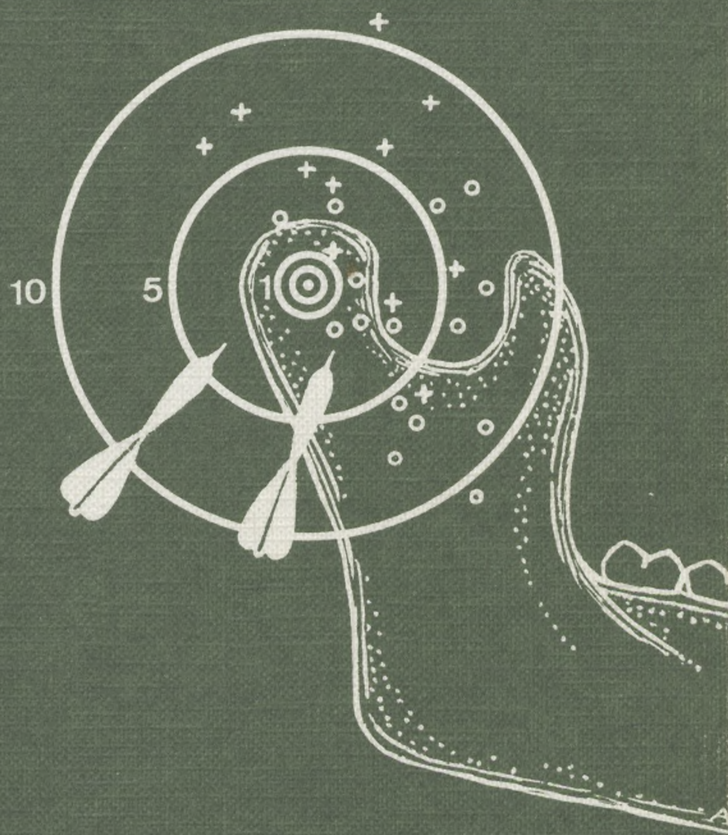
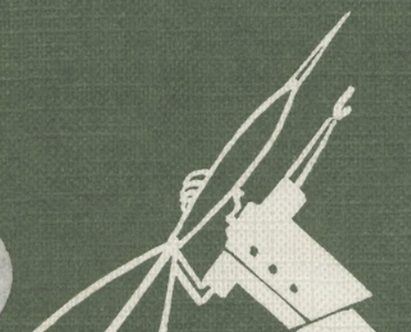
HINGE AXIS DETERMINATION OF THE MANDIBLE





A.E. BOSMAN

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AN INVESTIGATION OF THE ACCURACY OF MANDIBULAR HINGE AXIS DETERMINATION BY THE KINEMATIC METHOD AS COMPARED WITH SUBSTITUTIVE APPROXIMATIONS

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN DE GENEESKUNDE AAN DE RIJKSUNIVERSITEIT TE UTRECHT, OP GEZAG VAN DE RECTOR MAGNIFICUS PROF. DR. SJ. GROENMAN, VOLGENS BESLUIT VAN HET COLLEGE VAN DEKANEN IN HET OPENBAAR TE VERDEDIGEN OP DONDERDAG 19 SEPTEMBER 1974 DES NAMIDDAGS TE 4.15 UUR

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ALBERT ECKART BOSMAN
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Aan Ank en de drie jongens

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Aan allen, die medewerkten aan het totstandkomen van dit proefschrift, van professor tot proefpersoon, mijn oprechte dank.

"Writing is a means for learning and re-examining our beliefs."

C.O. Boucher, 1972

TABLE OF CONTENTS

INTRODUCTION AND AIMS OF THE INVESTIGATION

In the study of occlusion and articulation of the human dentition, the upper and lower teeth are viewed in relation to each other. In order to overcome the restrictions of a confined field and limited angle of vision in the mouth, an articulator is used in which are mounted exact models duplicating the teeth in their respective arches. If besides the static relations the movements of the mandible are also to be imitated, then these movements and the position of the teeth in relation to the temporomandibular joints must be recorded for the individual and transferred to the articulator.

While the dynamics of mandibular movement correspond basically to a moving system with 6 degrees of freedom, most articulators cannot reproduce all of these movements. A movement which, however, can be performed by all articulators is the rotation around a transverse axis. It is assumed by various authors that such a rotation around a fixed axis can also be performed by the mandible, and that it is important to duplicate this movement when alterations in the vertical dimension are involved. Studies of the mandibular movements by *Fischer (1935)* and *Posselt (1952)* have shown that the mandible is capable of complex movements composed of rotations and translations but that pure rotation around a transverse axis is also possible. This rotation corresponds to the first part of the posterior border movement of the mandible, also referred to as the "terminal hinge movement."

There exists a great variety of opinion in the literature with regard to this movement. A number of authors believe that in the study and restoration of occlusion it is of great importance to reproduce this rotation movement in the articulator. Others doubt whether this movement can be performed by the individual because they are of the opinion that no axis of rotation can be determined. It must indeed be taken into consideration that the long axes of the mandibular condyles are not in a straight line but form an angle with each other, so that from the anatomical point of view it seems unlikely that both condyles can rotate simultaneously around a common axis.

It is stated by a number of authors that the terminal hinge movement is actually possible but that this is a non-physiologic movement to which little or no clinical significance should be attached. Other authors, however, on the basis of scientific developments during the last decades, consider the terminal hinge movement and the determination of its "hinge axis" to be essential for the diagnosis and treatment of occlusal and temporomandibular joint disturbances.

Apart from the position taken with regard to these views, it can be stated that in order to reproduce the rotation movement of the mandible it is necessary to determine the exact location of the hinge axis. Most authors agree that this axis cannot be pinpointed on the basis of external anatomical landmarks. The question as to whether locating this axis by mechanical means is reasonably possible in a clinical procedure has led to the present investigation.

There is sparse information in the literature regarding the degree of accuracy with which the hinge axis can be determined using clinically accepted methods. This is most probably due to the difficulties inherent in clinical investigations of this nature. One of the main problems in evaluating determinations of the hinge axis is the fact that there is no possibility of comparing these with the position of the "real hinge axis."

The accuracy of a clinical determination of the hinge axis is determined by a number of factors, such as the apparatus and method chosen, the investigator, and further a number of clinical variables mainly depend on the subject. In the present investigation an attempt was made first of all to test the precision of the method under study in a laboratory investigation without clinical variables in order to provide a control for interpretation of the results of the subsequent clinical investigation. Then the accuracy with which the hinge axis could be determined on a clinical level was investigated with a number of test subjects. For this part of the investigation use was made of the kinematic method of axis location, the method most extensively applied to date. After this the results were used as a basis of comparison for examining two other methods which are extensively reported in the literature and which are most commonly used in attempts to reproduce in the articulator the dynamic relationships of the upper and lower jaws. Finally, by means of a roentgenographic technique, the position of the registrations yielded by each of the three methods was investigated in relation to the underlying mandibular condyles.

CHAPTER I

REVIEW OF LITERATURE ON THE HINGE MOVEMENT OF THE LOWER JAW

I.1 EARLY INVESTIGATIONS

18th AND 19th CENTURIES. It was not before the end of the last century that the interest of the medical profession was drawn to the movements of the lower jaw. Only a few publications are known from before 1900. In 1737 the anatomist *Monro* described the muscles that move the jaw. Like other anatomists of those days, he thought the normal opening movement to be a simple hinge movement similar to the movements in many other articulations of the body. To prevent the condyle from slipping forward "the muscles that open the mouth are so situated that when they act, they must also pull the jaw backward." The axis around which this rotation takes place goes, according to *Monro,* through both condyles of the jaw, just below the upper side.*

In a comprehensive treatise *Ferrein* in 1744 distinguished four principal movements of the lower jaw: the forward movement, the backward movement, the lateral movement from the center to either side, and the movement of depression and elevation. He disputed the opinion current at that time that the opening movement is a simple rotation, and he proved that the condyles during this movement do not stay in the glenoid cavity but move forward along the articular eminences. According to *Ferrein* the lower jaw turns around a variable axis which passes through the ascending ramus or just behind it. When the mouth is forced to a wide opening, says *Ferrein,* the opening axis rises distinctly and approaches the condyles.

Hunter (1771) says that with the depression of the lower jaw the condyle turns and at the same time moves a little forward, so that the opening is considerably enlarged. This movement shows that the rotation point is located just below the condyle, on a line from the condyle to the angle of the mandible.

Langer (1860) generally supports the findings of *Ferrein.* He remarks, however, that in postmortem subjects during the opening of the mouth no slide of the condyles is seen, but that the condyles rotate in the cavity of the articular disc. By means of needles placed in the condyle, *Langer* could locate by trial and error the approximate position of the rotation axis. In this way he proved that the axis of rotation of this movement is situated within the contour of the condyle.**

* For a schematic representation of the various locations of the axis of rotation as presented by Monro and others, see figure I.1.

** *Luce (1889)* criticizes the fact that anatomists use cadavers too often to demonstrate the movements of the joints. His own opinion is that the most important factor in the regulation of the finer jaw movements in the living subject is the synergism and antagonism of the different muscles.

Langer also analyzed the paths of movement of different reference points of the lower jaw as observed in the living subject. He noticed in postmortem subjects that with an opening of a little more than an inch the lower incisors viewed in the sagittal plane come to a point exactly under the first molar. This could not be found in living individuals, not even when the lower jaw was forcefully pushed backwards. When this was done the lower incisors did not come further back than directly below the upper canine.

Langer also employed a method of registration. He found that in the living subject the path of movement of the lower incisors was so slightly curved, or even straight, that the center of motion could not be within the lower jaw but had to be behind the ascending ramus. From his investigations *Langer* concluded that the opening movement of the lower jaw is compound by nature, consisting of a rotary movement and a forward movement. According to him there is no doubt that even in the compound movement the condyle bears the rotation axis, and that during the opening of the mouth this axis, together with the condyle, is shifted along the articular eminence. *Langer* formulates the view that the lower jaw rotates around a momentary axis travelling in space.

Meanwhile, various articulators had been developed in the years following their first introduction by Evans in 1840. These served to maintain the upper and lower casts in the correct relationship to each other in the procedure for constructing full dentures and also to imitate the jaw movements. From this time the search for an opening axis of the mandible is no longer a purely scientific quest. The imitation of the opening movement requires a correct positional relationship of the casts to the rotation axis of the articulator. In this connection, however, the question remained as to exactly where the opening axis is located in the living subject.

Bonwill in 1858 developed an articulator of such shape and movements that it "corresponds exactly with the mechanism of the human jaws," and with which "one can restore Nature's lost art." *Bonwill* was the first, in 1887, to underline the importance of the correct relation of the models to the joints of the articulator. From an investigation on 2000 human skulls, he found that, with variations of not more than half an inch, the average jaw measures about four inches between the centers of the condyloid processes and from each of them to the contact point of the lower central incisors. Thus the lower jaw forms a perfect equilateral triangle. This assertion is further attested by *Bonwill* in 1899, where he claims to have examined 4000 dead and at least 6000 living jaws. From these findings *Bonwill* concluded that with the aid of a pair of dividers the lower model should be oriented in the articulator with the contactpoints of the lower incisors 4 inches from the joints on either side.

TURN OF THE CENTURY. Following *Bonwill's* investigations many publications on the movements of the lower jaw appear around the turn of the century.

Luce (1889), like *Marey (1894)* and later *Ulrich (1896)*, made use of a photographic technique for the registration of paths of movement. *Luce* attached a bright silver bead to a wooden pin firmly inserted between the inferior central incisors. The subject was placed in strong sunlight so as to obtain a bright reflexion from the silver bead. By means of a photographic time exposure during the opening of the mouth, the path of movement of the bead was registered from the side.

In later experiments a light framework reaching around the face was attached to the lower incisors with silver beads at the front teeth, above the angle of the mandible and above the condyle. From his registrations *Luce* concluded that there is no fixed transverse axis of movement, but that during the initial opening movement the condyles move forward immediately and even move a considerable distance during a small degree of opening.

Walker (1896) applied a technique similar to that of *Luce.* As contrasted with the latter, *Walker* did find a point that moved neither backward nor forward. He located this point at the back of the ramus about 15 mm below the upper surface of the condyle. According to him all of the mandible below this point falls backward during the opening of the mouth and all above it, including the condyle, moves forward. *Mora (1895), Godon (1907)* and *Prentiss (1923)* indicate that there is a point of no movement at the mandibular foramen, so that, according to *Prentiss,* no trauma will be incurred by the fifth cranial nerve during jaw movements.

The idea that there is a fixed opening axis in the normal opening movement of the mouth is still widely accepted in this period. *Gray (3rd ed., 1864), Hoffman and Schwalbe (1877), Charles Tomes (3rd ed., 1889)* and others state that in small openings the temporomandibular articulation functions simply like a hinge. Only when the depression of the jaw is considerable do the condyles glide from the glenoid fossae to the articular eminences. According to *Tomes,* the axis around which the jaw moves is, due to the bend of the ramus, far behind the glenoid cavity and nearly in the plane of the masticating surfaces of the teeth. In a publication on a "misunderstood movement of the temporomandibular joint," *Constant* in 1900 disputes this opinion. He states that even the most moderate depression of the mandible is impossible without a coincident forward movement, which results in a rotation center directly beneath the condyle at a point two thirds of the way along a line drawn from the glenoid cavity perpendicular to a line extending horizontally from the base of the jaw. *Constant* does say, however, as *Hunter* had already concluded from his observations more than a hundred years before, that in infants and old people who have lost their teeth the center of motion of the mandible is located within the condyle.

In April 1901 *Tomes and Dolamore* describe experiments with photographic records and tracings of jaw movements on smoked paper. During the opening the mandible appeared to move approximately in the arc of a circle with its center 1 to 1½ inches below the level of the condyle and usually considerably behind the condyle.

In two articles (Sept. 1901) *Constant* again disputes this opinion sharply. In the 6th edition (1904) of his *Manual of Dental Anatomy, Tomes* admits that his previous assumptions have been proved to be incorrect and that from the first opening movement the condyle commences to travel forward.

Gray also, in his later (14th) edition of 1897, states that the ginglymoid or hingelike movement and the gliding movement both take place simultaneously. *Turner (1907)* formulates the view that the lower jaw rotates around a horizontal axis passing through the condyles which themselves are moved simultaneously downward and forward. During the movement of depression of the jaw the glide is thus continuously combined with rotation.

Even later some authors still believe that in small openings of the jaw the condyles simply rotate on a transverse axis against their fibro-cartilages. *Parfitt (1903)* indicates that the extent of the trajectory of rotation measures 6 mm at the incisors, *Campion (1905)* indicates 10 mm, and *Snow (1907 and 1911)* 6 to 12 mm. *Prothero (1908 and 1916)* believes that a hingelike movement takes place in the initial opening of the mouth and to a limited extent in the crushing of certain varieties of brittle food. Others, like *Frank (1909), Breuer (1910), Rumpel (1911)* and *Hall (1920),* hold that the axis of rotation is not located within the condyle but at some distance below it.

MOVING AXIS. *Chissin (1906)* states that in thin individuals it is easy to establish by means of palpation that the condyle travels forward and downward immediately after opening. *Chissin* regards the opening movement of the mouth as the sum of an infinite number of small parts. For each part a momentary axis of rotation is found at the intersection of the perpendiculars on the registered paths of movement of the condyle and a point of the chin. It became apparent to him that when the opening of the mouth is divided into three equal parts, the three axes belonging to these parts of the movement do not coincide. The axis of the last part, as *Ferrein* had also indicated, is found near the condyle. *Chissin* locates the momentary axis of the first part of the mouth opening behind the upper part of the ramus of the mandible.

From experiments on himself, *Bennet (1908)* comes to the same conclusion of a momentary axis for each part of the opening movement. Although there is movement of translation from the very commencement, the initial center of rotation located below and behind the condyle is, according to *Bennet,* of great importance to the question of the height of the bite in articulators.

Gysi in 1910 writes that exact experiments have shown that when the jaw opens the small distance necessary to correspond to the height of the overbite, the condyles remain in their normal resting position. Consequently, the rotation point in this small opening movement lies in the axis through the condyles. According to *Gysi* only this rotation point need be considered in the opening movement of an articulator, and the search for other rotation points of the mandible has no real practical value but is "more a scientific sport like the search for the north pole of the earth."

In later publications (1912, 1915, 1926, 1929) *Gysi* recognizes the immediate forward shift of the mandible in opening movements and finds that the opening axis travels from moment to moment. Dividing the total path of movement during the opening of the mouth in the same way as described by *Chissin, Gysi* also finds a momentary axis for each part. Only the first part of the opening movement, however, with its axis 1 cm behind the condyle in the plane of occlusion, is relevant to the prosthodontist. This is the rotation axis that later Gysi-articulators are accommodated for.

After the publications of *Chissin, Bennet, Gysi* and others, the discussion of a possible fixed opening axis subsides and most authors consider the normal opening of the mouth to be a movement of rotation around the condyles combined with concurrent translation. This is permitted *(Gray, 1897)* by the temporomandibular articulation, which consists of two distinct joints: one between the condyle of the jaw and the interarticular fibro-cartilage, and another between the fibro-cartilage and the glenoid fossa. In the lower compartment, between condyle and fibro-cartilage, the movement is of a ginglymoid or hinge-like character; in the upper compartment the translation takes place, the fibro-cartilage together with the condyle gliding forward to the eminentia articularis.

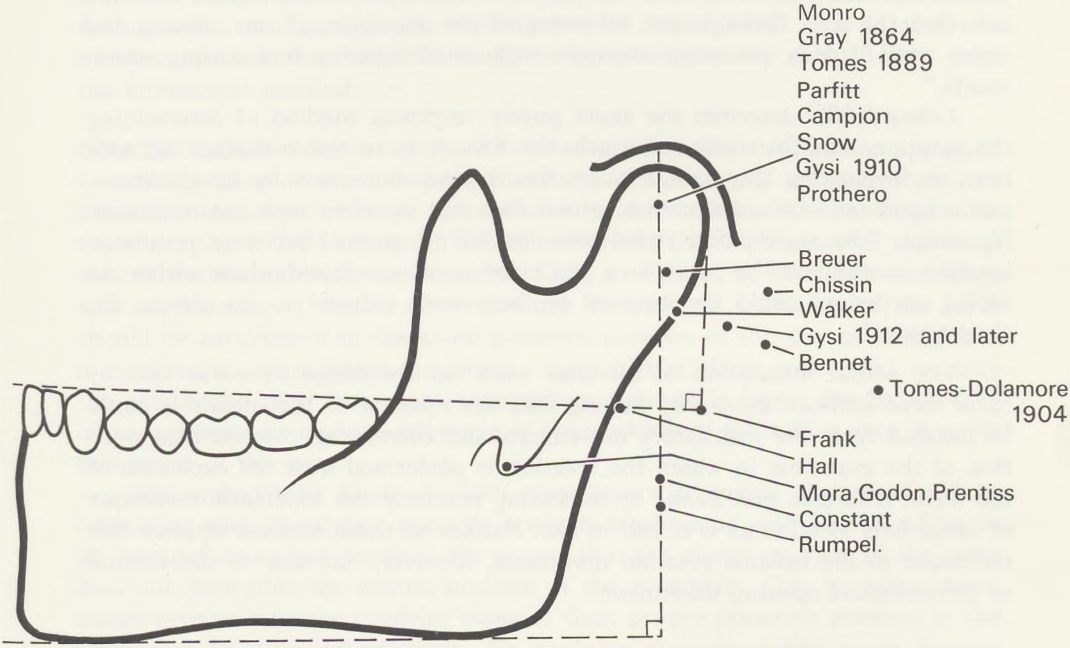


Fig. I.1. Locations of the transverse axis of the opening movement as indicated by different authors.

HINGE AXIS. In publications in 1909, 1911 and 1912, *Eltner* states that the search for a rotation center of the movement of normal mouth opening is useless and mathematically impossible. The movement in the lower compartment of the joint is a pure hinge movement around a transverse axis, which he calls the "hinge axis," passing through the center of the condyles. *Eltner* says this hinge movement can be performed by every individual starting from occlusion of the teeth until the posterior side of the ramus touches the anterior part of the mastoid process. The chin should be supported by the operator's hand and the patient opens the mouth while "protruding the upper jaw" or bringing the tongue backward to the palate. He says this hinge movement as a rule is different from the normal opening movement. However, according to *Eltner,* the occlusion of the teeth is obtained at the most posterior position of the mandible. That is why he concludes that raising the bite is a matter of pure hinge movement in the lower part of the joint with the axis passing through the condyles.

Andresen (1912) locates the axis as passing through the outer tubercle of the condyles and demonstrates a kinematographic method of finding the axis. Similarly to *Eltner,* he uses an adjustable face bow attached to the mandible and a writing stylus above the condyles. "The writing stylus of the registrator practically does not move from one position of the jaw to the other, and one can find the axis through the tubercles of the condyles, if one adjusts the stylus until it does not move anymore with small opening and closing movements."

Lehne (1920) describes the same purely empirical method of determining the rotation axis. In order to attach the face bow to the mandible he uses both an impression tray, which raises the vertical dimension by its thickness, and a band-and-wire construction, which does not interfere with the occlusion. He writes, "the registration stylus was directed to points that were presumed rotation centers until a point or a dot sized area was found where either no arcing excursions could be observed or these were reduced to an almost dot sized figure."

The actual foundation of all later work on the hinge axis was laid by these three authors: *Eltner* by finding that the rotation of the mandible could be isolated from the translatory movements and correlating the retruded position of the mandible in which the rotation is performed with the occlusion of the teeth; *Andresen* and *Lehne* by indicating precisely the kinematic technique of hinge axis location as it is still in use. Neither of these authors applied this technique to the isolated rotation movement, however, but only to the normal or physiological opening movement.

HINGE MOVEMENT. In 1924 *Kantorowicz* says that the pure hinge movement in the lower compartment of the joint is possible when the head is manually supported at the chin. The weight of the head pushes the lower jaw backwards so that the hinge movement, though not a physiologic movement, is performed.

In 1928 the anatomist *Sicher* states that he has shown the pure hinge movement to be possible for the living subject. What is involved is a voluntary movement which can be performed while the lower jaw is being held backwards. Although in postmortem subjects this hinge movement can be extended to the maximum opening of the mouth, in the living subject this is only possible up to two thirds of the mouth opening. According to *Sicher (1929),* this limitation is due to the compression of soft tissues between the ramus of the mandible and the mastoid process.

Schwarz (1926) indicates that the jaw movements are interrelated with the position of the head. He contends that the hinge movement occurs not only under voluntary control but also automatically during the normal mouth opening when the head is tilted backwards.

Fischer (1935 and 1939) studies the movements of the mandible and records a three-dimensional figure outlined by the lower incisal contact point during border excursions of the lower jaw. He comes to the conclusion that there is no backward movement possible starting from the intercuspal position of the natural teeth and, as *Eltner* also concluded, that the occlusion in dentures should be established with the condyles in their most retruded position in the glenoid fossae. Although the hinge movement and the physiological opening movement are different, according to *Fischer,* both movements start from the same intercuspal position of the jaw. This is in contradiction to the findings of a roentgenographic investigation of *Zaske (1937),* that in a certain number of cases the mandible could be forced backwards about 1 mm from the intercuspal position.

GNATHOLOGY. Meanwhile the American gnathologist *McCollum,* apparently not cognizant of the European literature, independently came to the same kinematic technique of hinge axis location as *Andresen* and *Lehne.* In publications in 1926, 1929, 1938 and 1939 he recognizes the importance of the hinge axis of the mandible for two reasons. First, as *Eltner,* he considers the hinge axis as the axis of centric closure, which means that occlusion of the teeth should be established in the same posterior position of the jaw as is required to perform the pure hinge movement. Second, *McCollum* states that locating the axis is the most important registration, because it forms the basis of all other registrations and the influence of the position of the axis is seen in every movement of the jaw.

The orthodontist *Stallard (1937)* postulates that cuspal closure should be coincident with "condylar centricity," which is obtained with the mandible in its retruded or centric position. He asserts that the closed position of the teeth does not determine the centric position of the mandible. This is rather determined primarily by the condyles being in their proper posterior position in the temporomandibular articulations. He explains that the joints never become adapted to the forward forced closure because the condyles withdraw to their normal posterior position as soon as the forcing cusps are eliminated. *McCollum (1938)* adds that only when the mandible is in centric relation, that is with both condyles in their most retruded position in the fossae, can the hinge axis be recorded with the kinematic or, as he calls it, trial-and-error method. Moreover, changes in the vertical dimension in the articulator can only be correctly performed when the opening and closing axis of the instrument corresponds with the axis of the patient's mandible.

I.2 RECENT APPROACHES

Whereas in previous years articulators were mostly employed for the construction of dentures, the Gnathological Society, founded in 1926 by McCollum, called attention to the analysis and treatment of the natural dentition. Consequently, there was a demand for a higher degree of accuracy, the aim being an exact reproduction of the jaw movements. In cooperation with its members McCollum developed an articulator called the "gnathoscope," which he considered "capable of duplicating the exact movements of the mandible." Four years later, in 1934, Stuart, Wightman, McQueen and he developed a face bow known as the "gnathograph," which he regarded as capable of recording all mandibular movements. No interocclusal wax records, which only record one or more arrested positions of the mandible, were used. With this instrument graphical recordings were made with a number of writing styluses which could also record all intermediate positions.

From that time until the present the Gnathological Society has consistently propagated the concept of gnathology. The basic starting point is the assertion that ideally the mandible should be in centric position to the maxillae. The condyles are then in their most posterior or retruded positions in the glenoid fossae. Gnathologists consider determination of the hinge axis one of the essentials in reconstructive dentistry. Since the hinge axis can only be found by the kinematic method from a rotation of the mandible in its most posterior position, this position is also called the (terminal) hinge position. However, the question as to whether the ideal position of the mandible is identical with the most retruded position remains open to discussion. Many authors, for instance, *Granger (1952, 1954, 1958, 1960, 1963), Lucia (1953, 1960, 1961), J.R. Thompson (1954), Kornfeld (1955), Cohen (1960), Kaplan (1963), De Pietro (1963),* and *Kahn (1964),* as part of the philosophy of gnathology consider that the two positions should coincide. They base their opinion on many years of clinical evidence that the use of the hinge axis is physiologically acceptable.

TWO INDEPENDENT AXES. *Page (1951, 1955, 1958), Rader (1955), Hoffman (1958), Brekke (1959), Slavens (1961)* and *Messerman (1963),* representing the approach of transographics, contend that functional closure of the mandible occurs with one or both condyles in hinge position. They assume that the two condyles of one individual are never aligned symmetrically because of differences in size and shape and positional relationship. They maintain that each condyle has its own transverse axis, which must be independently determined, and that each axis, being at right angles to the sweep of rotation, is completely independent of the other. This so-called split axis results in a deviation of the mandible during the opening or arcing movement. Both nonaligned *intra*condylar axes are represented in the transograph as pin-in-sleeve joints. To accommodate torque of the articulator as equivalent to mandibular deviation during opening and closing the transograph was made slightly flexible. The validity of the concept of two independent transverse axes is demonstrated, according to these authors, by the acceptance of several occlusal wax records varying from 2 to 18 mm thickness and accurate hinge closure in the articulator. *Schweitzer (1957)* raises the question why in this approach the condylar axes while not aligned must still always be parallel. *Trapozzano (1957)* states that bending of the articulator is not a controlled action, and *Weinberg (1959)* rejects the claim of two independent axes on a theoretical basis.

The question whether one or two hinge axes exist has been answered by the experiment with the elongated crossbars. This experiment has been carried out by Branstad, Garvey and Okey (1950), Lauritzen (1957), Lucia and Celenza (1959), and the Hinge Axis Committee of the Greater New York Academy of Prosthodontics (1959) as mentioned by *Lucia (1961)*, and by *Aull (1963)*. In this experiment the hinge axis is kinematically determined on each side of the face both close to the surface of the skin and at 12 inches distance. The existence of two independent axes would be substantiated by non-alignment of the lines through the hinge axis points thus determined on either side of the face. However, all investigators reported the same finding that all four hinge axis points were on one line, which excludes the presence of two non-aligned axes.

WHICH HORIZONTAL POSITION? *Schuyler (1929, 1953, 1959)* says that every effort should be made to reproduce the hinge axis accurately, but does not believe this can be done without error. From the most retruded position the mandible should be allowed to move forward without cusp interference about 0.75 mm. This range of antero-posterior freedom should be established in all fixed and removable restorations. This "long centric" or "free centric" occlusion is also accepted by *Pankey and Mann (1960, 1963)* and *Beyron (1969, 1973)*. According to *Ramfjord (1973)*, this range should be 0.5 mm or less. *McLean (1939, 1942)* states that centric closure takes place on the hinge axis, but that this is not necessarily the most retruded position to which the jaw can be forced. "True centric" is according to him the most retruded position which the patient can assume with comfort and from which the jaw can make mandibular excursions with comfort and facility.

Gerber (1971) strongly warns against the most retruded position of the mandible. This causes an unphysiologic disto-caudal displacement of the condyles which results, according to him, in an increase of the vertical dimension in the molar area and in a decrease in the bicuspid area. Both *Gerber and Weinberg (1973)* correlate the functional relationship of the mandible with roentgenographically proved bilateral centricity of the condyles in the glenoid fossae.

As to the horizontal position of the mandible in relation to the skull, *Hall (1929), Kurth (1938, 1942, 1959), Boos (1940), Sicher (1956), Posselt (1958), Tempel (1959), Osborne (1966), Jankelson (1973)* and others consider a position about 0.5 - 2.0 mm anterior to the most retruded position as physiological. An electromyographic study of *Moyers (1956)* showed that only 32% of edentulous subjects showed muscle relaxation and balance when the condyles are in their most retruded positions.

BORDER POSITION FUNCTIONAL? Opponents of the hinge axis philosophy argue that the procedure for its determination is only possible when the mandible is carried through a number of unphysiologic border positions. Therefore, if the retruded position could be shown to be a functional position, this approach would gain considerably in strength. *Ramfjord and Ash (1971)* consider centric relation as a functional border position of the mandible in swallowing. These functional retruded contacts were also observed by *Jankelson (1953). Graf and Zander (1963)* investigated tooth contacts by means of intra-oral telemetry. During the masticatory strokes no contacts of upper and lower teeth were found in the retruded maxillomandibular relationship. These, however, frequently occurred during swallowing and cleansing movements, as well as contacts in the intercuspal position. The number of contacts in both positions suggested that there is a relationship between them. In a later investigation of *Butler and Zander (1968)* retruded tooth contacts were also found during the chewing sequence, prior to the swallowing act. These findings are not confirmed by *Pameijer, Brion, Glickman and Roeber (1968, 1969, 1970),* who used an intra-oral telemetry system which enabled them to investigate tooth contacts in three different positions of the mandible simultaneously in one subject. These authors observed relatively infrequent tooth contact in a retruded position of the mandible. Even after occlusal adjustment which eliminated deflective or interceptive contacts from the retruded position, the number of tooth contacts in this position during chewing or swallowing was not increased.

Sheppard and Sheppard (1971) also observed only few contacts in a retruded maxillomandibular relationship in patients with complete dentures. However, *Pameijer (1973)* states that while people chew only an average of 8 to 10 minutes per day the real question is what happens during the other 23 hours and 50 minutes.

Ramfjord (1961) reported from an electromyographic investigation of patients with bruxism that a harmonious muscular contraction pattern could only be obtained after an occlusal adjustment that eliminated the slide from centric relation to centric occlusion and established a stable occlusion in this terminal hinge position. From his clinical investigations *Ramfjord* found that an occlusal discrepancy of as small as 0.1 mm in front of centric relation can be responsible for muscular spasms during swallowing.

Posselt (1971) found in patients with temporomandibular joint disease that adjustment of the occlusion which removed interfering contacts in the retruded position resulted in reduction or elimination of tenderness of the masticatory muscles to palpation and of clicking of the joints.

Reynolds (1970) reported from an investigation on 50 caries free individuals that the incidence of occlusal wear facets was smallest in centrically related dentitions. He concluded that maximum intercuspation should occur at terminal hinge (centric) relation. *Beyron (1973)* states that, since contacts in the retruded position occur during bruxism, mounting of the casts in this position enables the detection of potential interference in the retrusive range, so it will not be built into the restoration.

HINGE MOVEMENT. *Fischer (1935), Posselt (1952)* and *Beyron (1954)* have ascertained that the mandible in its most posterior position performs a rotary movement. This was confirmed by an electromyographical study of *Woelfel, Hickey and Rinear (1957).* They inserted needle electrodes in the external pterygoid muscles. During hinge opening no activity of these muscles was observed. The authors concluded that there was no forward movement of the condyles in the fossae, since this could only be the result of action of the external pterygoid muscles. *Posselt (1952, 1957, 1968)* concluded from his studies on the movements of the mandible that this terminal hinge movement can be performed voluntarily by powerful contraction of the middle and posterior fibres of the temporal muscles and also passively if the patient relaxes his jaw muscles and the operator carries out the movement.

Sicher (1964) ascribes the voluntary retrusion of the mandible to the effect of the posterior bundels of the temporal muscles, the deep portions of the masseters and sometimes the digastric and geniohyoid muscles. *Cohen (1960)* suggests the use of an elastic headstrap as a mechanical retruding device. However, *Posselt (1957, 1968), McLean (1942), Nyffenegger, Schärer and Jahn (1971), Ramfjord (1973)* and many others recommend that this border movement be performed by the operator.

Knap, Richardson and Bogstad (1970) studied graphical recordings in the sagittal plane with 10 subjects. From these registrations the upper part of the retruded stroke appeared to be a straight line rather than an arc. These authors conclude that the retruded motion appears to be a combination of rotation and translation of the condyle.

RETRUDED POSITION. Furthermore, many authors disagree on the term "(most) retruded position." *Posselt (1952)* found that the mandible is practically incapable of being displaced posteriorly any measurable distance from the arrow point relation of the Gothic arch tracing. *Zola and Rothschild (1961)* studied the retruded position of the mandible as obtained with different techniques in 25 individuals. They found that the amount of retrusion in 24 of the subjects was the same when acquired by normal retrusive guidance with the operator's hand, forceful guidance, or muscular retrusion by the subject himself. *Ziebert and Knap (1973)* also found equal retrusion with the operator's guidance or with auto-retrusion by the subject, and they conclude that distal displacement of the mandible beyond the physiologic range in a healthy temporomandibular joint is impossible in clinical practice. *L.J. Boucher (1961),* from a study of 12 patients, found that under anesthesia and curare the mandible could be displaced posteriorly in 11 patients. This finding is confirmed in a study by *McMillen (1972). Ingervall, Helkimo and Carlsson (1971)* applied different pressures on the mandible of conscious subjects in a distal direction. They found a significant reproducibility of the mandibular antero-posterior position when the same force was applied. However, with a distal pressure of 2.5 kg the mandible was retruded 0.06 mm more than with 1.5 kg and 0.16 mm more than with a pressure of 0.5 kg. Because different retrusive forces can result in different positions, some authors, for instance *Atwood (1968)* and

Ramfjord (1973), recommend that in retruding the mandible no unnatural force should be applied that can cause discomfort to the patient.

As to the limiting factor in the temporomandibular joint, *Aprile and Saizar (1947)* found that it is not the external or internal lateral ligament but rather the periarticular capsule that is mainly responsible for the limitation of the distal displacement of the mandible. This is confirmed by *Posselt (1952), Arstadt (1957), Brekke (1959),* and also *Sicher (1964),* who (in contrast to his position in 1929) attributes the limitation of the retrusive movement not to compression of the soft tissues behind the condyles but exclusively to the stretch of the horizontal bundels of the temporomandibular ligaments, which in turn protect the retroarticular tissues. For this reason *Sicher* considers the hinge position a unique and well-defined position. Although distal displacement is primarily restricted by ligaments, *Steinhardt (1958)* says that the muscles also play an important role. *Zola (1963)* believes that in the hinge movement of the mandible the pivoting point is the articulation between the medial pole of the condyles and the articular facets located on the medial walls of the glenoid fossae. With the articular disc interposed, according to *Zola,* the condyle is prevented from moving posteriorly and superiorly by the raised border of the articular facet. This should account for the regularity of the rotational movement of the mandible, which would not be the result of muscular action. This is in contradiction to *L.J. Boucher (1961, 1962),* who performed various experiments with human subjects. After severing the capsular ligaments both unilaterally and bilaterally he could not observe any difference of the maxillomandibular relationship when the mandible was forced to its most retruded position. *Boucher* concludes that muscles limit the posterior border movements of the mandible. *Saizar (1971)* proposes the meniscus theory and says that the condyles are prevented from retrusion by the interarticular discs, being stopped by the fitting of the postero-superior facets against the bony surface of the glenoid cavity. In this way the discs should function as buffers between the bony surfaces.

SIGNIFICANCE OF HINGE AXIS. Assuming that the most retruded position of the mandible at the given vertical dimension is one position of the terminal hinge path and that this position has its value in dentistry, opinions differ widely on the question of the clinical value of the hinge movement or the hinge axis, except for their purely scientific importance. In this respect it can be said that location of the hinge axis makes it possible to establish the positional relationship of the teeth to the axis in three dimensions. With the aid of a face bow this relationship can be transferred in order to orient the casts to the opening axis of the articulator. If the vertical separation of the casts has to be changed on the articulator, the face bow record and transfer procedure are essential *(Swenson, 1970).* The change of vertical dimension can be of importance in the construction of artificial dentures as well as in reproducing relationships of natural teeth, for instance when interocclusal wax records of varying thicknesses are employed *(Brotman, 1960).*

Posselt (1968) says that transfer to the articulator of the relationship of the patient's terminal hinge axis to his teeth makes it possible to reproduce any position of the terminal hinge movement, including the retruded contact position. "This is necessary when making intraoral records and transferring the lower cast to the articulator as two wax records of the retruded position seldom have the same thickness. With an exact reproduction of the terminal hinge movement the reproducible and therefore correct mounting position of the lower cast can be checked." This check of an interocclusal record, also deemed necessary by *Lucia (1961),* is made possible by a refinement in the articulator mounting technique known as the split-cast method and described by *Needles (1923), Lauritzen (1964)* and *Lucia (1961).*

Furthermore *Lucia (1953), Posselt (1968), Granger (1963)* and *Kaplan (1963)* also take into consideration all other registrations related to the hinge movement of the mandible, so that after the hinge component is reproduced hinge and translatory movements can be combined to reproduce the mandibular excursive movements correctly. *Bergström (1950)* found that the best reproduction of the protrusive movement in the articulator is obtained when condylar axis and articulator axis coincide. *Weinberg (1959)* states that "clinically no purpose is served by recording the path of the moving transverse hinge axis (functional movement) without first locating the 'starting' or terminal hinge position. Therefore, the 'trained' mandibular hinge movement is used to locate the non-moving transverse hinge axis." *Weinberg and Shore (1959)* also make clear that the transverse hinge axis plus one other anterior point serve to locate the maxillary cast in the articulator. *C.O. Boucher (1960)* states that if locating the hinge axis is an accurate means for locating the centric relation, its value cannot be questioned.

While a number of authors, *Sloane (1951, 1952), Collet (1955), Brotman (1960), Aull (1963)* and *Lauritzen (1970),* recognize the importance of kinematically locating and transferring the hinge axis of the mandible, others consider the exact kinematic location of the hinge axis impossible or unnecessary. *Craddock and Symmons (1952)* state that the search for the hinge axis is of no more than academic interest for it will never be found to lie more than a few millimeters distance from the assumed center in the condyle itself. *Levao (1955)* regards its value as only theoretical, since other inaccuracies result in greater discrepancies. *Shanahan and Leff (1962, 1966)* consider the strain in forcing the mandible backward to record the hinge axis as unphysiologic and reject this axis as being unsound and artificial.

Kurth and Feinstein (1951) and *Borgh and Posselt (1958)* conclude from experiments on mechanical devices that by means of the kinematic method it is not possible to locate the hinge axis with sufficient accuracy.

While *Lazzari (1955)* had still advocated the simple use of a regular face bow, *Trapozzano and Lazzari (1961 and 1967)* found the results of hinge axis determination even with an adjustable face bow too inaccurate to justify its use. From their investigations they found that in the majority of subjects more than one hinge axis point on either side of the face could be located. Since, according to these authors, other points can serve as terminal hinge axis points, they consider changing the vertical dimension on the articulator contra-indicated.

"ARBITRARY AXIS." Another group is formed by those who believe that the use of a face bow in establishing the correct positional relationship of the casts in the articulator is indicated, but that the added accuracy of the exact hinge axis location and its transfer is not justified. They adjust the face bow to one of the many points mentioned in the literature and supposed to represent the position of the opening axis of the mandible. However, there is a wide variation in the location of these so-called arbitrary centers of rotation. All of these points are derived from external anatomical landmarks, that is from a line from some part of the ear to the outer corner of the eye.

Schallhorn (1957) compared the location of the kinematically determined axis with an arbitrary point 13 mm anterior to the posterior margin of the tragus. He found that in 95% of his subjects the kinematic center was located within 5 mm of the arbitrary point, with a mean distance of 1.7 mm, and concluded that the use of the arbitrary axis for face bow mountings is justified, since an error of 5 mm is assumed to be within the allowable limits by *Arstadt (1954)*. *Lauritzen and Bodner (1961)* measured the distances between arbitrary and kinematic centers in 50 patients. They found that only 33% of the actual hinge axis points were located within 5 mm of the arbitrary point, which was determined to be 13 mm anterior to the external meatus of the ear as indicated by the Richey condyle marker.

Teteruck and Lundeen (1966) also arrived at the figure of 33% within 6 mm of the hinge axis for another arbitrary point 13 mm anterior to the foot of the tragus. With a special ear face bow this was found to be 56.4% and after a correction of its mounting hole 75.5%.

Beck (1959) compared three different arbitrary points with the location of the kinematically determined hinge axis. The mean distance between the three arbitrary points and the kinematic point was found to be 10.7, 5.7 and 4.1 mm. Although he advocated the face bow transfer, he concluded that it is justified to use an arbitrary axis. This is also concluded by *Brandrup-Wognsen (1953)*, and by *Christiansen (1959)* and *Schlosser and Gehl (1953)*, who also state that a good technique includes a palpation of the condyles to check the accuracy of the arbitrary method. *Gerber (1970)* advocates the use of a face bow oriented to condyle points derived from palpation of the lateral poles of the condyles.

MATHEMATICAL APPROACH. Concerning the clinical significance of the hinge axis, a number of authors have approached the question by means of a mathematical calculation of the errors involved when the exact location of the hinge axis is disregarded. However, it remains difficult to correlate millimeters of error with clinical effects. From a calculation of *Craddock and Symmons (1952)* it appeared that a set of casts oriented 2 cm anterior to their proper positions in the articulator would show a vertical disclusion of the teeth of 0.3 mm in the molar region, which would require 0.5 mm reduction in the incisor region to correct. They consider this discrepancy too small to justify the use of a face bow in full denture construction.

Arstadt (1954) found that "an error of 5 mm from the hinge axis results in an error of only 0.2 mm in the articulator, i.e. after a hinge movement of 2 mm in the articulator, the molar of the lower jaw will have contact with its antagonist 0.2 mm mesial or distal to the intraoral occlusal position."

Weinberg (1959, 1961) comes to about the same values. An error of 5 mm posterior to the hinge axis after transfer to the articulator with a wax record of 6 mm thickness at the incisors resulted in a horizontal error of 0.19 mm at the second molar and 0.10 mm at the incisors. *Weinberg* concludes that this can be considered a negligible error so that the anatomic average location of the transverse hinge axis is justified.

Brotman (1960) compares the effect of different variables on the resulting occlusal error. He finds that the *direction* in which the error of the axis location has been made influences the magnitude of the occlusal error. The maximum error is found if the axis is mislocated in a direction perpendicular to a line between the axis and the occluding teeth. This is also the position of *Fox (1967)*. Both *Brotman* and *Fox* computed the maximum occlusal error with 5 mm jaw separation and 5 mm error in hinge axis location to be between 0.2 mm and 0.3 mm. *Fox* concludes from his findings that location of the hinge axis within 1 mm is necessary in crown and bridge prosthesis. In complete denture service an arbitrary axis would be acceptable.

In 1969 *F. Bosman and Derksen* also computed the occlusal errors as a result of errors of the hinge axis location in different directions. They found that the maximum occlusal discrepancy is 0.67 mm in a horizontal and 0.45 mm in a vertical direction with 5 mm jaw separation and 10 mm error in hinge axis location. If the horizontal discrepancy would result in a mesial shift of the mandible, it can be accommodated for by establishing a "long centric." If, however, the horizontal error would result in a distal displacement of the mandible, there is no possibility of correcting this error since the mandible cannot be moved posteriorly from its retruded contact position. The autors conclude that if the vertical dimension on the articulator is to be changed, the hinge axis of the patient has to be determined and transferred.

ACCURACY OF HINGE AXIS LOCATION. From this review of literature it can be seen that in general two groups of authors can be distinguished: one group which does not believe that the use of a face bow in dentistry is justified and another group which does believe that the use of a face bow is indicated in denture construction or treatment of the natural dentition. The latter group can again be divided into those who believe that an approximation of the hinge axis is sufficient as a reference for the face bow and those who believe that this axis should be located exactly.

Since it is generally agreed at this time that a hinge movement can be performed by the mandible in its most retruded position, the question arises in regard to the accuracy with which the axis of rotation can be determined. On this point little is known. *McCollum (1929)* states that the hinge axis "can be definitely located," and *Granger (1952)* even says "with extreme precision." *Schuyler (1953)* says that in locating the axis no two operators would locate exactly the same point and that probably no operator could relocate the same point without a tattoo mark. *Schallhorn (1957)* indicates that an area with a radius of 1.5 mm would be approximately the range of variation. This is also found by *Hendrikson (1960)*. Referring to this author *Posselt (1968)* states that some experiments have indicated that the extent of terminal hinge opening is too small for precise registration of the hinge axis points. *Trapozzano and Lazzari (1961 and 1967)* found that multiple hinge axes could be located, and that it was possible to show that two styluses at widely separated hinge points could both be without movement during rotation of the mandible if they were located along the protrusive path of the condyle.

The accuracy of the determination of the terminal hinge axis is dependent on a variety of factors and has thus far been mainly a matter of conjecture. The degree of accuracy with which determinations can be carried out can only be ascertained by a controlled test of its reproducibility.

CHAPTER II

VARIOUS METHODS OF DETERMINING THE HINGE AXIS OF THE MANDIBLE

II.1 INTRODUCTION

In order to clarify the principles upon which the various methods of determining the rotation or hinge axis rest, a few basic concepts of kinematics are first noted. The rotation of a body around a single axis is a movement in which two points of that body remain at rest. All points which lie on a straight line passing through these two points also remain at rest. This line is called the axis of rotation. Any point of the body which does not lie on this axis describes during the rotation of the body an arc of a circle in a plane perpendicular to the axis and parallel to any plane similarly defined by the path of any other point not lying on the axis. Such planes are called parallel planes. The center of a circle described in this way in a parallel plane is a point lying on the axis and remains, therefore, at rest during the rotation of the body.

One can determine the center of such a circle geometrically by constructing perpendiculars at the midpoints of two different chords of the circle. The point of intersection of these two bisecting perpendiculars is the center of the circle and so one point lying on the rotation axis. By repeating this procedure in another parallel plane a second point lying on the rotation axis is found. The rotation axis of the body is defined as the straight line passing through these two points.

The geometrical construction described here does not lend itself to clinical application in the search for the transverse axis of rotation. The rotation trajectory of the mandible is too small (10° to 20°) for a reliable construction. The principle is used, however, in various clinical methods.

II.2 CLINICAL METHODS

Almost all methods of determining the hinge axis of the mandible depend on locating two points of this axis, one point on each side of the face.

Andresen (1912) and *Lehne (1920)* describe the purely empirical method of determining the rotation axis of the mandible.

McCollum (1939) also describes this clinical method of determining the hinge axis, which, although it is applied with a certain effectiveness, he calls the "trial and error" method. Later, because of the nature of the procedure, this method is also called the mechanical-empirical or kinematic method.* In the nearest possible approximation of a sagittal plane on each side of the head the center is estimated of a circle to which belongs the arc described during a rotation movement by a point mechanically related to the mandible. For this procedure *McCollum* uses two separate face bows fastened rigidly to the upper and lower jaws** with a "flag" attached to the upper face bow, serving as a parallel plane on which the registrations can be made.

An adjustable face bow is attached to the lower jaw so that the two together can be regarded as a structural unit. If the mandible performs a rotation, then this is true of the face bow as well. The two sagittal arms of the face bow can be adjusted independently of each other in a sagittal plane. At the end of each arm a registering pin or stylus is attached in a transverse direction. The method of locating the rotation axis amounts to determining the position in which the point of the stylus remains at rest during the rotation.

To do this the point of the stylus is set as nearly as possible at the place where the axis is thought to be located, that is, at the estimated place of the condyle of the mandible. During the rotation of the lower jaw the point of the stylus will describe an arc of a circle in a parallel plane (fig. II.1, C-C'). One then constructs in the mind a perpendicular bisecting the chord of this arc. The center of the circle (M) must be located on this perpendicular and on the concave side of the arc. One then moves the stylus along this imaginary line so that the movement of the stylus during the rotation movement becomes progressively smaller as the stylus approaches the axis. If the movement of the stylus begins to increase again, the point of closest approach to the axis has been passed. If it were possible to estimate exactly by eye this imaginary perpendicular line, then it would be possible to work along this line bit by bit until the stylus arrives at precisely the correct place. In practice, however, the chance of estimating this exactly is very slight, so that in the position of closest aproximation (M') the stylus will continue to move somewhat. When this movement is minimal the point M is the nearest, lying to one side of the estimated perpendicular and on a line perpendicular to it in turn.

Now one approaches the point M anew by estimating the perpendicular (m') which bisects the chord of the remaining arc and locating the point of minimal movement again along this line (M"). After this second attempt the goal will generally have been approached very closely, but it may be that the procedure must be repeated a few times before the point of the stylus no longer moves visibly during the movement of rotation. When this position of the stylus is found, one assumes that the point M and thus one point of the rotation axis has been located.

* While the term "mechanical-empirical" seems to be more descriptive of the nature of the method, the term "kinematic" is the most widely used in the literature.

** The apparatus developed by McCollum has been changed little since his time. The upper face bow used in the present investigation and the face bow designed by Lauritzen (figs. VI.2 and VI.3) are essentially similar to it.

The whole procedure is then repeated on the other side of the patient's head. In this way a second point of the rotation or hinge axis is obtained, and so the axis is determined.

Fischer (1953, 1954) states that in order to find the rotation axis the paths of movement of two points of the mandible must be known, or better, of various points around the supposed location of the axis. In order to register these paths of movement, *Fischer* attaches to the lower jaw a circular wire frame to which several shiny steal beads have been soldered. During the performance of a rotation movement of the lower jaw a photographic time exposure is made with stroboscopic illumination. A number of momentary exposures is obtained which indicate the path of movement of each bead.

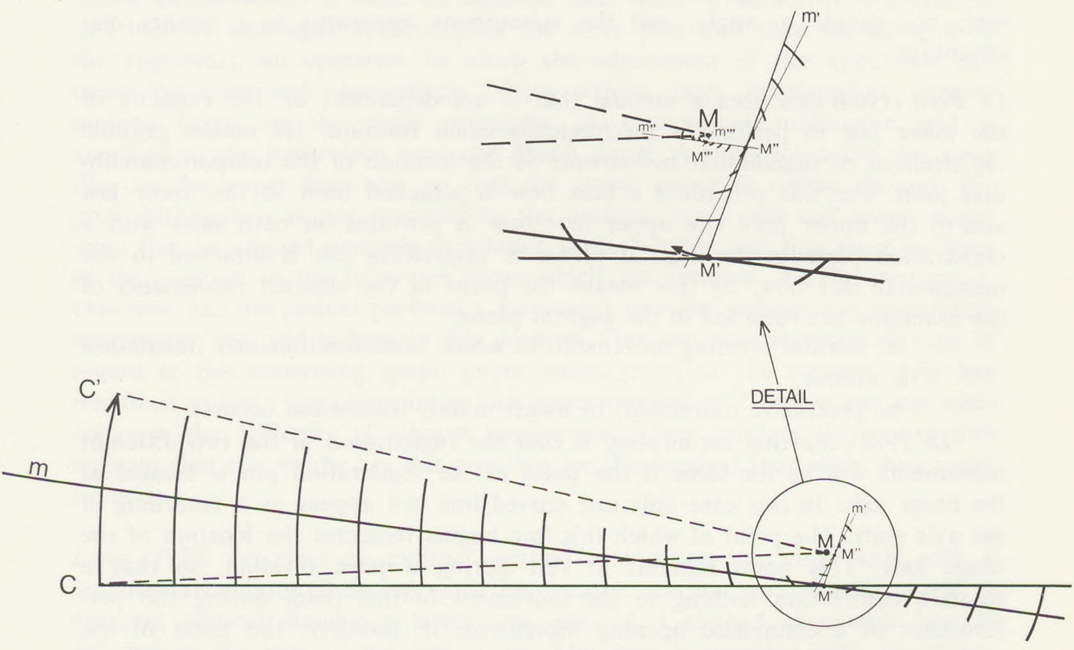


Fig.II.1. Schematic presentation of the principle of locating the center of rotation M according to the kinematic method. Movement of the point of the stylus in a parallel plane describes the arc of a circle C - C'. On the chord of this arc the bisecting perpendicular m is estimated. The stylus point is moved along this bisecting perpendicular on the concave side of the arc until minimal movement occurs (M'). On the arc described at that place the bisecting perpendicular is again estimated and this line is also tested until the point of minimal movement is found. This procedure is continued until no more movement of the stylus can be observed.

Another procedure of *Fischer's* is to register the movement of various points simultaneously in a graphical way. To do this he attaches a large flag to the upper jaw in the sagittal plane and to the lower jaw a face bow with three registration pins around the supposed location of the hinge axis. During a rotation the paths of the three points are recorded on the registering surface. Just as in the photographic technique, the hinge axis is located by constructing perpendiculars to the chords of the paths travelled.

Chick (1960) describes a photographic method of registering the various rotation axes of the lower jaw. A large frame of balsa wood is fastened rigidly to the lower teeth and thus to the mandible. A black paper screen covered with a large number of white dots (more than 1500) is attached to the frame. While the patient performs rotation movements with the lower jaw, a time exposure (1.5 sec.) of the screen is made with a camera. Because of the relatively long time of exposure, the dots appear on the photographic negative as curved lines. From the concentric configuration of these lines the rotation axis can be determined as the point that has shown no movement. The method is, however, not simple to apply, and the voluminous apparatus is a further disadvantage.

Le Pera (1964) describes a method that is not dependent on the capacity of the lower jaw to perform a mechanically exact rotation. He makes graphic registrations of mandibular movements at the location of the temporomandibular joint. For this procedure a face bow is attached both to the lower jaw and to the upper jaw. The upper face bow is provided on both sides with a registration plate in the sagittal plane. A registering pin is attached to the mandibular face bow. By this means the paths of two distinct movements of the mandible are recorded in the sagittal plane:

a. normal opening movement, in which both rotation and translation occur;
b. protrusive movement, in which mainly translation occurs.

Le Pera's starting assumption is that the registration of the two different movements will be the same if the point of the registration pin is located at the hinge axis. In this case only one curved line will appear as a recording of the axis shift. The point at which this line begins indicates the location of the hinge axis. This point remains at rest during a pure rotation, so that a rotation contributes nothing to the movement of this point during the performance of a compound opening movement. If, however, the point of the registration pin is not at the axis, then the registrations of the two different movements will be different. On this basis, according to *Le Pera,* the location of the rotation axis can be deduced with greater precision than with other methods.

If it is assumed that the two translatory movements are the same, *Le Pera's* starting point is correct. Although this investigator comments in his article that this method is at least five times as accurate as other methods, the registrations made by him are rather rough, while the precision of the method is not demonstrated quantitatively.

Gregory, Shryock and Baum (1969) describe a method which is, similarly to that of *Chick,* based on a photographic registration. In this method only a single rotation movement of the lower jaw is required on the part of the patient in order to determine the axis.

An unexposed x-ray film of 3 × 4 cm is attached to a face bow on the upper jaw in the area of the temporomandibular joint. To the lower face bow at the end of the sagittal arm a lead grid is attached with perforations at a distance of 1 mm from each other. While the patient performs a rotation movement with the lower jaw, the x-ray film is exposed from the side for 2 sec. with the long cone technique. The areas exposed through the perforations appear on the film as concentric arcs of circles. The center of rotation is found in the middle and is manifested as a point. If it appears that no single exposed point has remained at rest, then it is possible to estimate the location of the axis with reasonable precision between the points that produced the smallest arcs.

In clinical application the method of *Gregory, Shyrock and Baum* is rather cumbersome. It must be doubted that there is sufficient precision in this indirect technique of developing the x-ray film and then replacing it in the apparatus, an operation in which the adjustment of the apparatus can easily be disturbed. Accordingly, these writers later developed a simpler method based on the same principles. A transparent millimeter grid is attached to the lower face bow and graph paper is substituted for the x-ray film on the upper face bow, so that the graph paper is visible through the grid. Although it is not reported by the authors, both grid and graph paper must first be aligned precisely in relation to each other and this must be done in the position of the lower jaw from which the rotation will be performed. One now has the patient perform a maximum rotation without any translatory movement. The grid is fixed in this position. One can now ascertain directly in regard to the underlying graph paper which point of the rotating grid has remained at rest. The objection to this latter method of *Gregory* and his associates is the difficulty of clinical application. These authors themselves also indicate that the results are less accurate for this method than with their x-ray technique.

Long (1970) describes an indirect method of locating the hinge axis with a modified articulator (Buhnergraph). Two centric relation wax records, made at different vertical dimension levels, are used. A U-shaped aluminum bow is attached to the base of the articulator. This bow is provided with an adjustable stylus on each side of the articulator and near the articulator axis. The condylar elements of the articulator are removed so that the upper cast and the upper member of the articulator can move freely. A piece of graph paper is fastened to the lateral face of each condylar housing. With the thin wax record interposed between upper and lower cast, a point is marked on the graph paper with the stylus on each side oriented arbitrarily. A second point is marked with the thick (6 mm) interocclusal record interposed between the casts. If these two points should coincide they are assumed to be on the hinge axis. If they do not coincide they are considered to be two points of an arc of the sort the stylus describes in the kinematic location of the hinge axis of a patient. The hinge axis is assumed to be on the bisecting perpendicular of the line connecting the two marked points. To find the axis the procedure of the two markings at different vertical dimensional levels is repeated after the styluses have been moved along the perpendicular and then at right angles to it.

The hinge axis is found, as has been elucidated theoretically (page 19), at the intersection of the two bisecting perpendiculars. This, however, may be difficult because of the small arcs of movement and the relatively rude instruments of registration, as the authors admit. Although the principle of this method of hinge axis location is correct, the trajectory of rotation of the mandible is, as has been stated, too small for a reliable mathematical construction.

Finally one other procedure must be reported, that of *Lauritzen (1970),* who is a proponent of the mechanical-empirical or kinematic method. He offers a few general considerations regarding the clinical procedure which help make an effective search for the axis simpler. It is clear that approaching the axis more closely is no problem when the stylus is located far from the rotation axis. The movement described is then so clearly recognizable as an arc that one can see rather easily in which direction to move the stylus. Difficulties appear, however, when the distance from the rotation axis becomes so small that the arc thus described is observed as a straight line. The direction toward the axis can then no longer be deduced from any visible concave shape of the arc. Effective further search in this way is no longer possible.

For this last phase *Lauritzen* has suggested a simple procedure. When the patient performs an opening movement, the stylus on the right side of his face, wherever it is in relation to the actual axis, makes a circular movement to the right. If the point of the stylus is compared to the end of a clock hand (fig. II.2), it can be deduced from the direction of movement of the point on which side of the line thus described the rotation axis — whether of a clock hand or of the patient's mandible — must be located. Given the help of this analogy, one has sufficient information from a single opening movement to know in which direction the stylus must be moved. Care must be taken, however, that the stylus rotates in a clockwise direction. On the left side of the patient's face the same opening movement of the mandible will produce a counter-clockwise movement of the stylus. Therefore the patient must perform a closing movement of the mandible in the determination of the axis on the left side.

Besides this suggestion regarding the *direction* in which the rotation axis is to be sought, *Lauritzen* also gives an indication in regard to the *distance* from the arc to the axis. In this connection he comments that this distance to the axis is approximately equal to four times the length of the registered arc. This figure is correct when the angle of rotation of the mandible is equal to 1/4 of a radian, that is, $1/4 \times 57°21' = 14°20'$. Since this angle is in reasonable agreement with the extent to which, according to most authors, the lower jaw is capable of performing a pure rotation (10° to 20°), *Lauritzen's* suggestion can be regarded as a useful aid in practice.

In this chapter a number of methods reported in the literature for determining the hinge axis have been described. Of these the kinematic method is

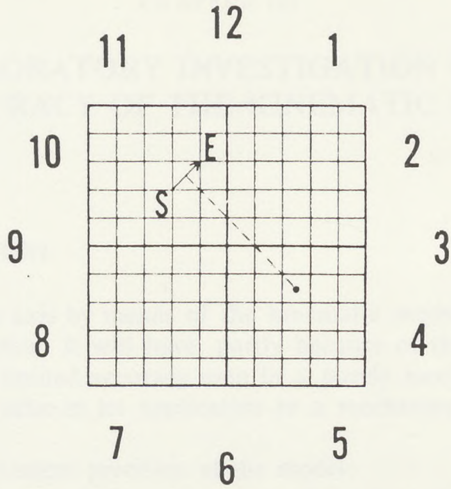


Fig. II.2. Procedure of Lauritzen when there is very little movement of the point of the stylus. In a single rotation movement, the movement of the stylus point from start (S) to end point (E) of the movement must be in a clockwise direction. This occurs on the patient's right during opening and on his left during closing. The hinge axis is then to be sought in the direction of the imagined axis of the clockhand at a distance approximately 4 times the length of the arc thus described. (Diagram taken from *Lauritzen, 1970,* p. 6).

undoubtedly the most important, since this is the one which is most generally applied. There are nonetheless a number of objections to be made in connection with its clinical application. For instance, the result is dependent on the ability of the patient to perform a pure rotation with the mandible without any translation taking place. The further problem can occur that the patient is unable to perform a rotation of sufficient magnitude to make the determination of the axis possible. It is also inherent in the method that the point of the stylus moves progressively less as one approaches the axis, so that progressively greater problems of observation appear during the procedure. Consequently visual acuity of the operator may begin to exert an influence. The result is moreover dependent on the experience, competence, interest and concentration of the operator.

McCollum also recognized these difficulties. He writes already in 1939 that he has looked long for clinically more appropriate methods, but that finally the kinematic method has appeared to him to be the most useful. The other methods described here have actually appeared as incidental publications in the literature and have evoked almost no imitation. For this reason, it has been decided to utilize the mechanical-empirical or kinematic method in the present investigation.

CHAPTER III

LABORATORY INVESTIGATION OF THE ACCURACY OF THE KINEMATIC METHOD

III.1 INTRODUCTION

Locating the rotation axis by means of the kinematic method is in principle a dynamic-visual operation. It will have, partly because of the empirical character of the method, a limited accuracy even in a purely mechanical experiment. The errors that may arise in its application to a mechanical model are dependent on:

1. the mechanical precision of the model;
2. factors determined by the nature of the procedure;
3. factors connected with the investigator.

If the same procedure is applied to test subjects, then the number of variables is further increased. Without going into this in more detail here, it can be posited that if errors inherent in the method result in an excessive degree of inaccuracy, then the value of axis determination by this method is cast in doubt. For this reason a number of authors have instituted laboratory investigations of the accuracy of the method. Some of them depend on the results of these experiments in their criticism of the clinical determination of the hinge axis.

Kurth and Feinstein (1951), for example, conducted an investigation with the aid of an articulator with an adjustable face bow attached to the movable upper arm. Rotations of 11° were performed. It appeared to them that the stylus point could be set anywhere within an area of 2 mm in diameter and still remain without observable movement during the rotation. These authors conclude from their investigation that it is most unlikely that the axis can be determined with any degree of accuracy in a clinical procedure.

Borgh and Posselt (1958) registered the results of 30 determinations on the left and the right joints of an articulator. For angles of rotation of 10° and 15° they found that the registrations fell within an area of 1.5 mm and 1.0 mm in diameter respectively. These authors confirm the results of *Kurth and Feinstein* and state that the axis could not be determined without error for an articulator and the angles of rotation mentioned.

Lauritzen and Wolford (1961) also carried out a laboratory investigation with a face bow arm attached to an apparatus specially developed for this purpose. 45 axis determinations were made by a number of investigators experienced in the technique with angles of rotation of 15°, 10°, and 5°. With 15° and 10° of rotation these authors found that 95% of the determinations fell within an area with a diameter of 0.4 mm and that with an angle of 5° this was the case with 75% of the determinations. Their conclusion was that the accuracy attained is sufficient for clinical determination of the axis.

Since the opinions of various authors differ so widely and since the results are of essential importance for the judgment of clinical results, it was decided to investigate independently the accuracy of the method in a laboratory investigation set up to reproduce as nearly as possible the clinical situation. Moreover, for a comparison of the results of the clinical investigation with those of the laboratory investigation, it is desirable that both be carried out by the same investigator.

III.2 APPARATUS

A Dentatus articulator (type ARH*) was utilized as the basic instrument. The functions and relations of this instrument correspond sufficiently to clinical circumstances to make reasonably representative results probable.

The articulator (fig. III.1) is mounted solidly on a stable base plate and provided on each side with an aluminum plate making the construction very rigid.

Windows are made in these plates at the location of the left and right articulator joints. To the outer side of each window a cassette is attached (fig. III.2) in which an x-ray film of 3 × 4 cm can be inserted. The cassette is provided with a cover and a square opening of 28 × 28 mm. On the inside of the cover four pins are placed at the corners in such a way that when the cover is closed the pins pierce the x-ray film inserted in the cassette, so that it is held securely in position (fig. III.3). The successive axis determinations can be registered on this x-ray film by puncturing it from the lateral side with a sharp instrument.

In order to be able to register several determinations on one film without being influenced by previous determinations, there is a groove between the film and the cover in which a strip of graph paper can be inserted. In this way the x-ray film is hidden from the eye during the determination of the axis.

The axis of rotation of the articulator can be recorded on the same x-ray film from the medial side. For this purpose a precisely fitted extension provided with a sharp point is attached to the ends of the articulator axis. This extension can easily be moved along the axis shaft without observable play. To reduce the chance of deflection to a minimum, the extension is further supported by a fitting in the wall of the cassette that allows it to glide smoothly. By sliding the extension laterally the emulsion layer of the x-ray film can be punctured. By this means the positions of the determinations can be compared with the actual position of the rotation axis.

In order to determine the accuracy of the method for various degrees of opening, a device is attached with which the degree of opening of the articulator can be limited. For this purpose a compass with its center corresponding to the axis of the articulator is attached to the aluminum construction. A small projecting bar can be slid along the compass and clamped tightly in

* AB Dentatus, Stockholm, Sweden.

any position to keep the arm from opening further than the angle at which it is set (fig. III.1).

For determining and registering the transverse axis of rotation the adjustable face bow as designed by Lauritzen* was used (fig. III.4). This face bow is

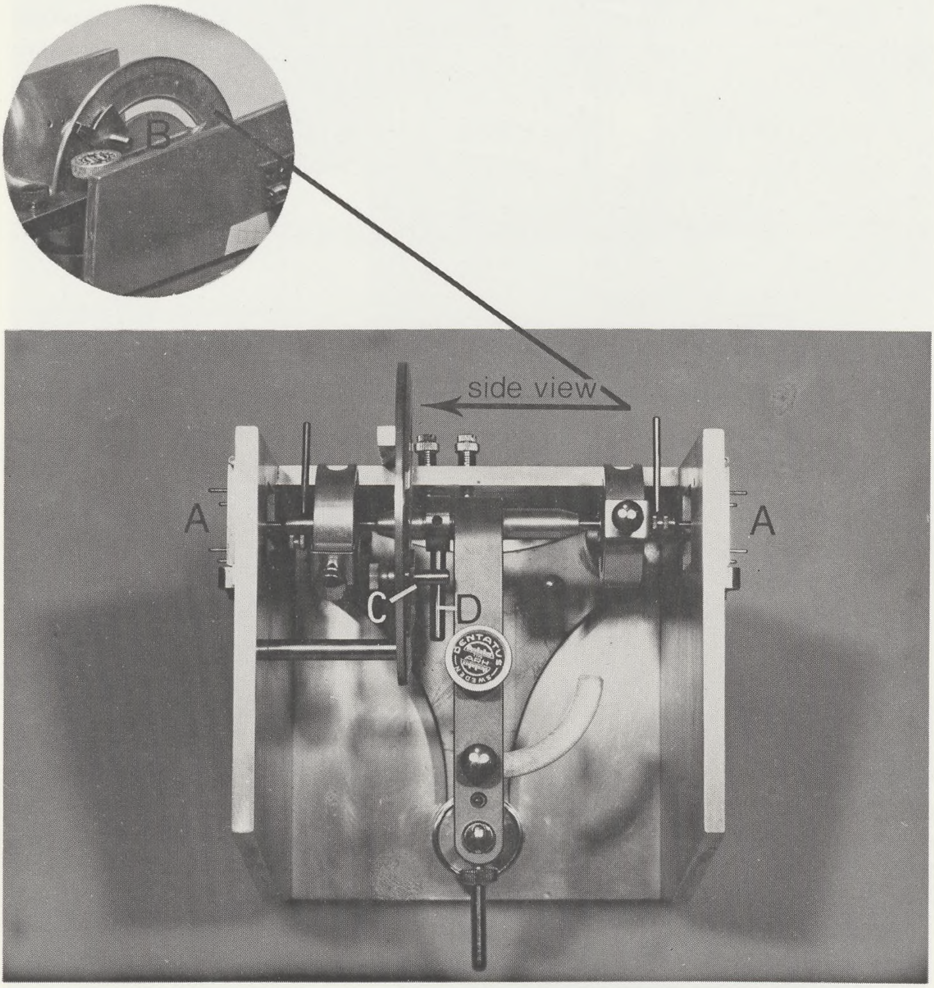


Fig. III.1. Dentatus articulator mounted on a stable base plate and provided with aluminum side plates. To this construction are attached the cassettes (A) and a compass (B) with a movable bar (C). On the articulator arm is located another bar (D) which is arrested by it, thus limiting the opening of the articulator. By means of this device the angle of rotation is completely adjustable and can be read from the compass.

* Almore Manufacturing Co., Portland, Oregon, U.S.A.

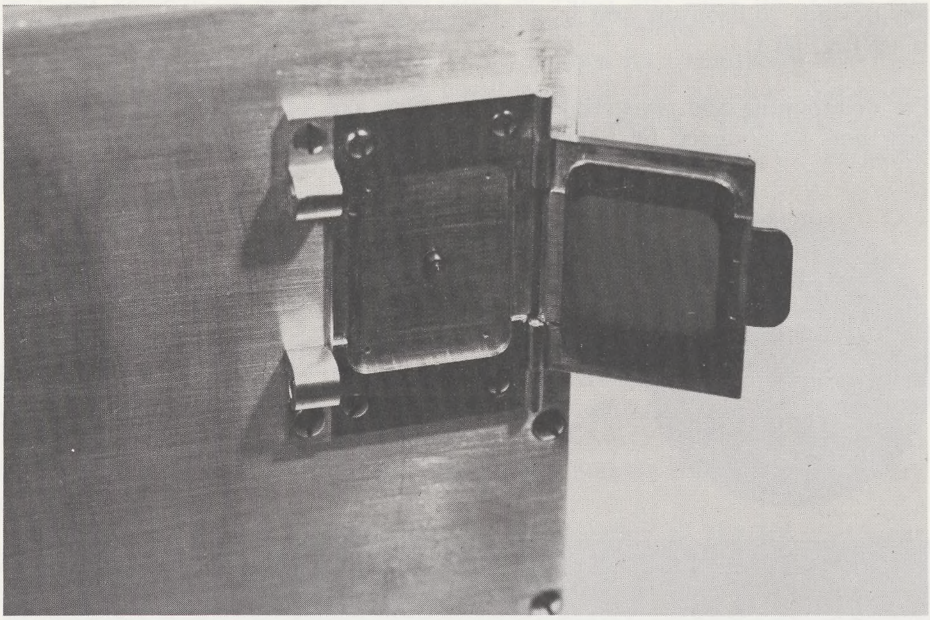


Fig. III.2. At the location of the articulator joints cassettes are attached to the outside of the aluminum plates. Into these filmholders a 3 × 4 cm x-rav film can be inserted.

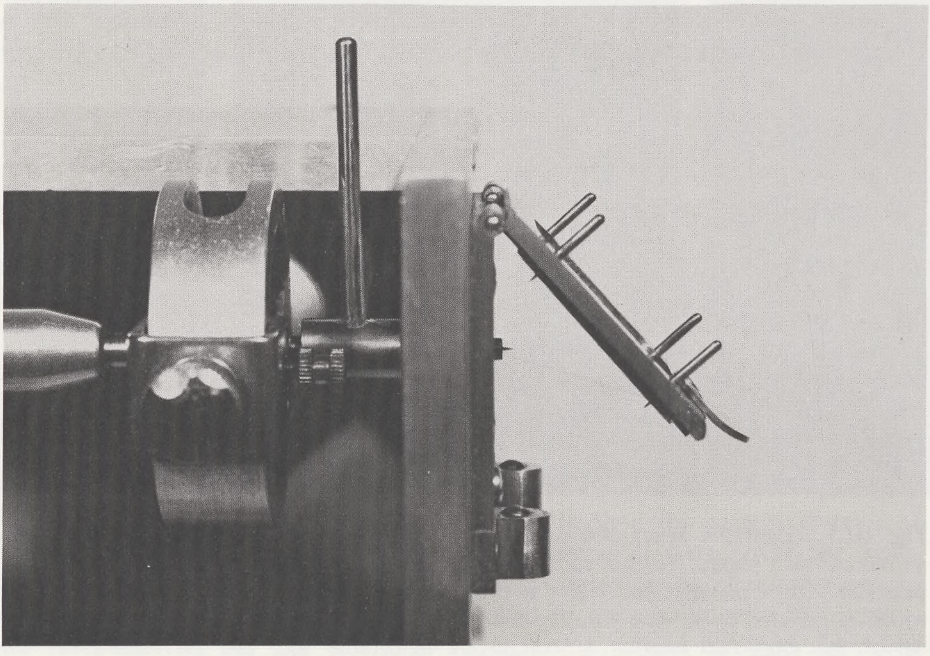


Fig. III.3. The point of the actual rotation axis can be recorded on the x-ray film from the medial side by means of an extension on the axis shaft of the articulator. When the cover is closed 4 small pins perforate the x-ray film.

especially suitable for this purpose because of its very light weight and because it can be adjusted easily and very precisely. The face bow consists of a transverse bar to which two sagittally oriented arms are attached by means of universal locking clamps. These side arms have a telescoping structure and can be varied in length by means of adjustment screws. The arms are also provided with adjustment screws so that they can be rotated in a vertical plane. At the end of each arm and perpendicular to it there is a slide fitting through which a registration pin or stylus can be inserted and moved in the transverse direction. Given these various possibilities of adjustment, the point of the stylus can be moved in all three dimensions.

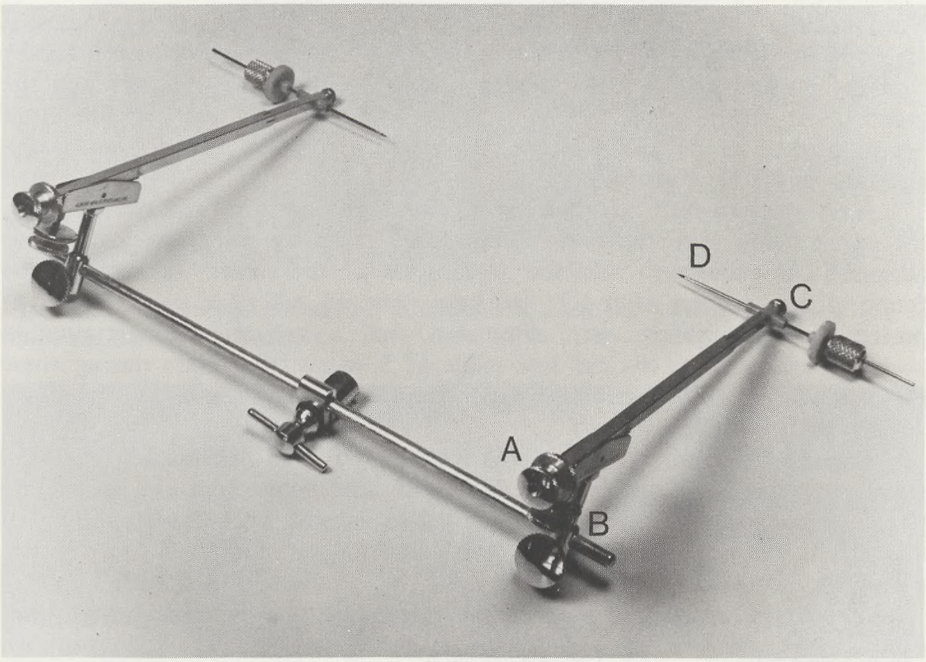


Fig. III.4. Adjustable face bow as designed by Lauritzen. The side arms are comprised of two telescoping parts so that they can be extended or retracted by means of an adjustment screw (A). Each arm can be moved vertically by means of another adjustment screw (B). At the end of the arm is located a slide fitting (C) through which passes the registration pin or stylus (D).

The Dentatus articulator in its commercial design is provided with an incisal pin that can be clamped to the upper arm by means of a screw. For the present investigation a horizontal bar was attached to this pin in such a way that the face bow could be secured to it by means of a universal locking clamp (fig. III.5).

To avoid errors in puncturing, the stylus must be mounted perpendicular to the film. This is accomplished by positioning the transverse arm of the face bow parallel to the articulator axis.

III.3 PROCEDURE

A number of blind determinations of the axis were carried out on the left and the right side of the instrument according to the kinematic, or mechanical-empirical method described in the preceding chapter. The procedure was as follows.

First an x-ray film was exposed for a relatively short time and developed. In this way a uniform gray registration plate with an emulsion layer on each side was obtained that was well suited to photographic enlargement after the registrations were made. This film was placed in the cassette and then covered with a strip of graph paper inserted in the groove of the cassette (fig. III.6). Next the angle of rotation for the upper arm of the articulator was adjusted and a determination was carried out. The point determined was recorded by carefully puncturing the outer emulsion layer of the x-ray film through the graph paper with the point of the stylus. It was important that the film itself not be pierced in this operation, since this would produce a much too rough and thus imprecise registration.

After this puncture had been made, the face bow arm was turned away, the adjustments were randomly altered and the strip of graph paper was advanced far enough so that the perforation in the paper was beyond the frame of the cassette. After this had been done all reference points from the preceding determination were eliminated, and a subsequent determination could be carried out. No use was made of a magnifying glass during these registrations in order to make the given situation correspond as closely as possible to clinical circumstances.

Finally the actual position of the rotation axis was indicated on the film from the medial side. In order to distinguish this point from the determinations obtained by the kinematic method it was marked with a scratch. Thus it was possible to record on one film in a blind test a number of test registrations and also the actual point of the axis.

In order to provide a reference line in relation to which the registrations could be examined, a line was drawn on the film parallel to the Frankfort horizontal plane, that is, parallel to the base of the articulator.

After this the x-ray films were ready for enlargement in order to carry out the measurements. It appeared rather often that registrations coincided partly or completely with each other or with the actual axis point, which caused difficulties in interpretation. For this reason no more than three determinations were carried out per x-ray film.

In regard to the angle of rotation of the upper arm of the Dentatus articulator, values were selected that correspond to anatomical relations. It is reported in the literature that the rotation trajectory of the mandible measured at the incisors can vary between 12 and 25 mm. From these givens and the dimensions of the triangle of Bonwill, the corresponding angles of rotation can be calculated. These will then lie between 8° and 17° (fig. III.7).

Proceeding on this basis, it was originally decided to include two angles of rotation in the present investigation, namely 15° and 10°. However, because

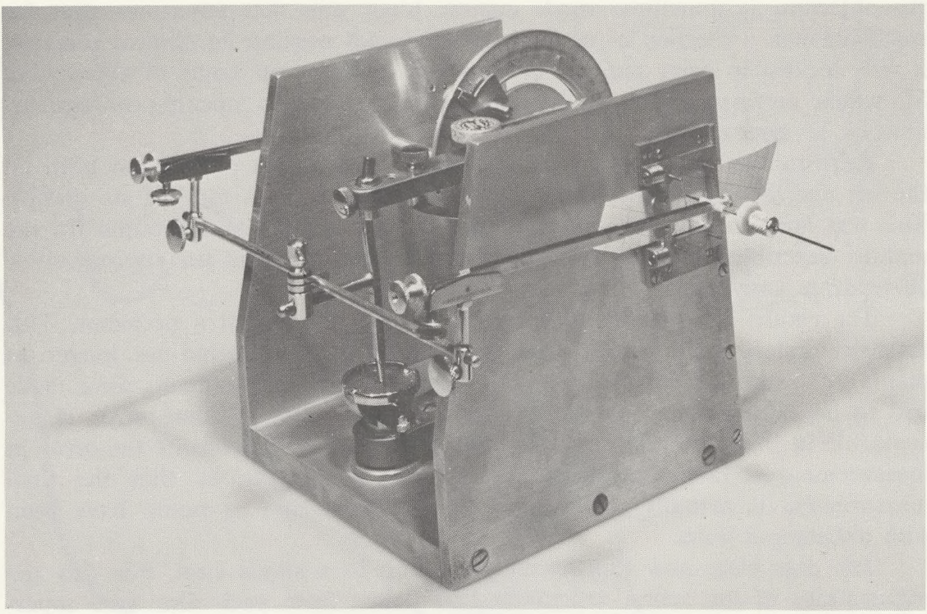


Fig. III.5. The incisal pin of the articulator is equipped with a horizontal bar to which the face bow is attached.

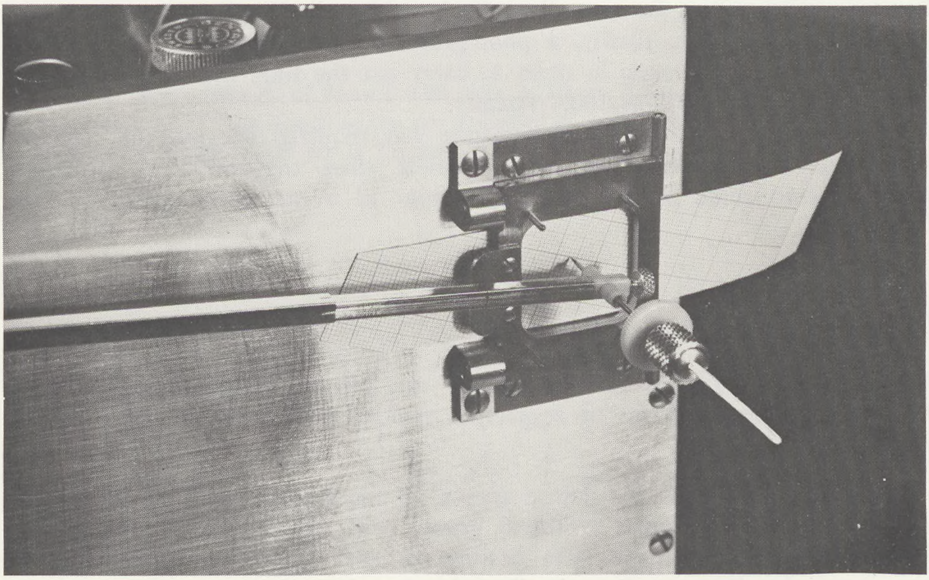


Fig. III.6. A strip of graph paper is inserted in the cassette in front of the x-ray film. Movements of the stylus can be analyzed more easily against this background. After a registration the paper is advanced until the perforation is beyond the window. During the whole operation the underlying extension of the articulator axis shaft is hidden from view.

the objection is sometimes made against hinge axis determinations that for some patients a rotation of as little as 10° is not possible in clinical practice, it was decided to carry out the investigation also for an angle of rotation of 5°, which corresponds to an incisally measured mouth opening of approximately 7.5 mm.

Registrations were carried out for these three angles of rotation both on the left and the right sides of the articulator, that is, in a total of six groups. This was done in pairs but alternating with various angles of rotation. In the manner described, the data from each group were recorded on approximately 30 separate x-ray films.

The results were enlarged 60× linearly with the aid of a projector. This extensive enlargement meant that the registrations appeared no longer as points but rather as circles. The points from which measurements were made had to be estimated as the center points of these circles. Some error is unavoidable in this estimating, but for the calculation of the results the error in measurement is later divided by the enlargement factor, so that the final measurement is actually considerably more precise than it would have been with unenlarged films.

The data were now transferred per group to a single card. For this the registrations of the actual articulator axis points from each film were superimposed and the x-ray films were oriented in the sagittal plane in reference to the Frankfort horizontal.

The picture obtained in this way displays the location of the actual rotation axis point and at the same time the locations of all collected registrations (fig. III.8). From this, finally, a photographic print was made with another enlargement of 3× linearly in order to carry out the final measurements. The total enlargement was thus 180× linearly.

Enlargement to this extensive degree was required because the registrations sometimes appeared to be extremely close together. The distances between them could in this way be brought to a measurable scale (0.5 to 70 mm).

III.4 RESULTS

A total of 365 registrations were carried out. These are distributed in table III.1 in 6 groups in terms of respective angles of rotation and sides of the articulator.

For the analysis of the data a system of coordinates was laid out on the final photograph for each of the 6 groups with the X-axis parallel to the Frankfort horizontal plane. The position of each point was determined by measuring the distances from the horizontal and vertical axes. The measurements were made with vernier calipers the ends of which were sharpened to fine points. The instrument was provided with a dial gauge for the nonius reading accurate to 0.05 mm. The mean, the standard deviation and the standard deviation of the mean were calculated for the values thus determined.

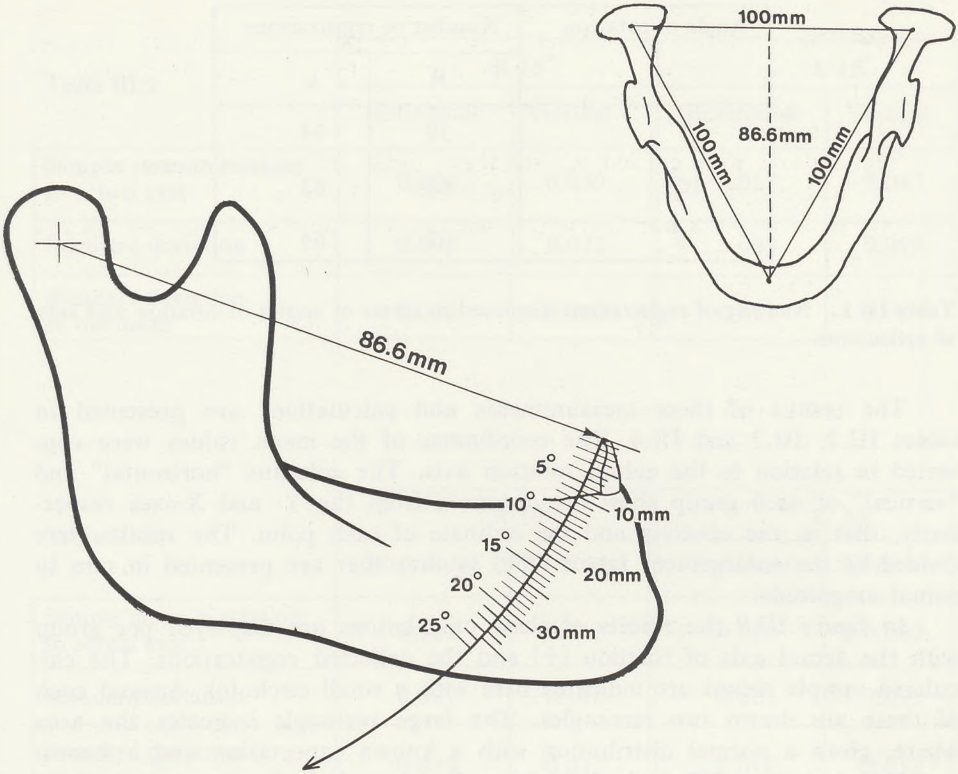


Fig. III.7. For a triangle of Bonwill with sides of 10 cm the perpendicular is 86.6 mm. In a rotation of 17° the length of the arc described is approximately 25 mm. In a rotation of 5° the length of the arc is 7.5 mm.

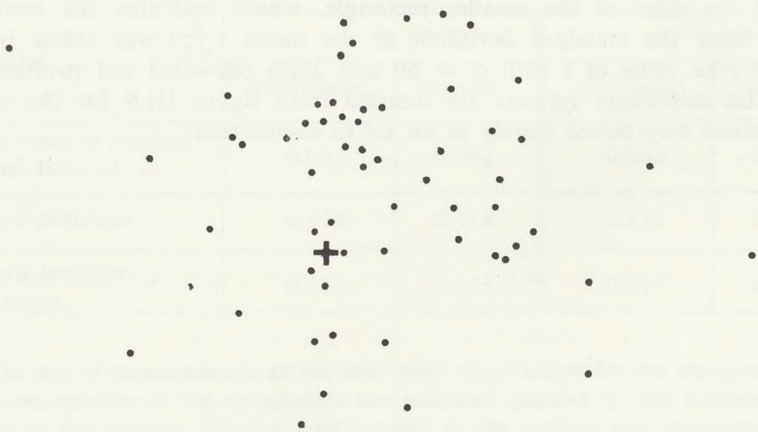


Fig. III.8. One of the six groups (R 15°) with the collected registrations. The location of the point of the actual axis of rotation is indicated by +.

Angle of rotation	Number of registrations	
	R	L
15°	59	54
10°	63	63
5°	62	64

Table III.1. Number of registrations displayed in terms of angles of rotation and sides of articulator.

The results of these measurements and calculations are presented in tables III.2, III.3 and III.4. The coordinates of the mean values were converted in relation to the actual rotation axis. The columns "horizontal" and "vertical" of each group show the distances from the Y- and X-axes respectively, that is, the abscissa and the ordinate of each point. The results were divided by the enlargement factor (180) so that they are presented in mm in actual magnitude.

In figure III.9 the results of these calculations are displayed per group with the actual axis of rotation (+) and the collected registrations. The calculated sample means are indicated here with a small circle (o). Around each of these are drawn two rectangles. The large rectangle indicates the area where, given a normal distribution with a known expectation and a known standard deviation, 95% in both horizontal and vertical directions, or in total approximately 90% of the determinations may be expected. In order to indicate the dispersion, the large rectangle is constructed by taking twice the calculated standard deviation (s) of the means in both directions. The dimensions of these areas of dispersion are presented in table III.5.

For the sides of the smaller rectangle, which indicates the confidence region, twice the standard deviation of the mean ($\frac{s}{\sqrt{n}}$) was taken in each direction (the value of t with $\varphi = 60$ and 2½% one-sided tail probability is 2.00). The coordinate systems are omitted from figure III.9 for the sake of clarity, since they served merely as an aid to calculation.

Table III.2

	R 15°		L 15°	
	Horizontal	Vertical	Horizontal	Vertical
Sample mean in relation to actual axis	0.034	0.039	–0.017	–0.047
Standard deviation	0.092	0.072	0.084	0.099
Standard deviation of the mean	0.012	0.009	0.011	0.014

Table III.3

	R 10°		L 10°	
	Horizontal	Vertical	Horizontal	Vertical
Sample mean in relation to actual axis	0.082	0.065	0.010	–0.002
Standard deviation	0.097	0.136	0.082	0.099
Standard deviation of the mean	0.012	0.017	0.010	0.013

Table III.4

	R 5°		L 5°	
	Horizontal	Vertical	Horizontal	Vertical
Sample mean in relation to actual axis	0.093	0.066	0.048	–0.070
Standard deviation	0.125	0.116	0.135	0.127
Standard deviation of the mean	0.016	0.015	0.017	0.016

Results in mm of measurements of the axis point registrations for the six groups. The positions in relation to the coordinates are indicated parallel to the horizontal axis positively in the anterior direction and parallel to the vertical axis positively in the superior direction.

	R	L
15°	0.37 x 0.29	0.34 x 0.40
10°	0.37 x 0.54	0.33 x 0.40
5°	0.50 x 0.46	0.54 x 0.51

Table III.5. Dimensions in mm of the areas of dispersion of the axis point registrations for the 6 groups.

III.5 DISCUSSION

Given the calculations made of the mean, the standard deviation and the standard deviation of the mean for this sample, conclusions in regard to the population are only allowable if the statistical distribution is known. In this respect it is particularly important to know if the material is normally distributed. A general examination of the distributions displayed in figure III.9 gives no indication that the investigation had to do with non-normally distributed observations. Application of the F-test to the calculated variances in the horizontal and vertical directions showed no significant differences ($P > 0.05$) for the 6 groups of registrations.

A test for normality was also conducted by constructing a sum-curve on normal probability paper. The curve that appeared deviated so little from the straight line present for a normal distribution that it is justified to proceed for this discussion on the assumption that the material is normally distributed. Actually, the deviation from the line indicated that occurrences at the extremes of the distribution were fewer than those at the extremes of a normal distribution. This means that more than 95% of the determinations appear to lie within $m \pm 2$ s.

The order of magnitude of the arcs described by the stylus point suggests that in the border area of barely visible movement and no longer visible movement the limits of perception of the unaided eye play a role.

To obtain a better understanding of the relation between dispersion and visual acuity, the resolving power of the eye must be taken into consideration (fig. III.10). This is generally taken to be one minute of an arc. For this value the minimum separabile, that is, the least distance that two objects may be apart and still be observed as separate, is dependent on the punctum proximum or near point of the eye. This point offers the greatest visual angle for the distinguishing of two points. In this respect 20 to 25 cm is generally considered normal. The distance varies considerably, however, among different people. The present investigator, for instance, has a punctum proximum of 15 cm. Given this figure, it can be calculated that at this distance he can just distinguish two points 0.044 mm from each other but if they are closer

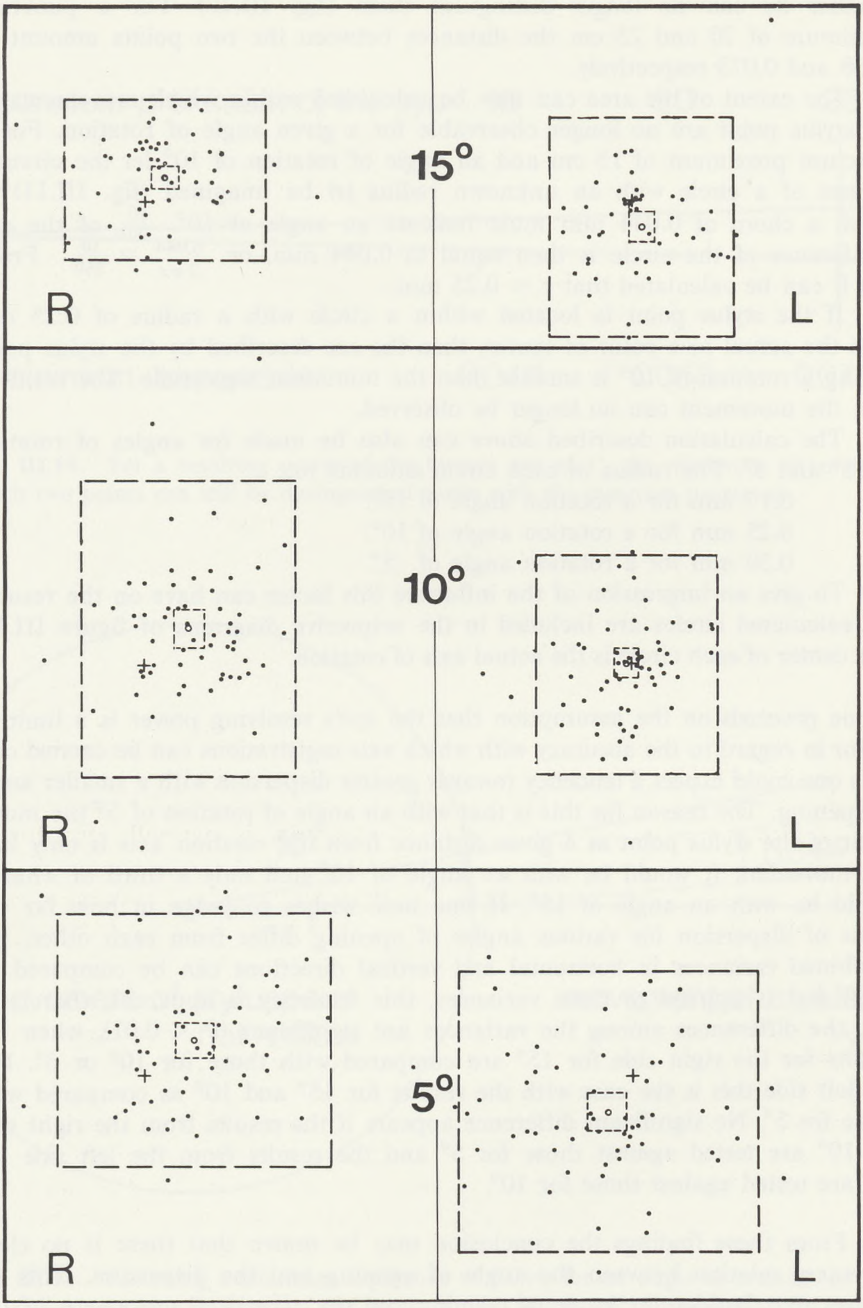


Fig. III.9. The six groups of registrations presented in terms of respective angles of rotation and right or left side. + indicates the location of the actual axis of rotation; O indicates the average of the registrations in each group. The field marked by the smaller rectangle corresponds to the confidence region and the field marked by the larger rectangle corresponds to the dispersion area.

together he can no longer distinguish them (fig. III.10). For a punctum proximum of 20 and 25 cm the distances between the two points amount to 0.058 and 0.073 respectively.

The extent of the area can now be calculated within which movements of the stylus point are no longer observable for a given angle of rotation. For a punctum proximum of 15 cm and an angle of rotation of 10° let the circumference of a circle with an unknown radius (r) be imagined (fig. III.11) of which a chord of 0.044 mm must indicate an angle of 10°. $\frac{10}{360}$ of the circumference of the circle is then equal to 0.044 mm, or $\frac{0.044}{2\pi r} = \frac{10}{360}$ From this it can be calculated that r = 0.25 mm.

If the stylus point is located within a circle with a radius of 0.25 mm with the actual axis point as center, then the arc described by the stylus point during a rotation of 10° is smaller than the minimum separabile. The result is that the movement can no longer be observed.

The calculation described above can also be made for angles of rotation of 15° and 5°. The radius of each circle amounts to:

0.17 mm for a rotation angle of 15°,
0.25 mm for a rotation angle of 10°,
0.50 mm for a rotation angle of 5°.

To give an impression of the influence this factor can have on the results, the calculated circles are included in the respective diagrams of figure III.12. The center of each circle is the actual axis of rotation.

If one proceeds on the assumption that the eye's resolving power is a limiting factor in regard to the accuracy with which axis registrations can be carried out, then one could expect a tendency towards greater dispersion with a smaller angle of opening. The reason for this is that with an angle of rotation of 5° the movement of the stylus point at a given distance from the rotation axis is only half the movement it would be with an angle of 10° and only a third of what it would be with an angle of 15°. If one now wishes to judge in how far the areas of dispersion for various angles of opening differ from each other, the combined variances in horizontal and vertical directions can be compared. If the F-test is applied to these variances, this tendency is apparent, that is to say, the differences among the variances are significant ($P < 0.01$), when the results for the right side for 15° are compared with those for 10° or 5°. For the left side this is the case with the results for 15° and 10° as compared with those for 5°. No significant difference appears if the results from the right side for 10° are tested against those for 5° and the results from the left side for 15° are tested against those for 10°.

From these findings the conclusion may be drawn that there is no clear necessary relation between the angle of opening and the dispersion. This indicates that besides the angle of opening and the associated movement of the stylus point, there are apparently other factors which also determine the accuracy and which, in contrast to the limitation of visual acuity, are independent of the angle of opening. Thus the relative stability of the face bow arm and the consequent imprecision of the stylus registrations may play a role.

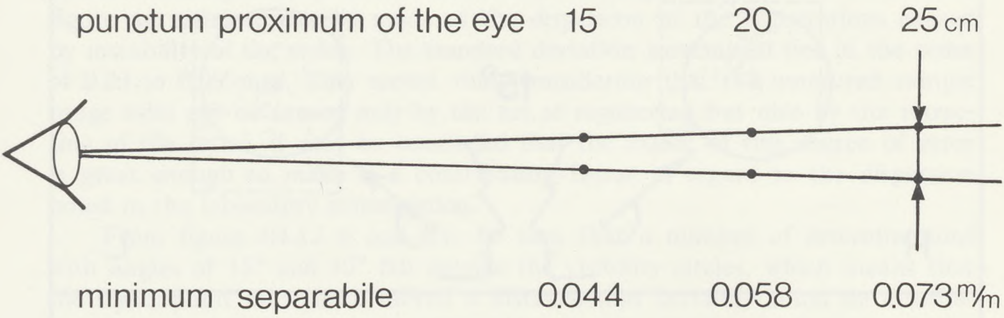


Fig. III.10. For a resolving power of the human eye of 1', the minimum distance at which two points can still be distinguished varies with the punctum proximum.

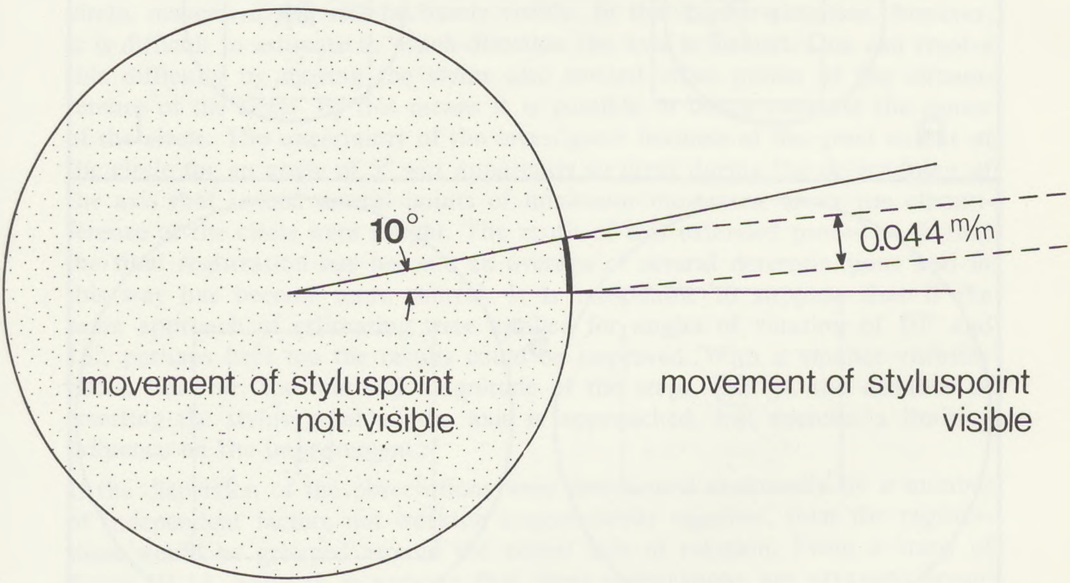


Fig. III.11. Assuming a minimum separabile of 0.044, for an angle of rotation of 10° the radius can be calculated of the circle within which the movement of the stylus point is no longer observable.

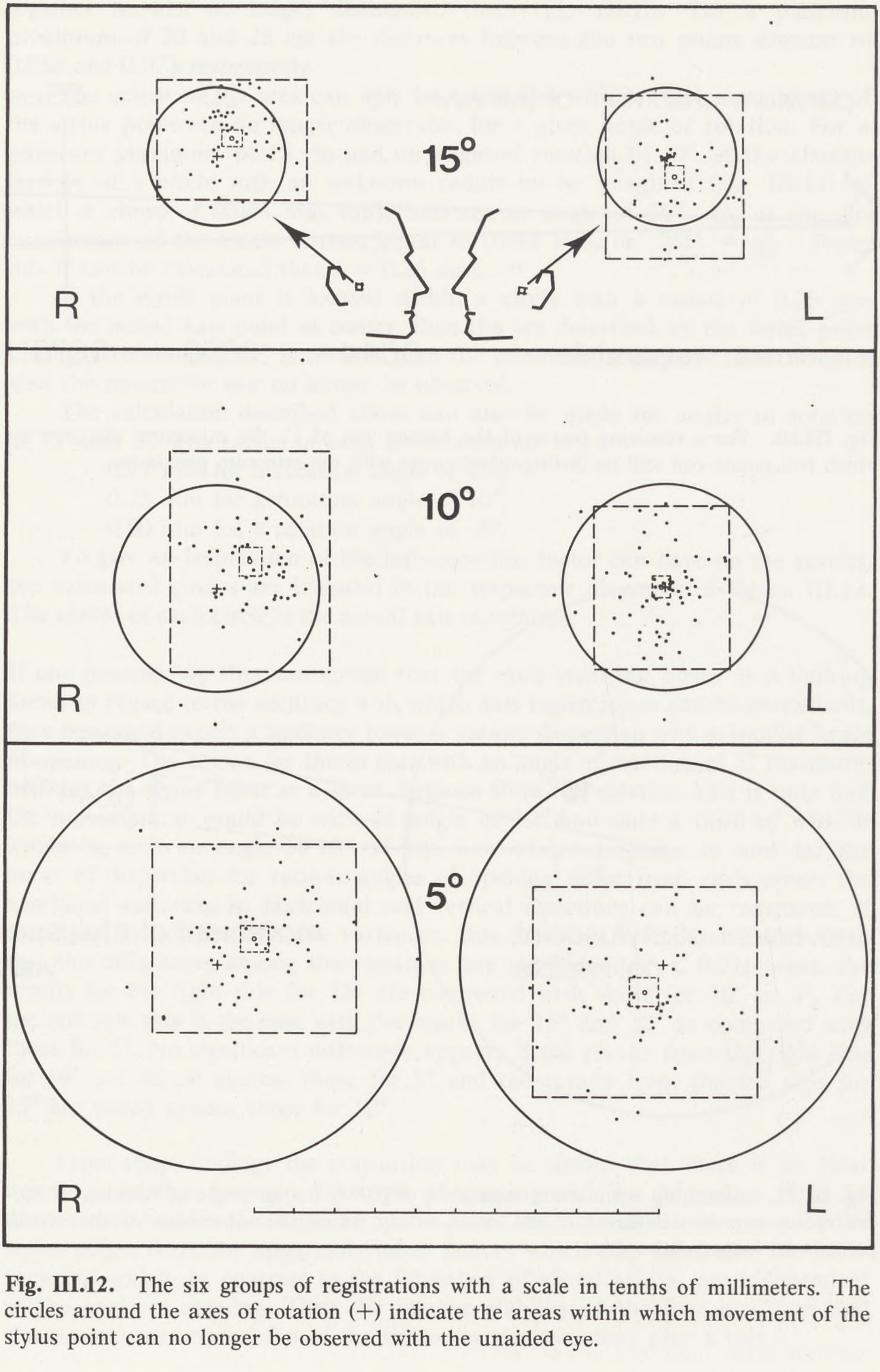


Fig. III.12. The six groups of registrations with a scale in tenths of millimeters. The circles around the axes of rotation (+) indicate the areas within which movement of the stylus point can no longer be observed with the unaided eye.

Of what order of magnitude this imprecision can be was determined by means of a test that will be described later as part of the discussion of the clinical investigation (p. 56). This offers a range of 0.22 mm. From this figure an estimate can be made of the dispersion of the registrations caused by instability of the stylus. The standard deviation ascertained lies in the order of 0.03 to 0.09 mm. This means that, considering that the measured sample range need not be caused only by the act of registering but also by the retracting of the stylus, it may be concluded that the extent of this source of error is great enough to make it a contributing factor in regard to the dispersion noted in the laboratory investigation.

From figure III.12 it can also be seen that a number of determinations with angles of 15° and 10° fall outside the visibility circles, which means that the stylus point must have moved a distance that certainly could be discriminated by the eye. It may be suggested that in the adjusting of the stylus point the procedure was terminated too soon. This does not apply to the investigation for an angle of rotation of 5°, for which the registrations and areas of dispersion although eccentric lie clearly within the circles where movement is no longer visible.

An explanation of this phenomenon might be that this result was obtained by estimating within the circle. If the stylus is located just at the edge of the circle, movement will still be barely visible. In this border situation, however, it is difficult to estimate in which direction the axis is located. One can resolve this difficulty by moving the stylus also toward other points of the circumference of the circle. By this means it is possible to better estimate the center of the circle. The uncertainty of the investigator because of the great extent of the circle for an angle of 5° was apparently so great during the determining of the axis that indeed several points of minimum movement along the circumference of the circle were sought. The result of this extended procedure is that the final registration has become an average of several determinations and in this way has become more central. It is reasonable to suppose that if the same approach of estimating were applied for angles of rotation of 10° and 15°, perhaps here too the results could be improved. With a smaller visibility circle, however, the minimal magnitude of the steps, that is, the distance of resetting the stylus point as the axis is approached, will exercise a limiting influence on the improvement.

If the dispersion of the observations were determined exclusively by a number of independent factors not working systematically together, then the registrations would be grouped around the actual axis of rotation. From a study of figure III.12, however, it appears that these registrations are arranged eccentrically. In 5 of the 6 groups the actual axis point lies outside the calculated confidence regions as indicated by the small rectangles. This points to the presence of a systematically effective error in the constantly repeated decision as to whether the stylus point is still moving or not.

A possible explanation might be that the left-handedness of the investigator played a role. On the right side of the test apparatus, where the face bow arm is adjusted with the right hand, this could lead to a more apparent systemic error than on the left side.

In addition, the distribution of the registrations will be determined by the direction from which the stylus point moves from outside into the limiting circle of visibility and by the magnitude of the steps. In this way a non-arbitrary or indeed a preferential direction of entrance of the stylus into the circle may offer an explanation of the eccentricity of the registrations.

Mechanical inacccuracies in the apparatus can also be the cause of a systematic error. It is imaginable, for instance, that the axis of the articulator might not be exactly true. To check this a number of registrations were carried out with the articulator in a closed and in a 180° open position. With two such extreme positions a possible eccentricity of the stylus point could be made observable. The registrations appeared, however, to coincide exactly, so that this source of error can be further ignored.

The possibility was also considered that errors in registration might occur if the stylus did not travel exactly parallel to the rotation axis when moved through its transverse fitting to puncture the x-ray film. Care was taken, however, to insure that the horizontal bar and with it the stylus were kept as parallel as possible to the axis shaft of the articulator.

Next a consistent small deviation could have occurred during the puncturing due to the instability of the face bow arm, as has already been mentioned.

Further factors that play a role are the observation distance, the direction from which observations are made (possibly reducing the amount of movement discriminated), parallax, routine and concentration of the investigator. It is clear that these factors are difficult to quantify.

Since it has appeared that the extent of the registration error due to instability of the stylus can be of the order of that of the investigation, it is most reasonable to presume that the error associated with the puncturing of the film by the stylus acquired a systematic character. No other explanation for the eccentric localization of the majority of the registrations could be found later.

III.6 CONCLUSIONS

In the laboratory investigation conducted as described above the dispersion of the registrations in locating the rotation axis according to the kinematic method amounted to roughly 0.4 × 0.4 mm for rotation angles of 15° and 10°. These findings corroborate those of *Lauritzen and Wolford (1961).*

The order of magnitude of this dispersion corresponds approximately to that of the areas within which movement of the stylus point is no longer observable because of the limits of perception.

The dispersion for an angle of rotation of 5° amounts to approximately 0.5 × 0.5 mm. Although the explanation proposed in relation to estimating inside the circle within which movement of the stylus point is no longer visible holds as well for angles of more than 5°, the results show that determination of the rotation axis for this angle is possible with more accuracy than could be expected on the basis of the eye's resolving power.

CHAPTER IV

CLINICAL INVESTIGATION OF THE ACCURACY OF THE KINEMATIC METHOD

IV.1 INTRODUCTION

Following on the laboratory investigation, in which determinations of the axis of rotation were carried out according to the kinematic method with the help of a mechanical instrument derived from an articulator, in a corresponding manner the hinge axis of the mandible was determined for a group of test subjects in a clinical situation.

This clinical investigation was carried out on a group of 30 subjects, 22 male and 8 female, mainly dental students aged 20 to 30 years. The investigation required that a sufficient number of teeth in upper and lower jaw be present to affix the apparatus securely. All except one had a full or nearly full complement of at least 27 teeth. The test subjects had no complaints in regard to temporomandibular joint disturbances.

IV.2 APPARATUS

The apparatus used in the clinical investigation consisted of face bows for upper and lower jaw, each provided with an apparatus for affixing it to the teeth, and an extra-oral registration table with a stylus for tracing Gothic arches.

a. *Attachment apparatus*

For the lower jaw the adjustable face bow designed by Lauritzen was used. A small metal clutch tray for attaching the face bow to the teeth is provided by the manufacturer along with this apparatus. This clutch tray encompasses the lower front teeth and bicuspids. It should be fastened rigidly to these teeth by means of an impression material that becomes very stiff after setting. This method of affixing the face bow entails the objection that it interferes with the occlusion of the teeth. Because of the thickness of the impression material and clutch tray, the vertical dimension is increased and will be even more enlarged if a vertical overbite is present in the front teeth. The increase is then the total of overbite and thickness of clutch tray and impression material, and it can thus easily amount to 5 mm at the front teeth. *McMillen (1972)* found an increase of the vertical dimension of 7.3 to 11.7 mm with the use of clutches in upper and lower jaws with a central bearing device. The effect is that the initial part of the rotation trajectory of the mandible is no longer available for the determination of the hinge axis. *Knap, Espinoza and Ziebert (1973)* found an average of 5.2 mm increase of the vertical dimension at the incisors as a result of an occlusally closed clutch. In order to eliminate this difficulty, a new attachment apparatus was devised (fig. IV.1). The clutch consists of two hinged metal arms curved in the shape of the dental arches. They have in cross section a T-shape for the sake of maximum strength.

The procedure for affixing these clutches firmly to the teeth was as follows. Impressions were made of the subject's upper and lower jaws, and a set of plaster casts was made. In each quadrant from the cuspid to the last molar a small amount of plaster was cut from these models on the buccal side at the places of the interdental papillae, so that some undercut was obtained. In this way sufficient retention could be attained for affixing the apparatus even for young patients with predominantly short clinical crowns.

In order to attach the clutch arms to the interdental spaces, blocks were formed of autopolymerizing acrylic resin. These blocks covered the cervical part of the buccal surfaces of the teeth and part of the mucosa. Only the horizontal part of the T-shaped metal clutch arms was covered, so that the acrylic blocks could easily be removed from them. In this way it was possible to leave the metal clutches intact and thus to use them again for a following subject. The proper position of the blocks in relation to the clutch arms during the tests was assured by means of triangular notches in the horizontal part of the arms. By means of these acrylic blocks, the attachment apparatus could now be fixed in the mouth of the patient by tightening the adjustment screw. In the process of making these individually fitted clutches care had to be taken that the resin covered the buccal surfaces of the teeth only to the extent that the antagonists did not come in contact with it. In this way an attachment apparatus was produced which could be anchored securely to the upper and lower arches and which did not interfere with the occlusion and articulation of the teeth (fig. IV.5).

b. *Tracing apparatus for the Gothic arch*

The attachment apparatus or clutch was provided at the front with a horizontal extension. The transverse bar of the face bow could be attached to this by means of a universal locking clamp (fig. IV.2, IV.3). A registration table was attached to the end of this extension or stem by means of a hinge joint. An object glass of a microscope could be clamped to this table with two springs. By smoking this glass, it was possible to register Gothic arch tracings on it. Further, the stem of the maxillary clutch was provided with a stylus which, similarly to the registration table, was attached to the extension by means of a hinge joint. In this way, both parts could be set in the desired position. Since in the procedure for making Gothic arch tracings the vertical dimension continually changes during the necessary excursions of the mandible because of the cusp height, the stylus was mounted in a slide fitting. In this way it could move only in the direction of its own length and easily enough to maintain contact with the glass plate due to its own weight.

c. *Face bow apparatus*

As has already been remarked, for the mandible the adjustable face bow as developed by Lauritzen was used.

The apparatus for the maxillae (fig. IV.3) was derived from that of *McCollum (1939)*. On the transverse bar of this face bow are mounted two short perpendicular arms that run closely along each side of the head. At the end of each arm a flag is located that functions as film holder measuring 3 × 3½ cm. This is made in such a way that the inclination can be adjusted in the sagittal plane.

The flag corresponds to the x-ray film cassettes as they were attached to the aluminum side plates in the laboratory tests. An x-ray film can be inserted from the back of the holder. Also as in the laboratory apparatus, there is a groove in the upper and lower rims of the flag so that a strip of graph paper can be inserted in front of the film.

The apparatus for the mandible is made as light as possible (100 gr) so as to disturb the mandibular excursions as little as possible. Weight plays a lesser role in regard to the upper apparatus. Here rigidity was the major consideration in the construction.

IV.3 PROCEDURE

Before placing the apparatus in the mouth, simple instructions were given to the subject. A few exercises were done in order to have him reach the desired posterior position and perform the rotation independently. Since it appeared later that help had to be offered for the repeated reproduction of this position, the patient was shown at the same time how a light pressure on the chin would be applied by the hand of the investigator in order to be of assistance to him. He was further taught to avoid contact between upper and lower teeth during the procedure. This was because the stylus point would otherwise vibrate due to the shock of the occlusal contact. He was also instructed not to excede the position of maximum rotation, since the determination of the axis would also be made more difficult by an initial translation.

After this the upper and lower apparatus were attached to the teeth. The registration table and pin were mounted on the horizontal extensions for the tracing of the Gothic arches. To minimize the distortion of these tracings, the table was positioned as nearly parallel as possible to the triangle of Bonwill with the stylus perpendicular upon it *(Tempel, 1959)*.

Although *Eberle (1951)* advises that the patient be placed in a supine rest position in order to let gravity help in obtaining the centric position, this was not done in the present investigation. To eliminate possible skin movement between supine and erect position, the patient was seated in an upright position with the Frankfort horizontal plane parallel to the floor. This gave for all experiments a constant posture which did not prevent the subject from obtaining the most posterior position of the mandible *(Kabcenell, 1964)*. Also

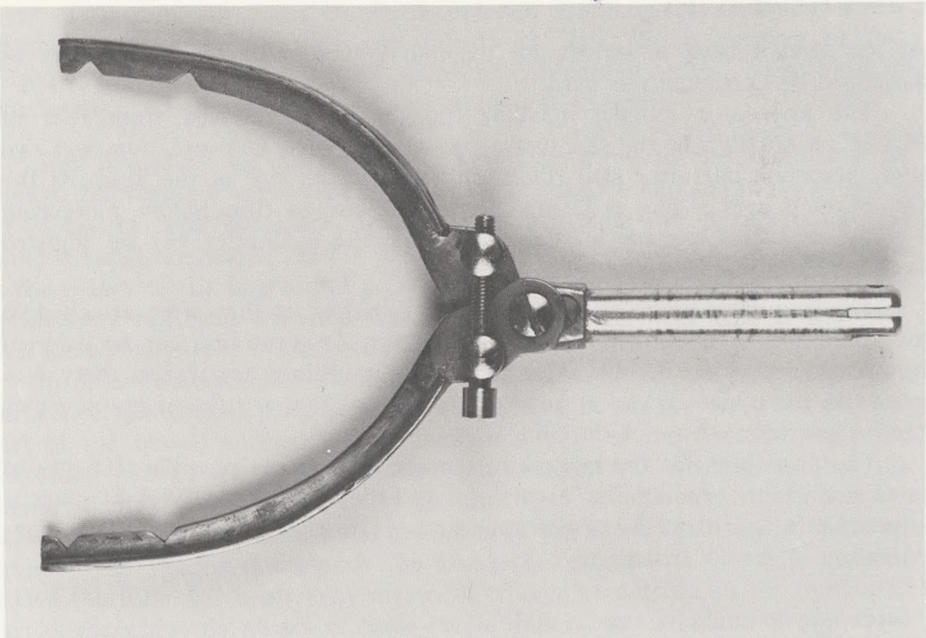


Fig. IV.1. Attachment clutch for affixing upper and lower apparatus to the dental arches.

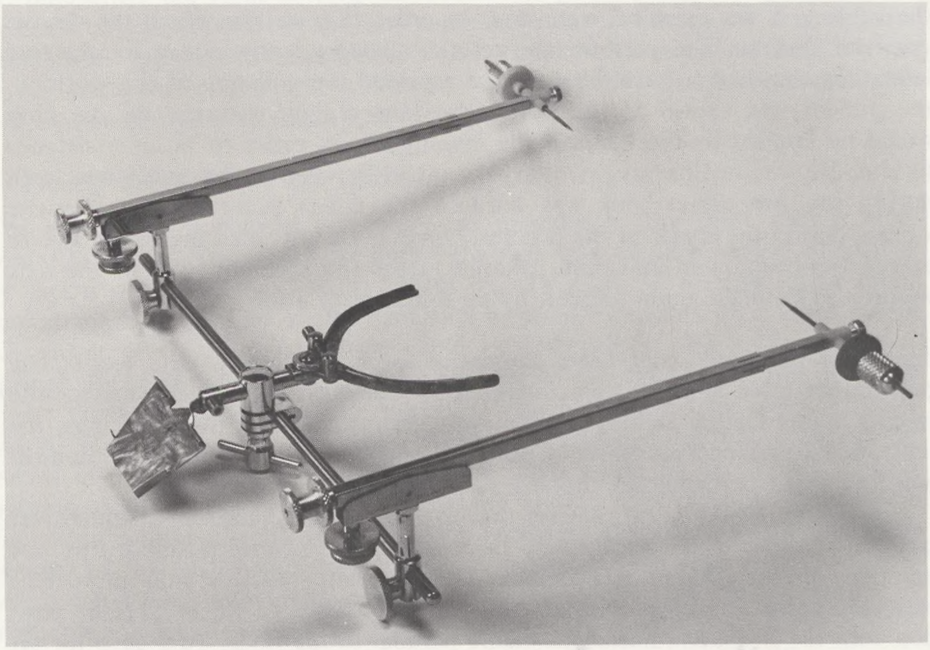


Fig. IV.2. Mandibular apparatus, consisting of attachment clutch, registration table for Gothic arch tracing, and face bow as designed by Lauritzen.

according to *Ingervall (1971)* the most retruded position of the mandible is not influenced by the subject's posture or by the recording method, using either the hinge movement or the Gothic arch tracing.

The objective of the Gothic arch tracing was to ascertain whether the subject was able to perform rotation movements independently, or if necessary with help, and from which position of the mandible the movement would take place. As is well known, for the kinematic determination of the axis it is necessary that the rotation movement be performed repeatedly. The adjustment of the stylus requires a number of corrections, another each time following a new rotation movement. If the rotation movement around an axis can be reproduced by the subject, then the registration point of the vertical pin on the registration table will also be reproduced. The latter can be checked with the Gothic arch apparatus.

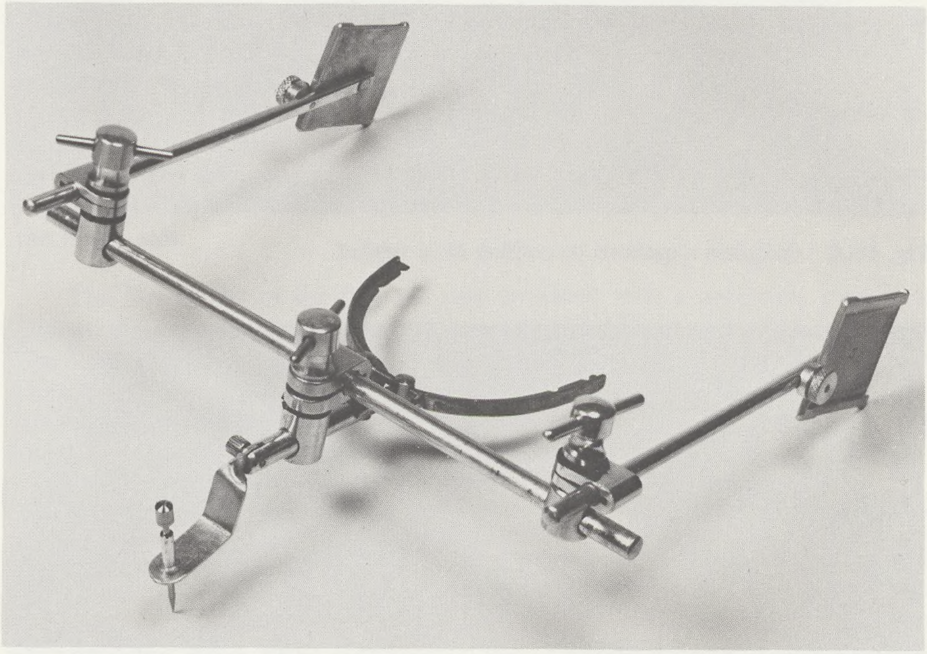


Fig. IV.3. Maxillary apparatus, consisting of attachment clutch, registration stylus, and aluminum side arms with adjustable film holder.

The position of the mandible with maximum intercuspation of the teeth was first registered on the registration table and then the contact position that was obtained with the "guided closure" technique as described by *Posselt.* This latter registration is obtained by moving the mandible of the patient loosely up and down with the operator's hand on the chin until the patient follows this guiding in so relaxed a way that the hand of the investigator detects no more resistance. At that moment a 'hinge-like" movement *(Posselt, 1968)* is performed that can be extended to the first occlusal contact. Although it is not likely that the required complete relaxation of the muscles can be attained

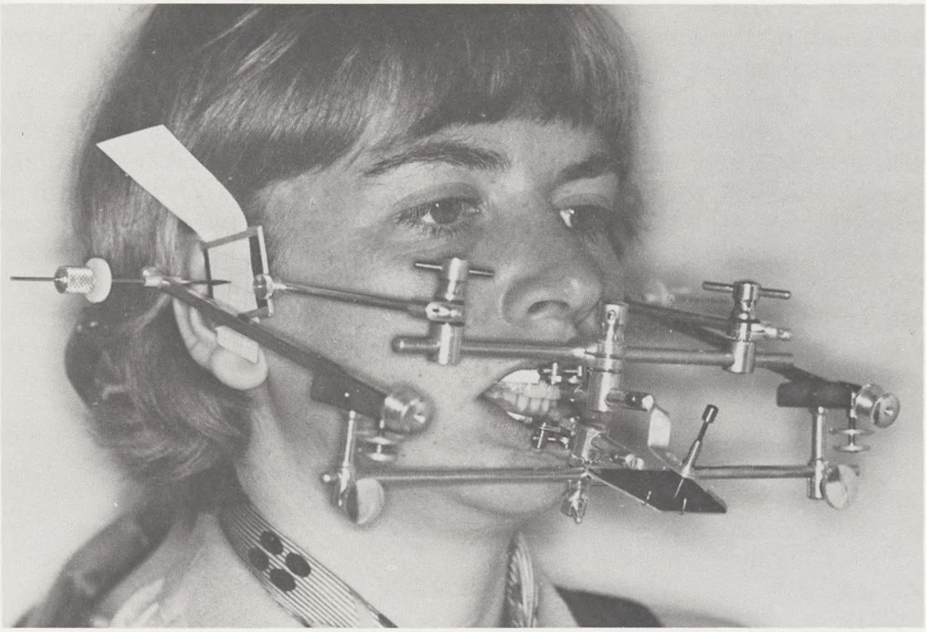


Fig. IV.4. Complete apparatus in position on a subject.

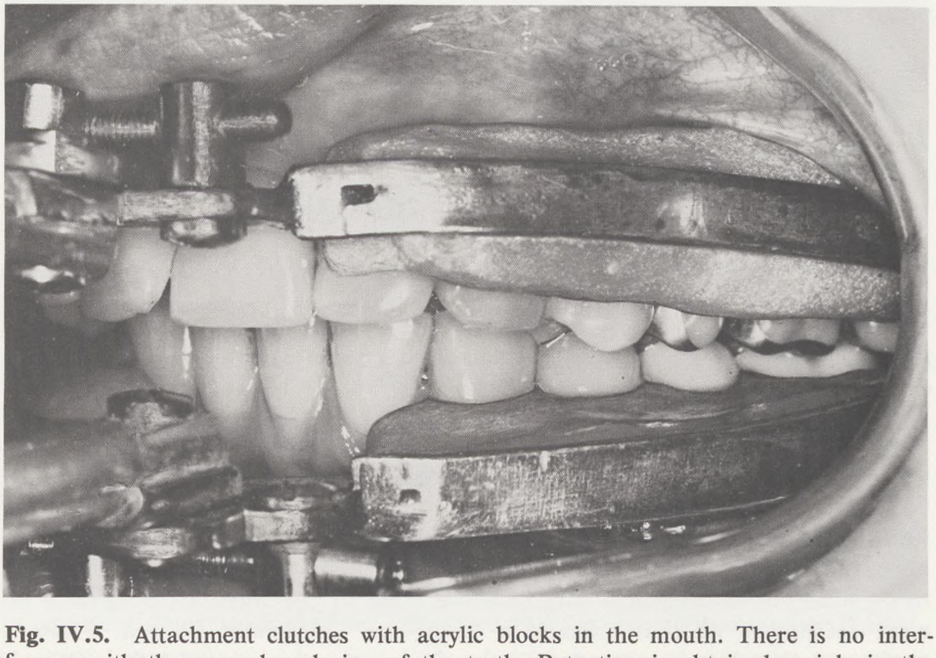


Fig. IV.5. Attachment clutches with acrylic blocks in the mouth. There is no interference with the normal occlusion of the teeth. Retention is obtained mainly in the interproximal spaces.

with the apparatus described above in the mouth, one does obtain in any case a registration in which no posteriorly directed pressure is exerted on the mandible by either operator or patient, so that the "guided closure" is approached as nearly as possible in this way.

Next, after a little practice, two tracings of a Gothic arch were made on the smoked registration plate. These tracings were fixed with a cellulose lacquer. The most posterior position of the mandible, indicated by the apex of the Gothic arch, was obtained by the patient's own exertion. Because of the tiring of the groups of muscles actively involved in this operation (Mm. masseteres, temporales, geniohyoidei, mylohyoidei and digastrici), the patient could reproduce repeatedly the tracings only with great exertion or not at all. It was thus logical in repetitions of the test to assist the patient. To do this a light posteriorly directed pressure was exerted holding the chin of the subject with the thumb and index finger of the investigator (fig. IV.6), so that the stylus could be brought to the apex of the Gothic arch. The mandible was, however, not *forced* backward in this operation, the criterion being that the subject was not to feel the support as an uncomfortable pressure.

It appeared that this was the only possible way to achieve reproducible results, both for the tracing of the apex of the Gothic arch and for the registrations of the left and right lateral border movements. It was for this reason that the guiding of the mandible was included as part of the determination of the hinge axis.

The film holder of the flag was now provided with a uniformly gray x-ray film which, as in the laboratory test, was covered with a strip of graph paper. The flag was positioned parallel to the median plane over the arbitrary point already indicated on the skin. The long side of the flag was adjusted by eye parallel to the Frankfort horizontal, which was indicated by a rubber band, and fixed with an adjustment screw.

The accuracy with which this could be done was separately investigated. With one subject the Frankfort horizontal was indicated with a rubber band around the head, and the film holder was adjusted parallel to it 20 times estimating by eye. For each adjustment a photograph was made on which the angle between the indicated Frankfort horizontal and the film holder could be measured. The mean angle of the film holder to the rubber band amounted to — $0^\circ 6'$, that is to say, tipped a little backwards. The standard deviation of the mean amounted to $0^\circ 26'$. Since the possible error of adjustment appeared to be very small, no further account was taken of it in the analysis of the data for which the Frankfort horizontal was used as a reference line.

The stylus of the Lauritzen bow was then adjusted over the film holder of the maxillary face bow.

In the same way as in the laboratory test, a number of determinations were made per subject on the left and right sides and registered on the emulsion of the x-ray film through the graph paper. After each registration the paper was advanced so as to make orientation to the preceding determination impossible.

The number of determinations carried out per patient was limited by fatigue on the part of the subject or the investigator. Consequently the number of registrations on each side varied from 3 to 7 per patient. While no magnifying glass was used in the laboratory investigation for enlargement of the visual angle, this was attempted in the clinical investigation. The manipulation of the magnifying glass during the registrations was awkward, however, and the movements of the stylus point could be sufficiently observed with the naked eye. It seemed therefore that the magnifying glass was not a valuable aid in the registrations.

After all axis point registrations had been carried out the strip of graph paper was removed. The registrations were now visible and the average of these points could be estimated by eye. To transfer this average point to the skin, the stylus was adjusted over this point with the teeth in maximum intercuspation. Then the arm of the upper face bow with the flag was removed, so that this point could be marked on the skin of the subject with the stylus. It was labeled with a 3 (fig. IV.7) in connection with the profile photograph to be made later in the procedure. Then the whole apparatus was removed.

IV.4 RESULTS

With 30 subjects a total of 249 axis point determinations was obtained, of which 124 were on the right side and 125 on the left. As has been stated, these were recorded on x-ray films, with a minimum of 3 and maximum of 7 registrations per film. The number of determinations for a given subject on each side of the face was the same. 7 of the 249 registrations were later found to be unusable, since they coincided with others.

For the analysis of these registrations the films were photographically enlarged 10 times. Then a system of coordinates was laid out on each enlargement such that the X-axis was established parallel to the reference line indicated on the film. For each enlargement the sample mean was determined in terms of the distances from the established X- and Y-axes. In contrast to the situation in the laboratory tests, the position of the actual axis of rotation is not known in regard to test subjects. Therefore no more could be done than to approach the location of this axis as precisely as possible. The greatest possibility of accomplishing this is to calculate the mean of the values found in the successive determinations. The distances of the various registrations on each film from these mean points were calculated and are presented in mm in table IV.1 (see appendix).

Then an estimate of the dispersion of axis point determinations for the whole population was made on the basis of the values obtained for the individual members. For this the variance was calculated from the combined variances of the small samples of maximally 7 determinations. The number of degrees of freedom for the sample of 124 axis point determinations for the right side amounts to 94 and for the sample of 125 determinations for the left side to 95. For the calculations it was assumed that the data in regard to

Fig. IV.6. Guidance of the mandibular movements by means of a light posteriorly directed pressure with the hand of the investigator.

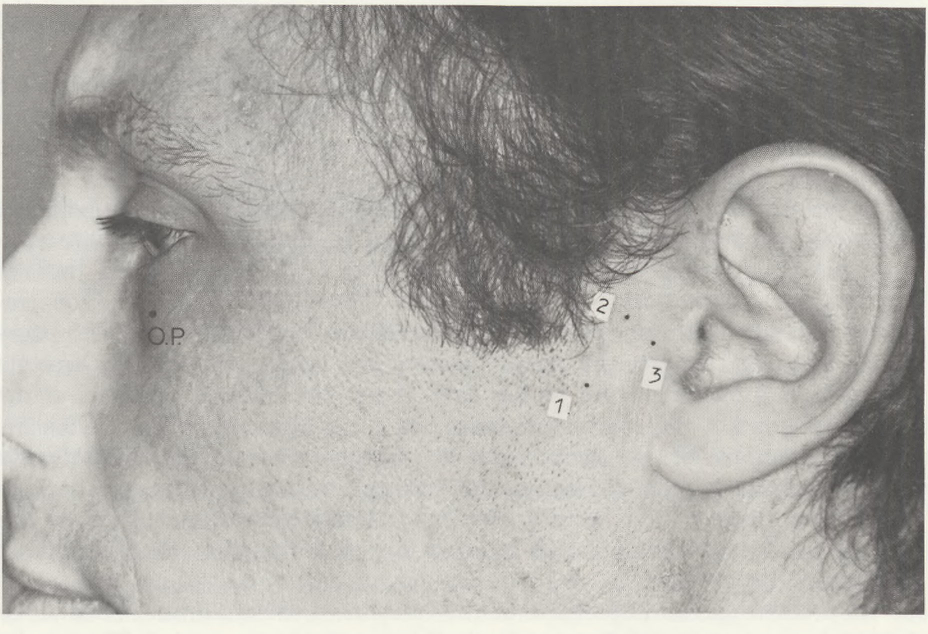


Fig. IV.7. Profile picture of a test subject. Indicated on the skin are the points 1 (palpation method), 2 (arbitrary method), and 3 (kinematic method), as well as the orbital point (O.P.).

these subjects represented a random sample of a normally distributed population. The results of this calculation, divided by the photographic enlargement factor 10, are presented in mm in table IV.2.

	R	L
Standard deviation horizontal	0.463	0.418
Standard deviation vertical	0.391	0.445

Table IV.2. Standard deviation of the registrations in mm of 30 test subjects classified in terms of right and left side.

IV.5 MOUTH OPENING

In the laboratory investigation the registrations were carried out with three angles of rotation. These were chosen on the basis of rough estimates reported in the literature concerning the trajectory over which the mandible can make a hinge movement.

For the examination of test subjects no fixed angle of rotation was held to, but rather use was made of the trajectory of rotation available in each individual subject. In order to ascertain the angles of rotation available for hinge axis determination, the maximum rotation trajectory of the mandible within which the registrations had to be carried out was measured for the various test subjects. To do this the position of maximum rotation of the mandible was first determined by having the subject open the mouth with the posteriorly directed guidance already described to the point that clear resistance was noted by the operator. Further opening of the mouth would then be accompanied by translation of the mandible. The extent of the rotation trajectory was now obtained by measuring the distance between the incisal edges of the upper and lower right central incisors and adding the vertical overbite of the relevant incisors. Since, as has been stated, the extreme positions of the maximum rotation trajectory must be avoided, the part actually available for the test was smaller. It should also be reported that in 24 subjects the retruded contact position did not correspond with maximum intercuspation, so that in this group of test subjects the rotation trajectory was reduced by the increase of the vertical dimension required for obtaining the retruded contact position.

In order to get an impression of the relation of the maximum rotation to the maximum opening of the mouth, the latter was also measured. The results of this part of the investigation are displayed in mm in table IV.3 (see appendix) and table IV.4.

	Men			Women		
	Vertical overbite	Maximum opening	Maximum rotation	Vertical overbite	Maximum opening	Maximum rotation
Sample mean	2.5±0.3	54.4±1.4	27.5±0.9	2.5±0.3	53.6±3.2	27.3±1.3
Standard deviation	1.5	6.8	4.2	0.8	9.0	3.5
Extreme values	0-5	45-68	20-35	2-4	41-65	23-33

Table IV.4. Results in mm of measurement of mouth opening in 30 subjects.

The sample mean of the maximum opening in men, 54.4 mm, appeared to be lower than was found by *Derksen and F. Bosman (1965):* 57.3 mm; *Travell and Bigelow (1960):* 59 mm; and *Nevakari (1960):* 57.5 mm. It appeared to be higher than that measured by *Sheppard and Sheppard (1965):* 52.6 mm.

The sample mean of the values found in the women test subjects is, as other writers have also found, lower than in men. The value of 53.6 mm is equal to that of *Derksen and F. Bosman,* almost equal to that of *Travell and Bigelow:* 53 mm; and *Nevakari:* 54 mm; and higher than that of *Ingervall (1970):* 51 mm.

The maximum rotation trajectory appeared to be an average of 27.5 mm for men and 27.3 mm for women. This is more than is reported bij *McCollum (1939):* 12.5 - 25 mm; and *Posselt (1957):* up to 20 mm, and the same author in later publications (1958, 1968): 20 - 25 mm. It corresponds to *Fischer (1939):* 20 - 30 mm; and *Brekke (1959):* 20 - 30 mm; and is the same as the value indicated by *Knap, Espinoza and Ziebert (1973):* 27.4 mm.

In general the extent of the rotation trajectory appears to amount to half of the maximum opening. This is in deviation from *Sicher (1929, 1951, 1964),* who indicates a figure of two thirds for this relation. The values found in this investigation correspond to an angle of rotation of the mandible of ± 18° (fig. III.7).

IV.6 DISCUSSION

When the standard deviations of the clinical investigation are compared with those of the laboratory experiment, the linear dispersion of the determinations carried out on living subjects appears to be approximately four times greater than with the mechanical model.

One of the causes of this must certainly be sought in the relative stability of the apparatus used in the clinical investigation. In spite of the rigid attachment to the teeth and the heavy construction of the maxillary face bow, the flag shows a certain movability that is not present in the laboratory investigation. The contribution to a greater dispersion as a result of less stability in the apparatus was, therefore, examined in a separate investigation.

For this ancillary investigation the x-ray film on the flag was repeatedly punctured in a blind test, proceeding from a fixed adjustment of the stylus arm, which was secured with locknuts. Between the subsequent registrations the graph paper was advanced beyond the window of the flag. The mandible was always in the same position in this procedure, since the registrations were made with the teeth in maximum intercuspation. In total, 15 determinations were carried out on one test subject on the left side and 15 on the right. The dispersion of the registrations could be judged on the basis of a tenfold enlargement of the films. It appeared that the registration points, which had a diameter of 0.16 mm, displayed an extremely small dispersion and that almost all overlapped with each other. The distance between the two most extreme registrations amounted to no more than 0.29 mm.

This dispersion cannot be attributed to movement of the flag alone, since another source of error could not be eliminated, namely the movement of the stylus point due to the relatively long face bow arm and its consequent flexibility. For this reason the reproducibility of the stylus registrations was also examined. This was done by puncturing the x-ray film with a fixed adjustment of the Lauritzen bow 20 times on the left and on the right side using the laboratory set up. The dispersion was also very small here, and almost all registration points overlapped with each other. The distance between the two most extreme registrations amounted to 0.22 mm.

This investigation, however, cannot be expected to give a completely accurate picture of the error that can occur in the registration by the stylus point, since in this investigation the stylus also had to be retracted every time before puncturing the film. Because of this another error can occur not involved in the normal registration procedure which is carried out only once in a given position. Therefore one may assume that the dispersion found in this investigation presents an exaggerated picture.

If one proceeds on the basis of the greatest range found in this subsidiary test, the standard deviation of the registrations as caused by the two sources of error tested can be estimated on the basis of the chance distribution for the range of the sample. This standard deviation lies in the order of 0.04 - 0.11 mm. Comparison of this figure with the standard deviation found in the test subjects (± 0.4 mm) shows that the instability of the flag on the maxillary face bow and of the stylus on the mandibular face bow makes only a small contribution to the dispersion of observations in the clinical tests.

Besides the factor of relative stability of the apparatus, the greater dispersion in the results of the clinical investigation will have been caused by the more complex circumstances under which the investigation was carried out with living subjects. In this regard it must also be considered that it is by no means certain that a pure rotation of the mandible, that is, free of any translatory movement can be performed by a test subject. In carrying out the investigation it occurred in fact repeatedly that no complete freedom from movement could be attained in the adjusting of the stylus point and that the position of least movement of the stylus had to be accepted. Remarkably, this did not always lead to a greater dispersion of registrations. The remaining movement of the stylus point indicates that in a number of cases a small translation in one direction or another occurred concomitantly with the rotation.

As a third factor, it can also be supposed that the interaction of different forces upon the mandible during repeated axis determinations caused a small disparity in the location of the rotation axis. If this is so the stylus point may have been brought to rest at different positions during different registrations.

The further possibility must be taken into account that the causes of the systematic deviation observed in the laboratory investigation also influenced the location of the clinical hinge axis registrations. The extent of this is, however, so small that the influence on the clinical results can be ignored.

The possibility exists finally that the repeated rotating of the mandible during a given determination did not always occur in the same posterior border position. In that case it would be difficult to find the position in which the stylus point is motionless against the graph paper background, since a number of adjustments had to be made for each registration. Although the reproducibility of the posterior border position could be demonstrated for each subject with the aid of a Gothic arch tracing, it was obviously not possible to carry out this control during the procedure of determining the hinge axis.

When all the factors that can cause a dispersion of registrations in the clinical investigation are taken into consideration, it seems most likely that a small concomitant translation along with the rotation of the mandible and a possible disparity in the location of the axis as a result of the influence of different forces on the mandible contribute the most to the dispersion actually observed.

The accuracy with which hinge axis determinations can be carried out, that is to say, the area within which the registrations may be expected, can be estimated from the results that have been obtained as these are presented in table IV.2.

For the purpose of calculating the dimensions of this area of probable dispersion, approximately four times the value of the observed standard deviation (mean $\pm$ 2 s) can be taken in the horizontal and vertical directions.* These dimensions amount to approximately 1.7 $\times$ 1.7 mm for this investigator. For a different investigator the same dimensions of the area of probability cannot be expected without further qualification. The standard deviation calculated in the present investigation is derived from 124 determinations and dependent on a number of factors that need not be the same with various investigators.

* With the numbers of degrees of freedom $\varphi = 94$ and $\varphi = 95$, the values of t with a one-sided tail probability of 2½% both amount to 1.99.

CHAPTER V

POINTS OBTAINED WITH THE PALPATION METHOD AND WITH THE ARBITRARY METHOD

V.1 PROCEDURE

In clinical practice, the face bow transfer from the patient to the articulator is carried out not only on the basis of hinge axis points ascertained with the kinematic method but also on the basis of points determined in other ways. Although it was not expected that these would lead to an accurate approximation of the hinge axis, two points determined in different ways are examined in this investigation in order to test them against the results of the kinematic method. One of these points is found by palpating the mandibular condyle and estimating the center of it. The other is derived from the "arbitrary" points described in the literature. These two points were also indicated on the skin of the test subject (fig. IV.7).

THE PALPATION METHOD. In approximating the axis according to the palpation method, one proceeds on the assumption that the rotation axis passes through the centers of the condyles. The condyle is physically located by means of the index finger. When the center of the palpable part of the condyle is presumed to have been located, this point is indicated with a dot on the skin.

This part of the present investigation was not carried out by this author, since it soon appeared that the estimates made were influenced by his experience in connection with the topography of kinematically determined axis points. For this reason it was decided to have this location indicated for each subject by colleagues. They were advised for this purpose to palpate carefully, both with the mandible at rest and while the condyle was in motion. The estimated location of this palpation point was marked with a dot on the skin and labeled with the number 1.

Aside from the question as to whether the actual rotation axis passes through the externally palpated part of the condyle (the long axes of the two condyles run from the outer aspect medially in the posterior direction, *Amer, 1952; Sicher, 1964*), the question also arises as to how reproducible this point is. A separate investigation was conducted concerning this question, the results of which are reported later in this chapter.

THE ARBITRARY METHOD. Although the term "arbitrary point" is constantly used in the literature, the point thus referred to is in no way arbitrary. The location of this point is based on external anatomical landmarks of the ear and the eye, with the connecting line between the tragus and the canthus as the usual basic reference feature. It is always assumed that the point lies above (the center of) the condyle.

In regard to the precise location of this arbitrary point there is no agreement in the literature. Moreover, the determination of the location is often so vaguely described that precision is impossible. The tragus, for instance, the cartilaginous prominence in front of the external opening of the ear, has a height of ± 10 mm, so that reference to it as the orienting feature is a very inexact indication of which point is to be taken. The same is true of the meatus acusticus externus, from which, for instance, *Hanau (1930)* measures 13 mm toward the canthus (the corner of the eye). *Gysi (1914)* takes as arbitrary point 10 mm anterior to the tragion. *Bergstrom (1950)* also proceeds from the tragion, but concerning the location of the tragion there are also various opinions: the middle of the tragus *(Pernkopf, 1963)*; the upper edge of the tragus *(Van Loon, 1915)*; or the identation directly above the tragus *(Bergstrom, 1951; Boucher, 1963)*.

Fischer (1954) takes as starting point 10 mm anterior to the tragus, *Brandrup-Wognsen (1953)* 12 mm and *Beyron (1942)* and *Schallhorn (1957)* 13 mm in front of the posterior margin of the tragus. *Lazzari (1955)* takes as arbitrary point 11 mm anterior to the top of the tragus and *Thomas (1971)* 11 mm anterior to the top of the tragus on a line to the canthus and then 5 mm in the inferior direction. *Tetteruck and Lundeen (1966)* and *Hickey (1968)* proceed from a point 6 mm in front of the ear plug of an ear face bow, and *Beck (1959)* takes a point 10 mm in front of the center of the meatus acusticus and 7 mm below the Frankfort horizontal.

For the present investigation, in consultation with *Derksen* a point on the skin 12 mm anterior to the highest point of the meatus acusticus externus on a line to the canthus has been taken. This point seems to be a reasonable average of the various arbitrary points indicated in the literature and has the advantage that one proceeds on the basis of a point rather than a part of the body. This point was also indicated on the skin and labeled with the number 2.

For each subject the distances were now measured between the three points indicated on the skin. Moreover, after marking the orbital point, two profile photographs were made (fig. IV.7), so that the various points could later be compared in regard to topography.

V.2 THE DISPERSION OF THE REGISTRATIONS

In the investigation described above only one registration was carried out per subject according to the palpation method and one according to the arbitrary method. The material provides therefore no information concerning the reproducibility of the results of each method. For this reason comparison of the two with each other is not justified on this basis. If the palpation and arbitrary methods are to be compared, information must be obtained concerning reproducibility as well as concerning the position of the registrations in relation to the actual hinge axis. For this purpose a separate investigation was carried out. In order to characterize the populations the areas of dispersion were again indicated with m ± 2 s. It was further assumed here also that the registrations are normally distributed.

a. *Arbitrary method*

For 3 subjects 10 determinations were carried out according to the arbitrary method by a single investigator, both on the left and the right sides. The points 12 mm in front of the highest point of the meatus acusticus and on a line to the canthus were registered on a card stuck to the skin of the subject. The investigation was conducted blindly in so far that the investigator registered the points on the card with a red pen while he was himself wearing red colored glasses. In this way he was kept from seeing points already registered.

The determinations were carried out alternating from one side to the other 10 times in succession. The results were recorded on profile photographs in relation to the kinematically determined hinge axis. It appeared that the registrations in all cases were so close to each other that many could no longer be individually distinguished. A similar small dispersion was obtained in a test with two other investigators. The differences among them in regard to the positions of the dispersion areas were also so small that these results are not reported further here.

The best quantification of the dispersion was obtained by estimating the standard deviation by means of the probability distribution of the sample range. The results are reported in table V.1; the areas of dispersion are also indicated here in relation to the hinge axis (+).

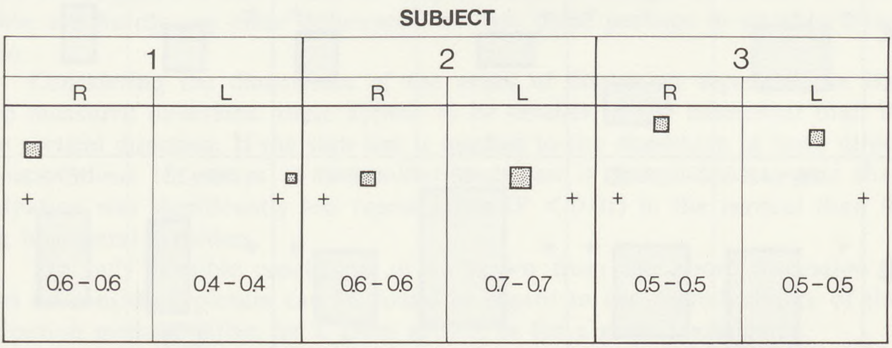


Table V.1. Areas of dispersion of samples of 10 registrations according to the *arbitrary method.* The sides of the squares have a length of four times the standard deviation. The hinge axis is indicated by +. The standard deviations in horizontal and vertical directions are reported underneath in mm.

b. *Palpation method*

Next 10 determinations on each side of the face were carried out for the same 3 subjects according to the palpation method. In order to find out whether results are strongly correlated with respective investigators, this part of the investigation was repeated consecutively by 3 different investigators. Again the investigation was carried out blindly with the use of a red pen and red glasses.

In this investigation no use could be made of cards stuck to the skin because this would interfere with the palpation itself. Therefore the registrations had necessarily to be marked directly on the skin. These determinations were also made 10 times consecutively alternating from one side to the other. And here also the hinge axis according to the kinematic method was registered. The results were then recorded on profile photographs. These photographs were enlarged two times linearly. With the aid of a system of coordinates the arithmetic mean of the 10 registrations, the location of this mean in relation to the hinge axis as located by the kinematic method, and the standard deviation were calculated separately for each side of the face. The results of this part of the investigation are displayed in table V.2 in a way similar to and with a similar scale as for the arbitrary method. The calculated means (lying on the intersection of the diagonals of each rectangle) are displayed in their actual positions in relation to the hinge axis. Around the means the areas of dispersion are shown, the length of the sides of the rectangles being 4 times the standard deviation. The calculated values of the

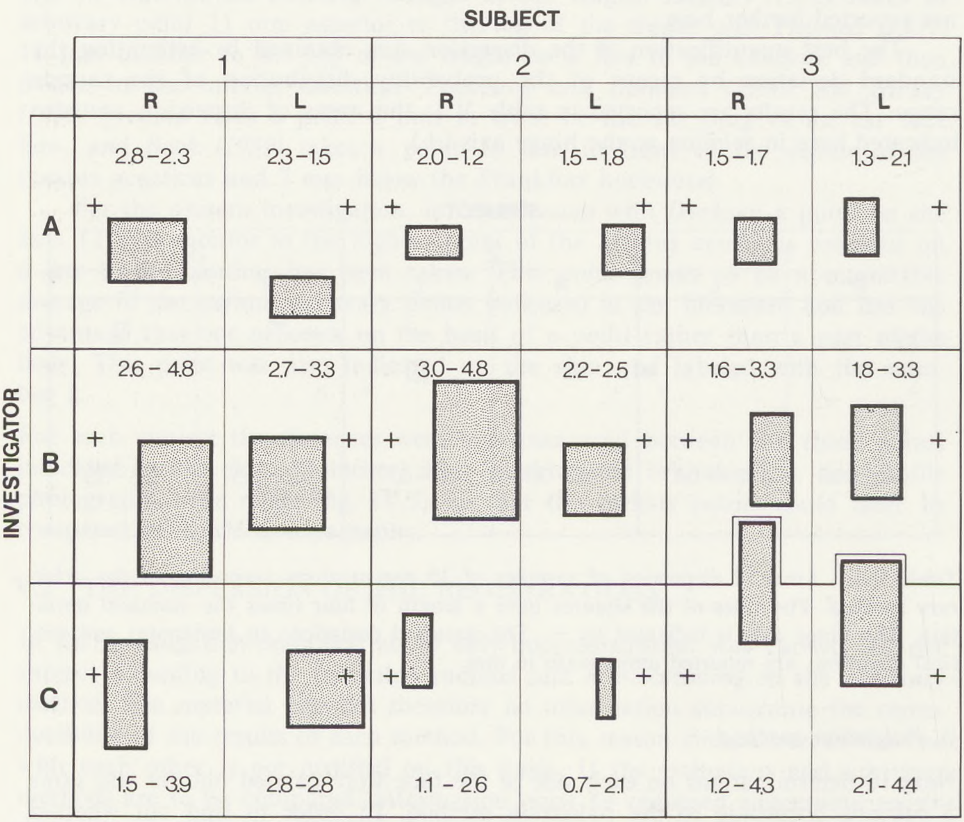


Table V.2. Areas of dispersion of samples of 10 registrations according to the *palpation method.* The investigation was carried out by 3 investigators with the same 3 subjects as used for the data reported in table V.1. The calculated standard deviations in horizontal and vertical directions are given in mm. The hinge axis is indicated by +.

standard deviation in horizontal and vertical directions are reported in mm in each section.

On inspection of the results as they are presented in table V.2, the drawing of important conclusions from this material does not seem justified. The extent of the data is too small.

There is some indication that the palpations of investigator A are more reproducible for subjects 1 and 2 than those of investigator B. This difference is less clear for subject 3, while investigator C shows for this subject a dispersion of the same extent as investigator B. For the latter the palpation method seems to be most reproducible for subject 3. For investigator C, by way of contrast, this is the case for subject 2, while investigator A shows almost the same results for these two subjects.

Comparing the results from left and right sides, it appears that each area of dispersion has a different position in relation to the hinge axis for subject 1 with investigator A and for subject 2 with investigator C. The positions are so different that the areas hardly coincide or do not coincide at all in a superimposition of the hinge axis points in mirror image. It might be concluded from this that these differences in location of the condyle by palpation are based on anatomical differences on the two sides of subjects 1 and 2. This supposition is not confirmed, however, if the results are checked for subject 1 with investigators B and C and for subject 2 with investigators A and B. Here there are hardly any clear differences, or they point perhaps in another direction.

Considering the dimensions of the areas of dispersion separately in the two measured directions, these appear to be smaller in the horizontal than in the vertical direction. If the sign test is applied to the dispersion in both directions of these 18 groups of determinations, than it does indeed appear that palpation was significantly less reproducible ($P < 0.01$) in the vertical than in the horizontal direction.

The only possible conclusion to be drawn from the above discussion is that no consistant picture can be found in regard to the reproducibility of the palpation method, either for a given subject or for a given investigator.

c. *Comparison of these methods*

If the results of this investigation of the palpation method are considered as a whole and compared with the results of the arbitrary method, it appears that there are notable differences between them. All areas of dispersion of the registrations obtained according to the arbitrary method (table V.1) are smaller than those obtained according to the palpation method (table V.2). Taken in general, there is a difference of a factor of 4 linearly, so that the reproducibility of the arbitrary method must be judged better than that of the palpation method.

If the distribution of the registrations of the two methods as presented in figure VI.1 are now considered, it is clear that every registration of a determination according to the arbitrary method is one element belonging to one of the populations of which examples are given in table V.1. If the registered points are regarded as the means of such populations, then the areas of dispersion obtained as means from table V.1 can be extended around these points. A similar handling of the data can be followed for the dispersion of the registrations according to the palpation method. The dimensions of the average area of dispersion, derived from table V.2, amount to 7.7 × 11.7 mm. If these areas were extended around all registrations, the suspicion could arise in regard to the palpation method that the dispersion for one individual subject, because of its relatively great extent, is mainly responsible for the dispersion observed for the 30 subjects together. This supposition can be tested with the data concerning the dispersion of registrations according to the palpation method. When the hinge axes of the various investigators and subjects from table V.2 are superimposed, it appears that the areas of dispersion for left and right sides hardly coincide or do not coincide at all. Furthermore, it appears from calculation that the dimensions of the areas of dispersion for the 30 individual subjects amount to approximately 15 × 19 mm. If the positions of the dispersion areas of table V.2 in relation to the hinge axis were the same as those for the 30 test subjects, then it could be expected that the mean dispersion calculated from table V.2, for which the dispersion of the means is not included, would be equally great as the dispersion for the 30 test subjects, for which this dispersion is included. It appears that this is not the case, which indicates that anatomical variations do indeed account for the dispersion observed for the 30 subjects.

CHAPTER VI

LOCATION OF THE THREE "AXIS" POINTS INDICATED ON THE SKIN IN RELATION TO EACH OTHER

VI.1 PROCEDURE AND RESULTS

As has been stated above, the three points obtained by the palpation method (1), the arbitrary method (2) and the kinematic method (3) were indicated on the skin of each subject and the distances between them measured. By means of left and right profile photographs, on which the orbital point was also indicated, and with the use of a large roentgen-viewer, these givens were collected in one figure. For this procedure the photographs were covered with a sheet of drawing paper, for which the correct position was determined by superimposing point 3 on the paper and orienting the Frankfort horizontal parallel to a given line in the figure. Since the profile photographs were not enlarged on exactly the same scale, from these prints only the angles formed in relation to the Frankfort horizontal by the connecting lines between point 3 and points 1 and 2 respectively could be transferred. The length of the line segments was taken from the distances measured directly on the skin during the investigation.

In this way the position of points 1 and 2 for the 30 subjects could be established in the figure in relation to the hinge axis. Figure VI.1 gives a picture of the dispersion of these points for the whole group of test subjects. In regard to the accuracy of this picture, it must be stated that it was consistently point 3, that is, the arithmetic mean of a number of hinge axis determinations, that was superimposed. In the collecting of data for this figure no account could be taken of the dispersion of the hinge axis determinations, which was small but nonetheless present. In order to indicate the scale, concentric circles with radii of 0.5, 1, 5 and 10 mm around the hinge axis points have been included in figure VI.1. From these circles it can be seen how many of the registered points are located at a distance of 0 to 5 mm, 5 to 10 mm, and more than 10 mm from the hinge axis as it was determined by the kinematic method. These numbers are broken down in terms of palpation and arbitrary methods and reported in table VI.1.

From these data it can be calculated that for the palpation method on the left and right sides together only 17% of the registrations are located within 5 mm of the hinge axis. 51% lie between 5 and 10 mm, and 32% of the registrations lie at a distance of more than 10 mm from the axis. For the arbitrary method 45% of the registrations are located at a distance of less and 55% at a distance of more than 5 mm from the hinge axis. From this it might be concluded that the latter method is more precise than the former. In fact, however, a comparison of the two methods on the basis of the data collected

	Palpation method		Arbitrary method	
Distance in mm from the hinge axis	R	L	R	L
0 - 5	5	5	13	14
5 - 10	15	16	16	13
>10	10	9	1	3
Total number of registrations	30	30	30	30

Table VI.1. Numbers of registrations for 30 subjects classified in terms of method of determination, side of the face and distance from the kinematically determined hinge axis.

here is not justified. The registrations for the arbitrary method are the work of a single investigator with 30 subjects. The registrations for the palpation method were on the other hand carried out by 30 different investigators. The reason for this was the extremely subjective nature of the latter method. One must as it were be open-minded and unprejudiced in carrying out a palpation. As soon as an investigator has any knowledge of the results of one of the other two methods, influence of this knowledge on his palpation is almost unavoidable, as has been stated earlier (p. 59). In order nonetheless to obtain results for this method that were as objective as possible, the palpation was not done by the present investigator himself or even by a few others, but as many different investigators as possible were enlisted in this part of the investigation. Since it is apparent from what has just been said that it was impossible to follow exactly the same procedure for the two methods, this defect had to be accepted.

The means and the standard deviations were calculated for both methods from the collected registrations. This was again accomplished with the help of a system of coordinates in relation to which the horizontal and vertical distances were measured. The two highest registrations obtained by the palpation method (see figure VI.1) were not taken into account in the calculations. For each of these, both on the right and on the left sides of the face, it was shown by means of a test developed by *Dixon (1950)* that they do not belong to the population and may thus be regarded as outliers.

The means determined are presented in figure VI.1 with a black circle and an enlarged cross. The values calculated are presented in table VI.2.

VI.2 DISCUSSION

If the various methods are now compared with each other, it appears that the kinematic method yielded the greatest reproducibility under the circumstances

	Palpation method				Arbitrary method			
	R		L		R		L	
	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.
Distance of the sample mean from the hinge axis	6.0	4.1	6.6	4.0	2.2	2.0	2.4	1.4
Standard deviation	3.6	5.1	3.9	4.3	2.6	4.3	2.8	4.7

Table VI.2. Results in mm of the registrations according to palpation and arbitrary methods for 30 subjects.

of the investigation. The area within which approximately 90% of the determinations for new test subjects from the population may be expected is indicated in figure VI.1 by a circle with a radius of 1 mm around the hinge axis.

In locating the hinge axis in clinical practice, one will not as a rule limit oneself to a single determination before making use of the result in the further clinical procedure. For the sake of greater accuracy it is desirable to carry out several determinations and then utilize the average. In this case one takes a larger sample and so increases the accuracy. The new standard deviation amounts to $\frac{s}{\sqrt{n}}$ for which s = the standard deviation found in the investigation and n = the number of determinations in the new sample. From this it appears that the value $\frac{s}{\sqrt{n}}$ decreases as the number of axis determinations in the new sample increases. The areas of dispersion of new sample means can be deduced from this value (sample mean $\pm\ 2\ \frac{s}{\sqrt{n}}$). The areas calculated for various numbers of new axis determinations are presented in table VI.3 in mm.

Number of axis determinations in the new sample	Dimensions of the area of dispersion			
	R		L	
	Horizontal	Vertical	Horizontal	Vertical
1	1.85	1.56	1.67	1.78
2	1.31	1.11	1.18	1.26
3	1.07	0.90	0.97	1.03
4	0.93	0.78	0.84	0.89

Table VI.3. Dimensions in mm of the areas of dispersion based on an arithmetic mean of 1 to 4 registrations.

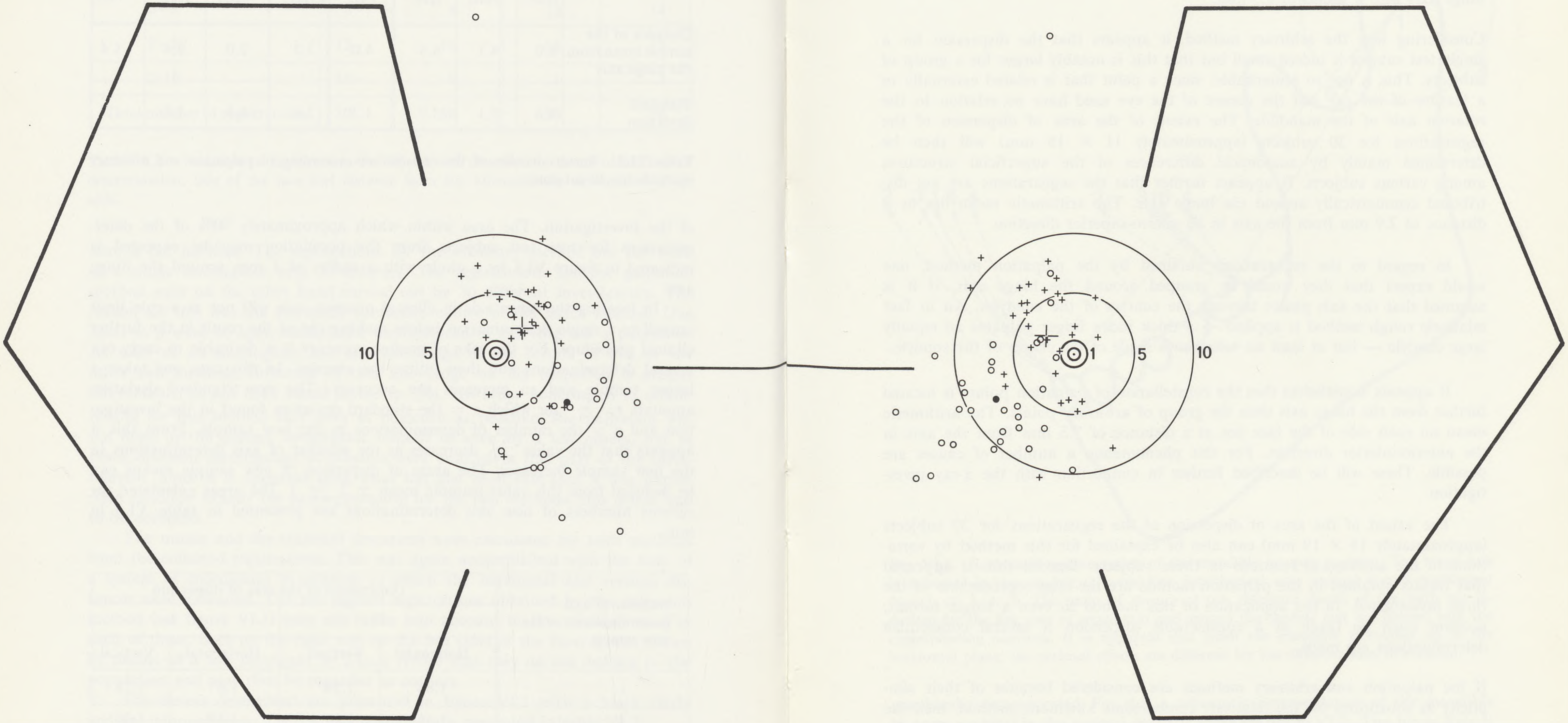


Fig. VI.1. Schematic representation of the ears with registrations of 30 test subjects in relation to the hinge axis (◎) as determined kinematically for each subject. The registrations obtained according to the palpation method are indicated by O, and the arithmetic means of these registrations by ●. The registrations obtained according to the arbitrary method are indicated by + and the arithmetic means of these by +. There is a horizontal reference line to which the Frankfort horizontal of the profile photographs was oriented in parallel relation. Concentric circles are included with radii of 0.5, 1, 5, and 10 mm around the hinge axis.

From the values that have been found it is apparent that with an arithmetic mean of 3 determinations in a new sample the majority of these means may be expected to fall within an area of approximately 1 × 1 mm. This corresponds roughly to the area indicated in figure VI.1 by the circle around the hinge axis with a radius of 0.5 mm.

Considering now the arbitrary method, it appears that the dispersion for a single test subject is indeed small but that this is notably larger for a group of subjects. This is not so remarkable, since a point that is related externally to a feature of the ear and the corner of the eye need have no relation to the rotation axis of the mandible. The extent of the area of dispersion of the registrations for 30 subjects (approximately 11 × 18 mm) will then be determined mainly by anatomical differences of the superficial structures among various subjects. It appears further that the registrations are not distributed symmetrically around the hinge axis. The arithmetic mean lies at a distance of 2.9 mm from the axis in an antero-superior direction.

In regard to the registrations obtained by the palpation method, one would expect that they would be grouped around the hinge axis, if it is assumed that the axis passes through the centers of the condyles. An in fact relatively rough method is applied — a thick index finger palpates an equally large condyle — but at least an estimate is made of the center of the condyle.

It appears nonetheless that the constellation of palpation points is located further from the hinge axis than the group of arbitrary points. The arithmetic mean on each side of the face lies at a distance of 7.5 mm from the axis in the anterio-inferior direction. For this phenomenon a number of causes are possible. These will be described further in connection with the x-ray investigation.

The extent of the area of dispersion of the registrations for 30 subjects (approximately 15 × 19 mm) can also be explained for this method by variations in the anatomical relations in these subjects. Besides this, it appeared that results obtained by the palpation method are the least reproducible of the three investigated. In the application of this method to even a single subject, account must be taken of a considerable dispersion if several consecutive determinations are made.

If the palpation and arbitrary methods are considered because of their simplicity as substitutes for the relatively cumbersome kinematic method, then the question arises as to which of the two is to be recommended. The arithmetic mean of registrations obtained by the arbitrary method does lie closer to the hinge axis than that obtained by the palpation method, but no absolute value ought to be attributed to this observation. It has been shown mathematically that a deviation away from the hinge axis does not have an equally great effect in every direction in regard to occlusal relations *(Brotman, 1960, F. Bosman and Derksen, 1969)*. These differences of cause and effect can also be

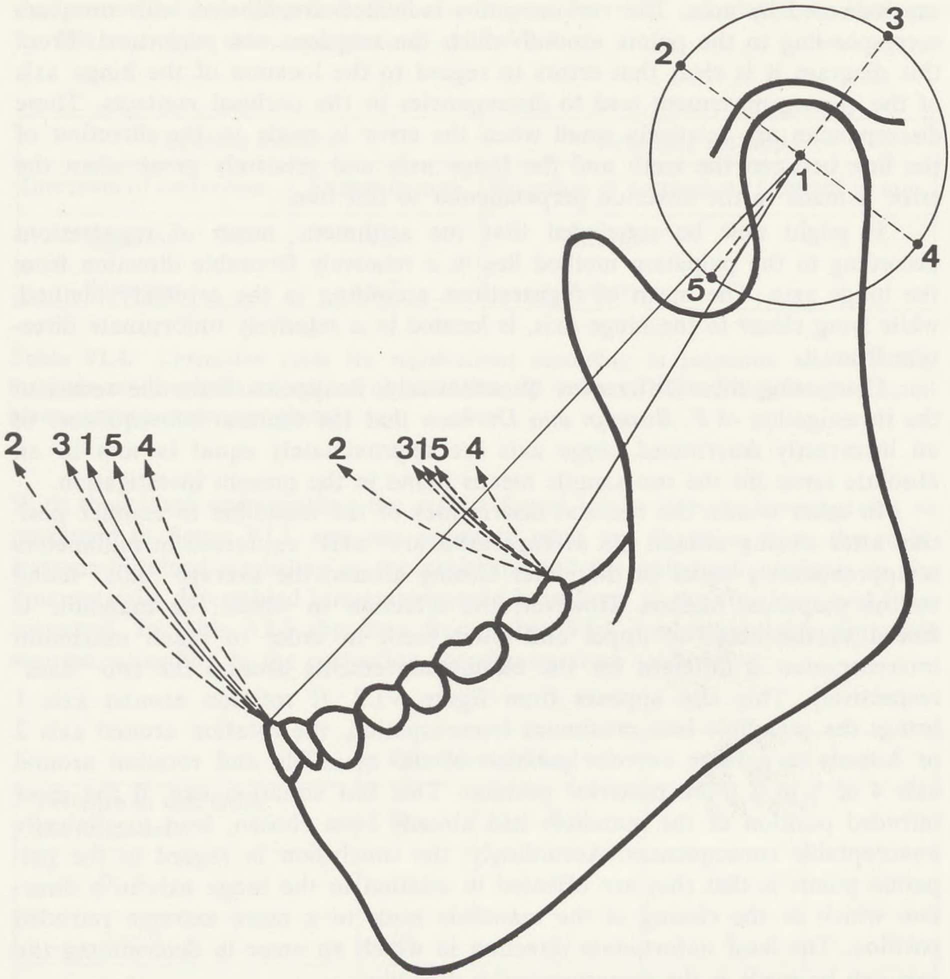


Fig. VI.2. Schematic representation of the mandible in open position. The hinge axis is indicated in the condyle (1) with four hypothetical axes around it and equidistant from it (2, 3, 4, 5). The paths of closure of two reference points of the teeth are indicated for the five axes of rotation at and around the condyle and are labeled with the corresponding numbers. It is apparent that when the mandible is rotated up to the horizontal plane, the occlusal effects are different for the different axes of rotation.

graphically demonstrated. For this a schematic representation of the mandible in open position in the sagittal plane is given in figure VI.2. The hinge axis is indicated in the condyle by the number 1. Four points equidistant from the axis have been indicated. Points 3 and 5 lie on the line bisecting the angle formed by the lines drawn from the hinge axis to the incisors and molars respectively. Points 2 and 4 lie on a perpendicular to this bisecting line. For two reference points of the teeth (incisal edge of lower incisor and distal cusp of the second molar) the paths of the closing movement to the plane of occlusion are indicated by arcs. The various paths indicated are labeled with numbers corresponding to the points around which the rotations are performed. From this diagram it is clear that errors in regard to the location of the hinge axis of the closing movement lead to discrepancies in the occlusal contacts. These discrepancies are relatively small when the error is made in the direction of the line between the teeth and the hinge axis and relatively great when the error is made in the direction perpendicular to this line.

It might now be concluded that the arithmetic mean of registrations according to the palpation method lies in a relatively favorable direction from the hinge axis. The mean of registrations according to the arbitrary method, while lying closer to the hinge axis, is located in a relatively unfortunate direction from it.

Comparing these differences quantitatively, it appears from the resuls of the investigation of *F. Bosman and Derksen* that the occlusal consequences of an incorrectly determined hinge axis are approximately equal in mm in an absolute sense for the two sample means found in the present investigation.

In other words, the occlusal discrepancy of the mandible in contact position after closing around the average arbitrary "axis" expressed in millimeters is approximately equal to that after closing around the average "axis" found by the palpation method. However, the direction in which the mandible is forced by the cusps of upper and lower teeth in order to reach maximum intercuspation is different for the closing movements around the two "axes" respectively. This also appears from figure VI.2. If rotation around axis 1 brings the mandible into maximum intercuspation, the rotation around axis 2 or 3 leads to a more anterior position of the mandible and rotation around axis 4 or 5 to a more posterior position. This last situation can, if the most retruded position of the mandible had already been chosen, lead to clinically unacceptable consequences. Accordingly, the conclusion in regard to the palpation points is that they are oriented in relation to the hinge axis in a direction which in the closing of the mandible leads to a more extreme retruded position. The least unfortunate direction in which an error in determining the axis can be made is the postero-superior direction.

The investigation described was carried out for 30 subjects on both sides of the face. The results of the investigation of reproducibility of results of the two methods as this is presented in tables V.1 and V.2 show that there is no complete symmetry between registrations on right and left sides of a given subject for either the palpation or the arbitrary method. It does appear, however, that the sample means for these methods for 30 subjects on both sides are almost similarly situated in relation to the hinge axis. From this symmetry it can be concluded that variations in regard to side of the face do not occur systematically. This is a fortunate circumstance if one wants to correct one of the two methods (as a substitute for the kinematic method) on the basis of the results obtained. In order to reach optimal results, it is possible to correct a registration by the coordinates of the sample means found here in relation to the hinge axis. Accordingly, with the palpation method one must revise in the postero-superior direction, and with the arbitrary method one must revise in the postero-inferior direction. The coordinates for this, calculated as averages for left and right sides, are given in table VI.4.

Palpation method		Arbitrary method	
Direction of correction	Extent in mm	Direction of correction	Extent in mm
Superior	4.0	Inferior	1.7
Posterior	6.3	Posterior	2.3

Table VI.4. Correction table for registrations according to palpation and arbitrary methods on the basis of values obtained for 30 subjects. The Frankfort horizontal plane serves as reference plane.

With these data and recalling the results found in the present investigation as presented in figure VI.1, one can ascertain what the distances from the registrations obtained according to the arbitrary and the palpation methods to the kinematically determined hinge axis would have been if the first two had been corrected. In table VI.5 the data from table VI.1 are presented again after revision according to the correction coordinates from table VI.4.

	Palpation method		Arbitrary method	
Distance in mm from the hinge axis	R	L	R	L
0 - 5	13	17	20	19
5 - 10	15	11	9	9
> 10	2	2	1	2
Total number of registrations	30	30	30	30

Table VI.5. Numbers of registrations for 30 subjects classified in terms of method of determination, side of face and distance from the kinematically determined axis *after correction according to the coordinates reported in table VI.4.*

From these data it can be calculated that even after correction 35% of the arbitrary determinations and 50% of the determinations according to the palpation method are still located at a distance of more than 5 mm from the calculated arithmetic mean of the kinematic determinations of the axis.

Even if the described correction for distance and direction in relation to the hinge axis is applied to a registration, however, it must be remembered that this does not yield any improvement in the accuracy of the method itself.

Nor can any reduction be expected in regard to the dispersion due to anatomical variations.

In regard to both of these variables which cannot be influenced, the arbitrary method was adjudged better than the palpation method. Therefore, if the location of the hinge axis is to be approximated and the kinematic method is not applied, preference is to be given to the corrected arbitrary method.

CHAPTER VII

ROENTGENOGRAPHIC INVESTIGATION OF THE LOCATION OF THE THREE POINTS INDICATED ON THE SKIN IN RELATION TO THE UNDERLYING CONDYLE

VII.1 INTRODUCTION

After an exact determination of the location of the hinge axis has been carried out according to the kinematic method, the relation of this location to external anatomical landmarks can be ascertained. However, no information has been obtained regarding its relation to the underlying bone structures, specifically the mandibular condyle.

This relation has been studied by various investigators. *McCollum (1939)* investigated two postmortem specimens by means of roentgenograms. With a roentgenopaque mark on the skin he indicated the position of the hinge axis. An x-ray film was then inserted in a groove on the medial side of each joint parallel to the median plane. The exposing rays were directed perpendicularly to this film. In this way *McCollum* obtained a projection in a transverse direction of the condyle and the identifying mark. He found that for the four joints he investigated the rotation axis passed through the condyles. *Beyron (1942, 1954)* examined 10 patients by means of superimposed tomograms. He found that the transverse hinge axis passed through or close to the condyles. *Fischer (1952)* found that almost all the centers of rotation determined by him in several subjects were located within the outlines of the condyles. *Brandrup-Wognsen (1953)* and *Levao (1955)* report that the axis of rotation does not necessarily pass through the condyles, while *Levao* is further of the opinion that if the stylus is without motion in the preauricular area this may also reflect a rotation around an imaginary axis not passing through the condyles.

Posselt (1957) investigated the position of the rotation axis in 19 subjects by means of lateral cephalograms. This author found that in every case the rotation axis passed within the contour of the condyle, although in a number of cases it was close to the outline. *Goodkind (1967)* made lateral cephalograms of 10 edentulous patients. He also found that during a rotation of the mandible in its retruded position the axis was located within the condylar outlines.

Hickey, Allison, Woelfel, Boucher and Stacy (1963) investigated mandibular movements with a pin to which a light was attached and which was inserted directly into the condyle. They report that the condyles could be maintained in a retruded position during the hinge movement, but that a center of rotation could not be found in the area of the condyle.

Le Pera (1964) reports a roentgenographic investigation of the position of the hinge axis in a large number of patients after this was located by a method he describes. The film was placed on the side of the patient on which the roentgenopaque mark on the skin was also attached, and the x-ray cone was placed on the other side in such a way that it touched the skin in the area of the temporomandibular joint. *Le Pera* reports that in his investigation the rotation axis appeared in no case to pass through the condyles, and he concludes that the rotation axis cannot be the same as the "intercondylar axis," a term apparently referring to an axis through the center of right and left condyles. This axis, according to him, is located above and in front of the hinge axis.

The present investigation has demonstrated that the center of the condyle as found by palpation does not correspond to the hinge axis. The arithmetic mean of 30 registrations according to the palpation method was located 7.5 mm from the hinge axis in the antero-inferior direction. The cause may have been that the group of investigators did not palpate correctly, that is, that something other than (the center of) the condyle was palpated. It is also possible that in the test subjects the hinge axis either did not pass through the condyle at all or passed through a part of the condyle lying approximately 7.5 mm from the palpated outer pole as measured in the sagittal plane. The latter is conceivable, since the length of the condyle amounts to about 20 mm and the anatomical long axis runs in a posterior direction from the outer aspect medially.

In order to obtain information in this regard as well as concerning the relation in the sagittal plane of the hinge axis to the mandibular condyle, a roentgenographic investigation was instituted.

VII.2 APPARATUS AND PROCEDURE

The position of the tree points described above was indicated on the skin by means of metal pins held in position with adhesive tape and with the point of the pin at the point to be registered. In order to distinguish them the identifying pins were marked with one, two or three grooves to indicate the respective points on the skin. In this way a clearly visible image was obtained on the x-ray film.

The usual roentgen techniques for examining the temporomandibular joint generally make use of an oblique angle of exposure in order to avoid disturbing shadows from bony structures of the skull. Although the contour of the condyle can be made most clear in this way, these oblique projections do not yield the desired picture of the relation of the identifying marks on the skin to the underlying tissues. For a proper image of the indicated location of the hinge axis in relation to the structures recorded, it is desirable that the direction from which the film is exposed correspond to the direction of the hinge axis. If this is the case, the projection of the axis (which appears as a point) indicates where it passes through the tissues. This consideration was accordingly the point of departure for the present investigation. As has already been stated, this angle of exposure entails the disadvantage that heavy bony parts of the skull as well as the other temporomandibular joint are projected over the condyle involved, which interferes with the interpretation. The problem was resolved by making use of linear tomography. With this technique it is possible to obtain the image of a cross section at a predetermined depth.

In the method as applied in this investigation (fig. VII.1) the x-ray focus (F) and the film (p) move simultaneously in opposite directions. During the exposure the focal spot moves from F1 to F3 around a rotation axis C and the film moves around the same axis from p1 to p3. The movement during the swing of the tomograph is such that:

1. the film remains parallel to the cross section being recorded;
2. point C of the cross section remains projected on the same point on the film;
3. the distances from F to C and from C to its projection on the film remain constant.

From these givens it can be deduced that the position of every other point (e.g. B) in the plane of the cross section (s) as it is projected onto the film remains constant. Tissues in the plane of the cross section (s) are in this way sharply recorded during the rotational movement of the tomograph. This does not apply for points outside the plane of the cross section. The projections of these points (e.g. A and D) continually change position on the film during the swing and their images will therefore be blurred. With this technique a sharp image of the condyle can be obtained without interfering superimposition of other structures.

The thickness of the interpretable slice or cross section is inversely proportionate to the angle of swing. The total extent of the swing of the tomograph had therefore to be determined and adjusted in terms of the intended result.

To find the optimum adjustment a number of tomograms were produced for a skull with angles of swing varying from 1°-30°. It appeared that the best results were obtained with an angle of 10°. The whole condyle could be registered with this angle. The angle was adjusted for the tomograph in such a way that during the exposure an angle of 5° was traversed on each side of the hinge axis.

The proper depth under the skin surface had also to be selected for optimum results. Therefore a number of test exposures were made at intervals of 0.5 cm from 0.5-3.5 cm depth measured from the surface of the skin. It was found that with the selected angle of rotational swing (10°) and the consequent thickness of the interpretable slice, the best results were obtained with a depth of 2 cm under the skin. This depth was maintained throughout the investigation.

The disadvantage of this technique, oriented completely to the condyle, is that the metal pins fixed to the skin at the locations of the determined points 1, 2 and 3 do not lie in the chosen plane of the cross section and consequently are not sharply recorded on the film. An image a few millimeters wide is produced on the film as a result of the movement of focus and film. For the

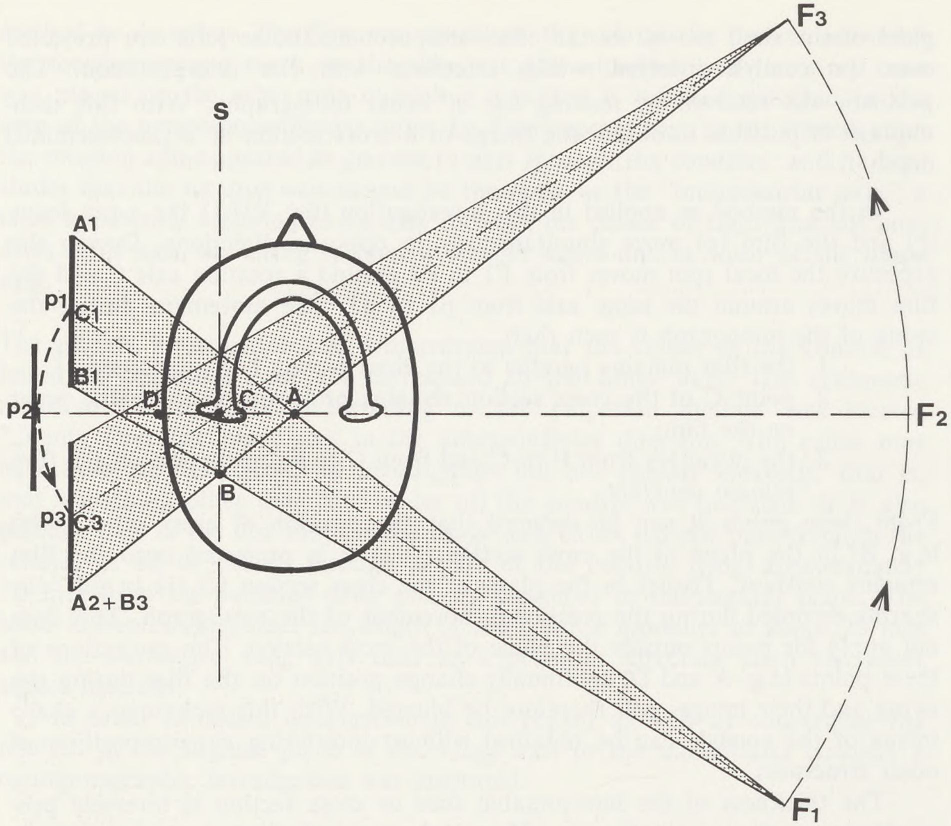


Fig. VII.1. Schematic diagram of the tomography of the mandibular condyle as applied in the present investigation. Movement of the focal spot from F1 to F3 around a vertical axis (C) through the condyle and simultaneous movement of the film around the same axis from p1 to p3. During the exposure an equal angle is traversed on each side of the hinge axis. Points lying within the plane of the cross section (s) are recorded sharply on the film. Point A is projected onto the top of the film at p1 and onto the bottom at p3. It has thus moved across the whole film during the swing of the focus (F1-F3) and is therefore not sharply recorded. An identifying mark on the skin (D) will also appear blurred on the film. p2 indicates the position of the film at which a separate exposure is made with the focus stationary at F2. In this way the images of the tomogram and the stationary exposure are superimposed on the same film.

Technical data:

Distance focus to film	: 88 cm
Distance focus to plane of cross section	: ± 78 cm
Angular speed	: 5.6°/sec
Field size at the film	: ± 6 × 9 cm
Tomographic contacts	: — 5° and 5°
Stationary exposure	: 85 kV, 40 mA, 0.3 sec
Tomogram	: 85 kV, 9-12 mA
Distance skin to plane of cross section	: 2 cm
Grid	: 16/cm, ratio 1:8

evaluation of the films it would be possible to take the midpoint of the projected path of movement of each pin, since the length of travel is equal on each side of the hinge axis. A better result is obtained, however, by making a separate exposure on the same film with the x-ray tube at the position F2 (fig. VII.1) with the central axis of the beam aligned to the hinge axis. The film is then also located at the midpoint of its trajectory (p2), so that the identifying mark of point 3 indicates the place where the axis passes through the tissues. Since the metal pins have a high contrast in the resulting pictures, a relatively short exposure in this position is sufficient to produce a good image of the pins on the film. Although the undesirable superimposition of other bony structures occurs at this step, it was found that the contribution of this factor on image formation did not interfere with interpretation.

The technique of superimposing an exposure of the identifying marks on the skin with the focus stationary onto a tomogram of the condyle satisfied the demand for registering the marks in relation to underlying structures. It was carried out for all subjects on left and right sides.

The subjects were instructed to keep the mandible in the posterior contact position during the exposures. The head of the subject was immobilized in such a position that the exposing x-rays were parallel to the Frankfort horizontal plane during the movement of the apparatus. This is generally done by means of two ear plugs in the external auditory meatus. In order to avoid movement of the pins attached to the skin during this part of the procedure, the plugs were not inserted in the meatus itself but rather in a fold of the upper part of the ear. It was assumed that in this way the head of the subject was immobilized with the hinge axis parallel to the line connecting the ear plugs. Measurements on the profile photographs showed that indeed anatomical differences between left and right sides of the test subjects were not great enough to require consideration of any important deviations.

VII.3 RESULTS

A total of 60 roentgenograms was obtained for the 30 subjects according to the technique described. With the use of a large roentgen viewer and a magnifying glass tracings were made from these roentgenograms of the condyle, articular fossa and eminence, and bony auditory meatus. Next the position of the three points registered on the skin was taken from the grooved pins. The drawings obtained in this way are presented in pairs in figure VII.2 (appendix).

In order to evaluate the locations of the various registered points, the condyle proper will be defined as that part of the neck and condyle as they are drawn which has equal dimensions horizontally and vertically as measured from the superior surface.

In regard to the kinematically determined hinge axis points, it appears that all are located within the contours of the condyles. Some of these are situated close to the outlines. If the distances on the roentgenograms are corrected for the enlargement factor involved in the x-ray technique (1.13 ×), it appears that 12 points are at a distance of less than 2 mm from the contours. All of these points are located in the superior part of the condyle, sometimes a little in the anterior and sometimes a little in the posterior direction. The other 48 points seem to be located more centrally in the condyle without a clear tendency toward a given region. In order to further evaluate the dispersion of the hinge axis locations in the condyles two schematic condyles were drawn with circular circumferences (fig. VII.3). For each tracing the center of the condyle was defined as the intersection of the diagonals of the square around the condylar outline. The size of the square was determined by the maximum anteroposterior condylar dimension and its top was tangent to the upper side of the condyle. The position of each hinge axis point in relation to this condylar center was defined by direction and proportionate distance from the outline. These data were transferred to the left and right schematic representations of the condyles. In this way the 30 hinge axis points for each side could be compared as to location in their respective condyles. From figure VII.3 it can be seen that most of the determinations fall within the areas

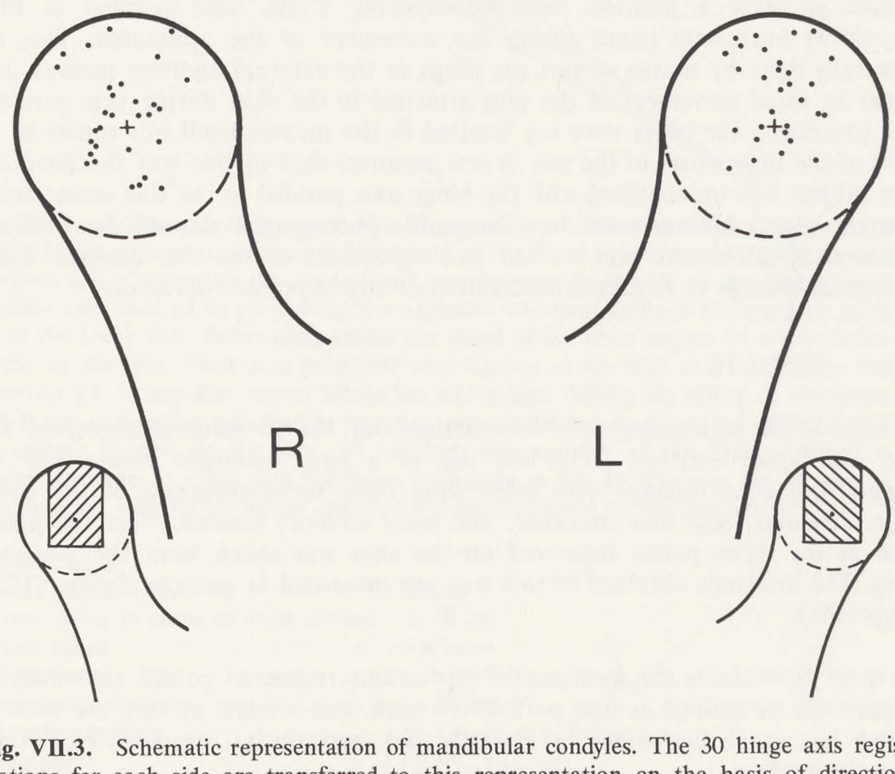


Fig. VII.3. Schematic representation of mandibular condyles. The 30 hinge axis registrations for each side are transferred to this representation on the basis of direction and proportionate distance from the outline. The shaded areas in the smaller diagrams indicate where 90% of the determinations were found.

around the condylar center and above it. 90% of the determinations are located in the shaded area, which is one radius of the circle in width, as indicated in the small diagrams. Few are found to be in the anterior, posterior or inferior segments of the condyles.

Although in a number of cases the position of the hinge axis points in the condyles on left and right sides display a certain symmetry, it is also true that in a number of cases clear differences are apparent on the two sides. It should be remarked that also in regard to the condyles themselves in a number of cases a morphological asymmetry can be observed.

Evaluating next the position of the points obtained by the palpation method, it would be logical to presume that while this method does not in fact determine the hinge axis it does indicate the palpable part of the condyle. The registered points might then in any case be expected to lie within the contours of the condyle tracings.

It appears, however, that 33 of the 60 points are located outside the tracings. The palpation procedure in these cases led to the determination of a point on the skin that does not lie above the condyle. While the investigators were requested to indicate the condylar center in the retruded position of the mandible, the palpation procedure also requires anterior movements of the mandible. It is most likely that the consequent anterior translation of the condyle was misleading to the investigators, so that they registered in fact a protrusive position of the condyle.

As to the reason why the sample mean of the palpation points is located 7.5 mm from the hinge axis in the antero-inferior direction (cf. the discussion in chapter VI), it is uncertain in regard to the 27 points within the condylar contour whether they as well as the points outside the condyles are the result of inaccurate palpation. It is equally conceivable that they do indicate the center of the palpable part of the condyle. The hinge axis might then pass through a part of the condyle lying further inside the skull and so inaccessible to palpation. This explanation would be in agreement with the opinion of *Zola (1963)* that rotation of the mandible takes place around the medial pole of the condyle. This pole is located posteriorly from the lateral pole. This may be the reason, along with the evident error which occurs in the palpation procedure, for the relatively great distance between the registrations obtained according to the kinematic method and those obtained according to the palpation method.

In regard to the registrations obtained according to the arbitrary method there is little comment to be made as a part of the roentgenographic investigation. It is no cause for surprise that a number of the registrations (21) fall outside the tracings of the condyles. No exact anatomical relation can be expected between the bony condyle on the one hand and the soft tissues of the ear and the eye on the other. Information from these registrations in relation to the underlying condyle is in any event of little importance.

CHAPTER VIII

SUMMARIZING CONCLUSIONS

Several conclusions can be drawn from the results obtained in the different parts of the investigation. It appears that with the laboratory model the determination of the axis of rotation according to the mechanical-empirical method could be carried out with sufficient accuracy. The limits of the accuracy achieved corresponded approximately with the limits that are set by the resolving power of the eye. This resulted in an area of dispersion of the registrations of approximately 0.4 × 0.4 mm with a rotation angle of 15° and 10° and approximately 0.5 × 0.5 mm with a rotation angle of 5°. From this it can be concluded that errors inherent in the nature of the method or dependent on the investigator are so small that in the light of the desired objectives the kinematic method is accurate enough to justify clinical application. Even with a rotation angle of 5° a dispersion was found that can be described as very small in relation to the results from the clinical procedure.

The hinge movement, by means of which the axis determinations were carried out for subjects tested, was obtained by guiding the mandible in the most retruded position with a light posteriorly directed pressure from the operator's hand. The Gothic arch registrations showed that this position was reproducible in the plane of registration and could also be repeated by the subjects themselves.

The dispersion of the hinge axis registrations for the 30 test subjects was approximately 4× as large linearly as for the laboratory model and amounted to approximately 1.7 × 1.7 mm. It appeared from a number of introductory tests that instability in the apparatus may, because of its extent, have had a significant influence in the laboratory investigation. Nonetheless, the contribution of this instability to the dispersion of the clinical determinations will have been relatively small. The dispersion observed was probably determined mainly by a mechanically inexact rotation of the mandible and by a possible displacement of the hinge axis as a result of different forces acting differently upon the mandible.

Using the values found for the subjects, an estimate was made of the dimensions of the area within which hinge axis determinations may be expected to fall. If an average of 3 determinations is taken, then the dimensions of the confidence region are approximately 1.0 × 1.0 mm.

It was found further that with extreme values of 13°-23° the arithmetic mean of the maximum available trajectories of rotation in the material from the subjects corresponded to a rotation angle of the mandible of 18°. This was approximately half the maximum mouth opening.

With regard to the other two methods of approximating the hinge axis, it was shown that the sample mean according to the palpation method is located further from the kinematically determined axis point than the sample mean according to the arbitrary method. The reproducibility of results obtained by the palpation method is also less. A comparative summary of the various areas of dispersion found is presented in table VIII.1.

Kinematic method laboratory investigation	Kinematic method clinical investigation	Arbitrary method clinical investigation	Palpation method clinical investigation
0.4 x 0.4	1.7 x 1.7	11 x 18	15 x 19

Table VIII.1. Comparison of the various areas of dispersion expressed in mm.

The sample mean according to the palpation method is located at a distance of 7.5 mm in the antero-inferior direction from the kinematically determined hinge axis, and the sample mean according to the arbitrary method is at a distance of 2.9 mm from it in the antero-superior direction. In order to apply a correction to these observed deviations such that the observed sample means will be made to coincide with the kinematically determined hinge axis, correction coordinates are given in table VI.4 for both alternative methods.

If the figure generally given in the literature of 5 mm as the maximum permissible error for a method of determining the hinge axis is accepted, then it should be realized that even after correction of the two alternative methods here under discussion a number of determinations are located beyond this distance from the hinge axis. From the data of the investigation it appeared that after correction 50% of the determinations according to the palpation method and 35% of the determinations according to the arbitrary method still are at a distance of more than 5 mm from the kinematically determined axis. If the arbitrary method is chosen nonetheless because of its simplicity in application, then the point 12 mm in front of the highest point of the external auditory meatus on a line to the canthus should be corrected. According to the results of the present investigation, the correction should amount to 2.3 mm posteriorly and 1.7 mm inferiorly using the Frankfort horizontal as reference plane.

With regard to the significance of a given error, it should be realized that the direction of the error in relation to the hinge axis is important. The occlusal consequences are the least with an error in the postero-superior direction.

In the roentgenographic investigation the topographical relation in the sagittal plane of the various points determined and the condyles of the mandible was examined. The tracings of the tomograms showed that 33 of the 60 points found by palpation were located outside the contours of the condyles. Although it might be assumed that indicating the lateral pole of the condyle by means of palpation would not be difficult, this apparently did not lead to the desired result in the majority of cases.

The kinematically determined axis points were found to lie without exception within the outline of the condyle. While some of these points were located close to the upper outline of the condyle, the majority of them were more centrally located, with nearly no incidence in the anterior, inferior and posterior regions.

Although the various parts of the investigation were all carried out on both left and right sides, no notable differences were observed between the two sides in the investigation as a whole.

From the small dispersion found in the kinematically determined axis points, it is clear that the mandibular hinge movement which the subjects could perform can be regarded as a reasonably exact rotation. It can further be stated that the kinematic method of determining the hinge axis, as the most reliable of the methods investigated, shows a dispersion which is considerably smaller than the maximum accepted by many authors, namely a circle with a radius of 5 mm which corresponds to an area of approximately 9 × 9 mm. It is therefore concluded that the kinematic determination of the hinge axis in a clinical procedure is possible and justified.

POSTSCRIPT

In the introduction to the laboratory investigation it was stated that the value of hinge axis determinations must be cast in doubt if errors inherent in the method of determination result in an excessive degree of inaccuracy. If the method itself can be considered sufficiently accurate, the same can be said in regard to errors in the clinical procedure of axis determination. It was possible to demonstrate in this investigation that the contribution of the error inherent in the method to the error observed in the clinical axis determinations was small. Nonetheless, from the results of the clinical investigation all that can be deduced is the degree of accuracy with which the hinge axis can be located and thus the terminal hinge movement be reproduced. It can further be deduced how much more accurately this is possible with the kinematic method than with other methods.

It has been shown by mathematical calculation *(Brotman, 1960; F. Bosman and Derksen, 1969)* that an error of 5 mm distance from the hinge axis, often accepted as reasonable *(Weinberg, 1959, 1961; Arstadt, 1954),* can lead to a horizontal discrepancy of 0.2-0.3 mm in the occlusal contacts of a patient.

Some authors consider this little, others are of the opinion that it is much. Judgment in this regard is partially dependent on the objectives in view. It is conceivable that for the construction of complete dentures, because of their relative instability during function in the mouth *(Smith, Kydd, Wijkhuis and Phillips, 1963),* a lower degree of accuracy is acceptable than for the treatment of the natural dentition. It is, however, also in regard to the natural dentition, not easy to determine whether or not a given occlusal discrepancy can be accepted in clinical practice. In this regard the dental profession has set no standard norms.

A number of authors point in this connection to the importance of endogenic or psychogenic causes in the prevention of temporomandibular joint disturbances. *Ramfjord (1971)* refers to the physiological adaptive capacities of the biological system. And he feels that adaptation can be found in the occlusion of the teeth and in the neuromuscular system, which seems to possess a great potential for adaptation. According to *Ramfjord,* "the adaptive capacity of the neuromuscular system depends to a great extent upon the irritability threshold of the central nervous system (fusimotor activity), which is influenced by emotional and psychic tension. Therefore, occlusal interferences may or may not lead to neuromuscular or other functional disturbances within the masticatory system."

In the light of this, it will not be easy to determine with certainty whether or not the added accuracy provided by the kinematic method of hinge axis determination is actually required in a clinical situation. The great diversity of patient response to injurious influences makes it practically impossible to establish general rules.

A definite need exists, however, to be able to predict individual responses, with their possible pathological sequelae, to errors introduced in the occlusion. In this connection it should be realized that therapy in restorative dentistry involving the occlusion has a predominantly curative character with no more than a repressive effect. A better knowledge of injurious influences and their effect on the functioning of the masticatory system would provide a better basis for preventive measures. Much more research into this difficult field is needed.

SUMMARY

This investigation has been undertaken to study various aspects of hinge axis determination and their possible clinical implications. For this purpose the origin of the question as well as current controversial points of view related to the problem were discussed in the review of literature.

Next a number of methods for determining the hinge axis of the mandible were described. The most widely accepted method, the mechanical-empirical or kinematic method was chosen for the present investigation. The accuracy of the method without clinical variables was investigated in a laboratory experiment. In a blind test with an articulator and an adjustable face bow the accuracy was determined with which the rotation axis of an articulator can be located. On the basis of the dispersion areas of a number of axis determinations on right and left sides the accuracy of the method was determined for rotation angles of 15°, 10° and 5°. A number of factors limiting the accuracy were discussed, and special reference was made to the relation of the dispersion to the limits set by the resolving power of the eye.

In the clinical part of the investigation the reproducibility of hinge axis determination was tested for 30 experimental subjects. To the lower arch an adjustable face bow was attached and to the upper arch a flag with a roentgen film on which the successive hinge axis determinations could be registered. The hinge movement was performed with a light posteriorly directed pressure applied to the chin by the operator's hand. With Gothic arch tracings it was shown that a reproducible starting position of the mandible could be obtained with this guidance. The dispersion of hinge axis determinations was calculated from 249 clinical registrations. This dispersion was approximately 4 × greater linearly than the dispersion of axis determinations in the laboratory experiment and amounted to an area of 1.7 × 1.7 mm. The maximum rotation of the mandible during the hinge movement was measured at the incisors and amounted to a mean value of 27.4 mm, which corresponds to an opening angle of the mandible of 18°.

Besides the kinematically determined hinge axis points on both sides of each subject, points were determined according to the palpation method and according to the arbitrary method. These registrations were also indicated on the skin. In this way the dispersion of these points could be calculated with the kinematically determined hinge axis as reference. In a separate investigation the reproducibility of determination according to these methods was tested for 3 subjects. On the basis of the results the arbitrary method was judged more accurate than the palpation method. The positions of the calculated sample means of both methods showed a systematic deviation in relation to the kinematically determined hinge axis. Even after correction of these methods for this deviation it appeared that 35% of the arbitrary determinations and 50% of the determinations according to the palpation method were located more than 5 mm from the kinematically determined hinge axis.

In a roentgenographic investigation the positions of the 3 points indicated on the skin were examined in relation to the underlying mandibular condyle. These points were indicated with roentgenopaque marks. For each subject a tomogram was made of the condyle on each side and then on the same film a stationary exposure of the marks on the skin. Next with the aid of tracings the positions of the kinematic hinge axis determinations for each side were examined in a schematic representation of the condyle. It appeared in all cases that the mandibular hinge axis was located within the central part or in the superior segment of the condyle tracing. More than 50% of the points obtained by the palpation method were located outside the contours of the condylar tracings.

The conclusions drawn on the basis of all data are summarized in chapter VIII.

SAMENVATTING

Het beschreven onderzoek is ingesteld om verschillende aspecten van de scharnierasbepaling met de mogelijke klinische implicaties te bestuderen. Daarvoor is in het literatuuronderzoek ingegaan op het ontstaan van deze vraagstelling en tevens op de thans bestaande controversiële standpunten over een aantal onderwerpen, die verband houden met de vraagstelling.

Vervolgens is een aantal methoden om de scharnieras van de onderkaak te bepalen beschreven. De meest toegepaste methode, de mechanisch-empirische of kinematische methode werd gekozen voor het onderzoek. In een laboratoriumonderzoek is de nauwkeurigheid van de methode zonder klinische variabelen onderzocht. Hierbij werd gebruik gemaakt van een articulator en een instelbare face bow, die voor dat doel werden omgebouwd, zodat in een blindproef kon worden onderzocht met welke nauwkeurigheid de rotatieas van de articulator kan worden opgespoord. Bij drie rotatiehoeken, 15°, 10° en 5° werd een aantal asbepalingen aan linker en rechter zijde uitgevoerd. De nauwkeurigheid van de methode werd bepaald aan de hand van de spreidingsgebieden van deze bepalingen voor de betreffende rotatiehoeken. Voorts werd een aantal factoren die de nauwkeurigheid beperken besproken, waarbij speciaal aandacht is besteed aan de relatie van de spreiding met het oplossend vermogen van het oog.

In een klinisch onderzoek werd vervolgens bij 30 proefpersonen een aantal scharnierasbepalingen uitgevoerd met behulp van een instelbare face bow volgens Laurizen, die is bevestigd aan de ondertandboog. De registraties werden vastgelegd op een vlag met een röntgenfilm, die aan de boventandboog was bevestigd. De scharnierbeweging werd uitgevoerd door de onderkaak tijdens het openen en sluiten met een lichte dorsaal gerichte druk van de hand van de onderzoeker te geleiden. Met Gothische boogregistraties werd aangetoond, dat met behulp van deze geleiding een reproduceerbare uitgangspositie van de onderkaak kan worden verkregen. Met de uitkomsten van het klinische onderzoek werd eveneens de spreiding van de asbepalingen berekend. Deze spreiding was lineair ongeveer 4 × zo groot als de spreiding van de asbepalingen in het laboratoriumexperiment en bedroeg ongeveer 1.7 × 1.7 mm. De maximale rotatie van de onderkaak tijdens de scharnierbeweging werd gemeten en bedroeg bij de incisieven gemiddeld 27.4 mm. Dit komt overeen met een openingshoek van de onderkaak van ongeveer 18°.

Behalve de kinematisch bepaalde scharnieraspunten werden bij iedere proefpersoon aan beide zijden punten bepaald volgens de palpatiemethode en volgens de arbitraire methode. Deze registraties werden eveneens op de huid aangegeven. Zodoende kon met de bepaalde scharnieras als referentie de spreiding van deze punten worden berekend. In een separaat onderzoek werd de reproduceerbaarheid van bepalingen volgens beide laatste methoden bij 3 proefpersonen nagegaan. Op grond van de resultaten werd de arbitraire methode nauwkeuriger beoordeeld dan de palpatiemethode. De positie van de berekende gemiddelden van beide methoden toonde een systematische afwijking ten opzichte van de kinematisch bepaalde scharnieras. Ook na correctie van de methoden voor deze systematische afwijking bleek nog 35% van de arbitraire bepalingen en 50% van de bepalingen volgens de palpatiemethode op meer dan 5 mm van de kinematisch bepaalde scharnieras te liggen.

Tenslotte werd in een röntgenonderzoek de positie van de 3 op de huid aangegeven punten ten opzichte van het onderliggende caput mandibulae onderzocht. De punten werden daartoe van röntgencontrasterende merktekens op de huid voorzien. Van elke proefpersoon werd aan beide zijden een tomogram van het caput gemaakt met op dezelfde film een stilstaande opname van de merktekens. Vervolgens werden met behulp van overtekeningen van de röntgenfoto's de posities van de kinematisch bepaalde aspunten vergeleken in schematische voorstellingen van beide kaakkopjes. Hierbij bleek dat in alle gevallen de kinematisch bepaalde scharnieras van de onderkaak in het centrale deel of in het craniaal gelegen segment van de overtekening van het caput mandibulae was gelegen. Meer dan de helft van de door palpatie gevonden punten lag niet binnen de contouren van overtekeningen van de kaakkopjes.

Uit het totaal van gegevens zijn de conclusies samengevat in hoofdstuk VIII.

Subject	R $x-\bar{x}$	R $y-\bar{y}$	L $x-\bar{x}$	L $y-\bar{y}$
1	−0,030	0,274	0,500	−0,333
	0,050	0,154	0,260	0,147
	−0,020	−0,426	−0,760	0,187
2	0,410	0,444	−0,110	0,324
	−0,100	0,234	−0,050	0,194
	−0,310	−0,676	−0,060	−0,516
3	−0,570	0,510	0,493	0,284
	0,080	0,150	0,163	−0,086
	0,490	−0,660	−0,657	−0,196
4	−1,424	−0,700	−0,370	0,314
	0,186	0,990	0,020	0,534
	1,236	−0,290	0,350	−0,846
5	−0,207	0,284	−0,567	0,297
	−0,187	−0,106	0,283	0,077
	0,393	−0,176	0,283	−0,373
6	0,386	0,097	−0,344	0,160
	−0,194	0,067	0,076	0,240
	−0,194	−0,163	0,266	−0,400
7	−1,020	0,340	−0,254	1,484
	0,190	0,030	0,426	0,094
	0,830	−0,370	−0,174	−1,576
8	−1,800	−0,700	0,120	0,594
	0,540	0,410	−0,210	−0,236
	1,260	0,290	0,090	−0,356
9	0,056	0,757	0,376	0,220
	0,296	−0,333	−0,054	−0,320
	−0,354	−0,423	−0,324	−0,500
10	0,220	0,240	0,053	0,477
	0,170	−0,470	0,043	0,027
	−0,390	0,230	−0,097	−0,503
11	−0,532	0,338	−0,196	0,804
	0,048	−0,352	−0,286	0,194
	0,058	0,048	0,164	0,204
	0,118	0,058	0,084	−0,176
	0,308	−0,092	0,234	−1,026
12	−0,530	0,934	0,746	0,726
	0,230	0,074	0,526	−0,114
	0,280	−0,286	−0,004	−0,484
	0,090	−0,286	−0,624	−0,224
	−0,070	−0,436	−0,644	0,096

Table IV.1. Results in mm of axis point determinations for 30 subjects. Columns $x-\bar{x}$ and $y-\bar{y}$ give the distances in horizontal and vertical directions respectively from each registration to the calculated sample mean for each subject. The position in relation to this sample mean is indicated positively in *anterior* direction along the horizontal axis and in the *superior* direction along the vertical axis. Registrations marked with a dash appeared to be unusable for technical reasons.

	R		L	
Subject	x−x̄	y−ȳ	x−x̄	y−ȳ
13	0,062	0,454	0,372	0,223
	0,022	−0,176	0,202	−0,037
	−0,088	−0,276	−0,088	−0,177
	----	----	−0,488	0,007
14	0,320	0,060	0,735	0,210
	−0,320	−0,060	−0,045	−0,110
	----	----	−0,255	−0,010
	----	----	−0,435	−0,090
15	0,310	0,383	−0,834	0,790
	−0,210	0,173	−0,844	0,420
	−0,110	−0,077	1,676	−1,210
	0,010	−0,477	----	----
16	0,231	0,146	0,515	−0,232
	0,061	−0,014	0,215	−0,542
	0,061	−0,014	−0,015	0,458
	−0,099	0,036	0,035	0,308
	−0,099	0,036	−0,175	0,048
	−0,079	−0,094	−0,485	0,078
	−0,079	−0,094	−0,095	−0,112
17	0,356	0,136	−0,140	0,156
	0,086	0,206	−0,250	−0,194
	0,026	−0,244	0,020	0,016
	−0,164	0,126	0,080	0,056
	−0,304	−0,224	0,290	−0,034
18	−0,015	0,230	−0,384	−0,108
	−0,225	0,110	−0,254	−0,228
	−0,315	−0,140	−0,114	0,172
	0,085	−0,030	0,266	−0,058
	0,235	0,050	0,486	0,222
	0,235	−0,220	----	----
19	−0,094	0,264	0,338	0,790
	0,206	0,094	0,288	0,460
	0,206	0,014	−0,022	−0,270
	−0,064	−0,126	−0,472	−0,320
	−0,254	−0,246	−0,132	−0,660
20	−0,070	0,610	0,400	0,396
	−0,190	0,180	0,120	0,046
	−0,240	−0,290	−0,070	0,126
	0,300	0,100	−0,120	−0,474
	0,200	−0,600	−0,330	−0,094
21	0,286	0,067	−0,084	0,230
	0,006	−0,023	0,036	−0,020
	−0,294	−0,043	0,046	−0,210
22	−1,198	0,416	−0,464	−0,188
	−0,038	0,366	−0,254	−0,218
	0,082	0,036	−0,174	0,132
	0,322	0,026	0,206	−0,108

	R		L	
Subject	$x-\bar{x}$	$y-\bar{y}$	$x-\bar{x}$	$y-\bar{y}$
	0,832	−0,844	0,686	0,382
23	0,006	−0,440	0,692	−0,202
	−0,044	0,220	0,292	0,148
	−0,074	−0,050	0,182	−0,362
	−0,254	−0,100	−0,178	0,278
	−0,444	0,370	−0,988	0,138
24	−0,158	0,388	−0,336	−0,214
	−0,288	0,058	−0,076	−0,224
	0,072	0,058	0,514	−0,144
	0,182	−0,112	−0,126	0,226
	0,192	−0,392	0,024	0,356
25	−0,292	0,572	−0,235	0,528
	−0,142	0,022	−0,125	0,048
	−0,112	−0,318	0,215	−0,222
	0,138	−0,128	0,145	−0,352
	0,408	−0,148	----	----
26	−0,130	0,495	−0,097	0,242
	−0,010	0,175	−0,177	0,072
	−0,330	−0,105	−0,107	0,042
	0,070	−0,115	0,053	0,112
	0,270	−0,005	0,013	−0,208
	0,130	−0,445	0,313	−0,258
27	−0,360	0,290	−0,138	0,272
	0,060	0,370	−0,208	0,132
	0,090	0,210	−0,068	−0,098
	0,160	−0,310	0,202	−0,068
	0,050	−0,560	0,212	−0,238
28	0,412	−0,045	0,012	0,353
	0,162	0,525	0,202	−0,117
	0,172	−0,355	0,022	−0,077
	−0,748	−0,125	−0,238	−0,157
29	0,575	0,123	0,537	0,475
	0,215	−0,157	0,167	−0,175
	−0,135	0,283	−0,243	−0,045
	−0,655	−0,247	−0,463	−0,255
30	0,436	0,808	−0,228	0,352
	0,336	0,248	−0,108	0,292
	−0,124	−0,572	0,052	0,002
	−0,264	−0,352	0,022	−0,148
	−0,384	−0,132	−0,058	−0,538
	----	----	0,322	0,042

Subject	Men			Women		
	Vertical overbite	Maximum opening	Maximum rotation	Vertical overbite	Maximum opening	Maximum rotation
1	1	53	31			
2	3	48	28			
3				2	46	23
4				2	48	26
5	1	46	28			
6	1	46	26			
7	2	54	28			
8	0	50	22			
9				4	59	26
10				2	48	28
11	4	50	26			
12	2	46	22			
13	2	48	27			
14	4	52	31			
15	3	54	29			
16	0	52	22			
17	5	65	35			
18	4	49	27			
19				2	65	33
20	5	54	31			
21	0	55	22			
22	3	57	32			
23				2	64	31
24	4	63	20			
25				3	41	23
26	2	68	34			
27	3	66	32			
28	2	61	26			
29	3	60	26			
30				3	58	28

Table IV.3. Presentation in mm of the mouth opening and vertical overbite as measured in 30 subjects. The maximum opening and the maximum rotation are obtained from the sum of the interincisal distance and vertical overbite.

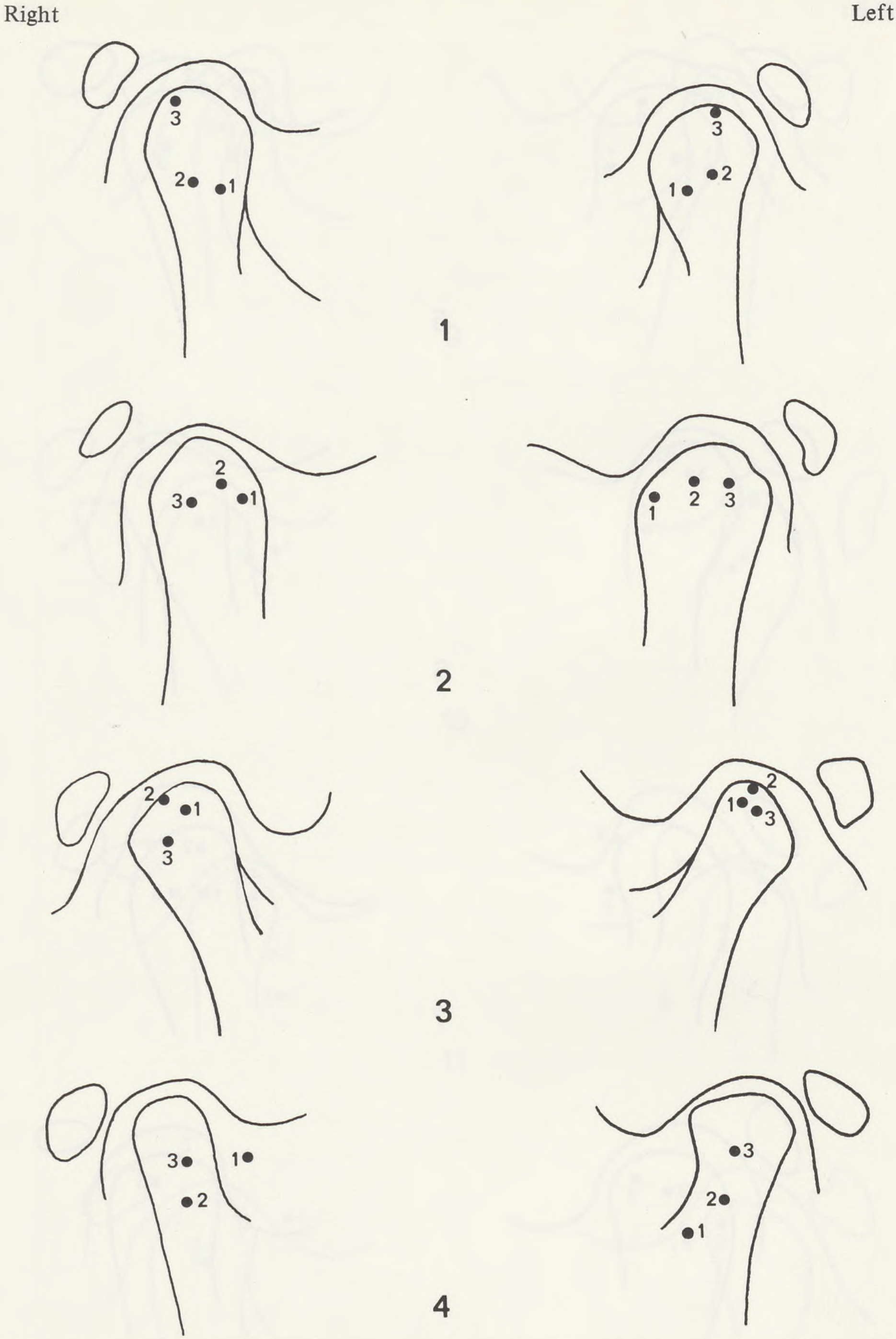
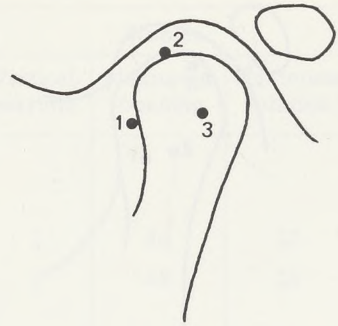


Fig. VII.2. Tracings of the tomograms of 30 subjects oriented to the Frankfort horizontal plane. The positions are indicated of the points registered on the skin according to the palpationmethod (1), the arbitrary method (2) and the kinematic method (3).

Right | Left



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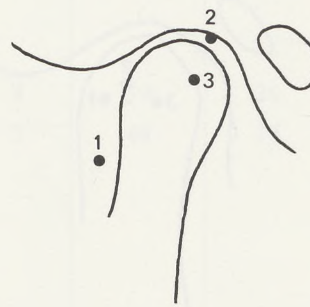

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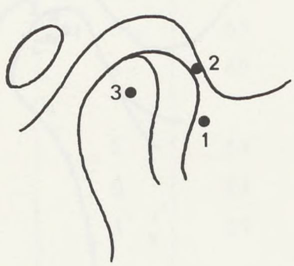

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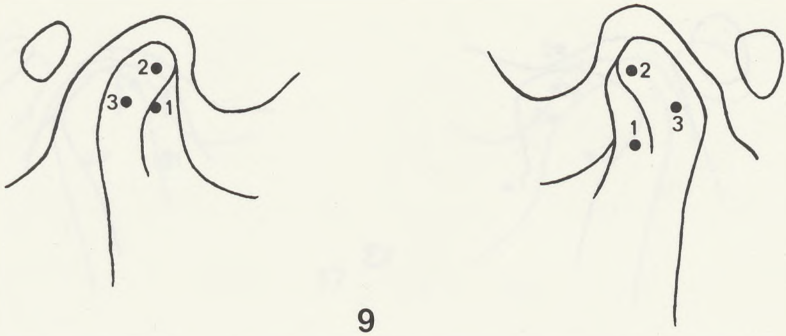

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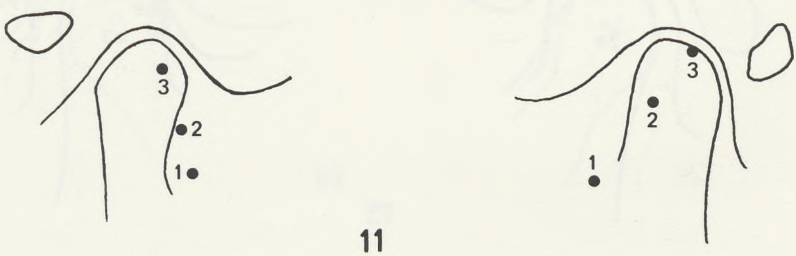

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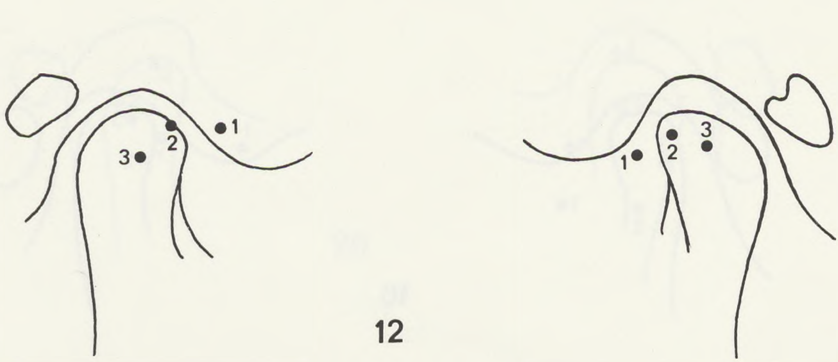

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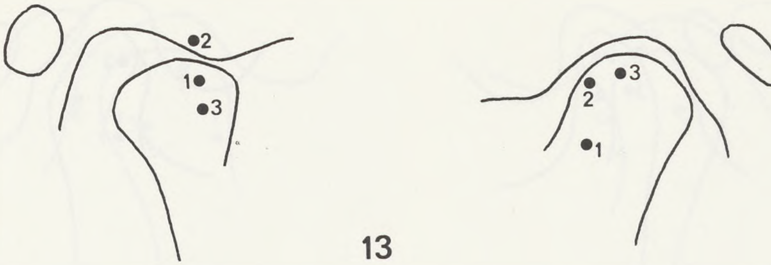

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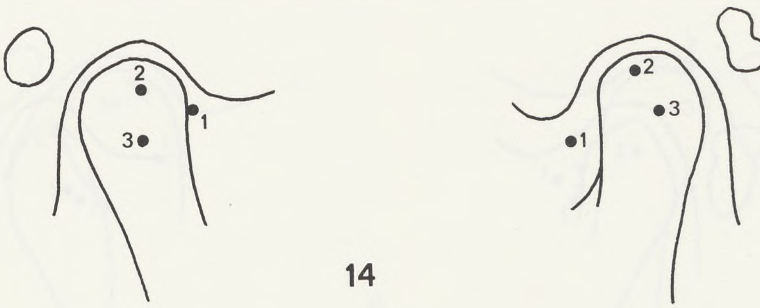

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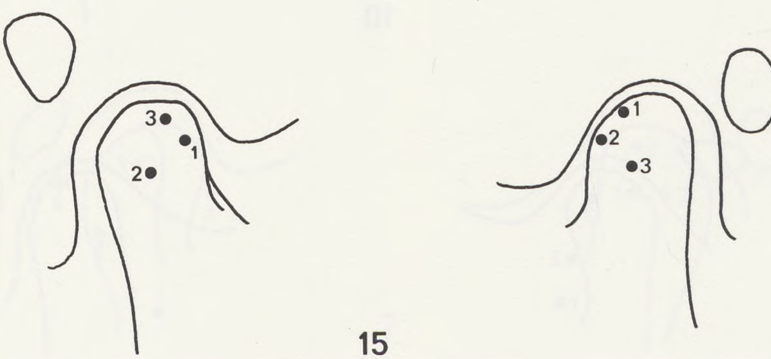

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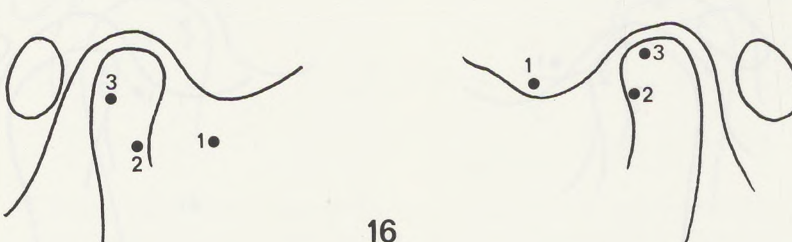

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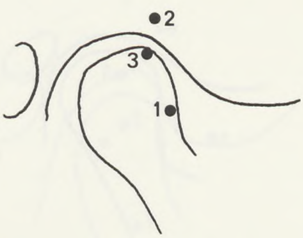

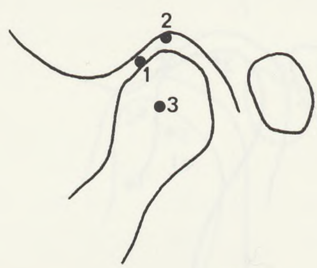

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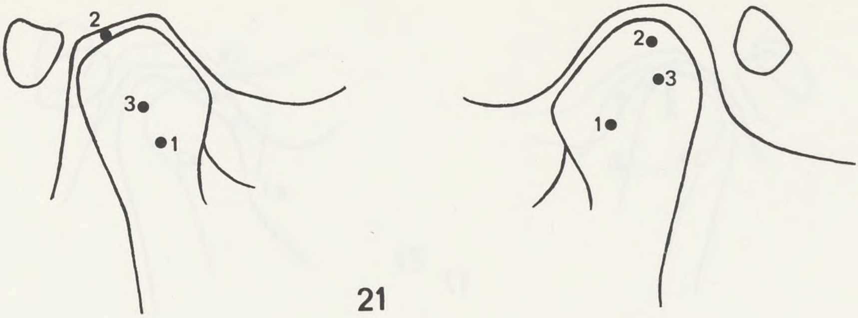

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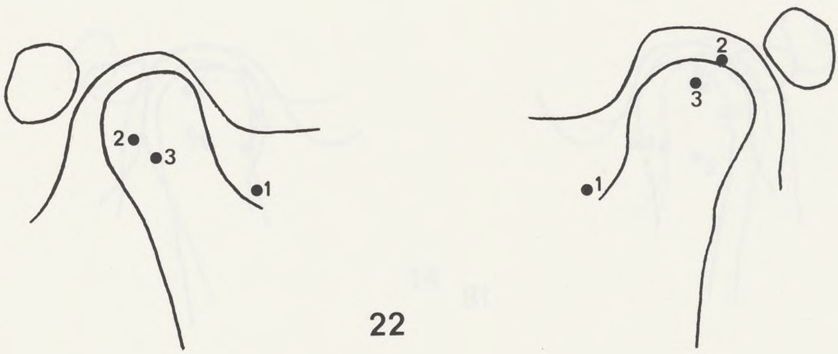

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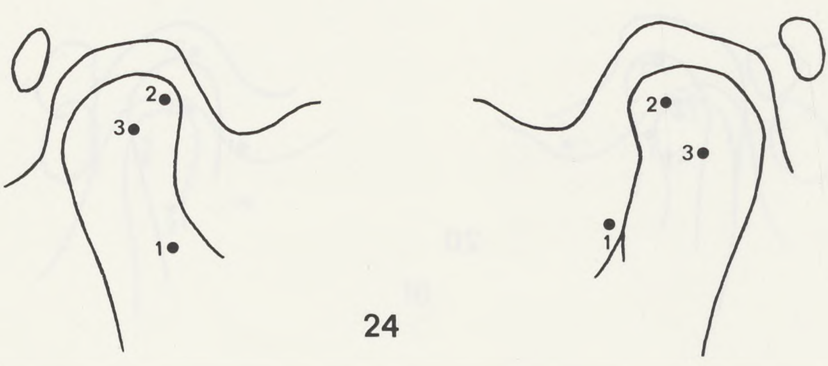

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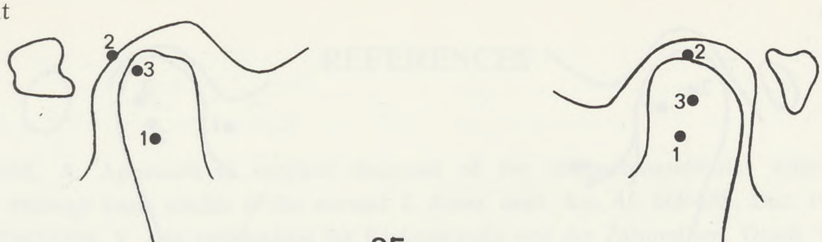

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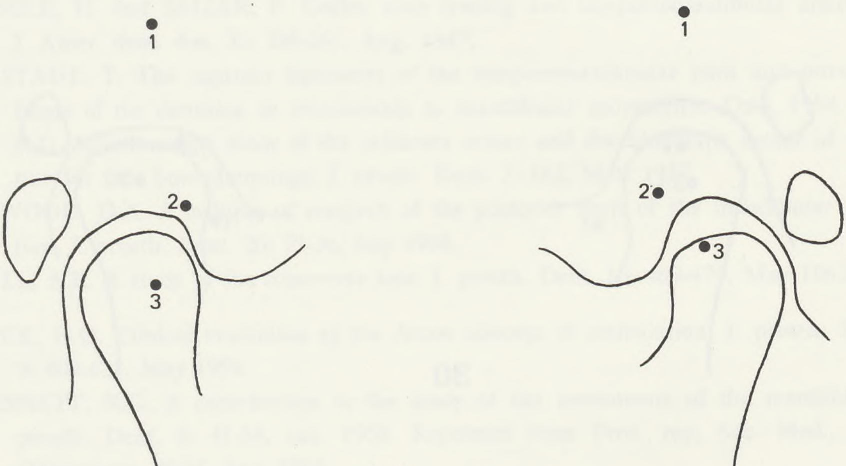

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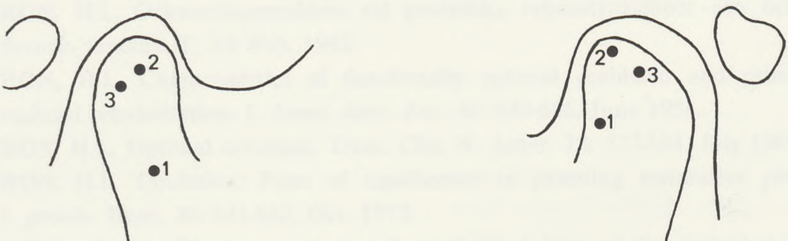

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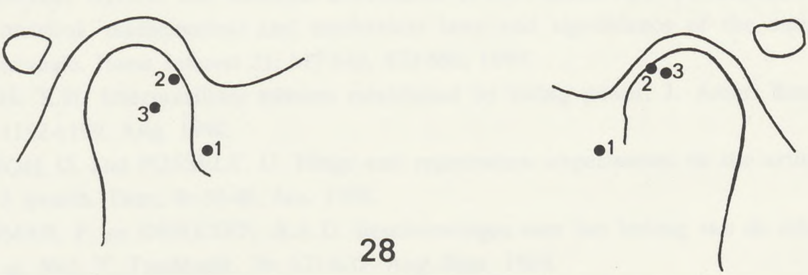

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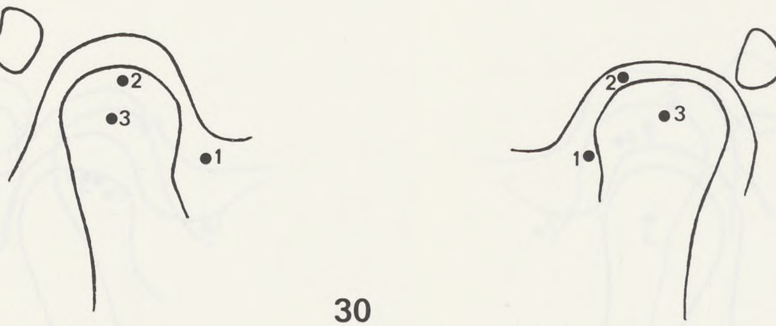

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CURRICULUM VITAE

Op 14 april 1935 geboren als zoon van Ir. Albert Bosman en Martha Specovius bracht ik mijn jeugd door in Baarn. In 1953 behaalde ik het einddiploma gymnasium-β op het Baarns Lyceum. In september van dat jaar volgde inschrijving aan de Rijksuniversiteit te Utrecht voor de tandheelkundige studie.

Het doctoraalexamen werd afgelegd in juni 1958 en de studie werd afgesloten met het tandartsexamen op 13 november 1959. In augustus van dat jaar werd het huwelijk gesloten met Ank Dieperink, waaruit drie zonen werden geboren.

Een jaar van mijn militaire diensttijd werd doorgebracht bij de Onderzeedienst van de Koninklijke Marine. Daarna volgde een plaatsing van bijna 2 jaar als tandarts op Hr. Ms. "Karel Doorman".

In 1962 en 1963 verbleef ik voor een rotating internship aan de Zoller Dental Clinic van de Universiteit van Chicago in de Verenigde Staten. Van oktober 1963 tot 1965 was ik op het Tandheelkundig Instituut der Rijksuniversiteit Utrecht werkzaam bij de onderafdeling Gnathologie, daarna bij de subvakgroep Kronen en Bruggen van de vakgroep Prothetische Tandheelkunde. In 1971 volgde de benoeming tot wetenschappelijk hoofdmedewerker.

Sinds 1966 oefen ik eveneens praktijk uit in de stad Utrecht.

STELLINGEN

I

[illegible]

II

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III

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IV

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V

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VI

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VII

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Drukkerij Los — Naarden

STELLINGEN

I

Bepaling van de scharnieras van de mandibula geeft de beste mogelijkheid tot reproductie in de articulator van het eerste deel van de dorsale grensbeweging.

II

Het bepalen van de scharnieras is een procedure, die niet mag worden verward met het bepalen van de horizontale relatie van onder- en bovenkaak.

III

De term "hinge relation" of "hinge position" van de mandibula is misleidend.

IV

Bij het waarderen van een fout bij het schatten van de positie van de scharnieras dient rekening te worden gehouden met de richting waarin deze fout werd gemaakt.

V

Het is merkwaardig dat een doelgerichte palpatie van het kaakkopje in een groot aantal gevallen leidt tot een onjuiste plaatsbepaling.

VI

De "remount" procedure moet zowel bij de vervaardiging van de prothese als bij occlusaal herstel van het natuurlijk gebit worden gezien als een belangrijk middel tot verfijning van de occlusie.

VII

Het verdient aanbeveling om bij de orthodontische behandeling naast het streven naar een esthetisch resultaat evenzeer aandacht te schenken aan de functionele occlusie- en articulatie verhoudingen.

VIII

Bij de beoordeling van een röntgenbeeld past men in principe een subtractie van beelden toe. Kennis van de normale anatomie en kennis van de wijze waarop het beeld tot stand is gekomen is hiervoor onontbeerlijk.

IX

De tandtechnicus verdient een eervollere plaats naast de tandarts.

X

Bij de geneeskundige behandeling in ziekenhuizen dient meer aandacht te worden besteed aan informatieve begeleiding van de patiënt en zijn verwanten.

XI

Het leed van de Indiaan, zoals hij de ondergang van zijn wijze van leven heeft ervaren is door de blanke mens niet begrepen.

XII

Het grootste deel van de activiteiten van de muziekscholen hoort thuis bij het basis- en voortgezet onderwijs.

XIII

Er is een trend bij de banken om zich zodanig te beveiligen dat men beter achter, dan voor de balie kan staan.

XIV

Tijdnood is een nood van deze tijd.

Stellingen behorende bij het proefschrift van A.E. Bosman:
"Hinge axis determination of the mandible", Utrecht, 19 september 1974.