TEMPOROMANDIBULAR JOINT DISORDERS' IMPACT ON PAIN, FUNCTION, AND DISABILITY

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Abstract

Aims: To determine the association between more advanced stages of temporomandibular joint intra-articular disorders ("*TMJ intraarticular status*"), representing a transition from normal joint structure to TMJ disc displacement with and without reduction (DDwR and DDwoR) to degenerative joint disease (DJD), and patient-reported outcomes of jaw pain, function, and disability ("*TMD impact.*")

Methods: This cross-sectional study included 614 cases from the Validation Project with at least one temporomandibular disorder (TMD) diagnosis. *TMJ intraarticular status* was determined by three blinded, calibrated radiologists using magnetic resonance imaging and computed tomography as one of normal joint structure, DDwR, DDwoR, or DJD, representing the subject's most advanced TMJ diagnosis. *TMD impact* was conceptualized as a latent variable consisting of (i) pain intensity (Characteristic Pain Index from the Graded Chronic Pain Scale [GCPS]), (ii) jaw function (Jaw Functional Limitation Scale); and (iii) disability (Disability Points from GCPS). A structural equation model (SEM) estimated the association of *TMJ intraarticular status* with the latent measure *TMD impact* as a correlation coefficient in all TMD cases (N=614) and in cases with a TMD pain diagnosis (N=500).

Results: The correlations between *TMJ intraarticular status* and *TMD impact* were 0.05 (95% CI -0.04 to 0.13) for all TMD cases and 0.07 (95% CI -0.04 to 0.17) for cases with a pain diagnosis, which are neither statistically significant nor clinically relevant.

Conclusion: Conceptualizing worsening of TMJ intra-articular disorders as four stages and characterizing impact from TMD as a composite of jaw pain, function, and disability, this cross-sectional study found no clinically significant association. Models of *TMJ intraarticular status* other than ours (normal structure → DDwR → DDwoR → DJD) should be explored.

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Introduction

Temporomandibular disorders (TMD) are a heterogeneous group of disorders affecting the masticatory system with pain as the dominating characteristic. Temporomandibular joint (TMJ) intra-articular disorders (ID) are also prevalent, notably TMJ disc displacements (DD) and degenerative joint disease (DJD). The impact of these ID on patients is of interest because interventions to treat structural TMD disorders, such as TMJ surgery, differ from interventions targeting pain-related TMD. Hence, clinical decision-making could be influenced if ID are related to jaw pain, function, and disability, but this clinical impact is not well understood.

Many people view ID as a group of disorders that starts as DD with reduction (DDwR), develops to DD without reduction (DDwoR), and then to DJD (de Leeuw et al 1995a; Rasmussen 1981; Wilkes 1989). Conversely, others have suggested that most individuals with DDwR never develop DDwoR or DJD (de Leeuw et al 1995b; Sale Bryndahl and Isberg 2013; Westesson and Lundh 1989), and if they do, it has little impact on jaw pain, function, or disability. Thus, it is not clear how TMJ structural status impacts patients.

Previous investigations assessing this research question suffered from lack of a comprehensive set of reliable, valid patient-reported outcomes (PROs) characterizing TMD's multidimensional impact, limited sample size, selected study populations, or lack of imaging techniques for validly diagnosing DD and DJD (Boering 1966; Kurita et al 2006; Laskin 1994; Rasmussen 1981). The Validation Project provides data that overcome these methodological problems: Using a large number and the full spectrum of TMD cases, TMJ intra-articular status was assessed by magnetic resonance imaging (MRI) and computed tomography (CT), and the impact of TMJ disorders was assessed by a comprehensive set of patient-reported outcomes (PROs), consisting of jaw pain intensity, jaw function, and pain-related disability.

The present study's aim was to investigate in TMD cases whether more advanced stages of structural *TMJ intraarticular status* were related to jaw pain, jaw function, and disability.

Methods

Setting and subjects

This cross-sectional study included subjects of the Validation Project, a multicenter project of the University of Minnesota, the University of Washington, and the University at Buffalo. From those 705 subjects, we included 614 TMD cases with at least one consenus-based TMD physical diagnosis rendered by 2 TMD experts at each site (Schiffman et al 2010), representing a convenience sample of clinic and community TMD cases (85% female; average age ± standard deviation 37.1 ± 13.1 years). Subjects were included in the present study based on presence of any TMD diagnosis regardless of whether they were clinical or community cases or what symptoms they reported. For more details regarding study subjects and setting, see (Ahmad et al 2009; Schiffman et al 2010; Anderson et al 2011). The present report follows the STROBE statement for cross-sectional studies.

***TMJ intraarticular status*: Soft and hard tissue structural stages of the TMJ**

Three blinded, calibrated radiologists interpreted bilateral TMJ CT and MRI and rendered one of these diagnoses: normal joint structure (“Normal”), DDwR, DDwoR, or DJD (Ahmad et al 2009). For each subject, the most advanced diagnosis of the two TMJ was determined, resulting in N=81 cases with normal joints (all had painful TMD), N=217 cases with DDwR (N=154 with a painful TMD), N=75 cases with DDwoR (N=63 with a painful TMD), and N=241 cases with DJD (N=202 with a painful TMD). Among cases with DDwR N=145 (69%) and among cases with DDwoR N=21 (28%) were found to have bilateral displacement. For cases with DJD, bilateral involvement was found for N=102 (42%).

For the analyses presented here, *TMJ intraarticular status* was treated as a stepwise variable advancing from normal structure to DJD with DDwR and DDwoR as intermediate stages. The inter-rater reliability of the 3 radiologists for determining stages of *TMJ intraarticular status* was good to excellent ($kappa_{DDwR}$=0.78, 95% CI:0.68-0.86, $kappa_{DDwoR}$=0.94, 95% CI:0.89-98, $kappa_{DJD=}$0.71, 95% CI:0.63-0.79) (Ahmad et al 2009).

***TMD impact*: A latent variable combining jaw pain, function, and disability**

TMD impact was conceptualized as a latent variable, a construct characterizing how TMD impacts patients. It consisted of three PROs:

- Pain intensity, measured by Characteristic Pain Intensity (CPI) from the Graded Chronic Pain Scale (GCPS) (VonKorff et al 1992): Score range, 1-100 points, higher scores indicate greater pain.
- Jaw function, measured by Jaw Functional Limitation Scale 20 (JFLS-20) global scale (Ohrbach Larsson and List 2008) : Score range, 1-200 points, higher scores indicate worse jaw function. The JFLS has three subscales: *Mastication, Vertical Jaw Mobility*, and *Emotional and Verbal Expression*.
- Jaw disability, measured by Disability Points (DP) from the GCPS (VonKorff et al 1992): Score range, 0-100 points, higher scores indicate worse disability.

TMD impact was the dependent variable in the SEM analyses; the three PROs represented the SEM measurement model.

Data analysis

TMJ intraarticular status was treated as a measure taking values 1, 2, 3, and 4 for Normal, DDwR, DDwoR, and DJD, respectively. We chose this simple model, with an equal distance of severity between stages, in the absence of evidence for more complicated models describing how the stages differ in terms of severity. This conceptualization of *TMJ intraarticular status* allowed us to investigate whether overall worsening of TMJ structures had a patient-perceived impact.

We first estimated simultaneously, using multivariate multiple regression, the association between *TMJ intraarticular status* and each PRO. This analysis investigated whether jaw pain, function, and disability increased with more advanced stages of TMJ disorders, taking into account the correlations among the PROs and adjusting for possible confounding effects from age (entered linearly) and sex. We also restricted analyses to TMD cases with DDwR, DDwoR, and DJD (3-level *TMJ intraarticular status*) to investigate whether results would be similar in a more homogeneous sample of TMD cases with intraarticular diagnoses. In addition to these tests of a specific formulation of *TMJ intraarticular status*, in secondary analyses we performed a test using unordered *TMJ intraarticular status* categories. Here, DDwR, DDwoR, and DJD were each tested in the multivariate regression model against the Normal (base) category, assessing whether any *TMJ intraarticular status* level is associated with each PRO. Finally, in exploratory analyses, we used the JFLS' three subscales individually as outcome variables in linear regression analyses.

Second, we used SEM to estimate the effect of *TMJ intraarticular status* on *TMD impact*, which summarizes the three PROs in a latent variable. The SEM provides a more interpretable effect measure, a correlation coefficient, for the association between *TMJ intraarticular status* and *TMD impact*. The magnitude of this coefficient, and therefore the clinical relevance of the *TMJ intraarticular status*-*TMD impact* association, can be judged by comparing it with guidelines for effect sizes (Cohen 1988). In the first step, we fitted a measurement model relating the CPI, JFLS, and disability scores to the latent variable *TMD Impact*. Fit statistics for this model could not be calculated because the model is just identified. According to recommendations for assessing goodness of fit for such a model (Brown 2012), we assessed the magnitude of the loadings, their standard errors, and their statistical significance. In a second step, we added the exposure variable as the structural part of the SEM analysis.

We performed all analyses in two sets of TMD cases, those with and without a painful diagnosis, representing populations to which we want to generalize our results. For details about the hypotheses investigated and the targeted populations, see Appendix.

Results

Descriptions of jaw pain, function, and disability

Cases with any TMD diagnosis

TMD cases with or without a pain diagnosis presented with substantial jaw pain, limitations in jaw functioning, and disability (Fig 1). Average CPI for cases with structurally normal joints – all of whom had a pain diagnosis – was a moderate 51 on a 0-100 scale. Cases with DDwoR or DJD – some of whom did not have a pain diagnosis – had slightly lower average pain intensity. Cases with DDwR had the lowest average CPI, 31. Patterns of scores for jaw function limitation and for disability were similar to jaw pain. Overall, PRO scores were not higher for theoretically more advanced stages of *TMJ intraarticular status*.

Cases with TMD pain diagnosis

TMD cases with a pain diagnosis presented slightly higher average pain, functional limitation, and disability than cases with any diagnosis, because all these cases had at least one TMD pain diagnosis (Fig 1).; however, the changes from excluding those without pain diagnoses were small. As with all TMD cases, PRO scores were not higher for theoretically more advanced stages of *TMJ intraarticular status*. The largest observed difference between diagnoses was for jaw disability, comparing normal and DDwR on the one hand versus DDwoR and DJD on the other, but even this difference was only a couple points.

Correlation among jaw pain, function, and disability

Cases with any TMD diagnosis

The three PROs, jaw pain, jaw function limitation, and disability, had pair-wise correlations between 0.52 and 0.62.

Cases with TMD pain diagnosis

Pair-wise correlations were slightly lower in this group, between 0.44 and 0.52. Confidence intervals (95%) around these coefficients were tight (±0.05-0.07). These substantial correlations suggested that these outcomes could be combined into a composite, latent outcome of *TMD impact*.

Association between *TMJ intraarticular status* and *TMD impact*

Cases with any TMD diagnosis

In the unadjusted multivariate regression, *TMJ intraarticular status* was significantly associated with JFLS, but not with CPI or disability (Table 1). The *combined* association of *TMJ intraarticular status* with all three PROs (JFLS, CPI, disability scores) was statistically significant (P<0.001). A one-step increase in *TMJ intraarticular status* was associated with a 4-point increase in JFLS (0-200 range). The standardized effect size for a difference between the extreme groups (Normal [level 1] minus DJD [level 4]) was only -0.09 (95% CI: -0.34 to 0.16), indicating that JFLS scores worsened only slightly with *TMJ intraarticular status*. According to guidelines (Cohen 1988), this is smaller than a "small" effect, so despite the statistically significant association between *TMJ intraarticular status* and JFLS score, the relationship has no clinical relevance. Adjusting these analyses for age and sex had negligible effect (Table 1).

In unadjusted analyses restricted to TMD cases with intraarticular diagnoses, the combined association of *TMJ intraarticular status* with all three PROs (JFLS, CPI, disability scores) was also statistically significant (P<0.001). A one-step increase of *TMJ intraarticular status* was associated with a 4-point increase in CPI (95% CI: 1 to 6 points), a 7-point increase in JFLS (95% CI: 5 to 9 points), and a 1-point increase in disability scores (95% CI: -1 to 3 points). Again, adjusting these analyses for age and sex had negligible effect.

In our secondary analyses, testing unordered levels of *TMJ intraarticular status* (in contrast to the ordered *TMJ intraarticular status* above) while adjusting for age and sex, a mixed picture appeared (Table 2). Compared to Normal, DDwR had less pain, less functional impairment, and less disability. Also compared to

Normal, both DDwR and DJD had less pain and less disability but more functional impairment. While the effect of DDwR was statistically significant for pain, functional impairment, and disability, the effect of DJD was significant only for pain and disability, and the effect for DDwoR was significant only for disability. In exploratory analyses using JFLS subscales as outcome variables, *TMJ intraarticular status* was statistically significantly associated with the *Mastication* and the *Vertical Jaw Mobility* scale, but not with the *Emotional and Verbal Expression* scale.

In the SEM, combining the JFLS, CPI, and disability scores into a latent *TMD impact* variable, the correlation between *TMJ intraarticular status* and *TMD impact* was 0.05 (95% CI-0.04-0.13 Figure 2). In the latent variable's measurement model, all loadings were very high, precise (i.e., had narrow confidence intervals), and statistically significant, supporting the fit of the model. This minimal correlation was neither clinically relevant nor statistically significant, and the upper limit of its confidence interval excluded moderate and large associations. Again, age and sex adjustment changed results negligibly. As expected, in the SEM analyses, jaw pain, jaw function limitation, and disability had strong (0.85, 0.73, and 0.71 respectively) and precise (all 95% CI: ±0.05) loadings on the latent *TMD impact* measure.

Cases with TMD pain diagnosis

Results in this subset of cases were similar to results for cases with any TMD diagnosis, regardless of whether analyses were performed for ordered (Table 1) or unordered levels (Table 2) of *TMJ intraarticular status* or whether analyses were restricted to TMD cases with intraarticular diagnoses. Results of the multivariate regressions were almost identical without and with age/sex adjustment, with *TMJ intraarticular status* having a statistically significant but clinically trivial association with JFLS (*Mastication* and *Vertical Jaw Mobility* subscales in particular), but no association with CPI or disability (Table 1). Again, an overall association with all three variables was also present.

In the SEM, the correlation between *TMJ intraarticular status* and *TMD impact* was 0.07 (95% CI: -0.04 to 0.17), neither clinically relevant nor statistically significant, with the upper limit of the confidence interval excluding moderate and large associations and negligible effect of age and sex adjustment.

Discussion

The results of this cross-sectional study suggest that what is currently understood as a change of TMJ structure from normal joint structures to DD to DJD may not be perceived by patients as relevant in terms of jaw pain, function, and disability.

It is challenging to compare our findings to the literature because the association between structural *TMJ intraarticular status* (stages of ID) and PROs has not been studied using the latent variable *"TMD impact."* In addition, the literature presents only fragmented evidence. Some studies assessed only disc position and other studies focused on osseous changes, while our study assesses both and integrates them in one model. While we characterized *TMD impact* as a latent composite of jaw pain, jaw function, and disability, the impact of TMD can be conceptualized and, consequently, measured differently. However, some studies have reported the association of ID stages to pain and, to a lesser degree, to jaw function and disability.

Intra-articular Disorders and Pain

Several authors (Bertram et al 2001; Campos et al 2008; Emshoff et al 2001; Westesson and Lundh 1989) have reported significant associations between ID stages and jaw pain, but only one (Emshoff et al 2003) reported the magnitude of this association. Using MRI in subjects with and without TMJ pain, the study found that TMJ pain occurred significantly more often in patients with DDwoR with DJD (OR [odds ratio] = 11.7; 95% CI 0.96-42.7) and DDwoR without DJD (OR=10.2; 95% CI 1.91-54.1). Conversely, other studies (Ohlmann et al 2006; Palconet et al 2012) did not find an association between ID stages and TMJ pain, or reported a small correlation between maximum condylar change on cone-beam computed tomography (CBCT) and pain rating (Palconet et al 2012). Longitudinal studies provided evidence that outcomes for patients with different ID stages differed little at follow-up and were good in general. For example, in 40 patients with DDwoR for a period of 2.5 years without treatment; 75% of the cases had decreased pain (60% became asymptomatic) while only 25% showed no improvement or required treatment (Kurita et al 1998).

Intra-articular Disorders and Function

We found no studies of the association of JFLS with *TMJ intraarticular status*. However, using the Jaw Disability Scale from the Research Diagnostic Criteria for TMD, which includes some items consistent with the JFLS, (Karacayli et al 2011) found that chronic TMD pain patients with MRI-depicted DDwR, compared to healthy controls, had more difficulty with jaw function including talking, smiling, and cleaning their teeth or face. In their classic articles, Rasmussen and Wilkes reported that jaw pain and function were related to stages of ID (Rasmussen 1981; Wilkes 1989); however, jaw function was mainly assessed by range of motion. Rasmussen reported that TMJ pain increased and jaw function was compromised progressively through the stages of DD, but then improved with development of DJD. However, in Rasmussen's study 20% of subjects with DJD had persistent jaw muscle pain and 25% of subjects with DJD continued to have limited mouth opening (i.e., jaw functional limitation). Thus, many subjects with DJD had jaw pain and limited function. Wilkes' findings from a surgical case series have been broadly accepted by clinicians as supporting a biomedical model of DD progressing to a debilitating "end stage" DJD accompanied by increased jaw pain and functional limitation. While some authors showed that condylar hypomobility was significantly associated with DDwoR (Campos et al 2008), others reported only a small correlation between maximum condylar osseous change and range of motion (Palconet et al 2012). Another study provided strong evidence against clinical relevance of ID stages for dysfunction (Schiffman et al 1992) concluding that ID stages were not related to clinical signs of dysfunction.

Intra-articular Disorders and Disability

When the GCPS was used to assess disability in 37 chronic pain patients with MRI-depicted DDwR, patients had a disability score of zero points, but their oral health-related quality of life (OHRQoL) scores were worse compared to healthy controls (Karacayli et al 2011). Also, OHRQoL scores were worse in patients with DDwoR with limited mouth opening than in patients with DDwR (Reissmann et al 2007). Conversely, no differences were found between cases with DD and DJD using the Limitation of Daily Functions instrument (Kino et al 2005) or the Pain Disability Index (Bush and Harkins 1995).

Study Limitations

Shortcomings of our findings are related to study design and population as well as the studied concepts and variables.

To interpret our results causally, the stages of intraarticular status needed to precede the pain and functional impairments. This seems plausible, but pain and its inflammatory process can also lead to TMJ changes (de Bont and Stegenga 1993; Zarb and Carlsson 1999). Our cross-sectional study design limits a causal interpretation.

Our study population is heterogeneous, which is advantageous for generalizability of findings but may have hampered detection of more subtle associations.

Our model of TMJ structural stages with equal distances between the four stages is simple. While numerous articles (de Leeuw et al 1995a; de Leeuw et al 1995b; Kurita et al 2006; Rasmussen 1981; Westesson and Lundh 1989; Wilkes 1989) support this staging with DD as intermediate stages and DJD as the final stage, other more complex models may exist that explain *TMJ intraarticular status*.

Our model of *TMD impact* is also simple. Pain, function, and disability are essential domains of suffering for symptomatic TMD patients, but other components may also be important.

For a more detailed discussion of methodological considerations, see the Appendix.

Conclusion

This cross-sectional study found no association between *TMJ intraarticular status* and *TMD impact* represented by pain, jaw function, and disability. This suggests that TMJ intraarticular disorders have minimal impact on patients' reported pain, function, and disability. This also suggests that treatments focusing on TMJ intraarticular disorders, such as surgery, may have limited impact on patient-reported outcomes (Schiffman et al 2014). Validation of this finding in longitudinal studies is necessary and models of *TMJ intraarticular status* other than ours (normal structure → DDwR → DDwoR → DJD) should be explored.

***Table 1**. Association between ordered levels of TMJ intraarticular status (Normal→DDwR→DDwoR→DJD) and jaw pain (CPI), function (JFLS), and disability, analyzed using unadjusted and adjusted multivariate multiple regression, in TMD cases with any TMD diagnosis or cases with only a painful TMD diagnosis.*

Analysis	***Dependent variable***	***Independent Variable***	***Any TMD diagnosis****		***Painful TMD diagnosis****	
			Intercept	Coef (95% CI)	Intercept	Coef (95% CI)
Unadjusted	CPI (0-100)	Normal→DDwR →DDwoR→DJD	41	0 (-1 to 2)	50	1 (-1 to2)
	JFLS (0-200)	Normal→DDwR →DDwoR→DJD	21	4 (2 to 6)	26	4(2 to6)
	Disability (0-100)	Normal→DDwR →DDwoR→DJD	17	-1 (-2 to 1)	21	-1 (-3to1)
	CPI	Normal→DDwR →DDwoR→DJD	40	0 (-2 to 2)	48	1 (-1 to2)
		Age		-0.1 (-0.3to 0.1)		0.0 (-0.1 to 0.2)
		Sex		6 (0 to 12)		1 (-4 to7)
	JFLS	Normal→DDwR →DDwoR→DJD	17	3 (1 to 5)	22	4 (2 to 6)
multiple sion)		Age		0.0 (-0.2 to 0.2)		0.1 (-0.1 to 0.3)
		Sex		4 (-2 to 10)		1 (-6 to8)
	Disability	Normal→DDwR →DDwoR→DJD	11	-1 (-3 to 0)	13	-1 (-3 to 0)
		Age		0.1 (0.0 to 0.3)		0.2 (0.1 to 0.4)
		Sex		3 (-2 to 8)		1 (-5 to7)

* Two subjects were excluded from analyses because of missing JFLS data

***Table 2*. Association between unordered levels TMJ intraarticular status (DDwR, DDwoR, or DJD versus base category Normal) and jaw pain (CPI), function (JFLS), and disability, analyzed using adjusted multivariate multiple regression, in TMD cases with any TMD diagnosis or cases with only a painful TMD diagnosis.**

Analysis	***Dependent variable***	***Independent Variable***	***Any TMD diagnosis****		***Painful TMD diagnosis****	
			Intercept	Coeff. (95% CI)	Intercept	Coeff. (95% CI)
Adjusted (multiple regression)	CPI	DDwR#	52	-17 (-24 to -10)	48	-2 (-8 to 3)
		DDwoR#		-5 (-13 to 4)		5 (-2 to 12)
		DJD#		-8 (-15 to -2)		0 (-5 to 6)
		Age		-0.2 (-0.3 to 0.0)		0.0 (-0.1 to 0.2)
		Sex		7 (1 to 13)		2 (-4 to 8)
	JFLS	DDwR#	28	-12 (-19 to -6)	26	-5 (-12 to 3)
		DDwoR#		3 (-5 to 11)		10 (1 to 19)
		DJD#		2 (-5 to 9)		7 (0 to 14)
		Age		0.0 (-0.2 to 0.1)		0.1 (-0.1 to 0.3)
		Sex		5 (-1 to 11)		3 (-4 to 9)
	Disability	DDwR#	17	-10 (-15 to -4)	15	-4 (-10 to 3)
		DDwoR#		-7 (-14 to 0)		-3 (-11 to 4)
		DJD#		-8 (-14 to -3)		-5 (-11 to 1)
		Age		0.1 (0.0 to 0.2)		0.2 (0.0 to 0.4)
		Sex		3 (-2 to 8)		1 (-5 to 7)

* Two subjects were excluded from analyses because of missing JFLS data, # compared to Normal (joints)

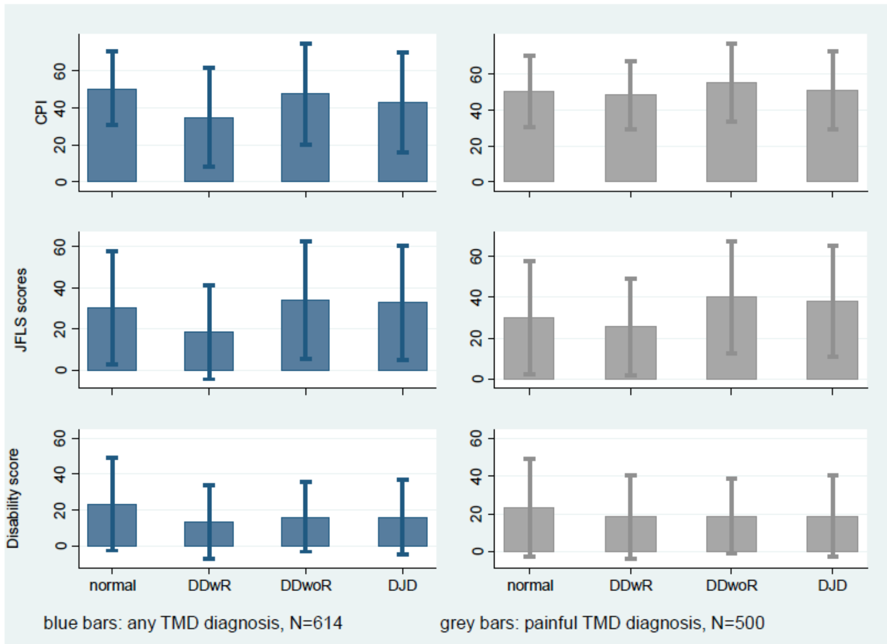

Figure 1. Averages ± standard deviations for Characteristic Pain Intensity, CPI (0-100), Jaw Function Limitation Scale, JFLS (0-200), and jaw disability scores (0-100) for all TMD cases (blue bars) and for TMD cases with a pain diagnosis only (gray bars).

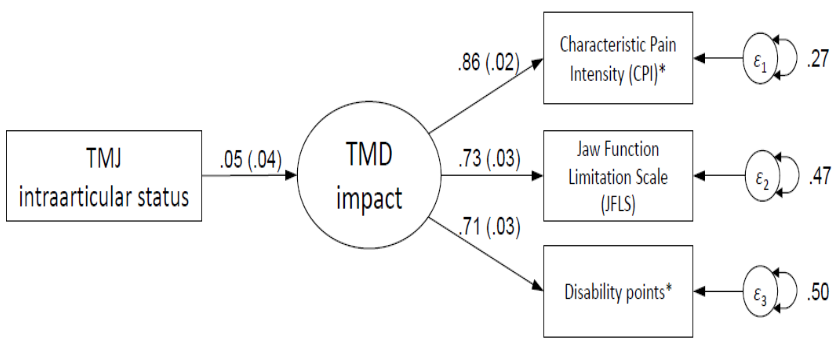

Figure 2. Structural equation model for the association between TMJ stages and TMD impact. The oval represents the latent factor TMD impact, the rectangles represent measured indicators for the latent factor with their error variances (circles) or the measured exposure variable TMJ stages. The lines connecting the latent factor to indicators are factor loadings, and the line connecting the exposure variable TMJ stages to the latent outcome TMD impact is the correlation between exposure and the latent factor. Numbers provided are standardized values. Analyses were performed with Stata 12 used a maximum likelihood estimation, assuming jaw pain, function, and disability items were continuous.

Bibliography

Ahmad M, Hollender L, Anderson Q, Kartha K, Ohrbach R, Truelove EL*, et al*. (2009) Research diagnostic criteria for temporomandibular disorders (RDC/TMD): development of image analysis criteria and examiner reliability for image analysis. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 107:844-860.

Anderson GC, John MT, Ohrbach R, Nixdorf DR, Schiffman EL, Truelove ES, List T, *et al.* (2011) Influence of headache frequency on clinical signs and symptoms of TMD in subjects with temple headache and TMD pain. *Pain* 152(4):765-71

Bertram S, Rudisch A, Innerhofer K, Pumpel E, Grubwieser G, Emshoff R. (2001) Diagnosing TMJ internal derangement and osteoarthritis with magnetic resonance imaging. *J Am Dent Assoc* 132:753-761.

Boering G. (1966) Temporomandibular joint arthrosis: an analysis of 400 cases.(dissertation). The Netherlands: University of Groningen.

Brown TA. (2012) Confirmatory factor analysis for applied research. Guilford Press.

Bush FM, Harkins SW. (1995) Pain-related limitation in activities of daily living in patients with chronic orofacial pain: psychometric properties of a disability index. *J Orofac Pain* 9:57-63.

Campos MI, Campos PS, Cangussu MC, Guimaraes RC, Line SR. (2008) Analysis of magnetic resonance imaging characteristics and pain in temporomandibular joints with and without degenerative changes of the condyle. *Int J Oral Maxillofac Surg* 37:529-534.

Cohen J. (1988) Statistical Power Analyses for the Behavioral Sciences. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum.

de Bont LG, Stegenga B. (1993) Pathology of temporomandibular joint internal derangement and osteoarthrosis. *Int J Oral Maxillofac Surg* 22:71-74.

de Leeuw R, Boering G, Stegenga B, de Bont LG. (1995a) Radiographic signs of temporomandibular joint osteoarthrosis and internal derangement 30 years after nonsurgical treatment. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 79:382-392.

de Leeuw R, Boering G, Stegenga B, de Bont LG. (1995b) TMJ articular disc position and configuration 30 years after initial diagnosis of internal derangement. *J Oral Maxillofac Surg* 53:234-41; discussion 241-2.

Emshoff R, Rudisch A, Innerhofer K, Bosch R, Bertram S. (2001) Temporomandibular joint internal derangement type III: relationship to magnetic resonance imaging findings of internal derangement and osteoarthrosis. An intraindividual approach. *Int J Oral Maxillofac Surg* 30:390-396.

Emshoff R, Brandlmaier I, Gerhard S, Strobl H, Bertram S, Rudisch A. (2003) Magnetic resonance imaging predictors of temporomandibular joint pain. *J Am Dent Assoc* 134:705-714.

Karacayli U, Mumcu G, Cimilli H, Sisman N, Sur H, Gunaydin Y. (2011) The effects of chronic pain on oral health related quality of life in patients with anterior disc displacement with reduction. *Community Dent Health* 28:211-215.

Kino K, Sugisaki M, Haketa T, Amemori Y, Ishikawa T, Shibuya T*, et al*. (2005) The comparison between pains, difficulties in function, and associating factors of patients in subtypes of temporomandibular disorders. *J Oral Rehabil* 32:315-325.

Kurita H, Uehara S, Yokochi M, Nakatsuka A, Kobayashi H, Kurashina K. (2006) A long-term follow-up study of radiographically evident degenerative changes in the temporomandibular joint with different conditions of disk displacement. *Int J Oral Maxillofac Surg* 35:49-54.

Kurita K, Westesson PL, Yuasa H, Toyama M, Machida J, Ogi N. (1998) Natural course of untreated symptomatic temporomandibular joint disc displacement without reduction. *J Dent Res* 77:361-365.

Laskin DM. (1994) Current controversies in surgery for internal derangements of the temporomandibular joint: etiology and pathogenesis of internal derangement of the temporomandibular joint. *Oral and maxillofacial surgery clinics of North America* 6:217-222.

Ohlmann B, Rammelsberg P, Henschel V, Kress B, Gabbert O, Schmitter M. (2006) Prediction of TMJ arthralgia according to clinical diagnosis and MRI findings. *Int J Prosthodont* 19:333-338.

Ohrbach R, Larsson P, List T. (2008) The jaw functional limitation scale: development, reliability, and validity of 8-item and 20-item versions. *J Orofac Pain* 22:219-230.

Okeson JP. (2005) Bell's Orofacial Pains. The Clinical Management of Orofacial Pain, 6th ed. Carol Stream, IL: Quintessence Publishing Co, Inc; p. 343.

Palconet G, Ludlow JB, Tyndall DA, Lim PF. (2012) Correlating cone beam CT results with temporomandibular joint pain of osteoarthritic origin. *Dentomaxillofac Radiol* 41:126-130.

Rasmussen OC. (1981) Description of population and progress of symptoms in a longitudinal study of temporomandibular arthropathy. *Scand J Dent Res* 89:196-203.

Reissmann DR, John MT, Schierz O, Wassell RW. (2007) Functional and psychosocial impact related to specific temporomandibular disorder diagnoses. *J Dent* 35:643-650.

Sale H, Bryndahl F, Isberg A. (2013) Temporomandibular joints in asymptomatic and symptomatic nonpatient volunteers: a prospective 15-year follow-up clinical and MR imaging study. *Radiology* 267:183-194.

Schiffman EL, Anderson GC, Fricton JR, Lindgren BR. (1992) The relationship between level of mandibular pain and dysfunction and stage of temporomandibular joint internal derangement. *J Dent Res* 71:1812-1815.

Schiffman EL, Velly AM, Look JO, Hodges JS, Swift JQ, Decker KL*, et al*. (2014) Effects of four treatment strategies for temporomandibular joint closed lock. *Int J Oral Maxillofac Surg* 43:217-226.

Schiffman EL, Ohrbach R, Truelove EL, Tai F, Anderson GC, Pan W*, et al*. (2010) The Research Diagnostic Criteria for Temporomandibular Disorders. V: methods used to establish and validate revised Axis I diagnostic algorithms. *J Orofac Pain* 24:63-78.

VonKorff M, Ormel J, Keefe FJ, Dworkin SF. (1992) Grading the severity of chronic pain. *Pain* 50:133-149.

Westesson PL, Lundh H. (1989) Arthrographic and clinical characteristics patients with disk displacement who progressed to closed lock during a 6-month period. *Oral Surg Oral Med Oral Pathol* 67:654-657.

Wilkes CH. (1989) Internal derangement of the temporomandibular joint: pathologic variations. *Arch Otolaryngol Head Neck Surg* 115:469-477.

Zarb GA, Carlsson GE. (1999) Temporomandibular disorders: osteoarthritis. *J Orofac Pain* 13:295-306.

Data analysis (Appendix)

Tested hypotheses

1. Multivariate multiple regression investigated simultaneously the association between ordered *TMJ intraarticular status* and each PRO. Specifically, we tested the null hypothesis that there is no linear trend associating a 4-level *TMJ intraarticular status* with each PRO.

2. Multivariate multiple regression investigated simultaneously the association between unordered *TMJ intraarticular status* and each PRO. Specifically, we tested the null hypotheses of no association between any of the *TMJ intraarticular status* levels and the three PROs.

3. Multiple regression investigated the association between ordered *TMJ intraarticular status* and JFLS' subscales in three separate analyses. Specifically, we tested the null hypotheses that there is no linear trend associating a 4-level *TMJ intraarticular status* with any of JFLS' three subscales.

4. SEM analysis investigated the association between ordered *TMJ intraarticular status* and TMD impact. Specifically, we tested the null hypothesis that there is no linear trend associating a 4-level *TMJ intraarticular status* with the latent variable TMD impact.

Investigated samples

We investigated two groups of TMD cases:

1. TMD cases with any diagnosis and

2. TMD cases with a painful diagnosis (this latter group is a subset of the former)

The two groups of TMD cases represent relevant patient populations found in TMD treatment centers:

1. Cases with any TMD diagnosis represent a TMD population with a range of painful and non-painful signs and symptoms. Most TMD patient populations in treatment centers consist of cases with and without pain.
2. Cases with only pain-related TMD diagnoses represent a TMD population with the most important symptom, masticatory muscle and TMJ pain. Most TMD patient populations in treatment centers consist mainly of cases suffering from pain.

Study limitations (Appendix)

TMJ structural status and *TMD impact* are two complex concepts and simplifying them leads to limitations. The TMJ structural status model we investigated represents core aspects of beliefs held by many TMD practitioners or represents components of TMJ structural etiopathogenesis provided in textbooks (Okeson, 2005), that is, that DD commonly precedes degenerative osseous changes or that DDwR usually occurs before DDwoR. While this may represent a common situation, it is known that transition from structurally normal joints to DDwoR or even DJD can happen. Data supporting our model of *TMJ intraarticular status* is as limited as data supporting any other model; our analysis tests the most commonly cited model and represents diagnoses a clinician typically receives from a radiologist interpreting their patients' MRIs or CTs.

While we detected some differences in patient-reported outcomes between cases with normal joints and cases with disc displacements or degenerative changes in our secondary analyses, these differences were difficult to interpret. The magnitude of the effects was not clear and the pattern of findings was not consistent, i.e., effects were not always in the expected direction, and statistically significant findings in cases with any TMD diagnosis were not significant any more than in the smaller group of cases with a painful TMD diagnosis. While more heterogeneous samples such as the participants of the RDC/TMD Validation Project have a substantial potential to generalize findings to other populations of interest, more homogenous groups of subjects such as our cases with an intraarticular disorder may have advantages for detecting associations. In these cases with intraarticular diagnoses, TMJ structure was associated with Characteristic Pain Intensity (CPI). Likely this association was present because some patients with DDwR had a disorder without substantial pain, lowering their CPI scores compared to DDwoR and DJD. In another subset of our subjects, in painful TMD cases, the association between TMJ structure and CPI was less pronounced and not statistically significant. All these secondary analyses provide interesting insight into the patient-perceived impact from structural TMJ status; however, because we tested multiple variables in several subsets of TMD cases, these findings require validation in future studies.

In summary, the present study's results cannot characterize change of soft and hard TMJ tissues longitudinally and cannot exclude the possibility that certain components of TMJ structure may have an influence on certain aspects of what is important for patients