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Bennett Movement: The Effect of Increased Vertical Dimension and Posterior Reference Location

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BENNETT MOVEMENT: THE EFFECT OF INCREASED VERTICAL DIMENSION AND POSTERIOR REFERENCE LOCATION

BY

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DEDICATION

To my dear and loveable wife, Rochelle, who is a constant source of inspiration and encouragement to me, I dedicate this paper.

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VITA

The author, Raymond Berlin, D.M.D., was born in Birmingham, Alabama. He attended primary school and graduated from Altoona High School in Altoona, Alabama. He entered the University of Alabama in 1949 and obtained a Bachelor of Science degree in 1953. He was elected to Phi Beta Kappa and Omicron Delta Kappa, national honorary fraternities.

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CHAPTER I

INTRODUCTION

Beginning around 1900, mandibular movements had become a point of interest and controversy. This led to a development of numerous philosophies of occlusion and jaw movement. One of these philosophies was gnathology of which one of the basic tenets is the concept of reproducibility of the border movements of the mandible. The literature is often contradictory concerning this topic. Much attention has been focused on these movements with the increase in refinement of equipment to duplicate mandibular movements.

The Bennett movement, or lateral translatory movement of the mandible, is probably one of the most important clinically significant mandibular movements; yet, it is probably the most controversial movement of the mandible. The importance of the Bennett movement was emphasized by McCollum (1939) when he stated that the shape of the Bennett movement has as much as, and probably more, influence upon the articulating surfaces of the teeth than any other component of jaw motions. Granger (1954) agreed that the Bennett movement is by far the most important of all mandibular paths. Guichet (1969) agreed with the above noting the amount of Bennett movement tends to increase as the occlusion becomes more mutilated.

Recognizing the clinical importance of recording and allowing for the Bennett movement in restorative dentistry, numerous methods of studying the Bennett movement have been reported in the literature.

The purpose of this study is primarily to determine if increasing the vertical dimension will affect the recording of the Bennett movement on a pantograph tracing. The study would then concomitantly note any difference in the tracing of the Bennett movement if the pantograph apparatus were oriented to posterior reference points located by an anatomic average as opposed to orientation to the terminal hinge axis position. Finally, the study would explore the possibility of using a method of quantitative measurement whereby one pantograph tracing can be compared consistently to another.

CHAPTER II

REVIEW OF LITERATURE

Although the lateral translatory mandibular movement has been observed and described by many, there are different explanations as to why it occurs. McCollum (1955) explained the Bennett movement as an effect of a lateral mandibular movement that occurs when the geometric centers, around which the lateral movements of the jaw rotates, lie back of the hinge-axis. When this happens, then in lateral movements of the mandible, there is a definite side shift in the condyles. If the centers of the lateral movements of the jaw lie in the hinge-axis, then there is no side-shift or Bennett movement in the lateral movement of the condyle.

Posselt (1962) also felt that the vertical axis for right and left lateral movements are not located in the working-side condyle but are positioned somewhat posterior to each working-side condyle. Thus, in a lateral movement the working-side condyle will shift slightly lateral in the direction of movement and sometimes slightly downwards. This bodily lateral shift of the mandible is called the Bennett movement: the more posterior to the condyle the axis is situated, the larger will be the Bennett shift.

Granger (1954) described the Bennett movement as a power movement in a lateral mandibular movement that occurs as the condyle that is rotating on the working side also moves bodily across the fossa. Bennett movement referred to the lateral paths of the discs in lateral excursions of the mandible. In a lateral excursion, the balancing condyle moves forward, down and inward on the glenoid fossa, and at the same time rotates on the disc. Its limitation of movement against the inner curbing of the glenoid fossa determines the Bennett movement. The working condyle rotates on the disc, and they both move outward across the fossa to the extent determined by the balancing condyle. Both condyles are rotating and gliding simultaneously. It is this lateral path across the fossa which is the Bennett movement. Granger stated that of all mandibular paths, the Bennett movement is by far the most important.

Sicher (1954) explained the Bennett movement to illustrate the principle of split-second timing of muscle action. He stated that in a right lateral movement, the left lateral pterygoid muscle is the prime mover while the posterior bundles of the right temporal muscle contract in order to hold the right condyle in place so that the mandible can rotate around it. Furthermore, the contraction of the retracting fibers of the right temporal muscle occurs after an initial swing of the entire mandible laterally and anteriorly to avoid strain in the capsule that would be caused by a rotation of the resting condyle in situ. This time lag between contraction of the left lateral pterygoid muscle and the right temporal muscle is responsible for the Bennett movement.

DePietro (1963) stated that the lateral translation of the working condyle, the Bennett movement, is influenced by three factors: (1) the symmetry of the condylar element, (2) the amount of deviation of the condylar element from the horizontal axis, and (3) the positions of the vertical and sagittal centers in the condylar element. In a symmetric condylar element, the configuration of its medial aspect permits rotation with no interference; hence no Bennett movement is needed to permit rotation of this structure. When this element is irregularly shaped and its long axis is aligned obliquely to the horizontal axis, the condyle must move laterally to free itself from the medial aspect of the fossa in order for rotation to take place. If the long axis of the condyle is parallel to the horizontal axis, as it rotates, the medial surface of the fossa does not interfere with the arc formed by the surface of the rotating condyle and no Bennett movement is needed. The greater the deviation of the long axis of the condyle from the horizontal axis, the greater Bennett movement necessary to prevent interference of the medial surface of the condyle with the medial surface of the fossa as the mandible makes a lateral movement. Also, the more lateral the position of the vertical center of rotation in relation to the working side condyle, the more Bennett movement is necessary to allow for rotation to the place without interference from the medial fossa wall.

Guichet (1977) explained the mandibular side shift as being an expression of slack or stretch in the ligaments of the articular capsule of the rotating condyle. The theory is that as the lateral pterygoid muscle on the orbiting side contracts to move the orbiting condyle medial-ward; the rotating condyle moves out until some of the slack in its articular capsule is consumed. Subsequently, the rotating condyle is braced in this position or moves outward slightly as the orbiting condyle advances. He stated that the amount of mandibular side shift tends to increase as the occlusion becomes more mutilated. Young adults with good occlusion will exhibit less side shift as a group than older groups that have lost teeth with subsequent tipping of the posterior teeth. Thus cusps are introduced in the occlusal scheme as prematurities or fulcrums. This can excite bruxism and introduce fulcrums in the posterior occlusion which allow bruxing muscles to effect force vectors in the temporomandibular joints in such a manner as to stretch the capsules.

Guichet further believed research studies have shown that during the first four millimeters of forward movement of the orbiting condyle, the side shift occurs at a greater amount or rate than it does in the remainder of the movement. Orbiting path recordings are generally essentially straight after the stylus has advanced four or five millimeters from the centric relation position as seen on the posterior horizontal plate of a pantographic tracing. The mandibular side shift which occurs during the first four millimeters of forward movement of the orbiting condyle is classified as immediate, early, distributed, or progressive side shift depending on the rate at which it occurs. A progressive side shift is a mandibular side shift which occurs at a rate or amount which is directly proportional to the forward movement of the orbiting condyle. An immediate side shift is a mandibular side shift in which the orbiting condyle moves essentially straight medially as it leaves centric relation. An early side shift is a mandibular side shift in which the greatest rate of side shift occurs early in the first four millimeters of forward movement of the orbiting condyle as it leaves centric relation. A distributed side shift is a mandibular side shift in which the greatest rate of side shift is distributed throughout the first four millimeters of forward movement of the orbiting condyle from centric relation. From that point on, the majority of side shifts are progressive in nature. This was verified in a study by Lundeen and Wirth (1973). The immediate side shift component of the mandibular side shift is measured on the horizontal plane orbiting path record and is expressed in units of tenths of a millimeter. This value is almost always less than two millimeters. The progressive side shift component of the mandibular side shift is measured relative to the sagittal plane and expressed in degrees. This is sometimes referred to as the Bennett angle. This value is almost always less than twenty degrees.

Dull (1965) declared that since the immediate side shift occurs at the beginning of a lateral jaw movement when the posterior teeth are either not separated or only slightly separated, the presence and degree of the immediate side shift has a great and profound influence on the shape of the occlusal surfaces of the teeth, primarily the width of the central grooves of posterior teeth. The progressive side shift of the mandible has primary influence on the medio-lateral inclination of balancing inclines of posterior cusps on the orbiting side. It also has an influence on the direction of the ridges and grooves of posterior teeth, primarily on the tooth contacts on the orbiting side.

Lundeen and Wirth (1973) using a pantographic apparatus developed by Lee (1969) did an interesting study in which three dimensional tracings of manbibular movements were cut in plastic blocks. In comparison of condylar movements of 50 subjects, 20 to 55 years of age, they found that in the lateral movement of the mandible two portions could be identified: the immediate side shift portion and the Bennett angle portion. The immediate side shift occurred during the first few millimeters of the movement as the drill tip moved inward, forward, and downward. The inward curved portion varied from 0 to 3.0 mm., with a median of approximately 1.0 mm. The Bennett angle was the remainder of the pathway shown as arcs of circles which were very nearly parallel to each other. Their data showed that a lateral path which encompassed most individual paths consisted of a 1.5 mm. immediate side shift followed by a progressive side shift of 7 1/2 degrees. Once the immediate side shift had occurred, very little variation was seen in the rest of the movement for different subjects. The immediate side shift component is of particular importance when compared to the total lateral pathway because in a projection of the superior view of the immediate side shift of the lateral movement compared with the travel of the disto buccal cusp of the lower first molar on the same side shows a movement ratio that approached 1:1. Bellanti and Martin (1979) also observed that the measurement of the immediate side shift on a pantographic tracing was the same as that on an articulator, which would indicate a ratio of 1:1. These observations confirmed that the immediate side shift is a translation type of movement rather than rotation. Therefore mandibular movements do have translations as well as rotations. Bellanti and Martin (1979) also found that the immediate side shift occurred in 30% of their subjects when the subjects made voluntary uninduced lateral excursions.

A study by Lundeen and Wirth (1973) also showed no appreciable changes in the pathways of the drill when the length of the central-bearing screw was increased as much as 20 mm. They also found that recordings of condyle movement made when the drill was not oriented to the hinge axis were affected by the central-bearing mechanism of the clutches.

Guichet (1977) stated that as the orbiting condyle moves downward, forward, and inward when the patient executes a lateral movement, the rotating condyle consequently moves outward as much as three millimeters in some cases. If viewed in a sagittal plane, as the rotating condyle moves outward, referred to as latero-trusion, it may have an upward component (latero-surtrusion), downward component (latero-detrusion), forward component (latero-protrusion), or backward component (latero-retrusion), or exhibit a combination of these displacements. Guichet (1977) visualized these lateral displacements of the rotating condyle much like a cone three millimeters long having an included angle formed by opposing walls of the cone of 60 degrees. The apex of the cone is positioned at the center of rotation of the condyle with the long axis of the cone coincidental to the transverse horizontal axis. When the rotating condyle moves outward it may move along any perimeter of the wall of the cone or along any path within the cone. Lundeen and Wirth (1974) reported the sagittal displacement of the working-side condyle as being outward and backward in all but two instances in the fifty patients in their study. Upward or downward displacements of the rotating condyle has its principle effect on the height of the working cusps on the rotating side. Backward or forward displacements of the rotating condyle has its principle effect on the intermeshing of the working cusps on the rotating side; that is, ridge and groove direction.

Lateral translatory movement of the mandible had been mentioned in the literature long before Bennett described the movement to which his name was attached. Bell, (1833) while describing lateral mandibular movements, stated, "the whole jaw is, in fact, thrown in a small degree on one side by this movement." This report is one of the earliest references to a phenomenon subsequently termed the "Bennett movement".

Balkwill (1866) also commented on the existence of a lateral mandibular translatory movement. He noticed, in studies carried out on human and monkey skulls, when viewed from above, the posterior borders of the mandibular condyles lie on the arc of a large common circle the center of which is anterior to the front teeth. The lateral poles of both condyles are markedly curved, and each conforms to the arch of small circles with centers lying well behind the most distal teeth on either side. He suggested that when the jaw moved to one side, the lateral path travelled by the molar teeth on the working side would be around the arc of a circle with a center anterior to the mouth. The teeth would thus move forward and outward. However, the second part of the movement would take place around an axis behind the teeth, thus providing a lateral and posterior component. A combination of these movements could thus appear as a direct lateral movement, possibly with a forward component.

Bonwill, (1899) in his equilateral triangular theory of lateral movement, stated that during lateral movements of the mandible, the working-side condyle stands still, or does not move backward, but merely revolves or rotates in the socket.

Walker (1897) contended that during lateral mandibular movement the balancing-side condyle moved forward and downward and the working-side condyle countered with a slight upward and backward movement. This concept was based on his contention that the vertical axis of rotation passed through a point medial to the working side condyle. Therefore, the working side condyle moved backward by one-third the distance travelled forward by the balancing side condyle.

Luce (1889) did a study of jaw movements using photographic recordings. The pathways he recorded and reported closely resembled those described by Posselt over 60 years later.

Campion (1902) investigated mandibular pathways during opening movements that a form of mandibular clutch and a photographic recording system. He deducted that lateral movements of the jaw were accompanied by a posterior movement of the working side condyle. His results could be open to question since his recording wire was situated some distance lateral to the lateral pole of the condyle.

Bennett's (1908) famous observation was actually an incidental finding in a study primarily concerned with mandibular movements when the mouth was opened. Bennett's study was done using himself as the subject with his brother assisting in the study. Bennett noticed that when his jaw was moved to one side there was a direct bodily movement of the entire mandible towards the working side. The jaw did not simply rotate around the working side condyle but rotated and moved laterally. This direct lateral movement was subsequently termed the Bennett movement. Bennett's experimental method was very ingenious at the time it was done but he was very cautious in reporting his findings and explicitly stated the shortcomings of his experimental method. He was very self-critical and cautioned against making any sweeping conclusions from his observations which seemed to have gone unheeded.

Landa's (1958) critical analysis of Bennett's study raised some pertinent points. As mentioned previously, the "Bennett movement" was mentioned only casually in Bennett's article and it was incidental to the main discussion. Landa concluded that Bennett's claim for a "considerable" shift laterally of the mandibular condyle on the working side was lacking in validity. He noted that Bennett's optical method of investigation was highly original as a method of approach in the study of mandibular movements, but lacking in scientific precision in several ways;

1. Bennett conducted his investigations on himself only with his missing mandibular molars and its associated pathologic occlusion.
2. Bennett's experiments were conducted with the mandible in an extreme state of strained relations and strained occlusions.
3. Asymmetry of Bennett's jaw may have produced abnormal movements.

Landa concluded that Bennett movement as a true side-to-side shift of the condyle was not noted in the subjects and skulls that he examined except as a manifestation of a pathologic condition.

Brotman's (1960) interpretation of what Bennett saw compared it to viewing a swinging pendulum from the side which led to misinterpretation.

CHAPTER III

STUDIES OF MANDIBULAR MOVEMENT

A. ANATOMIC INVESTIGATIONS

There have been various different methods of studying mandibular movement. Anatomic investigations have represented efforts of relating function to form.

Landa (1958) in his study of Indian and Greenland skulls that had dentitions worn considerably by attrition, found evidence of lateral condylar translation in only 3 of 175 skulls studies. He stated that the position of the condyles, in their respective glenoid cavities is such that their lateral poles are directed forward and outward while the medial poles are directed posteriorly and medially. Thus, in a lateral movement, the rotating condyle, in rotating around its veritical axis, the lateral pole of the condyle became more prominent laterally when it lay in the same horizontal line with its adjacent medial pole. Thus, the lateral pole on the working side became more prominent in the lateral direction without the slightest gliding of the mandibular condyle bodily in an outward direction.

Landa (1958) also did a study on cadavers by attaching T-wires to exposed condyles through the cranium and moving the mandibles in a lateral movement until the buccal cusps of the lower teeth effected contact with the buccal cusps of upper teeth. He also showed in this study that there was no shifting of the mandibular condyle laterally.

Landa (1958) also reviewed roentgenographic studies which he felt did not substantiate the existence of the Bennett movement. However, Landa himself stated at length in a whole paragraph about the unreliability and dangerous speculation of reading diagnostic features into a roentgenogram of the condyle in centric occlusion and another of the same condyle in working occlusion. He also underlined the unreliability of superimposing tracings made from such roentgenograms. While a roentgenographic study of the various condylar positions associated with various mandibular positions may be utilized in an investigation such as this, it should not be considered conclusive.

Sicher (1962) stated that there is only one reproducible position of the mandible in the deceased that imitates the position of the mandible in the living; namely the position of full occlusion. When the teeth are in full occlusion, no bony contact existed at the mandibular articulation of a skull. There was always a space between the mandibular condyle and the cranial base at the articular tubercles. If one now tried to open the jaws or to swing the mandible to the right or left, thus breaking occlusal tooth contact, then indeed the mandible slipped upward and backward and the condyles falsely "braced" themselves against the post glenoid process. Such experiments not only showed the reason for the wrong claims in the literature but also showed unequivocally any attempt to study mandibular movements on the skull is doomed to failure and must result in wrong conclusions. Sicher felt the temporomandibular ligament limited mandibular displacement so the condyles cannot brace themselves against the post glenoid fossa. He pointed out mandibular movements were described by muscle activity rather than by bone contacts as ligaments.

B. PHOTOGRAPHIC METHODS

Photographic methods of analysis of mandibular movements were done by Chick (1960) and Hickey (1963) and associates. Only two subjects were used in each study, probably because of experimental complexities. Chick found lateral mandibular movements were mainly rotational so the path travelled by the condyle depended on its relation to the axis of rotation.

Hickey and associates (1963) used three dimensional motion picture photography on two subjects to study mandibular movement. Movement of a pin inserted directly into the condyle was observed and compared with the movement of a pin attached to the lower incisor teeth. The activity of both pins was recorded in the horizontal, sagittal and frontal planes by three synchronously running motion picture cameras. They observed that there was no evidence of pure rotation of the condyle without translation during any of the masticatory strokes they analyzed. Their findings included:

1. The pathway of the working side condyle on voluntary lateral sliding movements was different from lateral movements with the teeth out of contact.

2. A direct lateral movement of the condyle was present in voluntary lateral movements of the mandible. This lateral movement ranged from

4 mm. in a maximal excursion with no tooth contact to 0.3 mm. during the tooth contact of masticatory function.

3. There was probably a range of adaptability of condyle movement within the TMJ that varies between patients and within the same patient at different periods. This may account for the fact, the occlusion of either artificial or natural teeth, if within this range of adaptability, may cause no apparent TMJ discomfort or pathologic condition, but the same occlusion in the identical patient at a later time or in a different, older, or unhealthy patient could produce discomfort and pathologic changes.

C. PANTOGRAPHIC STUDIES

Tracing devices have been used to study mandibular movements and provide the advantage of producing a continuous record. A disadvantage ascribed to tracing devices is that they are attached to the mandible by clutches and therefore the lateral movement tracings are obtained at an increased vertical dimension. Conflicting reports on the effect that this increased vertical dimension will have on the tracing of lateral movements have been reported. Hickey, et al., (1963) found that the direct lateral translation (Bennett movement) varied with the vertical separation of the jaws. This finding may not be valid since these findings were based on tracings that were made when the teeth contacted and then compared to tracings obtained at an open vertical dimension when the teeth were out of contact. The contact of the teeth influenced the type of tracing obtained.

Kotowicz, Clayton and Smith (1970) showed consistent results at differing vertical separations with a pantographic system.

Clayton, et al., (1971) used pantograph tracings to determine whether graphic tracings could be affected by styli positions in relationship to changes in vertical dimension. In five subjects studied, tracings made on the posterior horizontal tables showed no difference when the vertical dimension was opened at the stud a maximum of 4 mm. The Bennett movement would be reflected in the tracing obtained at the posterior horizontal table of a pantograph tracing. They also showed that the orientation of the styli in relationship to the hinge axis can affect graphic tracings on the anterior horizontal plate and the posterior vertical plate. It was not clear in their report whether this orientation had an effect on the tracing obtained on the posterior horizontal plate.

Lucia (1961) pointed out that the Bennett movement can be recorded correctly only at the vertical dimension of occlusion.

Isaacson (1958) using a gnathograph and studying 26 patients, ages 19-60 years, found a Bennett movement near the vertical dimension of occlusion in all patients examined. He found no relationship between patients age or sex and the Bennett movement.

Prieskel (1972) stated pantographic procedures may well play a valuable role in clinical dentistry but these techniques have disadvantages as research tools for studying the Bennett movement at the vertical dimension of occlusion. He believed if we are to understand the Bennett movement, the only sure way is to make the records directly from the lateral end of the working-side condyle as the teeth move from centric occlusion. Hickey's study (1963) revealed a variation of the Bennett movement with the vertical separation of the jaws. This was true, however, at the more closed vertical dimension when the teeth were in contact whereas at the more open vertical dimension, the teeth were out of contact. Contact of the teeth could definitely influence the Bennett movement recording.

McMillen (1972) studied mandibular border movements in 10 subjects under general anesthesia and with complete muscle flaccidity obtained by injecting succinylcholine chloride. He found after anesthetization that wider lateral border movements were recorded in all ten subjects. The direct side shift of the mandible averaged 0.65 mm wider, and the subsequent progressive side shifts averaged 0.77 mm wider at a distance of 5 mm anterior from the centric relation position. He concluded muscles, ligaments, and bony structures all share the role of limiting mandibular movements.

Gibbs, et al., (1971), in studying chewing movements with the Case Gnathic Replicator in 12 subjects, found the presence of a Bennett movement averaging 1.5 millimeters in all subjects. This study was done while the jaws were moving during function so there was some influence of the teeth which produced tooth guided movements.

Ramfjord and Ash (1971), stated that mandibular movements can be influenced by tooth guidance (deflective occlusal contacts), by the type of food being chewed, and by individual differences among patients.

Clayton, et al., (1971) showed that subjects can function to the border tracing recorded by a pantograph provided tooth guidance (deflective occlusal contacts) was not present to deflect the functional movements away from the border tracings. This study suggested that occlusion in harmony with border tracings may be the most physiologic.

D. ROENTGENOGRAPHIC STUDIES

Alvares (1970) in a roentgenographic study of lateral mandibular condylar movements attempted to correlate the Bennett angle with the gothic arch angle. He found no correlation between these two angles. The so-called Bennett angle did not necessarily have anything to do with the Bennett movement (lateral translation) as a Bennett angle will be produced on the non-working side even in the absence of a translating working condyle.

E. ULTRASOUND STUDIES

Preiskel (1970) used ultrasound as a measuring device to measure lateral mandibular movement. He used an ultrasound scanner that works on the echo sounder principle. An ultrasonic pulse is emitted and, as it passes from one structure to another, some energy is reflected from the interface and some transmitted. The distance from the interface can be calculated on a time basis. By placing an ultrasonic probe on the skin overlying the lateral pole of the condyle, he was able to measure condylar movement towards and away from the probe. The probe was held in position by a modified racing driver's crash helmet. Repeatability of position and angulation of the probe in subsequent investigations was achieved by aligning the apparatus with a plumb-line device. He measured the Bennett movement in 27 subjects, 19 to 23 years of age, starting from a position of maximum intercuspation and having the patient move the mandible laterally to cuspid tip to tip position. Two sets of acrylic overlays for the cuspids were made which did not interfere with the subject's centric occlusion, but merely altered the guidance from the palatal surface of the cuspid and modified the edge to edge position. One overlay increased the vertical dimension 1 mm at the lateral position and the thicker one resulted in an increase of approximately 2 mm. Placing the overlays increased the canine guidance and the total movement required was slightly greater. The small overlays produced a significant increase in the lateral translation recorded while the larger overlays produced still greater movements. It seems the larger measurements resulted simply from the canines having further to travel.

Preiskel (1971) investigated possible correlation between the natural relationships of opposing canine teeth and the lateral translation of different subjects' mandibles when they moved their jaws to one side. Canine relations were examined by means of casts, and lateral translatory movements measured by ultrasound. The results showed little correlation between translatory (Bennett) movement and canine relationship: that is, overjet, overbite, and distance traveled by canines.

F. COMPARISON STUDIES

Some studies have been initiated to test the reproducibility of pantographic tracings under different conditions. Jackson (1979) reported on an investigation to test the reproducibility of pantographic tracings of the border movements of different subjects at various postural positions under medicated and nonmedicated situations using oral administration of 2 mg. of valium as the medication. The technique he used was to obtain pantographic tracings on glass flags covered with liquid shoe-polish wax using a Denar pantograph. A special device was designed so glass flags could be repositioned at any time in exactly the same position. The tracings obtained were etched with hydrofluoric acid, the wax removed, and the etched tracings were then stained with black India ink. By use of a precision metal device with right angles, it was possible to superimpose the glass flags one on the other. Photographs were then made using a dissecting microscope. The obtained photographs were visually analyzed and referred to two catagories: (1) a superimposition of the two tracings or (2) a discrepancy of the superimposition of the recordings. Among the conclusions reached from the study were: (1) There is a significant difference in reproducibility between medicated and nonmedicated subjects. (2) The percentage coincidence of border tracings increases significantly when the patient is pantographed while under the influence of medication (Valium). (3) The angulation of the body (45' or 90' to the floor) does not appear to be significant for reproducing border tracings. (4) The lateral side shift of the jaw cannot always be reproduced accurately. (5) The neuromusculature appears to be the over-riding factor governing mandibular border movements.

The comparisons made in the above study depended on the researcher's ability to visually determine whether a tracing was coincidental with another tracing. Also, one part of a tracing could be coincidental with another tracing and another part of the same tracing may not be coincidental. There is no way of quantitatively comparing one tracing to another.

Roura and Clayton (1975) did a study to observe mandibular movements of subjects with TMJ dysfunction as recorded by a pantograph and to observe the effect of therapy with occlusal bite splints on the subjects' TMJ dysfunction and on their ability to reproduce border movements. The ability of the subjects to retrace the border movements was analyzed by measuring the width of the lateral excursion lines with a magnifying glass at 36 standardized points on the tracings. Whenever more than a single line was recorded at a particular point of measurement, the width of the two or three lines plus the distance between the lines were included in the measurement. The values measured for the initial and final visits for the five subjects were analyzed statistically to determine if the tracings were reproducible. This procedure of comparison lended itself to somewhat more quantitative analysis than Jackson's (1979) method.

Roura and Clayton (1975) determined that a subject with no apparent clinical signs and symptoms of TMJ dysfunction can make reproducible mandibular border movement tracings as recorded by a pantograph; whereas subjects with TMJ dysfunction may not be able to make reproducible mandibular border movement tracings. Five subjects with TMJ dysfunction showed difficulty in making reproducible mandibular border movements as recorded by a pantograph. These subjects were treated with occlusal bite splints, and muscle activity was studied by electromyography. After one month of treatment three subjects showed relief of clinical symptoms and improved EMG muscular activity. Three of the five subjects' mandibular movements did not improve to the point of making reproducible border movements on a pantograph.

CHAPTER IV

MATERIALS AND METHODS

Fourteen subjects were used in this study, ages 24 to 39. They had no temporomandibular joint symptoms or dental or systemic problems.

The Denar pantograph was utilized in recording the mandibular movement tracing. Maxillary and mandibular clutches were fabricated directly in the subject's mouth according to the manufacturers directions using Bosworth's Fastray acrylic. After fabrication, the clutches and center bearing screw height were carefully adjusted to the subjects jaw closure. The center bearing screw was opened just enough so that on closure and jaw excursions the only interocclusal contact was on the center bearing screw. Careful examination was made to make sure the clutches did not interfere with each other during mandibular movement.

Posterior reference points were located on the side of the face according to average anatomic measurements using the Denar Reference Plane Locator.

The anterior crossbars assemblies were secured to the maxillary and mandibular clutches and the clutch anchors were secured to the anterior crossbars so that their sidearms were tangent to the buccal surfaces of the posterior teeth. After insuring that there is no soft tissue impingement by the clutch anchors, the clutch assemblies are rigidly fastened to the maxillary and mandibular teeth with a small amount of

Coe Nogenal which engaged the clutch anchors with the buccal surfaces of the teeth.

The hinge axis analyzer was positioned on the maxillary crossbar so that the flag lies in a sagittal plane. The hinge axis locator was then secured to the mandibular crossbar so that the stylus was supported by its tubular housing close to the flag. The terminal hinge axis was then located by having the subject open and close in arcing movements and, with the aid of the microadjustments, moving the stylus up, down, forward, or backwards until the tip of the stylus did not make a perceptible migration as the mandible was arced. The terminal hinge axis was then marked on the patient's skin. None of the subjects had the terminal hinge axis coincidental with the posterior reference mark located using average anatomic measurements. The difference ranged from 3 millimeters to 10 millimeters, with the terminal hinge axis usually located posterior to the average anatomic measurement.

The hinge axis analyzer and locater was removed from the maxillary and mandibular crossbars and the Denar pantograph was oriented to the patient. The recorder sidearm assembly was oriented on the mandibular crossarm so that the posterior reference pins were aligned with the terminal hinge axis dots when the mandible was in terminal hinge position or centric relation. The scriber sidearms were attached to the maxillary cross-bar so that the posterior vertical stylus would engage the posterior horizontal recorder blanks equidistant from the inner, outer, and anterior margins when the mandible was in centric relation. The stylus control valve was connected to the pantograph manifold and the Denar Power

Supply filled with a CO_2 cartridge. This CO_2 pressure allowed the styli to be raised or lowered by means of depressing or releasing the button on the stylus control valve.

The central bearing screw was opened minimally to provide clearance between the maxillary and mandibular clutches; the only contact was the central bearing screw. A measurement was taken between the maxillary and mandibular clutches anteriorly where they were attached to the cross arms.

Centric relation was verified by having the subject move his mandible forward and back, then depressing the posterior vertical styli which would record a dot on the posterior horizontal plate. A pantographic recording was then made having the subject make a protrusive, right and left lateral excursion. The recording on the posterior horizontal plate was the only one made since this is the recording which would exhibit the Bennett movement. The central bearing screw was then opened to increase the vertical dimension by 5 mm. at the same point where the previous measurement was taken. A second pantograph tracing was made on the same record blank on which the previous tracing was made. The pantograph record blanks with the tracings were then removed from the tracing tables and preserved.

The pantograph tables were then re-oriented aligning the posterior reference pins to the subject's posterior reference marks that were located using an anatomic average as previously described. New record blanks were affixed to the posterior horizontal tables and a second set of recordings were made; one at a minimal vertical opening and a second at an increased vertical opening of 5 mm. as previously described. The record blanks with the tracings were then removed and placed on a record card for each subject.

Each recording blank was photographed using a Minolta 35 mm camera with a bellows and 100 mm lens mounted on a copying stand so that each exposure was made at the same distance from the lens with the same settings. A millimeter rule was included in the picture so that standardized measurements could be made in the prints. An 8" X 10" enlargement print was made of each recording blank.

An Apple Computer was programmed to enable comparison of one curved line to another by utilizing a digitizer. A digitizer consists of a tracing stylus and a mounting board which is connected to the computer. As the stylus of the digitizer is moved manually along a curved pathway, points at approximately 0.01 millimeter intervals are plotted on an X, Y axis and given a numeric value. As the stylus is moved along a second curved pathway that is being compared with the first pathway, points are plotted on an X, Y axis at 0.01 millimeter intervals for this curve. The computer then computes the difference in distance between each one of the interval points on the curved lines, computing a mean difference in millimeters for each ten plotted points. The computer print-out would then give the mean difference in millimeters between the two lines at approximately 0.1 millimeter distances that the stylus moved along the two curved lines being compared. This procedure allows for very accurate comparison of two curved lines. The difference between the two pantograph tracing lines being compared was calculated for the first 5 millimeters of movement of the stylus starting from centric relation because variations in Bennett movement tracings occur within this initial range as was found by Lundeen and Wirth (1973).

CHAPTER V

FINDINGS

The following tables summarize the data collected including the values computed using the T test for statistical analysis.

In a comparison of the tracings recorded with a pantograph of the Bennett movement on the posterior horizontal plate, there was a statistically significant difference ($p<.05$) in all fourteen subjects when the vertical dimension was increased 5 millimeters measured just anterior to the maxillary anterior teeth. There was a statistically significant difference in changing the vertical dimension when the pantograph apparatus was oriented to the exact hinge axis location, as well as, the anatomic average axis location. The mean difference in all the tracings that were oriented to the exact hinge axis location on the right side was 0.3218 millimeters with a range from .7232 millimeters to .0468 millimeters. On the left side, the mean difference was .2678 millimeters with a range from .6920 millimeters to .0066 millimeters.

The mean difference in all the tracings that were oriented to the average measurement location on the right side was .3039 millimeters with a range from .6525 millimeters to .0781 millimeters. On the left side, the mean difference was .2163 millimeters with a range from .5856 millimeters to 0 millimeters. This difference between the 2 tracing lines is such a small measurement that the clinical importance would be relatively insignificant. It would be adviseable to keep the vertical opening of the jaws at a minimum when doing a pantograph tracing. Although vertical dimension is slightly increased during the procedure, it has an insignificant influence on the tracing obtained.

In all subjects the terminal hinge axis location was different from the axis located using average anatomic measurements utilizing the Denar Reference Plane Locator. The difference ranged from 3 millimeters to 10 millimeters with the terminal hinge axis usually located posterior to the average anatomic measurement.

SUBJECT I

COMPARISON OF DIFFERENCES IN TRACINGS IN MILLIMETERS

PANTOGRAPH ORIENTED TO HINGE AXIS

	RIGHT	LEFT
mean	.2675	.2032
largest	.3383	.2784
smallest	.2202	.0965
T	54.3422	27.7233

PANTOGRAPH ORIENTED TO ANATOMIC AVERAGE

	RIGHT	LEFT
mean	.2696	.4047
largest	.3081	.4675
smallest	.2257	.1842
T	71.7407	42.9746

SUBJECT II

COMPARISON OF DIFFERENCES IN TRACINGS IN MILLIMETERS

PANTOGRAPH ORIENTED TO HINGE AXIS

	RIGHT	LEFT
mean	.5093	.0615
largest	.6261	.1652
smallest	.3108	.0066
T	37.9516	8.1654

PANTOGRAPH ORIENTED TO ANATOMIC AVERAGE

	RIGHT	LEFT
mean	.4028	.1088
largest	.4587	.1918
smallest	.2893	.0111
T	42.0713	11.6608

SUBJECT III

COMPARISON OF DIFFERENCES IN TRACINGS IN MILLIMETERS

PANTOGRAPH ORIENTED TO HINGE AXIS

	RIGHT	LEFT
mean	.2774	.3664
largest	.3047	.4192
smallest	.2404	.3024
T	101.2611	75.7042

PANTOGRAPH ORIENTED TO ANATOMIC AVERAGE

	RIGHT	LEFT
mean	.2342	.1703
largest	.3172	.2437
smallest	.1841	.0915
T	51.1865	23.9365

SUBJECT IV

COMPARISON OF DIFFERENCES IN TRACINGS IN MILLIMETERS

PANTOGRAPH ORIENTED TO HINGE AXIS

	RIGHT	LEFT
mean	.1992	.2713
largest	.3642	.3161
smallest	.1297	.1817
T	22.1958	56.2065

PANTOGRAPH ORIENTED TO ANATOMIC AVERAGE

	RIGHT	LEFT
mean	.2472	.0579
largest	.3052	.2128
smallest	.1880	.0003
T	49.3940	6.2550

SUBJECT V

COMPARISON OF DIFFERENCES IN TRACINGS IN MILLIMETERS

PANTOGRAPH ORIENTED

TO HINGE AXIS

	RIGHT	LEFT
mean	.2376	.1502
largest	.2862	.2473
smallest	.1872	.0687
T	58.5799	18.7703

PANTOGRAPH ORIENTED

TO ANATOMIC AVERAGE

	RIGHT	LEFT
mean	.2975	.1539
largest	.3460	.2239
smallest	.2464	.0714
T	67.4223	16.6559

SUBJECT VI

COMPARISON OF DIFFERENCES IN TRACINGS IN MILLIMETERS

PANTOGRAPH ORIENTED TO HINGE AXIS

	RIGHT	LEFT
mean	.1809	.2189
largest	.2349	.3898
smallest	.1333	.1128
T	47.0469	17.6948

PANTOGRAPH ORIENTED TO ANATOMIC AVERAGE

	RIGHT	LEFT
mean	.2526	.2042
largest	.3566	.2843
smallest	.1922	.1517
T	11.2795	30.3738

SUBJECT VII

COMPARISON OF DIFFERENCES IN TRACINGS IN MILLIMETERS

PANTOGRAPH ORIENTED TO HINGE AXIS

	RIGHT	LEFT
mean	.6331	.3778
largest	.7232	.4447
smallest	.5522	.2661
T	57.0159	52.6867

PANTOGRAPH ORIENTED TO ANATOMIC AVERAGE

	RIGHT	LEFT
mean	.1764	.2991
largest	.2422	.3763
smallest	.0781	.1785
T	26.8867	35.2557

SUBJECT VIII

COMPARISON OF DIFFERENCES IN TRACINGS IN MILLIMETERS

PANTOGRAPH ORIENTED TO HINGE AXIS

	RIGHT	LEFT
mean	.1274	.2784
largest	.2009	.3425
smallest	.0596	.2089
T	18.3273	40.1061

PANTOGRAPH ORIENTED TO ANATOMIC AVERAGE

	RIGHT	LEFT
mean	.1657	.1778
largest	.2741	.2714
smallest	.0979	.1051
T	27.1240	20.7429

SUBJECT IX

COMPARISON OF DIFFERENCES IN TRACINGS IN MILLIMETERS

PANTOGRAPH ORIENTED TO HINGE AXIS

	RIGHT	LEFT
mean	.1482	.2202
largest	.2173	.3374
smallest	.0468	.1212
T	17.7933	18.7004

PANTOGRAPH ORIENTED TO ANATOMIC AVERAGE

	RIGHT	LEFT
mean	.2714	.1841
largest	.3531	.3051
smallest	.1837	.1065
T	28.7078	23.9879

SUBJECT X

COMPARISON OF DIFFERENCES IN TRACINGS IN MILLIMETERS

PANTOGRAPH ORIENTED TO HINGE AXIS

	RIGHT	LEFT
mean	.5690	.5482
largest	.6917	.6920
smallest	.1436	.2121
T	28.0898	28.9349

PANTOGRAPH ORIENTED TO ANATOMIC AVERAGE

	RIGHT	LEFT
mean	.4975	.3236
largest	.6525	.4090
smallest	.1450	.2352
T	24.1685	42.8847

SUBJECT XI

COMPARISON OF DIFFERENCES IN TRACINGS IN MILLIMETERS

PANTOGRAPH ORIENTED TO HINGE AXIS

	RIGHT	LEFT
mean	.3041	.1666
largest	.3870	.3384
smallest	.1829	.0673
T	41.7410	14.0433

PANTOGRAPH ORIENTED TO ANATOMIC AVERAGE

	RIGHT	LEFT
mean	.2891	.0778
largest	.3562	.2776
smallest	.2174	.0045
T	51.7781	6.4426

SUBJECT XII

COMPARISON OF DIFFERENCES IN TRACINGS IN MILLIMETERS

PANTOGRAPH ORIENTED TO HINGE AXIS

	RIGHT	LEFT
mean	.2649	.3072
largest	.3434	.4005
smallest	.1938	.2160
T	46.6794	34.0432

PANTOGRAPH ORIENTED TO ANATOMIC AVERAGE

	RIGHT	LEFT
mean	.3500	.1988
largest	.4190	.3458
smallest	.2947	.1209
T	54.8314	21.4279

SUBJECT XIII

COMPARISON OF DIFFERENCES IN TRACINGS IN MILLIMETERS

PANTOGRAPH ORIENTED TO HINGE AXIS

	RIGHT	LEFT
mean	.4529	.3054
largest	.5887	.3929
smallest	.0775	.2191
T	26.5517	30.5056

PANTOGRAPH ORIENTED TO ANATOMIC AVERAGE

	RIGHT	LEFT
mean	.3522	.1803
largest	.4155	.2700
smallest	.2506	.1126
T	48.4182	27.2333

SUBJECT XIV

COMPARISON OF DIFFERENCES IN TRACINGS IN MILLIMETERS

PANTOGRAPH ORIENTED TO HINGE AXIS

	RIGHT	LEFT
mean	.3335	.2927
largest	.4291	.4623
smallest	.2448	.1574
T	31.9747	18.7007

PANTOGRAPH ORIENTED TO ANATOMIC AVERAGE

	RIGHT	LEFT
mean	.4382	.4875
largest	.4896	.5856
smallest	.3194	.3887
T	56.5137	50.3715

CHAPTER VI

DISCUSSION

Methods of evaluating one pantographic tracing with another has been reported in the literature. Reproducibility of pantographic tracings was found to be a sign of normal, healthy stomato-gnathic systems (Guichet, 1977). Roura and Clayton (1975) used pantographic tracing comparisons to study the effectiveness of occlusal bite splint therapy on TMJ dysfunction. Also Jackson (1979) tested the effectiveness of Valium on reproducibility of pantographic tracings. One of the disadvantages of these methods was the lack of any quantitative comparison between tracings. Both of these studies were based on the researcher's visual ability to determine whether one tracing was coincidental with another tracing. One of the objects of the present study was to devise a way in which one pantograph tracing would be quantitatively compared to another tracing by measuring the distance between points on the tracing plotted along on X, Y axis at the same distances along the curves utilizing a digitizer and a computer. I know of no other studies in which a comparison was made as was done in this study.

Even though much has been written on the Bennett movement, there has been some controversy over the actual existence of the Bennett movement, what causes it if it does exist, its' relative clinical importance, and various ways of registering or recording this mandibular movement.

The actual existence of the Bennett movement can no longer be refuted as evidenced by a review of the many studies reported in the literature that support this phenomenon; such as McCollum (1955), Granger (1954), Sicher (1954), Guichet (1977), Lundeen (1973), Lucia (1961), Isaacson (1958), Sheppard (1967), as well as, Bennett (1908) to name but a few.

There are several different explanations as to the cause of the Bennett movement. The most plausible explanation would be a combination of several factors. In a lateral jaw movement, there would be a contraction of the contralateral lateral pterygoid muscle with an accompanying contraction of the ipsilateral posterior temporal muscle (Sicher, 1954). As the contralateral condyle moves downward, forward, and inward, it follows a path governed by the inner curbing of the glenoid fossa (Granger, 1954). There is a certain amount of slack or stretch that exists in the ligaments of the articular capsule. In a lateral movement, the amount of slack in the ligaments of the ipsilateral condyle is taken up as that condyle moves out and begins to rotate (Guichet, 1977). The combination of the above produces the lateral translatory movement of the mandible which we call the Bennett movement.

Most investigators feel that the Bennett movement is of prime importance clinically in its effect on occlusal morphology. The immediate portion of the side shift, since it occurs at the beginning of lateral movement when the teeth just leave centric occlusion or the position of maximum intercuspation, has a very profound effect on the occlusal morphology of the opposing teeth. It primarily influences the width of the central grooves of posterior teeth. The progressive part of the side shift has its primary influence on the medio-lateral inclination of balancing inclines on the posterior cusps as well as the direction of the ridges and grooves of posterior teeth, primarily on the contralateral side (Dull, 1965)(Guichet, 1977). Consideration of this clinical effect must be appreciated and taken into account if occlusal interferences and irritations are to be avoided with their concomitant pathological sequelae.

Several methods of registering and recording mandibular movement have been done to enable investigators to study the Bennett movement. Very limited information has been gleaned from anatomical specimen studies (Landa, 1958). One has to be cautious when drawing conclusions from observations utilizing dry skulls as erroneous claims may result (Sicher, 1962). Photographic studies have produced some insight into the Bennett movement but most of these studies were done on a very limited number of subjects due to the relative complexity of design of these studies (Chick, 1960) Hickey, 1963).

Roentgenographic studies have limited value in studying mandibular movements.

Prieskel (1970) (1971) has devised a method using ultrasound as a measuring device to study mandibular movements. This method seems to have limitations due to the relative complexity of the apparatus and quantitative measurement being in a single plane or direction.

Tracing devices utilizing the pantograph have been used to great advantage in studying mandibular movements especially the Bennett movement. The pantograph has advantages over other methods that have been used for mandibular movement study. By the use of clutches attached to the maxillary and mandibular teeth, contact between the teeth can be disengaged so that a total three dimensional recording of the entire range of mandibular border movements can be recorded without the teeth guiding mandibular movement. It was thus necessary to open the individual's vertical dimension with the central bearing screw of the clutches to eliminate tooth contact during utilization of the pantograph in this manner. This is one of the disadvantages leveled at pantograph utilization as this increased vertical dimension is said to affect the recording that is obtained by tracing jaw movement. The validity of this claim is one of the objects of this study. Even though statistical analysis of this study showed a difference in the tracings obtained, the magnitude of such differences was so minute that they are relatively clinically insignificant. It would still be advisable to use only the minimal vertical opening necessary when doing a pantograph tracing. The Denar pantograph, because of features such as its' pneumatically powered tracing styli, provides for a relatively simple, fast, accurate method of recording mandibular movement and jaw positions. This enables the operator to obtain a total recording of the patient's mandibular movement and to discriminate between erratic abnormal jaw movements and pure peripheral movements in a practical efficient manner. The nature of the extra-oral pantograph tracing devices allows for double-check capability of pure jaw movement without interference or influence of tooth contact. The Denar pantograph especially can be attached to an articulator that has full adjustment capabilities and the articulator can be programmed to duplicate the entire range of mandibular movements that were recorded. Clinical use of such an instrument is thus not only feasible but advantageous where indicated.

One of the difficulties in a comparison study such as this would be a method of standardization of attaching the recording blanks to the recording table. This proved not to be a problem in this study because both sets of tracings were recorded on the same blanks without changing the orientation of the blank to the table. Perhaps future studies could utilize some method similar to the one used by Jackson (1979) to standardize the placement of the tracing plates. This would allow utilization of the method used in this study to make a quantitative comparison between tracings made on two different plates or recording blanks.

Another difficulty encountered was the operator steadiness in tracing the digitizer stylus over the enlargement made of the pantograph tracing. This is one part of the study that was subject to operator variability or error.

In this study, the computer that was utilized with the digitizer was programmed to give only the differences between different points on the lines that were traced and recorded on the same blank. If comparisons were to be made between tracings on different recording blanks, the computer would have to be programmed to assign numerical values to points along a tracing on the X, Y axis.

Future research projects are definitely feasable utilizing the method used in this study to do comparison studies of pantographic tracings.

CHAPTER VII

SUMMARY

Fourteen dental students were used to study the effects of changing the vertical dimension on pantograph tracings of the mandibular lateral translatory movement. A method was devised whereby two curved tracings could be quantitatively compared with each other utilizing pantograph tracings analyzed by means of a digitizer connected to a computer for analysis.

The collected data was statistically evaluated using the T test.

CHAPTER VIII

CONCLUSIONS

1. A digitizer connected to a computer can be used to quantitatively compare one pantograph tracing with another.

2. There was a statistically significant difference between pantograph tracings obtained at different vertical dimensions.

3. The statistically significant difference was noted between pantograph tracings whether the pantograph was oriented to the exact hinge axis location or the axis located by average measurement.

4. The exact hinge axis location differed in position from the average measurement location.

5. The hinge axis location was different on each side in the same individual.

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APPENDIX

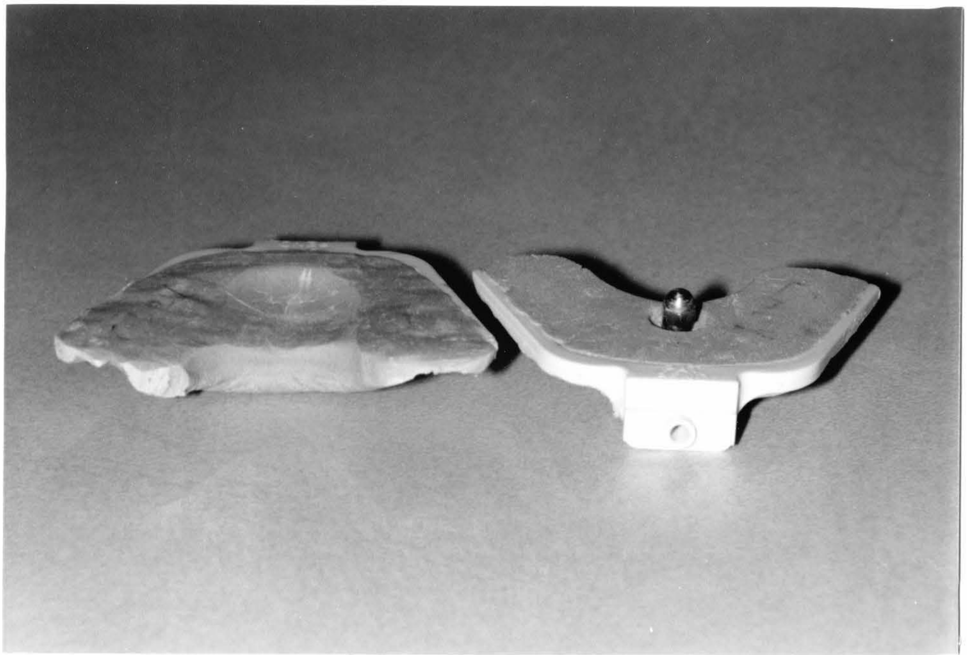

Figure 1. Upper and lower clutches with central bearing screw in lower clutch.

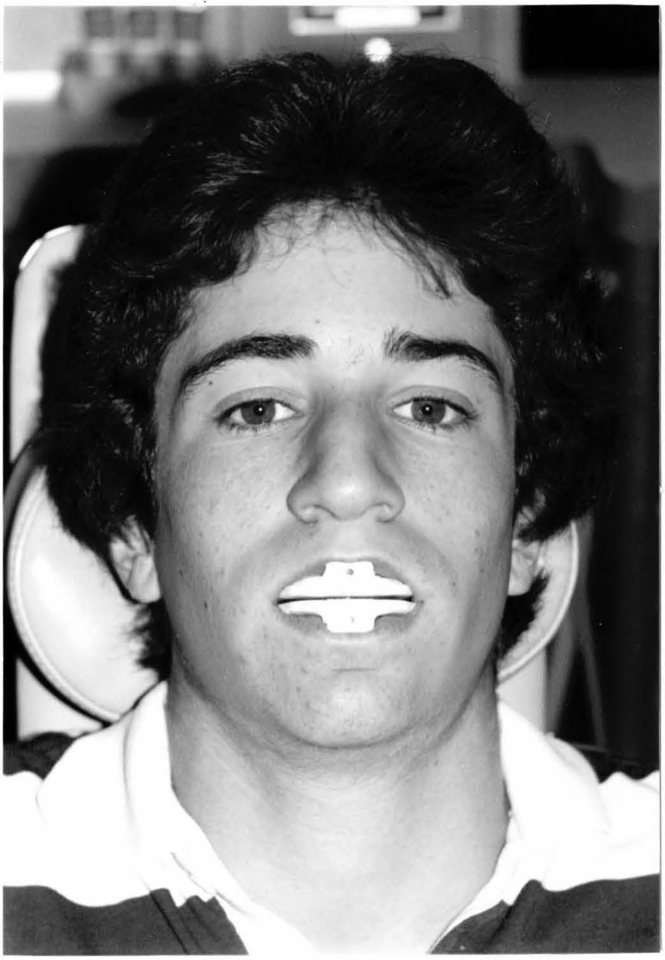

Figure 2. Subject with clutches in the mouth.

Figure 3. Average anatomic location of posterior reference points on subject using the Denar Reference Plane Locator.

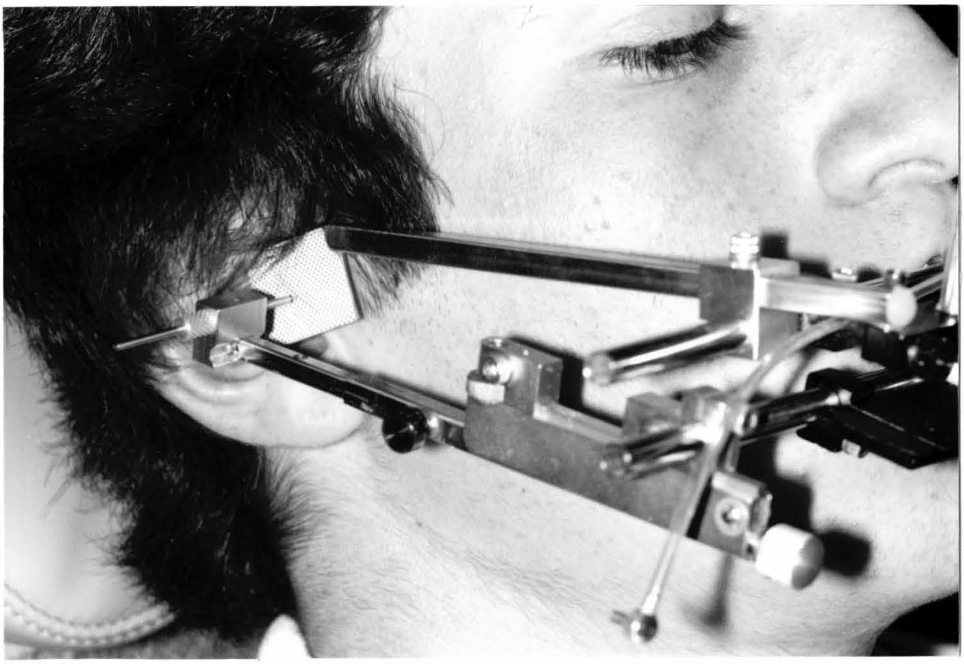

Figure 4. Hinge axis location of the posterior reference points on subject using the Denar Hinge Axis Locator.

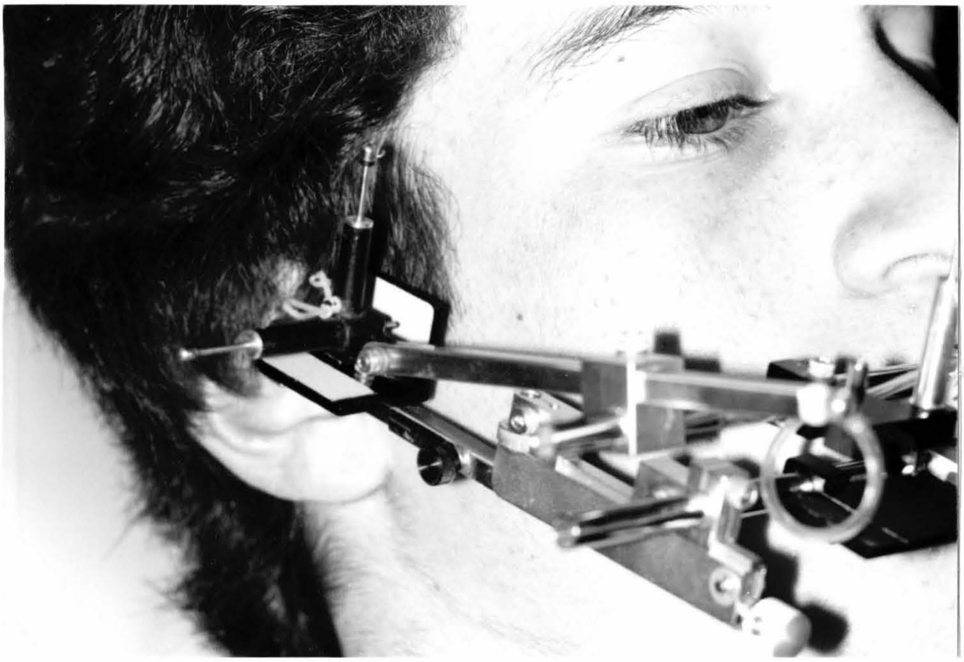

Figure 5. Orientation of Denar Pantograph on subject.

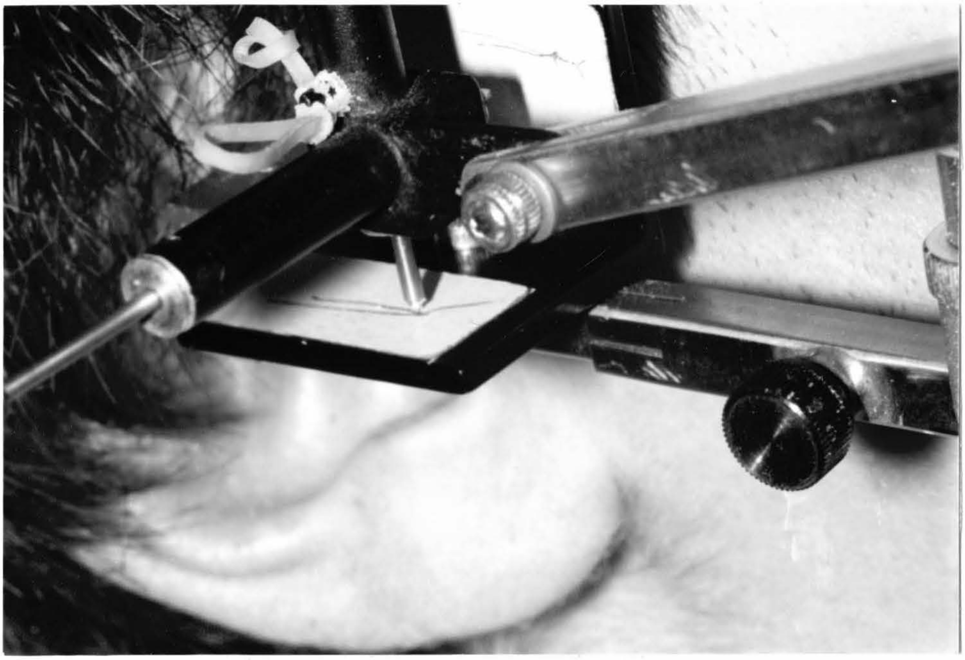

Figure 6. Posterior horizontal plate with stylus assembly and record obtained.

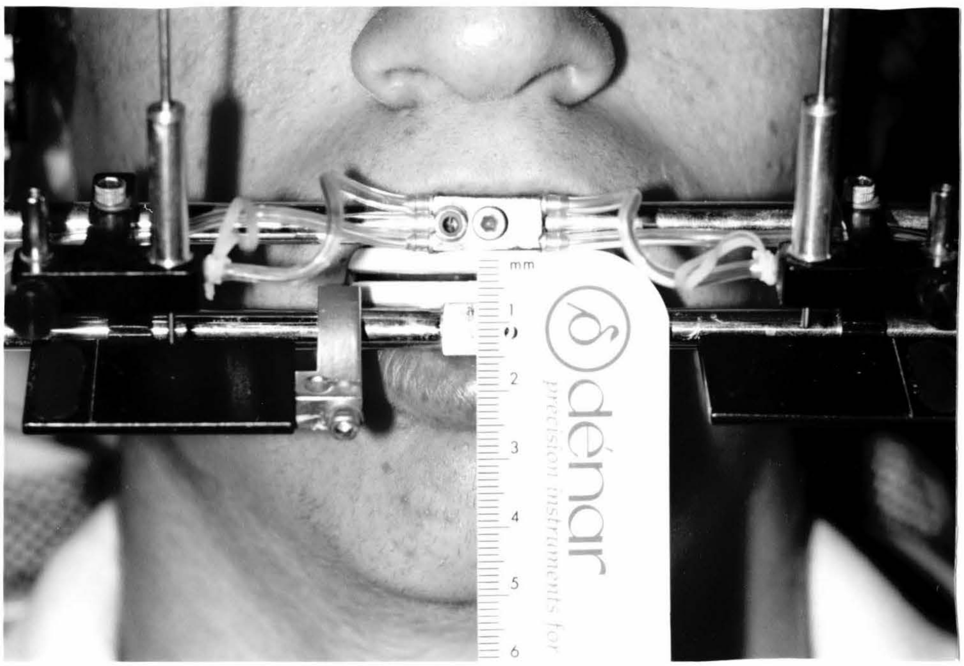

Figure 7. Measurement of vertical dimension at anterior crossbar assembly.

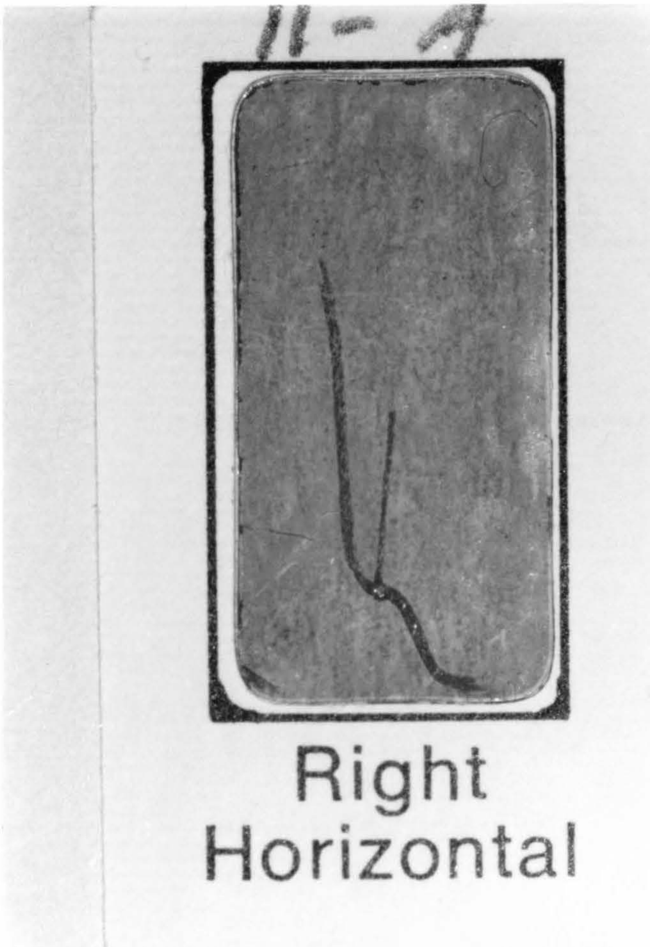

Figure 8. Tracing obtained on posterior horizontal plate.

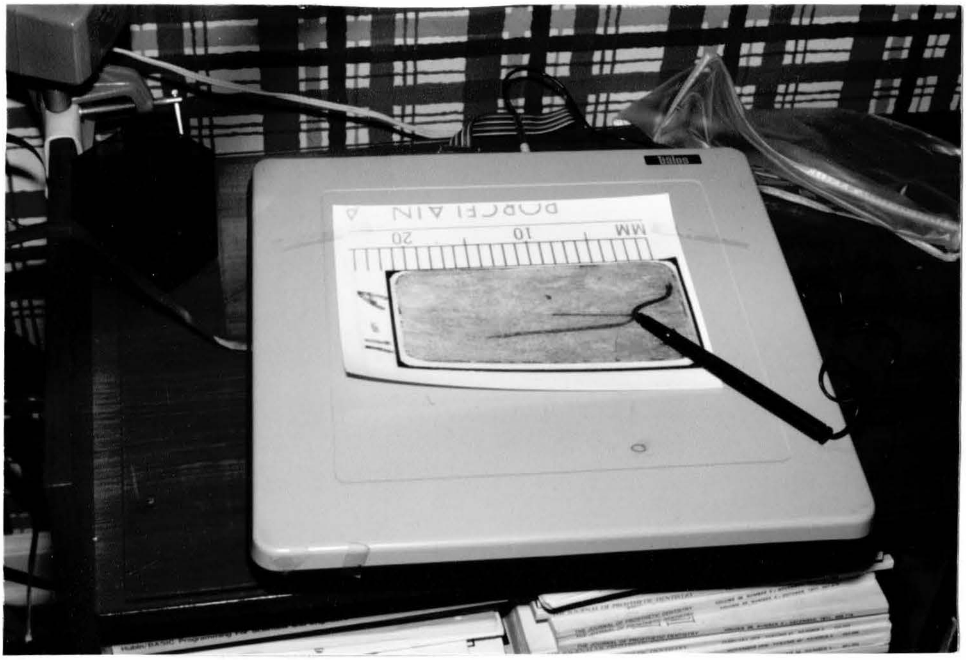

Figure 9. Digitizer with board and tracing stylus.

Figure 10. Apple II computer set-up.

APPROVAL SHEET

The thesis submitted by Raymond Berlin has been read and approved by the following committee:

Dr. William Malone, Director
Professor, Fixed Prosthodontics, Loyola

Dr. Patrick Toto
Professor, Oral Pathology, Loyola

Dr. Joseph Gowgiel
Associate Professor, Anatomy, Loyola

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the thesis is now given final approval by the Committee with reference to content and form.

The thesis is therefore accepted in partial fulfillment of the requirements for the degree of Master of Science in Oral Biology.

6/4/80 — Date

William W. Malone — Director's Signature