Variation in Movement Traces of the Kinematic Center of the Temporomandibular Joint

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Aim: *The purpose of this study was to compare the variation in movement traces of the kinematic center of the temporomandibular joint with that of 4 nearby condylar reference points.* **Methods:** *Jaw movement recordings were made with an optoelectronic jaw movement recording system. Four asymptomatic participants performed 14 to 18 open-close mandibular movements. The movements were performed with deliberate alterations of the rotation/translation ratio during opening. The kinematic center of the condyle and 4 nearby condylar points (the corner points of a square placed in the condylar sagittal plane, centered around the kinematic center, and with an edge length of 10 mm) were used as reference points. The standard deviations in the downward displacements at the halfway point in the mandibular opening of these reference points were calculated as a quantification of the variation in the movement tracings of these points.* **Results:** *The movement traces of the kinematic center showed the smallest variation in comparison to the traces of the 4 nearby reference points (2-way analysis of variance and subsequent contrast analysis; P = 0.0026).* **Conclusion:** *In comparison to 4 nearby condylar reference points, the movement traces of the kinematic center show the lowest sensitivity to variations in the way mandibular movements are performed.*
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Key words: jaw movement recording, temporomandibular joint, kinematic center

According to the guidelines of the American Academy of Orofacial Pain,[1] 2 diagnostic criteria must be present for a disc displacement with reduction within the temporomandibular joint (TMJ) to be determined: *(1)* reproducible joint noise occurs during opening mandibular movement and again just before the teeth occlude during closing, and *(2)* soft tissue imaging reveals a displaced disc that improves its position during jaw opening. However, sometimes it is difficult to establish whether these criteria are met or not. The closing click is usually much softer than the opening click[1] and sometimes cannot be heard. This complicates the comparison of the mandibular position at the time of the opening and closing click. Moreover, imaging techniques such as magnetic resonance imaging (MRI) and arthrography are expensive and available only at specific sites (usually hospitals); arthrography also has an invasive character. The recording of sagittal condylar movement traces during mandibular movements may be a good alternative for the evaluation of internal derangements. Condylar recording devices are less expensive, more readily available than the earlier mentioned imaging techniques, and they provide a dynamic impression of condylar function.

Studies that have compared the results of condylar movement traces with those of a clinical examination, MRI, or arthroscopy have come to different conclusions. Parlett et al[2] and Ozawa and Tanne[3] compared the results of axiographic recordings with those of MRI findings. They concluded that axiography is marginally effective in identifying disease when it is present. According to these authors, axiography is not accurate enough to diagnose a TMJ condition, especially in the case of a chronic and/or adaptive derangement. On the other hand, Romanelli et al,[4] in a study of the accuracy of clinical examination, axiography, arthrography, and MRI in detecting internal derangements in the TMJ, considered axiographic devices to be an accurate means of detecting internal derangements. These different conclusions may be a result of problems encountered in the interpretation of the imaging results and/or technical problems with the recording of condylar movements. The high incidence of normal, asymptomatic subjects revealing disc abnormality on MRIs, symptomatic disc derangement patients revealing normal arthrographic findings, and normal subjects showing some disc displacement on arthrograms led Okeson[5] to conclude that "false positives and false negatives are very common with these techniques and therefore, care must be taken regarding their interpretation."

The recognition of an internal derangement with the use of axiography is usually based on the distinction between different types of movement patterns, such as normal, "figure-eight" (crossing of opening and closing traces), limited, and other irregularities.[3,6–9] However, these movement types may be more characteristic for the condylar reference point, which is used to track condylar movements, than for the presence of an internal derangement. Since open-close mandibular movements have both translatory and rotatory components, each condylar reference point has its own unique movement path.[10] A limited movement path of a reference point may be the result of a specific combination of rotations and translations and may have nothing to do with an internal derangement. Differences in the relation of rotation and translation between opening and closing can, in a symptom-free joint, give rise to "figure-eight" movement patterns, whereas variations in the relationship between rotation and translation may account for irregularities in movement traces. This illustrates that for the interpretation of condylar movement traces, the choice of condylar reference point is important.

The concept of the "kinematic axis" in the reconstruction of condylar movements was originally suggested by Kohno.[11] It was later used by Pröschel et al[12] and was slightly adapted and renamed the "kinematic center" by Yatabe et al.[13] According to Yatabe et al, the kinematic center is the condylar reference point that closely follows the contour of the articular eminence during opening. Since its movement traces are determined mainly by the contour of the articular eminence, the traces of the kinematic center are rather insensitive to variations in the rotatory component of mandibular movement. Consequently, the movement traces of the kinematic center may show less variability than those of other condylar reference points. In the present study, this latter assumption is further investigated. The aim of this study was to compare the sensitivity of the movement traces of the condylar kinematic center to variations in the rotatory component of mandibular movements with that of traces of 4 other nearby reference points.

Materials and Methods

Participants

Four healthy individuals (3 men and 1 woman, aged 25 to 49 years) without signs or symptoms of a craniomandibular disorder participated in the study after having given informed consent. Special attention was given to the absence of TMJ sounds. The participants were asked to perform the following:

1. Four to six mandibular open-close movements during a 10-second period.
2. Four to six protrusive-retrusive movements during a 10-second period.
3. Fourteen to eighteen symmetrical open-close movements during a 20-second period. The movements were performed with deliberate alterations of the rotation/translation ratio during opening. This was accomplished by carrying out protrusive movements of different extent during the initial phases of opening (Fig 1). After opening, the participants were asked to perform habitual closing movements. The 20-second recordings were used for the analysis of the sensitivity of the tracings of a condylar reference point to variations in the rotatory component of mandibular opening.

Recording System

Mandibular movements were recorded by means of a custom-made OKAS-3D system.[14] OKAS-3D is an optoelectronic system capable of recording mandibular motion with 6 degrees of freedom at a sampling frequency of 300 Hz per coordinate. For the simultaneous recording of the position of the mandible and the maxilla, 3 pairs of photocells were located on each of 2 lightweight frames (12 g), which were rigidly glued with Histoacryl Blue (B. Braun) to the vestibular surfaces of the upper and lower incisors and canines by means of individually made polyacrylic clutches. The upper frame recorded the movements of the head and the lower frame recorded the combined movements of the head and mandible. Two cathode-ray tube displays, oriented perpendicular to each other, tracked the movements of the photocells. The formulae of rigid body mathematics were used offline to calculate the movement path of any point of the mandible relative to the maxilla. At the start of an experiment, the coordinates of the lower incisal point and of the lateral pole of the condyles with respect to the mandibular reference frame were recorded by means of a specially developed pointer. The position of the lateral pole was found by palpation. The horizontal planes of the lower and upper reference frames ran parallel to the occlusal plane, and the vertical planes ran parallel to the medial plane of the subject's head.

The Kinematic Center

According to Yatabe et al,[13,15] the kinematic center is the condylar reference point whose movement path follows, during opening movements, the contour of the articular eminence. It is situated in the mathematical center of that (circular) part of the articular surface of the condyle/disc complex, which is in contact with the articular eminence during opening and protrusive movements. The movement traces of the kinematic center for opening and protrusive condylar movements will then coincide. The 4 to 6 opening movements[5] and the 4 to 6 protrusive movements of the 10-second recordings were used to find the kinematic center of a particular joint. The software used in this study scans the sagittal condylar plane (the sagittal plane that runs through the lateral pole of the condyle) for that point, which meets the requirement of coinciding opening and protrusive movement traces.

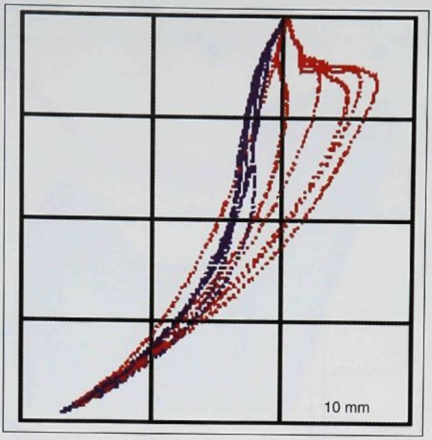

Fig 1 Superposition of the sagittal movement traces of the lower incisal point of a symptom-free individual. Six open-close movements are shown, the opening movements of which were strongly varied. *Red* = opening movements; *blue* = closing movements.

Data Analysis

For the analysis of the sensitivity of the movement traces of a condylar reference point to variations in the rotatory component of mandibular movement, the 14 to 18 opening movements performed during the 20-second recordings were analyzed. The movement traces of the condylar kinematic center were compared with those of 4 nearby reference points, ie, the corner points of a square placed in the condylar sagittal plane, centered around the kinematic center, and with an edge length of 10 mm (Fig 2). The variation in subsequent opening movement tracings of a reference point was quantified by calculating the standard deviation in the downward displacements of that reference point, at the halfway point in the opening movement. Differences in the variation in tracings of the 5 reference points of the 8 joints were analyzed with a 2-way analysis of variance (ANOVA), followed by a contrast analysis. Probability levels of $P < 0.05$ were considered statistically significant.

Results

The deliberate alterations of the rotation/translation ratio during mandibular opening are

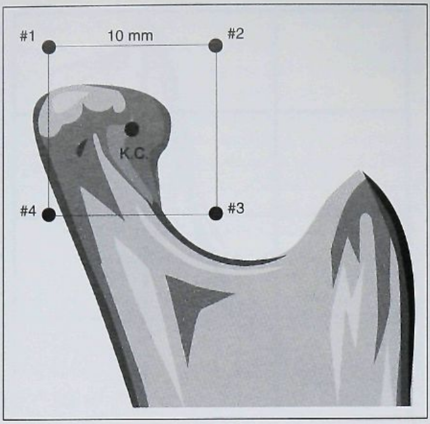

Fig 2 Diagram of the 5 condylar reference points: the kinematic center (K.C.) and the 4 corner points of a square placed in the sagittal condylar plane, centered around the kinematic center, and with an edge length of 10 mm.

illustrated in Fig 1. This figure shows, for one of the individuals, the superimposed sagittal movement traces of the lower incisal point for 6 of the open-close movements performed during the 20-second recording. Figure 3 shows the simultaneously recorded and superimposed sagittal movement traces of the 5 condylar reference points (the kinematic center and the 4 corner points) of this participant. It illustrates that trace characteristics such as shape, length, crossings between opening and closing traces, and the distance between opening and closing traces depend upon the selected reference point. Figure 3 also suggests that the opening traces of the kinematic center show the smallest variation.

A significant difference was found between the variations in opening tracings of the 5 condylar reference points (ANOVA, $P < 0.0001$). The variation in opening tracings of the kinematic center was significantly smaller than the variations in the traces of the other 4 reference points (Fig 4; contrast analysis; Scheffe's $F = 5.32$; $P = 0.0026$).

Discussion

The recording of the movements of a body with 6 degrees of freedom provides complete knowledge of the 3-dimensional motion of that body. When, as is the case with the masticatory system, the morphology of the joint is known (for instance through the use of MRI or computed tomography), the full motion of the condyle relative to the articular eminence can be reconstructed.[16–18] This allows the analysis of the relative distance between the condyle and the fossa during function.[16–18] Unfortunately, at this time, these techniques are still time-consuming, rather complicated, sensitive to systemic errors, and expensive. Therefore, they are less suitable for routine use in a clinical setting. As an alternative, the tracking of single condylar points is used in the study of condylar motion.

The planar motion of a body can be expressed as a sequence of translations of an arbitrary point on that body and rotations about this point. The rotations are always the same, regardless of the point chosen, but the translations are not. As a consequence, each point will perform its own unique movement trajectory,[12,19–21] but this trajectory can never fully describe the 3-dimensional motion of a body.[18] However, in practice, the motion of a body is often identified with that of a particular point of that body. So is the motion of a ball rolling down a hill often identified with that of its center moving parallel to the surface of the hill. The kinematic center, used in this study for the description of condylar motion, is situated in the center of the part of the (circular) surface of the condyle/disc that articulates with the articular eminence.[13,15] According to the results of biomechanical modeling of the masticatory system,[22–24] the condyle/disc is in close contact with the articular eminence during jaw opening; this outcome is supported by recent findings on the intra-articular distance within the TMJ during free and loaded mandibular movements.[25,26] The kinematic center then stays at a constant distance from the articular eminence during the whole range of opening. Its movement traces are determined mainly by the contour of the articular eminence and are not sensitive to variations in the rotational component of mandibular movement. This presents the possibility of studying condylar movements with respect to the articular eminence, and it may also explain the findings in this study that the movement traces of the kinematic center show the smallest variation in comparison with those of other condylar reference points. Since patients with a clicking TMJ often perform irregular mandibular movement, a low sensitivity to these irregularities may be an important aspect in the recording of condylar movements.

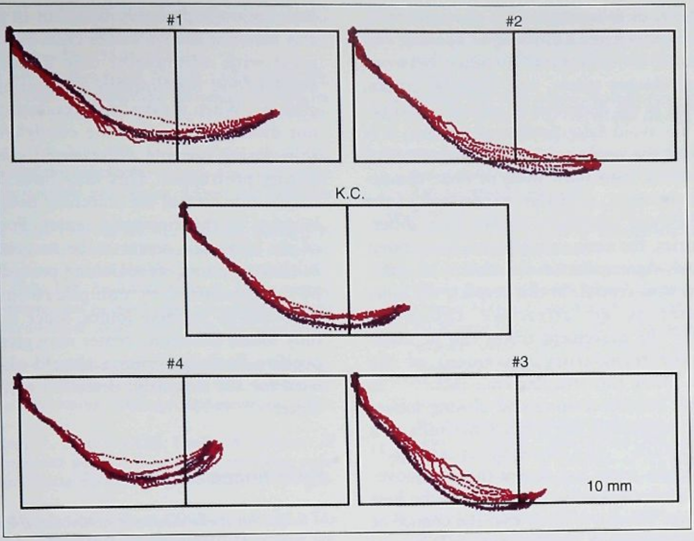

Fig 3 The superimposed sagittal movement traces of 5 condylar reference points, recorded simultaneously with the movement traces of the incisal point shown in Fig 1. Note that trace characteristics, such as shape, length, crossings between opening and closing traces, distance between opening and closing traces, and variation in traces differ with respect to the reference point. The top left point of a tracing corresponds to the condylar position with the mandible in the intercuspal position. *Red* = opening movements; *blue* = closing movements; K.C. = kinematic center.

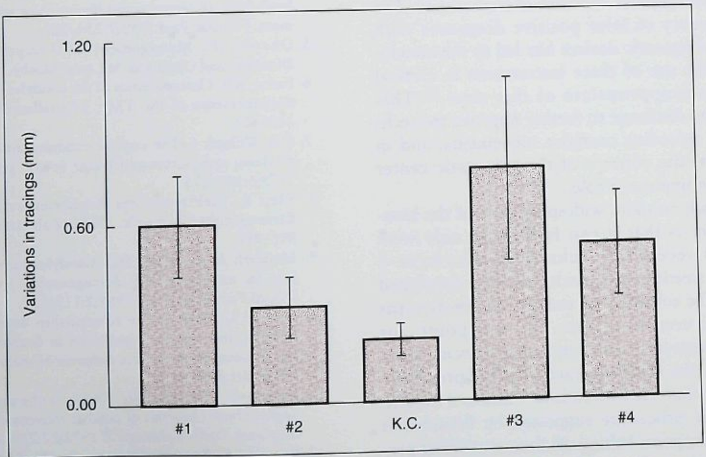

Fig 4 Values (mean ± SD, in mm) of the variation in tracings of the kinematic center (K.C.) and the 4 nearby reference points. The variation in tracings of the kinematic center was smaller than the variation in tracings of the 4 corner points ($P < 0.0026$).

Observations of movement trace characteristics, such as a limited length, a crossing of opening and closing traces, a substantial distance between opening and closing traces, and irregular traces, are often used in the diagnosis of internal derangements.[3,6–9] To avoid false positive diagnoses, it is important that the single-point movement traces of an asymptomatic joint show none of these characteristics. Furthermore, to enable comparison of the results of condylar movement studies from different laboratories, the same condylar reference point must be used. Agreement on the choice of reference point is thus crucial. In this respect, the kinematic center is an attractive choice to make.[12,13,15,21] Its movement traces can be interpreted as the translatory movement of the condyle/disc along the articular eminence.[13,15] In asymptomatic joints, opening and closing movement traces are smooth, are just a few tenths of a millimeter apart,[15] and show no crossings.[21] Furthermore, this study has shown that the movement traces of the kinematic center show the best reproducibility. Thus, it is likely that the chance of false positive findings is smaller when tracings of the kinematic center are used instead of those of, for instance, the hinge axis point,[6–9,27] the lateral pole,[9,14] or a point 15 mm medially displaced with respect to the lateral pole of the condyle.[10] In most cases, the location of these condylar reference points does not coincide with the kinematic center,[12,13,28] and therefore their movement traces differ from those of the kinematic center; they probably also possess different characteristics. The high frequency of false positive diagnoses with electronic diagnostic devices has led to the conclusion that the use of these instruments in clinical practice is inappropriate at this time.[29] This increases the challenge to further improve the techniques for recording condylar movements, and in this respect, the concept of the kinematic center may play an important role.

An obstacle to more widespread use of the kinematic center is that it can be located only with movement recording techniques that have 6 degrees of freedom and with specially developed software. The software we used in this study scans the sagittal condylar plane for that point, for which the protrusive condylar traces coincide maximally with the opening traces.[13] This procedure differs from that used by Kohno[11] and is a modification of the procedure suggested by Pröschel et al.[12] An assumption behind all these searching procedures is that the condyle/disc relationship remains the same during the various mandibular movements studied. In asymptomatic joints, this assumption is probably true, but in clicking joints this may not always be the case. For instance, in a joint with an anterior disc displacement, the condyle/disc relationship changes at the time of clicking. When the disc reduces during opening but not during protrusion, the condyle/disc relationship during opening differs from the relationship during protrusion. This may have consequences for the outcome of the searching procedure for the location of the kinematic center. For the concept of the kinematic center to be successfully applied in clicking joints, its searching procedure must not be compromised by complications sometimes encountered in these joints. Since a less successfully found kinematic center may give rise to false positive findings, criteria should also be formulated for the successful detection of the kinematic center.

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