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ORIGINAL ARTICLE

Temporomandibular disorders and neck pain in primary headache patients: a retrospective machine learning study

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ABSTRACT
Objectives: To evaluate the linkage underpinning different clinical conditions as painful TMD and neck pain in patients affected by primary headaches.
Materials and methods: In this machine learning study, data from medical records of patients with headaches as migraine, tension-type headache (TTH) and other primary ones, referring to a University Hospital over a 10-year period were analysed. VAS was used to evaluate the intensity of the TMD and neck pain. Moreover, the magnetic resonance imaging was used to supplement the clinical data.
Results: A total of 300 patients (72 male, 228 female), mean aged 37.78 ± 5.11 years, were included. Higher TMD and neck pain VAS in migraine patients were reported. The machine learning analysis focussed on type of primary headache demonstrated that a higher TMD VAS was correlated to migraine, whereas a higher neck pain VAS was correlated to TTH or migraine. Concerning the TMD type, arthrogenous and mixed TMD were correlated to mild-moderate TMD pain (depending on neck pain intensity), whereas myogenic TMD was correlated to moderate-severe TMD pain.
Conclusions: Machine-learning approach highlighted the complexity of diagnosis process and demonstrated that neck pain might be an influential variable on the belonging to different group of headaches in TMD patients.

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Temporomandibular disorders; facial pain; migraine; tension-type headache; neck pain

Introduction

Temporomandibular disorders (TMD) is an umbrella term that refers to disorders associated with the masticatory muscles of the stomatognathic system, temporomandibular joint (TMJ), or both [1]. Painful TMD are considered as the main cause of non-odontogenic pain in the orofacial region [2] and it is estimated that 25% of the adult population presents signs and/or symptoms of TMD, with a female/male ratio ranging from 1.5 to 2.5 [3]. The aetiology is not clear, considering the complexity of TMD that have a multitude of risk factors, including oral parafunctions, trauma, and psychological factors [4,5]. According to Diagnostic Criteria for TMD (DC/TMD) Axis I, TMD could be divided in muscle disorders or intra-articular disorders [6]. Indeed, in addition to muscle and joint involvement, neck pain and headache are considered as frequent clinical manifestations of TMD that should be taken into consideration for conservative treatment (e.g. occlusal splints, laser therapy, transcutaneous electrical nerve stimulation, physical therapy, oxygen-ozone therapy, and behavioural therapies) [7–10].

In this context, headache disorders are among the most common causes of disability worldwide [11]. More in detail, primary headache disorders, including migraine and tension-type headache (TTH), are considered as important global health problems due to their high prevalence [11]. Indeed, the prevalence of headache disorders is 46% for headache generally, 42% for TTH, and 11% for migraine [12]. It has been recently evaluated in the scientific literature the strict relationship between TMD and headache [13–16], not only in terms of sharing common pathogenic mechanisms and clinical features, but also considering that one condition might influence or promote the development of the other [17]. Both conditions could cause facial pain, and are frequently associated with the development of craniofacial allodynia during painful exacerbation [18]. Indeed, pain in both conditions has been attributed to common dysfunctions of the central pain regulation mechanisms [19]. Furthermore, the concomitance of TMD and migraine has showed to worse levels of hyperalgesia and cutaneous allodynia, probably due to the sensitisation of central and peripheral nervous system

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and the impairment of the descending modulatory pain pathways [18–20].

TMD pain might also cause limitations in the activities of daily living (ADLs) with severe family and socio-occupational repercussions owing to its effects on mental wellbeing, health-related quality of life (HRQoL), and limiting workplace performance [21]. Moreover, almost 80% of migraine patients suffer from neck pain, and these patients showed a higher prevalence of TMD than the healthy population [22,23].

Machine learning statistical approaches have been recently applied in the clinical field to different extents, starting from principal component analysis (PCA), and clustering methods [24,25]. More in detail, clinical classifiers using algorithms and statistical methods allowing 'learning' from prediction parameters might be useful to better understand correlation among different clinical conditions [26].

In the scientific literature the correlation among primary headaches, TMD, and neck pain has been investigated, albeit their strict correlation has not been supported by strong evidence.

Therefore, the present study aimed at evaluating the linkage underpinning different clinical conditions as painful TMDs (myogenous, arthrogenous, and mixed) and neck pain in patients affected by primary headaches.

Material and methods

Participants

This retrospective study analysed data from medical records of patients with diagnosis of migraine, TTH, or and other primary headaches, according to the International Classification of Headache Disorders [27,28], that referred to the Gnathology Unit of University Hospital 'Maggiore della Carità' of Novara, Italy, over a 10-year period from January 2010 to December 2019. Exclusion criteria were: (1) assumption of analgesic drugs in the week before the clinical evaluation or assumption of medication for prophylactic treatment of headache; (2) history of overuse of symptomatic medications according to the criteria proposed by the ICHD-3; (3) evidence of concurrent illness; (4) history of undergoing head-neck surgery; (5) an ongoing orthodontic, speech-language or dental treatment or ongoing physical therapy treatment for neck pain; (6) psychiatric diseases or neurological diseases other than headache; (7) patients experiencing a headache attack at the moment of evaluation

The study was approved by the Local Ethics Committee (CE 59/10, prot.343). All participants were asked to carefully read and sign an informed consent, and researchers provided to protect the privacy and the study procedures according to the Declaration of Helsinki, with pertinent National and International regulatory requirements. Moreover, the study was performed in accordance with the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) Guidelines.

TMD diagnosis

A high-experienced dentist evaluated the potential study participants according to the specific diagnostic criteria for TMD, considering the period in which patients were assessed. More in detail, the patients had diagnosis of TMD based on the research diagnostic criteria for temporomandibular disorders (RDC/TMD) [1] from 2010 to 2013, and according to the diagnostic criteria for TMD (DC/TMD) [6] from 2014 to 2019.

The diagnosis of TMD involves Axis I for the clinical examination and Axis II for the pain-related disability. Thus, Axis I classifies TMD into three groups:

- Group I. Muscle diagnoses: (a) myofascial pain; (b) myofascial pain with limited opening
- Group II. Disc displacements: (a) disc displacement with reduction; (b) disc displacement without reduction, with limited opening; (c) disc displacement without reduction, without limited opening.
- Group III. Arthralgia, osteoarthritis, osteoarthrosis: (a) arthralgia; (b) osteoarthritis of the temporomandibular joint; (c) osteoarthrosis of the temporomandibular joint.

On the other hand, Axis II allows the assessment of pain-related disability, evaluating relevant behavioural, psychological status, and psychosocial functioning (e.g. depression and somatisation, pain status variables, and disability levels).

In the present investigation, only DC/TMD Axis I findings were reported, without considering the psychosocial assessment provided by the DC/TMD axis II. Therefore, the following DC/TMD Axis I diagnostic subgroups were considered in this study: myogenous TMD (diagnoses for groups Ia or Ib), arthrogenous TMD (diagnoses for groups II or III), and mixed TMD (diagnoses for groups I and II/III).

TMD and neck pain evaluation

A Visual Analogue Scale (VAS) was used to evaluate the intensity of pain in terms of TMD pain and neck pain, perceived by the patient at the clinical evaluation, though a self-administered score ranging from 0 (absence of pain) to 10 (worst pain ever).

MRI evaluation

A 1.5-Tesla MRI unit (Siemens Symphony, Erlangen, Germany) with a 6 × 8-cm diameter surface coil, which allowed for simultaneous imaging of both TMJs, was used. The closed and open mouth technique was used, and sagittal sections were obtained perpendicular to the long axis of the condyle. Coronal sections were obtained as well. No sedation or intravenous contrast administration was used. All images should be oblique so that sagittal oblique images are perpendicular to and coronal oblique images are parallel to the long axis of the condyle. The imaging protocol consisted of a T1-weighted axial spin echo image, which acted as the localiser. The scans included 3-mm sections, 15-cm field of view, and a 256 × 224 matrix. T1-weighted images were obtained using a 520-ms/11 ms repetition time/echo time (TR/TE) sequence. T2-weighted images were obtained using a 2740-ms/107-ms TR/TE sequence. The TMJs were imaged in the coronal and sagittal planes. A mouth-opening device was used, which allowed for incremental opening at 1-mm intervals.

For each individual subject in the sample, MR images of the TMJ were used to evaluate: (a) internal disorder (anterior disc displacement with reduction [ADDWR]; anterior disc displacement without reduction [ADDWoR]) [29,30]; (b) hypermobility (subluxation); (c) degenerative diseases (osteoarthritis). The condylar translation was considered excessive if the condylar head translated beyond the articular eminence (subluxation) [31]. Moreover, MRI diagnosis of osteoarthritis was defined as the presence of condylar deformities associated with flattening, subchondral sclerosis, surface irregularities, erosion and osteophyte [32].

Inferential statistical analysis and machine learning

All continuous variables are expressed as means ± standard deviations; categorical variables are expressed as counts/percentages. Nominal values were tested with X^2, ordinal values were tested with Mann-Whitney test. For further details see Table 1.

Multivariate methods have been recently applied in the clinical field to different extents, starting from PCA, and clustering methods [24,25]. Supervised multivariate classification models have also been applied, the most exploited tools being: linear discriminant analysis, factorial discriminant analysis and *K* nearest neighbours [33].

Therefore, a linear discriminant analysis was used for automated classification of TMDs and headache using all the VAS scale of TMD and cervical neck pain. The linear discriminant analysis assumes a gaussian distribution and defines linear discrimination boundaries between the categories, where it maximises the variance between classes [26]. A classification evaluation metrics was performed through the model precision, recall, the F1-score and the area under the ROC curve (AUC). Precision meant the ratio of correct positive predictions to the total predicted positives, while the recall ratio of correct positive predictions to the total positive observations. At the same time the F1 Score evaluated the harmonic mean of the precision and recall scores, while sample average of the AUC values from the test samples. The cross-validated AUC provides a reasonable estimate for the classification accuracy for future analysis [34]. The covariance matrices should be equal and were checked with the Box's *M* test. When the significance of statistical does not override the critical level, then the equivalence of the covariance matrices is corroborative. When the test shows statistical significance, then the assumption is violated, and the sets are considered different [35]. Lastly, a decision boundary map (DBM) was performed as a set of 2D points for which individuals densify more frequently, hence where they are classified in the same class [36]. Decision zones are separated by decision boundaries, which are pixels in which labels (colors) differ from those of at least one neighbouring 8-pixel in the DBM. Thus, the DBM shows, among other things, how high-dimensional space is actually partitioned into decision zones, how large these zones are, how adjacent they are to each other, and how uniform the decision boundaries between classes are [37]. The analysis trough R 3.5.2 (R foundation, Vienna, Austria) with MASS and ROCR R-packages and JASP 0.16 (JASP project, Amsterdam, Netherlands) was performed.

Random forest regression, exploiting lesser variables, omits variables during the calculations to change the explained variance and determines the intrinsic consequence of including or excluding the variables. The outcome is a rank expressed as mean increase Gini (IncNodeGini, the purity of the splits of the decision trees), therefore the larger the IncNodeGini the larger the importance of a given variable, and as mean decrease accuracy (IncMSE%, a measure of sum of squares as a prediction error) [38].

Results

Out of 327 medical records of patients with primary headache, a total of 300 patients, mean aged 37.78 ± 5.11, respected the eligibility criteria and were included for the final analysis. The study participants were 72 male and 228 female, with a female/male ratio of 3.17/1. One hundred one were diagnosed as TTH patients, mean aged 38.35 ± 5.08 years, 12 male and 89 female; 54 (9 male and 45 female) were diagnosed as migraine patients, with a mean age of 37.91 ± 4.89 years old; lastly, 154 subjects had other primary headaches, mean aged 37.35 ± 5.89 years with male/female ratio of 12/132.

In the sample, the 72.22% of patients with migraine had a diagnosis of TMD, higher than patients with TTH (63.37%) and significantly higher than those with other primary headaches (55.17%; $p = .030$).

Patients with migraine had a TMD VAS (6.03 ± 2.11) significantly higher than TTH patients (4.39 ± 1.68; $p = .002$) and other primary headaches patients (5.54 ± 1.59; $p = .003$); moreover, migraine patients also showed a neck pain VAS (6.65 ± 3.01) significantly higher than TTH patients (6.19 ± 1.52; $p = .030$) and other primary headaches patients (5.21 ± 1.44; $p = .001$). Table 1 reports further details on the differences in outcome measures according to the diagnosis of primary headache.

According to the machine learning approach, the linear discriminant analysis of headache reported a precision of 0.633, a recall of 0.633, a F1 score of 0.609 and an AUC of 0.627. Box's *M* statistic had a χ^2 of 27.583 with a $p < .001$. Since the result is significant ($p < .05$), so there is sufficient evidence that we reject the hypothesis that the group's covariance matrices are equal.

Therefore, a decision boundary map was plotted based on the neck and TMD pain scale, providing a correlation between the type of headache and the VAS, as shown in Figure 1.

TTH or migraine might be reported for a neck pain VAS > 6. At the same time, for a TMD VAS > 6, there was a correlation with migraine, whereas a TMD VAS < 6 showed to be correlated to TTH.

Table 1. Differences in outcome measures according to the diagnosis of primary headache in the sample ($n = 300$).

	TTH ($n = 101$)	Migraine ($n = 54$)	Other primary headaches ($n = 145$)	TTH vs migraine *p*-value	TTH vs other primary headaches *p*-value	Migraine vs other primary headaches – *p*-value
Diagnosis of TMD	64 (63.37%)	39 (72.22%)	80 (55.17%)	.271	.200	.030*
Myogenous TMD	*25 (24.75%)*	*21 (38.89%)*	*29 (20.00%)*	*.288*	*.452*	*.049**
Arthrogenous TMD	*16 (15.84%)*	*9 (16.67%)*	*26 (17.93%)*	*.266*	*.444*	*.040**
Mixed TMD	*23 (22.77%)*	*9 (16.67%)*	*25 (17.24%)*	*.233*	*.456*	*.041**
TMD VAS	4.39 ± 1.68	6.03 ± 2.11	5.54 ± 1.59	.002*	.452	.003*
Presence of neck pain	68 (67.33%)	40 (74.07%)	83 (57.24%)	.381	.117	.032*
Neck pain VAS	6.19 ± 1.52	6.65 ± 3.01	5.21 ± 1.44	.030*	.001*	.001*
ADDWR	29 (28.71%)	14 (25.93%)	31 (21.38%)	.713	.593	.501
Monolateral	*21 (20.79%)*	*11 (20.37%)*	*25 (17.24%)*	*.662*	*.512*	*.498*
Bilateral	*8 (7.92%)*	*3 (5.56%)*	*6 (4.14%)*	*.729*	*.582*	*.453*
ADDWoR	13 (12.87%)	5 (9.26%)	21 (14.48%)	.187	.196	.543
Monolateral	*10 (9.90%)*	*3 (5.55%)*	*14 (9.66%)*	*.116*	*.099*	*.482*
Bilateral	*3 (2.97%)*	*2 (3.70%)*	*7 (4.83%)*	*.211*	*.150*	*.465*
Hypermobility/ subluxation	9 (8.91%)	5 (9.26%)	16 (11.03%)	.941	.594	.721
Monolateral	*4 (3.96%)*	*3 (5.55%)*	*7 (4.83%)*	*.923*	*.630*	*.694*
Bilateral	*5 (4.95%)*	*2 (3.70%)*	*9 (6.21%)*	*.876*	*.517*	*.708*
Osteoarthritis/ osteoarthrosis	5 (4.95%)	2 (3.70%)	7 (4.83%)	.723	.198	.732
Monolateral	*3 (2.97%)*	*1 (1.85%)*	*4 (2.76%)*	*.654*	*.170*	*.675*
Bilateral	*2 (1.98%)*	*1 (1.85%)*	*3 (2.07%)*	*.711*	*.192*	*.633*

Continuous variables are expressed as means ± standard deviations; categorical variables are expressed as counts/percentages. Nominal values were tested with X^2; ordinal values were tested with Mann-Whitney test. TTH: tension-type headache; TMD: temporomandibular disorders; VAS: visual analogue scale; ADDWR: anterior disc displacement with reduction; ADDWoR: anterior disc displacement without reduction; *: significant *p* values.

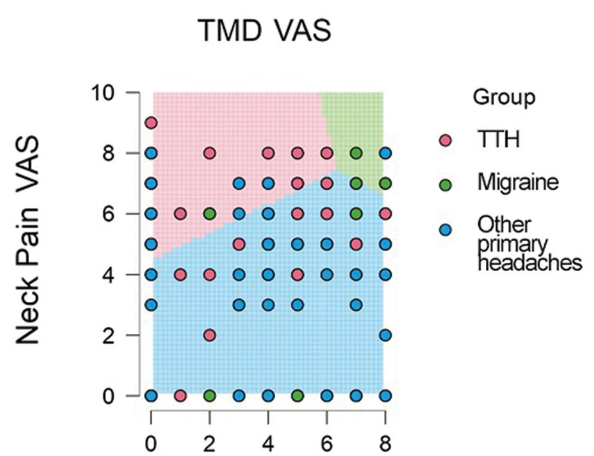

Figure 1. Headache decision Boundary Map. A Decision Boundary Map (DBM) is a 2D image that shows a representation of how space is divided into decision zones based on the two VAS scores.

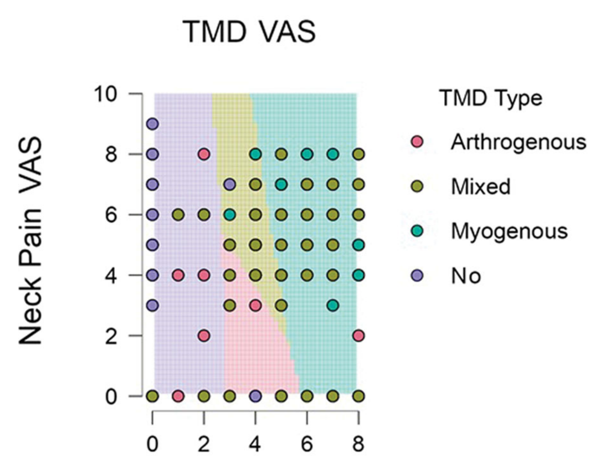

Figure 2. TMD decision Boundary Map. A Decision Boundary Map (DBM) is a 2D image that shows a representation of how space is divided into decision zones based on the two VAS scores.

The linear discriminant analysis of TMDs reported a precision of 0.630, a recall of 0.671, a F1 score of 0.629, and an AUC of 0.802. Box's *M* statistic had a χ^2 of 218.315 with $p < .001$. Since the result is significant ($p < .05$), so there is sufficient evidence that we reject the hypothesis that the group's covariance matrices are equal. Then, a decision boundary map was plotted based on the neck and TMD pain scale, providing a prediction of the type of TMD based on the VAS scores, as shown in Figure 2.

For TMD VAS > 5, a correlation with myogenic disorder appeared regardless of the pain felt at the cervical spine. In case of mild or moderate TMD VAS (ranging from 3 to 5), neck pain VAS > 5 might correlate to mixed TMD, whereas a neck pain VAS < 5 might correlate to arthrogenous TMD.

Lastly, the importance of the single variables was assessed based on the different group of headaches in patients with diagnosis of TMD, reporting that neck pain was the most influential variable (mean decrease in accuracy = 59.43; total increase in node purity = 60.04). See Table 2 for further details. As validation, the MSE value stood at 0.46 with an R2 of 0.58.

Table 2. Variable importance with TMD for different type of headache.

	Mean decrease in accuracy	Total increase in node purity
Neck pain	59.43	60.04
ADDWR	12.48	13.94
Sex	7.63	6.98
Age	4.10	2.10
Hypermobility	0.00	0.00
Osteoarthritis	0.00	0.00

The rank is expressed as mean decrease accuracy (a measure of sum of squares as a prediction error); the larger the value the larger the importance of a given variable) and Gini mean increase value (the purity gain of the splits of the decision trees). ADDWR: anterior disc displacement with reduction.

Discussion

This machine learning study aimed at defining the linkage among TMD (myogenous TMD, arthrogenous TMD, and mixed TMD) and neck pain in patients affected by TTH, migraine, and other primary headaches.

The results of the present study reported that TMD were frequently overlapped in patients with primary headaches. Indeed, a diagnosis of TMD was found in 63.37% of TTH, 72.22% of migraine, and in 55.17% of patients with other primary headaches. Migraine patients showed a higher mean TMD VAS (6.03 ± 2.11) compared to TTH and other primary headaches groups ($p = .002$ and $p = .003$, respectively). Moreover, TMD diagnosis was more frequent in patients with migraine (72.22%) then in patients with TTH (63.37%) and significantly higher than those with other primary headaches (55.17%; $p = .030$).

It was interesting to note that myogenous TMD was the most common subtype (38.89%) in patients with migraine; this finding is in line with a study of Ashraf et al. [39] that evaluated the relationship between painful signs of TMD and the presence of migraine using a large sample of 5876 adults, and results of their study showed a statistically significant association between muscular TMD and the presence of migraine.

It seems that arthrogenous TMD may be a rather localised phenomenon, whereas myogenous TMD might be combined with some more general functional changes [19]. Indeed, muscular TMD may be linked to migraine through the phenomenon of central sensitisation and cutaneous allodynia in the distribution of the trigeminal nerve [18,40,41]. In this context, Chaves et al. [18] showed increased hyperalgesia to both heat and cold and increased mechanical pain sensitivity in cephalic and extra-cephalic areas in patients with migraine plus TMD. Since individuals with migraine and TMDs are two to three times more likely to experience cutaneous allodynia symptoms, it is possible hypothesise that having one disorder (e.g. migraine) might predispose to the development or diagnosis of the other (e.g. TMD) [42]. Moreover, the scientific literature showed that both patients with diagnosis of migraine or TMD presented with high levels of anxiety, depression, and stress than asymptomatic subjects [43,44], exhibiting higher levels of pain-related catastrophization [45].

About neck pain, results of the present study reported that it was found in 67.33% of TTH, 74.07% of migraine, and in in 57.24% of patients with other primary headaches. Moreover, neck pain VAS was significantly higher in migraine patients then both TTH ($p = .030$) and other primary headaches patients ($p = .001$). Furthermore, there was a significant difference also between neck pain VAS of TTH and other primary headaches patients ($p = .001$). As depicted by Table 2, results of the present study revealed that neck pain was identified as the most influential variable on the correlation of different group of headaches and the presence of TMD.

More in detail, the decision boundary plot in machine learning analysis focussed on the primary headache type showed that a neck pain VAS > 6 was correlated with a TTH or migraine and that a TMD VAS > 6 was correlated to the only migraine (see Figure 1).

Furthermore, concerning the machine learning approach on TMD type, a myogenic TMD reported a TMD VAS > 5 independently from the neck pain intensity; nevertheless, in case of a mild-moderate TMD VAS ranging from 3 to 5, neck pain VAS plays a key role in the correlation with mixed TMD (for neck pain VAS > 5) and an arthrogenous TMD (for neck pain VAS < 5), as shown by Figure 2.

In the scientific literature, it is reported that patients with diagnosis of migraine and TTH commonly might experience neck pain [46], and the linkage among them could be related to the trigemino-cervical nucleus, in which primary afferent inputs from both trigeminal and upper cervical nerves converge [47]. Thus, neck pain may be a referred pain and part of the headache symptomatic complex [47]; otherwise nociception from upper cervical structures may refer pain to the head, resulting in cervicogenic headache [27]. Moreover, increased pain sensitivity of the cervical muscles in TMD patients and the decreased pain threshold of the masticatory muscles in patients with chronic neck pain have been observed [48]. In this context, Liang et al. [42] demonstrated that subjects with masticatory myofascial pain have greater neck disability than asymptomatic controls and that the greater the degree of neck disability, the greater the anterior temporalis, sternocleidomastoid and upper trapezius muscle sensitivity. Moreover, in literature it was showed that physical therapy for cervical neck pain was effective in reducing pain in patients with tension-type headaches [49], cervicogenic headache [50], and recently in patients with TMD and migraine [51]. Indeed, Calixtre et al. [51] conducted a randomised controlled trial to determine whether mobilisation of the upper cervical region and craniocervical flexor training decreased orofacial pain and headache impact in women with TMD. Their results presented a reduction of pain with significant between-groups differences with a significant change in headache impact between groups. Garrigós-Pedrón et al. [43] randomised a total of 45 participants with chronic migraine and TMD into two groups: a cervical group and a cervical and orofacial group. Both groups continued their medication regimens for migraine treatment and received physical therapy. The cervical group received physical therapy only in the cervical region, and the cervical and orofacial group received physical therapy in both the cervical and orofacial regions. The Authors demonstrated that both groups reported a significant improvement in pain intensity and headache impact, although cervical and orofacial treatment was more effective than cervical treatment alone for increasing pressure pain threshold in the trigeminal region and producing pain-free maximum mouth opening.

This study is not free from limitations: first, the retrospective study design that did not allow a cause-effect relationship; second, the difference in number of subjects in the three groups albeit it should be considered the huge sample size (300 patients with primary headaches); third, in this retrospective study, the Axis II for the diagnostic criteria for TMD (regarding pain-related disability, psychological status, and psychosocial functioning) was not taken into consideration; lastly, there was a lack of data on the different subtypes for migraine and TTH.

However, to the best of our knowledge, this is the first decision-making study on TMD investigating the correlation with primary headaches and cervical neck pain, through a machine learning approach, considered as a relatively new statistical method in the scientific field.

Conclusions

Taken together, findings of this study showed that TMD and cervical neck pain could be very frequent in subjects affected by primary headaches, reporting a higher TMD and neck pain VAS in patients with migraine. The machine learning analysis focussed on type of primary headache reported that a higher TMD VAS was correlated to migraine and a higher neck pain VAS was correlated to TTH or migraine. Concerning the TMD type, arthrogenous and mixed might be correlated to mild-moderate TMD pain (depending on neck pain intensity), and myogenic TMD might be correlated to moderate-severe TMD pain. Albeit this model of machine learning could be considered as reliable due to the huge sample size, future research is needed to confirm these data to provide more information on this novel statistical approach for the management of TMD in patients with headache.

Informed consent

Informed consent was obtained from all subjects involved in the study.

Author contributions

Conceptualisation, MF, MM, PLFB, AdS; methodology, MM, AdS, NM; formal analysis, NM; data curation, MM, FF, MB, FP, PLFB; writing-original draft preparation, MF, MM; writing-review and editing, AdS; visualisation, NM, FF, MB, FP, AA, AG; supervision, AdS. All authors have read and agreed to the published version of the manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

Dataset is available on request.

References

[1] Dworkin SF, LeResche L. Research diagnostic criteria for temporomandibular disorders: review, criteria, examinations and specifications, critique. J Craniomandib Disord. 1992;6(4):301–355.

[2] Progiante PS, Pattussi MP, Lawrence HP, et al. Prevalence of temporomandibular disorders in an adult Brazilian community population using the research diagnostic criteria (axes I and II) for temporomandibular disorders (the Maringá study). Int J Prosthodont. 2015;28(6):600–609.

[3] Machado LPeS, Nery CdG, Leles CR, et al. The prevalence of clinical diagnostic groups in patients with temporomandibular disorders. Cranio. 2009;27(3):194–199.

[4] Okeson JP. Management of temporomandibular disorders and occlusion. 7th ed. St. Louis (MI): Missouri Elsevier Mosby; 2012.

[5] Manfredini D, Cerea S, Pavan C, et al. Personality traits are potentially associated with the presence of chronic temporomandibular joint pain in patients without effusion as determined by T-2 weighted magnetic resonance. Cranio. 2018;36(2):91–97.

[6] Schiffman E, Ohrbach R, Truelove E, et al. 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. 2014;28(1):6–27.

[7] Ferrillo M, Ammendolia A, Paduano S, et al. Efficacy of rehabilitation on reducing pain in muscle-related temporomandibular disorders: a systematic review and meta-analysis of randomized controlled trials. J Back Musculoskelet Rehabil. 2022;18:1–16. 10.3233/BMR-210236.

[8] Velly AM, Botros J, Bolla MM, et al. Painful and non-painful comorbidities associated with short- and long-term painful temporomandibular disorders: a cross-sectional study among adolescents from Brazil, Canada and France. J Oral Rehabil. 2022;49(3):273–282.

[9] Deregibus A, Ferrillo M, Grazia Piancino M, et al. Are occlusal splints effective in reducing myofascial pain in patients with muscle-related temporomandibular disorders? A randomized-controlled trial. Turk J Phys Med Rehab. 2021;67(1):32–40.

[10] de Sire A, Marotta N, Ferrillo M, et al. Oxygen-ozone therapy for reducing pro-inflammatory cytokines serum levels in musculoskeletal and temporomandibular disorders: a comprehensive review. Int J Mol Sci. 2022;23(5):2528.

[11] Vos T, Flaxman AD, Naghavi M, et al. Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet. 2012;380(9859):2163–2196.

[12] Stovner L, Hagen K, Jensen R, et al. The global burden of headache: a documentation of headache prevalence and disability worldwide. Cephalalgia. 2007;27(3):193–210.

[13] Memmedova F, Emre U, Yalın OÖ, et al. Evaluation of temporomandibular joint disorder in headache patients. Neurol Sci. 2021;42(11):4503–4509.

[14] Stuginski-Barbosa J, Macedo HR, Bigal ME, et al. Signs of temporomandibular disorders in migraine patients: a prospective, controlled study. Clin J Pain. 2010;26(5):418–421.

[15] Barbieri AA, Costa ALF, Perez Gomes JP, et al. Association of volume and voxel intensity of the articular disc and lateral pterygoid muscle in migraine patients: a study with magnetic resonance imaging. Acta Odontol Scand. 2020;78(3):189–195.

[16] Yekkalam N, Wänman A. Association between signs of hyperalgesia and reported frequent pain in jaw-face and head. Acta Odontol Scand. 2021;79(3):188–193.

[17] Gonçalves DA, Camparis CM, Speciali JG, et al. Temporomandibular disorders are differentially associated with headache diagnoses: a controlled study. Clin J Pain. 2011;27(7):611–615.

[18] Chaves TC, Dach F, Florencio LL, et al. Concomitant migraine and temporomandibular disorders are associated with higher heat pain hyperalgesia and cephalic cutaneous allodynia. Clin J Pain. 2016;32(10):882–888.

[19] Furquim BD, Flamengui LM, Conti PC. TMD and chronic pain: a current view. Dental Press J Orthod. 2015;20(1):127–133.

[20] Conti PC, Costa YM, Gonçalves DA, et al. Headaches and myofascial temporomandibular disorders: overlapping entities, separate managements? J Oral Rehabil. 2016;43(9):702–715.

[21] Yap AU, Zhang MJ, Cao Y, et al. Comparison of psychological states and oral health-related quality of life of patients with differing severity of temporomandibular disorders. J of Oral Rehabil. 2022;49(2):177–185.

[22] Kang JH. Neck associated factors related to migraine in adolescents with painful temporomandibular disorders. Acta Odontol Scand. 2021;79(1):43–51.

[23] von Piekartz H, Lüdtke K. Effect of treatment of temporomandibular disorders (TMD) in patients with cervicogenic headache: a single-blind, randomized controlled study. Cranio. 2011;29(1):43–56.

[24] Schreiber JB. Issues and recommendations for exploratory factor analysis and principal component analysis. Res Social Adm Pharm. 2021;17(5):1004–1011.

[25] Han L, Shen P, Yan J, et al. Exploring the clinical characteristics of COVID-19 clusters identified using factor analysis of mixed Data-Based cluster analysis. Front Med (Lausanne). 2021;8:644724.

[26] Baskaran M, Ong EL, Li JL, et al. Classification algorithms enhance the discrimination of glaucoma from normal eyes using high-definition optical coherence tomography. Invest Ophthalmol Vis Sci. 2012;53(4):2314–2320.

[27] Headache Classification Subcommittee of the International Headache Society. The international classification of headache disorders: 2nd edition. Cephalalgia. 2004;24(Suppl 1):9–160.

[28] Headache Classification Committee of the International Headache Society (IHS). The international classification of headache disorders, 3rd edition (beta version). Cephalalgia. 2013;33(9):629–808.

[29] John ZAS, Shrivastav SS, Kamble R, et al. Three-dimensional comparative evaluation of articular disc position and other temporomandibular joint morphology in class II horizontal and vertical cases with class I malocclusion. Angle Orthod. 2020;90(5):707–714.

[30] Chintakanon K, Sampson W, Wilkinson T, et al. A prospective study of TWIN-BLOCK appliance therapy assessed by magnetic resonance imaging. Am J Orthod Dentofacial Orthop. 2000;118(5):494–504.

[31] Sharma R, Muralidharan CG, Verma M, et al. MRI changes in the temporomandibular joint after mandibular advancement. J Oral Maxillofac Surg. 2020;78(5):806–812.

[32] Bertram S, Rudisch A, Innerhofer K, et al. Diagnosing TMJ internal derangement and osteoarthritis with magnetic resonance imaging. J Am Dent Assoc. 2001;132(6):753–761.

[33] Maroco J, Silva D, Rodrigues A, et al. Data mining methods in the prediction of dementia: a real-data comparison of the accuracy, sensitivity and specificity of linear discriminant analysis, logistic regression, neural networks, support vector machines, classification trees and random forests. BMC Res Notes. 2011;4(1):299.

[34] James G, Witten D, Hastie T, et al. An introduction to statistical learning. New York: Springer; 2013.

[35] Moawed SA, Osman MM. The robustness of binary logistic regression and linear discriminant analysis for the classification and differentiation between dairy cows and buffaloes. Int J Stat Appl. 2017;7(6):304–310.

[36] Lee C, Landgrebe DA. Decision boundary feature extraction for neural networks. IEEE Trans Neural Netw. 1997;8(1):75–83.

[37] Oliveira AAM, Espadoto M, Hirata R, Jr, et al. SDBM: supervised decision boundary maps for machine learning classifiers. Proceedings of the 17th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications. 2022. p. 77–87.

[38] Pinto M, Marotta N, Caracò C, et al. Quality of life predictors in patients with melanoma: a machine learning approach. Front Oncol. 2022;25(12):843611.

[39] Ashraf J, Zaproudina N, Suominen AL, et al. Association between temporomandibular disorders pain and migraine: results of the health 2000 survey. J Oral Facial Pain Headache. 2019;39(4):399–407.

[40] Yin Y, He S, Xu J, et al. The neuro-pathophysiology of temporomandibular disorders-related pain: a systematic review of structural and functional MRI studies. J Headache Pain. 2020;21(1):78.

[41] Greenspan JD, Slade GD, Bair E, et al. Pain sensitivity and autonomic factors associated with development of TMD: the OPPERA prospective cohort study. J Pain. 2013;14(12 Suppl):T63–74.e746.

[42] Liang Z, Galea O, Thomas L, et al. Cervical musculoskeletal impairments in migraine and tension type headache: a systematic review and meta-analysis. Musculoskelet Sci Pract. 2019;42:67–83.

[43] Garrigós-Pedrón M, La Touche R, Navarro-Desentre P, et al. Widespread mechanical pain hypersensitivity in patients with chronic migraine and temporomandibular disorders: relationship and correlation between psychological and sensorimotor variables. Acta Odontol Scand. 2019;77(3):224–231.

[44] Giannakopoulos NN, Keller L, Rammelsberg P, et al. Anxiety and depression in patients with chronic temporomandibular pain and in controls. J Dent. 2010;38(5):369–376.

[45] Costa YM, Porporatti AL, Stuginski-Barbosa J, et al. Additional effect of occlusal splints on the improvement of psychological aspects in temporomandibular disorder subjects: a randomized controlled trial. Arch Oral Biol. 2015;60(5):738–744.

[46] Côté P, Yu H, Shearer HM, et al. Non-pharmacological management of persistent headaches associated with neck pain: a clinical practice guideline from the Ontario protocol for traffic injury management (OPTIMa) collaboration. Eur J Pain. 2019;23(6):1051–1070.

[47] Bogduk N. The neck and headaches. Neurol Clin. 2014;32(2):471–487.

[48] Hong SW, Lee JK, Kang JH. Relationship among cervical spine degeneration, head and neck postures, and myofascial pain in masticatory and cervical muscles in elderly with temporomandibular disorder. Arch Gerontol Geriatr. 2019;81:119–128.

[49] Castien RF, van der Windt DAWM, Grooten A, et al. Effectiveness of manual therapy for chronic tension-type headache: a pragmatic, randomised, clinical trial. Cephalalgia. 2011;31(2):133–143.

[50] Jull G, Trott P, Potter H, et al. A randomized controlled trial of exercise and manipulative therapy for cervicogenic headache. Spine (Phila Pa 1976). 2002;27(17):1835–1843.

[51] Calixtre LB, Oliveira AB, de Sena Rosa LR, et al. Effectiveness of mobilisation of the upper cervical region and craniocervical flexor training on orofacial pain, mandibular function and headache in women with TMD. A randomised, controlled trial. J Oral Rehabil. 2019;46(2):109–119.