Lower Jaw Movements Measured by Optoelectronic Movement Recording

A pilot study

Christopher Staversjö
Magnus Wänman
Lower Jaw Movements Measured by Optoelectronic Movement Recording

A pilot study

2017

Authors: Christopher Staversjö and Magnus Wänman

Tutor: Catharina Österlund
ABSTRACT

Due to the complex nature of jaw movements, three-dimensional (3D) movement recording provide information about the jaw movement capacity. The aim of the present report was to test the reliability of measuring lower jaw movements using a 3D movement recording system and to calculate the lower jaw movement volume.

Lower jaw movements, recorded by 3D optoelectronic movement analysis system (MacReflex®) was compared with reference values from a digital caliper. Pre-tests were performed to develop a software to calculate the lower jaw movements in separate dimensions and its volume. Pilot tests with two test persons followed to register the lower jaw movements and calculate lower jaw movement volume.

The results indicate low reliability of lower jaw movements measured by movement recording system compared with reference values from digital caliper, reflected by delta values ($\Delta = \text{max} - \text{min}$). The values from the movement recording system indicate high variability reflected by higher levels of standard deviation for movement recorded values compared with digital caliper and by percentage values calculated from the differences between mean values of movement recording and digital caliper. The calculated lower jaw movement volume was 10.3 cm$^3$ and 17.2 cm$^3$ for the test persons, respectively.

Conclusively, the results imply that further testing of the method is needed with larger series and test-retest reliability analysis to evaluate the possibility to improve accuracy of tracing jaw movements with recording device. The 3D-movement recording system together with the software could be used for calculation of lower jaw movement volume but its accuracy could not be validated.
INTRODUCTION

Temporomandibular disorders
The ability to perform normal jaw functions such as biting, chewing, swallowing, yawning and speech, without being restricted by pain or dysfunction is significant from a health perspective. Temporomandibular disorders (TMD) is a generic term for pain and dysfunction affecting the jaw muscles and the temporomandibular joint (TMJ) or surrounding tissues (Okeson, 2013). TMD is characterized by pain and dysfunction in the regions of the temples, TMJ and jaw muscles, impaired movement capacity of the lower jaw and TMJ noises (Dworkin & LeResche, 1992). TMD and orofacial pain can pose a negative effect on quality of life and may also affect the ability to perform daily activities (Dahlstrom & Carlsson, 2010; Shueb et al., 2015). TMD pain is a common longstanding pain condition in the jaw-face region affecting approximately 10 percent of the adult population (LeResche, 1997). The need for treatment owing to TMD has been estimated to be in the range from 1-30 percent of the population with a mean value of 16 percent (Al-Jundi et al., 2008). Diagnostic Criteria for Temporomandibular disorders (DC/TMD) is a recently launched method for clinical use as well as for research (Schiffman et al., 2014). DC/TMD contains diagnostic criteria for the most common TMD pain–related disorders, TMJ intra articular disorders as well as degenerative joint disease. In DC/TMD the clinical evaluation of the lower jaw movement range is an important parameter.

Jaw- and neck sensori-motor function
Jaw function is regulated by the cortical motor centers, the midbrain and the brain stem. Information necessary for muscle control is provided in complex neural networks. The brain stem receives input through afferent fibers from peripheral sensory receptors, such as periodontal mechanoreceptors and the muscle spindles of jaw-closing muscles. This information is organized in the midbrain, brain stem and cortex to send out suitable signals through efferent nerve fibers which results in contraction or inhibition of jaw muscles (Morquette et al., 2012; Okeson, 2013). Normal jaw function involves coordinated activation of lower jaw, the TMJ, the atlanto-occipital joints, jaw- and neck muscles and innervation from trigeminal as well as cervical nerves (see for example
Normal jaw function is the result of coordinated jaw- and neck muscle activity with head extension movements during jaw-opening and head flexion during jaw-closing (Eriksson et al., 2000).

**Lower jaw movements**

The TMJ movement during jaw opening and closing involve both rotation and translation of the condyles. The movement of the lower jaw can be divided into border movements and free functional movements. Border movements are those at the outer range of motion while functional movements occur during functional activity, such as chewing, and within the border movements (Okeson, 2013). The maximum range of the lower jaw movement, in three dimensions, was first described by Ulf Posselt 1952 by combining the lower jaw border movements in the sagittal, horizontal and frontal planes (Posselt, 1952) (Figure 2a). Normal maximal lower jaw movement capacity for adults ranges between 40 - 75 mm for opening and between 6 - 15 mm for protrusion and laterotrusion (Agerberg, 1974).

**Restricted lower jaw movements**

Impairment of lower jaw movements can be caused by different conditions. Common factors include pain conditions affecting the jaw muscles, TMJ or neck (Dworkin et al., 1990). Other conditions are mechanical obstacles such as TMJ disc displacements, disc adherences and ankyloses (Okeson, 2013). Furthermore, radiotherapy as a treatment for cancer/tumours in the head-neck and oro-facial regions can also severely affect jaw movement capacity (Bensadoun et al., 2010). Motor disorders such as Parkinson’s disease also affect jaw opening capacity (Bakke et al., 2011). Fear avoidance can cause limited jaw opening capacity. Acute experimental pain may change jaw motor coordination with slower and more variable movements in pain catastrophizing individuals (Akhter et al., 2014).

**Measuring lower jaw movements**

To measure the range of lower jaw movements a ruler or a digital caliper is normally used in the dental clinic. The examination according to DC/TMD involves measurements of pain free jaw opening, maximal unassisted and maximum assisted jaw
opening even if it is painful, and laterotrusive right and left and protrusive movements, even if it is painful (Schiffman et al., 2014). Besides measures with a ruler, different methods have been tested experimentally to capture the lower jaw movements. One method is to use optoelectronic devices with light emitting diodes (LED) and a motion detector (Fang and Kuo, 2008; Travers et al., 2000). Another method is to use an ultrasonic motion detector. The ultrasonic device capture the distance of movements by sending out pulses and measuring the time it takes or the pulse to return (Al-Jundi et al., 2008; Frisoli et al., 2017; Mazzetto et al., 2017). A four-dimensional analysis method has been tested using a combination of three dimensional (3D) CT of the cranium and lower jaw, laser scanner and LED-technique (Terajima et al., 2008). The methods mentioned are expensive and difficult to use in the dental clinics. Studies on simpler methods has been made using a hand camera and black and white markers (Adly et al., 2013) or tracking system using a RGB (Red, green, blue) camera and a standard laptop (Tanaka et al., 2016). Other methods that have been tested include accelerometer, video fluoroscopy and electromagnetic fields (Adly et al., 2013). In a comparative study using two-dimensional videography and ultrasonic measurements system to quantify lower jaw movement showed no significant difference between maximum opening and the reference system. Laterotrusion showed to be overestimated by the videography system and to show greater variability (Frisoli et al., 2017).

A change in maximal lower jaw movements is commonly used as a parameter for treatment outcome. When measuring lower jaw movements with a ruler or digital caliper, you may miss details in the movement pattern and the total lower jaw volume. Changes in the lower jaw volume may be a better indicator for the impairment and improvement of jaw functions. It may be possible to evaluate the envelope of movement, i.e. the volume of the lower jaw movement patterns, both border and functional movements. Change in these volumes may turn out to be an indicator of treatment outcome for jaw function capacity if it can be measured with high reliability. The lower jaw is capable to move in a six degrees of freedom (Knap et al., 1970). Most often, in natural jaw function the lower jaw move in more than one dimension. Due to the complex nature of lower jaw movements, it is possible that three-dimensional (3D) movement recording analysis of the movements could give more information about the
jaw movement capacity and jaw function compared to measures in only one dimension. Therefore, it is interesting to develop reliable and valid test methods to measure movements. In this study, we wanted to analyze the reliability of the measurements of separate lower jaw movements with a wireless 3D optoelectronic movement recording system and evaluate if it is possible to calculate and visualize the maximal lower jaw movement volume.

Aims
The aims of the study were:

- To evaluate the reliability of the measurements of separate lower jaw movements (mm) with a wireless 3D optoelectronic movement recording system.
- To compare maximal vertical and horizontal lower jaw movements registered with a 3D optoelectronic movement recording system to registrations with a digital caliper.
- To calculate and visualize the total lower jaw movement volume (cm$^3$).

Hypotheses
The hypotheses were:

- Measurements of the maximal lower jaw movements with wireless 3D optoelectronic movement recording system can be done with high reliability.
- Measurement of maximal lower jaw movements with wireless 3D optoelectronic movement recording system will not differ significantly from measurements with a digital calliper.
- The maximal lower jaw movement volume can be calculated and visualized based on registrations of the borderer movements of the lower jaw.
MATERIALS AND METHOD

Ethical reflection
The study was approved by the Local Ethical Board, Umeå University. Ethical considerations that was considered for the study were the risk for short-termed, transient pain/tiredness in the jaw muscles, TMJ and head-neck region in the two test persons. The risk for harm was considered very low.

Literature search
Articles were searched on PubMed using the MeSH terms; jaw and movement. As a complement the MeSH terms, the terms movement recording, movement analysis, optoelectronic, 3D and lower jaw volume was used. In addition, hand search was done on google scholar and Libris. Articles was also provided by the supervisor. In total, 20 articles were read in full text.

Test persons
To test the hypotheses and for practical reasons two test persons, the authors, were included (test person one and test person two).

Movement recording
For the experimental tests, movements of the lower jaw and head were recorded simultaneously in 3D with wireless optoelectronic system at sampling rate of 50 Hz (Mac Reflex®; Qualisys, Gothenburg, Sweden) (Josefsson et al). Two cameras recorded the movements of a tripod of retro-reflective markers attached to the bridge of the nose (to track head movements) and a single marker on the chin (to track lower jaw movements). Details of the set-up have been described previously (Eriksson et al., 2000).

Software
There was no known available software compatible with the MacReflex system to calculate and visualize the lower jaw movements in separate dimensions and the lower jaw volume. Therefore, we co-worked with the Department of Community Medicine and Rehabilitation, Umeå University. We supported them with recorded measuring data
for developing a custom-made software. The software mathematically compensated for the head-neck movements, calculated the lower jaw movements relative to the head and illustrated the lower jaw volume from the recorded movements.

**Outcome variables**

The outcome variables were;

- Jaw opening movement amplitude (mm): the distance from starting position (slight teeth contact in centric occlusion (CO)) to maximal jaw opening, including vertical overbite. In the 3D coordinate system referred to as Y-dimension.
- Jaw laterotrusive movement right or left (mm): the distance from starting position (slight teeth contact in CO) to maximal right or left laterotrusive movement. In the 3D coordinate system referred to as X-right or left dimension.
- Jaw protrusive or retrusive movement (mm): the distance from starting position (slight teeth contact in CO) to maximal forward protrusive movement. In the 3D coordinate system referred to as Z-forward or backward dimension.
- Calculated total lower jaw movement volume (cm$^3$).

**Pre-test**

A series of pre-tests was performed, prior to the pilot tests, to sample necessary data to develop the software for calculation and visualization of the lower jaw movements and the movement volume. The pre-tests were done with the movement recording system, reflex markers, jaw movements, a ruler and a cup and a glass with known volume. The pre-tests compared a known distance or volume with the recorded one.

**Pilot test**

A series of tests were done to test the test re-test reliability of the measurements of maximal lower jaw movements using the movement recording system and to compare these measurements to the reference values of a digital caliper. The pilot test was also designed to test the possibility to calculate the total lower jaw volume.
Two separate series, A and B, of measurements were conducted during five consecutive days. *Pilot test A* compared maximal lower jaw movements in opening (Y-dimension), right and left laterotrusion (X-dimension) and forward protrusion and backward retrusion (Z-dimension). The X-, Y-, Z- dimensions were recorded with the movement recording system compared to measurements done with a digital calliper (Table 1a). *Pilot test B* samples lower jaw movement coordinates for calculating the total volume with the movement recording system (Table 1b).

**Statistical methods**

The data were analysed by descriptive; mean (mm), min-max (mm) and standard deviation (SD). As a measure of test-retest reliability for the movements recorded values by the movement recording system, a mean delta-value ($\Delta = \text{max-min}$) was calculated. As a comparison between values from movement recording and from digital caliper the formula $(m-d)/m \times 100$ was used ($m =$ mean value of the movement recording system, $d =$ mean value from the digital caliper).

**RESULTS**

**The reliability of the measurements of separate lower jaw movements with wireless 3D optoelectronic movement recording system**

**Jaw opening amplitude /y-dimension**

In maximal jaw opening, the mean delta value was 3.4 mm for test person one and 4.1 mm for test person two (Table 2a and Figure 1b).

**Jaw laterotrusive movement /x-dimension**

In maximal jaw laterotrusive movement right, the mean delta value was 2.3 mm for test person one and 3.3 mm for test person two. In maximal jaw laterotrusive movement left, the mean delta value for the movement recording was 3.2 mm for test person one and 3.0 mm for test person two (Table 2a, Figure 1b).
Jaw protrusive movement /z-dimension

In maximal jaw protrusive movement, the mean delta value was 7.1 mm for test person one and 4.1 mm for test person two (Table 2a, Figure 1b).

Comparison between maximal jaw movements with 3D optoelectronic movement recording system and digital caliper

Jaw opening amplitude /y-dimension

For maximal jaw opening the difference between the mean values of the movement recording and the digital caliper for test person one and two were 12 % and 0.4 %, respectively (Table 2b).

Jaw laterotrusive movement /x-dimension

In maximal jaw laterotrusive movement right, the difference between the mean values of the movement recording and the digital caliper for test person one and two were 29 % to 46 %, respectively. In maximal jaw laterotrusive movement left, the difference between the mean values of the movement recording and the digital caliper for test person one and two were 2 % to 38 %, respectively (Table 2b).

Jaw protrusive movement /z-dimension

In maximal jaw protrusive movement the difference between the mean values of the movement recording and the digital caliper for test person one and two were 35 % to 29 %, respectively (Table 2b).

The lower jaw movement volume

The mean total lower jaw movement volume for test person one and two were 10.3 cm$^3$ and 17.2 cm$^3$, respectively (Table 2c, Figure 1c).
DISCUSSION

The main findings of this pilot study were that repeated measurements of the lower jaw movements with 3D optoelectronic movement recording (MacReflex) did not show reliable values in comparison with the reference values from the digital caliper. The outcome values from the movement recording were in general larger than values from the digital caliper in all dimensions, especially in X- dimension (laterotrusive movement) and in Z- dimension (protrusive movement). Therefore, we reject the hypotheses one and two, assuming that measurements of the maximal lower jaw movements with wireless 3D optoelectronic movement recording system can be done with high reliability and will not differ significantly from reference values from the digital caliper. The third hypothesis that the maximal lower jaw movement volume can be calculated and visualized based on registrations of the boarder movements of the lower jaw was accepted, but its accuracy could not be validated.

The indicated low reliability, are reflected by the delta (Δ) values (Table 2a, Figure 1b). The low reliability of maximal jaw opening with the optoelectronic system was disappointing in relation to previous studies showing high reliability of measurements with calipers (Wahlund et al., 1998). We have no explanation for the large differences between the reference values from the digital caliper for lateral and protrusive movements compared to those registered with the movement recording values. One possibility, may be that the registrations by hand with digital caliper measure one dimension (the lateral movement, X-dimension), while the movement also involves a forward component (Z-dimension) and sometimes even a downward movement (Y-dimension), which is caught by the optoelectronic device. With the movement recording system, the outcome distance is the combined movement in three- dimensions, the vector of the distance, which is longer than the movement in only one- dimension. Therefore, movement analysis certainly provides an added value of the movement patterns in the jaw system. Another explanation, may be that the software program overestimates the registered values and needs to be adjusted in the mathematical formulas used in the software. To explore that, further analysis will be needed to assure or improve the software program.
To be sure that the reflex marker set up was appropriate for the tests, we used the same set up that has been described previously. The reflex markers settings on the bridge of the noose and chin versus teeth attached markers can be reliably used for jaw movement analysis (Häggman-Henrikson et al., 1998). Moreover, the accuracy of the MacReflex system for precision in measurements has been shown to be high (Eriksson et al., 2000). To be sure that the movement recording system (MacReflex) was calibrated in X-, Y-, Z- dimensions, calibration measurements were done with the aid of a calibration frame, showing exactly correspondence between values from the recording system and the values from a digital caliper.

The values from movement recording system indicate high variability as reflected by the higher levels of standard deviation for movement recorded values compared with digital caliper and by the percentage values calculated from the differences between the mean values of the movement recording and the digital caliper (Table 2b, Figure 1a). One possible explanation for the variability in the movement recording values may be that measurement of the maximal interincisal distance during opening with a calliper clearly define the end-point while free movements can involve a higher level of variability. The variability in the free movements registered by the optoelectronic device can be interpreted as a variability in the sensory-motor system. This variability in movement outcome can be an advantage when the jaw sensori-motor system is affected by pain, injury or disease.

The software could calculate and visualize the total lower jaw movement volume from zig-zag movements of the lower jaw. The graphic illustrations of the envelope of jaw mobility visualized seem to correspond to the lower jaw border movements described by Posselt (Posselt, 1952) (Figure 2a and 2b). When calculating lower jaw movement volume, the software stratifies the measured coordinates according to a factor called “stepsize”. In this pilot study stepsize was set at 1.0. In future studies, optimizing of step size levels may prove a smoother outline and illustrated movement volume.
A previous study compared measurements obtained by digital caliper and a 3D ultrasonic system. The study also found differences in protrusion movements between the methods (Mazzetto et al., 2017). It is hard to compare the outcome values from two different methods for movement measurements. The digital caliper is a reliable measurement method for movements especially when the movement has one direction. The caliper is cheap, easy to handle and useful in the clinic, but it may not give the full picture of the movement patterns. A movement recording system if it is reliable can allow for more detailed quantification and visualization of complex movement patterns, and that are of value for the specialist and researcher.

Conclusively, the results of the pilot study imply that further testing of the method is needed with larger series and test-retest reliability analysis to evaluate the possibility to improve accuracy of tracing jaw movements with recording device. The pilot study has thus produced some insight and more questions that need to be addressed before the 3D-movement recording system (MacReflex) together with a software program can be used for lower jaw volume calculations and included in treatment outcome analyses.

ACKNOWLEDGEMENTS

We want to thank Helena Grip, Department of Community Medicine and Rehabilitation, Umeå University who developed the software used for calculating values for separate lower jaw movements and illustrating the lower jaw movement volume. We also want to thank our tutor Catharina Österlund, Umeå University.
REFERENCES


**Table 1a. Study design for pilot test A.**

<table>
<thead>
<tr>
<th>Test number</th>
<th>Method</th>
<th>Design</th>
<th>Number of tests</th>
<th>Number of days</th>
<th>Outcome variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Movement measurement, with the aid of Mac Reflex system and a digital caliper</td>
<td>Maximal jaw opening (Y-dimension). Start position light teeth contact in CO</td>
<td>5</td>
<td>5</td>
<td>Jaw movement amplitude (mm)</td>
</tr>
<tr>
<td>2</td>
<td>Movement measurement, with the aid of Mac Reflex system and a digital caliper</td>
<td>Maximal laterotrusive movement (X-dimensions). Start position light teeth contact in CO</td>
<td>5</td>
<td>5</td>
<td>Jaw laterotrusive movement (mm)</td>
</tr>
<tr>
<td>3</td>
<td>Movement measurement, with the aid of Mac Reflex system and a digital caliper</td>
<td>Maximal protrusive movement (Z-dimensions). Start position light teeth contact in CO</td>
<td>5</td>
<td>5</td>
<td>Jaw protrusive movement (mm)</td>
</tr>
</tbody>
</table>
Table 1b. Study design for pilot test B.

<table>
<thead>
<tr>
<th>Test number</th>
<th>Method</th>
<th>Design</th>
<th>Recording time</th>
<th>Outcome variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Movement recordings with MacReflex</td>
<td>Maximal circular lower jaw movements, from slight teeth contact CO to maximal jaw opening</td>
<td>60 seconds</td>
<td>Volume (cm³)</td>
</tr>
<tr>
<td>2</td>
<td>Movement recordings with MacReflex</td>
<td>Maximal zig-zag lower jaw movements (anterior-posterior), from slight teeth contact CO to maximal jaw opening</td>
<td>60 seconds</td>
<td>Volume (cm³)</td>
</tr>
<tr>
<td>3</td>
<td>Movement recordings with MacReflex</td>
<td>Maximal zig-zag jaw movements (left-right), from slight teeth contact CO to maximal jaw opening</td>
<td>60 seconds</td>
<td>Volume (cm³)</td>
</tr>
</tbody>
</table>
Table 2a. Outcome of pilot test A with 3D optoelectronic movement recording and digital caliper for each day.

<table>
<thead>
<tr>
<th>Day</th>
<th>Dimension</th>
<th>Test person one</th>
<th>Test person two</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (mm)</td>
<td>SD</td>
<td>Δ (max-min)</td>
</tr>
<tr>
<td>1</td>
<td>Jaw opening</td>
<td>47.6</td>
<td>1.8</td>
</tr>
<tr>
<td>2</td>
<td>Jaw opening</td>
<td>46.3</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>Jaw opening</td>
<td>49.8</td>
<td>1.2</td>
</tr>
<tr>
<td>4</td>
<td>Jaw opening</td>
<td>49.5</td>
<td>1.2</td>
</tr>
<tr>
<td>5</td>
<td>Jaw opening</td>
<td>49.3</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Movement recording</td>
<td><strong>48.5</strong></td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Digital caliper</td>
<td><strong>42.7</strong></td>
<td>0.9</td>
</tr>
<tr>
<td>1</td>
<td>Laterotrusion right</td>
<td>14.0</td>
<td>1.9</td>
</tr>
<tr>
<td>2</td>
<td>Laterotrusion right</td>
<td>10.5</td>
<td>0.9</td>
</tr>
<tr>
<td>3</td>
<td>Laterotrusion right</td>
<td>13.7</td>
<td>0.8</td>
</tr>
<tr>
<td>4</td>
<td>Laterotrusion right</td>
<td>13.6</td>
<td>0.3</td>
</tr>
<tr>
<td>5</td>
<td>Laterotrusion right</td>
<td>16.9</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Movement recording</td>
<td><strong>13.7</strong></td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Digital caliper</td>
<td><strong>9.7</strong></td>
<td>0.3</td>
</tr>
<tr>
<td>1</td>
<td>Laterotrusion left</td>
<td>10.4</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>Laterotrusion left</td>
<td>11.5</td>
<td>2.8</td>
</tr>
<tr>
<td>3</td>
<td>Laterotrusion left</td>
<td>9.0</td>
<td>0.8</td>
</tr>
<tr>
<td>4</td>
<td>Laterotrusion left</td>
<td>7.9</td>
<td>1.5</td>
</tr>
<tr>
<td>5</td>
<td>Laterotrusion left</td>
<td>9.1</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Movement recording</td>
<td><strong>9.6</strong></td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Digital caliper</td>
<td><strong>9.7</strong></td>
<td>0.7</td>
</tr>
<tr>
<td>1</td>
<td>Protrusion</td>
<td>14.0</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>Protrusion</td>
<td>13.4</td>
<td>2.0</td>
</tr>
<tr>
<td>3</td>
<td>Protrusion</td>
<td>14.7</td>
<td>3.5</td>
</tr>
<tr>
<td>4</td>
<td>Protrusion</td>
<td>15.7</td>
<td>2.4</td>
</tr>
<tr>
<td>5</td>
<td>Protrusion</td>
<td>17.4</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>Movement recording</td>
<td><strong>15.0</strong></td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>Digital caliper</td>
<td><strong>9.8</strong></td>
<td>0.3</td>
</tr>
</tbody>
</table>
Table 2b. Outcome of pilot test A with 3D optoelectronic movement recording and digital caliper on test person one and two.

<table>
<thead>
<tr>
<th>Movement Dimension</th>
<th>Test person one</th>
<th>Test person two</th>
<th>Difference between (m) and (d) in percent (m-d)/m X 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement recording</td>
<td>Digital caliper</td>
<td>Movement recording</td>
<td>Digital caliper</td>
</tr>
<tr>
<td>Mean (mm)</td>
<td>Min-Max (mm)</td>
<td>Mean (mm)</td>
<td>Min-Max (mm)</td>
</tr>
<tr>
<td>Y-opening</td>
<td>48.5</td>
<td>44.3-51.8</td>
<td>42.7</td>
</tr>
<tr>
<td>X-right</td>
<td>13.7</td>
<td>9.8-18.3</td>
<td>9.7</td>
</tr>
<tr>
<td>X-left</td>
<td>9.6</td>
<td>5.9-15.7</td>
<td>9.7</td>
</tr>
<tr>
<td>Z-forward</td>
<td>15.0</td>
<td>11.0-21.9</td>
<td>9.8</td>
</tr>
</tbody>
</table>
Table 2c. Outcome of pilot test B with 3D optoelectronic movement recording and calculated movement volumes. The table also shows recorded min and max values for maximal recorded movements in Y, X and Z – dimensions.

<table>
<thead>
<tr>
<th>Test person</th>
<th>Lower jaw movement volume</th>
<th>Total Y movement</th>
<th>Total X movement</th>
<th>Total Z movement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (cm³)</td>
<td>Min–Max (cm³)</td>
<td>Mean (mm)</td>
<td>Min–Max (mm)</td>
</tr>
<tr>
<td>1</td>
<td>10.3</td>
<td>9.3–11.4</td>
<td>47.6</td>
<td>44.2–52.4</td>
</tr>
<tr>
<td>2</td>
<td>17.2</td>
<td>13.9–22.2</td>
<td>53.0</td>
<td>48.2–57.0</td>
</tr>
</tbody>
</table>
**Figure 1a.** Outcome of jaw movement values for test person one and two with comparison between values from movement recording (MacReflex) compared with digital caliper.

JO = jaw opening movement

LtrR = Laterotrusion right

LtrL = Laterotrusion left

Prot = Protrusion

Movrec = movement recording

Digcap = Digital caliper
Figure 1b. Outcome delta values (Δ=max-min), for test person one and two in performed jaw movements in four different dimensions.

JO= jaw opening movement
LtrR= Laterotrusion right
LtrL= Laterotrusion left
Prot= Protrusion
Figure 1c. Outcome of lower jaw movement volume for test person one and two.
**Figure 2a.** The lower jaw border movement in sagittal horizontal and frontal view, first described by Ulf Posselt in 1952. The superior border is determined by teeth contact while others are being determined by ligaments and other anatomical structures in the temporomandibular joint.

**Figure 2b.** Graphic illustration of calculated maximal lower jaw movement volume for test person two. Note that the illustration seems to correlate well to the lower jaw border movements described in figure 2a.