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ORIGINAL ARTICLE

CONTENTS

Comparison of foot contact area and plantar pressures distribution in subject with temporomandibular disorders and asymptomatic individuals

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ABSTRACT
Aim: To determine the differences between the foot contact area and the distribution of plantar pressure between patients with different subtypes of temporomandibular disorders and asymptomatic individuals.
Materials and methods: A total of 48 patients with temporomandibular disorders (17 with disc disorders subtype; 14 with myofascial subtype; 17 with mixed diagnosis) and 33 asymptomatic subjects (control group) diagnosed by Research Diagnostic Criteria for Temporomandibular Disorders were perform posturography examination using FreeMED MAXI ground reaction force platform (Sensor Medica; Guidonia Montecelio, Roma, Italia) under different mandibular conditions (rest position, clenching, clenching on cotton rolls). The following parameters were used for statistical analysis: percentage distribution of plantar pressure (left/right foot and forefoot/backfoot) and foot contact area.
Results: Changes in foot posture parameters are visible in both patients with temporomandibular disorders and in the control group, under different visual and mandibular conditions.
Conclusions: The findings suggest a clear necessity for higher-quality studies with larger sample sizes.

KEY WORDS: temporomandibular disorders, temporomandibular joint, masticatory muscles, foot, posture

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INTRODUCTION
Temporomandibular disorders (TMD) represent a collective term encompassing numerous pathologies of the temporomandibular joint (TMJ), muscles of the masticatory system and their surrounding structures, including soft tissues and nerves [1]. The most frequent symptoms of TMD manifest as pain in the masticatory muscles, TMJ discomfort, restricted mandibular abduction and joint sounds [2]. The etiology of this disorder is multifactorial, taking into account primarily biomechanical and psychosocial factors [3–5].

Posture is defined as the position of the human body in space. The central nervous system is responsible for controlling posture, regulating the tone of peripheral muscles in response to stimuli from the vestibular system and the visual organ [2, 3]. Recent studies increasingly highlight the potential influence of the stomatognathic system on postural regulation and overall body balance [3].

The connection between the stomatognathic system, TMD, and posture has garnered significant interest among researchers; however, consensus remains elusive. The authors emphasize the necessity of high-quality studies involving larger cohorts, use of reliable TMD assessments based on standardized criteria, division of study populations by TMD subtypes, and use of objective measures of body posture [2, 6]. The strongest evidence suggest a relationship between TMD and cervical spine disorders [7]. It is postulated that changes in body posture may serve as compensatory mechanism, particularly in adjacent body segments such as the masticatory system and the cervical spine [8]. The TMJ, through its ligamentous connections and myofascial chains with the cervical spine, creates a functional complex that can be described as the "cranio-cervical mandibular system" [7, 9]. Observational studies indicate that individuals with TMD exhibit a higher prevalence of forward head posture compared to the general populace [10], a phenomenon associated with a shortening of the neck extensors and sternocleidomastoid muscles [11]. This association appears particularly pronounced in patients with the myogenic subtype of TMD. Furthermore, changes in head and cervical spine positioning may induce adaptive changes in the center of gravity [12], which in turn may be a factor inducing adaptations in the entire body posture. Transfer of dysfunction to distant anatomical regions may be related to the existence of myofascial chains. Mechanoreceptors located in the fascial tissues have the ability to contract in response to stimuli, which leads to the distribution of tension to neighboring muscles along the myofascial chain [13, 14].

The presence of postural alterations in distant body segments in patients with TMD were observed in the shoulder posture, pelvis and spine [15]. It has long been suggested that postural adaptations observed in TMD patients may be due to the need to minimize pain and modify musculoskeletal stress zones, resulting in changes in the longitudinal arches of the feet [16]. However, the quality of many studies addressing this topic is often regarded as low, with some research disputing any correlation between TMD and body posture [15].

Confirmation of the existence of a relationship between TMD and body posture, as well as determination of the direction of these relationships, may help to determine the factors predisposing and/or perpetuating TMD. The abundance of evidence regarding the links between TMD and deviations in body posture indicate the need to extend dental diagnostics to include body posture examinations [7]. On the other hand, considering that the compensatory capacity of the myofascial system to transfer dysfunctions is limited and exceeding this tolerance limit leads to the occurrence of symptoms [17] implementing therapeutic measures at an early stage of transferring dysfunctions seems to be an important preventive measure against the development of musculoskeletal disorders.

AIM

The aim of the study was to determine the differences between the foot contact area and the distribution of plantar pressure between patients with different subtypes of temporomandibular disorders and asymptomatic individuals.

MATERIALS AND METHODS

The research was carried out in compliance recommendations of the Declaration of Helsinki and received approval from the Bioethics Committee at the Medical University of Lublin (KE-0254/256/12/2022). Prior to participation, all subjects were thoroughly briefed on the study protocol and gave their written consent.

Participants were selected from patients attending the temporomandibular disorders treatment clinic, as well as from students of the Medical University of Lublin. The criteria for exclusion were as follows: age (18-40); pain of masticatory muscles or TMJ during posturographic examination; presence of spontaneous pain in the TMJ area; visual disturbances if the last check-up with an ophthalmologist was more than 12 months ago; conditions that may have influenced body balance (ex. neurological disorders); previous injuries to the musculoskeletal system in the last 6 months; scoliosis or other evident problems with the posture; presence of fewer than 28 teeth; previous craniofacial injuries; previous surgical treatment in the head and neck area in the last 6 months before the examination; open bite; crossbite; Angle's II or III class; lack of four support zones in the dental arches; missing more than four teeth in both dental arches; having dentures (regardless of type); professional athletes; alcohol consumption within the last 24 hrs; training/cultivating sports or conservative dental treatment within the past 24 hrs; BMI below 18.5 and above 24.99.

The diagnosis of TMD was performed by a specialists in prosthodontics, using the Polish version of Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) [18]. Based on the above criteria, the subjects were divided into a study group (patients with TMD) and a control group (subjects without TMD symptoms). Then, the study group was divided into subgroups of disorders: myofascial subtype, articular subtype (incuding disc and joint disorders) and mixed subtype (myofascial and articular subtype) [19].

The posturographic examination was performed using the FreeMED MAXI pedobarographic platform (Sensor Medica; Guidonia Montecelio, Roma, Italy). Two measurements were performed:

- to assess the foot contact area, a static test was performed in three mandibular conditions (rest mandibular position; maximum teeth clenching; maximum teeth clenching on cotton rolls), each test lasting 5 seconds;
- to assess the distribution of plantar pressure (left/right foot and forefoot/hindfoot), a posturographic

test was performed in six mandibular and visual conditions (rest mandibular position; maximum teeth clenching; maximum teeth clenching on cotton rolls; each condition with eyes open and closed), each test lasting 30 seconds [12].

Participants were positioned on a force platform, 150 cm away from a wall. During the measurements, a quiet environment was maintained, free from any distracting stimuli that could affect body balance. The participants were instructed to maintain the best possible stability, with their arms relaxed at their sides, facing the wall without focusing on any specific point on it [20].

RESULTS

STATISTICAL ANALYSIS

The calculations were performed using Statistica™ version 13.3 (TIBCO Software Inc., Palo Alto, CA, USA). The normality of the data distribution was checked with the Shapiro-Wilk test. Student's t-test or Mann-Whiney U-test were used to compare two groups in case of non-conformity with the normal distribution. The Friedman ANOVA and Kendall Coeff of Concordance (Chi squered) were used for subgroup comparisons. The Kruskal-Wallis test (H) was used to compare repeated measurements pf the foot contact surface in different mandibular conditions. When analyzing the load distribution on the right and left foot, the subgroups were compared using Kruskal-Wallis ANOVA. The occlusal conditions were compared using Friedman ANOVA. Kendall's coefficient of concordance (Kendall's W) was used as a measure of effect size, where 0.1 – < 0.3 (small effect), 0.3 – < 0.5 (moderate effect) and >= 0.5 (large effect). When analyzing the load distribution on the forefoot and hindfoot between subgroups (4), a parametric analysis of variance with repeated measures was performed on two levels: occlusal conditions (3) and visual conditions (2). Additionally, contrasts analysis for One-Way ANOVA was performed for planned comparisons between each subgroup and the control group. The ANOVA effect size was expressed by eta squered: 0.01 – small effect size, 0.06 – medium effect size, and 0.14 – large effect size. The significance level of the tests was $\alpha < 0.05$. Descriptive statistics were presented using the mean (M), standard deviation (SD), median (Me), and minimum and maximum (Min, Max) values.

The study group consisted of 81 volunteers who were assigned to the control group (CG) (n=33, n_{men}=7) or the group with TMD (SG) (n=48, n_{men}=6). The groups did not differ statistically significantly in terms of age (CG=24.15±2.68; SG=25.06±3.98, p=0.64) and BMI (control group=21.54±3.70; SG=21.89±3.00, p=0.49). Next, people with TMD were divided into subgroups based on the type of disorder: myofascial (n=14), mixed (n=17) and articular (n=17).

FOOT CONTACT AREA

Descriptive statistics regarding the foot contact area in the individual subgroups are presented in Table 1.

Analysis using the Mann-Whitney U test for two groups (SG and CG) did not show any statistically significant differences between the groups except for the measurement during teeth clenching. In the SG, the values of the foot contact area were smaller than in the CG during teeth clenching (for the left limb, Z=1.97, p=0.048, for the right limb, Z=1.99, p=0.045).

When comparing the subgroups with the CG, no statistically significant differences were found between the subgroups (Table 2).

Comparing different mandibular conditions, statistically significant differences were found in all subgroups (Table 3). The smallest values of the foot contact surface were noted at rest, while the largest values were noted when teeth were clenched on the rolls.

PLANTAR PRESSURE DISTRIBUTION

There were no statistically significant differences between the SG and the CG in the plantar pressure distribution between the right and left foot or between the forefoot and hindfoot. There were also no statistically significant differences between the subgroups or between the subgroups and the CG. Comparison of mandibular conditions with eyes open in the two groups showed statistically significant differences in the case of the control group, where greater asymmetry between the right and left side was visible when clenching on the rollers. No differences were found in the SG (chi^2=0.80, p=0.67). In the case of closed eyes, statistically significant differences between mandibular conditions of the same nature were observed in the SG (chi^2=9.56, p=0.008, W=0.10). Mandibular conditions in the subgroups differed in a statistically significant manner only in the case of the myofascial subgroup (Table 4).

In the case of the distribution on the forefoot and hindfoot, the conditions related to visual control were found to be statistically significant. During the measurements with closed eyes, the load on the forefoot increased significantly relative to the hindfoot compared to the open eyes. Contrast analysis comparing

Table 1. Descriptive statistics for the foot contact area in individual subgroups

Group	Mandibular condition / side	M	SD	Me	Min	Max
CG	Rest / L	106,39	20,50	106	67	151
	Rest / P	103,12	20,88	104	33	136
	Clench / L	112,45	20,05	113	79	152
	Clench / P	108,03	17,15	106	78	137
	Clench Rolls / L	112,67	20,30	111	74	153
	Clench Rolls / R	107,55	18,44	110	69	141
Myofascial	Rest / L	93,71	17,95	91	60	128
	Rest / R	92,29	21,66	92,5	59	145
	Clench / L	96,43	18,76	89	61	135
	Clench / R	95,79	24,21	93,5	62	158
	Clench Rolls / L	106,15	27,58	102	68	176
	Clench Rolls / R	102,23	27,73	95	69	174
Mixed	Rest / L	104,35	22,31	102	68	148
	Rest / R	99,47	22,62	91	71	137
	Clench / L	106,24	22,84	106	68	155
	Clench / R	101,00	22,33	93	70	142
	Clench Rolls / L	109,76	23,74	113	67	152
	Clench Rolls / R	103,24	20,30	103	70	142
Articular	Rest / L	103,41	28,61	98	70	157
	Rest / R	101,12	29,77	91	68	175
	Clench / L	106,06	28,79	103	68	164
	Clench / R	104,65	28,24	96	68	178
	Clench Rolls / L	109,53	25,65	110	67	154
	Clench Rolls / R	111,00	26,79	107	65	155

Rest – resting mandibular position; Clench – maximum teeth clenching; Clench rolls – maximum teeth clenching on cotton rolls; L – left foot; R – right foot; M – mean; SD – standard deviation; Me – median; Min – minimum values; Max – maximum values

the subgroups with the CG showed statistically significant differences only for the articular group during rest and with open eyes (t=2.43, p=0.02). The articular group statistically significantly loaded the forefoot relative to the hindfoot than the CG (Table 5).

DISCUSSION

The findings of previous research examining the influence of temporomandibular disorders on foot posture yield inconsistent results. Similarly, the outcomes of this research do not present coherent conclusions.

In the analysis of the foot contact area, both intra-group and inter-group differences were observed. Comparative assessments revealed that the foot contact area was significantly reduced in the TMD group during maximal clenching when contrasted with the CG. However, no statistically significant differences were identified when comparing the CG with the various subtypes of TMD. Intra-group analyses demonstrated that all groups exhibited a greater foot contact area during maximal clenching on cotton rolls compared to the resting position of the mandible.

In the comparative analysis of plantar pressure, no statistically significant differences were detected between CG and the SG, nor among the study group and TMD subtype groups. Intra-group analyses revealed a pronounced asymmetry in plantar pressure between the right and left sides within the CG during clenching while the eyes were open. Conversely, similar asymmetrical patterns were observed in the SG during clenching with the eyes closed. Furthermore, a distinct variation in mandibular conditions was noted exclusively within the subgroup with myofascial subtype of TMD.

The influence of TMD on foot posture was observed in Cuccia's study [21]. Comparing the TMD group and the control group in three occlusal conditions (resting position, clenching, placing cotton

Table 2. Kruskal-Wallis statistic result for comparisons of 4 groups (control, myofascial subtype, mixed subtype, articular subtype)

Mandibular condition	Side	Kruskal-Wallis (H) test	p-value
Rest	L	3,42	0,33
	R	4,02	0,22
Clench	L	5,37	0,15
	R	4,95	0,16
Clench Rolls	L	1,17	0,76
	R	2,37	0,50

Rest – resting mandibular position; Clench – maximum teeth clenching; Clench rolls – maximum teeth clenching on cotton rolls; L – left foot; R – right foot

Table 3. Results of Friedman ANOVA statistics for comparisons of mandibular conditions (rest, maximum teeth clenching, maximum teeth clenching on cotton rolls) in individual subgroups

Group	Side	chi squered statistics	p-value
CG	L	36,91	<0.001
	P	22,65	<0.001
Myofascial	L	13,50	0.001
	P	19,10	<0.001
Mixed	L	14,24	0.001
	P	13,29	0.001
Articular	L	11,72	0.003
	P	13,73	0.001

L – left foot; R – right foot

rolls between the arches without clenching), the author noted significant differences in baropodometric variables. In the intra-group analysis of the TMD group, significant differences were observed between the resting position (REST) and maximum teeth clenching (VTC), and between VTC and the position with rolls between the teeth (CR) in such parameters as the total surface of feet [cm^2], the mean load pressure on the plantar surface [g/cm^2], forefoot vs. rearfoot surface, forefoot vs. rearfoot loading. However, statistically significant differences in baropodometric parameters during different occlusal conditions were also observed in the control group. In this study, in both groups (TMD and CG), an increase in the total surface of feet value was observed during maximum teeth clenching compared to the resting position of mandible [21]. In our study, we did not observe any differences in the foot contact area between the resting position of the mandible and maximum teeth clenching, both in the SG and CG. However, we did observe a statistically significant increase in this parameter during maximum clenching on the cotton rolls in each group. Additionally, in the Cuccia's study, placing cotton rolls between the dental arches resulted in a change in the distribution of loads between the forefoot and the hindfoot [21]. In our study, no influence of mandibular conditions on changes in load distribution between the hindfoot and forefoot was observed in any of the groups. The differences in the results of both publications can be explained by significant methodological differences. Cuccia's study used the American Academy of Orofacial Pain criteria for diagnosing TMD [21], whereas our study employed the DC/TMD questionnaire, a tool that is widely recommended for the diagnosis of temporomandibular disorders [19]. Additionally, in both works the cotton rolls were used in a different way. In our study, the subjects were asked to clench their teeth on the rolls as much as possible, whereas in the work of Cuccia et al. the rolls were placed between the arches of the subjects, without additional clenching of the teeth [21].

In the study by Souza et al., changes in global body posture were observed in both the TMD and asymptomatic groups, but these changes were more significant in the symptomatic group. The TMD group showed more pronounced heel valgus and differences in plantar pressure distribution (lower forefoot and higher backfoot pressure) compared to the asymptomatic group [22]. In our study we noticed a relationship between visual conditions and forefoot load. During eyes closed, the load on the forefoot was greater than during eyes open. Moreover, we observed a greater forefoot load in patients with the articular form of TMD compared to

Table 4. Comparisons of plantar pressure distribution (right and left foot) between subgroups

Variable	Control group		Myofascial		Mixed		Articular		Group comparison	Comparison of mandibular conditions		
	M	SD	M	SD	M	SD	M	SD	Kruskal-Wallis ANOVA	group	Friedman ANOVA EO	Friedman ANOVA EC
EO Rest L	51,97	4,33	51,79	4,25	52,41	4,00	50,76	3,98	H =1,57 p =,66			
EO Rest R	48,03	4,33	48,21	4,25	47,59	4,00	49,24	3,98	H =1,57 p =,66	control group	chi=6,81, **p=,03** **W=,10**	chi=3,91, p=,14
EC Rest L	51,31	4,80	50,79	2,19	51,53	4,05	51,06	3,68	H =,82 p =,84			
EC Rest R	48,97	4,84	49,21	2,19	48,47	4,05	48,94	3,68	H =1,11 p =,77			
EO Clench L	51,61	4,08	51,43	3,92	52,12	3,76	51,00	3,59	H =,701 p =,87	myofascial	chi=,77 p=,68	chi=6,68, **p=,04** W=,24
EO Clench R	48,39	4,08	48,57	3,92	47,88	3,76	49,00	3,59	H =,70 p =,87			
EC Clench L	51,94	4,26	50,79	2,04	51,94	4,04	50,82	3,34	H =,99 p =,80			
EC Clench R	48,06	4,26	49,21	2,04	48,06	4,04	49,18	3,34	H =,99 p =,80	mixed	chi=,51, p=,77	chi=1,59, p=,45
EO Clench Rolls L	52,76	3,91	51,14	3,88	52,24	3,51	51,71	3,92	H =1,35 p =,71			
EO Clench Rolls R	47,24	3,91	48,86	3,88	47,76	3,51	48,29	3,92	H =1,35 p =,71			
EC Clench Rolls L	52,25	4,05	51,36	2,90	52,47	4,35	51,53	3,91	H=,58 p =,90	articular	chi=1,47, p=,48	chi=3,00, p=,22
EC Clench Rolls R	47,75	4,05	48,64	2,90	47,53	4,35	48,47	3,91	H =,58 p =,90			

EO – eyes open; EC – eyes closed; Rest – resting mandibular position; Clench – maximum teeth clenching; Clench rolls – maximum teeth clenching on cotton rolls; L – left foot; R – right foot

the CG, however, only during the resting position of the mandible with eyes open. Contrary conclusions were reached by Saito et al., who, in their study, denies the relationship between TMD and foot posture. In the paper, no differences were found between the group of patients with articular disc displacement in the TMJ and the group without TMD during the assessment of the longitudinal arches of the foot. However, significant differences between the groups were observed in the posture of the pelvis, lumbar and thoracic spine, head and jaw posture [16]. Similar conclusions were reached by Munhoz et al. [23]. Authors did not observe a relationship between patients with TMJ internal derangement and global body posture in their study. Also Sakaguchi et al., did not observe statistically significant differences in the anteroposterior and laterolateral distribution of plantar pressure when comparing different mandibular positions in healthy individuals [24]. However, there are significant differences in methodology between the above studies (different group selection criteria, analysis of other posture parameters and use of other measurement tools) which does not allow for an accurate comparison of their results.

The relationship between body posture and TMD is also demonstrated by research focused on the treatment of TMD. In the work of Chess et al., 80% of TMD patients treated with an occlusive splint for 7 months showed improvement in plantar pressure distribution [25]. According to some authors, the use of an occlusal splint in patients with TMD may result in the improvement of occlusal conditions, providing a stable occlusal relationship and centric relation occlusion, which may lead to neuromuscular balance [26, 27]. This in turn may lead to adaptation of the subject's morphostatic pattern and changes in the distribution of postural muscle tension, resulting in a change in body posture [28]. However, the conclusions from the literature review by Ferrillo et

Table 5. Comparisons of plantar pressure distribution (forefoot, hindfoot) between subgroups

Variable	Control		Myofascial		Mixed		Articular		ANOVA		
	M	SD	M	SD	M	SD	M	SD	Subgroup comparison	Mandibular condition comparison	Visual condition comparison
EO forefoot	37,15	7,30	36,71	4,02	39,38	7,99	42,06	6,03	F=1,21 p=,31	F=,14 p=,86	F=13,03 p<,001 eta=,15
EO hindfoot	62,85	7,30	63,29	4,02	60,62	7,99	57,94	6,03			
EC forefoot	38,48	6,80	38,46	5,69	40,47	7,59	42,59	6,55			
EC hindfoot	61,84	6,74	61,54	5,69	59,53	7,59	57,41	6,55			
EO clench forefoot	38,64	7,08	38,18	4,39	38,97	7,60	41,26	5,39			
EO clench hindfoot	61,36	7,08	61,82	4,39	61,03	7,60	58,74	5,39			
EC clench forefoot	38,34	7,07	38,39	4,29	40,35	7,18	41,88	4,75			
EC clench hindfoot	61,66	7,07	61,61	4,29	59,65	7,18	58,13	4,75			
EO clench rolls forefoot	37,58	7,41	38,25	4,74	39,03	7,47	41,56	5,58			
EO clench rolls hindfoot	62,42	7,41	61,75	4,74	60,97	7,47	58,44	5,58			
EC clench rolls forefoot	38,55	7,14	40,00	5,62	40,03	7,46	41,75	5,44			
EC clench rolls hindfoot	61,45	7,14	60,00	5,62	59,97	7,46	58,25	5,44			

EO – eyes open; EC – eyes closed; Rest – resting mandibular position; Clench – maximum teeth clenching; Clench rolls – maximum teeth clenching on cotton rolls

al. suggest that the clinical significance of occlusal splints in the treatment of postural defects may be negligible, although they do emphasize the need for a multidisciplinary team in the treatment of patients with TMD [26].

The significant differences in the results of studies on the effect of TMD on body posture may be due to several factors. First, body posture is characterized by high variability in the general population [23]. Postural dysfunctions are also caused by many factors, such as bad habits, sedentary work, emotional factors, and the causes of postural disorders are best explained by the biopsychosocial model [29]. It is possible that changes in body posture in patients with TMD are limited only to the center of gravity parameters, not translating into significant deviations in foot posture parameters.

The analysis of papers on this subject reveals numerous limitations that should be considered in the future studies protocols: the use of tools other than the recommended ones for the assessment of TMD, the lack of division of the study group into TDM subtypes, the use of subjective methods for assessing body posture, and the small study group.

CONCLUSIONS

Changes in plantar pressure distribution (left/right foot, forefoot/hindfoot) and in foot contact area are observed in both patients with temporomandibular disorders and asymptomatic individuals. Future studies should use valid measurement tools to assess foot posture and established criteria for diagnosing TMD, and significantly increase the size of the study group.

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CONFLICT OF INTEREST
The Authors declare no conflict of interest.

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