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ANALYSIS OF MOVEMENT OF MANDIBULAR CONDYLE IN SAGITTAL PLANE

BY

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ABSTRACT

The movement of the condyle was recorded with reference to the movement at the incisal point in the sagittal plane. As a result a kinematic axis as the center of the mandibular movements was found, and it became clear that the whole mandibular movement in the sagittal plane could be divided into the rotation around the kinematic axis and the translation of the axis along the condyle path. The kinematic axis was compared with the hinge axis. The former was located antero-superiorly to the latter, and in a few cases the hinge axis was located outside of the condyle.

INTRODUCTION

For the study of the mandibular movement, it is essential to analyze the movement of the condyle accurately. The movement of the condyle has been observed chiefly by pantographic tracing and roentgenograms which were taken in the usual manner with a stationary tube. Accurate analysis of the movement, however, has been insufficient, because the movement of the condyle seems to be small and complicated and the condyle which lies in the side of the base of the skull could not be observed directly.

The objective of this research is to observe and analyze the movement of the condyle with reference to the mandibular movement in the sagittal plane by means of cephalometric laminagraphy and multiple electronic flush apparatus.

APPARATUS AND METHOD

A. Cephalometric laminagraphy

Siemens universal planigraph was used for laminagraphy. A head positioner was newly designed for this apparatus to fix the head of the subject in a definite position. The subjects were comfortably seated in an upright

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position. The head was held with the Camper plane being kept horizontal and parallel to the film sagittally. The ear rods of the head positioner, which were placed in the direction of the central X-ray, were put into the corresponding external auditory canal in order that the central X-ray is perpendicular to the sagittal plane of the head (Fig. 1).

The laminagraphic section was adjusted so as to be in the middle of the right joint and parallel to the sagittal plane. A metal mark was attached to the incisal point of the lower dentition to have it indicated on the laminagram. In order to determine the middle of the temporomandibular joint and the depth from which the section should be taken, measurements were made on the antero-posterior skull X-ray cephalograms.

Laminagrams of the temporomandibular joints were taken in a series of positions on the path of the sagittal mandibular border movement such as the intercuspal position, the edge-to-edge occlusion, the protruded contact position, the maximal opening position, the retruded contact position and several other positions on the path of the posterior border movement.

Accuracy of the laminagram:—Distortion of the laminagram was 0.5%, errors on tracing and measurement were about 0.3 mm and the section of the laminagram was 2 mm in thickness.

B. Multiple electronic flush apparatus

The principle of measurement was as follows: Sagittal movements of

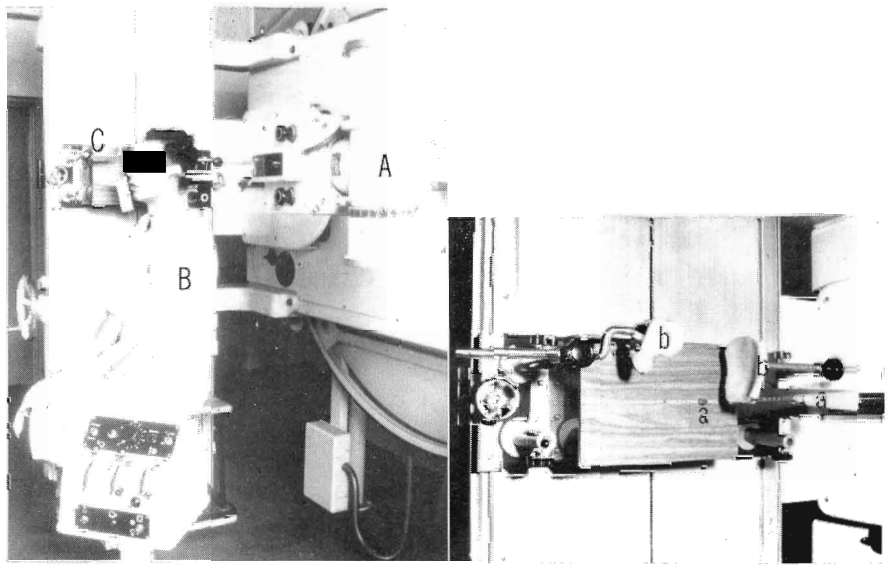

Fig. 1. Arrangement of cephalometric laminagraphy and subject.
A. Universal planigraph. B. Subject.
C. Head positioner (a. Ear rod. b. Head support).

the two luminous point marks, which were attached anteriorly to the mandible in the sagittal plane, were registered with the multiple electronic flush apparatus, and the movement of any given point near the condyle was then calculated by the data of the registered mandibular movement by means of a devised computor method.

The subjects were seated upright. The head was fastened, with the Camper plane being kept horizontal in the same position as the laminagrams were being taken (Fig. 2). Metal labial or buccal splints were attached to the upper and lower teeth with zinc oxide eugenol cement. The upper one served to fix the head, and on the lower one two luminous point marks were attached anteriorly to the point of incision inferius in the sagittal plane (Fig. 2).

The two luminous point marks on the lower jaw were photographed in the dark room with a time of six cycles per second, and the sagittal border movement and habitual opening and closing movements were recorded as a continuity of numerous dots on the dry plate of the camera. The dots were measured by establishing coordinates on the plate. Then, the coordinates of the condyle point "C(X, Y)", which showed a definite relation to the two point marks "A(x_a, y_a)" and "B(x_b, y_b)", were computed by the following formula (Fig. 3).

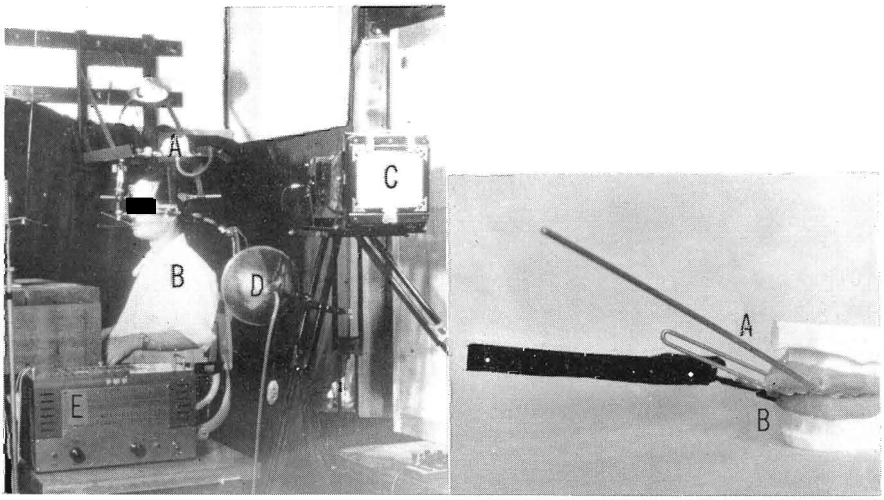

Fig. 2. The whole apparatus for testing mandibular movement (left).
A. Head support. B. Subject. C. Camera. D. Flush tube.
E. Muliple electronic flush apparatus.
Splint (right). The upper one (A) is attached to the frame of the head support and served to fix the upper jaw. On the lower one (B), two luminous point marks are attached anteriorly to the incisal point.

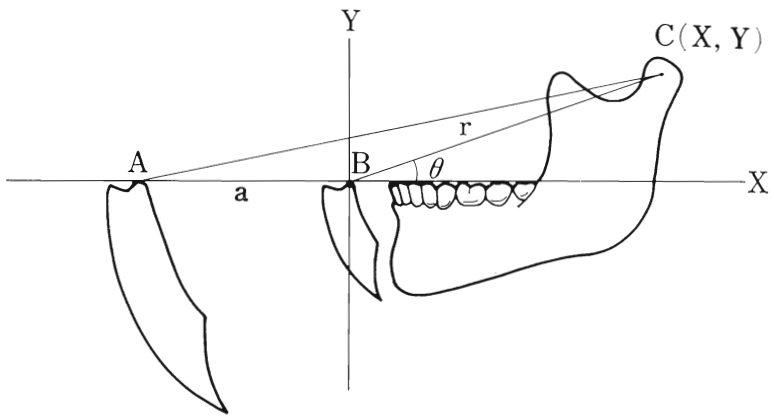

Fig. 3. Principle of calculation of the movement of the condyle. The movement of the condyle point "C" was calculated by the sagittal mandibular movements at points "A" and "B". a: Straight line segment AB. r: Straight line segment BC.

$$X = r/a\{(x_b - x_a)\cos\theta - (y_b - y_a)\sin\theta\} + x_b$$
$$Y = r/a\{(y_b - y_a)\cos\theta + (x_b - x_a)\sin\theta\} + y_b$$

That is, corresponding to the change of the positions of "A" and "B", the condyle point "C" changes its position. By connecting the condyle points, the path of the condyle movement was obtained.

On the other hand, the relation of the condyle point "C" to the two points "A" and "B" can be changed by varying r and θ in the formula. Consequently the path of any point around the condyle during the movement was calculated.

The condyle path was thought to be different in form and property according to the location of the measured point around the condyle. Therefore, about 120 points were selected in and near the condyle and their paths were calculated with an electronic computor NEAC 2101. The location of the point was determined by the preceding cephalometric laminagraphy.

Mandibular movements measured here were such movements in the sagittal plane as: 1. Protrusive excursion and anterior border movement; 2. Retrusive movement and posterior border movement; and 3. Habitual opening and closing movement.

Accuracy of the apparatus:—The main cause of the error in the measurement is the distortion of the camera-lens system, the error due to this being at the most 0.2%.

Subjects:—Ten subjects between the ages of 19 and 35 were tested. Almost all of these subjects had functionally an adequate occlusion and

none of them had any complaints related to the temporomandibular joint and masticatory muscles.

Condyle Position in Mandibular Fossa

Fig. 4 is a typical example of a laminagram. The contour drawings of the laminagrams superimposed are presented in Fig. 5.

Intercuspal position:—Generally the condyle was situated closer to the posterior slope of the articular eminence and the space between the condyle and the articular fossa was, on the average, 1.6 mm at the anterior wall of the articular fossa, 3.5 mm at the bottom of the fossa and 2.1 mm at the posterior wall.

Edge-to-edge occlusion, protruded contact position and maximal opening position:—In the edge-to-edge occlusion, the condyle was situated in between the anterior part of the articular fossa and the crest of the articular eminence. The condyle reached the crest of the eminence in all cases in the protruded contact position. Then the condyle moved anteriorly to the crest of the articular eminence as the mouth opened to its maximal position. In this position the condyle was situated at the most protruded position in the temporomandibular joint.

Retruded contact position:—With regard to the retrusive movement from the intercuspal position to the retruded contact position, the retrusive or retrocranial displacement of the condyle, ranging from 0.3 to 1.6 mm, was

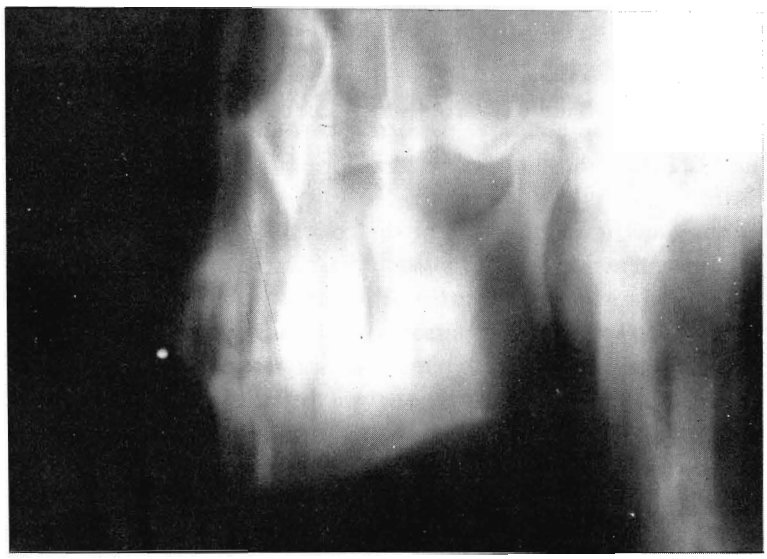

Fig. 4. Typical example of a laminagram.

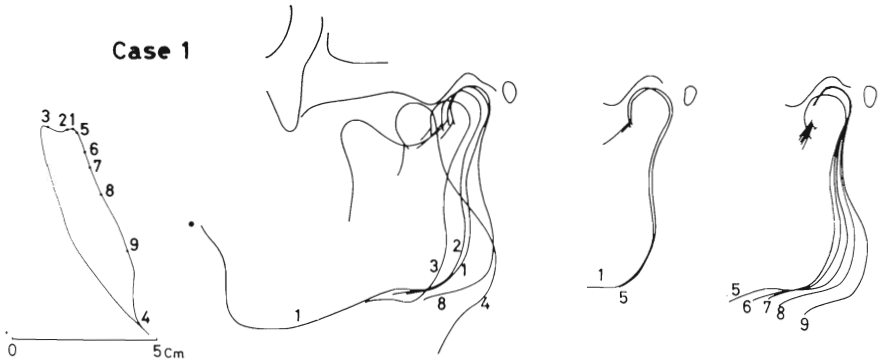

Fig. 5. Sagittal border movement at the incisal point (left), and contour drawings of laminagrams superimposed (right).
1. Intercuspal position. 2. Edge-to-edge occlusion. 3. Protruded contact position. 4. Maximal opening position. 5. Retruded contact position. 6–9. Posterior border position.

observed in six of ten subjects. In the rest, the displacement was not seen on the laminagrams.

Posterior border movement:—When observing the positions on the path of the posterior border movement, the condyle stayed in almost the same situation in the fossa in all cases except two. It was estimated that the mandible makes a hinge-like movement around the condyle in eight cases. In two cases, however, the forward movement of the condyle was observed. It was doubtful that the mandible makes a hinge-like movement in these two cases.

Sagittal Movements of Condyle

The tracing of the movement of 20 points out of about 120 points in and near the condyle, as shown in Fig. 6, was placed on the contour drawing of the cephalometric laminagram of the condyle.

The movement of the points showed a closed curve line corresponding to the sagittal border movement at the incisal point. The shape had an orderly variation in form and property according to the location of the points. Particularly a great difference was seen in their vertical width.

A specific point was obtained, the area of the range of the movement of which showed the narrowest belt-shape form. It was found in the condyle region in all cases, and the width ranged from 0.5 mm to 1.4 mm, an average of 0.7 mm. That is, the specific point always moves within the same narrow belt-shaped range as the mandible performs various sagittal movements. In other words, except for the specific point no other points do not move

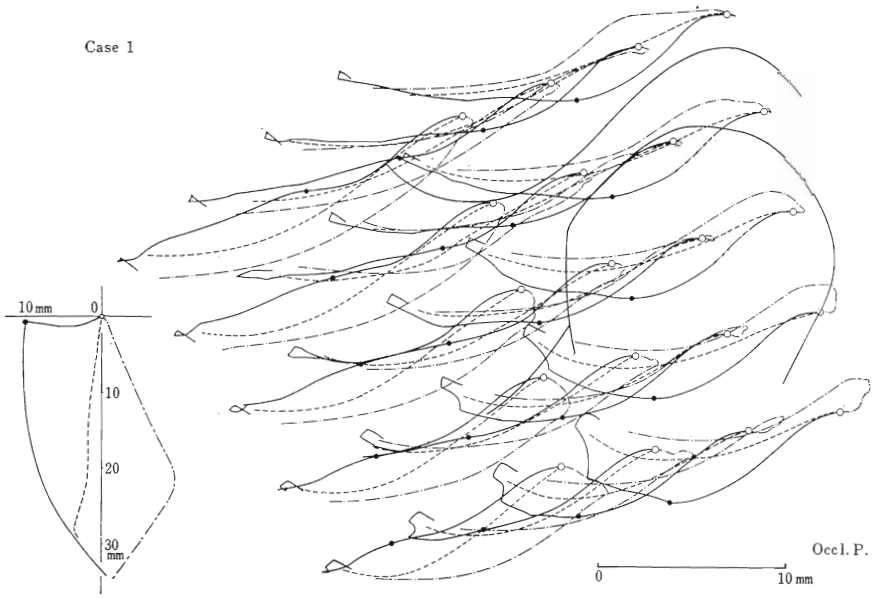

Fig. 6. The movements of 20 points in and near the condyle region are superimposed on a contour drawing of a laminagram of the condyle as a typical example. The shape of the range of the movements showed a closed curve line corresponding to the sagittal border movement at the incisal point. ○ : Intercuspal position. ● : Protruded contact position. —— : Protrusion and anterior border movement. —·— : Posterior border movement. - - - - : Opening momevent.

within the narrow range during the various sagittal mandibular movements (Fig. 7).

It can be considered that the whole mandibular movement in the sagittal plane is made by the rotation of the condyle around the axis connecting the specific points on both condyles and the translation of the specific axis along the narrowest belt-shaped range. We named this axis "Kinematic Axis".

The shape of the range of the movement in the condyle region showed a variation not only in its form but also in its property according to the place of the points around the kinematic axis point. It was clear in all cases that the path of the protrusion and anterior border movement was located above the path of the posterior border movement at the anterior point of the kinematic axis, and on the contrary, at the posterior point of the kinematic axis the path of the protrusion and anterior border movement was located below that of the posterior border movement. At the point above the kinematic axis the path of the protrusion was located above that of the posterior border movement near the intercuspal position, and then

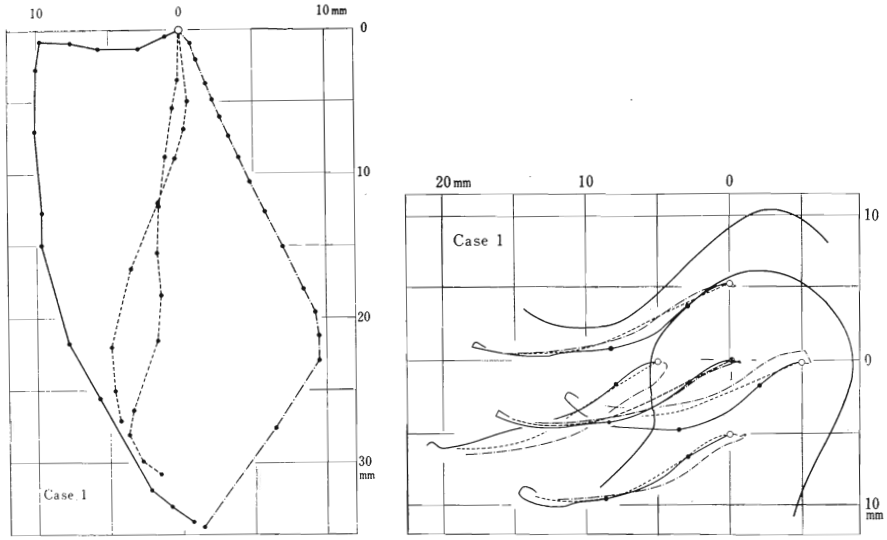

Fig. 7. The movements of the kinematic axis and other four points, which are located 5 mm anterior, posterior, superior and inferior to the kinematic axis (right), corresponding to the sagittal border movement at the incisal point (left).
⊙ : Kinematic Axis.

the former intersected the latter. At the point below the kinematic axis the paths were completely contrary to those at the upper point (Fig. 7). From the results, it is proper to consider that the mandible translates, rotating around the kinematic axis.

Sagittal Condyle Path

The sagittal condyle path is defined as the definite narrowest belt-shaped range where the kinematic axis moves during the whole sagittal mandibular movement. It showed a shape similar to the posterior slope of the articular eminence. About one-third of the path near the intercuspal position was considered to be a straight line, ranging from 4.7 mm to 8.3 mm, an average of 5.9 mm. Its inclination to the occlusal plane ranged from 27.5 degrees to 52.0 degrees, an average of 39.7 degrees (Table 1).

In the edge-to-edge occlusion, the position of the kinematic axis was nearly at the part of straight line of the condyle path in all cases. The inclination to the occlusal plane of the line, connecting both positions of the kinematic axis in the intercuspal position and the edge-to-edge occlusion, ranged from 26.1 degrees to 46.7 degrees, an average of 37.3 degrees. On the other hand, the inclination of the sagittal incisal path ranged from

Table 1. Inclination of sagittal condyle path and sagittal incisal path (degree)

Subject	Incisal path	Condyle path A	Condyle path B	Posterior slope of articular eminence
1	24.5	27.5	28.1	50.0
2	57.0	42.5	37.6	71.0
3	60.0	46.0	46.7	53.5
4	52.0	28.0	26.1	42.0
5	60.0	34.5	34.5	60.0
6	58.0	38.0	36.0	43.0
7	50.0	52.0	42.9	80.5
8	48.0	42.0	40.6	55.0
9	45.0	40.0	38.7	48.0
10	54.0	46.0	41.8	53.5
Average	50.9	39.7	37.3	55.7

A: Part of the straight line of the condyle path.
B: Part of the straight line connecting both positions of the kinematic axis in the intercuspal position and the edge-to-edge occlusion.

24.5 degrees to 60.0 degrees, an average of 50.9 degrees, and the inclination of the posterior slope of the articular eminence of the temporomandibular joint ranged from 42.0 degrees to 80.5 degrees, an average of 55.7 degrees. Inclination of the sagittal incisal path and the posterior slope of the articular eminence was greater than that of the sagittal condyle path (Table 1).

Hinge Axis and Kinematic Axis

The terminal hinge axis has been found clinically at the condyle region to be a stationary point when measured with the caliper pin of the face bow during the posterior border movement. In this study the hinge axis was found to be the least movable point while the subject was instructed to open from the retruded contact position to the point of curve in the path of the posterior border movement.

It was found quite difficult, if not impossible, for one person to repeat a definite posterior border movement many times. Therefore, the hinge axis point appeared in different places at each measurement on the same subject. In eight of ten subjects the hinge axis points were found in the region of the condyle, but in one case it was located in the rear of the condyle and in another case it was located at the neck of the condyle. In all cases the kinematic axis differed from the hinge axis, i.e. the former was located antero-superiorly to the latter and on an average 4.9 mm apart from

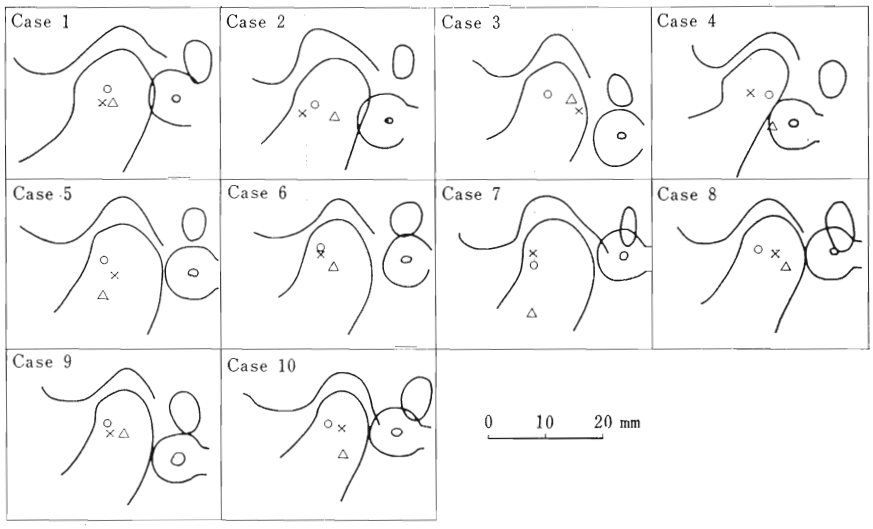

Fig. 8. The position of the kinematic axis, the hinge axis and the arbitrary condyle point of ten subjects are shown.
○ : Kinematic axis. △ : Hinge axis. × : Arbitrary condyle point (13 mm anteriorly to the tragus).

each other. On the other hand, the kinematic axis and the arbitrary condyle point (13 mm anteriorly to the tragus) were located, on an average, 2.9 mm apart from each other (Fig. 8).

The range of the movement of the terminal hinge axis was more than two widths of the range formed by the kinematic axis.

Discussion

During the opening movement, it has been accepted in general that the movement in the lower part of the temporomandibular joint, that is between the condyle and the disc, is mainly rotation, and the movement in the upper part, between the glenoid fossa and the disc, is gliding. Recently there have been many studies[1-3] to observe the movements of the condyle precisely. However, proper results were hardly obtained and the analysis was not accurate. The main cause for the different results in the measurement of the movement of the condyle is considered to be due to the position of the measured point being not specified on the condyle and to the use of various points in each investigation.

The author, using the cephalometric laminagram and the multiple electronic flush apparatus, examined the movement of the condyle in the sagittal plane at about 120 points in and near the condyle region. The

error of the multiple electronic flush apparatus was 0.1 mm, and including the mobility of the head and tracing error of the laminagram, the total error in this experiment seemed to be 0.3 mm.

Kinematic Axis:—The movement of the condyle showed various forms of closed curve according to the location of the measured points. Among the points a specific point was found in the condyle region. It showed the narrowest belt-shaped range during the various mandibular movements in the sagittal plane, the width of which was, on an average, 0.7 mm. Furthermore the path of the specific point during the opening movement and the protrusive movement of the condyle may be almost identical on the pantographic tracing. Therefore, it can be considered that the whole mandibular movement in the sagittal plane should be divided into the rotation around the axis connecting the specific points on both condyles and the translation of this axis along the narrowest belt-shaped range. We named this axis "Kinematic Axis" which is the center of the movement in the sagittal plane. The kinematic axis may be a kinesiological reference point for the condyle during the mandibular movement in the sagittal plane.

In principle, if the articular surface of the condyle is on a circular arc about the kinematic axis, the condyle may slide on a linear path rotating around the kinematic axis during the movement. However, the movement of the kinematic axis showed a belt-shaped range of a very small width, because of the compressibility of the disc and the structure of the articular surface of the temporomandibular joint.

Hinge axis and hinge movement:—Recently, the hinge movement and hinge axis are thought to be important. The reason is that the terminal hinge position can be utilized as the centric relation.

McCollum[4] described that the terminal hinge axis could be found at the condyle region as a stationary point when measured with a caliper pin of a face bow during the posterior border movement. Doubt, however, exists in the minds of other investigators[5,6] that not a single hinge axis exists but multiple hinge axes may exist. Some experiments[7] have showed that the extent of the terminal hinge opening is too small to register the hinge axis point precisely. Furthermore, it has not been confirmed that the mandible is capable of making a hinge-like closure in any protrusive position around the terminal hinge axis which is obtained as the center of an arc formed by the posterior border movement[8,9].

In this study, the hinge axis point was obtained differently by each measurement on the same subject. The reason was that the mandible could not always move on a definite path during the posterior border movement. As the result, multiple hinge axis points were found and located outside of the condyle region in 20% of the subjects, as in the reports by Sakuma[10] and Nemoto[11].

Kinematic axis and hinge axis:—The hinge axis was decided as the center of a specific movement such as the posterior border movement, while the kinematic axis is the center of all kinds of movements in the sagittal plane. Consequently the hinge axis may be found at a different position corresponding to the variation of the path formed by the posterior border movement, while on the contrary, the kinematic axis was found in a definite position in the condyle region and was not influenced by the variation in the border movement. Accordingly, the range of the movement of condyle at the terminal hinge axis can become more than two widths of the range at the kinematic axis. It was found that the condyle path of the opening movement differs from that of the protrusive movement by the pantographic tracing at the hinge axis point, as Shanahan has reported[12]. Furthermore, there is a great difference in the results of the measurement of the condyle path depending on the vertical dimension of the mandible. It is difficult to consider that all of the mandibular movements in the sagittal plane are explained by the rotation around the hinge axis and its translation, and they are reproduced by the gnathological method[13], where the terminal hinge axis is transferred to an opening-closing axis of an articulator.

It is concluded clearly that all of the mandibular movements in the sagittal plane can be explained by the rotation around the "Kinematic Axis" and its translation along the narrow belt-shaped condyle path.

CONCLUSIONS

1. The movement of the condyle showed a closed curve line corresponding to the sagittal border movement at the incisal point, and the shape showed a variation according to the point to be measured.

2. The specific point was found within the condyle region. At this specific point, the range of the movement showed a narrow belt-shape form, the width of which was, on an average, 0.7 mm.

3. It is considered that the whole mandibular movement in the sagittal plane can be divided into the rotation around the axis connecting the specific points on both condyles and the translation of this axis on the condyle path. We named this axis "Kinematic Axis" which is the center of the movement in the sagittal plane.

4. Multiple hinge axes were found on the same subject because of the influence of the variation in the posterior border movement, and the hinge axis was found to be outside of the condyle in 20% of the subjects.

5. The kinematic axis was located antero-superiorily to the hinge axis and on an average 4.9 mm apart from each other.

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