Patterns of Cervical and Masticatory Impairment in Subgroups of People with Temporomandibular Disorders–an Explorative Approach Based on Factor Analysis
Patterns of Cervical and Masticatory Impairment in Subgroups of People with Temporomandibular Disorders—an Explorative Approach Based on Factor Analysis

Abstract

Objectives

To identify clinical patterns of impairment affecting the cervical spine and masticatory systems in different subcategories of TMD by an explorative data driven approach.

Methods

For this observational study 144 subjects were subdivided according to Research Diagnostic Criteria for Temporomandibular Disorders into: healthy controls, temporomandibular joint (TMJ) signs without symptoms, TMJ affected, temporomandibular muscles affected, or TMJ and muscles affected. Factor analysis was applied to cervical spine and masticatory data while linear regression was applied to characterize clinical patterns in subgroups.

Results

Factor analysis identified five clinical dimensions which explained 59% of all variance: mechanosensitivity, cervical movement, cervical and masticatory dysfunction, jaw movement, and upper cervical movement. Regression analysis identified different clinical dimensions in each TMD subgroup.

Conclusion

Distinct clinical patterns of cervical spine and masticatory function were found among subgroups of TMD, which has clinical implications for therapeutic management.
Introduction

Temporomandibular disorder (TMD) is an umbrella term for structural and functional disorders related to the masticatory muscles and/or the temporomandibular joint (TMJ) with or without clinical signs and symptoms (1). It is the second most common cause of orofacial pain following dental pain (2). The prevalence of signs and symptoms related to TMD ranges widely, reported as low as 1% and as high as 75%, affecting more women and younger people which is uncommon for chronic pain conditions (2–6). The inconsistent epidemiological data is assumed to be a result of different unstandardized and heterogeneous diagnostic criteria used in the studies to define TMD and its symptoms (2, 7). The major clinical signs and symptoms associated with TMD are pain both local and referred into the temporal region of the head, lower face and neck, as well as clicking sound’s, reduced and painful mouth opening, and bruxism (8–10). However, not all individuals diagnosed with TMD have symptoms (11) and thus it is estimated that only 3% of people with signs of TMD seek medical aid (10).

Biological as well as psychological aspects are assumed to be factors in the development of TMD (12). As a consequence, according to Research Diagnostic Criteria/TMD (RDC/TMD), classification of TMD will include physical or psychological diagnoses. Under physical diagnosis, patients are classified into muscle disorders and/or disc displacements and/or arthralgia, osteoarthritis or osteoarthrosis (1, 6, 13).

The importance of diagnosis is to identify the appropriate management strategy from the broad spectrum of therapies described for this condition. Within the contributing factors to TMD the cervical spine is considered to play a crucial role (14). Studies show anatomical and pathophysiological interactions between the
cervical spine and TMJ region (15–21). For example, people with TMD show higher
prevalence and one-year-incidence for neck pain than those without TMD (20, 22).
Furthermore, it has been demonstrated that the neck disability index is highly
correlated with the jaw function scale (23). Studies have also demonstrated the
influence of various head and neck postures on the masticatory muscles and their
mechanosensitivity (18, 24). Additionally, there is some evidence that cervical
dysfunction is the consequence of TMD. As such, various authors describe a positive
effect of orofacial therapy (21, 25) on the function of the cervical spine. Yet, a clear
causal relationship remains unclear.
Despite this, there is little high quality research evidence that has investigated the
relationship between cervical dysfunction and TMD. Furthermore, according to the
author’s knowledge, there are no studies investigating whether subgroups of TMD
show distinct patterns of cervical and masticatory impairment. Finally, studies are
lacking that give a comprehensive picture of the interaction between the cervical spine
and the TMJ.
Consequently, the aim of this study is to describe and perform an extensive analysis in
a study sample consisting of individuals classified into five subgroups according to
physical diagnostic criteria of RDC/TMD. Subgroups of TMD are characterized with
respect to patterns of impairment based on clinical and functional measurements
associated with the masticatory and cervical systems. Therefore, instead of testing
predefined, clinically driven hypotheses (which is the common way), this study uses an
explorative data driven approach based on factor analysis. More detailed knowledge of
clinical patterns of cervical and masticatory impairment among subgroups of TMD may
ultimately direct management and thereby improve therapeutic outcomes.
Methods

Participants

For this observational study, subjects were recruited from physiotherapy practices in Northern Germany by information flyers. Subjects were evaluated for inclusion by a clinical expert with 15 years of experience managing orofacial pain according to the following criteria: (1) age at least 18 years, (2) score of less than 3 on the modified Chronic Grade Pain Scale (26–29) indicating chronic condition status, (3) conversant in the German language, (4) score of more than 3 measured on the CONTI questionnaire suggesting evidence of TMD (30).

Subjects acting as controls were selected from the same environment if they met the following criteria: (1) age at least 18 years, (2) conversant in the German language, (3) score of ≤ 3 measured by the CONTI questionnaire. Subjects were excluded if they had (1) a history of surgery or fractures in the neck and jaw or (2) neurologic deficits or (3) pain at night or other red flags or (4) were currently undergoing orthodontic treatment. Prior to participation, subjects gave written informed consent. The study was conducted in accordance with the Declaration of Helsinki and was approved by the local ethics committee of the University of Applied Science Of Osnabrück.

For further stratification subjects were subdivided according to RDC/TMD. Therefore the presence of painful and restricted mouth opening, painful masticatory muscles on palpation, and TMJ sounds were assessed. These criteria are designed to define the subgroup of TMD (31). As a consequence, patients with TMD (CONTI > 3) were subdivided into group “Arthogen” when joint disorders were present, group ”Myogen” when myofascial disorders were present, or into group “Mixed” when both joint disorders and myofascial disorders were present. Subjects acting as controls (CONTI ≤
were subdivided into group “Controls” having no TMD signs or pain or group “Just signs” having TMD signs that are not clinically relevant based on the Conti scale (30). Consequently, five subgroups were investigated with different diagnoses of TMD. We proposed that the “Mixed” group would be the most severe as they had both joint disorders and myofascial involvement.

**Functional measurements**

The TMJ and the cervical spine were examined and measured separately by two clinically experienced physiotherapists who had 8 hours intensive training in the management of orofacial disorders. The investigator who executed the neck measurements was blind to subjects TMD subgroup classification.

**TMJ Region**

**Range of motion**

Measurements of TMJ range of motion (ROM) included mouth opening, active lateral shift of the jaw to both sides as well as active backward and forward movement of the jaw. Inter- and Intra-rater reliability has been shown to be moderate to excellent for these measurements.

**Mechanosensitivity**

Mechanosensitivity of the Masseter and Temporalis muscles was determined by measuring pressure pain threshold (PPT) using an algometer (*Wagner instruments, Force dial FDK 10*). Pressure was applied at a constant rate of approximately 1 kg/cm2/s until subjects reported the point when the sensation changed from pressure to pain. Two readings were taken over each site and each muscle and averaged for analysis. PPT has been shown to be a valid and reliable method for measuring mechanosensitivity (32–34).
CONTI

124 The Conti questionnaire (30) was used for assessing TMD symptoms. This scale comprises ten questions concerning typical TMD features and has a score from 0, indicating no clinically relevant TMD, to 23. Prior to the examination subjects were asked whether they suffered from pain in the masticatory and cervical region.

129 PAIN

130 Pain was graded according to the Colored Analogue Scale (CAS) from 0 to 10. The CAS has high reproducibility (35).

132 Cervical spine

133 ROM

134 Active cervical ROM in all planes (flexion, extension, lateral flexion, and rotation) was measured by the Cervical ROM (CROM) device (36, 37). Maximum angles within comfortable limits were recorded. The CROM device is described as valid and reliable (36, 38, 39).

138 Mechanosensitivity

139 Mechanosensitivity of Upper Trapezius and Obliquus Capitis Inferior muscles were determined by measuring PPT using the method described above.

141 Neck disability index

142 The Neck disability index (NDI) was used to assess neck related disability and comprises 10 self-report questions covering activities of daily living, concentration and pain. The scale ranges from 0 (no pain and disability) to 50 (severe pain and disability) and has been shown to have good to excellent psychometric properties (40, 41).

146 Flexion-Rotation Test
Upper cervical rotation in end-range flexion (FRT) (42, 43) was recorded using a digital goniometer (Halo Medical Device), while pain during the FRT was recorded by the CAS.

Cranio-cervical Flexion-Test

The Cranio-cervical Flexion-Test (CCFT) was used to measure endurance of the cervical deep flexor muscles (44, 45) evaluated using a pressure biofeedback device (Chattanooga, USA) according to a reliable procedure described by Hudswell (46–48).

Number of cervical signs

Palpation of the three upper cervical spine motion segments was conducted to assess segmental mobility and pain. The number of symptomatic findings were aggregated and termed “cervical signs”. This procedure has good reliability (49).

All measurements are summarized in Table S1 available online.

Analysis

All statistical analysis was performed with R (50) including the psych package (51). Analysis of variance and chi² was used to test for differences in baseline characteristics between subgroups of participants. P-values < 0.05 were considered significant. The basis of our analysis strategy was as follows: Rather than confirming whether clinically driven predefined clinical patterns are present among subjects with TMD, we performed a data driven explorative analysis strategy in order to identify clinically relevant patterns among subgroups of individuals with TMD. Therefore we conducted five steps including factor analysis and linear regression analysis.

Step 1: Factor analysis was used as a dimension reduction method. Measured variables were condensed to a reduced number of factors that would still contain the majority of the information from the original data. The dimensionality of the data was assessed, where each factor represents a clinical dimension which was characterized with
respect to a clinical meaning. The appropriate number of relevant clinical dimensions was established by applying the Very Structure Criterion (52) and the Parallel Analysis Criterion (53) as implemented in the psychological package. Where inconsistency of the statistical solutions was detected the more interpretable solution with respect to clinical meaning was selected. The amount of information (variance) that is captured by each of extracted factors was calculated by determining their eigenvalues.

Step 2: graphical descriptive means were used to assess the ability of the data to discriminate people with TMD from controls in general. A scatterplot representing each individual’s score for each pair of factors was constructed demonstrating the general clinical relevance of the identified dimensions.

Step 3: the extracted factors (clinical dimensions), were interpreted with respect to a clinical and functional meaning. Therefore, all measured variables were correlated with the extracted factors. Their correlation coefficients represent their loadings on the factors. By inspecting the correlation coefficients of each measured variable with each factor the contribution of each variable to the respective factor was evaluated. As a consequence, the clinical meaning of the factors was interpreted. In order to facilitate interpretation, the factor solution was rotated before calculating the correlation structure, in our case by Varimax rotation. Conceptually, the factors have the function of summary variables of the underlying clinical dimension. The score of each individual on each factor was calculated. As a consequence, it was possible to quantify each person’s score on the respective clinical dimension, i.e. a low/high person’s score represents a low/high summary score of the respective clinical dimension.
Step 4: subgroup characterization was performed with respect to the clinical dimensions. Therefore, we aimed to determine to what extent each of the TMD subgroups was affected with respect to the respective clinical dimension. To do so we conducted the analysis with both the extracted factors, representing the clinical dimensions as summary variables, and with the original variables contributing to the respective clinical dimensions. For this purpose we used linear regression with subgroup membership as independent variables and all variables standardized (Mean=0, SD=1). Results are given as standardized mean differences and interpreted as effect sizes according to Cohen (<0.2 no effect, 0.2-0.5 small effect, 0.5-0.8 moderate, 0.8>large effect) (56). This approach is analogous to meta-analysis in order to be able to compare results across outcomes with different units.

Step 5: Finally, a summary was generated of how the TMD subgroups were characterized with respect to the identified clinical dimensions. Also, here the strength of clinical impairment in each dimension was given as interpretable values according to Cohen. Hence, the clinical pattern of each subgroup was presented indicating which clinical dimension was affected to which extent.

The quality of the factor analysis models was assessed using Bartlett’s test for sphericity (54) and the Kaiser-Meyer-Olkin test (55). For regression analysis, variables that assessed bilateral measurements were combined to one variable by calculating the mean of left and right sides as no significant side differences were present. Additionally, we added age and gender as covariates into regression models as potential confounders. If p-values of confounders according to t-statistics were >0.1, or changed the estimate less than 10%, those variables were withdrawn from the model.

**Results**
Of 175 people assessed for inclusion 144 participants met the study criteria. These people were divided into five subgroups and characterized with respect to clinical patterns of impairment based on clinical and functional measurements from the TMJ and cervical spine as depicted in the work flow diagram in Figure 1.

Baseline characteristics are summarized in Table 1. Bartlett’s Test of Sphericity was highly significant (Chi square = 1513.003, $P < 0.001$) and the KMO test was 0.82, supporting the suitability of the data for factor analysis.

Step 1 clinical dimensionality of data: We extracted 5 independent factors by factor analysis representing five clinical dimensions. In total, the five dimensions explained 59% of the total variance (dimension 1 - 23%, dimension 2 - 13%, dimension 3 - 8%, dimension 4 - 8%, and dimension 5 - 5%).

Step 2 general overview of distinction between subjects with TMD and controls: Figure 2 shows the scores of all individuals on each of the five factors, i.e. on each clinical dimension. Each scatter plot shows each individual’s score of a pair of dimensions. E.g. the very left top plot depicts scores of dimension 1 on the x-axis and scores of dimension 2 on the y-axis. Black Cs represent the control group including the control group with symptoms of TMD. Grey Ts represent the TMD group including sub-groups “Arthrogen”, “Myogen” and “Mixed”. Plots of dimension 1 to dimension 4 show, albeit some overlap of the dots, that the scores of subjects with TMD are separate to the scores of controls indicating that subjects with TMD generally possess distinct underlying clinical patterns compared to controls. This especially holds true for the third dimension. Factor 5 suggests no distinct pattern between the groups.
Step 3 Characterization of clinical dimensions. In Table 2 the factor loadings of each measured variable are listed. The key variables of each independent factor, i.e. clinical dimension, are marked in grey. The values are the correlation coefficients of each measured variable with each factor. This allows the clinical and functional interpretation of the clinical dimensions. As a consequence, factor 1 represents the clinical dimension “mechanosensitivity” as it includes all variables measuring mechanosensitivity of muscle sites in the masticatory and cervical region as well as the variable “cervical signs” (coefficient range: 0.64-0.89). Factor 2 is characterized by the clinical dimension cervical ROM which includes movement in all directions (coefficient range: 0.54-0.81). Factor 3 comprises both cervical and masticatory dysfunction measured by the NDI and CONTI questionnaires, as well as the presence of pain when performing the FRT (coefficient range: 0.47-0.72). As a consequence we called this clinical dimension “Cervical/masticatory dysfunction and pain”. Factor 4 represents the clinical dimension “jaw movements” which includes TMJ movement in all directions (coefficient range: 0.43-0.7). The last factor consists of the clinical dimension FRT ROM and the CCFT (coefficient range: 0.45-0.78).

Table 2:

Step 4 Characterization of TMD subgroups: Figure 3 shows the pairwise differences between each of the subgroups compared to the Control group with respect to all clinical dimensions including all contributing variables. Linear regression was used for this analysis. The first variable of each column and each pairwise comparison (summary variable) represents the extracted factors by factor analysis and is considered as the summary variable of each corresponding clinical dimension for the respective group comparison. Below each summary variable the contributing variables
to each clinical dimension, according to Table 2, are listed. The effects of the
subgroups “Mixed”, “Myogen”, “Arthrogen” and “Just signs” in comparison to the
reference group (control group without TMD signs) are presented as standardized
mean differences (SMD) and ±95% Confidence Intervals. It allows interpretation of the
coefficients in effect size. In the dimension “mechanosensitivity” the overall effect size
represented by its summary variable for the comparison “Mixed” group vs control
group is \(-0.83\ [-1.32; -0.38]\) suggesting a large effect. In others words this means that in
general, mechanosensitivity of the “Mixed” group is greatly elevated when compared
to “Controls”. This effect is consistent across all single variables of the clinical
dimension “mechanosensitivity”. The variables range from \(-0.77\) for Temporalis muscle
to 0.92 for “cervical signs”. The second largest effect size with respect to the clinical
dimension “mechanosensitivity” is observed between the “Myogen” group and the
control group with an effect size of \(-0.39\ [-0.96; 0.21]\). In the remaining two groups the
effect size is below \(-0.25\). For the dimension “cervical mobility” a similar pattern is
observed. Also here the “Mixed” group has the most reduced cervical ROM with an
effect size of \(-0.58\ [-1.06; -0.10]\) followed by the “Myogen” group having an effect size
of \(-0.38\ [-0.99; 0.23]\). The most affected direction in both the “Mixed” and “Myogen”
group is extension with effect sizes of \(-0.69\ [-1.16; -0.23]\) and \(-0.63\ [-1.19; -0.06]\)
respectively. The least affected variable in both groups is flexion (effect size in the
“Mixed” group: \(-0.27\ [-0.78; 0.24]\), effect size in the “Myogen” group: \(-0.36\ [-
0.98; 0.26]\).
Dimension “Cervical/masticatory dysfunction and pain”, is similarly impaired in all
subgroups apart from “Just signs” group. The large effect sizes of the summary
variables range from \(-0.94\ [-0.50; -1.38]\) in the “Mixed” group to \(-1.28\ [-0.72; -1.83]\) in
the “Myogen” group. The effect sizes for the single variables CONTI, NDI and pain during FRT range in the three affected subgroups between -0.78 [-0.33;1.20] and -1.69 [-1.35;-2.04]. Acute pain is only present in the “Myogen” group with an moderate effect size of -0.71 [-0.27;-1.15]. Dimension 4 ”jaw movement” is restricted across all subgroups with moderate effects sizes of the summary variables from -0.54 [-1.15;0.08] in the “Myogen” group to -0.77[-1.27;-0.26] in the “Mixed” group. Finally, the last dimension has no clinical meaning for any of the subgroups indicated by effect sizes lower than 0.20.

Figure 3:

Step 5 summary of clinical patterns in TMD subgroups:

In Table 3 the clinical patterns with respect to the cervical and masticatory systems of the subgroups are depicted. Arrows indicate to which extent a subgroup is restricted in each clinical dimension and represent effect sizes stemming from the summary variables of each clinical dimension shown in figure 3. One arrow is a small effect, two arrows a medium effect and three arrows a large effect. As a consequence, the “Mixed” group is the most affected group, with moderate to large limitations in the dimensions “mechanosensitivity”, “cervical ROM”, “cervical and masticatory dysfunction and pain” and “jaw movement”. The “Myogen” group is also affected in the same dimensions, however, less with respect to “mechanosensitivity” and “cervical ROM”. Groups “Arthrogen” and “Just signs” have only medium to large limitations in dimensions “cervical and masticatory dysfunction and pain” and jaw movement.

Table 3:

Discussion
In this explorative data driven analysis five independent clinical dimensions were identified based on 28 functional measurements from the cervical spine and masticatory systems using factor analysis with varimax rotation and linear regression analysis. These dimensions are interpreted as mechanosensitivity, cervical ROM, cervical and masticatory dysfunction, jaw movement and upper cervical ROM/endurance. The five factors explain 59% of all variance. Furthermore, the 144 subjects divided into five subgroups according to RDC/TMD were characterized with respect to the five clinical dimensions. The “Mixed” group is the most affected group with moderate to large limitations in all dimensions followed by the “Myogen” group with limitations in the same dimensions, however, less with respect to mechanosensitivity and cervical ROM. Groups “Arthrogen” and “Just signs” show medium to large limitations only concerning cervical and masticatory dysfunction and jaw movement. A clear dose response relationship was observed indicating that subjects with a diagnosis of TMD in two aspects (myogenic and arthrogenic) are most affected.

The main advantage of this explorative data driven approach is that it revealed clinical patterns that were quite unexpected and probably would have not been identified by a clinically driven approach. This is illustrated by two findings as examples: Firstly, the clinical dimension “mechanosensitivity” consisted of variables measuring mechanosensitivity at all muscle sites, not just over cervical or masticatory muscles. From the clinical point of view one might have expected two distinct dimensions, namely “cervical mechanosensitivity” and “masticatory mechanosensitivity”. However, due to the high correlation structure the analysis revealed that the two regions are highly interrelated with respect to mechanosensitivity and may not be seen as
clinically different problems. On the one hand this finding confirms the fact that subjects with TMD suffer from referred pain into the neck region. On the other hand, this finding perhaps suggests that patients with TMD are dominated by mechanism(s) of central sensitization with associated areas of secondary hyperalgesia.

A similar surprising result was seen for the variables NDI and CONTI which were found to occur together in one dimension. Even though it is known (25, 57–59) that these two variables are correlated, it was surprising that both variables were related so much to each other that they loaded equally highly on the same factor. From the clinical point of view one might have expected that the variable NDI would cluster together with variables measuring neck muscle mechanosensitivity or cervical ROM. Additionally, the CONTI might be expected to cluster together with jaw movements or variables measuring masticatory muscle mechanosensitivity.

In this study, ROM of the upper cervical spine together with endurance of the neck flexors were not found to have any clinical relevance for any subgroup. (60) This is in contrast to previous studies showing evidence of altered upper cervical spine ROM and muscle performance in TMD overall and in specific sub-groups of people with TMD (16, 59–61). The difference could be explained by the small sample size in some studies (60, 61), but that was not the case in the study by Armijo-Olivo and Magee (59).

Further studies are required to elucidate this. Less surprising is that fact that the “Mixed” group was the most affected group. One might expect this finding from the clinical point of view as well.

A further advantage of the present study is the use of the extracted factors as summary variables of each identified clinical dimension. In that way a summary score of each clinical dimension could be calculated for each individual. As a consequence
high/low individual scores mean large/low limitations in the respective dimension. The clinical relevance of this information requires careful consideration. These results confirm that patient’s with TMD are not homogenous, different subgroups exist with different clinical presentations. Each subgroup may therefore require a different form of intervention to address the underlying mechanisms.

Clinical Implications

The findings of this study have clinical implications for practice. In general there is a need to subgroup patients with TMD as they have distinct functional profiles with respect to the cervical and masticatory systems. Typically, this kind of procedure is conducted in daily clinical practice by therapists where individuals are categorized based on a comprehensive clinical evaluation in order to initialize individually tailored therapy and patient management programs (63). Similar broad-based evaluative approaches are undertaken in patients with low back pain (64). Furthermore it has been shown that sub-classification based therapy is more effective than standard protocols (65–68).

The fact that NDI and CONTI are highly interrelated to form one clinical dimension suggests that when patients present with high levels of impairment of TMD, high levels of disability of the cervical region should also be expected. This holds true across all subgroups of TMD. As a consequence, management should address impaired domains detected by the NDI and CONTI.

It would appear reasonable to suggest that for patients with arthrogenic and myogenic features of TMD, management should address mechanosensitivity of masticatory and neck muscles. However, the underlying pain mechanism in this dimension are indicative of central sensitization which requires a different management approach.
Impaired mechanosensitivity seems to be less likely among patients with myogenic TMD and almost nonexistent in patients with arthrogenic TMD.

Cervical ROM is another clinical dimension that seems to be problematic and needs attention in clinical practice in patients with “Mixed” TMD, but less so in myogenic and arthrogenic TMD. In contrast, restricted ROM of the TMJ is similarly present across all TMD subgroups.

In general, it can be noted that in none of the clinical dimensions does a single variable stand out that requires specific attention. For example, in the clinical dimension mechanosensitivity, there is not a single muscle alone that is affected. All muscles are equally affected. The same holds true for cervical ROM, where it is not a single movement but all planes that are equally affected.

Strengths

The strength of this paper is the application of factor analysis as an explorative data driven approach to characterize predefined subgroups with respect to until now unknown clinical patterns. This approach is unusual and not commonly applied. However, it has yielded unexpected but clinically meaningful and relevant implications. This was only possible due to a large sample size and detailed and extensive measurements which is uncommon in studies of TMD.

However, there are other statistical approaches that perform subgroup classification based on data modelling. Common statistical techniques include among others cluster or latent class analysis. Instead of predefining subgroups based on clinical diagnosis these techniques create subgroups based on the observed data. Consequently, built classes are interpreted and analyzed with respect to clinical relevance (69).

Limitations
A potential weakness of this study is the exclusion of patients with chronic disease. As a result, it is not possible to draw any conclusions regarding those patients. Furthermore, this study did not include psychosocial aspects in the factor analysis. In addition, in an attempt to control for potential confounders it was not possible to use a matched case controlled design. Matched case controlled designs allow more efficient statistical analysis approaches resulting in more power. Finally, in order to disentangle the temporal relationship between onset of cervical spine and masticatory complaints, a longitudinal study designs is necessary.

For the purpose of validation it is essential to replicate the study findings in further research. The presence of the identified clinical dimensions and patterns among subgroups of TMD need to be confirmed by confirmatory factor analysis in other samples.

Conclusion

An explorative data driven analysis was used for identifying clinical patterns among subgroups of TMD. These results have implications for clinical decision making and therapeutic management in patients with TMD. As a consequence, it is proposed that subgrouping patients with TMD is essential as these show distinctly different clinical patterns with respect to the masticatory and cervical spine systems in order to improve outcomes.

References


Table S1 online: Functional measurements of TMJ region and cervical spine

Variables were used for identifying clinical patterns among TMD patients by explorative data analysis

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conti Questionnaire</strong></td>
<td>Contains 10 questions that are related to problems originating from the temporomandibular region. Each question has three ranking options (0=none: 1=present: and 3=strong or bilateral). The likelihood of a CMD is divided into 4 subgroups: 4-9, none: 9-14, minimal: 15-21, moderate: 21-23, strong</td>
</tr>
<tr>
<td><strong>Colored Analogue Scale (CAS)</strong></td>
<td>Pain intensity scale similar to the visual analogue scale transformed in an increasing colored line in mm that represents the pain intensity</td>
</tr>
<tr>
<td><strong>Range of motion of TMJ</strong></td>
<td>Using a ruler of 15 cm, starting at 0, the active ROM of TMJ is measured including mouth opening, lateral shift, backward and forward movement of the jaw</td>
</tr>
<tr>
<td><strong>Mechanosensitivity of cervical and masticatory muscles</strong></td>
<td>The mechanical pressure pain threshold is assessed of the masticatory system and the neck muscles by a digital in kilogram force (Kgf). Muscles measured: Masseter, Temporalis, Upper Trapezius and Obliques Capitis Inferior</td>
</tr>
<tr>
<td><strong>Neck Disability Index (NDI)</strong></td>
<td>A dimension-specific index that reflects “functional limitation” in neck disorders (includes 10 items (activities) with six different response options, ranging from “no disability” (0) to “complete disability.” (5) The total score is 50. A higher score indicates more pain and disability</td>
</tr>
<tr>
<td><strong>Cervical Range of Motion (CROM)</strong></td>
<td>Measurement of cervical spine flexion, extension, rotation and lateral flexion using an inclinometer</td>
</tr>
</tbody>
</table>
**Cranial cervical Flexion Test (CCFT)**

Measures the cervical flexor muscle synergy during upper cervical flexion. A pressure sensor positioned under the neck enables targeted increases in upper cervical flexion ROM by raising pressure in the sensor at 2 mm Hg increments from a baseline of 20, rising to 30mm Hg.

**Flexon Rotation Test (FRT)**

Passive rotation of the cervical spine in maximal flexion measured in supine. Subjective pain response and range of rotation is recorded.

**N° of cervical signs**

Palpation of the three upper cervical spine motion segments was to assess segmental mobility and pain. Score is sum of number of symptomatic findings.

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| Table 1: baseline characteristic of the study participants according to subgroups |
|---------------------------------|-------------------|------------------|-----------------|-----------------|----------------|
| Healthy (n=21)                  | Just signs (n=23) | Arthrogen (n=18) | Myogen (n=19)   | Mixed (n=63)    |
| **Female sex: n (%)**           | 11 (52%)          | 18 (78%)         | 15 (84%)        | 15 (89%)        | 54 (83%)        | 0.045 |
| **Age in years: mean (SD)**     | 33.15 (9.86)      | 32.61 (7.91)     | 35.11 (9.58)    | 31.11 (8.55)    | 36 (13.61)      | 0.44 |
| **CONTI: mean (SD)**            | 1.619 (1.15)      | 1.91 (0.99)      | 6.50 (2.55)     | 7.23 (3.33)     | 8.57 (3.59)     | <0.0001 |
| **Mouth opening in mm: mean (SD)** | 46.95 (5.47) | 42.34 (4.45) | 42.61 (6.91) | 46.52 (5.11) | 42.30 (6.65) | 0.005 |

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**Table 2: Factor loadings of measured variables**
The table shows contribution of each measured variable to each identified dimension by means of correlation coefficients. Grey shaded cells indicate high contribution. Based on correlation coefficients clinical characterization of dimensions is carried out.

<table>
<thead>
<tr>
<th>variables</th>
<th>Factor 1 “mechano-sensitivity”</th>
<th>Factor 2 “cervical ROM”</th>
<th>Factor 3 “Cervical/mastic at. dysfunction and pain”</th>
<th>Factor 4 “jaw movement”</th>
<th>Factor 5 “ROM and endurance upp. cervical spine”</th>
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Table 3: clinical pattern of subgroups is shown with respect to the cervical and masticatory systems.

Legend table 3: Arrows indicate effects according to effect sizes. One arrow is a small effect, two arrows a medium effect and three arrows a large effect.
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Title figure 1: work flow diagram

Recruitment of 175 volunteers

In-/exclusion criteria

No TMD
CONTI ≤ 3

TMD
CONTI > 3

subgroup stratification according to RDC/TMD

Healthy (n=21)  Just signs (n=23)  Arthrogen (n=18)  Myogen (n=19)  Mixed (n=63)

Clinical and functional measurements of TMJ and cervical spine

Characterization of clinical patterns among TMD subgroups by explorative data analysis approach

Step 1: Establish the number of clinical dimensions in the data
Step 2: Present overview of ability to discriminate between TMD vs Control by data
Step 3: Interpret the clinical meaning of identified clinical dimensions
Step 4: Characterize TMD subgroups with respect to the clinical dimensions
Step 5: Present clinical patterns present in TMD subgroups

Legend figure 2: Black Cs represent the control group including the control group with symptoms of TMD (“Just signs”). Grey Ts represent the TMD group including the “Arthrogen”, “Myogen” and “Mixed” subgroup. Each plot shows scores of two dimension. E.g. the very left top plot depicts scores of dimension 1 on x-axis and scores of dimension 2 on y-axis. Separation of dots with respect to group membership indicate distinct patterns.
Title figure 3: Standardized mean differences of clinical dimensions between subgroups of TMD

Legend figure 3: Differences (±95% Confidence Intervals) are shown between each of the subgroups to control group with respect to all clinical dimensions calculated by linear regression analysis. Factors representing a summary variable of each clinical dimension and single variables contributing to respective dimension are depicted. Results are to be interpreted as effect sizes (beta). Model is adjusted for age and gender where necessary.