

# Centers of rotation during jaw movements

Anne S. McMillan, Duncan R. McMillan and Brian W. Darvell

Department of Prosthetic Dentistry and Dental Materials Science Unit, Faculty of Dentistry, Prince Philip Dental Hospital, University of Hong Kong, Hong Kong, and Department of Prosthetic Dentistry, Faculty of Odontology, University of Lund, Malmö, Sweden

McMillan AS, McMillan DR, Darvell BW. Centers of rotation during jaw movements. *Acta Odontol Scand* 1989;47:323–328. Oslo. ISSN 0001-6357.

Anatomists consider the articulation of movable joints to be complex, involving movable instantaneous centers of rotation (ICR). However, prosthodontists often treat the temporomandibular joint (TMJ) as a model of a simple hinge. The aim of this study was to examine the case for a movable ICR during habitual opening and closing jaw movements. Young, dentate subjects were examined with a kinesiograph. Jaw movements were performed and recorded. The center of rotation of each movement pattern was identified, and its location related to the position of the TMJ. The results showed that opening and closing jaw movements were predominantly non-coincident, with a movable ICR located at a variable distance and direction from the TMJ. There was no evidence to suggest that the TMJ functioned as a simple hinge during jaw movements. □ *Articulators; dental occlusion; temporomandibular joint*

*D. R. McMillan, Department of Prosthetic Dentistry, Faculty of Odontology, Carl Gustavs väg 34, S-214 21 Malmö, Sweden*

Most studies of anatomic joints make reference to the fact that bones of the body do not rotate around a fixed axis but rather around moving instantaneous centers of rotation (ICR) (1). When an attempt to form a biomechanical model is contemplated, it is prudent to determine the ICR to achieve fidelity of joint function. The mandible, with its paired joints, has been shown to have a movable ICR (2, 3).

Despite this, prosthodontists, in their quest to replicate jaw movement, using the articulator as a mechanical model, have sought to determine a reproducible jaw position at which all movements would commence and terminate. The first report of a method for locating the hinge axis (4) seemed to fulfill this goal. This technique for hinge axis location augmented the work of Snow (5), who had earlier devised the face-bow for transferring the hinge axis to an articulator. But the existence of a single physiologic axis of rotation has been questioned (6), even though, by application of pressure to the point of the chin, an axis of rotation may be created (2, 7). This dichotomy of belief, coupled with the prevalent

view of the dominant role of the temporomandibular joints (TMJ) in jaw movement, has generated a plethora of conflicting literature (8).

In view of the evidence that rotation about a hinge axis does not seem to be associated with functional jaw motion (9), the present study was undertaken to examine the case for a movable ICR during habitual jaw movements.

## Materials and method

Sixteen subjects aged 22–25 years were selected. Ten subjects were staff or students at the Prince Philip Dental Hospital, Hong Kong; six were students from the Faculty of Dentistry, University of Lund, at Malmö. All subjects had complete natural dentitions and reported no history of disorders of the masticatory system.

The position of a small magnet attached to a mandibular incisal point was tracked simultaneously in three mutually perpendicular planes by means of a Mandibular Kinesiograph (MKG) (model K5AR in

Hong Kong and model K6 in Malmö; Myotronics Research Inc., Seattle, Wash., USA). The output from an array of flux-gate magnetometers was used to generate the MKG oscilloscope (K5AR) or the monitor (K6) display of motion in the sagittal plane. The MKG could also display vertical, anteroposterior, and lateral displacements simultaneously in the form of 'sweep' plot versus time. This was used to examine lateral movements of the mandible. The display was photographed with an oscilloscope camera (model C-5C, Tektronix Inc., Beaverton, Ore., USA) and Polaroid 667 film (Polaroid (UK) Ltd., St Albans, Herts) or printed (K6) by an Imagewriter (Apple Computer Inc., Cupertino, Calif., USA) operating on Program 1.6A (Myotronics Research Inc.). The MKG measurement method has been described by McMillan & McMillan (9), Hannam et al. (10), and Jankelson (11).

Each subject performed specific open/close tasks. The first was an habitual open/close task (A), performed in a smooth, continuous manner, commencing and terminating in the intercuspal position (ICP). In the second task subjects were instructed to lightly tap their teeth together, commencing from mandibular rest position and then occluding in intercuspal position (B). These tests were repeated to confirm reproducibility before a representative sample was recorded. The procedures were repeated 1 week later.

A lateral cephalometric radiograph was taken of each subject by the method described previously (9). The projection from condyion to the incisal point was measured (Fig. 1). The projection error was 8.7% in Hong Kong and 8.3% in Malmö.

The habitual open/close movement traces in the sagittal plane were examined, using a radius guide to estimate the position of the ICR (C). The radius guide consisted of an acetate sheet with a set of concentric arcs at radius increments of 5 mm. The guide was placed over each trace, and, by superimposition and visual comparison, the radius providing the best fit to each major arc segment was identified. This procedure located the approximate center for that arc. The analysis of traces was performed by the same

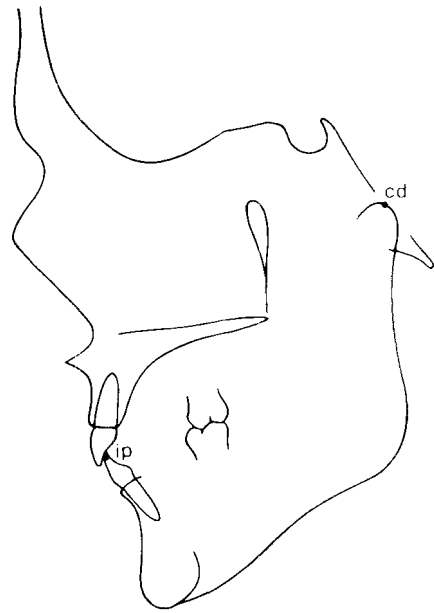


Fig. 1. Craniometric points on the lateral skull radiograph. ip = incisal point; cd = condyion.

person (A. S. McMillan) and then verified independently by another (D. R. McMillan). Within subjects, these radii were then compared with the linear distance from the condyion to the incisal point as measured on the radiographs. The apparent ICRs were plotted.

## Results

### *Habitual open/close jaw movements*

The habitual open/close movements of the 16 subjects described 1 of 4 distinct patterns when viewed in the sagittal plane (Fig. 2). Five subjects displayed coincident or near-coincident trajectories; six produced cross-over patterns; in four, the closing stroke was posterior to the opening one; and in one, the closing stroke was anterior to that on opening. In 13 subjects these movement patterns were consistent in overall configuration at both examinations. Of the remaining three, one subject produced a crossover stroke at the first session, whereas at the

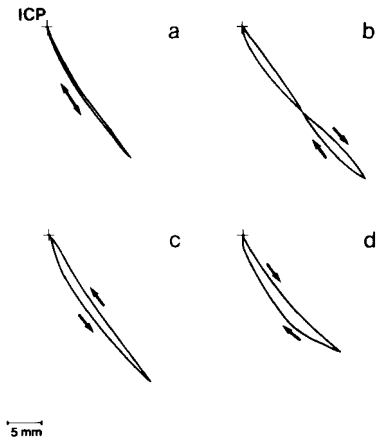


Fig. 2. Examples of the four types of open/close movement patterns described by an incisal point, viewed in the sagittal plane. ICP = intercuspal position, the position from which movement was initiated. 2a. Coincident open/close paths. 2b. The closing path initially anterior, crosses to complete closure posteriorly. 2c. The closing path is posterior to that on opening. 2d. The closing path is anteriorly placed.

second the closing stroke was consistently posterior to the one on opening. For the second subject, the converse of this was observed. The third subject produced a coincident display at the first recording session, whereas at the second the closing stroke was posterior to that on opening.

*Tooth tapping from rest position*

An example of a trace is shown in Fig. 3. A lateral component of movement was detected in 12 of the 16 subjects. Its range was 0.1–0.6 mm, with movement to the right in five subjects and to the left in seven. There was no significant shift in the value of the lateral component of movement between recording sessions (paired *t* test,  $0.40 > P > 0.30$ ).

*Location of ICRs*

Analysis of the habitual open/close traces for each subject, by means of the radius guide, indicated the presence of a movable ICR located at various distances and directions from the TMJ (Fig. 4).

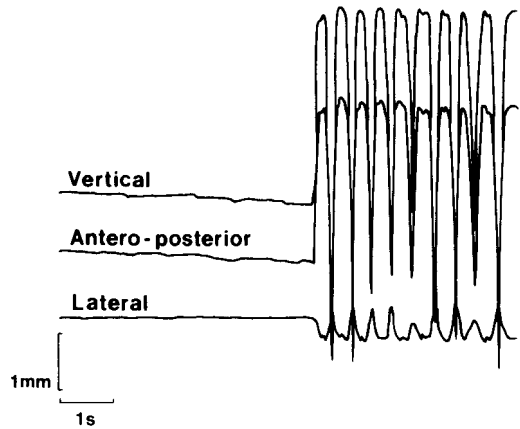


Fig. 3. An example showing the components of three-dimensional movement from rest position to intercuspal position. Movement in the vertical plane is indicated by consecutive projections above the line marked 'vertical'. Movement in the anteroposterior dimension is anterior when above the line marked 'anteroposterior', as depicted in this instance. In the horizontal plane, lateral movement is to the right when above the line marked 'lateral' or to the left when below the line, as shown.

**Discussion**

There are many proponents of the hinge-axis theory of mandibular movement, whereby the mandible opens and closes on an axis with a center of rotation in the region of the condyles (12, 13). However, the presence of a single, fixed axis has been disputed (2, 3). If a single hinge opening of the mandible existed for functional movements, the locus of an incisal point would be the arc of a circle with the center of rotation in the region of the TMJ, when viewed in the sagittal plane (2, 9). When viewed in this plane, only 4 of the 16 subjects displayed coincident habitual open/close movements consistently. The other 12 had disparate open/close trajectories. However, coincidence of open/close trajectories does not necessarily equate with a single axis or single arcs. Loci consisting of multiple arc segments is sufficient to invalidate the hypothesis of a single arc. These findings concur with those of Shanahan & Leff (14), who showed that habitual open/close jaw movements were non-coinci-

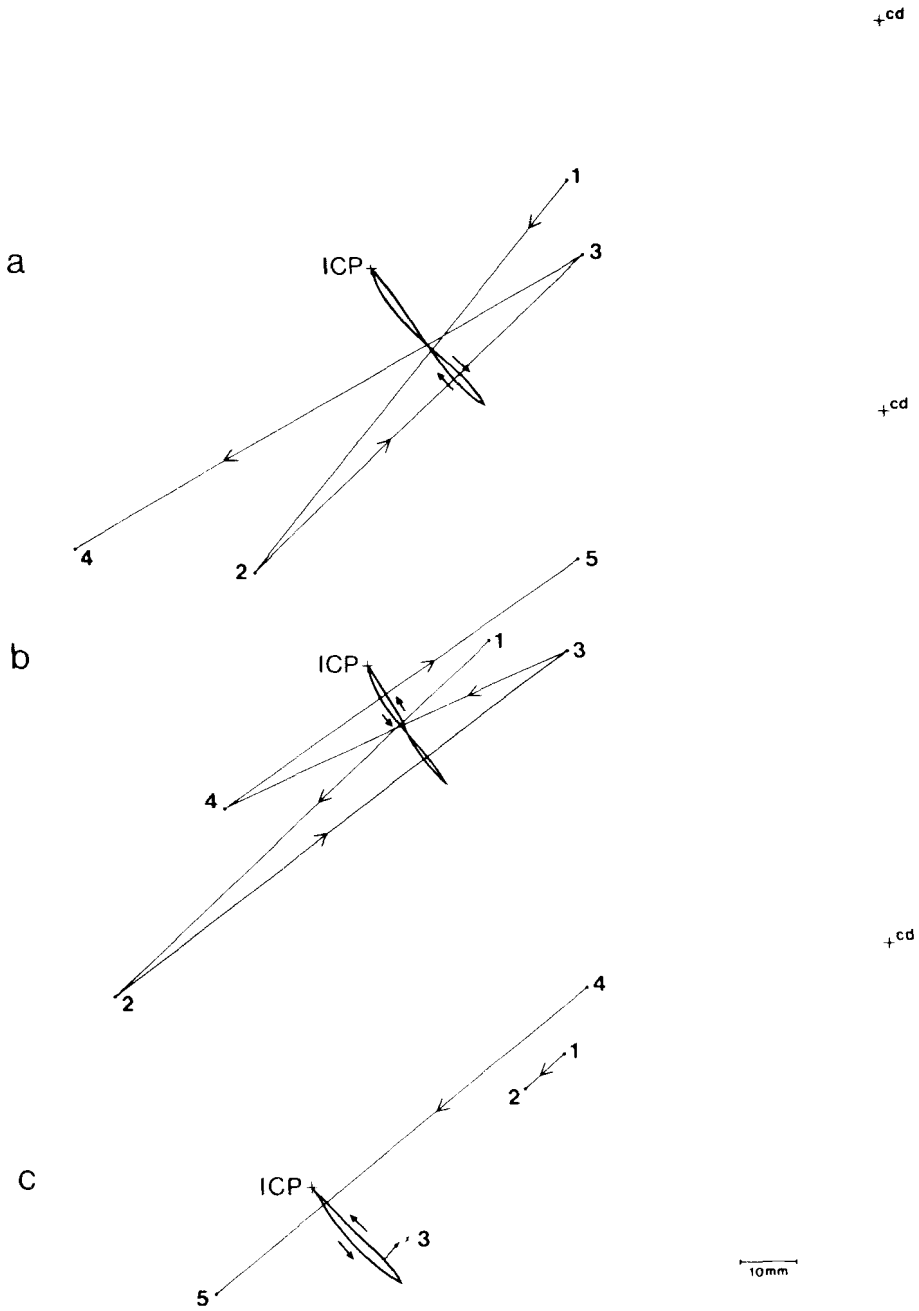


Fig. 4. Examples of open/close movement patterns, the instantaneous centers of rotation (ICR) for each of the major arc segments and the relationship of the ICRs to the craniometric landmark, condylion (cd). ICP = intercuspal position from which movement was initiated. 4a. The closing path anterior, crosses to complete closure posteriorly (X); four positions of the ICR are plotted. 4b. Another X pattern, with five locations of the ICR. 4c. The closing path is posterior to that on opening; five locations of the ICR are present. The double loop configuration indicates that the radius of the arc is greater than 150 mm, the largest radius available on the guide. In examples a, b, and c, the lines connecting the ICRs represent one possible locus for the ICR.

dent and that, within subjects, their configuration varied between recordings. Further analysis of the non-coincident open/close movement traces indicated the presence of an ICR situated at a variable distance and direction from the TMJ. The position of the ICR changed dramatically, and its location lay outside the mandible on several occasions. This finding supports the work of Shanahan & Leff (2) and Grant (1), who contended that the ICR was not situated in proximity to the TMJ and that the displacements of the ICR from the joint were of considerable magnitude. The tooth-tapping jaw movements (B) from rest position to intercuspal position were viewed in three planes to achieve a more comprehensive view of these movements. The three-dimensional nature of jaw movement was demonstrated. This observation concurs with that of George & Boone (15), who stated that closure from rest position through the interocclusal distance to intercuspal position represented a three-dimensional episode.

The MKG measurements were subject to minor errors of scale and some slight curvature similar to the optical effects of pin-cushion and barrel distortion. The effect of these was to increase the curvature of the arc segments towards the TMJ, making the radius slightly smaller when it was on that side and slightly larger when it was anterior to the mandible. The use of the radius guide to estimate the position of the ICR was subject to both inter- and intra-operator error with regard to which arc on the measuring device constituted the best fit for the major arc segments. These errors were considered to have no effect on the overall observations.

The presence of a movable ICR for habitual jaw movement demonstrates that the concept of a single hinge axis for jaw movement is untenable. As a consequence of this finding, the procedures involved in the reproduction of jaw movements on the articulator must be questioned because face-bow transfer of the position of the hinge axis is considered by some to be mandatory as a basis for faithful replication of jaw movement (13, 16, 17). In turn, the articulator is used in the development of occlusal schemes for fixed and removable prostheses. The val-

idity of the concepts of occlusal design must be open to question when the articulations are generated from a non-functional single hinge axis. In addition, the information to be gleaned on muscle and joint mechanics when using a movable ICR is markedly different from that obtained when using the TMJ as a stationary axis of rotation (1). The implications for biomechanical modeling of the mandible is significant in practical terms.

### Conclusions

In this study there was no evidence to suggest that habitual jaw movements, performed by young dentate subjects, occurred about a single axis of rotation located in the region of the TMJs. Jaw movement from rest position through the interocclusal space to intercuspal position was three-dimensional. In contradistinction to the presence of a single hinge axis, a movable ICR was present and situated at a variable distance from the TMJ.

*Acknowledgement.*—This project was supported in part by a grant from the Faculty of Dentistry, University of Hong Kong.

### References

1. Grant PG. Biomechanical significance of the instantaneous centre of rotation: the human temporomandibular joint. *J Biomechan* 1973;6:109–13.
2. Shanahan TEJ, Leff A. Mandibular and articulator movements. III. The mandibular axis dilemma. *J Prosthet Dent* 1962;12:292–7.
3. Trapozzano VR, Lazzari JB. The physiology of the terminal rotational position of the condyles in the temporomandibular joint. *J Prosthet Dent* 1967;17:122–33.
4. McCollum BB. Fundamentals involved in prescribing restorative dental remedies *Dent Items* 1939;61:522–35.
5. Snow GB. The present status of the articulator question. *Dentist's Mag* 1907;2:635–47.
6. Beck HO. A clinical evaluation of the arcon concept of articulation. *J Prosthet Dent* 1959;9:409–21.
7. Jankelson B, Adib F. Effect of variation in manipulative force on the repetitiveness of centric relation registration: a computer based study. *J Am Dent Assoc* 1986;113:59–62.
8. Winstanley RB. The hinge axis: a review of the literature. *J Oral Rehabil* 1985;12:135–59.

9. McMillan DR, McMillan AS. A comparison of habitual jaw movements and articulator function. *Acta Odontol Scand* 1986;44:291-9.
10. Hannam AG, De Cou RE, Scott JD, Wood WW. The kinesiographic measurement of jaw displacement. *J Prosthet Dent* 1980;44:88-93.
11. Jankelson B. Measurement accuracy of the mandibular kinesiograph—a computerized study. *J Prosthet Dent* 1980;44:656-66.
12. Jaarda MJ, Clayton JA, Myers GE. Measurement of cusp height and ridge and groove directions using an electrical transducer. II. Pantographics and the terminal hinge axis. *J Prosthet Dent* 1978;40:83-8.
13. Stern N, Hatano Y, Kolling JN, Clayton JA. A comparison of mandibular border movements generated by various articulators. I. Methodology. *J Prosthet Dent* 1988;60:194-201.
14. Shanahan TEJ, Leff A. Mandibular and articulator movements. *J Prosthet Dent* 1959;9:941-5.
15. George JP, Boone ME. A clinical study of the rest position using the kinesiograph and myomonitor. *J Prosthet Dent* 1979;41:456-62.
16. Price RB, Bannerman RA. A comparison of articulator settings obtained by using an electronic pantograph and lateral interocclusal recordings. *J Prosthet Dent* 1988;60:159-64.
17. Sorenson JA, Diener RM, Curtis DA. Inaccuracies using arbitrary hinge axis with electronic pantographic recordings. *J Dent Res* 1988;67:219.

---

Received for publication 9 May 1988