Reproducibility of jaw movements in patients with craniomandibular disorders

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SUMMARY It has never been investigated, if mandibular movements of patients with craniomandibular disorders (CMD) result in a lower reproducibility of dynamic functional parameters which are used for the individual articulator setting. The aim of the present study was to compare the reproducibility of electronically registered functional parameters in patients with CMD and in a control group. Dynamic functional parameters were recorded in 30 patients and 30 volunteers with a computerized ultrasound system (ARCUSdigma). The whole registration was performed three times during one session and three times at a second session 1 week later. The horizontal condylar inclination in the patient group gave a standard deviation of $2.17^\circ \pm 0.95^\circ$, indicating poorer reproducibility than in the volunteer group, for which the standard deviation was $1.37^\circ \pm 0.42^\circ$. The reproducibility of measurements of the Bennett angle was also poorer in the patient group than in the volunteer group, with standard deviations of $1.70^\circ \pm 0.62^\circ$ and $1.22^\circ \pm 0.40^\circ$, respectively. The standard deviations calculated for determination of incisal inclination during laterotrusion was $3.02^\circ \pm 1.49^\circ$ for patients and $2.30^\circ \pm 1.17^\circ$ for volunteers. The standard deviations for incisal inclination during protrusion was $2.02^\circ \pm 0.95^\circ$ for patients and $2.06^\circ \pm 1.82^\circ$ for volunteers. The reproducibility of measurement of horizontal condylar inclination, Bennett angle and incisal inclination during laterotrusion therefore showed significantly lower reproducibility in the patient group than in the volunteer group ($P < 0.05$). The overall reproducibility of the measurements was nevertheless good in both groups, with standard deviations under $3.1^\circ$, so that an individual setting of an articulator seems useful even in patients with CMD.

KEYWORDS: craniomandibular disorders, jaw movement, jaw recording, measurement, patient, reproducibility

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Introduction

Condylar movements are not only determined by the articular eminence, the disc and the ligaments of the temporomandibular joint, but also by occlusal and neuromuscular factors. The static and dynamic relationships between anatomical structures in the temporomandibular joints, antagonistic occlusal areas and their mutual functional relationship are therefore largely responsible for the normal and pathological function of the temporomandibular system (1, 2).

Today, individual registration of mandibular movements is possible with the help of electronic jaw recording systems (3–8), so that both qualitative and quantitative evaluation of mandibular movements is possible. Patients with craniomandibular disorders (CMD) frequently exhibit changes in these mandibular movements. Electronic jaw recording systems in patients with CMD have found changes in patterns of movements, such as shortening or asymmetry in the condylar pathways (9–11). There has also been discussion in the literature about changes in the reproducibility of mandibular movements in patients with CMD, as a consequence of alterations in arthrogenic and neuromuscular control (12–15). There have however been no publications on controlled clinical studies on
the effect of CMD on the reproducibility of dynamic functional parameters, which are used for individual articulator adjustment.

The object of the present study was therefore to determine the reproducibility of electronically calculated individual dynamic functional parameters in patients with CMD, in comparison with a control group of volunteers, using a modern extraoral jaw recording system.

Materials and methods

Selection of volunteers

The study was approved by the Ethics Committee of Hannover University Medical School. The study was undertaken with the understanding and written consent of each subject.

Thirty persons without CMD and 30 patients who were suffering from symptoms of CMD and who had visited the Department of Prosthetic Dentistry in Hannover Medical School for this reason were enrolled in the study. The criteria for inclusion in the volunteer group were eugnathic and complete dentition. Criteria for exclusion were symptoms of craniomandibular dysfunction, such as joint noises, restrictions to movements of the lower jaw and pain on pressure to the craniomandibular joints or the masticatory muscles. The criterion for inclusion in the patient group was the presence of CMD, which was diagnosed by using the research diagnostic criteria (RDC) for temporomandibular disorders (TMD) (16). In the patient group 17 patients had a clicking sound and 12 patients had a crepitus during mandibular excursions. Thirteen patients showed muscular pain on palpation, 10 had pain when the temporomandibular joint was palpated.

Criteria for exclusion in both groups were prior surgery in the region of the TMJ, the presence of systemic rheumatic disease, signs of psychosomatic illness, an incomplete complement of teeth and a removable dental prosthesis.

Electronic registration of mandibular movements

Mandibular movements were recorded with an ultrasound based electronic jaw recording system* to determine dynamic functional parameters. The precision of the used registration system has been documented in a published experimental study (17). The registration method of the ARCUSdigma, the so called articulator-related registration, is quite different from traditional electronic recording systems, allowing to transfer the articulator geometry virtually to the patient. The concept of articulator-related registration is using these virtually attached points to detect their movement patterns. As the mandible is a rigid body, three of these trajectories can be used to imitate mandibular movements in an articulator. Therefore articulator-related registration reduces the number of individual parameters necessary to imitate jaw motion and leads to a significant simplification in registration and cast transfer (17).

First the head frame with the receivers was attached. The maxillary position was then determined with a bite plate, which had previously been individualized with hard silicone†. Afterwards, the transmitter frame was attached to the mandibular teeth with a paraocclusal mandibular metal clutch with impressions of the facial surfaces of mandibular teeth in resin‡. The following tooth guided mandibular movements were recorded after initial instruction: maximum protrusive movement, maximum lateral movement to the right side and maximum lateral movement to the left side. The measurements were processed with specific software, allowing the calculation of the Bennett angle, the horizontal condylar inclination and the incisal inclination during protrusion and laterotrusion automatically.

The reproducibility of mandibular movements was determined by electronic registration of all movements three times during one session and three times at a second session 1 week later.

Statistics

Documentation and evaluation of the data was with data processing program SPSS/PC Version 11·0 for Windows§. The calculation of the reproducibility, separately calculated for each subject, was based on the decomposition of sum of squares: the total sum of squares of all measurements related to the subjects mean value was decomposed into the sum of squares within each session and between the two sessions. The

*ARCUSdigma, KaVo, Leutkirch, Germany.
†Futar D Occlusion, Kettenbach, Eschenburg, Germany.
‡PalatrayXL, Heraeus Kulzer, Hanau, Germany.
§SPSS Inc., Chicago, IL, USA.
reproducibility within a session is then defined as the square root of the mean sum of squares within the sessions (s.d.), based on \((2 \times 3) - 2 = 4\) degrees of freedom (d.f.), reflecting two sessions and three measurements within each session. The reproducibility between the sessions is the square root of the mean sum of squares between the sessions (s.d.) with \((2 - 1) = 1\) d.f. The overall reproducibility was the square root of the total sum of squares (s.d.) with \((2 \times 3) - 1 = 5\) d.f. The \(t\)-test for unpaired samples was used to compare the reproducibility of the patient and volunteer groups.

Furthermore the influence of joint sounds (clicking, crepitus), muscular pain and joint pain on palpation on the reproducibility of mandibular movements was analysed by using the method of multiple linear regression. A \(P\)-value <0·05 was considered statistically significant for all performed tests.

**Results**

Tables 1–3 summarize the reproducibility of the parameters of mandibular movement, as measured by computerized registration. For the registration of functional parameters within a session (Table 1), there was significantly lower reproducibility (significantly higher empirical s.d.) for the horizontal condylar inclination in the patient group than in the volunteer group \((P < 0·05)\). Analogous results were obtained for the reproducibility of the Bennett angle and the incisal

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**Table 1. Reproducibility within sessions**

<table>
<thead>
<tr>
<th></th>
<th>HCI</th>
<th>Bennett angle</th>
<th>Incisal inclination (Lat.)</th>
<th>Incisal inclination (Pro.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volunteers</td>
<td>1·08 ± 0·38</td>
<td>0·82 ± 0·26</td>
<td>1·55 ± 0·67</td>
<td>1·49 ± 1·29</td>
</tr>
<tr>
<td>CMD patients</td>
<td>1·45 ± 0·64</td>
<td>1·05 ± 0·33</td>
<td>2·10 ± 0·91</td>
<td>1·56 ± 0·73</td>
</tr>
<tr>
<td>Difference</td>
<td>−0·38</td>
<td>−0·23</td>
<td>−0·55</td>
<td>−0·07</td>
</tr>
<tr>
<td>Standard error of the difference</td>
<td>0·13</td>
<td>0·08</td>
<td>0·20</td>
<td>0·27</td>
</tr>
<tr>
<td>95% Confidence interval</td>
<td>−0·65 to −0·11</td>
<td>−0·40 to −0·06</td>
<td>−0·95 to −0·14</td>
<td>−0·60 to −0·47</td>
</tr>
<tr>
<td>Significance ((t)-test)</td>
<td>(P = 0·007)</td>
<td>(P = 0·008)</td>
<td>(P = 0·009)</td>
<td>(P = 0·807)</td>
</tr>
</tbody>
</table>

Lat., laterotrusion; Pro., protrusion.

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**Table 2. Reproducibility between two sessions**

<table>
<thead>
<tr>
<th></th>
<th>HCI</th>
<th>Bennett angle</th>
<th>Incisal inclination (Lat.)</th>
<th>Incisal inclination (Pro.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volunteers</td>
<td>0·77 ± 0·40</td>
<td>0·85 ± 0·44</td>
<td>1·50 ± 1·26</td>
<td>1·23 ± 1·48</td>
</tr>
<tr>
<td>CMD patients</td>
<td>1·45 ± 1·00</td>
<td>1·28 ± 0·67</td>
<td>1·93 ± 1·56</td>
<td>1·13 ± 0·87</td>
</tr>
<tr>
<td>Difference</td>
<td>−0·68</td>
<td>−0·43</td>
<td>−0·43</td>
<td>0·09</td>
</tr>
<tr>
<td>Standard error of the difference</td>
<td>0·20</td>
<td>0·16</td>
<td>0·36</td>
<td>0·31</td>
</tr>
<tr>
<td>95% Confidence interval</td>
<td>−1·08 to −0·20</td>
<td>−0·74 to −0·12</td>
<td>−1·15 to 0·29</td>
<td>−0·53 to 0·72</td>
</tr>
<tr>
<td>Significance ((t)-test)</td>
<td>(P = 0·001)</td>
<td>(P = 0·008)</td>
<td>(P = 0·236)</td>
<td>(P = 0·761)</td>
</tr>
</tbody>
</table>

Lat., laterotrusion; Pro., protrusion.

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**Table 3. Overall reproducibility**

<table>
<thead>
<tr>
<th></th>
<th>HCI</th>
<th>Bennett angle</th>
<th>Incisal inclination (Lat.)</th>
<th>Incisal inclination (Pro.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volunteers</td>
<td>1·37 ± 0·42</td>
<td>1·22 ± 0·40</td>
<td>2·30 ± 1·17</td>
<td>2·06 ± 1·82</td>
</tr>
<tr>
<td>CMD patients</td>
<td>2·17 ± 0·95</td>
<td>1·70 ± 0·62</td>
<td>3·02 ± 1·49</td>
<td>2·02 ± 0·95</td>
</tr>
<tr>
<td>Difference</td>
<td>−0·80</td>
<td>−0·48</td>
<td>−0·72</td>
<td>0·04</td>
</tr>
<tr>
<td>Standard error of the difference</td>
<td>0·19</td>
<td>0·15</td>
<td>0·34</td>
<td>0·37</td>
</tr>
<tr>
<td>95% Confidence interval</td>
<td>−1·18 to −0·42</td>
<td>−0·79 to −0·18</td>
<td>−1·39 to −0·04</td>
<td>−0·71 to 0·78</td>
</tr>
<tr>
<td>Significance ((t)-test)</td>
<td>(P = 0·000)</td>
<td>(P = 0·003)</td>
<td>(P = 0·038)</td>
<td>(P = 0·923)</td>
</tr>
</tbody>
</table>

Lat., laterotrusion; Pro., protrusion.

inclination during laterotrusion ($P < 0.05$). The difference between the groups was only non-significant for the incisal inclination during protrusion ($P > 0.05$).

Analysis of the reproducibility of functional parameters over the period of a week (Table 2) found that the standard deviation for horizontal condylar inclination, the Bennett angle and incisal inclination during laterotrusion was lower in the volunteer group than in the patient group. This difference was statistically significant for the horizontal condylar inclination and for the Bennett angle ($P < 0.05$).

As regards the overall reproducibility (Table 3), the standard deviation for horizontal condylar inclination for the patient group was $2.17^\circ \pm 0.95^\circ$, indicating significantly poorer reproducibility than the volunteer group, with a standard deviation of $1.37^\circ \pm 0.42^\circ$ ($P < 0.05$). The overall reproducibility of the Bennett angle was also significantly poorer in the patient group than in the volunteer group, with standard deviations of $1.70^\circ \pm 0.62^\circ$ and $1.22^\circ \pm 0.40^\circ$, respectively ($P < 0.05$). Analogously, the overall reproducibility of the incisal inclination during laterotrusion was also significantly poorer in the patient group than in the volunteer group, with standard deviations of $3.02^\circ \pm 1.49^\circ$ and $2.30^\circ \pm 1.17^\circ$, respectively ($P < 0.05$). On the other hand, the overall standard deviation of the incisal inclination during protrusion was calculated as $2.02^\circ \pm 0.95^\circ$ in the patient group and $2.06^\circ \pm 1.82^\circ$ in the volunteer group and this difference was not statistically significant ($P > 0.05$).

The multiple regression analysis showed no influence of clicking, crepitus, muscular and joint pain on the reproducibility of mandibular movements ($P > 0.05$).

**Discussion**

Evaluating the reproducibility of mandibular movements, it must be considered that the reproducibility is not solely dependent on the used recording system. Mandibular movements are influenced by the interaction between different morphological and structural components (18–21). These factors include condylar guidance (posterior guidance), tooth guidance (anterior guidance) and effects from the neuromuscular system.

In the present study the within session reproducibility of the values measured for horizontal condylar inclination, Bennett angle and incisal inclination during laterotrusion was significantly lower in the group of patients with CMD than in the group of healthy volunteers. One reason for this loss of reproducibility might be the lack of muscular coordination in patients with functional abnormalities, as neuromuscular changes have a marked effect on mandibular mobility and its reproducibility (22, 23). The reduction in reproducibility might also be caused by a reduction in condylar guidance as a consequence of arthrotic remodelling of the bony joint structures or changes in the structure and position of the disc and ligaments. A possible influence of joint sounds, muscular and joint pain on the reproducibility of mandibular movements was analysed in this study. But despite the fact, that some of these factors influence mandibular movements (24), in the present study none of these parameters showed a significant influence on the reproducibility. Different views have been published about the reduction in the reproducibility of axiographic movement traces in patients with CMD (25). In 1986, Clayton and Beard (26, 12) described a pantographic reproducibility index (PRI), which monitored the ability to reproduce border movements. The PRI was tabulated by recording several sets of tracings with a pantograph. The tracings were manually scored for reproducibility and a numeric PRI score was tabulated. It was considered that a deficit in the coordination of mandibular movements was a symptom of dysfunction.

The effect of time on reproducibility was additionally analysed in the present study by comparing the individual means of the functional parameters of the first and second session. The horizontal condylar inclination and the Bennett angle showed a significantly greater change of the means in patients with craniomandibular dysfunction than in volunteers. The good reproducibility of mandibular movements in volunteers with healthy joints agrees with the clinical results of Petrie et al. (13), who demonstrated that mandibular movements remain constant for 2–4 weeks. In contrast, the results of the present study show that, in patients with CMD, mandibular paths of movement represented by the change of means can change even within a week. This phenomenon can be explained on the one hand by the higher standard deviations within a session, which might lead to a higher fluctuation of the mean but might additionally be explained on the basis of changes in the degree of the dysfunction over time. Thus there can be additional changes in the neuromuscular or condylar guidance of the temporomandibular joint like for example muscle incoordination or muscle relaxation. These results are in accordance with the results of
Beard and Clayton (12), who found that fluctuations in the PRI over time was usually accompanied by signs and symptoms of CMD such as muscle tenderness, joint sounds and limited opening.

The overall standard deviation in this study is composed of the standard deviation from multiple measurements within one session and from multiple measurements over a period of a week; it should be regarded as the clinically relevant reproducibility. For the individual programming of articulators for the preparation of dental restorations, functional parameters from a recording system must be reproducibly determined both within a visit and at different time points. Comparison of the clinical reproducibility of the recording procedure used in this study with published values for other systems indicates, that the measurement errors of under 3–4° found here are clinically acceptable for articulator settings (27, 28). The comparison of the overall reproducibility with the apparative accuracy determined in another study, which ranged up to 1.5 degrees for the horizontal condylar inclination and up to −1.3 degrees for the Bennett angle (17) shows the remarkable low biological variability of mandibular movements in healthy volunteers. But even in the patient group, the overall reproducibility was not much higher than the apparative accuracy of the used registration system. As an individual setting of an articulator reduces clinically relevant occlusal errors almost completely (5), the results of the present study are indicating that even in patients with CMD an individual articulator programming would lead to fewer excursive occlusal interferences.

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References


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