THREE-DIMENSIONAL ANALYSIS OF JAW KINEMATIC ALTERATIONS IN PATIENTS WITH CHRONIC TMD – DISC DISPLACEMENT WITH REDUCTION

JAW KINEMATIC ALTERATIONS IN CHRONIC TMD

Original research

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ABSTRACT

The study investigated whether chronic TMD patients with disc displacement with reduction (DDR), performing non-assisted maximum jaw movements, presented any changes in their mandibular kinematics with respect to an age-matched control group. Moreover, it was examined if jaw kinematics and a valid clinic measure of orofacial functional status have significant associations.

Maximum mouth opening, mandible protrusion and bilateral laterotrusions were performed by 20 patients (18 women, 2 men; age, 18-34 years) and 20 healthy controls (17 women, 3 men; age, 20-31 years). The three-dimensional coordinates of their mandibular inter-incisor and condylar reference points were recorded by means of an optoelectronic motion analyzer, and were used to quantitatively assess their range of motion, velocity, symmetry and synchrony. Three functional indices (opening-closing, mandibular rototranslation, laterotrusion - right and left - and protrusion) were devised to summarize subject's overall performance, and their correlation with the outcome of a clinical protocol, the orofacial myofunctional evaluation with scores (OMES), was investigated.

TMD patients were able to reach maximum excursions of ~~mouth opening and mandibular protrusion~~jaw movements comparable to healthy subjects' performances. However, their opening and closing mandibular movements were characterized by remarkable asynchrony of condylar translation. They had also reduced jaw closing velocity and asymmetric laterotrusions.

The functional indices proved to well summarize the global condition of jaw kinematics, highlighting the presence of alterations in TMD-DDR patients, and were linearly correlated with the orofacial functional status. The jaw kinematic alterations seem to reflect both orofacial motor behaviour adaptation and a DDR-related articular impairment.

Key words: Temporomandibular joint, Kinematics, Temporomandibular disorders, Disc displacement, Condylar movements, Biomechanics.

INTRODUCTION

Temporomandibular disorder (TMD) is a problem involving the temporomandibular joint (TMJ) and/or the masticatory muscles; approximately 5-12% of the adult population is affected (1). Disc displacement with reduction (DDR) is the most common derangement within the TMJ (2), generally accompanied by pain, difficulties during mandibular movements, asymmetric jaw muscles activities and impaired orofacial function (3,4). These signs and symptoms have received considerable attention (1-4), although a deeper assessment of mandibular motor pattern and its association with orofacial functions in patients with chronic TMD- DDR has yet to be reported.

Recent investigations found that acute masseter muscle pain has only minor effects on chewing patterns, probably because the function does not exacerbate pain (5), and few changes in jaw kinematics occur in non-chronic TMD (6). T~~Al~~though, functional impairment may be a consequence of the chronicity, and there are still many questions about the relevant changes in motor patterns (7).

~~Orofacial motor functions require integrated participation of brainstem central pattern generators, cortical and subcortical regions to control jaw, tongue, lips, cheeks and supra-hyoid muscles, in order to meet the specificity of each function, variations in their course and mutual coordination, for example among mastication, breathing and swallowing.~~ Sensory inputs derived from the orofacial tissues are essential for motor control mechanisms (8) and previous experiences, including pain, may influence the sensorial processing and the motor output programming (9).

Three-dimensional (3D) kinematic analysis has been suggested as a useful, accurate and non-invasive supporting method to deepen the comprehension of oral motor control and TMJ function (10,11). Unfortunately, mandibular and condylar kinematics in DDR patients have been only partially assessed: some investigators focused on qualitative analyses of condylar trajectories during mouth opening and closing (12,13), while others performed quantitative, but incomplete analyses (14). Among the others, asymmetry and asynchrony of condylar movements, that may unevenly increase the load on a single joint (15), have never been investigated.

In this study we ~~D~~detailed the TMJ dynamic behaviour of DDR patients ~~can be efficiently detected~~ by means of an optoelectronic tracking system~~s~~, ~~which allow the recordings to be done with minimal obstruction. In particular, they enable~~focusing on the assessment of the relative contribution of jaw rotation (condyle-disc compartment) and translation (mandibular fossa-disc compartment) (6,10,16-19), since a~~. A~~lterations in their reciprocal magnitude have been identified as important indicators of TMJ dysfunction (14).

~~In this study, normal reference values were obtained for mandibular border movements, and summary indices developed. They recapitulate the normal patterns of several kinematic parameters in a single data measure to investigate the deviations from the norm and facilitate further association analyses.~~

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In particular, we wanted to assess whether alterations in mandibular kinematics might correlate with a valid clinic measure of orofacial functional status such as the orofacial myofunctional evaluation with scores (OMES) protocol, which has shown that patients with chronic TMD have impaired orofacial functions (3,4). Quantitative information about jaw kinematics and its association with orofacial functional status in patients with chronic TMD may contribute in understanding the pathophysiology, and in diagnosis and management of these musculoskeletal disorders.

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Therefore, the aims of this study were to investigate whether impairment of mandibular motor patter occurs in patients with chronic TMD, diagnosed with DDR, during non-assisted maximum jaw movements and, in ~~positive~~ case, whether it is associated with orofacial functional status. The tested hypotheses ~~tested~~ were that patients with chronic TMD-DDR would have worse performance of~~at~~ jaw kinematics than controls,~~;~~ ~~would have worse orofacial status than controls;~~ and that jaw kinematic efficiency~~s and orofacial status~~ would be positively related to orofacial status.

METHODS

Subjects

Twenty patients (18 women, 2 men; age, 18-34 years), who came to our institution for treatment of orofacial pain and TMD, were selected for the study. To be recruited they had to present history of myalgia and/or arthralgia symptoms in at least the 6 months prior to the study, with diagnosis of unilateral or bilateral DDR, and they should not have started any treatment yet. Twenty volunteer subjects without TMJ or craniocervical disorders history, matched for age and sex, were recruited for the control group (C, 17 women, 3 men; age, 20-31 years). Diagnosis was performed in accordance with the "Diagnostic Criteria for the Most Common Pain-Related Temporomandibular Disorders" (DC/TMD) (1). Clinical data were obtained using the Research Diagnostic Criteria for TMD, axis I (http://www.rdc-tmdinternational.org/) (20). Whatever the group, subjects with tooth absence (except the third molars), dental pain or periodontal problems, dentofacial deformities, crossbite, open bite, neurological or cognitive deficits, previous or current tumors or traumas in the head and neck region, pregnancy, current or previous orthodontic treatments, current use of analgesic, anti-inflammatory and psychiatric drugs were excluded from the study.

The institutional ethics committee approved the project (process number 14332/2011) and informed consent was obtained from all participants prior to start of the study. All procedures were non-invasive.

Jaw movement recording

Starting from the intercuspal position (ICP), free mandibular movements of maximum mouth opening (MMO) and closing, right and left mandibular lateral excursions and protrusion with sliding teeth contacts (five repetitions for each) were recorded using an optoelectronic 3D motion analyzer, operating at 500Hz (SMART-DX*). The subjects performed the tasks sitting on a stool without headrest, in an upright but relaxed position. Details about the calibration procedures and the 3D reconstruction of the mandibular inter-incisor point (IP) and the two condylar reference points (CRP) are provided in the Supplementary Section.

Data Analysis: The range of mandibular movements was assessed at maximum mandible descent (MMO), protrusion (MMP) and laterotrusions (MML), calculating the projections of the displacement of its landmarks (cranial-caudal, ventral-dorsal, medial-lateral) as well as its sagittal, coronal and horizontal angles (16) (Figure S1, Supplementary Section). During mouth opening and closing the peak-to-peak lateral deviation of IP was computed; also, the mean velocity of both IP and CRPs in the two phases was calculated in the temporal span between 5% and 90% of MMO. The sagittal mandibular movement during mouth opening and closing was further divided into its rotation and translation components (16); in each frame of motion, the relative percentage contribution of the two components to the total movement was calculated for each condyle. In order to compare different subjects, the mandibular movement was normalized on MMO distance (sagittal projection): mouth opening and closing were sampled in 10% steps, and for each step the corresponding percentage of translation component (CRP translation index) was calculated for both condyles. Then, the global CRP translation index was separately extracted for mouth opening and closing. The CRP inconstancy index was calculated as the standard deviation (SD) of inter-step percentages of translation (right and left condyles' translation indices were averaged for each step) to measure the variability of the mean condylar movement pattern throughout mouth opening and closing. For each step of MMO, the CRP asynchrony index was defined as the absolute difference between the simultaneous translation indices of the two condyles. Furthermore, the overall CRP asynchrony index was separately extracted for mouth opening and closing. For mandible laterotrusion, which is a bilateral task, and inter-condyle relationship in symmetric movements (mouth opening/closing and mandibular protrusion), right and left side mean values were calculated and further considered for the inter-group comparison. Besides, the inter-side differences were quantified by indices of symmetry (SI), calculated as the ratio between the lower side value and the higher of the two. SI variables ranged between 0% and 100% (respectively, the worst and the best symmetry conditions).

Three comprehensive functional indices (FI) were finally introduced to quantitatively summarize each subject's overall performance: FI_{OC} for mouth opening/closing parameters, FI_{T} for mandibular rototranslation characterization, FI_{LP} for mandible laterotrusion (right and left) and protrusion. At first, the tolerance interval covering a proportion of 95% of the control population ($TI_{95\%}$) was computed for each kinematic parameter, based on control group scores. One-sided or two-sided 95%-tolerance intervals were chosen depending on the characteristics of the indices (Table S1, Supplementary Section). Then, each subject's FIs were calculated as the ratio of the number of parameters with scores within the relevant $TI_{95\%}$ over the total assessed parameters. The index ranges from 0% (no patient's value is inside the relevant $TI_{95\%}$) to 100% (all patient's values are inside the relevant $TI_{95\%}$).

The method error of mandibular movement detection with the same instrumentation was previously assessed and deemed good (21).

Orofacial Myofunctional Evaluation

The OMES protocol was used to determine orofacial functional status in accordance with previously described methodology (4). This comprises appearance/posture, mobility and stomatognathic functions evaluation using predetermined scores, which may be summarized ~~on~~ in a total score; the higher the OMES score, the better the orofacial functional status.

Statistical analysis

The parameters of each task's repetitions were averaged. For both control and TMD groups, descriptive statistics (mean, SD) were calculated for all the measures. For each movement (mouth opening/closing, mandible laterotrusions, mandible protrusion), a multivariate analysis of variance (MANOVA) was applied among the relevant kinematic parameters (dependent variables) across the two groups (fixed factor). In case of significant MANOVA, post-hoc p~~P~~arametric t-tests for independent samples were applied to examine~~assess~~ which variables ~~inter-group differences~~differ across the group; for those variables that were not normally distributed in one or both groups (significant Kolmogorov-Smirnov test), Mann-Whitney U-test was used. Two-way ANOVA with repeated measures was applied to CRP translation indices for each 10%-step of MMO during mouth opening and closing (within-subject factor) across the two groups (between-subject factor). The same statistic test was used for CRP asynchrony indices for each 10%-step of MMO. Pearson's correlation tests were finally used to analyze the association between the OMES score and each of the three FIs.

The level of significance was set at $P<0.05$, with Benjamini-Hocberg~~Bonferroni~~ correction applied for ~~the three correlations~~multiple testing. ~~(P<0.017).~~ All statistical calculations were made using the software IBM SPSS Statistics 22.0 (IBM Corp., Armonk, NY, USA).

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RESULTS

The details of the participants' clinical results together with their demographic information are shown in Table 1.

In TMD patients the range of mouth opening was on average 4.1 mm smaller than in controls, with the corresponding mandibular sagittal angle of rotation reduced by 3.5°; yet, these differences were not significant. As regard the opening/closing trajectory of the inter-incisor point (IP) in the frontal plane projection, its peak-to-peak lateral deviation was significantly larger in TMD than in control group, whereas at the instant of maximum mouth opening (MMO) the two groups had almost the same, negligible IP lateral displacement. The velocity of the mandibular movement, instead, was lower in TMD patients, significantly during mouth closing (Table 2).

The rototranslation analysis of mandibular movement throughout mouth opening and closing showed a similar pattern in the two groups, where condyles nearly stop gliding at the end of mandible descent and at the beginning of its following ascent, performing an almost pure rotation (Figure 1). The global opening/closing movement translation indices confirmed the absence of single step differences between the two groups; also the inconstancy indices were quite the same (Table 2). However, the comparison of right and left condyles translation in each subject showed an almost doubled mean asynchrony index in the TMD group, statistically significant in both opening and closing phases. Specifically, except for the first half of mouth opening, TMD patients exhibited larger condylar asynchrony in almost all the other movement steps (Figure 2).

Patients' maximum mandibular laterotrusions were on average 1.4 mm shorter than reference values, but this difference was not statistically significant; instead, TMD ~~and~~ patients' laterotrusions were ~~also~~ significantly more asymmetric (Table 3). ~~TMD patients'~~ The asymmetry emerged both from~~or~~ the IP lateral displacement and from~~or~~ the balancing condyle forward displacement when comparing right and left laterotrusions~~ (Table 3)~~. Overall, no kinematic difference was found f~~F~~or mandible protrusion~~, no between-groups difference was found about either reference points' range of motion or intra-subject asymmetries~~ between the two groups.

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Patients' kinematic functional indices (FI) were significantly smaller than those of controls in each analyzed section. The TMD group had also a significantly lower OMES score than control group (82±4 vs. 95±5; t-test, P<0.001Table 1). Overall, FI_{OC}-mouth opening/closing and FI_{T}-mandibular rototranslation were linearly correlated with OMES score (FI_{OC}, r=0.488, P=0.001; FI_{T}, r=0.513, P=0.001). Also FI_{LP}-mandible laterotrusion (right and left) and protrusion had a good correlation with OMES score, but it was not significant (r=0.369, P=0.021).

DISCUSSION

From the principal findings, it was observed that chronic TMD-DDR patients were able to reach normal ranges of MMO and MMP, with symmetric final position and orientation of the mandible; however, their opening and closing were characterized by remarkable asynchrony of condylar translation. TMD adaptation seems apparent in the reduced jaw closing velocity and in the asymmetric MML. The proposed functional indices (FI) proved to well summarize the global condition of jaw kinematics and showed a good correlation with the orofacial functional status, highlighting the presence of alterations in TMD patients' performances.

MMO was somewhat smaller in TMD patients as already observed in patients with reduced anterior disc displacement (14), however the difference was not significant. Miyawaki and colleagues (14) did not report pain duration of their 10-patient test group, which could be a key information since in the long run the pain usually subsides, letting the mouth opening restore to acceptable levels (22). Furthermore, at MMO, several kinematic parameters of the TMD group (condylar range of motion; angular values describing mandibular orientation) showed no evident asymmetry in mandibular displacement compared to controls. Cumulative values of rototranslation components during mouth opening and closing were not different between groups, as already reported for short-lasting TMD patients (6). Actually, in presence of DDR, sudden changes in the rototranslation ratio should be expected when the condyle overcomes the disc obstacle during opening and when it glides behind the disc during closing (10), rather than a global translation reduction (14). A pattern of mouth opening and closing more determined by condylar rotation than by translation, which is characteristic of subjects with healthy stomatognathic system (16), was observed also in the current control and TMD groups, with nearly overlapped step-by-step trends. Condyles nearly stop translating at the end of mouth opening, performing an almost pure rotation, due to the progressive passive block provoked on the condyle head by the ligament tension (11, 16). However, it should be noticed that this kind of assessment, when different subjects are pooled, might conceal remarkable individual features, both in controls (18) and particularly in pathologic groups, where there is evidence for considerable inter-individual variability in the behavioural response to pain (23), as well as in the movement stage (step) of mouth opening/closing within which the disc reduction/displacement occurs (24). The beginning of mouth opening and the last step of mouth closing were characterized by the largest inter-subject variability; at these stages, steeper temporal bone eminence could play a role in hampering condylar translations, as was observed specifically in clicking joints (17).

The increased condylar asynchrony in patients, which is likely to reflect an out-of-step rototranslation pattern of the two condyles, would be explained by the unilateral or asynchronous bilateral changes of condylar acceleration concomitant with disc reduction and displacement, during opening and closing respectively. This finding is in line with the high fluctuation of the mandibular helical axis observed in subjects with TMJ click (10). The lateral deviation of the inter-incisor point during mouth opening and closing, which was significantly larger in TMD than in control group, is the result of the condylar asynchrony.

In TMD patients the mandibular movement resulted significantly slower than in controls during mouth closing; this finding is in accord with the lower maximum condylar velocities previously found in DDR patients (14), and could be interpreted as an adaptation strategy that protect the musculoskeletal system from further injury and pain (23).

Interestingly, like MMO, patients performed as extended and symmetric MMP as controls; differently, during alternate side MML, when the condyles in turn rotate (working condyle) and translate (balancing condyle), they performed lateral movements ~~smaller mean ranges of motion than controls,~~ with ~~also~~ larger values of asymmetry between right and left excursions of both IP and balancing condyle.

The functional indices (FI_{OC}, $F~~I~~_{IT}$, FI_{LP}, respectively describing opening/closing jaw motion, the corresponding mandibular rototranslation, mandible laterotrusion and protrusion), were notably smaller in patients than in healthy subjects, confirming the presence of mandibular anomalous kinematic behaviour in TMD patients. Also, all the three functional indices showed a good correlation with the scores of the clinically assessed orofacial functional condition.

According to results, patients with chronic TMD-DDR showed changes in orofacial behaviours during kinematic tasks and OMES protocol analyses. Overall, their mandibular movements were less symmetric and less synchronous than healthy subjectsThey have asymmetry, asynchrony, and reduced ability in single movements, as well as abnormal swallowing and chewing functions, whose origin is not easy to determine. It is plausible that changes in motor behaviours may have occurred to avoid pain and to protect tissues (23) which may have been beneficial in the short-term (7). Alternatively, due to the susceptibility of the orofacial functions to disorders (4, 25), changes may have preceded the TMD (3), leading to abnormal tissue loading and injury (7). Whatever the way, in a chronic condition, adapted behaviours seem part of the problem, and they may contribute to ongoing pain.

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According to results, patients with chronic TMD-DDR showed changes in orofacial behaviours during kinematic tasks and OMES protocol analyses with asymmetry, asynchrony, reduced ability in single movements and abnormal swallowing and chewing functions, whose origin is not easy to trace. Changes in motor behaviours may have occurred to avoid pain and to protect tissues (23) and it may have been beneficial in the short-term (7). Alternatively, due to the susceptibility of the orofacial functions to disturbances caused by several factors at any age (4, 25), changes may have preceded the TMD (3), leading to abnormal tissue loading and injury (7). Whatever the way, in a chronic condition adapted behaviours seem part of the problem and they may contribute to ongoing pain.

Therefore, patients with chronic TMD-DDR would benefit from strategies to improve orofacial motor control, reversing behaviour maladaptations. Moreover, the results support the use of the OMES protocol as a supplementary examination in TMD diagnosis to detect impaired orofacial functions requiring treatment, especially when no 3D kinematic analyses can be performed.

The female prevalence in the selected groups reflects the well-known larger percentage of women experiencing TMD (1-4). Thus, tThe main limitation of the study iswas that only two patients with unilateral TMD participated of the study, and this preventinged the comparison betweenof the dysfunctional and healthy sides. Future research should also examine older TMD patients. Instead, the female prevalence in the selected groups reflects the well-known larger percentage of women experiencing TMD (1-4).

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~~The main limitation of the study is that not only unilateral DDR were collected, preventing to directly compare dysfunctional versus healthy TMJs. Future researches should also analyze older TMD patients.~~

Overall, the current study showed that patients with chronic DDR may macroscopically appear to have a nearly normal set of mandibular motor patterns, but, at a deeper assessment, they seem to have obtained this by assembling various motor (mal) adaptations. The long-term effect of these altered conditions may be detrimental, and early treatment of TMD seems advisable in all patients. QUI SI PUO' METTERE INSIEME le due frasi

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In conclusion, the jaw kinematic alterations highlighted in TMD-DDR patients seem to reflect both orofacial motor behaviour adaptation and a DDR-related articular impairment.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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