Heliyon 10 (2024) e32872

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Diaphragm dysfunction is found in patients with chronic painful temporomandibular disorder: A case-control study☆

Yaqing Zheng [a,b,1], Yonghui Chen [a,*,1], Yifeng Li [a], Sijing Zheng [a], Shuping Yang [c]

[a] Department of Stomatology, Zhangzhou Affiliated Hospital of Fujian Medical University, Zhangzhou, 363000, China
[b] Department of Stomatology, Zhongshan Hospital, Fudan University (Xiamen Branch), Xiamen, 361015, China
[c] Department of Ultrasound, Zhangzhou Affiliated Hospital of Fujian Medical University, Zhangzhou, 363000, China

ARTICLE INFO

Keywords:
Respiration
Phychology
Biomechanical phenomena
Chronic pain
Ultrasonography
Co-morbidity

ABSTRACT

Aim: To determine whether patients with chronic painful temporomandibular disorder (TMD) had abnormal diaphragm function compared to healthy controls and to explore the correlation between diaphragm contractility, psychological status, and pain characteristics.
Methods: A single-blinded, case-control study was conducted involving 23 chronic painful TMD patients and 22 healthy volunteers. The examination and diagnosis were performed according to the Diagnostic Criteria for Temporomandibular Disorders, and questionnaires were used to evaluate pain, depression, anxiety, and physical symptoms status. B-mode ultrasound was used to measure diaphragm thickness and contractility. The sonographer responsible for measuring the diaphragm was blinded to group membership.
Results: 1. Depression, anxiety, and physical symptoms scores were significantly higher in the patients than in the controls ($p < 0.05$). 2. The Interference Score of pain was significantly correlated with depression and physical symptoms ($p < 0.01$). 3. Bilateral diaphragm contractility was significantly smaller in the patients than in the controls (right: $P = 0.003$; left: $P = 0.001$). 3. There was no correlation between diaphragm contractility on the left and right sides in the patients ($r = -0.112$, $P = 0.611$), while there was a positive correlation in the control group ($r = 0.638$, $P = 0.001$). 4. No correlation was found between the degree of diaphragm contractility, psychological status, and pain scores.
Conclusions: 1. Patients with chronic painful TMD have worse psychological status, including depression, anxiety, and physical symptoms. 2. Patients with chronic painful TMD have a smaller degree of bilateral diaphragm contractility and more significant left-right incongruity, which indicated that diaphragm dysfunction may be correlated with chronic painful temporomandibular disorder.

1. Introduction

Temporomandibular disorder (TMD) are the second most common musculoskeletal chronic pain disorder after low back pain,

☆ Trial registration: The study was Pre-registration in the Chinese Clinical Trial Registry (No: ChiCTR2100042263). http://www.chictr.org.cn/edit.aspx?pid=120348&htm=4.

* Corresponding author.
E-mail address: cyh1501@163.com (Y. Chen).

[1] These two authors contributed equally to this work.

https://doi.org/10.1016/j.heliyon.2024.e32872
Received 7 May 2023; Received in revised form 6 June 2024; Accepted 11 June 2024
Available online 14 June 2024

affecting 6–9% of adults globally [4]. TMD are associated with pain affecting the jaw and associated structures and may present with headaches, earache, clicking, popping, or crackling sounds in the temporomandibular joint, and impaired mandibular function [4]. Chronic painful TMD is characterized by persistence of pain for no less than 3 months [3], which greatly influences patients' quality of life [1]. Moreover, chronic painful TMD is frequently accompanied by pain or dysfunction in other parts of the body [5,6,14], including neck disability [7], back pain [8,9], pelvic floor myalgia [10], fibromyalgia [9], abnormal body posture control [11–13]. This complexity makes it necessary for physicians to provide comprehensive treatment options and explore the underlying mechanisms of TMD and its accompanying widespread musculoskeletal pain and dysfunction in depth. There exists a hypothesis that the muscle imbalances associated with poor breathing patterns may help to explain the mechanisms linking TMD and its musculoskeletal co-morbidities [40]. In addition, Bartley [32,33]has proposed that a breathing pattern may shift from a diaphragmatic respiratory one to a dysfunctional one with more auxiliary respiratory muscles as a result of chronic stress, anxiety, and sympathetic hyperexcitability, hence disrupting the balance of the postural musculature, that is, a change in breathing patterns may help to explain how biomechanical factors related to psychosocial effects lead to TMD. Experiments have shown that when diaphragm recruitment decreases, sternocleidomastoid muscle recruitment increases [17]. Furthermore, the sternocleidomastoid muscle, due to its anatomical characteristics, has a major influence on posterior cranial rotation and anterior head extension postures, and there is a significant impact on craniocervical alignment. At present, there is strong evidence supporting the presence of altered craniocervical posture in patients with myogenous TMD [13], and moderate evidence of sagittal spinal curves alterations in TMD patients [19].

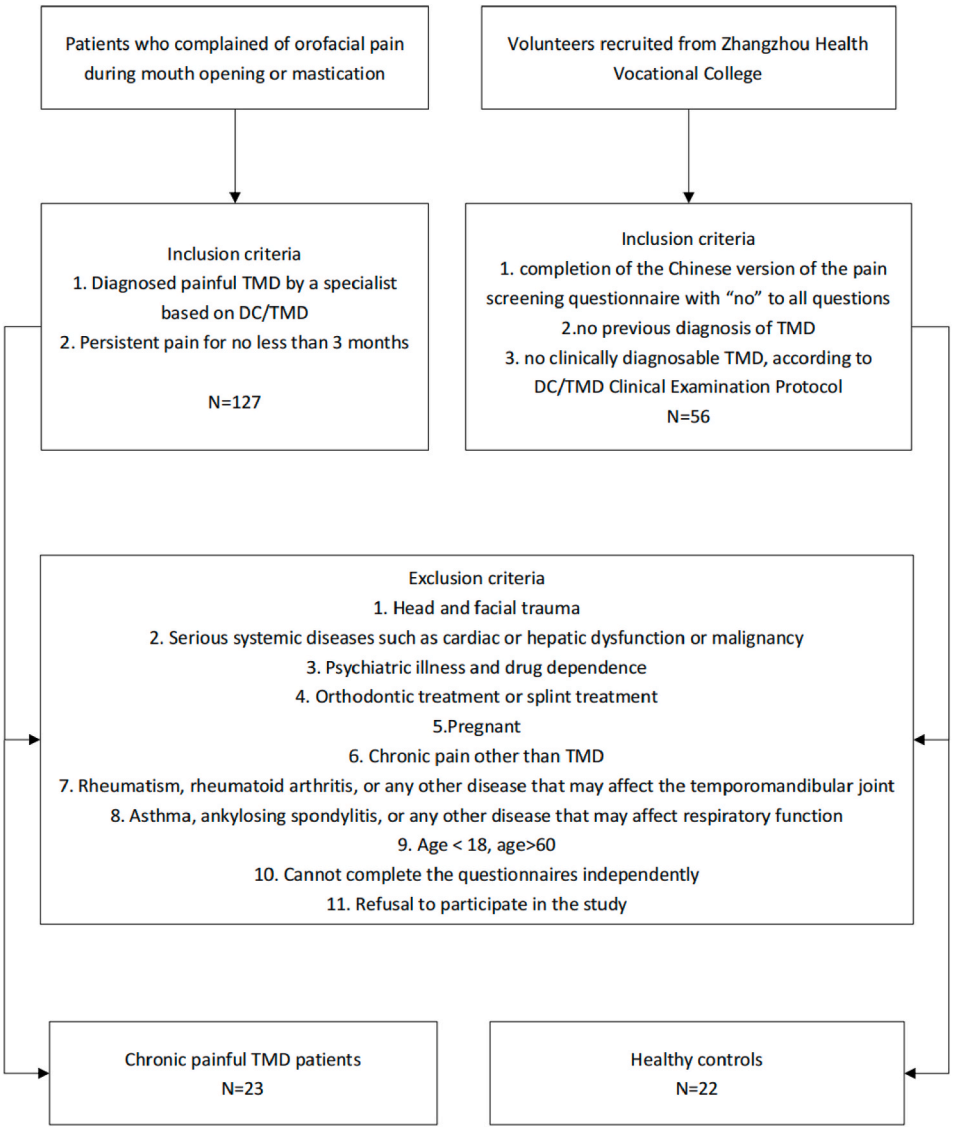

Fig. 1. Flowchart of study sample selection.
TMD, Temporomandibular disorders; DC/TMD, Diagnostic Criteria for Temporomandibular Disorders; N, number.

In recent years, the assessment and intervention of the diaphragm have received increasing attention in the research and clinical practice of musculoskeletal chronic pain and dysfunction. In addition, abnormal diaphragm function has been observed in patients with various musculoskeletal disorders and favorable outcomes have been obtained after specific interventions [21–23]. The diaphragm is a muscle with two tasks: providing inspiratory power and regulating trunk stability. On one hand, as the primary respiratory muscle, the diaphragm performs 70 %–80 % of the inspiratory function under quiet conditions [24]. Meanwhile, the diaphragm muscle, synergistically working with the muscles of the deep abdominal wall, pelvic floor, and deep posterior trunk, creates the basis of the body's core, which has a significant impact on the maintenance of trunk stability, spinal health, and even the biomechanics of many parts of the body [22,36,38]. In patients with TMD, is there abnormal diaphragmatic function? Currently, there is a lack of relevant research.

Exploring the diaphragmatic function of patients with TMD may help to deepen the understanding of the respiratory-related biomechanical mechanisms underlying TMD and the relationship between TMD and other common complications. Since diagnosis of intra-articular states of TMJ requires magnetic resonance imaging (MRI) or cone beam computed tomography (CBCT), and given that chronic pain is more representative compared to acute pain, we chose chronic painful TMD to start off the exploration of this issue in our current study. Therefore, the aims of this study were to 1) evaluate the relationship between chronic painful TMD and diaphragm function by measuring the degree of diaphragm contractility in patients with chronic painful TMD and healthy controls; 2) evaluate the correlation between diaphragm contractility, pain, and psychological states.

2. Methods

This study was approved by the Ethics committees of the Affiliated Zhangzhou Hospital of Fujian Medical University (No: 2021LWB007). The participants were informed about the procedures for the study and consented to have data and images published. Written consents from participants were obtained before inclusion.

Reporting of this study defers to the checklist of Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies [26].

2.1. Study design

This study was conducted with a single-blinded, case-control design. A trained dentist screened participants for inclusion criteria, and the investigator responsible for measuring diaphragm contractility was blinded to group membership. The questionnaires used in this study and the diagnostic classification of TMD were both from the Chinese version of Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) [2](supplemental file).

2.2. Participants

Forty-five subjects (23 Chronic painful TMD patients and 22 healthy controls) were enrolled in the study (Fig. 1). We recruited patients who complained of orofacial pain during mouth opening or mastication from the Department of Stomatology from March to August 2021. Inclusion criteria for participants with Chronic painful TMD were: 1) diagnosed painful TMD by a specialist based on DC/TMD; 2) persistent pain for $\geq$3 months. For both groups, inclusion criteria were 1) aged 18–60; 2) able to complete the questionnaires independently; no history of 1) head and facial trauma; 2) serious systemic diseases such as cardiac or hepatic dysfunction or malignancy; 3) psychiatric illness and drug dependence; 4) orthodontic treatment or Splint treatment. Furthermore, none of them 5) were pregnant or with 6) chronic pain other than TMD; 7) rheumatism, rheumatoid arthritis, or any other disease that may affect the temporomandibular joint; 8) asthma, ankylosing spondylitis, or any other disease that may affect respiratory function.

All healthy participants were volunteers recruited from among the staff and the students at a college through a poster campaign. Inclusion criteria for healthy controls included: 1) completion of the Chinese version of the pain screening questionnaire with "no" to all questions in it; 2) no previous diagnosis of TMD; 3) no clinically diagnosable TMD, according to DC/TMD.

2.3. Questionnaires on mental status and pain scoring

We employed validated questionnaires from DC/TMD of the Chinese version to score the psychological state of the participants. The Patient Health Questionnaire 15-item (PHQ-15), the Generalized Anxiety Disorder 7-item (GAD-7), and the Patient Health Questionnaire 9-item (PHQ-9) were used to assess the patients in terms of physical symptoms, anxiety, and depression, respectively. In addition, pain characteristics were obtained from the Chinese version of the Graded Chronic Pain Scale Version 2.0 (GCP) completed by the patients. The study used the Characteristic Pain Intensity (CPI) and the Interference Score (IS) to record the pain characteristics of patients with TMD, with the CPI representing the intensity of pain and the IS representing the extent to which pain affects life, social interaction, and recreation.

2.4. Diaphragm measurements

The diaphragm consists of 3 parts: the central tendon, the crural (or vertebral) portion and the costal portion. The costal portion apposition to the inner aspect of the lower rib cage is called the "zone of apposition". During respiration, the dome of the diaphragm remains relatively constant in size and shape. The inspiratory function of the diaphragm depends on the contraction of the "zone of

apposition", which initiates the descent of the dome and the elevation of the lower ribs [25]. Therefore, our study was to evaluate participants' breathing patterns by measuring the thickness and degree of contraction of the diaphragm's zone of apposition during quiet breathing.

Previous studies have confirmed that B mode ultrasound is a reliable measure of diaphragm thickness and contractility [27,28].The technique described by Sarwal [28] was used to obtain B mode ultrasound images of the diaphragm while the subjects were supine and breathing quietly. A linear array transducer (L12-3E; Mindray) with a frequency range of 8- to 12-MHz was placed at the anterior axillary line, with the transducer positioned to obtain a sagittal image at the intercostal space between the 7th and the 8th, or the 8th and the 9th ribs. The diaphragm was identified by its typical 3-layered appearance (an intermediate mixed echoic zone bordered by two hyperechoic zones) [29]. Ideally, the image should span two ribs with intercostal space between them. The sonographer maintained probe stability and captured the images at the end of a respiratory cycle to obtain three images at the end of quiet inspiration (Fig. 2A) and three more at the end of quiet expiration (Fig. 2B). Diaphragm thickness was measured by inserting an electronic caliper in the two hyperechoic fascia lines where the lines were most parallel. The diaphragm thickness at the end of quiet inspiration (Tinsp) and the thickness at the end of quiet expiration (Texp) were averaged from the previous screenshot measurements. The degree of diaphragm contractility was calculated by the following formula: (Tinsp-Texp)/Texp *100 % [28].

2.5. Endeavors to reduce bias

We invited each patient who met the diagnostic requirements to join our study. Selection bias was reduced by implementing the strategy of continuous inclusion. To minimize reporting bias and avoid data loss, the dentists had checked the veracity of participant responses and the completeness of all questionnaires before the participants left.

2.6. Statistical analysis

We calculated the power of the study using PASS 21.0.3 and performed power calculations based on the group size and the standard deviation of the degree of diaphragm contractility. SPSS 26.0 was used for the statistical analysis of all the other data. P–P (probability-probability) plots and histograms were used to explore data normality. Since height, weight, body mass index (BMI), diaphragm thickness, diaphragm contractility, and the score of average/worse TMD pain were all normally distributed, independent t-tests were

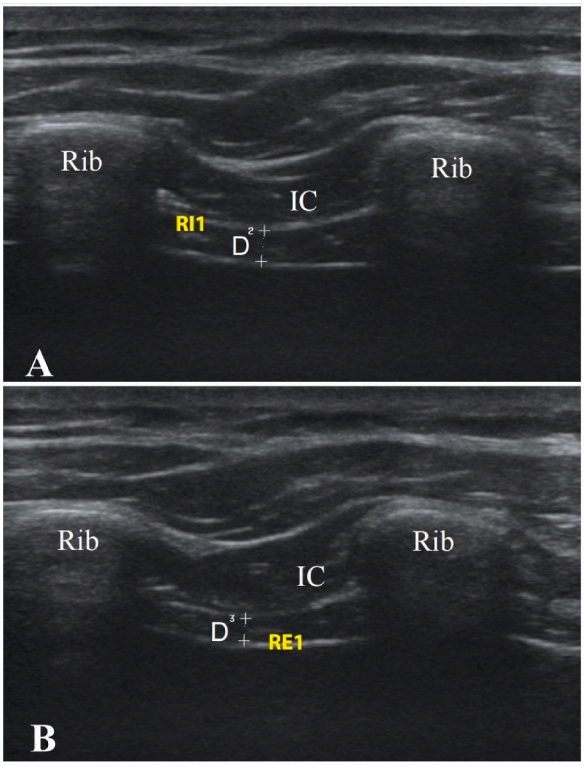

Fig. 2. B-mode ultrasonography image of the diaphragm at the end of quiet inspiration (A) and expiration (B).
IC, intercostal muscle; D, diaphragm; RI1, right inspiration-First screenshot; RE1, right expiration-First screenshot. (Yellow font is the remarks during measurement in the ultrasonic machine). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

used to compare these variables between the two groups. Subject age, disease duration of the patients, scores of Pain interference with daily activity, and the scores of PHQ-9, GAD-7, and PHQ-15 were not normally distributed, so we used the interquartile range for description: M (Q25, Q75) and the Mann–Whitney *U* test were used to compare these variables between the two groups. The chi-squared test was used to compare the gender distributions.

To evaluate the magnitude of the differences in diaphragm thickness and contractility between the two groups, Cohen's d effect sizes were calculated using mean and standard deviation (SD) [30]. The strength of the effect size was interpreted as weak ($d < 0.40$), moderate ($0.40 \leq d < 0.8$), or strong ($d \geq 0.80$). Spearman rank correlation was used to ascertain the inter-relationships between diaphragm contractility, the scores of pain characteristics, PHQ-9, GAD-7, and PHQ-15.

3. Results

Group sample sizes of 23 and 22 achieve 95.67 % (Left) and 90.31 % (Right) power with a significance level (alpha) of 0.05. Demographics, mental states, and pain characteristics of the participants are shown in Table 1. There was no significant between-group difference in demographics, including gender, age, height, weight, and BMI ($P > 0.05$). Chronic painful TMD groups had greater depression, anxiety, and physical symptoms scores than healthy controls ($P < 0.05$).

Table 2 shows the diaphragm thickness and diaphragm contractility of the two groups, and Fig. 3 shows diaphragm contractility for each participant. Patients with chronic painful TMD had lower bilateral diaphragm contractions than healthy controls ($P < 0.01$), with a strong effect size ($d > 0.80$). There was no significant difference in diaphragm thickness between groups ($P > 0.05$).

Correlations between diaphragm contractility, psychological states, and pain characteristics are presented in Table 3. Classification of correlation coefficients (r) (weak 0.1–0.3; moderate 0.4–0.6; strong 0.7–0.9) by Dancey was applied [31]. For the patients, moderate correlations were found between pain interference with daily activity and scores of depression and physical symptoms ($P < 0.05$). Moreover, a weak correlation was noted between left and right diaphragm contractility in the patients, while a moderate one in the controls. For both groups, the correlations between depression, anxiety, and physical symptoms scores were moderate to strong. Meanwhile, a weak correlation was noted between diaphragm contractility and psychological states, as well as between diaphragm contractility and pain characteristics.

4. Discussion

We used B-mode ultrasonography to measure diaphragm thickness at the end of quiet expiration and inspiration to calculate diaphragm contractility. The main finding of this study was that bilateral diaphragm contractility of chronic painful TMD patients was significantly weaker than that of the healthy controls during quiet breathing. Moreover, there was a weak correlation between the degree of contraction of the patient's right and left diaphragm, suggesting that there may be more asymmetry or incongruity. Therefore, our results partially support Bartley's conjecture that breathing pattern disorders explain how biomechanical changes associated with psychosocial states might lead to TMD [32,33]. However, because almost no correlation was found between the scores of psychological states and diaphragm contractility, we cannot support Bartley's inference that psychological factors lead to abnormal breathing patterns and cause TMD [33]. This may be due to the complex mechanisms of altered breathing patterns, which make it challenging to discover the correlation between psychological condition and degree of diaphragm contractility. Fluoroscopic studies revealed that the diaphragm exhibited hypertonia and became flattened and immobile when subjects were experimentally stimulated with negative emotions [34,35]. This study only measured changes in diaphragm thickness after rest in calm supine position, which

Table 1
Cohort demographic, mental states and pain characteristics.

Demographic	Chronic Painful TMD	Healthy Controls	P value
N	23	22	n/a
Female (%)	17 (73.91 %)	15 (68.18 %)	0.672
Age(yr)[a]	32.91 ± 12.36	27 ± 6.36	0.317
Height (cm)[a]	163.70 ± 8.67	165.23 ± 7.85	0.51
Body mass (kg)[a]	55.57 ± 9.69	57.59 ± 10.73	0.45
BMI[a]	20.62 ± 2.23	20.97 ± 2.69	0.56
PHQ-9[b]	4 (0, 8)	2 (0, 3.25)	0.007
GAD-7[b]	3 (0, 8)	2 (0, 3)	0.030
PHQ-15[b]	5 (2, 7)	1 (0, 3)	0.002
Disease duration, d[b]	180 (120, 365)	n/a	n/a
Pain Characteristics			
CPI	39.71 ± 17.63	n/a	n/a
IS	15.51 ± 19.61	n/a	n/a

TMD, temporomandibular disorder; N, number; BMI, Body Mass Index; PHQ-9, Patient Health Questionnaire 9-item; GAD-7, Generalized Anxiety Disorder 7-item; PHQ-15, Patient Health Questionnaire 15-item; CPI, Characteristic Pain Intensity; IS, Interference Score.
Pain Characteristics were obtained from the Graded Chronic Pain Scale. PHQ-9, GAD-7, and PHQ-15 are questionnaires from Diagnostic Criteria for Temporomandibular Disorders and represent depression, anxiety, and physical symptoms scores respectively.
[a] Data presented are the mean ± standard deviation.
[b] Data presented are the interquartile range: M (Q25, Q75).

Table 2
Hemi-diaphragm thickness at the end of quiet inspiration and expiration and the degree of contractility.

		Chronic Painful TMD	Healthy Controls	P	Cohen's d
Right	Thickness:inspiration(mm)	1.64 ± 0.59	1.51 ± 0.35	0.367	0.27
	Thickness:expiration(mm)	1.39 ± 0.55	1.15 ± 0.29	0.072	0.55
	The degree of contractility(%)	19.57 ± 10.61	33.85 ± 17.07	0.003[a]	1
Left	Thickness:inspiration(mm)	1.70 ± 0.55	1.60 ± 0.41	0.492	0.21
	Thickness:expiration(mm)	1.48 ± 0.53	1.26 ± 0.35	0.113	0.49
	The degree of contractility(%)	16.51 ± 9.55	28.86 ± 12.22	0.001[a]	1.13

TMD, temporomandibular disorder.
Data presented are the mean ± standard deviation.
[a] The Chronic painful TMD group exhibited significantly fewer values than healthy control groups ($P < 0.01$).

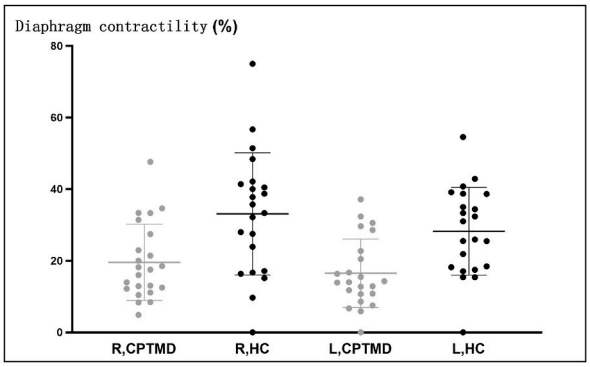

Fig. 3. Diaphragm contractility.
R, right; L, left; CPTMD, chronic painful temporomandibular disorder; HC, healthy controls. Grey dots represent patient groups and black dots represent control groups. The long and short lines represent the mean and standard deviation, respectively.

Table 3
Correlations between diaphragm contractility, psychological states, and pain characteristics.

	Right DC		Left DC		PHQ - 9		GAD - 7		PHQ - 15	
	CPTMD	HC	CPTMD	HC	CPTMD	HC	CPTMD	HC	CPTMD	HC
Right DC	1.000	1.000								
Left DC	−0.104	0.617[a]	1.000	1.000						
PHQ-9	−0.022	0.165	−0.092	0.247	1.000	1.000				
GAD-7	0.073	0.072	−0.005	0.361	0.729[a]	0.708[a]	1.000	1.000		
PHQ-15	0.046	−0.003	0.304	0.027	0.654[a]	0.545[a]	0.668[a]	0.250	1.000	1.000
CPI	−0.134	n/a	0.388	n/a	0.244	n/a	0.020	n/a	0.280	n/a
IS	0.067	n/a	0.248	n/a	0.614[a]	n/a	0.402	n/a	0.542[a]	n/a

CPTMD: chronic painful temporomandibular disorder; DC: diaphragm contractility; HC: healthy controls; PHQ-9, Patient Health Questionnaire 9-item; GAD-7, Generalized Anxiety Disorder 7-item; PHQ-15, patient Health Questionnaire 15-item; CPI, Characteristic Pain Intensity; IS, Interference Score; n/a: not applicable.
[a] $P < 0.01$.

does not provide a comprehensive picture of diaphragm morphology and function. In addition, it is suggested that changes in breathing patterns due to psychological factors may be an appropriate response or beneficial compensation for increased ventilatory or metabolic demands, but inappropriate muscle-using habits may remain after the factors leading to altered breathing patterns have been eliminated, which may complicate the disease situation and symptoms [35]. These mechanisms, that is, poor psychological states and abnormal breathing patterns do not exist simultaneously, may help to explain why we did not observe a correlation between them. Besides, another possible explanation is that the abnormal diaphragm contractility present in patients with chronic painful TMD is unrelated to psychological conditions and instead there are other underlying mechanisms.

We hypothesized that abnormal diaphragmatic function in patients with chronic painful TMD may be due to two mechanisms. One of the possible mechanisms is that abnormal central sensorimotor control in TMD patients leads to aberrant diaphragm contraction. We hypothesized that injurious sensory inputs (including painful or abnormal occlusal sensations) in patients with chronic painful TMD may lead to altered motor outputs in centers, which might affect the diaphragm's motor strategy. In healthy people, the diaphragm can perform dual tasks simultaneously, namely, assisting in posture stabilization and maintaining ventilation without interfering with each other [36]. However, it has been found that the strategy of the central nervous system for controlling core stability may change in the

presence of pain syndromes [37]. With this strategy, the diaphragm seems to be more inclined to maintain posture than to breathe normally [38]. Evidence from functional magnetic resonance imaging shows that TMD patients have abnormal central sensorimotor circuits and aberrant brain signal variability in the primary sensory cortex and primary motor cortex [39]. Another possible mechanism may be that poor breathing patterns may lead to an imbalance in the cranial-cervical-mandibular muscle chain, which further leads to the development of TMD pain. The mechanical behavior of the diaphragm primarily depends on the contraction of the zone of apposition. When the abdominal wall musculature (descending ribs) is weak, or the curvature of the spine is abnormal, the ribs cannot remain in a good position, resulting in a reduced mechanical advantage for contraction of the diaphragm's zone of apposition [25,35]. When the diaphragm cannot perform the respiratory function properly, accessory inspiratory muscles (such as the sternocleidomastoid muscle and the scalenus muscle) have to undertake additional tasks, which will lead to headache, neck pain, cervical vertebra dysfunction and TMD [35,40]. Therefore, the abnormal diaphragm function in painful TMD patients may explain why they simultaneously suffer neck pain, cervical vertebra dysfunction, and even various musculoskeletal problems or postural misalignment.

The abnormal diaphragm contractility we found in TMD patients is consistent with what was previously found in patients with chronic low back pain [41], lumbopelvic pain [42], pelvic girdle pain [43], and chronic ankle instability [22]. In physiological studies, it has been well established that deep core muscles such as the diaphragm, pelvic floor, and transversus abdominis have an essential role in the body's movement. The central control of the core muscles follows a feed-forward regulation, which means that when the center sends out a limb movement command, the core muscles will be activated in advance to maintain postural stability by contracting and adjusting the pressure to prepare the limbs for the movement task [15,36,44]. This feed-forward regulatory mechanism that stabilizes the trunk is the physiological basis of the musculoskeletal system for the prevention of movement injuries. Diaphragm-related training has benefited patients with musculoskeletal or digestive problems such as shoulder pain [21], chronic low back pain [16], and gastroesophageal reflux disease (GERD) [18], which are common co-morbidities of TMD [3,9,20]. Currently, there is grade B evidence that breathing exercises improve pain, respiratory function, and/or quality of life in patients with chronic, non-specific low back pain [23]. Breathing exercises, as a non-invasive treatment, may be of great benefit to patients and further research is needed in the future.

4.1. Limitations

We acknowledge the limitations of this study. Due to the lack of relevant research, there is no precise definition or statistics on the incidence of diaphragm dysfunction. Hence, we were unable to calculate the sample size before hand. In addition, painful TMD was divided into myalgia, arthralgia, and headache attributed to TMD, but due to our small sample size, no subgroup analysis was performed. In the future, we may explore these questions further.

5. Conclusions

In conclusion, this preliminary study is the first to demonstrate the presence of weaker and less congruous diaphragmatic contractility in patients with chronic painful TMD. These findings are also consistent with some common co-morbid conditions associated with TMD. As an essential component of the systemic joint chain, the temporomandibular joint should not only be fram within the biomechanics of the craniocervical mandibular system. Instead, a focus on overall biomechanics is suggested since it may help to understand the mechanisms behind TMD and its common co-morbidities. This study of the diaphragm is just the beginning, and our findings may provide new insights into TMD-related research.

Funding

This study was supported by grants from the Climbing Program of Zhangzhou Affiliated Hospital of Fujian Medical University (Grant number: PDB202111).

Ethics declarations

This study was reviewed and approved by the Ethics committees of the Affiliated Zhangzhou Hospital of Fujian Medical University, with the approval number: [2021LWB007].

Data availability statement

All data used in the generation of the results presented in this manuscript will be made available upon reasonable request from the corresponding author.

CRediT authorship contribution statement

Yaqing Zheng: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Yonghui Chen:** Writing – original draft, Supervision, Resources, Project administration, Methodology, Conceptualization. **Yifeng Li:** Writing – review & editing, Investigation, Formal analysis, Data curation. **Sijing Zheng:** Writing – review & editing, Resources, Investigation. **Shuping Yang:** Writing – review & editing, Project administration, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors wish to thank the technical support of Department of Ultrasound, Zhangzhou Affiliated Hospital of Fujian Medical University.

Abbreviations

BMI	Body Mass Index
CPI	Characteristic Pain Intensity
CPTMD	Chronic painful temporomandibular disorder
DC/TMD	Diagnostic Criteria for Temporomandibular Disorders
GAD-7	Generalized Anxiety Disorder 7-item
GCP	Graded Chronic Pain Scale
IS	Interference Score
PHQ-15	Patient Health Questionnaire 15-item
PHQ-9	Patient Health Questionnaire 9-item
Texp	Thickness at the end of quiet expiration
Tinsp	Thickness at the end of quiet inspiration
TMD	Temporomandibular disorders
TMJ	Temporomandibular joint
P–P	probability-probability
MRI	magnetic resonance imaging
CBCT	cone beam computed tomography
GERD	gastroesophageal reflux disease

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e32872.

References

[1] Y. Cao, A.U. Yap, J. Lei, M.-J. Zhang, K.-Y. Fu, Oral health–related quality of life of patients with acute and chronic temporomandibular disorder diagnostic subtypes, J. Am. Dent. Assoc. 153 (2021) 50–58, https://doi.org/10.1016/j.adaj.2021.07.011.

[2] E. Schiffman, R. Ohrbach, E. Truelove, J. Look, G. Anderson, J.-P. Goulet, T. List, P. Svensson, Y. Gonzalez, F. Lobbezoo, A. Michelotti, S.L. Brooks, W. Ceusters, M. Drangsholt, D. Ettlin, C. Gaul, L.J. Goldberg, J.A. Haythornthwaite, L. Hollender, W. Maixner, M. van der Meulen, G.M. Murray, D.R. Nixdorf, S. Palla, A. Petersson, P. Pionchon, B. Smith, C.M. Visscher, J. Zakrzewska, S.F. Dworkin, Diagnostic criteria for temporomandibular disorders (DC/TMD) for clinical and research applications: recommendations of the international RDC/TMD consortium network* and orofacial pain special interest group, J Oral Facial Pain Headache 28 (2014) 6–27, https://doi.org/10.11607/jop.1151.

[3] R. Ohrbach, S.F. Dworkin, AAPT diagnostic criteria for chronic painful temporomandibular disorders, J. Pain 20 (2019) 1276–1292, https://doi.org/10.1016/j.jpain.2019.04.003.

[4] J.W. Busse, R. Casassus, A. Carrasco-Labra, J. Durham, D. Mock, J.M. Zakrzewska, C. Palmer, C.F. Samer, M. Coen, B. Guevremont, T. Hoppe, G.H. Guyatt, H. N. Crandon, L. Yao, B. Sadeghirad, P.O. Vandvik, R.A.C. Siemieniuk, L. Lytvyn, B.S. Hunskaar, T. Agoritsas, Management of chronic pain associated with temporomandibular disorders: a clinical practice guideline, BMJ (2023) e076227, https://doi.org/10.1136/bmj-2023-076227.

[5] G.D. Slade, R. Ohrbach, J.D. Greenspan, R.B. Fillingim, E. Bair, A.E. Sanders, R. Dubner, L. Diatchenko, C.B. Meloto, S. Smith, W. Maixner, Painful temporomandibular disorder, decade of discovery from OPPERA studies, J. Dent. Res. 95 (2016) 1084–1092, https://doi.org/10.1177/0022034516653743.

[6] B.A. Kleykamp, M.C. Ferguson, E. McNicol, I. Bixho, L.M. Arnold, R.R. Edwards, R. Fillingim, H. Grol-Prokopczyk, R. Ohrbach, D.C. Turk, R.H. Dworkin, The prevalence of comorbid chronic pain conditions among patients with temporomandibular disorders, J. Am. Dent. Assoc. 153 (2022) 241–250.e10, https://doi.org/10.1016/j.adaj.2021.08.008.

[7] F. Cuenca-Martínez, A. Herranz-Gómez, B. Madroñero-Miguel, Á. Reina-Varona, R. La Touche, S. Angulo-Díaz-Parreño, J. Pardo-Montero, T. del Corral, I. López-de-Uralde-Villanueva, Craniocervical and cervical spine features of patients with temporomandibular disorders: a systematic review and meta-analysis of observational studies, JCM 9 (2020) 2806, https://doi.org/10.3390/jcm9092806.

[8] K.-C. Lee, Y.-T. Wu, W.-C. Chien, C.-H. Chung, L.-C. Chen, Y.-S. Shieh, The prevalence of first-onset temporomandibular disorder in low back pain and associated risk factors, Medicine. (Madr). 99 (2020) e18686, https://doi.org/10.1097/md.0000000000018686.

[9] G. Slade, Overlap of five chronic pain conditions: temporomandibular disorders, headache, back pain, irritable bowel syndrome, and fibromyalgia, J Oral Facial Pain Headache 34 (2020) s15–s28, https://doi.org/10.11607/ofph.2581.

[10] L. Griffiths, S. Derisavifard, D. Alaiev, M. Funaro, M. Levy, J. Kreshover, R. Moldwin, S. Bahani, PD01-12 pelvic floor myalgia and temporomandibular joint dysfunction: a common and clinically important RELATIONSHIP8.6.1, J. Urol. 206 (2021) e35–e36, https://doi.org/10.1097/ju.0000000000001965.12.

[11] L. Ries, F. Bérzin, Analysis of the postural stability in individuals with or without signs and symptoms of temporomandibular disorder, Braz. Oral Res. 22 (2008) 378–383, https://doi.org/10.1590/s1806-83242008000400016.

[12] G. Perinetti, J. Primozic, D. Manfredini, R. Di Lenarda, L. Contardo, The diagnostic potential of static body-sway recording in orthodontics: a systematic review, Eur. J. Orthod. 35 (2012) 696–705, https://doi.org/10.1093/ejo/cjs085.

[13] T.C. Chaves, A.M. Turci, C.F. Pinheiro, L.M. Sousa, D.B. Grossi, Static body postural misalignment in individuals with temporomandibular disorders: a systematic review, Braz. J. Phys. Ther. 18 (2014) 481–501, https://doi.org/10.1590/bjpt-rbf.2014.0061.
[14] R. Ohrbach, G.D. Slade, E. Bair, N. Rathnayaka, L. Diatchenko, J.D. Greenspan, W. Maixner, R.B. Fillingim, Premorbid and concurrent predictors of tmd onset and persistence, Eur. J. Pain 24 (1) (2019) 145–158, https://doi.org/10.1002/ejp.1472.
[15] P.W. Hodges, C.A. Richardson, Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement, Exp. Brain Res. 114 (1997) 362–370, https://doi.org/10.1007/pl00005644.
[16] Y.-J. Oh, S.-H. Park, M.-M. Lee, Comparison of effects of abdominal draw-in lumbar stabilization exercises with and without respiratory resistance on women with low back pain: a randomized controlled trial, Med Sci Monit 26 (2020) e921295, https://doi.org/10.12659/msm.921295.
[17] E.H. Breslin, B.C. Garoutte, V. Kohlman-Carrieri, B.R. Celli, Correlations between dyspnea, diaphragm and sternomastoid recruitment during inspiratory resistance breathing in normal subjects, Chest 98 (2) (1990) 298–302, https://doi.org/10.1378/chest.98.2.298.
[18] X. Sun, W. Shang, Z. Wang, X. Liu, X. Fang, M. Ke, Short-term and long-term effect of diaphragm biofeedback training in gastroesophageal reflux disease: an open-label, pilot, randomized trial, Dis. Esophagus 29 (2015) 829–836, https://doi.org/10.1111/dote.12390.
[19] S.T. Christensen, J. Hartvigsen, Spinal curves and health: a systematic critical review of the epidemiological literature dealing with associations between sagittal spinal curves and health, J. Manip. Physiol. Ther. 31 (2008) 690–714, https://doi.org/10.1016/j.jmpt.2008.10.004.
[20] L. Yuanyuan, F. Ming, N. Lina, F. Yu, L. Yan, L. Yong, L. Xiaodong, T. R, C. Jihua, Associations among gastroesophageal reflux disease, mental disorders, sleep and chronic temporomandibular disorder: a case-control study, CMAJ (Can. Med. Assoc. J.) 191 (2019 August 19) E909–E915, https://doi.org/10.1503/cmaj.181535.
[21] I. Fernández-López, D. Peña-Otero, M. de los Á, Atín-Arratibel, M. Eguillor-Mutiloa, C. Bravo-Llatas, M. Genovés-Crespo, F.J. Callejas-González, Effects of diaphragm muscle treatment in shoulder pain and mobility in subjects with rotator cuff injuries: a dataset derived from a pilot clinical trial, Data Brief 35 (2021) 106867, https://doi.org/10.1016/j.dib.2021.106867.
[22] M. Terada, K.B. Kosik, R.S. Mccann, P.A. Gribble, Diaphragm contractility in individuals with chronic ankle instability, Med. Sci. Sports Exerc. 48 (2016) 2040–2045, https://doi.org/10.1249/mss.0000000000000994.
[23] B.E. Anderson, K.C.H. Bliven, The use of breathing exercises in the treatment of chronic, nonspecific low back pain, J. Sport Rehabil. 26 (2017) 452–458, https://doi.org/10.1123/jsr.2015-0199.
[24] T.A. Wilson, A. Legrand, P. Gevenois, A. Troyer, Respiratory effects of the external and internal intercostal muscles in humans, J. Physiol. 530 (2001) 319–330, https://doi.org/10.1111/j.1469-7793.2001.0319l.x.
[25] S. Loring, A. Troyer, Actions of the Respiratory Muscles, CRC Press, 1995, pp. 587–616, https://doi.org/10.1201/9781420000665-34.
[26] for the S. Initiative E. von Elm, D.G. Altman, M. Egger, S.J. Pocock, P.C. Gøtzsche, J.P. Vandenbroucke, The strengthening the reporting of observational studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies, Bull. World Health Organ. 85 (2007) 867–872, https://doi.org/10.2471/blt.07.045120.
[27] C.J. Harper, L. Shahgholi, K. Cieslak, N.J. Hellyer, J.A. Strommen, A.J. Boon, Variability in diaphragm motion during normal breathing, assessed with B-mode ultrasound, J. Orthop. Sports Phys. Ther. 43 (2013) 927–931, https://doi.org/10.2519/jospt.2013.4931.
[28] A. Sarwal, F.O. Walker, M.S. Cartwright, Neuromuscular ultrasound for evaluation of the diaphragm, Muscle Nerve 47 (2013) 319–329, https://doi.org/10.1002/mus.23671.
[29] J. Ueki, P.F. De Bruin, N.B. Pride, In vivo assessment of diaphragm contraction by ultrasound in normal subjects, Thorax 50 (1995) 1157–1161, https://doi.org/10.1136/thx.50.11.1157.
[30] S. Wassertheil, J. Cohen, Statistical power analysis for the behavioral sciences, Biometrics 26 (1970) 588, https://doi.org/10.2307/2529115.
[31] C.P. Dancey, J. Reidy, Statistics without Maths for Psychology, seventh ed., 2017 [M].
[32] J. Bartley, Breathing and temporomandibular joint disease, J. Bodyw. Mov. Ther. 15 (2011) 291–297, https://doi.org/10.1016/j.jbmt.2010.06.002.
[33] J.R. Bartley, Gastroesophageal reflux disease, temporomandibular disorders and dysfunctional breathing, CMAJ (Can. Med. Assoc. J.) 191 (2019) E1255, https://doi.org/10.1503/cmaj.73545. E1255.
[34] S.G. Wolf, Diaphragmatic spasm: a neglected cause of dyspnoea and chest pain, Integr. Physiol. Behav. Sci. 29 (1994) 74–76, https://doi.org/10.1007/bf02691282.
[35] R. Courtney, The functions of breathing and its dysfunctions and their relationship to breathing therapy, Int. J. Osteopath. Med. 12 (2009) 78–85, https://doi.org/10.1016/j.ijosm.2009.04.002.
[36] P. Hodges, S. Gandevia, Activation of the human diaphragm during a repetitive postural task, J. Physiol. 522 (2000) 165–175.
[37] P.W. Hodges, The role of the motor system in spinal pain: implications for rehabilitation of the athlete following lower back pain, J. Sci. Med. Sport 3 (2000) 243–253.
[38] P. Kolář, J. Šulc, M. Kynčl, J. Šanda, O. Čakrt, R. Andel, K. Kumagai, A. Kobesová, Postural function of the diaphragm in persons with and without chronic low back pain, J. Orthop. Sports Phys. Ther. 42 (2012) 352–362, https://doi.org/10.2519/jospt.2012.3830.
[39] M. Lim, T.D. Nascimento, D.J. Kim, V.L. Ellingrod, A.F. DaSilva, Aberrant brain signal variability and COMT genotype in chronic TMD patients, J. Dent. Res. 100 (2021) 714–722, https://doi.org/10.1177/0022034521994089.
[40] R.J. Jr. Hruska, Influences of dysfunctional respiratory mechanics on orofacial pain, Dent. Clin. 41 (2) (1997) 211–227.
[41] Maryam Ziaeifar, et al., Diaphragm thickness, thickness change, and excursion in subjects with and without nonspecific low back pain using B-mode and M-mode ultrasonography, Physiother. Theor. Pract. 38 (13) (2022) 2441–2451, https://doi.org/10.1080/09593985.2021.1926022.
[42] César Calvo-Lobo, et al., Ultrasonography comparison of diaphragm thickness and excursion between athletes with and without lumbopelvic pain, Phys. Ther. Sport : official journal of the Association of Chartered Physiotherapists in Sports Medicine 37 (2019) 128–137, https://doi.org/10.1016/j.ptsp.2019.03.015.
[43] K. Nassiri, M. Abedi, F. Dehghan Manshadi, A. Akbarzadeh Baghban, M. Heydarpour Meymeh, Comparison of the reliability of sonographic measurements of diaphragm thickness and mobility in individuals with and without pelvic girdle pain, Iran red crescent, Med. J. 21 (2020) e97449, https://doi.org/10.5812/ircmj.97449.
[44] P.W. Hodges, J.E. Butler, D.K. McKenzie, S.C. Gandevia, Contraction of the human diaphragm during rapid postural adjustments, J. Physiol. 505 (1997) 539–548, https://doi.org/10.1111/j.1469-7793.1997.539bb.x.