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Effect of Shortened Dental Arch on Temporomandibular Joint Intra-articular Disorders

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Abstract

Aims: To investigate whether a shortened dental arch (SDA), as identified by reduced posterior occlusal contacts, is a risk factor for the progression of temporomandibular joint (TMJ) intra-articular disorders (ID), as identified using imaging techniques.

Methods: This multi-site prospective observational study with a mean follow-up period of 7.9 years had a sample of 345 participants with at least one temporomandibular disorder diagnosis at baseline. SDA was defined as reduced occlusal posterior support due to lack of occlusal intercuspal contacts in the molar region on the left and/or right side. SDA was assessed at baseline and follow-up using metalized Mylar® Tape. The presence or absence of TMJ ID, and the specific TMJ ID diagnoses, for baseline and follow-up images were established by a calibrated, blinded radiologist at each of three sites using bilateral magnetic resonance imaging (MRI) for soft tissue imaging for disc displacement (DD) and bilateral multidetector computed tomography (CT) or cone beam computed tomography (CBCT) for hard tissue imaging for degenerative joint diseases (DJD).

Results: At baseline, TMJ ID status of both sides was not significantly affected by the presence of a SDA on the ipsilateral or contralateral side of the jaw (all $P > .05$). Furthermore, the presence or absence of a SDA at baseline was also not a significant predictor for a progression of the TMJ intra-articular status between baseline and follow-up (all $P > .05$).

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Conflict of interest statement

The authors report no conflict of interest.

Conclusion: Findings of this study suggest that there is no significant effect of SDA on progression of TMJ ID.

Keywords

Shortened dental arch; temporomandibular joint; intra-articular disorders; observational study; risk factor

Temporomandibular disorders (TMD) are characterized by pain in the temporomandibular joints (TMJ) or the masticatory muscles, joint noises, or dysfunction and functional limitations such as impaired jaw movements.^{1, 2} Traditionally, the different TMJ intra-articular disorders (ID) have been thought to comprise a longitudinal progression from normal joint structure to disc displacement with reduction (DDwR), to disc displacement without reduction (DDw/oR), and then to degenerative joint diseases (DJD).^{3–5} DJD can be further sub-classified as Grade 1 DJD or Grade 2 DJD based on the level of severity.^{6, 7} Several factors may facilitate this progression including overt macro-trauma or micro-trauma from oral habits. Trauma from occlusal factors is also considered as an important risk factor.^{8–10} The investigation of ID is of special interest since occlusal-based treatment approaches for ID, including occlusal adjustments, are commonly being employed.^{11, 12}

Historically, tooth loss in the posterior dental arch has been regarded as a risk factor for structural changes in the TMJ.¹³ The loss of posterior support and a resulting reduction of the vertical dimension of occlusion have been thought to overload the TMJs and lead to ID. Whether missing posterior teeth, a condition described as a shortened dental arch (SDA),¹⁴ is related to TMD and specifically to ID has been investigated in a large number of studies with inconsistent results. Several studies have reported an association between SDA and ID with a higher prevalence of DD and DJD in subjects with SDA.^{9, 15, 16} In addition, replacement of missing posterior teeth has been reported to decrease the amplitude of clicking, a clinical sign of DDwR.¹⁷ Also, experimental reduction of posterior occlusal contacts results in cranial movement of the condyle,¹⁸ which could lead to adverse changes in TMJ loading and subsequent structural changes leading to DD or DJD. Conversely, other studies have reported no association between ID and SDA^{19–22} including that the presence of TMJ sounds did not differ substantially relative to posterior occlusal support.²³ In another study specifically investigating joint loading with SDA, no evidence for increased TMJ loading was observed.²⁴

These studies have several methodological limitations that may account for the contradictory findings. Most of the studies relied on self-report and/or clinical examination to assess for ID despite the fact that definitive diagnoses for DD and DJD require TMJ magnetic resonance imaging (MRI) and TMJ computed tomography (CT), respectively.²⁵ Furthermore, the majority of the studies were cross-sectional which precludes inferences regarding cause and effect. There are also shortcomings in the determination of SDA as most investigations have reported only missing teeth; however, if teeth are present but do not contact the teeth in the opposing dental arch, they do not contribute to occlusal support. Therefore, SDA is most accurately assessed by measurement of contacting posterior teeth. The aim of this study was to investigate whether SDA, as identified by reduced posterior

occlusal contacts, is a risk factor for the progression of TMJ ID, as identified using imaging techniques.

Materials and Methods

Subjects, study design and setting

This multi-site prospective observational study conformed with STROBE guidelines for human observational investigations.²⁶ Baseline and follow-up data came from the Validation and TMJ Impact Projects, respectively, both conducted at the University of Minnesota, the University of Washington, and the University at Buffalo.^{7, 27} At baseline, subjects aged 18 to 70 years old were recruited from two sources: direct referrals from local health care providers to the respective university-based TMD centers (*i.e.*, clinic cases) and responses to community advertisements (*i.e.*, community controls and cases). A total of 724 participants were recruited as a convenience sample between August 2003 and September 2006. Participants diagnosed with comorbid systemic pain conditions (chondromatosis, fibromyalgia, or rheumatoid arthritis; $n=19$) were excluded, resulting in 705 participants. Funding for subject recall for the TMJ Impact Project was approved for 400 subjects and a total of 401 subjects were seen for follow-up assessment with a mean follow-up of 7.9 years (SD: 0.8; range 5.8–10 years).⁷ The 401 participants were a convenience sample of the 594 participants in the Validation Project who gave permission to be contacted for a future study. Compensation for participation was \$200 at baseline and at follow-up. For the current study, baseline community and clinical cases with any TMD pain-related or TMJ ID diagnosis were selected to allow for a full spectrum of cases. The final sample size for the present study was 345 participants. For more details about study design, participant recruitment, and examination see Schiffman *et al.*^{7, 27}

This research was conducted in accordance with accepted ethical standards for research practice, undergoing review and approval by the Institutional Review Board at each of the three study sites.²⁷ Written informed consent was obtained from all participants prior to their enrollment.

Overview of Measurements

Baseline measurements: Participant demographic characteristics of the study population were assessed by questionnaire including, age, gender, education, and income. Measures for oral behavioral and psychosocial status were described in detail in the overview of the Validation Project.²⁷ These included measures for depression (Depression and Vegetative Symptoms), somatization (Nonspecific Physical Symptoms), and anxiety from the revised version of the Symptom Checklist 90 (SCL-90-R),²⁸ and characteristic pain intensity from the 7-item Graded Chronic Pain Scale (GCPS).²⁹ Additional psychosocial and behavioral assessments were perceived stress from the 10-item Perceived Stress Scale (PSS-10)³⁰ and oral behaviors from the 21-item Oral Behaviors Checklist (OBC).³¹ The results of the full range of assessments provide a complete description of the study population; however, only age and gender are included in the presented analyses. In addition, occlusal assessment was done clinically, and bilateral TMJ MRI and CT scans were acquired.

Follow-up measurements: All participants had occlusal assessment and bilateral TMJ MRI and CT scans.

Assessment of SDA

SDA was defined as no occlusal intercuspal contacts in the molar region on the left and/or right side adopted from the definition by Käyser.¹⁴ Specifically, all molars were either (1) missing and not replaced, or (2) when present or replaced, the molars did not have any occlusal intercuspal contact with the teeth of the opposing arch. Occlusal intercuspal contacts were assessed at baseline and follow-up by one of two calibrated examiners at each site using metalized Mylar® Tape (shimstock) with 8µm thickness for each individual occluding pair around the dental arch. Participants were instructed after the Mylar® strip was inserted between the pair of teeth: “Close firmly on your back teeth in your best bite and hold until I say open.” After teeth closure, the examiner pulled on the Mylar® strip to determine if it is held or slipped free. This method has good reliability for identifying posterior occlusal contacts.³² Examiners from all 3 study sites were brought together for training and calibration for this assessment.²⁷

Image Acquisition Protocols

All participants had bilateral TMJ MRI scans at baseline and follow-up for soft-tissue imaging, and multidetector CT (MDCT) was used for hard-tissue imaging at baseline and Cone Beam Computed Tomography (CBCT) at follow-up.^{7, 33} MRI scans were acquired during closed and open mouth by using a TMJ surface coil. At least six slices of each joint were obtained in sagittal and axially corrected coronal (closed-mouth views only) views. The baseline MRI used 1.5T magnetic fields and the follow-up study 3T. For MDCT and CBCT, at least 12 sections of each condyle (0.20 mm thickness slices) were generated in sagittal and axially corrected coronal views in the closed mouth position. CBCT has been shown to provide diagnostic information equivalent to MDCT with a substantially lower radiation dose for the patient and is currently considered the preferred imaging modality for the TMJ in dentistry.^{34, 35} Further details on the image acquisition protocols, as well as baseline and follow-up radiologists' reliability have been previously reported.^{7, 33}

Diagnosis of TMD

Baseline pain-related TMD diagnoses when present were based on the consensus of two criterion examiners at each of the three sites applying a comprehensive protocol including a semi-structured interview, review of questionnaires and clinical examination.²⁷ The clinical examination protocol was composed of all the measures as operationalized in the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) and several previously described examination procedures.³⁶ All six calibrated examiners who rendered these consensus-based diagnoses were experts in TMD and orofacial pain.

The presence or absence of TMJ ID, and the specific TMJ-based diagnoses, were established for baseline and follow-up images by three calibrated, blinded radiologists from each site who used a consensus-based diagnostic protocol. Diagnoses of DD and DJD were derived from TMJ MRI and CT, respectively, without considering the presence or absence of clinical symptoms. Inter-rater reliability of this assessment protocol was found to be good to

excellent with a kappa of .73 for DD and .76 for DJD. More specifics of the radiologists' reliability assessment and the assessment protocol have been reported.⁷ The diagnostic criteria for the stages of DD and DJD applied in this study are in Table 1. For this study, normal and indeterminate, i.e., when only one of two criteria for posterior band and intermediate zone that are required for the stage normal have been confirmed, were combined. Progression was defined as an increase in at least 1 stage in this model from baseline to follow-up: Normal → DDwR → DDw/oR → DJD Grade 1 → DJD Grade 2; and reversal was a decrease in at least 1 stage in this model.

Data analyses

The approach to investigate whether SDA is a risk factor for progression of TMJ ID involved several steps. First, socio-demographic, socio-economic, behavioral, psychosocial, and pain characteristics of the study sample at baseline were assessed using mean and standard deviation (SD) values for continuous measures, and frequencies and proportions for ordinal and categorical measures. Distribution of the different diagnoses regarding TMJ ID status was determined for each joint by side. Joint-specific findings were compared statistically using Wilcoxon signed-rank test to assess whether baseline intra-articular status was more severe in one of the sides. A tetrachoric correlation coefficient was calculated to assess association of prevalence of SDAs between both joints. Guidelines suggest that coefficients of $r=.1$ are considered small, $r=.3$ medium, and $r=.5$ large.³⁷

Second, the proportion of participants with SDAs for each joint-specific intra-articular state at baseline and follow-up was calculated to test whether SDA at baseline was associated with a more severe TMJ ID. Statistical significance was tested using Wilcoxon rank-sum test for each joint and assessment. Furthermore, the proportion of participants with progression, no change, and reversal in the TMJ ID status between baseline and follow-up was determined for each joint separately, and stratified for right and left sided occlusal status.

Third, whether SDA on either side was related to a more advanced TMJ ID state was tested using linear regression analyses. These analyses allowed assessment of the strength of the relationship between the anticipated risk factor, SDA, and the progression of TMJ ID. For these models, intra-articular status as the criterion variable was considered quasi linear, i.e., the increase in severity between each intra-articular status (Normal → DDwR → DDw/oR → DJD Grade 1 → DJD Grade 2) was assumed to be approximately equal in accordance with a previous study.³⁸ In the first model, association between SDA and intra-articular status at baseline was tested. In the second model, the effect of SDA at baseline on intra-articular status at follow-up was assessed, while statistically controlling for the intra-articular status at baseline. That is, testing was done for an effect of SDA on progression of TMJ ID. For this model, participants with the most severe intra-articular status (end stage DJD Grade 2) at baseline were excluded for the joint-specific analyses to allow for a progression of the disorder. The third model was identical to the second model, but only participants without a change in the SDA between both assessments were included; this provided a group with SDA at the beginning and the end of this longitudinal study. Models are presented with and without adjustment for age and gender.

All data on the ID state of both joints and SDA of both sides of the jaws were complete in 337 (97.7%) subjects. Only four subjects had missing information on the intra-articular status of the right joint and five for the left one. Data for occlusal posterior support were incomplete in one participant for the right side and two participants for the left side. Subjects with incomplete information were excluded from the analyses for the particular variables.

All analyses were performed using the statistical software package STATA (Stata Statistical Software: Release 13.1; StataCorp LP, College Station, TX, USA), with the probability of a type I error set at the .05 level without adjustment for multiple comparisons.

Results

Baseline characteristics of participants

Participants were predominantly female (85.8%), and mean ($\pm$ SD) age at baseline was 37.9 ± 12.9 years. Information on demographic characteristics, oral behavioral and psychosocial status, and pain intensity level is presented in Table 2. Based on TMJ imaging, about a fifth of the participants' right and left joints were classified as normal (Table 2). Prevalence of intra-articular joint disorders at baseline for the right TMJ was lowest for DDw/oR (7.3%) and highest for DDwR (30.8%) and for the left TMJ prevalence was lowest for DDw/oR (5.9%) and highest for DJD Grade 2 (31.5%), respectively, with no significant difference between both sides ($P=.954$). SDA was observed slightly more often in the participants' left-sided occlusion (11.7%) than in the right side (8.7%; Table 2). Findings for SDA were highly correlated between both sides of the jaws ($r=.66$, $P<.001$), with 4.4% of the participants presenting with bilateral SDA.

TMJ intra-articular status and shortened dental arches

In the side-specific analysis, the proportion of participants with SDA at baseline ranged for the right-sided SDA occlusion from 6.7% in participants with DJD Grade 2 in the right TMJ to 12.0% for DDw/oR, and for the left side SDA occlusion from 0.0% for DDw/oR to 13.1% for DDwR (Table 3). Even though the proportion slightly varied with respect to TMJ intra-articular status, no pattern of higher SDA values in more severe states was observed (both $P>.05$).

Findings at follow-up on the right side for SDA only marginally differed from those at baseline (Table 3). In contrast, the proportion of participants with SDA substantially increased from baseline to follow-up especially in participants with DDw/oR or with DJD Grade 1 in the left TMJ. Again, there was no association between severity of TMJ intra-articular status and proportion of participants with SDA for both sides (both $P>.05$).

When findings at baseline and at follow-up were compared, not considering the occlusal status, a progression in the right TMJ was observed in 25.9% of participants and in the left joint in 20.6%. Overall, a reversal was observed in the right TMJ in 19.4% of the participants and in 17.1% in the left TMJ. However, change in TMJ intra-articular status between baseline and follow-up was not associated with baseline occlusal status of the right or left side (all $P>.05$; Table 4).

Risk for progression in TMJ intra-articular status

At baseline, TMJ intra-articular status of both sides was not significantly associated with the presence of a SDA on the ipsilateral or contralateral side of the jaw (all $P > .05$; Model 1; Table 5). However, a SDA on the right side was associated with a reduced severity of ID status by -0.25 of a stage for the right TMJ and -0.29 of a stage for the left TMJ. This indicates that when a SDA is present that the ID is less severe, on average by one stage in one out of four participants, although these findings were not statistically significant (both $P > .05$). These results did not change substantially after adjusting for age and gender.

The presence or absence of a SDA at baseline was not a significant predictor for a progression of the TMJ ID status between baseline and follow-up (all $P > .05$; Model 2; Table 5). A SDA of the right side at baseline reduced the severity of the ID status of the right TMJ during the study period by on average of 0.41 stage, although this observation was not statistically significant ($P = .183$). The presence of a SDA on the right side of the jaw had no effect on the left TMJ ($P = .807$). In contrast, missing posterior support in the left side increased the severity of the ID status in both joints in the unadjusted and the adjusted analysis by on average a quarter stage, but the effect was not significant (all $P > .05$).

The third model included only participants with SDA at baseline and follow-up, and findings were slightly different (Model 3; Table 5). A SDA on the right side was related to a progression of the ID status in both joints (right: 0.30 stages, left: 0.70 stages) while a SDA of the left side improved the ID status in both joints (right: 0.17 stages, left: 0.55 stages). However, none of these effects was statistically significant (all $P > .05$). The adjusted analysis did not reveal substantially different findings.

Discussion

This is the first prospective study (with an average follow-up of 7.9 years) to investigate the risk of SDA on progression of TMJ ID that was reliably and validly assessed using MRI for soft tissue imaging of DD and CT/CBCT for hard tissue imaging of DJD. The findings from this study suggest that SDA is not a significant risk factor for the progression of TMJ ID.

If SDA had an effect on TMJ ID progression, it would be expected that a SDA on the right side should be related to the same changes in the ipsilateral and the contralateral TMJ as a SDA on the left side. In both regression models using the longitudinal data, regression coefficients for a SDA on the right side differed not only in the absolute value but also in the direction regarding the effect on TMJ ID status on the ipsilateral side and the contralateral side. This means that a SDA on one side would be protective for the ipsilateral TMJ while a SDA on the other side would be detrimental for TMJ ID in the ipsilateral TMJ. This is not biologically plausible and is likely the result of statistical variation. Furthermore, none of the regression coefficients exceeded the value 1 , representing a progression of the TMJ ID by one stage (e.g., from DDw/oR to DJD Grade 1), which was considered clinically relevant, and none of the regression coefficients were statistically significant. In summary, there is no evidence from this study that SDA has any adverse or protective effect on the progression of TMJ ID.

Comparisons with previous reports are constrained since this is the first prospective study to investigate the impact of SDA on progression of TMJ ID assessed by state of the art imaging. However, the baseline findings are consistent with some previous cross-sectional studies. Ciancaglini *et al.* did not find an association between the number of missing occlusal units and the presence of clicking and crepitus joint noises, the clinical signs of DDwR and DJD, respectively.²⁰ Other studies have reported no association between loss of molars in supporting zones and TMJ changes identified with panoramic radiographs¹⁹ or DD assessed by means of arthrograms.²¹ One prospective study with a 9-year follow-up assessed the impact of SDA on TMD but did not find an effect on the presence of clicking and crepitus joint noises.²²

Others have reported contrary findings. Dulcic *et al.* examined partially edentulous subjects with either occlusal contact in at least one but not all four supporting zones (Eichner class II) or no contact in any zone (Eichner class III).¹⁵ Subjects in the group with more contacting zones had more DD but less DJD than subjects in the group without contacts. This would correspond to a higher progression of TMJ ID in subjects with bilateral SDA. However, this study did not include a control group with contact in all supporting zones (Eichner class I) and determined the TMJ status with only clinical findings. Tallents *et al.* reported a slightly higher prevalence of missing posterior teeth in TMD patients with DD compared to asymptomatic controls with normal MRI findings.¹⁶ However, when only controls or TMD patients were assessed, no association between MRI findings of DD and missing posterior teeth was observed. Finally, Pullinger *et al.* reported that the number of missing molars was associated with DDwR and DJD.⁹ However, for a clinically relevant effect (odds ratio of at least 2), 5 or more posterior teeth had to be missing, which is a substantial number. Furthermore, the number of missing teeth cannot be easily translated into the presence of missing posterior support, and the cross-sectional design limits conclusions.

A SDA was operationalized as missing posterior support due to no occlusal intercuspal contacts in the molar region. These contacts were assessed with Shimstock of 8µm thickness using a valid and reliable method.³² Thicker foils might in some cases indicate an occlusal intercuspal contact resulting in a lower proportion of subjects with a SDA due to an increase in false positives, which is not desirable. The definition of SDA in this study differs from those applied in other studies. Alternatively, SDA can be defined just as the absence of posterior teeth,^{14, 39} sometimes assessed from casts⁹ or panoramic radiographs,¹⁹ limiting the comparability to the present study. However, it is assumed that the important biomechanical feature is the presence or absence of contact and not whether the teeth are missing or not. Missing contacts alone result in cranial movement of the condyle,¹⁸ which could lead to adverse changes in TMJ loading and subsequent structural changes leading to DD or DJD. Such a cranial movement of the condyle can occur during chewing, swallowing, or bruxism, whereas the latter can have a higher load with more adverse potential on the TMJs. Oral behaviors, including clenching and grinding of the teeth when asleep or during waking hours, were assessed in the Validation and TMJ Impact Projects using the OBC self-report questionnaire.³¹ However, germane to this discussion, the OBC only assesses the subject's awareness of the frequency of their bruxism – not the intensity and duration. Therefore, it is not possible to accurately estimate the load on the TMJ with this self-report instrument. For this reason, bruxism was not included as a predictor in the regression

models. Also, subjects with SDA might differ in the way they chew. Without molars, subjects have to chew in the premolar region, whereas subjects with molars but without occlusal intercusp contact could potentially chew in the molar region as well. The preferred location of chewing was not assessed in the study. However, since SDA had no effect on TMJ ID in this study, further variables such as bruxism or chewing location would probably not significantly affect the main finding of this study. Finally, no subgroup analysis for those subjects with all molars missing was performed due to insufficient sample size.

Strengths of this study included the large sample size allowing high precision for estimation of effects and the diagnoses of TMJ ID were based on interpretation of TMJ MRI and CT scans by 3 calibrated, blinded radiologists with good to excellent reliability. Furthermore, the prospective design of the study allowed for investigating the cause-effect relationship between SDA and TMJ ID. Finally, an additional analysis was performed to test whether the findings would change when more stringent criteria for the risk factor were applied, that is, presence of a SDA at the beginning and the end of the longitudinal study. This analysis also supported the conclusion of no effect of SDA on TMJ ID, although the 95% CI were wide due the small sample size, suggesting some caution in interpretation.

While the study sample was not representative for the general population, it does provide participants with the full spectrum of TMD by using a convenience sample from both clinical and community sources. Participants were selected based on methodological considerations of the Validation Project, which ensured a sufficient number of participants for each of the TMD diagnoses to improve generalizability of results²⁷ and it is not expected that findings would substantially differ if random samples had been used.

The clinical implication of this study is that the lack of posterior tooth support does not cause progression of TMJ ID. Given that TMD appliance therapy, especially mandibular anterior repositioning appliances, as well as sleep apnea appliances can cause SDA, that is lack of posterior molar contacts, the present findings suggest that treatment of this malocclusion may not be needed to prevent progression of TMJ ID. The same can be said of patients that present to their dentist with SDA occurring in their natural occlusion, or their acquired occlusion due to lack of – or prior – dental treatment. However, the results of this study do not suggest that replacing missing molars, or lack of posterior tooth contact, should not be treated for dental reasons.

Conclusions

Findings of this study suggest that there is no significant effect of SDA on progression of TMJ ID. Accordingly, there is no justification to replace missing molars or to restore missing posterior tooth contacts by providing dental treatments to prevent the progression of TMJ ID.

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References

1. Okeson JP. Orofacial pain: Guidelines for assessment, diagnosis, and management. Carol Stream: Quintessence; 1996.
2. Suvinen TI, Reade PC, Kemppainen P, Kononen M, Dworkin SF. Review of aetiological concepts of temporomandibular pain disorders: towards a biopsychosocial model for integration of physical disorder factors with psychological and psychosocial illness impact factors. *Eur J Pain* 2005;9:613–633. [PubMed: 15978854]
3. Rasmussen OC. Description of population and progress of symptoms in a longitudinal study of temporomandibular arthropathy. *Scand J Dent Res* 1981;89:196–203. [PubMed: 6943666]
4. Wilkes CH. Internal derangements of the temporomandibular joint. Pathological variations. *Arch Otolaryngol Head Neck Surg* 1989;115:469–477. [PubMed: 2923691]
5. de Leeuw R, Boering G, Stegenga B, de Bont LG. Radiographic signs of temporomandibular joint osteoarthritis and internal derangement 30 years after nonsurgical treatment. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1995;79:382–392. [PubMed: 7621016]
6. Ahmad M, Schiffman EL. Temporomandibular Joint Disorders and Orofacial Pain. *Dent Clin North Am* 2016;60:105–124. [PubMed: 26614951]
7. Schiffman EL, Ahmad M, Hollender L, Kartha K, Ohrbach R, Truelove EL, et al. Longitudinal Stability of Common TMJ Structural Disorders. *J Dent Res* 2017;96:270–276. [PubMed: 27856966]
8. Becker IM. Occlusion as a causative factor in TMD. Scientific basis to occlusal therapy. *N Y State Dent J* 1995;61:54–57.
9. Pullinger AG, Seligman DA, Gornbein JA. A multiple logistic regression analysis of the risk and relative odds of temporomandibular disorders as a function of common occlusal features. *J Dent Res* 1993;72:968–979. [PubMed: 8496480]
10. Cooper BC, International College of Cranio-Mandibular Orthopedics. Temporomandibular disorders: A position paper of the International College of Cranio-Mandibular Orthopedics (ICCMO). *Cranio* 2011;29:237–244. [PubMed: 22586834]
11. Velly AM, Schiffman EL, Rindal DB, Cunha-Cruz J, Gilbert GH, Lehmann M, et al. The feasibility of a clinical trial of pain related to temporomandibular muscle and joint disorders: the results of a survey from the Collaboration on Networked Dental and Oral Research dental practice-based research networks. *J Am Dent Assoc* 2013;144:e1–10. [PubMed: 23283934]
12. Kakudate N, Yokoyama Y, Sumida F, Matsumoto Y, Gordan VV, Gilbert GH, et al. Dentist Practice Patterns and Therapeutic Confidence in the Treatment of Temporomandibular Disorders in a Dental Practice-Based Research Network. *J Oral Facial Pain Headache* 2017;31:152–158. [PubMed: 28437512]
13. Costen JB. A syndrome of ear and sinus symptoms dependent upon disturbed function of the temporomandibular joint. *Ann Otol Rhinol Laryngol* 1934;43:1–15.
14. Käyser AF. Shortened dental arches and oral function. *J Oral Rehabil* 1981;8:457–462. [PubMed: 6975361]
15. Dulcic N, Panduric J, Kraljevic S, Badel T, Celic R. Incidence of temporomandibular disorders at tooth loss in the supporting zones. *Coll Antropol* 2003;27 Suppl 2:61–67.
16. Tallents RH, Macher DJ, Kyrkanides S, Katzberg RW, Moss ME. Prevalence of missing posterior teeth and intraarticular temporomandibular disorders. *J Prosthet Dent* 2002;87:45–50. [PubMed: 11807483]
17. Barghi N, dos Santos Junior J, Narendran S. Effects of posterior teeth replacement on temporomandibular joint sounds: a preliminary report. *J Prosthet Dent* 1992;68:132–136. [PubMed: 1403903]
18. Seedorf H, Seetzen F, Scholz A, Sadat-Khonsari MR, Kirsch I, Jude HD. Impact of posterior occlusal support on the condylar position. *J Oral Rehabil* 2004;31:759–763. [PubMed: 15265211]
19. Takayama Y, Miura E, Yuasa M, Kobayashi K, Hosoi T. Comparison of occlusal condition and prevalence of bone change in the condyle of patients with and without temporomandibular disorders. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008;105:104–112. [PubMed: 17449297]

20. Ciancaglini R, Gherlone EF, Radaelli G. Association between loss of occlusal support and symptoms of functional disturbances of the masticatory system. *J Oral Rehabil* 1999;26:248–253. [PubMed: 10194735]
21. Roberts CA, Tallents RH, Katzberg RW, Sanchez-Woodworth RE, Espeland MA, Handelman SL. Comparison of internal derangements of the TMJ with occlusal findings. *Oral Surg Oral Med Oral Pathol* 1987;63:645–650. [PubMed: 3473388]
22. Witter DJ, Kreulen CM, Mulder J, Creugers NH. Signs and symptoms related to temporomandibular disorders--Follow-up of subjects with shortened and complete dental arches. *J Dent* 2007;35:521–527. [PubMed: 17400355]
23. Ikebe K, Hazeyama T, Iwase K, Sajima H, Gonda T, Maeda Y, et al. Association of symptomless TMJ sounds with occlusal force and masticatory performance in older adults. *J Oral Rehabil* 2008;35:317–323. [PubMed: 18405267]
24. Hattori Y, Satoh C, Seki S, Watanabe Y, Ogino Y, Watanabe M. Occlusal and TMJ loads in subjects with experimentally shortened dental arches. *J Dent Res* 2003;82:532–536. [PubMed: 12821714]
25. Schiffman E, Ohrbach R, Truelove E, Look J, Anderson G, Goulet JP, 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;28:6–27. [PubMed: 24482784]
26. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies. *Int J Surg* 2014;12:1495–1499. [PubMed: 25046131]
27. Schiffman EL, Truelove EL, Ohrbach R, Anderson GC, John MT, List T, et al. The Research Diagnostic Criteria for Temporomandibular Disorders. I: overview and methodology for assessment of validity. *J Orofac Pain* 2010;24:7–24. [PubMed: 20213028]
28. Derogatis LR. SCL-90-R: Administration, scoring and procedures manual-II for the revised version. Towson, MD: Clinical Psychometric Research; 1999.
29. Von Korff M, Ormel J, Keefe FJ, Dworkin SF. Grading the severity of chronic pain. *Pain* 1992;50:133–149. [PubMed: 1408309]
30. Cole SR. Assessment of differential item functioning in the Perceived Stress Scale-10. *J Epidemiol Community Health* 1999;53:319–320. [PubMed: 10396541]
31. Markiewicz MR, Ohrbach R, McCall WD, Jr. Oral behaviors checklist: reliability of performance in targeted waking-state behaviors. *J Orofac Pain* 2006;20:306–316. [PubMed: 17190029]
32. Anderson GC, Schulte JK, Aeppli DM. Reliability of the evaluation of occlusal contacts in the intercuspal position. *J Prosthet Dent* 1993;70:320–323. [PubMed: 8229882]
33. Ahmad M, Hollender L, Anderson Q, Kartha K, Ohrbach R, Truelove EL, et al. Research diagnostic criteria for temporomandibular disorders (RDC/TMD): development of image analysis criteria and examiner reliability for image analysis. *Oral Surg Oral Med Oral Radiol Endod* 2009;107:844–860. [PubMed: 19464658]
34. De Vos W, Casselman J, Swennen GR. Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: a systematic review of the literature. *Int J Oral Maxillofac Surg* 2009;38:609–625. [PubMed: 19464146]
35. Hussain AM, Packota G, Major PW, Flores-Mir C. Role of different imaging modalities in assessment of temporomandibular joint erosions and osteophytes: a systematic review. *Dentomaxillofac Radiol* 2008;37:63–71. [PubMed: 18239033]
36. Dworkin SF, LeResche L. Research diagnostic criteria for temporomandibular disorders: review, criteria, examinations and specifications, critique. *J Craniomandib Disord* 1992;6:301–355. [PubMed: 1298767]
37. Cohen J Statistical power analysis for the behavioral sciences. 2. ed. Hillsdale, NJ: Lawrence Earlbaum Associates; 1988.
38. Chantaracherd P, John MT, Hodges JS, Schiffman EL. Temporomandibular joint disorders' impact on pain, function, and disability. *J Dent Res* 2015;94:79S–86S. [PubMed: 25572112]

39. Reissmann DR, Heydecke G, Schierz O, Marre B, Wolfart S, Strub JR, et al. The randomized shortened dental arch study: temporomandibular disorder pain. Clin Oral Investig 2014;18:2159–2169.

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Table 1 –

Diagnostic Criteria for DD and DJD Applied in this Study

Stages of DD	Criteria	
	Closed mouth position	Open mouth position
Normal Disc Position (including indeterminate)	Posterior band is between 11:30 and 12:30 clock positions, AND /OR Intermediate zone between condyle and the articular eminence.	Intermediate zone is located between the condyle and the articular eminence.
Disc Displacement with Reduction (DDwR)	Posterior band is located <u>anterior</u> to the 11:30 clock position, AND Intermediate zone is located <u>anterior</u> to the condyle.	Same as normal
Disc Displacement without Reduction (DDw/oR)	Posterior band is located <u>anterior</u> to the 11:30 clock position, AND Intermediate zone is located <u>anterior</u> to the condyle.	Persistent disc displacement
Stages of DJD		
Normal (including indeterminate)	No osseous changes OR Localized sclerosis and/or flattening	
Grade 1 Degenerative Joint Disease (Grade 1 DJD)	1. Osteophyte	<2mm measured from tip of condyle to expected contour of condyle
	2. Erosion	<2mm in depth & width
	3. Cyst	<2mm in depth & width
Grade 2 Degenerative Joint Disease (Grade 2 DJD)	1. Osteophyte	2mm
	2. Erosion	2mm or special case is when the whole condylar head is eroded
	3. Cyst	2mm
	4. Combination	2 signs of Grade 1 DJD

Adapted from Ahmad and Schiffman⁶ and from Schiffman *et al.*⁷

Table 2 –**Participant Characteristics at Baseline**

Participants		
n=345		
Mean (SD) or n (%)		
Age		
Years	37.9 (12.9)	
Gender		
Male	49 (14.2)	
Female	296 (85.8)	
Education *		
No college	52 (15.1)	
1 year of college	292 (84.9)	
Annual household income #		
Less than \$50,000	186 (54.6)	
\$50,000 – \$79,999	88 (25.8)	
\$80,000 or more	67 (19.7)	
Oral behaviors		
OBC sum score	24.2 (8.6)	
Perceived stress		
PSS-10 sum score	12.9 (6.3)	
Nonspecific physical symptoms (somatization) \$		
Low	202 (58.7)	
Moderate	96 (27.9)	
Severe	46 (13.4)	
Depression and vegetative symptoms ‡		
Low	233 (67.7)	
Moderate	80 (23.3)	
Severe	31 (9.0)	
Anxiety §		
Low	256 (74.4)	
Moderate	64 (18.6)	
Severe	24 (7.0)	
Graded chronic pain		
Characteristic pain intensity	39.6 (27.3)	
	Right side	Left side
TMJ intra-articular status ‡		
Normal	59 (17.3)	68 (20.0)
DDwR	105 (30.8)	99 (29.1)
DDw/oR	25 (7.3)	20 (5.9)

Participants		
n=345		
<i>Mean (SD) or n (%)</i>		
DJD Grade 1	62 (18.2)	46 (13.5)
DJD Grade 2	90 (26.4)	107 (31.5)
Occlusal status (SDA) ^π		
Missing molar support	30 (8.7)	40 (11.7)

OBC – Oral Behaviors Checklist; PSS – Perceived Stress Scale; STAI – State-Trait Anxiety Inventory

^{*} 1 missing value for education

[#] 4 missing values for income

^{\$} 1 missing value for nonspecific physical symptoms

[†] 1 missing value for depression and vegetative symptoms

[§] 1 missing value for anxiety

[‡] 4 missing values for TMJ intra-articular status of the right TMJ and 5 missing values for the left TMJ

^π 1 missing value for occlusal status of the right jaw and 2 missing values for the left jaw

Table 3 –

Proportion of Participants with SDA for Each TMJ Intra-Articular Status at Baseline and at Follow-Up

TMJ intra-articular status	Participants			
	Baseline		Follow-up	
	Right side	Left side	Right side	Left side
	n=340	n=338	n=342	n=342
	% (N with SDA / N with TMJ status)			
Normal	8.5 (5 / 59)	11.8 (8 / 68)	11.3 (7 / 62)	11.9 (8 / 67)
Disc Displacement with Reduction	10.6 (11 / 104)	13.1 (13 / 99)	9.4 (9 / 96)	6.6 (6 / 91)
Disc Displacement without Reduction	12.0 (3 / 25)	0.0 (0 / 20)	11.5 (3 / 26)	17.6 (3 / 17)
Degenerative Joint Disease Grade 1	8.1 (5 / 62)	10.9 (5 / 46)	8.8 (5 / 57)	16.7 (11 / 66)
Degenerative Joint Disease Grade 2	6.7 (6 / 90)	12.4 (13 / 105)	5.9 (6 / 101)	11.9 (12 / 101)
	<i>P-value</i> [*]			
	.495	.957	.233	.495

^{*} based on Wilcoxon rank sum test

Note: Denominators for each cell (N of subjects with TMJ intra-articular status) are identical to Table 1

Table 4 –

Proportion of Participants with Respect to Changes in TMJ Intra-Articular Status between Baseline and Follow-Up for Each Joint and Stratified for Right and Left Sided Occlusal Status

Change in TMJ intra-articular status	Right sided occlusal status		Left sided occlusal status	
	Without SDA n=309	With SDA n=30	Without SDA n=299	With SDA n=39
	% or p-value *			
Right TMJ				
Progression	25.9	26.7	26.4	23.1
Without change	56.0	43.3	53.5	61.5
Reversal	18.1	30.0	20.1	15.4
	.432		.899	
Left TMJ				
Progression	20.7	23.3		25.6
Without change	62.5	56.7	63.9	51.3
Reversal	16.8	20.0	15.7	23.1
	.846		.884	

* based on Wilcoxon rank sum test; p-value for statistical significance regarding presence of SDA

Table 5 –

Linear Regression Models for Association between Occlusal Status at Baseline and TMJ Intra-Articular Status Separately for Each Joint

		Right TMJ	
Dependent variable	Independent variable	Coefficient (CI)	P-value
#1 – TMJ intra-articular status at baseline		n=338	
Normal → DDwR → DDw/oR → DJD Grade 1 → DJD Grade 2	SDA right side	−0.25 (−0.86; 0.36)	.424
	SDA left side	0.12 (−0.43; 0.66)	.673
Normal → DDwR → DDw/oR → DJD Grade 1 → DJD Grade 2	SDA right side	−0.26 (−0.87; 0.35)	.397
	SDA left side	0.00 (−0.56; 0.55)	.992
	Age	0.01 (0.00; 0.03)	.061
	Gender	0.08 (−0.38; 0.55)	.723
#2 – TMJ intra-articular status at follow-up [#]		n=250	
Normal → DDwR → DDw/oR → DJD Grade 1 → DJD Grade 2	SDA right side	−0.41 (−1.02; 0.20)	.183
	SDA left side	0.20 (−0.38; 0.77)	.507
Normal → DDwR → DDw/oR → DJD Grade 1 → DJD Grade 2	SDA right side	−0.33 (−0.94; 0.27)	.280
	SDA left side	0.26 (−0.32; 0.84)	.380
	Age	0.00 (−0.02; 0.01)	.555
	Gender	0.52 (0.08; 0.96)	.021
#3 – TMJ intra-articular status at follow-up (same occlusal status at baseline and follow-up) [#]		n=199	
Normal → DDwR → DDw/oR → DJD Grade 1 → DJD Grade 2	SDA right side	0.30 (−1.04; 1.64)	.657
	SDA left side	−0.17 (−1.35; 1.00)	.773
Normal → DDwR → DDw/oR → DJD Grade 1 → DJD Grade 2	SDA right side	0.29 (−1.07; 1.65)	.674
	SDA left side	−0.07 (−1.25; 1.10)	.904
	Age	0.00 (−0.02; 0.01)	.931
	Gender	0.55 (−0.02; 1.12)	.059
		Left TMJ	
#1 – TMJ intra-articular status at baseline		n=337	
Normal → DDwR → DDw/oR → DJD Grade 1 → DJD Grade 2	SDA right side	−0.29 (−0.93; 0.35)	.376
	SDA left side	0.08 (−0.49; 0.65)	.781
Normal → DDwR → DDw/oR → DJD Grade 1 → DJD Grade 2	SDA right side	−0.26 (−0.89; 0.36)	.404
	SDA left side	−0.13 (−0.70; 0.43)	.640
	Age	0.03 (0.01; 0.04)	<.001
	Gender	0.84 (0.36; 1.32)	.001
#2 – TMJ intra-articular status at follow-up [#]		n=232	
Normal → DDwR → DDw/oR → DJD Grade 1 → DJD Grade 2	SDA right side	0.07 (−0.49; 0.63)	.807
	SDA left side	0.23 (−0.30; 0.76)	.397
Normal → DDwR → DDw/oR → DJD Grade 1 → DJD Grade 2	SDA right side	0.08 (−0.49; 0.65)	.788
	SDA left side	0.24 (−0.30; 0.79)	.382
	Age	0.00 (−0.01; 0.01)	.784
	Gender	−0.01 (−0.43; 0.40)	.943

Dependent variable	Independent variable	Right TMJ	
		Coefficient (CI)	P-value
#3 – TMJ intra-articular status at follow-up (same occlusal status at baseline and follow-up) [#]		n=182	
Normal → DDwR → DDw/oR → DJD Grade 1 → DJD Grade 2	SDA right side	0.70 (−0.28; 1.69)	.161
	SDA left side	−0.55 (−1.41; 0.31)	.205
Normal → DDwR → DDw/oR → DJD Grade 1 → DJD Grade 2	SDA right side	0.68 (−0.33; 1.69)	.188
	SDA left side	−0.56 (−1.43; 0.31)	.205
	Age	0.00 (−0.01; 0.02)	.779
	Gender	0.04 (−0.45; 0.53)	.865

only subjects without DJD Grade 2 at baseline; statistically controlled for baseline status