem from the fact that the treated area, i.e., the temporomandibular joint, was small. Nevertheless, an improvement after its use was obtained anyway. This is a peculiar feature of the procedure described because the TMJ area and the adjacent structures are very sensitive to external stimuli. Furthermore, in the authors' results, none of the studied patients reported any adverse effects from the therapy. Saito et al. evaluated whether there is an analgesic effect of cryotherapy after total hip arthroplasty (THA). In the group of patients who experienced THA and were treated with low temperatures, the pain after the procedure was much weaker. Moreover, the postoperative use of painkillers in the cryotherapy group was much lower than in the control group without the use of cold therapy. The results of this study confirm the potential benefit of this factor, which results in pain reduction during postoperative recovery of patients undergoing THA [35].

In another research, Więckiewicz et al. emphasised an especially important aspect in discussing the pain experience of the masticatory organ and the mental state of the patient. The analysis of many studies in these subjects indicated a correlation between masticatory pain and mental state changes [36]. This is a paramount aspect that, beyond any doubt, should be taken into account when defining a patient's eligibility for treatment, as well as during the therapy itself. This will allow for a multidirectional treatment and also covering the patient with psychological care. Rymaszewska et al. conducted research in this direction, assessing the impact of cryotherapy on psyche and mood disorders. In a group of 23 patients in the hospital suffering from depression, cold therapy was applied for 2 weeks. Antidepressants were not terminated. Symptoms were assessed at the beginning and end of the treatment using the 21-point Hamilton Depression Assessment Scale (HDRS). It was proved that the total HDRS score for each patient after cryotherapy was lower than the baseline score and was statistically significant. This indicates that cryotherapy had a positive effect on all symptoms, except for mood swings during the day and night. If research in this direction is extended, cryotherapy may become a supporting treatment for depression [37]. Symptoms subjected to the greatest improvement were anxiety and hyperactivity (90% of respondents), with both these factors certainly stimulating the development of TMD.

Through personal and other authors' research, it should be emphasised that the treatment of patients with the abovedescribed disorder also includes physiotherapy and physical therapy. Positive therapeutic effects are achieved by using laser therapy, heat therapy, light therapy, electrotherapy, electromagnetic field, manual therapy, proprioceptive neuromuscular traction, kinesitherapy, relaxation techniques, autogenous training, and biofeedback to change impaired behaviour [38]. Hals et al. consider that such a group of patients is often referred to as 'difficult' because few health professionals believe they are able to help individually; therefore, it is essential to put these patients under the care of a multidisciplinary team that will guide the entire treatment process at each level [39].

6. Conclusions

(1) Treatment with chosen MLT and CT physiotherapeutic methods, based on the analgesic effect in the course of TMD, brings a significant improvement in the subjective pain sensation determined on the VAS scale

(2) The applied therapeutic methods caused a decreasing tendency of pain during individual mandibular movements, and making a comparison between them allowed us to observe statistically significant differences in favour of the MLT

(3) The usage of selected physical factors and their beneficial effect on pain symptoms during the mandibular movements is an important aspect of everyday life and in the professional functioning of patients

(4) The inclusion of therapeutic methods can lead to increased satisfaction and patient comfort when undertaking TMJ manual therapy as well as long-lasting dental procedures

Data Availability

The datasets used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Review Article

Identification of Biomechanical Properties of Temporomandibular Discs

Edward Kijak ,[1,2] Jerzy Margielewicz,[3] and Małgorzata Pihut[4]

[1]*Department of Prosthetic Dentistry, Faculty of Medicine and Dentistry, Pomeranian Medical University, 1 Rybacka, Szczecin 70-204, Poland*
[2]*Department of Prosthetic Dentistry, Faculty of Medicine and Dentistry, Wroclaw Medical University, 1 Ludwika Pasteura, Wrocław 50-367, Poland*
[3]*Silesian University of Technology, Faculty of Transport and Aviation Engineering, 8 Krasińskiego, Katowice 40-019, Poland*
[4]*Department of Prosthetic Dentistry, Jagiellonian University Medical College, Montelupich, Krakow 31-155, Poland*

Correspondence should be addressed to Edward Kijak; edward.kijak@umed.wroc.pl

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Purpose of the Paper. The study was aimed at identifying the biomechanical properties of the temporomandibular disc. *Material.* Experimental and model tests were conducted on ten fresh porcine temporomandibular joint discs. The average thickness of disc tissue was, accordingly, 2.77 mm for the anterior zone, 3.98 mm for the posterior, and 1.54 mm for the intermediate. The selection of research material in the form of porcine discs was due to the similarity to human discs. *Methods.* Discs were loaded in cycles, a temporary course with the amplitude 3 N and frequency 0.07 Hz, and growth in the load was 1 N/s. The selection of load frequency was due to real conditions of temporomandibular joint functioning during mastication. The necessary experimental research was conducted on a testing machine with a measurement range of 2.5 kN. *Results.* The obtained numeric calculation results indicate that the number of load cycles has a decisive impact on the limitation of energy dispersion capacity through disc tissue. This phenomenon was observed in all the studies on the disc areas. Along with the growth in load cycles, discs are stiffened, and the most significant stiffness was observed in the intermediate area. *Conclusions.* Based on the conducted research, it should be concluded that excessive load affecting temporomandibular joints caused by the act of mastication and occlusal forces generated during parafunction and in people with defined long-term bruxism has crucial importance on biomechanical disc properties and hence the course of temporomandibular joint conditions.

1. Introduction

Temporomandibular disorder (TMD) is an umbrella term including group of conditions that cause pain and dysfunction in the masticatory muscles, the temporomandibular joint (TMJ), and their associated structures. They are a group of complaints associated with accelerating life pace, and therefore, we observe an increase in the incidence of this type of disorders. Stress, fatigue, anxiety, depression, sleep disorders, and a fast pace of life affect the human psyche [1] negatively. TMD and oral parafunctions seem to be a frequent problem in modern societies [2–5]. The etiopathology of the TMD is related to teeth arches, muscles, and periodontium. Their main causes involve both pathophysiological and psychosocial factors [6, 7]. The primary symptoms include pain during mandible movements, limitation of mandibular mobility, and acoustic symptoms recorded within TMJs [8]. It is estimated that TMD may relate from 75 to 90% of the surveyed population [9–11].

Epidemiologic tests, conducted in recent years, focus on the factors causing functional and morphological changes in the stomatognathic system. It has been proved that the multifactorial etiological causes may have a biopsychosocial base, as well as occlusal disorders, stress factors, mental conditions, generalized diseases of joints and hormonal disorders, congenital defects, headaches, and arthritis [12–16]. The latest extended TMD (DC/TMD) taxonomy takes into account as many as 37 disorders considered, which have been grouped into the following four categories: temporomandibular joint disorders, chewing muscle disorders, headache disorders, and related structure disorders [17].

The most common cause of the TMD is stress, especially long-term stress [18, 19]. Some studies show that headache is a much more common problem for participants with painful TMD [20]. Furthermore, some studies underline also the gender influence on TMD development. It has been proved that being under stress increases the activity of the masticatory muscles, which consequently results in TMD [21, 22].

Sleep disorders associated with stress include bruxism. Bruxism is an oral habit consisting of involuntary rhythmic or spasmodic nonfunctional gnashing, grinding, or clenching of teeth, unlike chewing movements of the mandible, which may lead to occlusal trauma that is characterized by the clenching and grinding of teeth. It can occur as awake bruxism (AB) and sleep bruxism (SB). AB is a distinct entity from SB and is characterized mainly by the clenching of teeth [23].

The sleep and awake bruxism are generally considered as different behaviours observed during sleep and wakefulness, respectively. It is therefore more appropriate to use a definition or in principle two separate definitions, which were developed under the International Consensus in 2018. So by sleep bruxism, one should understand "a masticatory muscle activity during sleep that is characterized as rhythmic (phasic) or nonrhythmic (tonic) and is not a movement disorder or a sleep disorder in otherwise healthy individuals." Awake bruxism is, according to the authors, "a masticatory muscle activity during wakefulness that is characterized by repetitive or sustained tooth contact and/or by bracing or thrusting of the mandible and is not a movement disorder in otherwise healthy individuals" [24]. The prevalence of AB in adults was reported to range from 22.1% to 31% while that of "frequent" SB was more consistent at 13% [25]. The bite forces during SB events can exceed the amplitude of maximum voluntary bite force when awake. The aforementioned leads to significant loading of teeth, the periodontium, temporomandibular joint (TMJ), as well as muscles of mastication [26].

An integral element of the mastication organ is the temporomandibular joints, the place of the moveable connection of the mandibular condyle with immobile cranial bones. The movements of both the mandibular condyle in the joints are coupled; i.e., despite having different natures, they proceed simultaneously. The nature of the movements of the mandibular condyle in the TMJ depends primarily on the structure of the joint, ligaments, and biomechanical properties of the discs. From a clinical point of view, the disc divides the articular cavity to the separate cavities: upper and lower, and the main role in its functioning is played by movement of fluids through the interstitial areas [27]. Cartilage tissues are sensitive to their mechanical environments [28].

The specific biomechanical properties of TMJ discs have a significant impact on the biomechanics of the temporomandibular joints. The mechanical function of the TMJ disc is determined by the composition and structure of its distinct extracellular matrix (ECM) [29].

The human TMJ disc is largely avascular, so cellular nutrients essential for maintaining a healthy ECM must be supplied by diffusion from the synovial fluid and blood vessels in the disc periphery [29]. Some studies have shown that mechanical loading limits nutrient availability within the TMJ disc by altering diffusivity. Electrical conductivity, a material property of biological tissues related to ion diffusivity in soft, hydrated tissues, decreased with increasing mechanical strain [30].

Studies conducted with the use of magnetic resonance (MR) indicate that, during movement of the mandibular condyle from the fovea articularis to the articular tubercle, discs are deformed [31]. Disc deformation is reflected by its narrowing or extension, depending on the current position of the heads in the articular space. In the work by Fung, attention was paid to the fact that the edges of TMJ discs are stiff and capable of transferring loads, while the intermediate zone is thin and flexible [32]. The main purpose of the external stiff areas of TMJ discs is to protect against an excessive increase in contact stresses between areas of heads and acetabulum [33].

The phenomena occurring in TMJ discs tissue during its deformation are difficult to direct observation. It is possible, however, to recognise them by applying model tests [34, 35], and an extremely useful piece of technique is the finite elements method [36, 37]. The compliance of the obtained computer simulation results with the state of the real structure is a necessary condition for skilful separation of the issue, by adopting appropriate boundary conditions and introducing material data typical of TMJ disc tissues properties. The purpose being an evaluation of biomechanical properties of TMJ discs, a particularly significant phase, seems to be the material data collection. Common awareness of this fact results in the fact that much attention was devoted to the evaluation of biomechanical properties of natural tissues, responsible for the transfer of forces, generated during motor activities. In the case of joints, the key problem is to define the biomechanical properties of the disc, taking into consideration diverse features of its particular fragments. The variety of material features facilitates the cooperation of mandibular condylar heads with panes of different shapes [38].

The main aim of this study was to assess the mechanical properties of pig joint discs as analogues of human TMJ disc. This identification was conducted based on recorded measurement data obtained during cyclic disc loading. The obtained data were the basis for determining the scattering and elastic properties of the joint disc. It is an attempt to mathematically describe the biomechanical properties of the articular disc tissues, in the anterior, intermediate, and posterior zones, which are subjected to cyclic loading. The results presented in this paper can be treated as a supplement to the information on specific biomechanical data, characterizing the elastic properties and the ability to dissipate energy by the tissues of the TMJ disc.

2. Materials and Methods

The object of identification of elastic and dissipation properties was on ten fresh porcine TMJ discs that were analyzed in three zones: the anterior (AZ), the intermediate (IZ), and the posterior (PZ). The porcine disc was chosen based on geometric, microstructural, and biochemical similarities to the human specimens. The average length in medial-lateral direction was 2.68 ± 0.214 cm, and average length in anterior-posterior direction was 1.41 ± 0.116 cm. However, the average thickness of the tissues of the disc in different studied areas amounted to the following: the anterior area 2.77 ± 0.101 mm, the posterior 3.98 ± 0.216 mm, and the intermediate 1.54 ± 0.060 mm. Research material was isolated from dead pig heads prepared within industrial slaughter meat plants. TMJ discs were obtained from a local abattoir in a manner consistent with institutional regulations. All the TMJ discs have been carefully dissected from pig heads by one experienced maxillofacial surgeon. The discs were identified and stored separately in 0.1 M phosphate buffered saline (PBS, pH = 7.2). During the experiments, the discs were kept at 37°C in PBS. All discs were identical in size because they were obtained from similar 100 kg animals. The experiments for each disc were completed during the day the test material was collected.

The first stage of the research was the definition of research material selection criteria. The fundamental requirement assumed no mechanical damage of TMJ disc tissues. The basis for conducting any model tests concerning the identification of mechanical properties of biological or technical materials is measurement data. In the presented work, laboratory tests were carried out on a universal testing machine, namely, Zwick, with a load range of 2.5 kN, controlled via the computer program Test Xpert. To exert a direct load on discs, a specially designed measurement stamp was used with a diameter of 5 mm, whose contact surface had a shape close to disc geometry. Adjusting the stamp's shape to the circumferential geometry of the disc was aimed at minimizing uncontrolled slips. After appropriate disc placement towards the stamp, it was loaded in cycles, with a saw-tooth course with constant load increase speed, amounting to 1 N/s, and a frequency equal to 0.07 Hz. Such a frequency approximately corresponds to real-functioning conditions of the temporomandibular joints during mastication. The frequency was determined based on own chewing measurement data recorded with the Zebris JMA electronic facial arch in a healthy, model patient [39]. The experimental studies do not reproduce the actual movement that takes place in the temporomandibular joints because it is so complicated that it is difficult to reproduce it on a testing machine. Nevertheless, care has been taken to ensure that the frequency with which the joint disc tissues is loaded corresponding to the actual loads during the act of chewing.

Additionally, a cycle from zero was implemented to the maximum value of 3 N. Border upper scope load has been adopted for the experiment in such a way so as not to cause excessive disc tissue crushing. Additionally, in the lower scope of cycles, the load remained insignificant, ensuring continuous disc contact with the measuring stamp. This negligible pressure in the lower load range assured that, in each subsequent cycle, disc tissues were loaded precisely in the same place. During the tests, we recorded force signals and displacement of the transverse beam of the testing machine synchronously. The recorded temporary runs of force signals and displacement were presented in the form of force-displacement characteristics (Figures 1(a) and 1(b)).

Because of difficulties in obtaining the repeatability of results, for model tests, only cases were selected with regular hysteresis loops, i.e., ones that did not demonstrate changes in the shape. Changes in the shape of the hysteresis loop were caused mainly by TMJ discs sliding on the measuring table and the excessive presence of soft tissue residues, left after preparing. Taking account of imprecise disc tissues preparation, biomechanical properties of the discs were identified only from the second cycle, as this cycle, in principle, may be considered stable. It is worth emphasising the fact that the impact of this type of disturbances is lower with each cycle that follows because residues in other soft tissues are being crushed. Consequently, their effect on the recorded characteristics is much limited.

The first stage of identification is separation from the recorded characteristics, particular load cycles and curves, corresponding to loading and unloading phases (Figure 1(b)). The next stage covers the characteristics' shift to the beginning of the coordinate system. The activity is intended to clear one of the integration boundaries as well as the simplification of the analytical functions record. At this point, it should be pointed out that process in such a way and measurement data do not affect the recorded hysteresis loops. During the cyclical TMJ disc tissues loading, part of the mechanical energy is dispersed. This phenomenon is associated, above all, with plastic deformation, and its size in a single load cycle is defined based on the surface area of the hysteresis loop (Figures 2(a) and 2(b).

On the basis of being recorded in different loading cycles of the hysteresis loops, the energy dispersion coefficient is identified:

$$\psi = \frac{A_H}{A_S} = \frac{\int_0^{q1} F_{OB}(q)dq - \int_0^{q1} F_{OD}(q)dq}{\int_0^{q1} F_S(q)dq}, \quad (1)$$

where A_H is the surface area of the hysteresis loop, A_S is the surface area under the curve representing elastic properties of the disc, $F_{OB}(q)$ is the load curve equation, $F_{OD}(q)$ is the load curve equation, and $F_S(q)$ is the curve equation representing elastic properties of the TMJ disc.

$$\begin{aligned} F_{OB}(q) &= a_1 \cdot q + a_2 \cdot q^2 + a_3 \cdot q^3, \\ F_{OD}(q) &= b_1 \cdot q + b_2 \cdot q^2 + b_3 \cdot q^3 + b_4 \cdot q^4 + b_5 \cdot q^5. \end{aligned} \quad (2)$$

Open representations of load and unload curves constitute the basis for setting static characteristics of the joint disc, which is calculated as an arithmetic mean. Additionally, static characteristics of discs may be approximated with great accuracy by a polynomial function of the third degree:

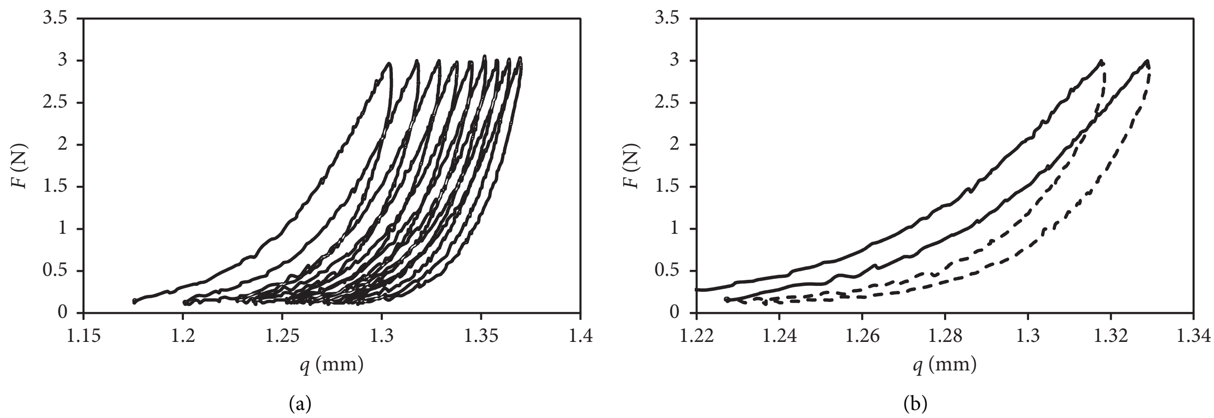

Figure 1: Force-displacement characteristics of TMJ discs: (a) ignoring the first load cycle; (b) separated load phases and unloading different cycles.

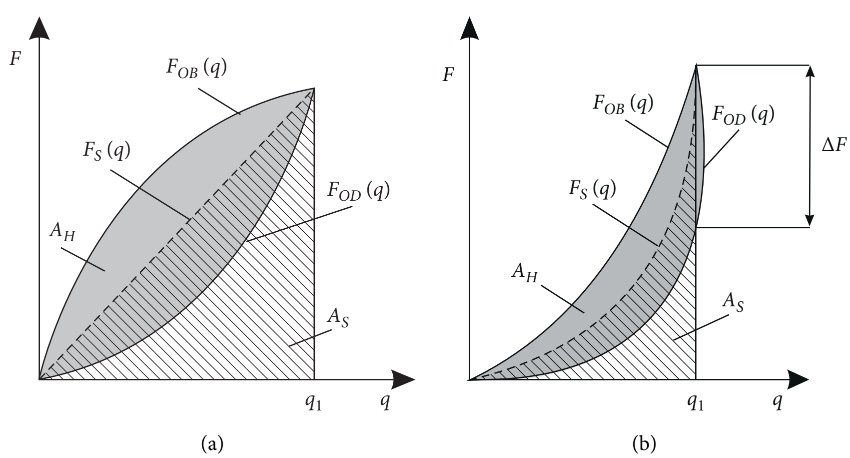

Figure 2: Hysteresis loops on the basis of which the nondimensional energy dispersion coefficient is identified: (a) material with linear properties; (b) material with nonlinear properties.

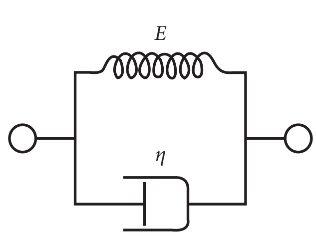

Figure 3: Kelvin–Voigt model-schematic representation.

$$F_S(q) = \frac{F_{OB}(q) + F_{OD}(q)}{2} = d_1 \cdot q + d_2 \cdot q^3. \quad (3)$$

The methodology presented in this chapter is a formal basis for identification of biomechanical properties of discs tissues. Based on physically identified parameters, it is possible to thoroughly reconstruct the phenomena occurring in the discs, using the nonlinear rheological model Kelvin–Voigt.

A Kelvin–Voigt material, also called a Voigt material, is a viscoelastic material having the properties both of elasticity and viscosity. The Kelvin–Voigt model, also called the Voigt model, can be represented by a purely viscous damper and purely elastic spring connected in parallel, as shown in Figure 3.

Since the two components of the model are arranged in parallel, the strains in each component are identical:

$$\varepsilon_{\text{Total}} = \varepsilon_S = \varepsilon_D, \quad (4)$$

where the subscript D indicates the stress-strain in the damper and the subscript S indicates the stress-strain in the spring. Similarly, the total stress will be the sum of the stress in each component:

$$\sigma_{\text{Total}} = \sigma_S + \sigma_D. \quad (5)$$

From these equations, we get that, in a Kelvin–Voigt material, stress σ, strain ε, and their rates of change in time t

Table 1: Dissipation properties of transport discs.

Cycle no.	Anterior zone ψ Mean (SD)	Anterior zone ΔF (N) Mean (SD)	Intermediate zone ψ Mean (SD)	Intermediate zone ΔF (N) Mean (SD)	Posterior zone ψ Mean (SD)	Posterior zone ΔF (N) Mean (SD)
2	0.94 (0.27)	0.78 (0.09)	0.73 (0.15)	0.45 (0.18)	0.84 (0.27)	0.56 (0.46)
3	0.80 (0.22)	0.62 (0.10)	0.65 (0.08)	0.39 (0.11)	0.69 (0.23)	0.44 (0.38)
4	0.71 (0.18)	0.51 (0.08)	0.61 (0.07)	0.35 (0.11)	0.63 (0.20)	0.38 (0.31)
5	0.67 (0.17)	0.46 (0.07)	0.58 (0.07)	0.31 (0.12)	0.59 (0.16)	0.33 (0.24)
6	0.61 (0.15)	0.41 (0.06)	0.55 (0.07)	0.30 (0.13)	0.56 (0.15)	0.31 (0.24)
7	0.59 (0.14)	0.40 (0.05)	0.54 (0.07)	0.29 (0.11)	0.54 (0.13)	0.27 (0.20)
8	0.56 (0.13)	0.33 (0.04)	0.53 (0.07)	0.25 (0.10)	0.51 (0.12)	0.26 (0.18)
9	0.54 (0.12)	0.30 (0.04)	0.52 (0.07)	0.24 (0.10)	0.51 (0.11)	0.25 (0.15)
10	0.54 (0.12)	0.32 (0.02)	0.52 (0.08)	0.28 (0.12)	0.49 (0.10)	0.23 (0.14)

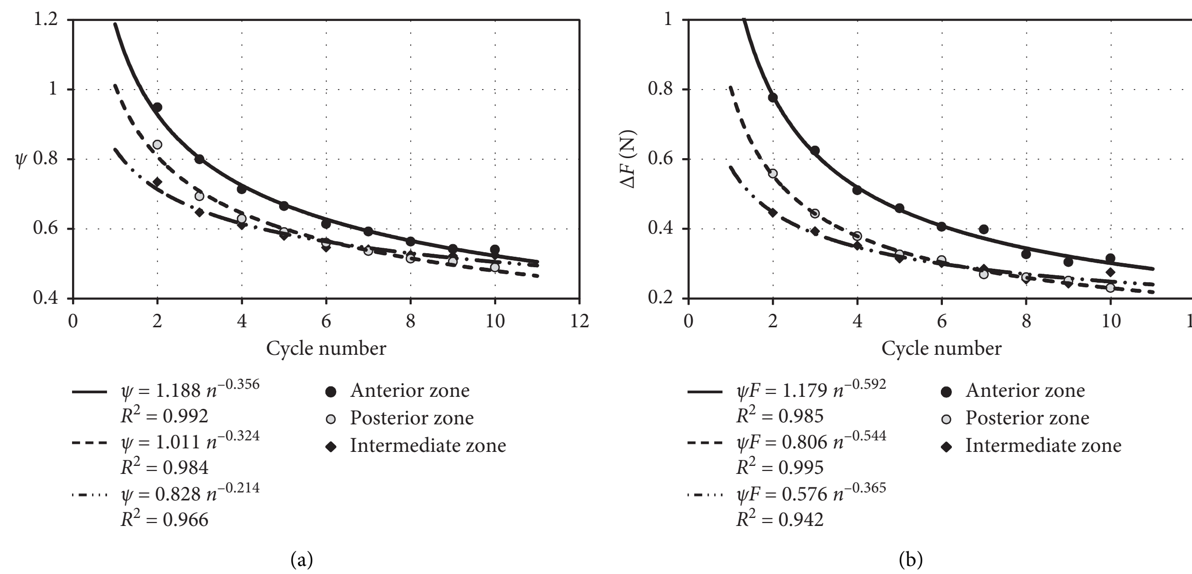

Figure 4: Average values calculated for particular load cycles: (a) energy dispersion coefficient ψ; (b) parameter ΔF.

are governed. The nonlinear rheological model proposed in this paper, which was used to model the articular disc tissues, is a good example of an experiment carried out on a testing machine.

3. Results

One of the fundamental elements of the model tests is the identification of physical parameters, which are stiffness and the energy dispersion coefficient. Biomechanical properties of evaluated discs, in particular the ability to recover the primary shape, after cessation of the load, are an individually variable feature. Under load conditions, both static and dynamic, in biological tissues, there are rheological phenomena, as a result of which the processes occurring in biological materials are predominantly reversible. In contrast to construction materials (technical), plastic deformation is most often of permanent nature. Despite the differences existing between biological and construction materials, the methodology of identification proceeds similarly, as the phenomenological description of phenomena is similar. In the identification of discs, biomechanical properties are carried out in the same manner as in the case of technical materials, such as rubber or steel. Means and standard deviations of biophysical parameters typical of dissipation properties of the studied TMJ discs in subsequent load cycles are specified in Table 1.

The effect of cyclical load on biomechanical properties of particular TMJ disc zones is shown graphically in Figures 4–6.

With the next load cycle, the disc tissue loses its ability to dissipate energy. In general, the dissipating properties are treated as a natural shock absorber, protecting the TMJ against overload (Figure 3).

The number of load cycles affecting disc tissues influences similarly parameter ΔF as the number of load cycles concerning the energy dispersion coefficient ψ (Figure 4(b)). The most significant difference of forces was observed during cyclical disc loading in the AZ area, while the lowest in the IZ zone. Between parameter ΔF and energy dispersion coefficient ψ, there is a linear causal relation (Figure 5(a)). The above dependence has been determined based on averaged data included in Table 1. This relation enables conducting an initial assessment of dissipation properties of

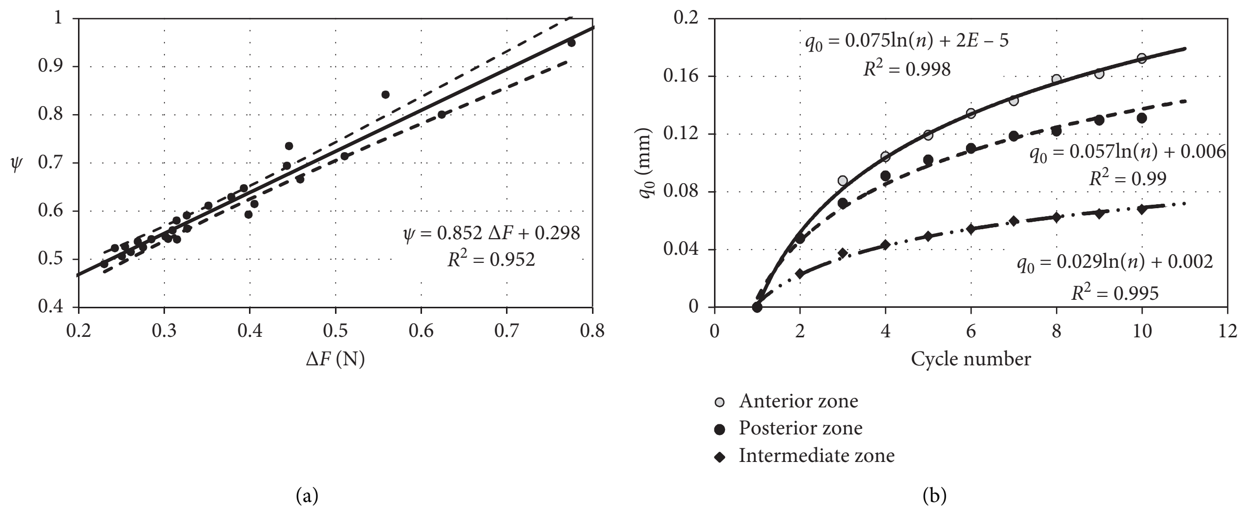

Figure 5: Model test results illustrating the effect of (a) energy dispersion coefficient ψ and (b) number of cycles on the parameter q_0.

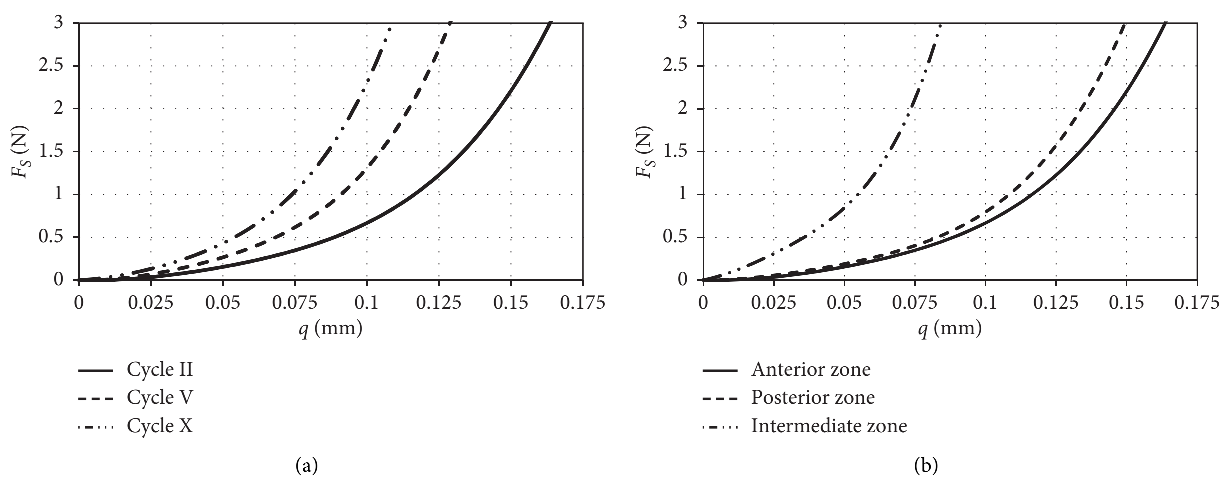

Figure 6: Course of static characteristics depending on (a) number of loading cycles and (b) TMJ disc load area.

discs already at the stage of experimental research. For this purpose, based on the prepared force-displacement characteristics, the value of parameter ΔF in the recorded load cycles should be determined. The upper and the lower confidence intervals pictured in the chart were calculated assuming the level of significance $\alpha = 0.01$. Based on completed measurements on the testing machine, it was stated that, after reaching a specified number of cycles, the material from which the discs are built reaches saturation. This phenomenon can be recorded on force-displacement characteristics and manifests itself in the stabilization of the hysteresis loop. One of the methods ensuring identification of the number of cycles at which disc tissue achieves saturation is the determination of initial displacements q_0 (Figure 5(b)). In the discussed approach, the disc has achieved saturation at the time of stabilization of the characteristics. The determined approximating curves clearly indicate that disc tissues achieve saturation most rapidly in the IZ zone. Regardless of the zone of disc load with external force, its static characteristics FS is stiffened along with the increase in the number of cycles (Figure 6(a)). The increment in load cycles makes elastic properties of examined areas show similar properties (Figure 6(b)). Additionally, primarily, it comes to levelling the rigidity of AZ and PZ disc regions, and it is determined by the thickness of particular examined areas.

The analysis of the obtained results indicates that the identified biomechanical properties of TMJ disc tissues may be with high accuracy, approximated with functions: polynomial, power, and logarithmic.

The model tests carried out indicate that, with the cyclic loading, the stiffness of the disc tissues increases (Figure 6). An increase in stiffness in individual load cycles causes a change in the directional factor of the biomechanical characteristics reproducing the relationship between displacement q and force F. The biomechanical characteristics in Figure 6 indicate that the stiffness of the disc in AZ and PZ zones is comparable. In the IZ zone, on the contrary, the disc is almost twice as rigid.

The change in biomechanical properties in particular cycles was identified based on hysteresis loops, which corresponded to particular load cycles. The loss of energy dissipation capacity is directly related to the reduction of hysteresis loops. In other words, the smaller the area of the hysteresis loop, the lower the energy dissipation capacity of the joint disc.

4. Discussion

TMD etiology has been proven to be multifactorial, and bite disorders may be one of the causes. The symptoms of TMD correlate with age, sex, and dental and occlusal conditions. [3, 4, 40]. The occurrence of bone lesions in the condyles correlates with age but poorly correlates with gender and condition of teeth and occlusion in patients with and without TMD [41].

In the correct occlusion, while clenching strong teeth, TMJ is not subject to greater loads. On the contrary, when it comes to the emergence of premature contacts, then it is possible to observe growth in occlusal forces. In normal occlusion, TMJ is generally not subject to greater strain when clamping teeth. In some patients, an increase in occlusive forces can be observed in case of premature contacts and increased chewing muscle tension.

These disorders may be natural and may also result from the actions of dentists. Both can lead to unnatural chewing patterns. This abnormal chewing pattern occurs in unnatural positions within the TMJs and the articular discs, resulting in dislocation, joint sounds, and pain in and around the TMJs. With age, there are also changes in condylar morphology: the condylar head and joint nodule are flattened. No changes in the joint angle (CPI) are observed [41]. Increased muscle tension also occurs in patients with bruxism. Few studies survey the relationship between bruxism and occlusal interferences. Manfredini et al. show that significant factors in the development of occlusal parafunctions are malocclusions and abnormal bites. It should be stressed that an occlusal aspect most often connected with psychological disorders gives the picture of full-blown bruxism [42].

The researcher also examined the psychic and occlusal factors in bruxism and concluded that there is an association between balancing side interferences and bruxism [42]. The stomatognathic system of patients appears to be able to accept and adapt to occlusal alterations because it has considerable adaptability. However, adaptation is possible within certain biological limits individually for each patient. Despite the substantial number of published papers about "TMD" and "occlusion," there are still controversy and contradictory opinions on the interaction between "occlusion" and "temporomandibular disorders." There is still existing confusion and contradiction in the dental literature about the role of "occlusion" in "TMD" [43].

It should also be borne is mind that the injuries as well as pathological states of the mastication organ may have an adverse impact on the biomechanical properties of discs. The damage created during injuries may often exceed the regenerative possibilities of TMJ discs and articular surfaces. The continuous, long-term load may be a source of increased friction, occurring between the disc and articular areas [44, 45]. This kind of load often contributes to an increase in porosity of articular surfaces. Excessive friction and load exceeding the maximum strength of the discs lead directly to the perforation of disc tissues. Tensile strength of disc tissues depends mainly on the direction and the area of external load. For instance, as Beatty and coauthors state [22], the maximum strength of IZ disc area is 37.4 MPa, when tensile stress operates in the direction front-back. While the load affects the central-transverse direction, the maximum strength is ca. 1.6 MPa.

The largest number of information about biomechanical properties of discs was obtained from research conducted on pigs and bovine discs, as they are structurally and functionally similar to human discs, which is indicated by some authors: Bermejo et al. [46] and Gonzales et al. [47]. Anatomically, in both of them, it is possible to distinguish strengthened anterior and posterior areas. In contrast, the IZ area is much thinner and hence more susceptible to the adverse effects of the load. The results of the assessments of the degree of human and pigs discs similarity are presented in the publication by Chladek and Czerwik [48], in which their thickness was measured down to 0.01 mm and the size of penetrator spherical cavity with a diameter of 5 mm. Additionally, the penetrator was pressed into the discs for ca. 15 s with force equal to about 1.2 N. As the similarity criterion the researchers assumed the percentage size of penetrator's cavity referred to the thickness of discs. Average relative errors of the thickness of human and pig discs in the AZ area amounted to ca. 7%, IZ ca. 31%, and PZ ca. 27%. On the contrary, average relative errors estimated based on penetrator's cavity amounted to 29% in the AZ area, 2% in the IZ area, and 27% in the PZ area. Such a similarity is sufficient and acceptable for implementation of further research, in the scope of the model loads evaluation, operating on human TMJ.

Research concerning the assessment of biomechanical properties of discs has already been published in many studies, e.g., Tanne et al. [49], Chin et al. [50], Lai et al. [51], and Tanaka et al. [52–54]. Comparing, however, research results obtained from various experiments causes tremendous difficulties, first of all, because discs are characterized by a nonuniform internal structure and individually variable biophysical properties. Also, the different course of the performed experiments is essential. The diversified methodology of conducting experimental research determines a broad spread of identified values of the elasticity modules that is within 1 to 100 MPa. Besides, its value is significantly affected by the speed of the studied tissue load. According to Beatty [22], the elasticity module of the pig disc stretched at 0.5 mm/s is ca. 27 MPa.

On the contrary, the elasticity module of the disc stretched at 500 mm/s is over three times greater and is ca. 83 MPa. These data indicate that it is necessary to define the guidelines that would standardize the course of experiments conducted on biological tissues. Only ensuring appropriate standards will enable us to compare the results obtained by various researchers. In addition, the main question should be asked: is the description of the elastic properties of discs showing nonlinear characteristics with Young's elasticity modulus reasonable methodically? Young's elasticity modulus is the coefficient including relations occurring between the stress and deformation following Hooke's law that characterizes mechanical properties of the materials only when they undergo elastic deformation. In a general sense, Young's elasticity modulus defines the directional coefficient of characteristic's inclination. In the case of materials showing linear mechanical properties, Young's modulus accepts a constant value regardless of material deformation. However, for materials of a nonlinear stress-deformation characteristics course, it is possible to determine many elasticity modulus values. It is caused by the fact that depending on the material deformation value, the directional coefficient of the tangential to characteristics is changed. Therefore, we are confronted by such a large spread of Young's modulus value, which can be found in published works.

Specialist literature, apart from publications where the authors focused on the evaluation of Young's elasticity modulus, on both human and animal discs, is also devoted to forcing-displacement characteristics research and stress-deformation. An example of this type of research is results published in the work by Beek et al. [55, 56] that were conducted on human discs from donors aged 73 to 86. On a specially designed laboratory post, the discs were deformed in cycles with a sinusoidal course in different areas. The obtained results indicate that, regardless of the deformation area, peak stress decreases with every subsequent cycle to the level until an agreed condition is reached. Additionally, peak stress in principle was determined after the fifth cycle. Such a nature of the course of biomechanical phenomena indicates cyclic relaxation of disc tissues. At this point, one should be reminded that cyclical material deformation in practice comes down to controlling cross-beam movement of the testing machine.

On the contrary, cyclical load differs from cyclical deformation because during material loading, the size controlled by the system of automatic regulation of the testing machine is the force. Results of identification presented in this paper were obtained in cycles loading discs, as a result of which the recorded temporary courses of deformation show the characteristics of cyclical crawling. From a theoretical point of view, the way of affecting material tissue plays no significant role, since, during cyclical deformation, as well as disc tissues load, part of the biomechanical energy is dispersed, as is stated by Tanaka and Van Eijden [57]. The formal basis for identifying its dissipation and elastic properties is hysteresis loops that are built based on force and displacement signals.

Based on the results of experimental and model tests, it can be stated that the number of load cycles substantially affects the surface area of the hysteresis loop, which means that, regardless of the zone of the examined disc area, its dissipation properties are being limited (Figure 3(a)).

A comparison of prepared dissipation properties of disc in AZ, IZ, and PZ zones indicates that the lowest ability to dissipate energy can be observed in the IZ disc zone. Accordingly, high number of load cycles, above five, makes the dissipation properties of particular disc zones demonstrate similar properties. The phenomenon taking place inside pig disc tissues is also proven by an increase in deformation, progressing despite unloading (Figure 2(b)). This phenomenon is visible very clearly in the first load cycles. This effect is limited along with subsequent cycles, and it should be assigned to the phenomenon of strengthening. Bearing the above in mind, it was decided to determine, as a significant function, also in each load cycle parameter ΔF, representing the difference of forces recorded during the loading and unloading of the TMJ disc. Additionally, this difference can be found for displacement q_1 defining the maximum value of recorded force during the loading phase. It is worth mentioning the fact that this phenomenon also exists in human disc tissues, which is proven by experimental research published in the work by Beek et al. [56].

We should have in mind that the biomechanical properties of discs are subject to changes as a result of various life factors. Comprehensive research was conducted as to alteration of viscoelastic properties, caused by ageing of the body, in skin or ligaments [58]. For instance, the elasticity modulus of a rat's skin increases along with maturation and decreases with the ageing of the body [59]. On the contrary, the authors in [60] demonstrated that, with the ageing of the body, the calcium content in discs increases. Lai, along with collaborators [51], showed that the elasticity module of human discs grew with age and suggested that it may be related to lowering the capability of collagen to remodel. Apart from collagen fibres, the disc contains a small number of flexible fibres. Collagen fibres provide the shape of the discs, while flexible ones are responsible for the restoration of its primary shape after cessation of load [61]. Collagen fibres are usually folded, at the moment of stretching the disc in the first place, and folds are stretched [62, 63]; however, in this phase, collagen fibres do not carry load [64]. Only in the subsequent phase, collagen fibres are stretched, and hence, they begin to carry the load.

Additionally, initially, these loads are small since the collagen net impedes the flow of interstitial fluid [65]. Further load makes the collagen net deform, as a result of which it comes to pressing the interstitial fluid from the loaded place through pores in the collagen net. The flow of fluid, as well as the change in the placement of collagen fibres, is reversible until the moment when the disc is deformed beyond the scope of physiological deformations. On the basis of the presented information, it can be assumed that, during the identification of biomechanical properties of disc tissues, it is inadvisable to conduct tests on cut-out samples. That is because during loading the cut samples, interstitial fluid is pressed out, as a result of which overestimated rigidity values are obtained. The effect of the preparation of samples for stress-deformation characteristics was presented in the work by Chladek and Czerwik [48]. Bearing in mind the information contained there, in this paper, we conducted experimental research only on discs, whose tissue consistency was not disturbed.

The authors of the manuscript are aware that despite its many advantages, the presented studies are not without limitations. They included a small number of tests and were carried out in conditions that are significantly different from physiological ones. However, as already mentioned, the movements of condylar are so complex that they cannot be simulated outside the living organism and, hence, the model tests.

5. Conclusions

The obtained results indicate that the cyclical loads affecting the joints adversely affect the ability of discs to dissipate energy:

(1) The most significant ability to dissipate energy was observed in the anterior and posterior zones of the TMJ disc. In the intermediate zone, the energy dissipation capacity is approx. 20% less than the anterior zone and about 10% less than the posterior zone.

(2) The joint disc tissues lose their ability to dissipate energy from the first load cycle. After ten load cycles, the energy dissipation capacity decreased by about 40%.

(3) Concerning the elastic properties, the intermediate zone is twice as rigid as the anterior and posterior zones. After ten load cycles, a 30% increase in joint disc stiffness was observed.

Such a statement is supported by clinical cases concerning patients with symptoms of teeth gritting and teeth occluding and excessively chewing gum, in whom symptoms of the mastication organ dysfunctions are observed. The obtained results indicate the importance of relaxation of masticatory muscles and unloading of the articular structures, both in the prevention and the treatment of temporomandibular conditions.

The results show how important it is to relax the masticatory muscles and relieve the stress on the joint structures, both in the prevention and treatment of TMD.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request (edward.kijak@umed.wroc.pl).

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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Review Article

Effectiveness of the Laser Application in Temporomandibular Joint Disorder: A Systematic Review of 1172 Patients

Abdalwhab Zwiri[1] **Manal Ahmad Alrawashdeh,**[2] **Mohammad Khan,**[1]
Wan Muhamad Amir W. Ahmad,[1] **Nur Karyatee Kassim,**[1,3] **Jawaad Ahmed Asif,**[1,3]
Khoo Suan Phaik,[4] **Adam Husein,**[1,3] **and Zuryati Ab-Ghani**[1,3]

[1]*School of Dental Sciences, Universiti Sains Malaysia, Health Campus, 16150 Kubang Kerian, Kota Bharu, Kelantan, Malaysia*
[2]*School of Computer Sciences, Universiti Sains Malaysia, 11800 Gelugor, Penang, Malaysia*
[3]*Hospital Universiti Sains Malaysia, 16150 Kubang Kerian, Kota Bharu, Kelantan, Malaysia*
[4]*Department of Oral Diagnostic and Surgical Sciences, School of Dentistry, International Medical University, 57000 Bukit Jalil, Kuala Lumpur, Malaysia*

Correspondence should be addressed to Abdalwhab Zwiri; dr_zwiri@yahoo.com and Zuryati Ab-Ghani; zuryati@usm.my

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Objective. The aim of this systematic review was to evaluate the effectiveness of laser application in temporomandibular joint disorder. *Methods*. PubMed, SCOPUS, Science Direct, Web of Science, and Google Scholar electronic databases were searched systematically with restricting the languages to only English and year (January 2001 to March 2020), and studies were selected based on the inclusion criteria. Study quality and publication bias were assessed by using the Robvis, a software package of *R* statistical software. *Results*. This systematic review included 32 studies (1172 patients) based on the inclusion and exclusion criteria. Most of the studies reported significant reduction of pain by the use of the laser during TMD treatment. Two-thirds of the study (78.13%) found a better outcome comparing with conventional one. According to Robvis, 84.4% of the studies were high methodological studies with low risk of bias. *Conclusion*. TMD patients suffer with continuous pain for long time even after conventional treatment. Laser therapy shows a promising outcome of pain reduction for TMD patients. Therefore, laser therapy can be recommended for the TMD patients' better outcome. This trial is registered with PROSPERO (CRD42020177562).

1. Introduction

Temporomandibular disorder (TMD) is defined as a series of clinical problems involving muscles of mastication, temporomandibular joints (TMJ), and related structures, identified by facial pain in the TMJ region and masticatory muscle, limited or deviated mandibular movement, and TMJ sounds during jaw movement and action [1]. While they have long been the subject of research, there are still many questions regarding their etiology, diagnosis, and management. Multifactorial TMD etiology is widely established, comprising the involvement of parafunctional behaviors, trauma, stress, and psychological, systemic, genetic, and occlusal causes. None of these variables has proved to outweigh the others, however [2]. The main reason for pain in the orofacial area that does not derive from dental arches is the TMD. In the community, at least one sign is confirmed by 40%–75% of healthy individuals, and at least one symptom of TMD is observed by 33%. 40–75% of healthy individuals in the population have at least one TMD sign, and 33% have at least one TMD symptom. Periarticular tissues (capsule, synovium, and TMJ ligaments), collateral ligaments, and posterior attachments are the most affected anatomical structures of TMJ due to these diseases [3]. Depending on the multifactorial etiology of these problems, the treatment typically requires more than one approach to optimize any potential results, such as medication, behavioral therapy, and physical therapy [2].

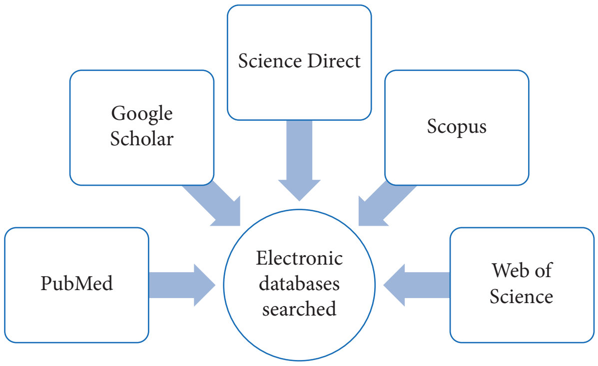

Figure 1: Five electronic databases searched for this review.

In the last few years, laser light has been extensively used in clinical dentistry for the treatment of soft tissue disorders, hypersensitivity of dentine, bone regeneration, and musculoskeletal pain. In TMD patients, LLLT has been used by conservative treatment methods to enhance function and decrease symptoms [3]. The main impacts of laser (LLLT) are biosimulative, regenerative, analgesic, and anti-inflammatory [4]. Helium-neon laser (He-Ne gas) and infrared laser with gallium-arsenium (Ga-As) diode or gallium-aluminum-arsenium (Ga-Al-As) rays are the most common types of laser rays. [5]. The LLLT, known as a soft laser, has low energy intensity and has no effect on skin temperature. The main effect of LLLT is based on the light-absorption process. This soft laser has a wavelength of between 630 nm and 1300 nm [3]. The relative clinical effectiveness of LLLT in treating temporomandibular (TMD) disorders is controversial. Several authors identified LLLT's effectiveness as superior to placebo treatment, while others observed no significant differences between LLLT and placebo for TMJ pain measures, in the view of fact that outcomes in LLLT trials can rely on sample size, population, treatment protocols, and methodology [6, 7].

Therefore, the aim of this systematic review was to find out the effectiveness of laser application in temporomandibular joint pain and review the evidence from previous studies with their sample size and methodology in the management of TMD. This review will provide a precise and obvious knowledge about the benefits and procedures of laser application, which have already been successfully established in TMD management.

2. Materials and Methods

2.1. Search Strategy. Articles were searched in five electronic databases (Figure 1) where the following keyword combinations were used: TMJD + laser, TMJ problem + laser, TMD + laser, TMJD/TMD management + laser application, and TMJ + laser application. Articles between the year 2001 and 2020 were reviewed and systematically searched for those literature published until March 2020. After final screening, total of 32 articles were included in this systematic review. The search encompasses articles (full text) written in English and published in peer-reviewed journals related to TMJ diseases where laser application was performed in different levels.

2.2. Study Selection. Here, the prime concern was to find out the uses of laser in temporomandibular disorder patients in terms of reduction of pain and tenderness, improvement of mouth opening and joint sounds, and improvement in the range of jaw motion. The criteria for inclusion have been established as papers using the search keywords mainly TMJ problems and laser application. At the other side, the papers that use laser in TMJ diseases along with other problems such as anatomical defects, anomalies, myofascial pain disorder syndrome (MPDS), soft and hard tissue pathology (tumor, cancer), and previous record of TMJ surgery were excluded from the study. In the context of the exclusion criteria, it also added that those studies were not conducted in human (such as animal studies), and publications in other languages beside English were excluded. The case reports and letter to editor were also excluded from this review. Titles and abstracts of identified studies were assessed independently to judge if the studies match the inclusion criteria.

2.3. Data Extraction and Organization. Data were extracted based on the first author, year of publication, number of samples, age and gender of samples, types of TMJ problem, laser types, laser energy and application rate, and results. The data were extracted and double-checked by the authors.

3. Results

3.1. Selection of Studies. At the beginning, this research search strategy provided a total of 5889 papers from databases such as PubMed, Web of Science, Google Scholar, SCOPUS, and ScienceDirect. The remaining 2378 papers were further screened after eliminating 3511 papers in the detection phase (nonhuman topics, summary documents, case reports, editorials, letters and comments, and duplicate studies). A total of 72 studies were considered worthy, but due to unusable data format, forty studies were excluded. Thus, eventually, based on the research goals and inclusion and exclusion requirements, 32 studies (1172 TMD patients in total) were included in this study (Figure 2), and the full text of all the included studies has been retrieved.

3.2. Study Characteristics. The key characteristics of the included studies are presented in Table 1. All the studies included were journal articles and most are adults. Among these 32 studies, thirteen were conducted in Brazil, five in European continent and Iran, respectively, three from India, two from Turkey and Taiwan, and one from Malaysia and Iraq. Ga-Al-As (LLLT) laser with a variation of 780–904 nm wavelength is used in most of the studies to treat the TMD patients. Twenty-five studies reported better outcome by reduction of TMD pain compared with conventional treatment modalities, while 7 studies did not find any significant difference between conventional and laser treatment.

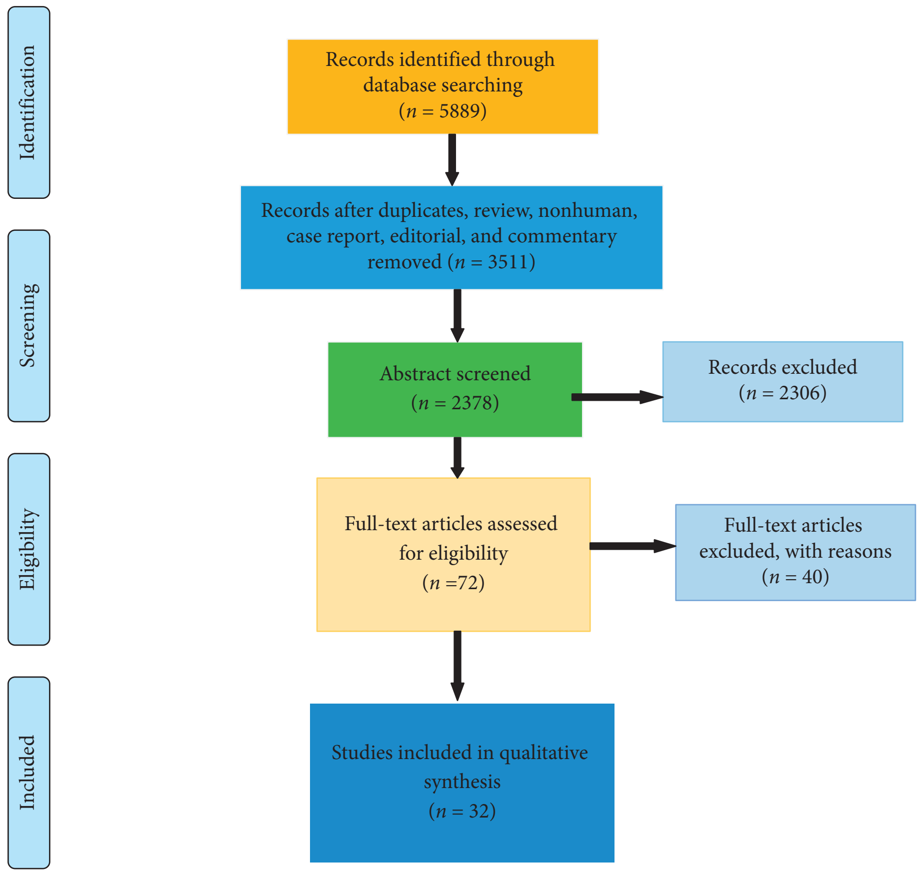

Figure 2: PRISMA flow chart diagram of search strategy and selection of the studies.

3.3. Risk of Bias Assessment. Publication bias was assessed by using *R*-based Robvis software package introduced by the National Institute for Health Research (NIHR) [36]. Based on visual inspection of the figure, there is no protentional publication bias in this study assessing the effectiveness of laser treatment for TMD patients (Figure 3). Out of 32 studies, twenty-seven (84.4%) are high methodological studies, which have an overall low risk of bias with some concerns, while only 5 studies have only high risk of bias.

4. Discussion

TMD management is very complex and contentious due to the difficulty of determining the exact reasons of the disease and its multifactorial character. The severity varies greatly, and the procedure is varying in terms of duration and invasiveness. Nevertheless, TMD treatment is intended to minimize discomfort, enhance mobility, and delay the progression of internal derangement as accepted by the American Society of Temporomandibular Joint Surgeons guidelines [1]. TMD has a multifactorial nature or etiology; therefore, it is very difficult to get the desired treatment outcome, especially for those patients experiencing severe pain and limited jaw movements.

However, this systematic review tried to overview the role of laser in the management of TMJ disorder patients. After completing this review, the result showed a huge role of laser in TMD management. Most of the studies used LLLT for management of TMD, where it showed a tremendous action in reducing pain, joint clicking, muscle tenderness, and jaw movements.

A study was conducted by Kulekcioglu et al. in 2003 among Turkish population to investigate the effectiveness of low-level laser therapy in the treatment of TMD. Results of the study showed a significant reduction of pain and improvement in maximum mouth opening, lateral motion, and number of tenderness points. According to Kulekcioglu et al. , LLLT in treating TMD may be considered as an alternative physical modality [8]. Another study by Kogawa et al. also found an increase in maximum mouth opening and a decrease in tenderness to palpation in TMD patient after receiving LLLT. Author recommended that LLLT was effective in the management of myogenic TMD [9].

On the other hand, some researchers also tried to find out the effectiveness of the laser treatment in TMD patient, and they concluded with no significant role of LLLT. In 2005, Abreu et al. conducted a study to assess the efficacy of low-intensity laser therapy (LILT) in temporomandibular joint (TMJ) pain and mandibular dysfunction patients. The study had 2 groups, placebo and experimental (LILT). They used the infrared laser (780 nm, 30 mW, 10 s, and 6.3 J/cm2) at three TMJ points. Even though the patient treated with laser had good pain reduction, the result showed no significant changes between placebo and laser groups.

Table 1: Major key characteristics of the included studies in this systematic review.

Author and year	Study population	Sample size	Study design	Age/gender	Problem	Laser type	Energy and application rate	Results
Kulekcioglu et al., 2003 [8]	Turkey	35 patients	RCT	20–59 years (female = 28, male = 7)	Orofacial pain, TMJ sounds, limited mouth opening, or TMJ locking	Ga-Al-As (LLLT), 904 nm wavelength	180 seconds, dosage: 3 J/cm^2 (15 sessions)	Significant reduction of pain and improvement in maximum mouth opening and lateral motion
Kogawa et al., 2005 [9]	Brazil	19 patients	RCT	Mean age, 26.4 years (female = 19, male = 0)	Temporomandibular disorders (TMDs)	Ga-Al-As (LLLT), wavelength of 830–904 nm	4 J/cm^2 (3 times a week, 10 sessions)	Significant increase in maximum mouth opening and a decrease in tenderness
Abreu Venancio et al., 2005 [10]	Brazil	30 patients	RCT	Not given	Temporomandibular disorders (TMDs)	Ga-Al-As (LILT), 780 nm wavelength	6.3 J/cm^2 (twice a week for 3 weeks, 6 sessions)	No significant changes
Kato et al., 2006 [2]	Brazil	18 patients	RCT	Mean age, 25.6 years	Temporomandibular disorders (TMDs)	LLLT, wavelength of 830–904 nm	4 J/cm^2 energy density (10 sessions, 3 times a week for 4 weeks)	Significant decrease in pain and improvement in muscle tenderness
Núñez et al., 2006 [11]	Brazil	10 patients	Non-RCT clinical trials	18–56 years (female = 8, male = 2)	Temporomandibular disorders (TMDs)	Ga-Al-As (LILT), 670 nm wavelength	3 J per site, total time 8 minutes	Significant improvement in mouth opening
Emshoff et al., 2008 [7]	Austria	52 patients	RCT	18 to 58 years	Patients with unilateral TMJ pain	Red-beam laser, 632.8 nm HeNe laser	1.5 J/cm^2 energy density (2 to 3 treatments per week for 8 weeks)	No significant differences in reducing pain
Cunha et al., 2008 [12]	Brazil	40 patients	RCT	(Female = 39, male = 1)	Temporomandibular disorders (TMDs)	Ga-Al-As (LLL), 830 nm wavelength	20 seconds, 100 J/cm^2 (once a week for 4 weeks)	No significant changes
Graciele Carrasco et al., 2008 [13]	Brazil	14 patients	RCT	Not given	Temporomandibular dysfunction (TMD)	Ga-Al-As (LILT), 780 nm wavelength	60 seconds, 105 J/cm^2 (twice per week for 4 weeks)	Significant improvement of masticatory efficiency
Lassemi , 2008 [14]	Iran	48 patients	RCT	(Female = 24, male = 24)	Temporomandibular disorders (TMDs)	Ga-As (LLLT), 980 nm wavelength	2 J per point (2 sessions with a 48-h interval)	Significant reduction of pain severity and clicking
Raheem et al., 2010 [5]	Iraq	34 patients	Non-RCT, convenience sampling	(Female = 21, male = 13)	Temporomandibular disorders (TMDs)	Semiconductor galium-aluminium (gas) LLLT, 785 nm wavelength	Energy density of 16 J/cm^2 (twice to thrice weekly and repeated 4 weeks, total 10 sessions)	Significant reduction of pain and improvement in maximum mouth opening, lateral motion, and muscle tenderness
Mazzetto et al., 2010 [15]	Brazil	40 patients	RCT	Not given	Temporomandibular disorders (TMDs)	Ga-Al-As (LLL), 830 nm wavelength	10 s, 5 J/cm^2	Significant improvement in pain reduction and mandibular movement
Dostalová et al., 2012 [16]	Prague	27 patients	Non-RCT	Mean age of male 18.57 and female 27.57 years	Temporomandibular disorders (TMDs)	Ga-Al-As (LLL), 830 nm wavelength	15 s, 4 J/cm^2 (once a week for 5 weeks)	Significant reduction of pain

Table 1: Continued.

Author and year	Study population	Sample size	Study design	Age/gender	Problem	Laser type	Energy and application rate	Results
De Godoy et al., 2013 [17]	Brazil	85 patients	RCT	15 and 18 years	Temporomandibular disorders (TMDs)	Ga-Al-As (LLL), 780 nm wavelength	20 s, 25 J/cm^2 (6 weeks, a total of 12 sessions)	Not significant
Catão et al., 2013 [18]	Brazil	20 patients	RCT	19 to 58 years (female = 18, male = 2)	Temporomandibular disorders (TMDs)	As-Ga-Al laser (830 nm wavelength), InGaAIP laser (830 nm wavelength)	4 J/cm^2 (three times a week for 4 weeks, 12 sessions)	Significant reduction in pain and improvement in mouth opening
Madani *et* al., 2014 [19]	Iran	20 patients	RCT	35–60 years (female = 19, male = 1)	TMJ osteoarthritis	LLLT (low level laser), 810 nm wavelength	6 J per point, 3.4 J/cm^2 (three times a week for 4 weeks)	No significant differences (for reducing pain and improving mouth opening)
Pereira et al., 2014 [20]	Brazil	19 patients	RCT	21–55 years (female = 15, male = 4)	Temporomandibular disorders (TMDs)	LLLT, wavelength: 660 nm (red laser) and 795 nm (infrared laser)	4 J/cm^2 (an interval of 48 hours, total 3 sessions)	Statistically significant in the treatment and remission of TMD symptoms
Sayed et al., 2014 [21]	India	20 patients	RCT	19–47 years (female = 9, male = 11)	Temporomandibular disorders (TMDs)	LLLT semiconductive (diodic) gallium arsenide (GaAs) laser, 904 nm wavelength	60 s, 4 J/cm^2 (3 times a week for 2 weeks)	Statistically significant in reducing the pain intensity, tenderness, joint sounds, and improvement in the range of jaw motion
Huang et al., 2014 [22]	Taiwan	20 patients	RCT	Not given	Temporomandibular joint disorders (TMDs)	LLLT, 800 nm wavelength	100.5 J/cm^2 (once a week)	Significant reduction of pain
Hu et al., 2014 [23]	Taiwan	29 patients	Retrospective convenience	17–67 years (female = 25, male = 4)	Temporomandibular disorders (TMDs)	Ga-Al-As (LLL), 810 nm wavelength	5s, 0.375 J/cm^2 (3 times per week for 4 weeks)	Significant improvement of treatment-resistant TMD
Seifi et al., 2017 [24]	Iran	40 patients	RCT	18–50 years	Temporomandibular joint disorders (TMDs)	Ga-Al-As (LLL), 810 nm wavelength	(Four half-hour sessions per week)	Significant decrease in pain and tenderness
Rezazadeh et al., 2017 [25]	Iran	45 patients	RCT	Not given	Temporomandibular disorders (TMDs)	Ga-Al-As (LLL), 980 nm wavelength	2.5 minutes, 5 J/cm^2 (8 sessions within 2 weeks)	Significant reduction of pain and tenderness
Douglas de Oliveira et al., 2017 [26]	Brazil	19 patients	RCT	21–55 years (female = 15, male = 4)	Temporomandibular disorders (TMDs)	Ga-Al-As (LLL), wavelength: 660 nm (red laser) and 790 nm (infrared laser)	1.06 s, 8 J/cm^2 (3 sessions)	Statistically significant in the treatment of TMD
Basili 2017 [27]	Italy	180 patients	Non-RCT	Not given	Temporomandibular disorders (TMDs)	LLLT, 830 nm wavelength	3 sessions	Significant reduction of pain
De Godoy et al., 2017 [28]	Brazil	16 patients	RCT	14–23 years	Temporomandibular disorders (TMDs)	LLLT, 780 nm wavelength	20 s, 25 J/cm^2 (12 sessions)	No significant changes
Shobha et al., 2017 [29]	India	40 patients	RCT	18–40 years	Temporomandibular disorders (TMDs)	Ga-Al-As (LLLT), 810 nm wavelength	60 s, 6 J/cm^2 (2-3 times a week, 8 sessions)	No significant changes

Table 1: Continued.

Author and year	Study population	Sample size	Study design	Age/gender	Problem	Laser type	Energy and application rate	Results
Kashmoola 2018 [1]	Malaysia	22 patients	Non-RCT	18–68 years	Temporomandibular disorders (TMDs)	LLLT	2-3 minutes, 0.5 W, 30 Hz daily for 3 days and then once a week for 2 weeks	Significant reduction of pain
Buduru et al., 2018 [30]	Romania	20 patients	Non-RCT	Not given	Temporomandibular joint disorders (TMDs)	LLLT, 660 nm wavelength	Energy intensity 90 mW (once each day, five days per week, for a total of 10 sessions	Significant reduction of pain
Peimani et al., 2018 [31]	Iran	72 patients	RCT	20–45 years	TMJ dysfunction	LLLT, 808 nm wavelength	144 J/cm^2 (2 times a week for 4 weeks)	Significant reduction of pain, clicking, and tenderness
Del Vecchio et al., 2019 [32]	Italy	90 patients	RCT	18–73 years (female = 78, male = 12)	Temporomandibular joint disorders- (TMJDs-) related pain	LLLT, 808 nm wavelength	5 J/min (twice a day for 7 days)	Significant reduction of pain
Tortelli et al., 2019 [33]	Brazil	12 patients	RCT	23–50 years	Temporomandibular disorders (TMDs)	LLLT, 808 nm ± 10 nm wavelength	2 J, (72h intervals, for a total of 6 sessions)	Significant decrease in pain and improve maximal opening capacity
Khairnar et al., 2019 [34]	India	42 patients	RCT	25–45 years	Temporomandibular joint disorders (TMDs)	LLLT, 660 nm wavelength	2.2 J/min	Significant role in treating TMD-related pain
Yamaner et al., 2020 [35]	Turkey	62 patients	RCT	Mean age, 31.51 ± 10.32 years (female = 59, male = 3)	Temporomandibular disorders (TMDs)	LLLT, 820 nm wavelength	10 s, 3 J/cm^2 (3 times a week, total 6 sessions)	Significant reduction of pain

Risk of bias domains

Study	D1	D2	D3	D4	D5	Overall
Kulekcioglu et al. (2003)	+	+	+	+	+	+
Kogawa et al. (2005)	−	+	+	+	+	+
De Abreu et al. (2005)	−	+	−	+	+	−
Kato et al. (2006)	+	+	×	+	−	×
Núñez et al. (2006)	×	×	+	+	−	+
Emshoff et al. (2008)	+	×	−	+	+	−
da Cunha et al. (2008)	+	−	−	×	+	−
Graciele et al. (2008)	+	−	+	+	+	+
Lassemi et al. (2008)	+	+	+	+	+	+
Raheem et al. (2010)	−	+	+	+	+	+
Mazzetto et al. (2010)	−	+	−	+	+	−
Dostalová et al. (2012)	+	+	×	+	−	×
De Godoy et al. (2013)	×	×	+	+	−	+
da Vasconcelos et al. (2013)	+	×	−	+	+	−
Madani et al. (2014)	+	−	−	×	+	−
Pereira et al. (2014)	+	−	+	+	+	+
Sayed et al. (2014)	×	×	+	+	−	+
Huang et al. (2014)	+	×	−	+	+	−
Hu et al. (2014)	+	−	−	×	+	−
Seifi et al. (2017)	+	−	+	+	+	+
Rezazadeh et al. (2017)	+	+	+	+	+	+
Douglas et al. (2017)	−	+	+	+	+	+
Basili et al. (2017)	−	+	−	+	+	−
De Godoy et al. (2017)	+	+	×	+	−	×
Shobha et al. (2017)	−	+	+	+	+	+
Kashmoola et al. (2018)	−	+	−	+	+	−
Budura et al. (2018)	+	+	×	+	−	×
Peimani et al. (2018)	×	×	+	+	−	+
Del Vecchio et al. (2019)	−	+	+	+	+	+
Tortelli et al. (2019)	−	+	−	+	+	−
Khairnar et al. (2019)	+	+	×	+	−	×
Yamaner et al. (2020)	×	×	+	+	−	+

Domains:
D1: bias arising from the randomization process
D2: bias due to deviations from intended intervention
D3: bias due to missing outcome data
D4: bias in measurement to the outcome
D5: bias in selection of the reported result

Judgement:
× High
− Some concerns
\+ Low

Figure 3: Risk of bias assessment of the study.

Therefore, the researcher did not recommend infrared LILT as a better treatment option. Though there are benefits of applying laser in TMDs management because of non-invasiveness and cost efficient, it has no reported side effects [10]. Another research was performed by Emshoff et al. in Austrian population to evaluate the effectiveness of LLLT in TMJ pain management. A red-beam laser (Model 2000; Helbo Medizintechnik, Austria) (632.8 nm HeNe laser, continuous wave, 30 mW output power, 1.5 J/cm2 energy density) was used. They used three follow-ups from baseline to measuring the visual analogue scale (VAS). The results also presented no significant changes in the management of TMJ. The study recommends that LLLT is no better at minimizing TMJ pain during action than placebo [7]. Similarly, da Cunha et al. reported no significant difference between placebo and laser groups [12]. Authors used Ga-Al-As (gallium-aluminium-arsenide) low-level laser (Biolux laser – Bio-Art, São) with 830 nm wavelength and an output of 500 mW for 20 sec. This study used craniomandibular index (CMI) and VAS for measuring effectiveness of treatment, which results in no significant difference in 2 different protocols, while the patient treated with LLLT reported better pain reduction [12].

Although some authors did not notice any important differences, some studies showed better results when comparing the LLLT with a placebo control group. In 2010, Raheem et al. observed that LLLT plays a significant role in TMDs management by reducing pain and improving maximum mouth opening, lateral motion, and muscle tenderness. Raheem et al. advised LLLT as an effective therapeutic option in myofascial pain dysfunction of TMJ for its analgesic and functional improvement [5].

Even though LLLT is a type of treatment widely applied in physiotherapy of musculoskeletal disorders, there are only some studies that discuss its use in the management of TMD. In 2012, Dostalová et al. performed a research to observe the activity of TMJ and its surrounding tissues and compared the objective results of the effect of LLLT. LLLT was beneficial in the progress of the range of TMD and facilitated a significant pain symptoms reduction [16]. According to Catao et al. , laser therapy was very effective in the pain control and mouth opening of TMDs patients [18]. A study conducted by Sayed et al. confirmed LLLT with satisfactory outcome reducing the pain intensity, number of tender points, joint sounds, and improvement in the range of jaw movement. Therefore, it is an effective and efficient method for treating TMDs [21].

Few more studies have been performed in 2017 by several researchers to evaluate the effectiveness of laser therapy in the treatment of TMDs. Based on the sample size, population, and study design, the result showed some controversy about laser treatment. In 2017, Rezazadeh et al. examined 45 Iran patients to discover the effectiveness of transcutaneous electrical nerve stimulation (TENS) and LLLT in treatment of TMD patients who did not respond to pharmacological therapy. The result showed a significant reduction of pain and tenderness in TMD patients [25]. Another study was performed by Seifi et al. in 40 patients of Iran to assess the result of low-level laser (LLL) therapy and transcutaneous electric nerve stimulation (TENS) on TMDs. The author suggested that TENS or LLL therapy may be useful in improving TMD symptoms at least for the short term [24]. de Godoy et al. carried out a study using a wavelength of 780 nm, energy density of 25 J/cm^2, power of 50 mW, power density of 1.25 W/cm^2, and a 20-second exposure. He did not find any significant differences after laser application [28]. This may be the use of the measurement tool used in the study. They compared the difference with the help of electromyography (EMG) signal, while VAS is more specific, accurate, and widely used for pain assessment. Similarly, Shobha et al. conducted a study using 8 sessions of active LILT with a specific diode laser (gallium-aluminum-arsenide, 810 nm, 0.1 W), while the most commonly used therapeutic laser in laser research has been the Ga-As-Al, a semiconductor laser. The laser group showed better improvement in pain reduction even after the 1-month follow-up compared to the placebo group in the VAS score, having no overall significant differences after receiving LLLT [29].

Though, clinically, the use of LLLT is a better procedure in managing TMJ pain. In 2018, a study completed by Buduru et al. showed a significant pain reduction and noticed that there is no disadvantage of LLLT. Thus, the author had recommended the use of LLLT for pain reduction in TMD patients [30]. According to Del Vecchio et al. , LLLT can significantly reduce TMD pain symptom, and it is very much effective in TMJD pain management (Del Vecchio et al.). Another study performed by Khairnar et al. also found a significant reduction of TMDs pain with LLLT. That study recommends LLLT for treating TMD-related pain with no underlying bony pathology [34].

In the present year 2020, a study was conducted by Yamaner et al. in Turkey to investigate the impact of the ozone and low-level laser (LLL) therapies on pain and function in TMDs patients with disc displacement with reduction. The results of the study support the application of ozone as an effective therapeutic tool for pain relief and LLL as a supportive therapy for temporomandibular disorders [35]. In this systematic review, the author tried to investigate the effectiveness of laser application in temporomandibular joint pain. However, the goal of this systematic review has been achieved. From the above discussion, it is clear that the use of laser in TMD patient is controversial because of its positive and negative outcomes in several studies. But after this review, it can be clearly suggested that the use of the laser has been recommended by most of the researchers. Laser application plays an effective and potential role in the treatment of TMDs patients.

Although the present study went through a systematic search strategy and review of the selective articles, one of the limitations of the present study was the database searching. Due to the limited access of database, the author only searched in five specific databases. This study advised to perform another systematic review with meta-analysis by including some more databases searching to strengthen the findings.

5. Conclusion

TMD patients mostly suffer with pain symptoms along with other problems. Nowadays, LLLT became very popular because of its effective role in pain reduction and no known side effects. This systematic review evaluated the effectiveness of the laser application in TMD patient by thorough investigation of the previous studies that have been conducted on laser. After this systematic review, LLLT can be recommended as a beneficial treatment approach for TMD patients.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication. All authors were involved in this study in different phases. AZ, MAA, and MK were involved in the study protocol design and database searching. ZG, AZ, and MK were involved in the study selection. Any dispute was discussed and solved with WMWA, NKK, JAA, KSP, and AH. AZ and MK wrote the manuscript, and all others edited and improved the manuscript for submission standard.

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Clinical Study

Electromyography as a Means of Assessing Masticatory Muscle Activity in Patients with Pain-Related Temporomandibular Disorders

Liliana Szyszka-Sommerfeld,[1] **Monika Machoy**,[1] **Mariusz Lipski**,[2] **and Krzysztof Woźniak**[1]

[1]*Department of Orthodontics, Pomeranian Medical University of Szczecin, Al. Powstańców Wlkp. 72, 70111 Szczecin, Poland*
[2]*Department of Preclinical Conservative Dentistry and Preclinical Endodontics, Pomeranian Medical University of Szczecin, Al. Powstańców Wlkp. 72, 70111 Szczecin, Poland*

Correspondence should be addressed to Liliana Szyszka-Sommerfeld; liliana.szyszka@gmail.com

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Aim. The aim of this study was to evaluate masticatory muscle electrical activity in patients with pain-related and pain-free temporomandibular disorders (TMDs) as well as in subjects with no TMD. *Methods*. Ninety children with mixed dentition were recruited to the study. Of this total, 30 subjects were diagnosed with pain-related TMD (TMD-P), 30 with pain-free TMD (TMD-PF), and 30 without TMD. We used Axis I of the Research Diagnostic Criteria for TMD (RDC/TMD) to assess the presence of TMD in the examined children. The electromyographical (EMG) potentials of the temporalis and masseter muscles were measured with a DAB-Bluetooth Instrument (Zebris Medical GmbH, Germany) at rest and during maximum voluntary clenching (MVC). *Results*. An analysis of the EMG recordings showed statistically significant intergroup differences in masticatory muscle electrical activity at rest and during MVC. Significantly higher rest temporalis muscle activity was noted in pain-related TMD subjects compared with that children from the pain-free TMD and non-TMD groups, as well as in TMD-PF children in relation to those without TMD. The EMG potentials of the temporalis muscle during MVC were much lower in patients with TMD-P than in pain-free TMD and non-TMD subjects. Masseter muscle activity at rest in the TMD-pain group was significantly greater, and masseter muscle EMG potentials during clenching were markedly lower than in patients with no TMD diagnosis. *Conclusion*. The use of electromyography to assess masticatory muscle function revealed alterations in the pattern of temporalis and masseter muscle activity in patients with pain-related TMD compared with the pain-free subjects.

1. Introduction

Temporomandibular disorders (TMDs) are associated with a number of clinical conditions that affect the stomatognathic system, in particular the masticatory muscles and the temporomandibular joint (TMJ) as well as associated structures [1–3]. The principal signs and symptoms of TMDs are muscle and joint tenderness or pain, joint noises, and disturbances in mandibular movements. The pain associated with TMD is persistent, recurring, or chronic in nature and not only concerns the TMJ and masticatory muscles but may also radiate to adjacent structures such as the teeth, ears, the neck, temples, forehead, and back muscles [2–4].

Factors that may play an important role in TMD multifactorial aetiology include traumas, local conditions such as occlusal interferences as well as systemic, iatrogenic, and psychological aspects [5–7].

Temporomandibular disorders are the main nondental cause of orofacial pain in children and adolescents [8]. The prevalence of TMD-signs and symptoms is rare in early childhood but becomes more in adolescence and adulthood. Previous epidemiological studies have reported subjective symptoms of TMD in between 1% and 50% of children and adolescents in the general population and pain-related TMD in between 1% and 22% of the youngest group of subjects [9–14]. The prevalence of TMD-signs in children and adolescents ranges from 3% to 33% [10–12, 15].

One of the most advanced and useful diagnostic tools providing clinical and research criteria for objective TMD assessment are the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) [2, 16]. This tool helps identify both physical and psychosocial aspects, standardizes the procedures followed in epidemiological studies, and has shown acceptable reliability in children and adolescents [17, 18]. Surface electromyography (sEMG) is widely applied as an additional noninvasive tool for assessing patients with TMD as well as for observing the electrophysiological behaviour of muscles under a variety of physiological conditions [19–25]. Due to the simplicity of this method and its safety and availability, it has also been used in studies on children [26–28]. An EMG evaluation of masticatory muscle function in TMD subjects provides a basis for diagnosing the disease, monitoring its progression and measuring the effectiveness of treatment. Numerous studies have shown that patients with TMD exhibit alterations in masticatory muscle EMG activity either as a result of the disorder itself or due to a compensatory mechanism associated with the symptoms [20, 29–32]. It has been demonstrated that individuals with pain-related TMD may alter the recruitment of their masticatory muscles as a result of sensorial-motor interactions, the pain associated with which it can modify the formation of action potentials and, possibly, myoelectric activity [33, 34]. In this context, it is important to determine the masticatory muscle electrical activity in patients with TMD, including pain-related TMD and pain-free TMD subjects.

To the authors' knowledge, only a few studies have been conducted on masticatory muscle function in the children with TMD [26, 27, 35]. As a consequence, research on the electromyographical activity of the masticatory muscles in such subjects with TMD problems is needed. Investigating the electromyographic features of children with TMD is key to early identification of problems that predispose such patients to pain and muscle/joint dysfunction in adulthood as well as to the development of treatment strategies that can improve their muscle function and prevent persistent TMD later in life [26, 35].

The aim of the study was to evaluate the EMG activity of the masticatory muscles in children with pain-related and pain-free TMD as well as in subjects with no TMD. We hypothesized that, in the case of EMG potentials of the temporalis and masseter muscles at rest and during maximum clenching, no differences exist between the analysed groups of patients.

2. Materials and Methods

2.1. Ethical Approval. The study protocol was approved by the Local Bioethics Committee of the Pomeranian Medical University and was assigned the number KB-0012/08/15. All the children's parents gave their informed consent to all the procedures performed. This clinical research was also registered as a case-control study in the ClinicalTrials.gov database and was assigned the number NCT04409067.

2.2. Participants. Ninety children with mixed dentition were recruited to the study. The subjects had been referred to the Orthodontic Clinic in Szczecin, Poland, for orthodontic treatment. We used Axis I of the Research Diagnostic Criteria for TMD (RDC/TMD) to assess the presence of TMD in the examined children. All the subjects were subdivided into three nonoverlapping groups: a TMD-pain group, a pain-free TMD group, and a non-TMD group. The groups were matched for age and gender. The inclusion criteria for all groups were mixed dentition (the subjects should be aged between 7 and 12 years) and express consent to participate voluntarily in the study. The TMD-pain group consisted of 30 children (16 girls and 14 boys) aged between 7.1 and 12.3 (mean 8.8 ± 1.5) with a pain-related TMD diagnosis. All the patients in the TMD-pain group had myogenous or arthrogenous TMD according to the RDC/TMD protocol. The pain-free TMD group consisted of 30 children (14 girls and 16 boys) between 7.3 and 12.6 years of age (mean 9.0 ± 1.3). To be included in the pain-free TMD group, the participants had to meet Axis I of the RDC/TMD criteria for a pain-free TMD diagnosis. The non-TMD group comprised 30 children (15 girls and 15 boys) aged between 7.2 and 12.5 (mean 8.9 ± 1.6) without any recognised TMD based on RDC/TMD, Axis I. Excluded from these study groups were subjects who had undergone orthodontic or masticatory motor system dysfunction treatment, systemic or rheumatologic diseases, a history of mouth breathing, surgery, traumas, or malformations in the head and neck regions.

2.3. Clinical and EMG Examination. The function of the stomatognathic system was assessed by means of a clinical and electromyographic examination. In the first part of the clinical examination, we took the general medical history of the patients. This included information on subjective TMD symptoms are jaw pain during functional activities, occurrence of frequent headaches, stiffness/fatigue of the jaw, limited mouth opening, grinding or clenching of teeth, and possible presence of TMJ noises. During the second part of the clinical examination, the children were diagnosed with one or more disorders according to RDC/TMD Axis I: Group I: muscle disorders (Ia with myofascial pain; Ib with myofascial pain with limited opening), Group II: disc displacements (IIa with reduction; IIb without reduction with limited opening; IIc without reduction but without limited opening), and Group III: other common joint disorders (IIIa arthralgia; IIIb/IIIc arthritis) [2, 17]. All the children were examined by a single trained assessor. The clinical examination performed using the Axis I RDC/TMD protocol included an assessment of pain on palpation, a measurement of mandibular, the range of motion, an evaluation of pain and joint noises during mandibular movements, and tenderness induced by muscle and TMJ palpation. Finally, based on the self-report, clinical criteria, and diagnosis, the pain-related TMD group included children with myalgia Ia, Ib (pain of muscular origin, including pain experienced in the masticatory muscles or face at rest and during functional activities, as well as pain associated with localized areas that are tender to palpation in the muscle at 3 or more sites), as well as arthralgia IIIa (joint pain during palpation and joint-related pain during mouth opening or during lateral excursion). The pain-free TMD group comprised children diagnosed with disc displacements IIa, IIb, and IIc.

Replicate assessments of clinical signs of TMD were recorded for 20 randomly selected patients in order to assess intraexaminer reliability. For this purpose, intraclass correlation coefficients (ICCs) were calculated for both continuous and dichotomous variables of the RDC/TMD examination. According to the guidelines for interpretation for ICC values, reliability was classified as "poor" (ICC < 0.4), "fair to good reliability" (0.4 ≤ ICC ≤ 0.75), or "excellent" (ICC > 0.75) [36, 37].

An intraoral examination was performed to assess occlusal characteristics in all the participants, including Angle's classification, posterior crossbite, overbite, overjet, and lateral open bite.

In the next part of the examination, electromyographic recordings with a DAB-Bluetooth Instrument (Zebris Medical GmbH, Germany) were taken for all the study subjects by a single experienced examiner. The protocol followed here has already been described by us in previous papers [27, 28, 38].

The EMG assessment was recorded with a bipolar surface electrodes (silver/silver chloride - Ag/AgCl, disposable, self-adhesive electrodes with a fixed interelectrode distance of 20 mm, a Noraxon Dual Electrode, Noraxon, USA) bilaterally placed on the children's skin above the body of the masseter muscle and the anterior temporalis muscle, running parallel to muscle fibers. According to Ferrario et al. [39], in the case of the temporalis anterior muscle, the electrodes were located vertically on both sides along the anterior margin of the muscle, while for the masseter muscle, the electrodes were placed paralell to the muscle fibers with the upper pole of the electrode located at the intersection between the tragus-labial commissura and exocanthion-gonion lines. A reference electrode was situated inferior and posterior to the right ear.

The skin of the patients was cleaned with 70% ethyl alcohol prior to the placement of the surface electrodes, and then an impedance test was performed with a Metex P-10 measuring device (Metex Instruments Corporation, Korea). Five minutes later, the EMG recordings commenced. The EMG measurements of the temporalis and masseter muscles were performed at rest and during maximum voluntary clenching (MVC) in the intercuspal position and on cotton rolls. For both recordings during MVC, the subjects were invited to clench as hard as possible for 5 seconds. The recording during MVC on the cotton rolls was used for normalization purposes. To standardize the EMG potentials of the masticatory muscles with tooth contact, two 10 mm thick cotton rolls were placed on the mandibular second premolars and molars or on the mandibular second milk molars and the first permanent molars of each participant,

Table 1: The intraoral examination results for the examined groups of children.

Variable		TMD-pain group		Pain-free TMD group		Non-TMD group	
		n	%	*n*	%	*n*	%
Vertical overlap	0–3 mm	12	40.0	14	46.7	16	53.3
	≥3 mm	13	43.3	12	40.0	10	33.3
	Reverse	5	16.7	4	13.3	4	13.3
Overjet	0–3 mm	11	36.7	11	36.7	14	46.7
	≥3 mm	14	46.7	14	46.7	12	40.0
	Negative	5	16.7	5	16.7	4	13.3
Posterior crossbite	No	17	56.7	19	63.3	21	70.0
	Yes	13	43.3	11	36.7	9	30.0
Angle class	I	14	46.7	15	50.0	18	60.0
	II	11	36.7	10	33.3	8	26.7
	III	5	16.7	5	16.7	4	13.3
Lateral open bite	No	26	86.7	26	86.7	27	90.0
	Yes	4	13.3	4	13.3	3	10.0

and 5 seconds of maximum clenching was recorded. Finally, the mean values of the EMG potentials (raw data) of the temporalis and masseter muscles measured both at rest and during MVC which were expressed as a percentage of the mean potentials (reference values) measured during the standardization test (clenching on the cotton rolls) according to the following formula: mean values (μV) at rest or during MVC/mean values (μV) during MVC on two cotton rolls x 100% (unit μV/μV%) [39].

A rest period of at least 5 minutes was allowed between each recording. The EMG recordings were repeated for all children at least three times. The EMG values obtained during the last two EMG measurements were averaged.

The DAB-Bluetooth Instrument was hooked up to a computer to process the data and present them graphically. The EMG signal was amplified, digitized, and digitally filtered.

The asymmetry between the activity of the left and right masticatory muscles was quantified by the Asymmetry Index (As, unit %, range from 0% to 100%), according to the following equation: $\text{As} = \sum_{i=1}^{N} |R_i - L_i| / \sum_{i=1}^{N} (R_i + L_i) \times 100$ [40].

The repeatability of the recording measurements was tested by ensuring that the same examiner performed duplicate EMG evaluations on the 20 subjects. The two EMG measurements were separated by a gap of 15 minutes. The data obtained from the repeated evaluations were presented as the normalized mean values of masticatory muscle activity at rest and during MVC. The repeatability of electrode localization was maintained by applying a standard scheme for the positioning of the surface electrodes [41].

2.4. Statistical Analysis. The Kolmogorov–Smirnov test was applied to determine the normality of data distribution. After determining the normality of the distributions, the mean values and standard deviations (SD) in μV/μV% for the normalized EMG values were compared and analysed.

Table 2: The repeatability of the recording measurements.

Region	Activity	1 examination		2 examination		P value
		Mean (μV/μV%)	SD	Mean (μV/μV%)	SD	
TA	Rest	6.43	2.29	6.45	2.21	0.978
	MVC	107.30	33.70	107.90	33.60	0.959
MM	Rest	5.32	2.71	5.42	2.66	0.910
	MVC	101.00	27.60	101.90	27.60	0.919

TA: temporalis anterior muscles; MM: masseter muscles; MVC: maximum voluntary contraction.

Table 3: Electrical activity of the temporalis and masseter muscles at rest for the examined groups of children.

Region	Variable	Gender	TMD-pain group			Pain-free TMD group			Non-TMD group		
			n	Mean	SD	n	Mean	SD	n	Mean	SD
TA	EA	Girls	16	8.01	1.68	14	6.73	1.76	15	5.54	1.25
		Boys	14	7.71	2.15	16	6.60	2.20	15	5.34	2.07
		Total	30	7.87	1.89	30	6.66	1.97	30	5.44	1.68
	AI	Girls	16	10.86	5.18	14	10.10	6.54	15	11.32	6.66
		Boys	14	14.59	8.10	16	12.20	7.16	15	9.66	4.25
		Total	30	12.60	7.54	30	11.13	6.53	30	10.49	6.36
MM	EA	Girls	16	6.01	2.40	14	5.28	2.25	15	3.90	1.92
		Boys	14	6.05	2.04	16	4.81	1.90	15	4.43	1.90
		Total	30	6.03	2.21	30	5.03	2.08	30	4.17	1.90
	AI	Girls	16	10.10	6.64	14	12.11	6.59	15	15.00	9.67
		Boys	14	10.29	5.89	16	12.84	7.91	15	14.74	8.72
		Total	30	10.19	6.36	30	12.50	7.97	30	14.87	7.52

TA: temporalis anterior muscles; MM: masseter muscles; EA: electrical activity (μV/μV%); AI: asymmetry index (%).

Table 4: Electrical activity of the temporalis and masseter muscles during maximum voluntary contraction (MVC) for the examined groups of children.

Region	Variable	Gender	TMD-pain group			Pain-free TMD group			Non-TMD group		
			n	Mean	SD	n	Mean	SD	n	Mean	SD
TA	EA	Girls	16	101.80	29.80	14	113.70	35.50	15	130.00	35.20
		Boys	14	94.70	21.60	16	115.00	27.80	15	129.10	51.20
		Total	30	98.49	31.61	30	114.38	31.09	30	129.57	43.20
	AI	Girls	16	14.74	8.58	14	11.29	5.51	15	16.56	9.83
		Boys	14	7.86	4.99	16	9.59	4.82	15	9.24	5.03
		Total	30	11.53	7.90	30	10.38	5.01	30	12.90	6.80
MM	EA	Girls	16	96.20	28.80	14	110.20	43.70	15	118.50	25.20
		Boys	14	94.50	29.40	16	102.10	32.60	15	120.40	45.90
		Total	30	95.42	28.58	30	105.88	37.71	30	119.43	36.42
	AI	Girls	16	13.85	8.95	14	9.41	5.65	15	9.24	6.83
		Boys	14	9.51	5.49	16	6.10	4.09	15	7.27	4.54
		Total	30	11.82	6.26	30	7.64	4.08	30	8.26	4.59

TA: temporalis anterior muscles; MM: masseter muscles; EA: electrical activity (μV/μV%); AI: asymmetry index (%).

When comparing a single pair of mean values, the Student's t test was applied. Analysis of variance (ANOVA) was used when multiple comparisons were intended. When ANOVA indicated a significant difference, a StudentNewmanKeuls post-hoc test was performed, with the level of significance set at 5% ($P = 0.05$). The differences in the prevalence of occlusal characteristics between the groups were determined by means of the chi-squared test.

3. Results

The reliability value for the RDC/TMD clinical examination ranged from good to excellent (from 0.68 to 1.0).

The results of the intraoral examinations for the groups are presented in Table 1. No significant intergroup differences were observed with regard to the prevalence of occlusal characteristics ($P > 0.05$).

Table 2 presents data on the repeatability of the recorded EMG measurements. No differences were noted between the two repeated EMG recordings when it came to masticatory muscle activity at rest and during MVC ($P > 0.05$).

The normalized EMG data, i.e., the activity of the temporalis and masseter muscles at rest and during MVC for the TMD and non-TMD groups, are shown in Tables 3 and 4.

An analysis of the EMG recordings revealed statistically significant intergroup differences in temporalis and masseter muscle EMG activity at rest (for the temporalis muscles $P \leq 0.001$; for the masseter muscles $P = 0.003$). Significantly higher rest temporalis muscle activity was observed in the pain-related TMD patients (7.87 μV/μV%) than in the pain-free TMD group (6.66 μV/μV%; $P = 0.018$) and the TMD-free group (5.44 μV/μV%; $P \leq 0.001$), as well as in TMD-PF children in relation to those without TMD ($P = 0.013$). The TMD-pain group exhibited significantly higher masseter muscle EMG potentials at rest (6.03 μV/μV%) compared with the non-TMD group (4.17 μV/μV%; $P \leq 0.001$) (Table 3).

During MVC, considerable disparities in the EMG potentials of the temporalis and masseter muscles were observed between the analysed groups (for the temporalis muscles $P = 0.003$; for the masseter muscles $P = 0.030$). Temporalis muscle activity during MVC was significantly lower in children with pain-related TMD (98.49 μV/μV%) in relation to pain-free TMD subjects (114.38 μV/μV%; $P = 0.036$) and non-TMD children (129.57 μV/μV%; $P \leq 0.001$). Furthermore, masseter muscle activity during clenching was much lower in the TMD-pain group (95.42 μV/μV%) than in the TMD-free group (119.43 μV/μV %; $P = 0.006$) (Table 4).

There were no significant intergroup differences in the Asymmetry Index for the temporalis and masseter muscles at rest and during MVC ($P > 0.05$) (Tables 3 and 4). Nor were there any major differences between girls and boys in each group with regard to the EMG potentials of the temporalis and masseter muscles in the rest position and during clenching ($P > 0.05$) (Tables 3 and 4).

4. Discussion

In the present study, surface electromyography (sEMG) was used to evaluate masticatory muscle activity in children diagnosed with TMD according to the RDC/TMD algorithm. The advantage of global electromyography is its noninvasiveness, because it uses surface electrodes located on the surface of the skin which is absolutely vital in studies involving a cohort of children [19]. We compared 3 groups of patients: pain-related TMD, pain-free TMD, and TMD-free. The results show that it is important to take into account alterations in the electromyographic potentials of the temporalis and masseter muscles in TMD subjects. We demonstrated that masticatory muscle electrical activity varied between the pain and pain-free groups. The EMG activity of the temporalis and masseter muscles at rest in subjects with a TMD-pain diagnosis was higher than in the pain-free groups. This hyperfunction of the masticatory muscles may be associated with a need for greater muscle recruitment in children diagnosed with pain-related TMD in the mandibular rest position [42, 43]. Minimal rest electromyographic activity of the temporalis and masseter muscles observed in children without TMD may indicate a balance between elevator and depressor muscles of the mandible [44]. We also observed that pain-related TMD children had lower masticatory muscle electrical potentials during MVC when compared with the pain-free patients. It was reported in previous studies that the masticatory muscles of symptomatic TMD patients were less efficient and lower EMG activity during clenching may indicate a reduction in their muscle force [45–47]. It was suggested that the bite-force increases in relation to muscle activity [48]. Muscle forces affect the structures of the stomathognatic system and may induce excessive loading on the tooth row and TMJs [49]. In our study, the reduced electrical potentials of the masticatory muscles observed in children diagnosed with pain-related TMD when clenching would suggest that a lower bite-force is to be expected. In this way, the alterations in temporalis and masseter muscle recruitment in the TMD-P subjects during MVC may be considered an effective mechanism of protection for damaged TMJs. Muscle forces are directed to minimize joint loads and muscular efforts as a normal protective control [50].

To date, information regarding masticatory muscle EMG activity in TMD children and adolescents is limited [26, 27, 35]. Early electromyographic analysis of the masticatory muscles in such patients with TMD problems is important for a better understanding of TMD neuromuscular characteristics in this age group and could ensure simpler and improved treatment procedures aimed at addressing muscle involvement in TMD and prevent chronic muscle/joint dysfunction in adulthood [26]. Our study reports on masticatory muscle activity in children with different TMD diagnoses depending on the occurrence of pain based on the Axis I RDC/TMD criteria. As there have been no similar studies, it is difficult to compare our results with others. Moreover, the comparisons are also complicated by the fact that some earlier studies did not include sEMG signal normalization. It is important that a proper EMG assessment should only be carried out with standardized (normalized) values, thereby providing information on the impact of occlusion on neuromuscular activity and ensuring removal most of biological and technical noise, such as anatomical variations, electrode position, nd skin and electrode impedance [51]. The normalization process is necessary for the preliminary processing of raw values to ensure intercomparisons and further analysis. In our study, to standardize the EMG potentials of the masticatory muscles with tooth contact, the subjects were asked to clench on two cotton rolls positioned on mandibular molars [39]. Normalization involved relating the electrical potentials of the muscles to the reference values obtained from the EMG measurements detected during the standardization recordings, that is, MVC with a control substance (cotton rolls). It has been reported that the EMG potentials collected in MVC have the best repeatability. Among the different protocols, an maximum voluntary clenching on cotton rolls has been reported to have the lowest interindividual variability, and for that reason, this method is now commonly used [24, 39, 51–53]. Nevertheless, our findings could be referred to those of Chaves et al. [26], who investigated differences in the electrical activity of the temporalis, masseter, and suprahyoid muscles in both children diagnosed with TMD based on the Axis I RDC/TMD criteria as well as in non-TMD patients. Thirty-four children aged 8–12 years were recruited in the study—17 children with TMD and 17 non-TMD subjects. The EMG raw and normalized data were obtained at rest and during maximum clenching. In contrast to our own study, Chaves et al. found no differences in the EMG values of the masticatory muscles during rest and clenching between patients with TMD and non-TMD subjects. In the case of TMD patients, they observed a lower mean electromyographic ratio for masseter muscles and anterior temporalis muscles (sEMG-M/AT ratio) during MVC. Lauriti et al. [35] evaluated the EMG activity of the masticatory muscles in adolescents with TMD. They recorded masticatory muscle activity in 42 participants aged 14 to 18 years with different degrees of TMD severity based on the Helkimo Index. The authors observed significant intergroup differences in the EMG potentials of the analysed muscles in the rest position and during maximum intercuspation. Their findings suggest that patients with TMD, especially those with more severe symptoms, exhibit masticatory muscle hyperactivity. One study [27] assessed of the temporalis and masseter muscle electrical activity in cleft lip and palate children diagnosed with pain-related TMD according to RDC/TMD criteria. The authors reported that, compared with non-TMD subjects, the EMG activity of the masticatory muscles in TMD-P children was higher at rest while temporalis muscle activity during MVC was lower. Moreover, they observed a significant increase in the Asymmetry Index for masticatory muscle rest activity in the TMD-pain group.

Numerous studies have demonstrated alterations in the EMG potentials of the masticatory muscles of adult patients with pain-related TMD [20, 25, 31, 32, 34, 54–57]. Glaros et al. [54] found that the electrical activity of the left temporalis and left masseter muscles at rest in TMD patients with myofascial pain was significantly higher than in pain-free controls. Similarly, Bodéré et al. [32] observed that the EMG potentials of the temporalis and masseter muscles in the rest position were far higher in adult patients with myofascial or neuropathic pain compared with healthy TMD-free subjects. The authors also found a significant difference in the EMG activity between the pain-free disc derangement disorders group and the pain groups (neuropathic and myofascial) for both muscles except for the masseter muscle of the neuropathic group. Furthermore, they noted significantly higher electrical activity at rest in patients with bilateral pain in relation to subjects with unilateral pain. Berni et al. [31] observed that women with myogenous TMD exhibited significantly greater electrical activity of the temporalis, masseter, and suprahyoid muscles at rest than women without TMD, whereas masseter muscle EMG activity during MVC recorded on parafilm in a TMD group of patients was significantly lower than in non-TMD subjects. Likewise, the results of a study published by Rodrigues et al. [34] revealed higher EMG potentials of the temporalis and masseter muscles at rest in patients with pain-related TMD compared with those of TMD-free subjects. Moreover, no differences were observed between TMD and non-TMD groups in terms of the masticatory muscle EMG activity during MVC. On the other hand, Majewski and Gale [55] reported no significant differences in temporalis rest electrical activity between TMD-pain patients and controls. Manfredini et al. [20] measured the EMG activity of the temporalis and masseter muscles in 36 adult patients diagnosed with myofascial pain based on the RDC/TMD criteria and 36 TMD-free asymptomatic subjects. They also did not observe any disparities in the electrical potentials of masticatory muscles at rest between TMD-pain and non-TMD patients, while EMG activity levels during clenching tasks were significantly greater in subjects with no TMD.

Tartaglia et al. [25] performed EMG recordings of the masseter and temporalis muscles during MVC in 103 patients aged 15–70 subdivided according to RDC/TMD criteria into 3 groups: myogenous, arthrogenous, and psychogenous patients. These groups in turn were compared with 32 control patients aged 19–69 without TMD. The authors found that, during clenching, the masticatory muscles of non-TMD subjects were characterised by much higher normalized EMG potentials and their temporalis muscles had greater symmetry than was the case with TMD patients. Tartaglia et al. suggested that electromyography of the masticatory muscles exhibits its diagnostic usability in an objective discrimination between different RDC/TMD subgroups. In another study by Tartaglia et al. [56], the authors assessed the EMG activity of the temporalis and masseter muscles in 30 patients with a mean age of 23 years diagnosed with arthrogenous TMD and long-term pain as well as in 20 patients aged 19–31 with no signs or symptoms of TMD. They observed that young adult TMD patients exhibited higher and more asymmetric normalized activity of the temporalis muscles during MVC compared with non-TMD controls. Santana-Mora et al. [57] found that the masticatory muscles of non-TMD individuals had higher EMG potentials than was the case with chronic pain individuals with unilateral TMD when clenching. Calculations based on the Asymmetry Index showed that patients with right-sided TMD exhibited preferential use of their left-sided masticatory muscles, whereas patients with left-sided TMD favoured their right-sided temporalis and masseter muscles.

In summary, the findings of the abovementioned reports as well as the results of our study confirmed the existence of differences in masticatory muscle electrical activity between pain-related TMD and pain-free subjects.

The similar intergroup prevalence of occlusal features observed in our report allows us to assume the absence of any relationship between alterations in masticatory muscle activity and malocclusions. However, we did not take into account all malocclusion-related factors. Moreover, another possible limitation of the study may be the fact that the pain-related TMD group included both myogenous and arthrogenous TMD children, since EMG muscle activity may vary in these subgroups of subjects. As a consequence, further studies would be needed to verify our study results.

5. Conclusions

An analysis of the EMG recordings revealed significant intergroup disparities in temporalis and masseter muscle electrical potentials at rest and during MVC. Children diagnosed with pain-related TMD exhibited significantly greater EMG activity in temporalis muscles at rest compared with those with the pain-free TMD and non-TMD groups while temporalis muscle electrical potentials when clenching were much lower. Masseter muscle activity at rest in pain-related TMD subjects was significantly higher, and masseter muscle EMG potentials during MVC were markedly lower than in children with no TMD diagnosis.

The use of electromyography to assess masticatory muscle function revealed alterations in the pattern of temporalis and masseter muscle activity in patients with pain-related TMD compared with the pain-free subjects.

Data Availability

The datasets supporting the conclusions of this article are included within the article. Access to other data will be considered by the corresponding author upon request.

Disclosure

The authors Liliana Szyszka-Sommerfeld and Monika Machoy contributed equally to this work.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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Research Article

Correlation between Parental-Reported Tooth Grinding and Sleep Disorders: Investigation in a Cohort of 741 Consecutive Children

M. Segù,[1] M. Pollis,[2] A. Santagostini,[1] F. Meola,[3] and D. Manfredini[2]

[1] *School of Dentistry, University of Pavia, 27100 Pavia, Italy*
[2] *School of Dentistry, University of Siena, 53100 Siena, Italy*
[3] *Spino D'Adda, Cremona, University of Siena, 53100 Siena, Italy*

Correspondence should be addressed to M. Pollis; matteo.pollis@gmail.com

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Purpose. A possible relationship between sleep bruxism (SB) and several sleep disorders has been suggested in children, which could influence sleep quality and quality of life. This study aims to assess such correlations in a large sample of school children. *Methods*. Parents of 741 consecutive children aged between 8 and 12 years filled the Sleep Disturbance Scale for Children (SDSC). It evaluated 45 items grouped in 8 components: duration of night-time sleep, sleep latency, bedtime problems, sleep quality, night awakenings, nocturnal symptoms, morning symptoms, and daytime sleepiness. An item evaluating parental-reported tooth grinding was also included. Correlation analysis was performed between parental-reported tooth grinding and all the other items. *Results*. A significant correlation between parental-reported tooth grinding and several sleep disorders concerning bedtime problems, night awakenings, nocturnal symptoms, and morning symptoms has been found. In general, correlation strength of significant pairs was low, ranging from 0.092 (sleep apnea) to 0.234 (movement while falling asleep). *Conclusions*. Parental-reported tooth grinding in children is correlated, even if weakly, with some sleep disorders concerning the sphere of bedtime problems, night awakenings, nocturnal symptoms, breathing symptoms, and morning symptoms. Further studies are needed to confirm these findings, with particular regard to the consistency of correlation outcomes between the parental reports and the sleep laboratory measures.

1. Introduction

According to the International Expert Consensuses, bruxism is defined as a repetitive jaw-muscle activity characterized by clenching or grinding of the teeth and/or by bracing or thrusting of the mandible, and it has two distinct circadian manifestations: it can occur during sleep or during wakefulness [1, 2]. Although a large amount of the literature about sleep bruxism (SB) has been performed, only few studies focused on children. A recent systematic review reports that the prevalence of SB in children is between 3.5 and 40.6%, decreasing with age and without gender differences [3]. Also, higher prevalence rates were found in children and adolescents (3–49%) than in adults (1–15%) [4]. Despite the high variability, which could depend on the adoption of parental report strategies to evaluate tooth grinding in children and makes it hard to define an actual prevalence value, the phenomenon is surely of clinical interest.

In two systematic reviews, Guo et al. listed the many factors that have been described in association with SB in children [5, 6]. Some studies assessed the relationship between parental-reported SB and sleep disorders (e.g., bedtime problems, night awakening, nocturnal symptoms, nocturnal breathing symptoms, and morning symptoms) [7, 8], whilst some others investigated for the association with behavioral problems, such as hyperactivity, poor school performance, and attention deficit. A large investigation by Restrepo et al. suggested that some sleep disorders are associated with parental-reported tooth grinding, even if further studies are needed to refine findings [9, 10]. Amongst them, breathing disorders (e.g., snoring, lack of sleep, mouth breathing, and restless sleep), whether in association with obstructive sleep apnea syndrome or not, are raising interest [6, 11].

Based on the above premises, there is an emerging evidence of a possible relationship between SB with several issues concerning the sleep features and quality as well as the presence of comorbid conditions. This study aims to assess such correlations in a large sample of consecutive school children by means of a large questionnaire-based investigation.

2. Materials and Methods

This case study was conducted in a private orthodontic practice between January 2016 and May 2019. A group of 741 consecutive children ($M = 409$; $F = 332$) aged between 8 and 12 years (mean age = 11.26 ± 4.05; mean weight = 25.21 ± 11.37) underwent a clinical evaluation, including an oral and orthodontic examination, performed by the same examiner. The Sleep Disturbance Scale for Children (SDSC) was administered to the accompanying parent or relative [12]. The accompanying person filled it in the waiting room or brought it at home, if the relative did not know any information about the child's sleep conditions.

3. Questionnaire

The SDSC questionnaire includes 45 items grouped into eight components (duration of night-time sleep, sleep latency, bedtime problems, sleep quality, night awakenings, nocturnal symptoms, morning symptoms, and daytime sleepiness). The first two components were defined by items 1 and 2, which concern sleep duration (categorized as follows: 1 = 9–11 h; 2 = 8-9 h; 3 = 7-8 h; 4 = 5–7 h; 5 = less than 5 h) and sleep latency (categorized as follows: 1 = less than 15 min; 2 = 15–30 min; 3 = 30–45 min; 4 = 45–60 min; 5 = more than 60 min). The other items can be answered based on a five-point Likert-type ordinal scale (1 = never; 2 = occasionally (once or twice a month or less); 3 = sometimes (one or twice a week); 4 = often (three or five times a week); 5 = always (every night)). Specifically, the parental-reported tooth grinding was evaluated by the question n°33 about the presence of tooth grinding during sleep ("Does she/he grind her/his teeth during sleep?") [12]. Selection of items was based on the clinical experience with sleep disordered children and from a review of previous sleep questionnaires reported in the literature. For more details, readers are referred to the original publication [12].

Instructions for completing the scale were always given to parents by the same investigator. The questionnaire, which takes the parents 10–15 min to complete, assesses sleep behavior and disorders that have been observed during the last 6 months of the child's life. All data have been entered in the database for statistical analysis using Delta-Dent (Outside Format) software. To evaluate the level of correlation between parental-reported tooth grinding and all the other items, the Spearman test was performed. The null hypothesis was that a correlation does not exist, and a threshold of p lower than 0.05 was set to reject the null hypothesis. All statistical analyses were carried out using SPSS 25.0 (IBM, Milano).

4. Results

There were no significant differences between boys and girls as far as age and weight were concerned (mean age: $M = 11.3 \pm 4.5$ ys; $F = 11.2 \pm 3.5$ ys) (mean weight: $M = 25.9 \pm 11.5$ kg; $F = 24.5 \pm 11.2$ kg).

Considering the subjects who answered the bruxism question ($N = 708$), 70.1% of children were not reported to have sleep-time tooth grinding, whilst in 14.4%, it was reported "occasionally," in 7.3%, "often," and in 4.1%, either "very often" or "always."

The Spearman test reported a significant correlation between parental-reported tooth grinding and several sleep disorders (correlation strength in parenthesis):

Bedtime problems: movement while falling asleep ($r = 0.234$), restless leg ($r = 0.131$), falling asleep sweating ($r = 0.133$), and tingling ($r = 0.096$)

Night awakenings: waking with leg cramps ($r = 0.120$) and waking up screaming in the night ($r = 0.155$)

Nocturnal symptoms: nocturnal hyperkinesia ($r = 0.182$), unusual movements during sleep ($r = 0.155$), pains of unknown origin during sleep ($r = 0.096$), nocturnal sweating ($r = 0.171$), sleep breathing difficulties ($r = 0.163$), sleep apnea ($r = 0.092$), snoring ($r = 0.157$), nightmares ($r = 0.152$), and sleep talking ($r = 0.231$)

Morning symptoms: difficulties in waking up in the morning ($r = 0.124$) and restless sleep ($r = 0.156$)

Mean values and SD of all items considered with the corresponding p value and r value are reported in Table 1.

5. Discussion

As known for several years, sleep disorders are common in children [12]. According to the last International Classification of Sleep Disorders (ICSD-3), sleep-related bruxism (SB) is included among the sleep-related movement disorders [5, 13, 14].

In the attempt to implement knowledge on the topic, this study has evaluated the possible association between SB and some behaviors and conditions related to sleep in children. The study was based on parental reports as a source of information. This strategy is common to most of the literature on SB in children, as the best method to collect data in large samples. Whilst the parental report may be considered a proxy for actual SB, it must be nonetheless remarked that the use of parental questionnaires is useful to collect data on several sleep behaviors and conditions that cannot be easily measured and that the child could not be aware of (e.g., sleep terrors, sleepwalking, and sleep talking). Parental information has proven to be an effective method for the detection of behavioral and developmental problems [15], and parental reports of sleep disorders are consistent with objective measurement [16, 17].

Table 1: Mean values and SD of all items considered with the corresponding p values and r values.

Components	Items	N	Mean	SD	p value	R
Bedtime problems	Movement while falling asleep	682	1.32	0.722	0.000	0.234
	Restless leg	687	1.77	1.097	0.012	0.131
	Falling asleep sweating	679	1.73	1.137	0.000	0.133
	Tingling	686	1.16	0.577	0.001	0.096
Night awakenings	Waking up with leg cramps	687	1.08	0.405	0.000	0.120
	Waking up screaming in the night	682	1.49	0.713	0.001	0.155
Nocturnal symptoms	Nocturnal hyperkinesia	688	2.01	1.162	0.000	0.182
	Unusual movements during sleep	682	1.35	0.772	0.000	0.155
	Pains of unknown origin during sleep	685	1.07	0.306	0.015	0.096
	Nocturnal sweating	680	1.72	1.024	0.000	0.171
	Sleep breathing difficulties	687	1.41	0.847	0.002	0.163
	Sleep apnea	682	1.12	0.500	0.001	0.092
	Snoring	686	1.71	0.980	0.002	0.157
	Nightmares	690	1.20	0.498	0.000	0.152
	Sleep talking	690	1.58	0.786	0.000	0.231
Morning symptoms	Difficulties in waking up in the morning	682	2.00	1.165	0.010	0.124
	Restless sleep	683	1.63	0.852	0.000	0.156

In our study, in general terms, some significant correlations emerged, even if their strength is generally weak. For instance, a correlation between parental-reported tooth grinding and bedtime problems, such as sudden movements while falling asleep ($r = 0.234$), restless legs movements, muscular pain or tingling, and falling asleep sweating, has emerged. According to Santos-Suosa et al., SB in individuals with difficulty in sleeping may be a possible result of a nervous system excitation response accompanied by body movements [7]. Furthermore, Goncalves et al. in a cross-sectional study reported an association between SB and problems with falling asleep, with an OR of 4.1 [18]. Also, as reported above, a couple of systematic reviews supported this relation [5, 6].

In this work, night awakenings (i.e., waking with leg cramps and waking up screaming in the night) and some nocturnal symptoms, such as nocturnal hyperkinesia, unusual movements during sleep, pains of unknown origin during sleep, and sleep sweating were also mildly associated with parental-reported tooth grinding. However, it is hard to compare these findings with the literature, since these specific aspects are rarely separately from other issues that influence sleep quality. Thus, more investigations are needed on the issue of comorbid sleep movements.

Interestingly, nocturnal breathing symptoms that were under investigation in this work showed a correlation with parental-reported tooth grinding (sleep breathing difficulties, sleep apnea, and snoring). These results are consistent with literature knowledge, which suggested an association with snoring in children [7]. Guo et al. included snoring among the risk factors related to the presence of bruxism [6], as also shown by another investigation that reported a relationship with respiratory disorders during sleep [19]. One of these disorders is oral breathing syndrome, the condition in which the child breathes through the mouth, thus resulting in oropharyngeal vibration, and generating the sound of snoring. In addition, there are suggestions that possible conditions leading to nasal obstruction, such as rhinitis and sinusitis, are associated with SB [20].

Our findings reported a correlation between nightmares and parental-reported tooth grinding. Rebeiro et al. showed that nocturnal agitation and nightmares were associated with possible SB in children [21]. Furthermore, Serra-Negra and colleagues observed that 71.4% of children who woke up frightened and 75% of those who awaken in the middle of the night had possible SB [19]. Brief nightmares and awakenings during sleep with palpitations are systemic features of SB [22, 23]. Also, an association with evening chronotype could exist, but the study of chronotype and its changes as a possible source of distress requires refinement, especially as far as the phenotyping of different chronotype profiles [21].

Some authors found that somniloquy is more frequent in children with SB [8], and our findings confirm these suggestions ($r = 0.231$). A possible explanation is that talking during sleep can be linked with SB that is affected by changes in brain oxygenation, which might be impaired with mouth breathing [19]. Another explanation may be that in this scenario, mouth breathing interferes with the sleep cycle and affects cerebral oxygenation, thus leading to somniloquy and involuntary muscle contractions of the facial muscles, triggering SB [24].

As for morning symptoms, the present study showed a correlation between parental-reported tooth grinding and morning headaches and restless sleep. Again, these findings are in line with the available literature supports. Goncalves et al. found a prevalence twice greater of morning headaches in children and adolescents with SB (OR = 2.6) [18]. Also, Bortoletto et al. asserted that children with SB have a greater risk of having primary headache [25]. According to some authors, patients with SB generally have morning headaches, which may depend on repetitive muscle contractions leading to tension headache [7]. On the other hand, in a case-control study of Bruni and colleagues, nocturnal symptoms were more frequent in migraine patients, especially breathing difficulties, snoring, sleep apnea, sleep talking, bruxism, and reports of frightening dreams, while tension-type headache patients were not different from controls [26]. Restless sleep could be considered as a consequence of all sleep disorders and, indeed, as mentioned above, it is also correlated to SB in children [6, 11]. A work of Vierola and colleagues has confirmed this statement suggesting that craniofacial pain is common in prepubertal children and is more frequent in those who show restless sleep and SB [27].

Some of the limitations concerning this study should be remarked. In particular, the data are cross-sectional, thus not being suitable for any inferences on causal relationships, and the collection of information was demanded to the parents. However, in studying a large cohort, using parents as a source of clinical information is, to a certain extent, a needed strategy for exploratory purposes. Investigations getting deeper into the specific associations by means of polysomnography are a recommended upgrade for the future. Notwithstanding, questionnaire approaches cannot be completely abandoned to study sleep disturbances of school-age children for obvious reasons of feasibility and compliance. It may be used as a simple screening measure and could also be helpful in analysing the relationship between overall sleep disturbance and other variables, such as age, health status, medical diseases, psychological conditions, and cognitive performances. Within these drawbacks, it must be pointed out that the strength of correlations is actually weak (low R values), which suggests that significance of correlations may be actually influenced by the large sample size and deserve careful reappraisal in future studies. In addition, not having divided the sample into different subgroups related to orthodontic features may not have revealed some possible relations with certain sleep disorders. For instance, as reported by Stauffer et al., several craniofacial anatomical factors (e.g., Angle class II div. II, Angle class III, anterior open bite, posterior cross bite, macroglossia, and more) seem to predispose to some sleep breathing disorders [28]. Future studies should be focused on this topic in order to get deeper into these interesting possible correlations.

6. Conclusions

In conclusion, the present findings suggest that parental-reported tooth grinding in children is correlated, even if weakly, with some sleep disorders concerning the sphere of bedtime problems (e.g., movement while falling asleep, restless leg, falling asleep sweating, and tingling), night awakenings (e.g., waking with leg cramps and waking up screaming in the night), nocturnal symptoms (e.g., nocturnal hyperkinesia, unusual movements during sleep, pains of unknown origin during sleep, sleep talking, and nightmares), breathing symptoms (e.g., sleep breathing difficulties, sleep apnea, snoring, and nocturnal sweating), and morning symptoms (e.g., difficulties in waking up in the morning and restless sleep).

Further studies are needed to confirm these findings, with particular regard to the consistency of correlation outcomes between the parental reports and the sleep laboratory measures. Moreover, it might be interesting to study the differences in the same clinical sample by grouping the orthodontic features and the hereditary and anamnestic variables (i.e., presence of sleep disturbances in the parents, presence of sleep problems in infancy, etc.), or to repeat and extend this study by combining the sleep disturbance scale data with other neurobehavioral variables.

Data Availability

The statistical data used to support the findings of this study are available from the corresponding author upon request.

Ethical Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the IRB of the University of Pavia and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent

Informed consent was obtained from all individual participants included in the study.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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Research Article

Association between Anatomical Features of Petrotympanic Fissure and Tinnitus in Patients with Temporomandibular Joint Disorder Using CBCT Imaging: An Exploratory Study

Edward Kijak[1,2] **Agnieszka J. Szczepek,**[3] **and Jerzy Margielewicz**[4]

[1]*Department of Prosthetic Dentistry, Faculty of Medicine and Dentistry, Pomeranian Medical University, Rybacka 1, 70-204 Szczecin, Poland*
[2]*Department of Prosthetic Dentistry, Faculty of Medicine and Dentistry, Wroclaw Medical University, Ludwika Pasteura 1, 50-367 Wrocław, Poland*
[3]*Department of Otorhinolaryngology-Head and Neck Surgery, Charité–Universitätsmedizin Berlin, Corporate Member of Freie Universität Berlin, Humboldt-Universität zu Berlin, and Berlin Institute of Health, 10117 Berlin, Germany*
[4]*Silesian University of Technology, Faculty of Transport and Aviation Engineering, Krasińskiego 8, Katowice 40-019, Poland*

Correspondence should be addressed to Edward Kijak; edward.kijak@umed.wroc.pl

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Mandible displacement is known to correlate with otological conditions such as pain in the ear canal, hearing loss, or tinnitus. The present work aimed to determine the association between the displacement of the condyle in a temporomandibular joint, the structure and position of the petrotympanic fissure (PTF), and comorbid tinnitus in patients affected by temporomandibular joint and muscle disorder (TMD). We enrolled 331 subjects with TMD (268 women and 63 men). The average age of women was 40.8 ± 16.8 years (range 13–88), whereas the average age of the examined men was 38 ± 14 years (range 13–74). We performed imaging studies of the facial part of the skull in the sagittal plane using a volumetric imaging method and a large imaging field (FOV) of 17 cm × 23 cm. The habitual position of the mandible was determined and used as a reference. Based on the imaging results, we developed a classification for the topography and the structure of the petrotympanic fissure. Thirty-three TMD patients (about 10% of the sample) reported having tinnitus. These patients had PTF configurations characterized by a rear (36.59%) or intracranial-cranial (63.41%) condylar displacement of the temporomandibular joint. Our findings imply that the TMJ- and tinnitus-positive group of patients possibly represents a distinct phenotype of tinnitus. We concluded that for such patients, the therapeutic approach for tinnitus should include TMD treatment.

1. Introduction

Tinnitus is a subjective perception of sound without an external acoustic signal occurring due to inappropriate activation of the auditory cortex. Tinnitus may be perceived as unilateral or bilateral phantom sound and be either continuous or intermittent symptom [1] of various conditions, including the malfunction of auditory periphery [2]. Activation of the auditory cortex of tinnitus patients in silence has been documented during imaging studies using positron emission tomography (PET) or functional magnetic resonance imaging (fMRI) [3]. Tinnitus may be a symptom of many conditions, including presbyacusis, otosclerosis, chronic otitis media, ototoxicity, labyrinthitis, noise-induced hearing loss, and congenital disorders. Besides, diseases that directly or indirectly affect neurons of the auditory pathway (multiple sclerosis, vestibular schwannomas, meningiomas, stroke, intracranial hemorrhage, and head injuries) may also associate with tinnitus. Tinnitus patients have often compromised hearing thresholds and speech perception and generally have a lower health-related quality of life [4].

Furthermore, comorbid conditions such as insomnia, anxiety, difficulties with concentrating, or negative thinking may induce a vicious circle, in which tinnitus causes progression of psychological problems, and they, in turn, induce progression of tinnitus [5, 6]. Approximately 15–20% of the adult population is affected by tinnitus, making tinnitus a severe socioeconomic problem [7]. Only in Europe, more than 70 million people report having tinnitus [8]. Psychosocial and emotional stresses play a particular role in the onset and chronification of tinnitus [9].

Emotional stress is one of the causes of masticatory muscle disorders, characterizing the temporomandibular disorders (TMD). The impact of psychological factors on the development of TMD is well documented. It can exemplarily be demonstrated by the high incidence of TMD in patients with a major depressive disorder [10–12]. Temporomandibular disorders are the third global dental problem after caries and diseases of the periodontium; however, they may be challenging to diagnose, especially in earlier stages. The leading causes of TMD include tendomyopathy and degenerative disease of the temporomandibular joint, among others [13]. TMD affects over 10% of the world population, and about 40% of patients with TMJ experience pain, whereas their age at diagnosis is steadily declining [14]. Epidemiological studies demonstrated that as much as about 75–90% of the Western population suffers from functional disorders of the stomatognathic system, with female gender skew [15–17]. Pain, jaw movement restriction, and acoustic effects, including popping and clicking in the joints, are considered the classic triad of symptoms of TMD [18]. In patients with the severe form of TMD, the main symptoms may be accompanied by a limited range of mandible movement, headache, or pain in the neck. Headaches are a common problem for participants with painful TMD [19]. Less frequent are the otolaryngological symptoms such as ear pain, hearing loss, sudden hearing loss, a feeling of fullness in the ear, sore throat, difficulty in swallowing, or tinnitus [20].

TMD-related tinnitus is considered to represent the somatosensory type of tinnitus [21, 22] and is diagnosed in 10–15% of the population with TMD [23]. Early research on TMD and comorbid tinnitus initiated by Costen described clinical cases of different otological conditions associated with a loss of teeth in the distal part of the dental arch, posterior support, or loss of prosthetic vertical dimension [24]. Costen proposed the mechanical compression of the auriculotemporal nerve to be caused by the dorsocranial condylar displacement, which in turn causes pain and various types of otalgia. There are as many supporters as opponents of Costen's theory. The condylar displacement can also induce compression of the synovial petrotympanic fissure, which directly communicates with the middle ear. All anatomical structures near synovial petrotympanic fissure, such as chorda tympani, branch of the facial nerve (VII), anterior tympanic artery and vein, anterior process, and anterior ligament of the malleus, could also be affected and therefore lead to otalgia. However, the reasons for tinnitus that only occasionally accompanies the TMD remain unclear.

In this research, we attempted to explain the link between the occurrence of tinnitus and the temporomandibular joint topography in TMD patients and to determine TMD-related factors that might be predisposing for tinnitus. To obtain the anatomical information, we used the X-ray imaging–CT volumetric analysis. The presence or absence of tinnitus was determined as an answer to an open question. We focused our analysis on the relationship between the structures of petrotympanic fissure (PTF), the condylar displacement of the temporomandibular joints in patients with TMD, and the presence of tinnitus.

2. Materials and Methods

The Ethics Committee approved this retrospective study of the Pomeranian Medical University, Szczecin, Poland (approval number KB-0012/30/13) and waived the need for informed consent. The study was conducted according to the principles in the Declaration of Helsinki.

The study group counted 331 patients who reported to the Department of Prosthodontics (Pomeranian Medical University in Szczecin, Poland) due to temporomandibular joint disorder in the years 2016–2018. Of the 331 subjects, 268 were women (age range between 13 and 88 years; average age 40.84 ± 16.71) and 63 were men (age range between 13 and 74 years; average age 38.5 ± 14.59 years). Women accounted for 80.97% of the study population and men for 19.03%, which is in agreement with earlier epidemiological observations of TMJ incidence. Although one patient in our cohort, who was below 18 years of age, was initially included in the study, this person was excluded from the data analysis because of the still ongoing process or cranial development—fissures are fulfilled with fibrous structure.

The selection of patients qualified for further analyses was based on the II RDC/TMD axis of diagnostic criteria for temporomandibular disorders (RDC/TMD) introduced by Dworkin and LeResche in 1992 [25]. The inclusion process was based on the existing medical records of previously diagnosed patients according to the accepted standards developed by the International Consortium RDC/TMD [26]. The inclusion criteria comprised medical records about existing or past temporalmandibular joint disorders consistent with group II of joint disorders. The selection also included the presence of otolaryngological symptoms, such as ear pain, hearing loss, sudden hearing loss, a feeling of fullness in the ear, or tinnitus. Since the selection was made based on medical documentation, the psychological status of the subjects was not assessed according to RDC/TMD Axis II diagnoses. Consequently, the study group consisted of persons who meet the criteria for groups IIa and IIb of the said classification. All participants underwent a thorough assessment in accordance with the RDC/TMD guidelines to receive Axis II diagnoses based on the official Polish adaptation of the RDC/TMD [27].

The exclusion criteria comprised previous mechanical injuries to the mandibular joint area: fractures, dislocations, former or present ear diseases (including infections), and hearing impairment. Another exclusion criterion was treatment of the dysfunction with occlusal splints and subjects without stable maxillamandibular relation.

The second eligibility condition was a previously performed CBCT imaging test. Only the examinations that were performed using the same technique and focusing on the same imaging field were considered for analysis. An area of view (17 cm × 23 cm) was obtained during craniofacial volumetric tomography (FOV), using a scanner for i-CAT Next Generation (ISI) cranial tomography (Hatfield, PA, USA) and software version 1.9.3.13. The applied exposure protocols were the default and manufacturer-recommended protocol (exposure settings: 90 kV, 5 mA, and 16.0 s). The head position with the Frankfurt plane paralleled, and the midsagittal plane was perpendicular in relation to the floor of the mouth. Patients were informed to sit still during exposure. Multiplanar data were reconstructed with a pixel size of 0.25 mm.

A total of 662 scans of temporomandibular joint (left and right for each of 331 patients) were analyzed in the sagittal plane in reference position, musculoskeletal position, or maximal intecuspidation. Habitual position is not repetitive and, in TMD patients, is often the result of pathological habit. It is impossible to take it under consideration. Such a stable occlusal relationship faithfully reflects the actual position of the condylar process concerning the surrounding anatomical structures.

2.1. Image Analyses. Based on the CT images, we performed a detailed analysis of petrotympanic fissure topography. Because the structure of craniofacial bone is of high diversity and there is a lack of existing evaluation criteria, we have developed our classification. It aimed at categorizing the craniofacial bone topography.

The analyses of CBCT images were performed by one person (the first author of the study), well experienced in evaluating this type of imaging. The evaluation steps, methodology, and reproducibility were established in collaboration with a professional radiologist. The analysis was performed using a personal computer equipped with an Intel(R) Core(TM) i7 4720HQ CPU and a 64 bit Windows version 8.1 operating system.

CBCT analysis was initiated by identifying the condylar process in the frontal plane window. After setting the intersection axis of the planes, the center of the condyle of mandible was determined in two horizontal (Figure 1, panel 1) and frontal (Figure 1, panel 2) planes. The enlarged image of the petrotympanic fissure was then analyzed (in the sagittal plane) in terms of the parameters tested (Figure 1, panel 3).

Next, the individual scans depicting the petrotympanic fissure were analyzed without changing the position of the planes positioned at the beginning of the analyzes. In this way, the reproducibility of analyzes in the remaining cases was achieved (Figure 2.)

Further analysis revealed that the entrance to the petrotympanic fissure could also be categorized into three distinct classes: open (O), semiopen (SO), and closed (C) (Figure 4).

Thus, the following combinations of the positioning and entrance shape are possible for petrotympanic fissure: L-O; L-SO; L-CR; M-O; M-SO; CR-M; H-O; H-SO; and H-CR.

To address Costen's theory assuming that the otological symptoms are related to the dorsocranial condylar displacement, the analysis of the topographical elements of the joint in the sagittal plane was performed, and four types of condylar position were identified (Figure 5):

(i) Rear (B)
(ii) Top-rear (BU)
(iii) Intracranial-cranial (U)
(iv) Unchanged with no evidence of displacement (CR)

The positioning and entrance shape of petrotympanic fissure is closely related to the length and width of the PTF channel. However, we have not used these parameters in our analyses for two reasons: first, it was because of already identified relations, and second, it was because both parameters are resulting from the positioning and shape (type) of PTE entrance.

2.2. Statistical Analysis. For the statistical calculations, we used Mathematica 10.4 software (Wolfram Research, Oxfordshire, United Kingdom). For all statistical analyses, the significance level (p) was set on 0.05. Based on the Shapiro–Wilk statistical test, the data obtained from the test group of women were not consistent with normal distribution because of the random variable representing the age. This conclusion was drawn from the fact that the probability value of the Shapiro–Wilk test (p) was ≤0.0001. In the group of male patients, the probability value of the Shapiro–Wilk test was $p \leq 0.0002$, which also supports the noncompliance with the normal distribution. In terms of age, the group of men and women did not differ significantly (the value of the nonparametric Mann–Whitney test was $p = 0.066$), allowing analysis of both genders together.

The analysis was continued with data, in which the skeletal structure of the face was presented in quantitative form. Before the correlation analyses, a proportion of individual factors in the analyzed group was determined. Statistical analysis (Person's correlation) χ^2 demonstrated that the age of women in our sample does not differ significantly from that of men (p value = 0.0566). Therefore, the two groups could be compared.

3. Results

First, we determined the frequency of symptom occurrence in our sample. Due to a large number of parameters analyzed and to visualize the results, we developed a customized presentation of results. Three rings represent the main parameters: the center ring reflects the frequency of a given position of the petrotympanic fissure, whereas the middle ring contains information about the frequency of a given entrance to the petrotympanic fissure. The outside ring includes information on the topography of the temporomandibular joints in the sagittal plane. The numerical values (represented by two numbers) defining individual configurations of condylar positions are placed outside the circle. The first number denotes the frequency of occurrences of a given setting, whereas the second number represents the number of tinnitus cases (Figure 6).

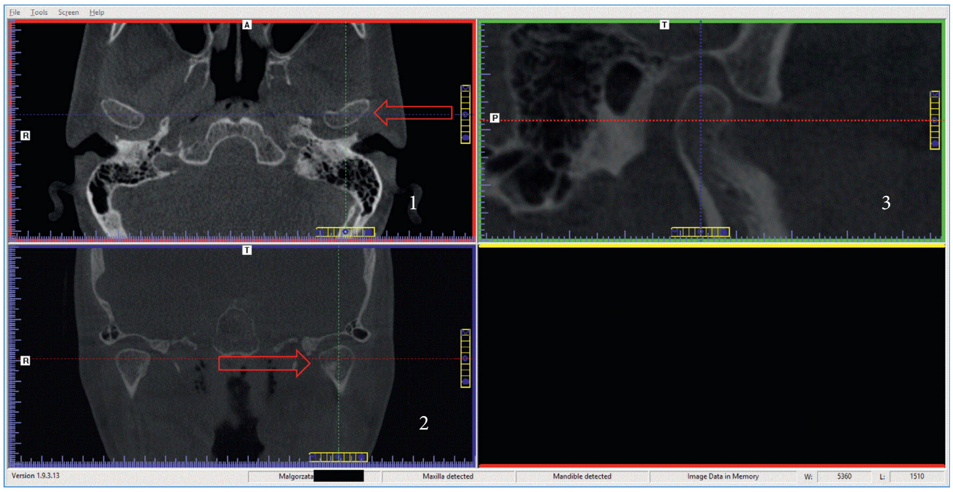
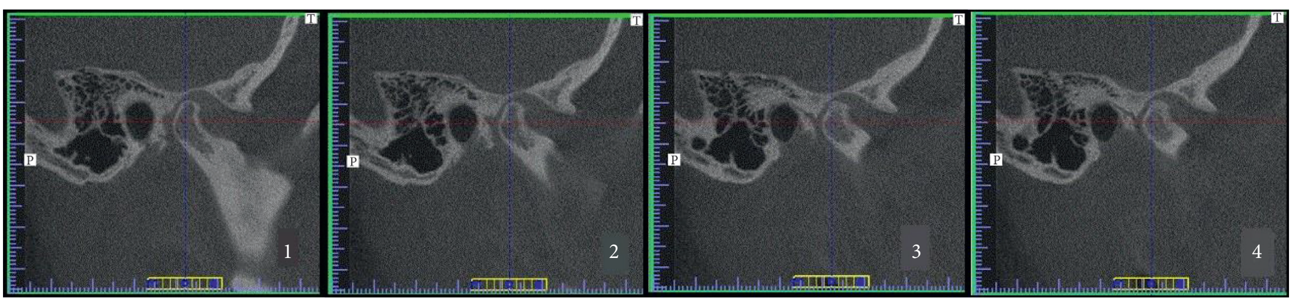
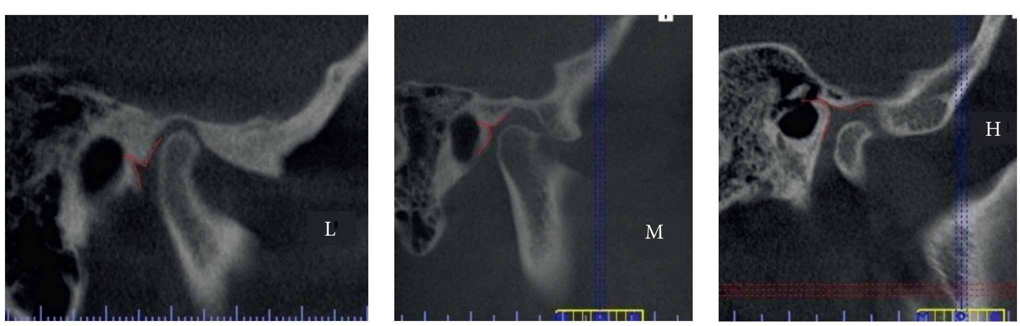


Figure 1: Steps of the petrotympanic fissure assessment of in the CBCT image.



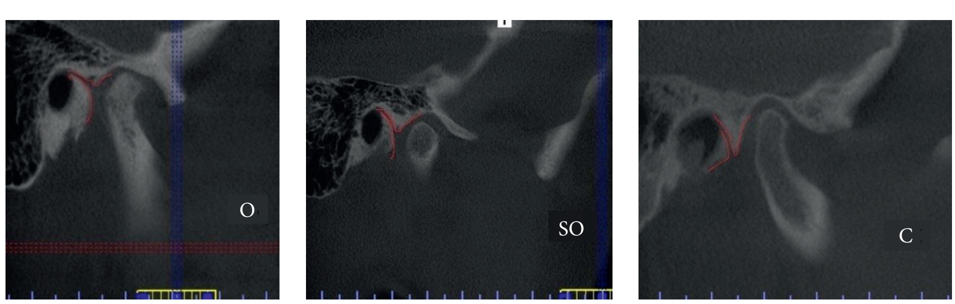
(a) (b) (c) (d)

Figure 2: Verification of reproducibility of analyses. (a–d) CBCT images of various patients from the analyzed cohort.



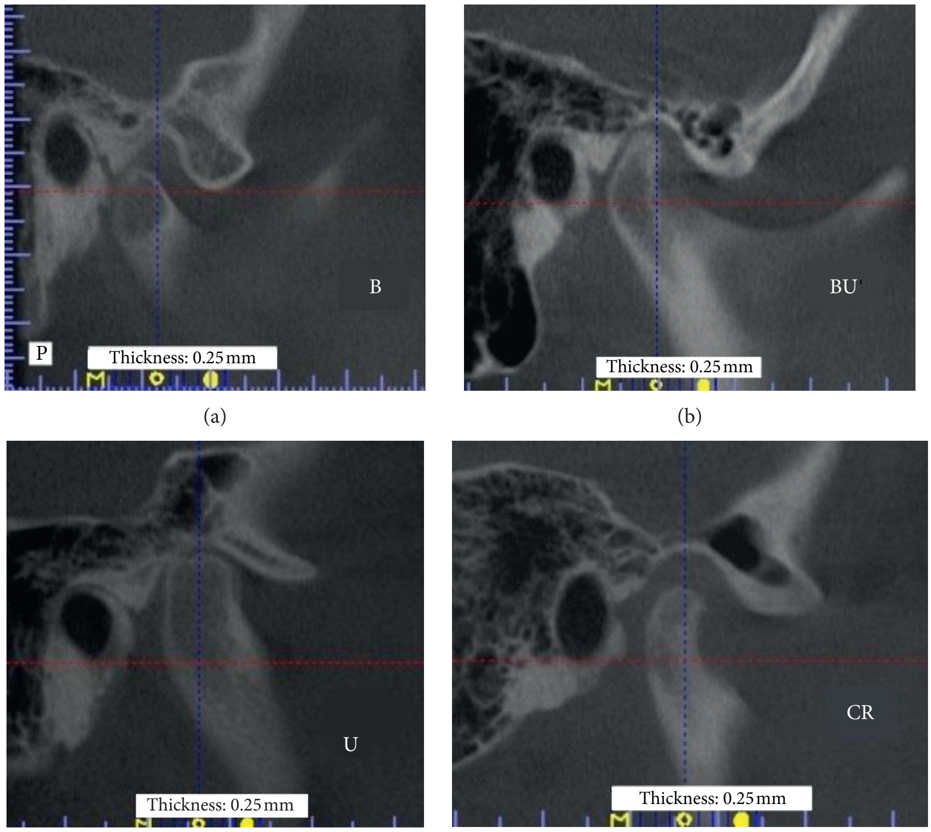
(a) (b) (c)

Figure 3: Example of three types of petrotympanic fissure positioning: (a) low-L, (b) midline-M, and (c) high-H (section in the sagittal plane). We distinguished three types of PTF position, marked with the appropriate symbols: low-L, midline-M, and high-H (Figure 3).



(a) (b) (c)

Figure 4: Classification of the entrance shape of a petrotympanic fissure: (a) open (O), (b) semiopen (SO), and (c) closed (C).



(a) (b) (c) (d)

Figure 5: Classification of the condylar position: (a) rear (B); (b) top-rear (BU); (c) intracranial-cranial (U), and (d) unchanged with no evidence of displacement (CR).

Figure 7(a) demonstrates an example of location and type of entrance to the petrotympanic fissure and top-rear, while Figure 7(b) illustrates the rear displacement (Figure 7(b)) in patients with TMJ and tinnitus. The CBCT image shows the apparent condylar displacement of a significant degree, virtually closing the entrance to the petrotympanic fissure with radiological signs of bone destruction.

Tinnitus was often reported by patients with rear (36.59%) or intracranial cranial (63.41%) condylar displacement of the temporomandibular joint ($p < 0.05$). According to Costen, such condylar displacement is necessary (but not sufficient according to our findings) for the occurrence of tinnitus. The shape and the position of petrotympanic fissure significantly correlate with the presence of tinnitus. In detail, the presence of tinnitus associates with open (85%) or semiopen (14.63%) form of entrance to petrotympanic fissure and with its midline (95.12%) or low position (4.88%).

In the analyzed group of participants, 33 subjects (9.97%) reported tinnitus, of which 2.42% had bilateral tinnitus. The prevalence of tinnitus was higher in women (93.75%) than in men (6.25%) (Figure 8), stressing the gender-related aspect in TMJ/tinnitus patients.

Table 1 contains the results of Fisher-Pitman permutation analyses used to test the null hypothesis about the correlation between the position plus type of entrance to petrotympanic fissure and the incidence of tinnitus. The reason for including only women was that only two men reported tinnitus. Both of these men had midline position "M" of the petrotympanic fissure entrance. One man had an open type "O," whereas the second had a semiopen "SO" type of the entrance shape. In both cases, the mandible was in rear position "B."

Probability was calculated using a chi-squared test, with the p level of significance set for 0.05. The resulting values indicate a lack of statistically significant differences in the occurrence of tinnitus when the same configuration of petrotympanic fissure in the left and right pond was present.

Our analysis provided additional information regarding the correlation between the age of patients with TMJ and the occurrence of tinnitus. The average age of patients with TMJ and tinnitus was above 40, suggesting that both symptoms occur predominantly in mature and older patients (Figure 8).

4. Discussion

The present work demonstrates that tinnitus is reported by 10% of 331 subjects with TMJ, corroborating the findings of other researchers who determined the prevalence of tinnitus in subjects with TMJ being 7.28% [28], 10% [29], or 15–20% [7]. However, Manfredini et al. reported the prevalence of tinnitus in patients with TMJ as high as 30.4%, which may be

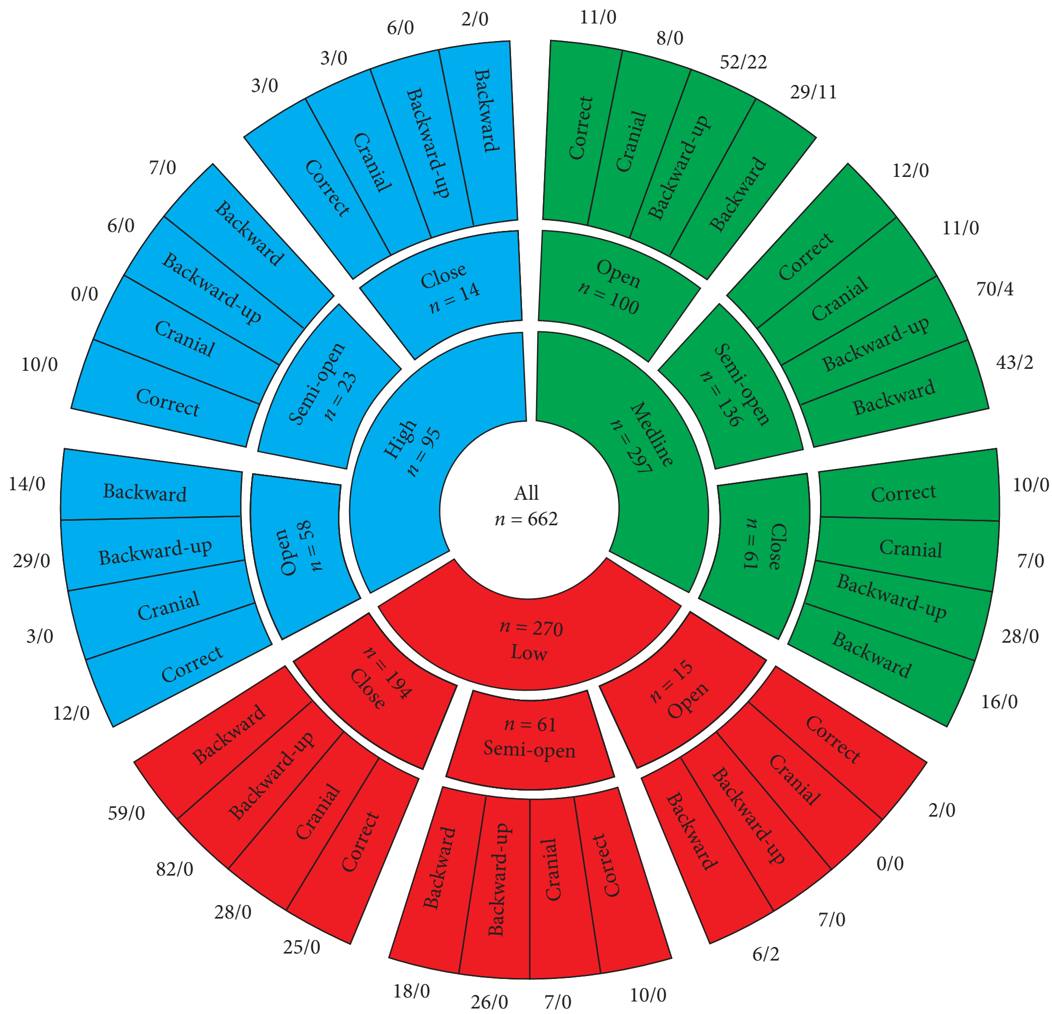
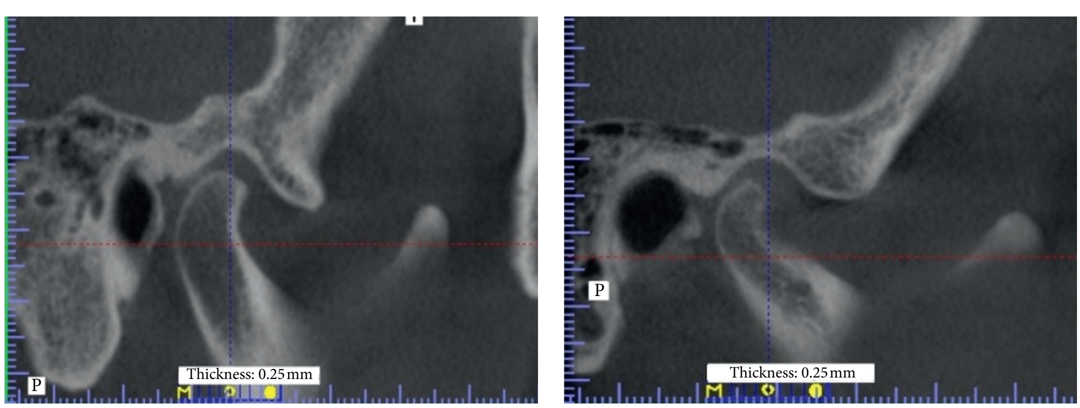


Figure 6: Permutations (without repetition) of parameters characterizing the skeletal and articular structures of petrotympanic fissure and the corresponding numbers of tinnitus occurrences.



(a) (b)

Figure 7: CBCT image of the topography of temporomandibular joint of the patients with tinnitus during the course of dysfunction: (a) 58-year-old female patient; (b) 68-year-old female patient.

due to a difference in inclusion criteria or collection of information about tinnitus [30]. The novel finding of the present work is that the occurrence of tinnitus associates with open (85%) or semiopen (14.63%) form of entrance to petrotympanic fissure and with its midline (95.12%) or low position (4.88%).

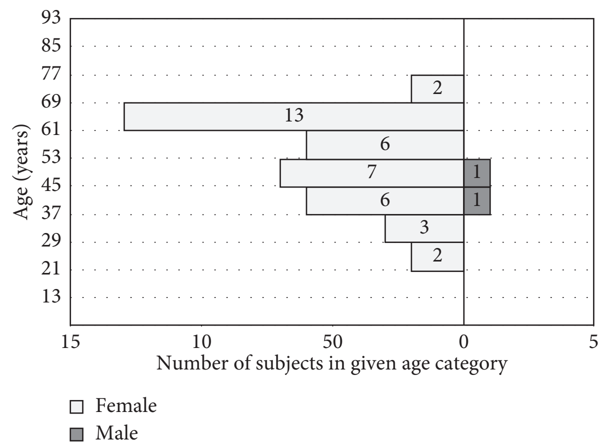


Figure 8: Association between subject age and the perception of tinnitus.

Table 1: Incidence of tinnitus in female subjects ($p < 0.05$).

Position	L, $n = 2$		M, $n = 17$ (94.9%)							
Type of entrance	Opened (5.1%)		Opened, $n = 32$ (82.1%)				Semiopened, $n = 5$ (12.8%)			
Condylar position	B		B		BU		B		BU	
Side	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
The number of tinnitus-positive cases (%)	0 (0)	2 (5.1)	6 (15.4)	4 (10.3)	10 (25.6)	12 (30.8)	1 (2.6)	0 (0)	3 (7.7)	1 (2.6)
p	0.234		0.424		0.509		0.317		0.316	

Over 85 years ago, Costen introduced the medical term "temporomandibular joint dysfunction" [24]. Costen described the syndrome based on eleven cases as a triad of temporomandibular joint complaints, headaches, and sensory disturbances in the area of the oral cavity. Costen suggested that the approximation of the lower jaw to the upper jawbone associated with a loss of posterior teeth may be the cause of TMJ [24]. Over the years, a lot of disagreement over Costen's theory has accumulated. Peroz pointed out that the functional disorders of the masticatory system may be accompanied by ear pain (37%) and tinnitus (3.7%) [31]. Peroz also suggested that otological symptoms with negative otoscopy might indicate TMJ. Keersmaekers et al. reported otological symptoms in 42% of patients with TMJ [32]. Using magnetic resonance imaging (MRI), Seedorf and Judah demonstrated that the prevalence of ear pain, as a primary symptom in TMJ, could reach 7.1% [33]. Tuz et al. recognized ear pain as the most common symptom in patients with TMJ with an incidence of up to 63% [34].

To date, there is a lack of evidence directly supporting the correlation suggested by Costen. Some researchers consider TMJ to be a multifactorial and multisymptomatic disease, with psychosocial elements [35]. Some others refer to the etiology of TMJ as idiopathic [36]. However, the anatomic features of the ear, one of the most specialized sensory organs in people [37] and the temporomandibular joint, seem to support Costen's theory. The articular disk of the temporomandibular joint is located in the temporal bone only 1 to 2 mm from the external auditory meatus. The proximity between the hearing and balance organs and the temporomandibular joint determines their common vascularization and innervation by the cranial nerve V (trigeminal nerve). Petrotympanic fissure provides direct contact between the auricular cavity and the middle ear. Often divided into petrotympanic or petrosquamous, the petrotympanic fissure may be used by infectious pathogens for a bidirectional transmission [38]. Moreover, the displacement of anatomical structures in the temporomandibular joint can cause a variety of symptoms associated with otological dysfunctions. One of the multiple theories attempting to explain the association between otological symptoms and TMD assumes that TMD results are either from excessive mechanical pressure on the discomalleolar ligament or from direct strain on the auriculotemporal nerve [39, 40]. It is also believed that the increased muscle tension of the jaw observed in patients with TMJ might result in a significant increase of the pressure on the temporomandibular joints and, thus, overloaded the surrounding tissues and muscles [38]. Although in our sample, all subjects had arthritis, the presence of increased muscle tension cannot be excluded. Muscle tension as a response to psychosocial stressors occurs in all patients with TMJ.

Interestingly, many reports indicate that TMD patients complain more often of tinnitus than of jaw problems [41]. The structures within the petrotympanic fissure (e.g., an anterior tympanic branch of the internal maxillary artery) could likely undergo mechanical stimulation due to the changes in the tension of maxillary muscles [34]. That, in turn, could lead to changes in cochlear microcirculation, such as hypoxia or even ischemia, and both of them are known to significantly affect the cochlear function [42, 43] by inducing degenerative processes, which in some patients could be responsible for the generation of tinnitus [44].

The temporomandibular joints are characterized by high adaptability and regeneration. However, after exceeding their regenerative capacity, the destructive changes that follow may be irreversible. Masticatory functional disorders occur in every younger patient. We noted that the average age of TMD patients with tinnitus was about 40 years, and our younger patients have not reported tinnitus. It is not in agreement with audiological research, which found that tinnitus occurs less frequently in patients younger than 54 years. Lockwood observed that in a general population over 55, about 30% complain of tinnitus [45, 46].

Çakur and colleagues classified PTF into three types: type 1 (wide tubular formation), type 2 (double conical structure), and type 3 (single conical structure) [47]. The same group has studied the correlation between the anatomic features of the petrotympanic fissure and the occurrence of tinnitus. The authors conducted CBCT imaging in 100 TMD patients, of whom 50% reported tinnitus and concluded that short fissure with wide entrance might predispose TMD patients to tinnitus (Çakur and Yasa, 2016) [48]. However, there are significant differences between the study of Çakur and ours. First, we analyzed the localization and the type of entry to the petrotympanic fissure and found them to be closely related to the length of PTF. The fissures belonging to the closed type are long and narrow. Therefore, we reasoned that the development of microcirculation conditions in the fissure vessels would be unlikely. Our study corroborates the notion about the close correlation between the location, the shape of the entrance to the petrotympanic fissure, and the rear condylar displacement. Interestingly, 95% of subjects with such a configuration reported tinnitus. This is the first report on the positive correlation between anatomical features of the petrotympanic fissure and the occurrence of tinnitus. Second, our sample was significantly larger (330 patients in our study vs. 100 patients in Çakur study) and differed regarding gender distribution and occurrence of tinnitus. Last, all our patients were referred to our unit because of group II-disorders of synovial character. In contrast, Çakur et al. used the presence of systemic diseases as one of the exclusion criteria.

There was no correlation between gender and the incidence of tinnitus in our sample. However, there was unequal gender distribution (about 80% women and 20% men), which was in agreement with epidemiological data indicating that TMD is diagnosed 3-4 times more often in women than in men. Miekle and Griest (1989) found that the majority of men suffering from tinnitus were exposed to noise [49]. According to Baguley and McFerran, the cause of tinnitus cannot be explicitly determined in about 67% of all tinnitus cases, which could reflect the changes in central auditory processing [50]. Disc dislocation may also play an important role in tinnitus generation. In agreement with that, Costa et al. confirmed that the more massive the disc displacement, the higher the incidence of effusion [51]. The presence of intra-articular effusion may also play a significant role in the generation of tinnitus.

The major pitfall of our study is a small sample of the TMD- and tinnitus-positive subjects. Future studies with a larger number of such patients should add statistical weight to our present observations. Another drawback of our research is a lack of audiological data generated by pure tone audiometry, the speech comprehension test, tympanometry, tinnitus matching, the minimum masking level, or the loudness discomfort level. Furthermore, the use of translated and validated psychometric instruments measuring tinnitus-induced distress, such as the Tinnitus Functional Index or Tinnitus Handicap Inventory, would be of great advantage [52]. Last, having a control group without TMJ could add insides to this type of research.

The present study aimed to elucidate the causative association between TMD-associated pathologies and tinnitus. Presented research does not support the existence of Costen syndrome. Based on the results, we conclude that the location and type of petrotympanic fissure may be a predisposing factor for tinnitus, especially in patients with TMD. Moreover, our research suggests that the nature of condylar displacement may be essential for tinnitus induction. Further studies should be conducted to extend the presented findings and to contribute to tinnitus phenotyping and the development of effective causative therapy for patients with tinnitus and TMD.

5. Conclusions

(1) This study documents the association between tinnitus and TMJ

(2) The location and type petrotympanic fissure may be a predisposing factor for tinnitus, especially in patients with TMJ

(3) The type of condylar displacement of the temporomandibular joint may be essential for tinnitus induction

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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Research Article

Self-Perceived Dentists' Knowledge of Temporomandibular Disorders in Krakow: A Pilot Study

Magdalena Osiewicz,[1] **Paulina Kojat**,[2] **Maria Gut**,[2] **Zuzanna Kazibudzka**,[2] **and Jolanta Pytko-Polończyk**[1]

[1]*Department of Integrated Dentistry, Dental Institute, Faculty of Medicine, Jagiellonian University Medical College, Krakow, Poland*
[2]*Students Scientific Group of Integrated Dentistry at the Department of Integrated Dentistry, Dental Institute, Jagiellonian University, Medical College, Krakow, Poland*

Correspondence should be addressed to Magdalena Osiewicz; magdalena.osiewicz@uj.edu.pl

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Introduction. The most common nondental orofacial pain conditions are temporomandibular disorders (TMDs). TMD basic examination and clinical management are included in a curriculum of each dentistry programme taught in Poland, but it is not clear how the dentists cope with diagnosis and possible treatment in their routine dental practices. The objective of the present study was to assess a level of self-perceived knowledge of TMD amongst dentists in Poland. *Materials and methods*. The participants, of whom all studied and graduated from a Polish university, were randomly selected from dental offices in Krakow (Poland). The selected dentists were administered an anonymous questionnaire, which contained questions measuring self-assessment of knowledge of TMD diagnosis and therapy and assessing knowledge of ethology and TMD symptoms. *Results*. Only 6.5% of the participants identified their TMD knowledge as very good, 32.3% assessed it as good, 39.3% thought it was sufficient, 20.4% as insufficient, and 1.49% considered it as poor. 9.4% of all participants have attempted to diagnose and treat TMD patients very often, 26.4% declared performing it often, 45.8% rarely, and 18.4% had never made such an attempt. There was a significant relationship between the dentists' knowledge and their attempts at diagnosing and treating TMD patients ($p < 0.05$). *Conclusion*. The level of TMD knowledge amongst the Polish dentists is still insufficient. Raising its level would considerably help the dentists to refer their patients to right specialists for a diagnosis and TMD treatment and/or interdisciplinary management of TMD patients.

1. Introduction

Temporomandibular disorders (TMDs) are characterized by pain of masticatory muscles (when in function), pain in the area of preauricular and/or temporomandibular joint (TMJ), limited and/or deviated mandibular movements, and TMJ sounds (i.e., clicking and/or crepitus) during function [1].

The most common nondental orofacial pain conditions are TMDs [2]. The studies of prevalence of TMD among the healthy Poles are based on two research studies: one carried out on 260 18-year-old adolescents, of whom 26.5% received one or more of TMD diagnoses according to Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD), and second on adults [3–5]. Another research showed that the frequency of TMD diagnoses among the Polish patients was similar to that of other populations [6]. In both research studies carried out on the Polish population, myofascial pain was the most frequent diagnosis. The number of patients requiring a TMD treatment varies considerably, ranging from 1.5% to 30% [7]. A multidisciplinary approach in TMD cases' treatment is crucial and may involve dentists, physical therapists, speech pathologists, physicians, and psychologists [8].

Although, both TMD's basic examination and clinical management are in a curriculum of each dentistry programme taught in Poland, it is not clear how dentists cope with diagnosis and possible treatment in routine dental practice [9].

Unfortunately, due to the lack of previous studies, there are no data on the self-perceived knowledge level of TMD among the Polish dentists to be compared with those retrieved from other countries. Considering the scarcity of research on this topic, the objective of present study was to assess the level of dentists' self-perceived knowledge of TMD in Poland.

2. Materials and Methods

2.1. Participants. 400 dental offices in Kraków (Poland) were randomly selected from Register of Entities Performing Medical Activities by the study's coordinator to randomly identify the study participants, of whom all studied and graduated from a Polish university. The selected dentists were contacted in person by one of the three dentistry students involved in the study. All participants were informed that no identifiable information will be published or released and that participation is voluntary. Each participant was given an anonymous questionnaire to be filled in a spare room, taking approximately 5–10 minutes to be completed. All data were confidentially analyzed.

Prior to the study, the participants were informed of its aim and asked to sign consent forms. The research program was approved by the Jagiellonian University Bioethics Committee (approval no. 1072.6120.83.2018KBET). The study was conducted in accordance with the recommendations of the Declaration of Helsinki. The research commenced in April 2018 and ended in August 2019.

2.2. Questionnaire. The participants were given an anonymous questionnaire containing 8 questions in total regarding: 3 questions on their self-assessment knowledge of TMD diagnosis and therapy and education in the field of TMD, 3 questions on TMD patient population and referrals, and 2 in regards to the participant's knowledge of TMD ethology and the symptoms which, in the participant's opinion, might indicate a TMD condition (Figure 1).

2.3. Statistical Analysis. For qualitative variables, percentages and raw counts were reported. Comparisons of qualitative variables in groups were conducted with the chi-squared test (with Yates' correction for 2×2 tables) or with Fisher's exact test (when low expected values had occurred). Analyses were conducted at 0.05 level of significance. *R* software, version 3.6.1, was used [10].

3. Results

A total of 201 volunteers participated in the anonymous study. The response rate was 50.3% (201/400).

3.1. Knowledge Self-Assessment and the Dentists' Education in the Field of TMD. Only 6.5% of the participants assessed their TMD knowledge as very good, 32.3% assessed it as good, 39.3% thought it was sufficient, 20.4% marked it as insufficient, and 1.5% considered it poor. 64.2% of the participating volunteers had received some training in diagnosing and/or treating TMD patients during their academic education. 50.2% of all the participants had attended some postgraduate training sessions after the graduation from a university.

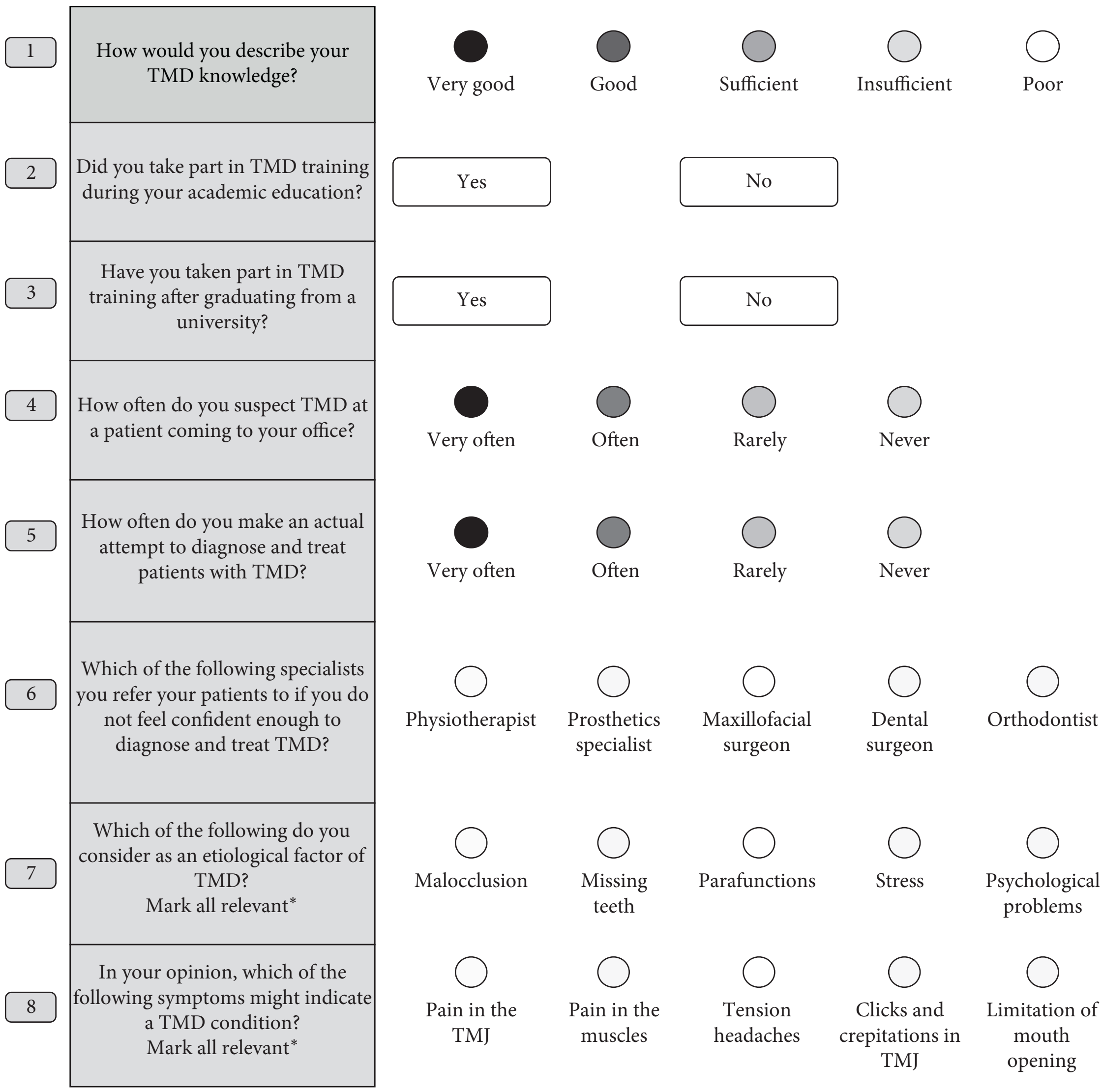
3.2. TMD Patient Population and Referral. Being asked if ever suspected any patients of having TMD symptoms, only 9% of the dentists chose the first option very often. 55.7% selected the second option often, 31.8% chose rarely, and 2.5% chose never. 9.4% of all participants have attempted to diagnose and treat TMD patients very often, 26.4% declared performing it often, 45.8% rarely, and 18.4% had never made such an attempt. Majority of the dentists reluctant to undertake diagnosis and implement some treatment for patients being suspected of TMD refers these patients to prosthetics specialists (56.7%). Some dentists refer their patients to physiotherapists (32.8%), and some others to maxillofacial surgeons (2%), dental surgeons (2.5%), and hardly never to orthodontists (1.5%) (Table 1).

3.3. Ethology and the Symptoms of TMD. When asked of major causes of TMD, almost all participants (93.5%) indicated stress as the main one. Similarly, 92% of participants thought that missing teeth were to blame, 90% chose parafunction as the main cause of TMD, 86.6% selected malocclusion, whereas 75.6% of dentists blamed psychological factors. If it comes to the syndromes, TMJ pain was selected as the most frequent (96.5%), followed by sounds in the TMJ area (92.5%), myofascial pain (90.5%), and tension headache (86.6%). A limitation of mouth opening (87%) was the least often symptom chosen. Next, the relationship between the questions was examined. There was only one significant relationship (as $p < 0.05$): the better the dentists' knowledge, the more often they attempt to diagnose and treat TMD patients (Table 2).

4. Discussion

The aim of the study was to assess the level of the self-perceived knowledge of diagnosing and treating TMD among the Polish dentists and to assess their knowledge of TMD ethology and symptoms.

According to the Regulation of the Minister of Health 2017 [11] regarding standard graduate academic program of practical classes for doctors and dentists, the practical classes in prosthodontics include patients' examination and diagnosis, prevention and treatment deriving from tooth loss, malocclusion, TMDs, and other disorders in uncomplicated clinical cases. Yet, the present study shows that only 6.5% of the participants described their knowledge of TMD as very good, whereas almost a quarter considered it as insufficient or poor. The result is similar to results of a research carried



*Multiple choice question

Figure 1: Anonymous questionnaire.

out in Germany, which tested dentists' confidence in diagnosing orofacial pain. As few as 2% of German dentists thought it was very good, whereas 35% considered it insufficient or poor [12].

About half of the Polish respondents (50.2%) agreed to participate in the postgraduate training in diagnosing or treating TMD, which corresponds with a study carried out in Sweden (51%) [13]. However, in Germany, 41% dentists took part in postgraduate courses [12].

The study clearly demonstrated that there was a significant relationship ($p < 0.05$) between the level of knowledge and attempts to diagnose and treat TMD: the better the knowledge, the attempts have been made more often. Unfortunately, due to the dentist's insufficient knowledge, patients with TMD are often misdiagnosed, which means they have to undergo various treatments for nonrelated disorders, and are referred to other specialists without a clear idea of who they should be referred to, which often leads to frustration, lack of satisfaction, and a compromised quality of life [14].

The Polish dentists who do not attempt to diagnose and treat patients suspected of TMD often refer them to a specialist in prosthetics instead. The latter were given over several months long training in TMD patients' diagnosis and treatments comparing to other medical specializations. However, the fact that over one-third of the examined dentists refers TMD patients for diagnosis and treatment to physiotherapists is worrying. Orofacial pain has a prevalence of about 10% in the general population, and many conditions share similar clinical features [15]. TMD occurrence has been reported in patients with some chronic pain conditions or psychological disorders and also life-threatening diseases, such as Lyme disease. Hence, the diagnoses should be carried out by a dentist who might be the first one to diagnose a patient's disease and refer the patient to a right specialist being able to prescribe without any further delay

Table 1: Descriptive statistics of questionnaire.

Question	Answer	n (%)
(1) How would you describe your TMD knowledge?	Very good knowledge	13 (6.5%)
	Good knowledge	65 (32.3%)
	Sufficient knowledge	79 (39.3%)
	Insufficient knowledge	41 (20.4%)
	Poor knowledge	3 (1.5%)
(2) Did you take part in TMD training during your academic education?	Training during study	129 (64.2%)
	No training	71 (35.3%)
	No answer	1 (0.5%)
(3) Have you taken part in TMD training after graduating from a university?	Postgraduate training	101 (50.2%)
	No training	98 (48.8%)
	No answer	2 (1%)
(4) How often do you suspect TMD at a patients coming to your office?	Very often	18 (9%)
	Often	112 (55.7%)
	Rarely	64 (31.8%)
	Never	5 (2.5%)
	No data	2 (1%)
(5) How often do you make an actual attempt to diagnose and treat patients with TMD?	Very often	19 (9.4%)
	Often	53 (26.4%)
	Rarely	92 (45.8%)
	Never	37 (18.4%)
(6) Which of the following specialists you refer your patients to if you do not feel confident enough to diagnose and treat TMD?	Physiotherapist	66 (32.8%)
	Prosthetics specialist	114 (56.7%)
	Maxillofacial surgeon	4 (2%)
	Dental surgeon	5 (2.5%)
	Orthodontist	3 (1.5%)
	No answer	9 (4.5%)
(7) Which of the following do you consider as an etiological factor of TMD? Mark all relevant.*	Malocclusion	174 (86.6%)
	Missing teeth	185 (92%)
	Parafunctions	181 (90%)
	Stress	188 (93.5%)
	Psychological problems	152 (75.6%)
(8) In your opinion which of the following symptoms might indicate a TMD condition? Mark all relevant.*	Pain in the TMJ	194 (96.5%)
	Pain in the muscles	182 (90.5%)
	Tension headaches	174 (86.6%)
	Clicks or crepitations in TMJ	186 (92.5%)
	Limitation of mouth opening	175 (87%)

*Multiple choice question.

the right treatment [16–21]. It is recommended to implement an interdisciplinary management of TMD patients, involving dentists, physical therapists, psychologists, ear/nose/throat specialists, and speech pathologists, especially when the pain is chronic [8].

The majority of the Polish dentists consider stress, parafunction, and psychological factors to be the main causes of TMD. 96% of the American dentists are convinced that stress plays an important role in causing TMD, 100% of Korean dentists agree with them, 88% of Mexican dentists, and 88% of Swedish agree too [22–25].

On the other hand, a similar number of the Polish dentists disagree with the idea, claiming that missing teeth and malocclusion are to be blamed. The results of this study are similar to those of Lopez-Frias et al.'s study carried out among the Spanish dentists, where 98.5% of respondents

Table 2: The relationship between the dentists' knowledge and their attempts at diagnosing and treating TMD patients.

Attempts to diagnose and treat	Knowledge				p
	Very good ($N = 13$)	Good ($N = 65$)	Sufficient ($N = 79$)	Insufficient or poor ($N = 44$)	
Very often	7 (53.85%)	6 (9.23%)	6 (7.59%)	0 (0.00%)	$p < 0.001^*$
Often	5 (38.46%)	25 (38.46%)	14 (17.72%)	9 (20.45%)	
Rarely	0 (0.00%)	27 (41.54%)	40 (50.63%)	25 (56.82%)	
Never	1 (7.69%)	7 (10.77%)	19 (24.05%)	10 (22.73%)	

$^*p$ value was calculated by using Fisher's exact test (in case of low expected values).

believed that occlusal alterations are accountable for TMD [26]. In 1934, the dental profession was drawn into the area of TMD because of the article written by James Costen, an otolaryngologist [27]. On the basis of eleven cases, he suggested that changes in a dental condition (e.g., over closure of bites, lack of molar support, and malocclusion) were responsible for various symptoms, such as impaired hearing, stuffy ears, tinnitus, masticatory muscle and joint pain, dizziness, sinus symptoms, and headache. Because of that for years, the focus of dental professionals' approach to patients with TMDs has been solely based on the assessment and correction of purported abnormalities of the occlusion [28]. Over the last few years, there has been a visible accumulation of evidence against using irreversible mechanical therapies in TMD treatment, in favour of bio-psycho-sociological approach to TMD. Besides physiological overloading, many epidemiological studies have demonstrated the existence of a strong relationship between TMDs and psychopathology, and the occlusal factors should no longer be taken into consideration in TMD diagnosis and treatment [29, 30].

According to a Polish graduate curriculum, the topic of TMD is included in prosthetics studies, which covers 285 hours of lectures and clinical classes [11, 31]. Yet, only one lecture and one practical class are dedicated to TMD management. According to the record book of clinical student training, after the class a student should "know the rules of performing and should be able to provide assistance to the initial treatment of TMD." This is the reason why the dentists are reluctant to diagnose and treat patients with TMD. It is not a surprise that the graduates do not feel prepared well enough to carry out a treatment they have never done before. In contrary, Swedish students have separate classes dedicated only to TMD, which prepare them to treat TMD patients far better than those in countries where very little time is given to TMD [32].

As the final remark, it must be pointed out that this is the first study on the self-perceived dentists' knowledge of TMD in Central/East Europe. Generalization of findings may be limited by the sample of dentists included in this study, which might have influenced the representativeness of the sample, with respect to the general Polish dentist population. The crucial limitation of the study is the lack of information about the demographics of the participants such as gender, age, lack of specialty, and years of experience. It is suggested to separate specialists and general dentists in future studies as well as take into consideration their work experience. In terms of limitations, the study was carried out on a relatively small group of dentists; therefore, it should be considered as a pilot study. In further studies, the sample group should be expanded to volunteers from other cities allowing for a cross-cultural comparison. Therefore, the presented results should be interpreted with caution and some further studies based on a bigger sample and including different dental specialties are recommended.

5. Conclusions

The study is the first one in Central Europe carried out among the Polish dentists with the use of a questionnaire. The results are within the range of those from other countries. However, Polish dentists' knowledge of TMD is still insufficient. Increasing TMD knowledge level among the dentists would considerably help them in referring their patients to the right specialist for further diagnosis and TMD treatment and/or interdisciplinary management of TMD patients. Therefore, it is very important to design a suitable study programme which would provide graduate dentists with necessary practice and knowledge of TMD.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

All authors state that they have no conflicts of interest.

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