THE SIGNIFICANCE OF THE BENNETT MOVEMENT AS A BORDER MOVEMENT ITS PANTOGRAPHIC REPRODUCIBILITY UNDER EXPERIMENTAL CONDITIONS

by

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INTRODUCTION

The study of mandibular movements has always been a challenging and fascinating aspect in the development of the dental profession. Early investigations were primarily concerned with the anatomic assessment of the masticatory system and the kinematics of the opening and closing movement. With the analysis of lateral jaw movements, in particular the Bennett movement, an area of contradiction and confusion was opened to dental research.

Introduced by Bennett[10] in 1908, the so-called Bennett movement rapidly developed into one of the mysticisms of dentistry. Being regarded as an immutable aspect of the mandibular border movements its clinical significance in restorative dentistry was heavily emphasized by the gnathologists. More recent investigations, however, seem to contradict the immutability of the Bennett movement.

Despite or, perhaps, because of the lack of scientific data in this area of dental research the significance of the Bennett movement as a border movement is still widely accepted by the dental profession. Its reproduction by a mechanical device, the articulator, set in accordance to the tracings of a pantographic recorder is considered of prime importance to attain the accuracy demanded for occluso-restorative procedures. As the pantographic survey is taken at an increased vertical dimension, the occlusal restoration, however, designed at the level of centric occlusion, the tracings recorded at different degrees of mouth opening have to represent identical condylar movement patterns to provide the prerequesites for an occlusal restoration which functions harmoniously within the masticatory system.

This study will attempt to evaluate by means of pantographic recordings the concept of immutability of the Bennett movement at different levels of vertical dimension and at different degrees of simulated lateral cuspal guidance.

REVIEW OF THE LITERATURE

First concepts of articulation were based upon the premise that during lateral mandibular movements protrusive condylar displacement was executed on the balancing side, while the working condyle remained in a fixed position, performing only rotational movements[1]. Several investigators soon began to challenge this concept, especially the theory of the rotating or "resting" working condyle. Walker[2], based on investigations of dry human skulls and of living subjects, reported on the vertical and sagittal displacement of the working condyle during lateral jaw movements and applied these findings to modify the contemporary articulation theories. Similar observations were made by Campion[3] who developed a graphic tracing device for the recording of mandibular movements. He, however, questioned the accuracy and therefore the validity of his own findings. These observations by Walker[2] and Campion[3] are often stated in relation to the Bennett movement[4], although no lateral displacement of the working condyle was reported in their publications. The laterotrusion of the working condyle during lateral mandibular movement, however, has to be considered as the main characteristic of the Bennett movement. As the discussion and review has to be based on a clear statement the following definition[5] of the Bennett movement, as related

to fixed partial prosthodontics, will serve as the guide--line and point of refernce:
"The bodily lateral movement or lateral shift of the mandible resulting from the movements of the condyles along the lateral inclines of the mandibular fossae during lateral movement".

Long before Bennett reported his findings of the lateral shift of the working condyle during lateral jaw movements similar observations and publications were made by various dental researchers. As communication systems in those days were rather underdeveloped and English not yet the scientific language, most of them never received much publicity.

In 1831, Bell[6], an English anatomist, described in a paragraph related to the muscles of mastication the action of the external pterygoid muscle during the lateral movement of the mandible. With regard to this particular mandibular movement he reported on a bodily lateral displacement of the mandible combined with a partial rotation around a center at the inner extremity of the "fixed" or working condyle.

In 1865 the Swiss anatomist Hermann Meyer[7], based on the study of dry skulls, stated the lateral translation of both condyles during lateral mandibular movements. The phase of laterotrusion was then followed by a rotation of the working condyle around a center at 6 to 8 mm behind the "resting condyle". Almost at the same time Balkwill[8] published a paper pointing out the forward and sideward directed components of the working condylar movement. In 1896 the Danish scientist Johan Ulrich[9] presented his study of the "Kinematics of the human temporomandibular joint". Besides the study of human dissection specimen, photographic recordings were performed of living subjects. Small silver balls were placed at the level of the occlusal plane but lateral to the condyles so that by photographic exposures during mandibular function the phases of the lateral movements could be interpreted. The photographic recording indicated an immediate bodily lateral shift of the mandible of about 1.5 to 3 mm followed by a rotational and further lateral and backward movement of the working condyle, while the balancing condyle moved forward and medially. He concluded, that therefore during lateral mandibular movements the moving axis of rotation was located posteriorly and medially of the working condyle. Further investigation of the masticatory function led to no conclusion because of the discriminative limitations of the recording system.

Bennett[10] gave a presentation of his findings in 1908. In a paper which was primarily concerned with the study of the opening path of the jaw, he incidentally introduced the phenomenon of the Bennett movement. Observing himself as the experimental subject and using a combined optical and graphic method, he detected a lateral and downward displacement of his working condyle during the laterotrusion of the mandible. He also noted an increased lateral translation of the working condyle of up to 3 mm with increased mouth opening. Despite the fact that he never paid special attention to these particular observations and he never claimed their general validity, his name was adapted to this special mandibular movement. Though the description of the Bennett movement should be based on the displacement of the working--side condyle, its relation to the path and timing of the balancing condyle cannot be neglected. The Bennett angle, however, which is defined as[5] "the angle formed by the sagittal plane and the path of the advancing condyle during lateral mandibular movement, as viewed in the horizontal plane" does also exist in the absence of the Bennett movement. It generates, however, the Bennett movement if the balancing condyle moves more medially during the lateral movement than the arc determined by the intercondylar distance will allow. These principles again formed the basis for the construction of Gysi's articulator, which was the first instrument able to reproduce the lateral shift of the mandible by mechanical means.

Bennett's observation, at the first time pronounced in front of a greater audience and because of its wide spread publication, stimulated further research and opened the discussion in this area of dental science.

Numerous investigators using various methods, techniques and instrumentation, somewhat reflecting the stage of scientific technology, tried to further explore and define the lateral component of mandibular movements. These investigations resulted either in the support, rejection or modification of Bennett's findings.

Gysi[11] repeated Bennett's experiments using the same technique and direct graphic recordings, and came to the same conclusions as Bennett. He recognized the importance of the Bennett movement with regard to the occlusal morphology of dental restorations, in particular its influence on the cuspal inclination. With the graphic verification of the "stationary" rotational centers of the mandibular movements and their incorporation in the construction plan of an articulating device, he finally succeeded in the development of an anatomical articulator. This articulator allowed for the first time moderate laterotrusion of the working condyle generated by a 15° degree inclination of the balancing path.

The basis of mandibular articulation as related to the presence of stationary or instantaneous centers of rotation, was again discussed by Fischer and answered in agreement with Gysi. Fischer[12] emphasized the use of the "individually" adjustable articulator realizing that for functional dental reconstruction the harmony of occlusal condylar morphology is of ultimate importance.

The influence on occlusal patterns ascribed to the Bennett movement must be considered as one of the main reasons for the continuing investigations in the study of this particular condylar movement.

Among the methods used for the investigation of the Bennett movement the pantographic recording still appears to be the most consistent, accurate, and clinically practicable approach in this area of dental research. The pantographic survey can be used to set the articulator and can therefore determine indirectly the occlusal morphology of oral restorations. As pointed out by Isaacson[13], the Bennett movement is best interpreted or "represented" by pantographic means on the posterior horizontal plates and can be quantitatively evaluated only after its relation to a measuring instrument, as the articulator. Thus, a differentiation must be made between the interpretation of graphic or pantographic tracings.

Bellanti[14] found by comparing semi- and fully-adjustable articulators that the capabilities of the semi-adjustable type were insufficient to reproduce the individual Bennett movement. Especially the lateral-backward movement of the working condyle, if not reproduced by the articulator, would create intolerable interferences in the occlusal restoration. Similar observations were made by Schreiber[15] who reported about the attempt to predetermine the amount of Bennett movement using the functional analysis of Lauritzen. Both authors agree regarding the necessity for a fully adjustable articulator to accomodate for the condylar laterotrusion. A comparison of different fully adjustable articulators led Weinberg[16] to conclude that only the gnathological type can reproduce the three-dimensional guidance of the working condyle.

In an articulator study about the influence of the end--controlling guidances on cusp inclination Mjor[17] described a decrease of cusp angulation with an increase of the Bennett angle for a given condylar inclination. Lukas and Spranger[18] documented the effect of unfavorable tooth loading due to the incorrect adjustment of the Bennett angle. Finally Ramfjord and Ash[19] emphasized the trigger factor on parafunctions of balancing interferences which are likely to be created by an incorrect recording or reproduction of the Bennett movement.

Mc Collum[20], as the advocator of the early gnathological school in dentistry, recognized the ultimate importance of the reproduction of the Bennett movement for extensive restorations, pointing out its influence on cusp height and fossa depth, ridge and groove direction, and the curve of

Wilson. His statements were made at the time when gnathologists still believed in the concept of bilateral balanced occlusion. With the modification of the gnathological concept to the idea of the mutually protected occlusion, the occlusal shaping of the upper and lower canines was discussed by Lucia[21] and Kahn[22]. It was emphasized that the amount of freedom necessary to be compatible with the Bennett shift had to be incorporated in the contacting surfaces of the canines in order not to collide with the condylar--determined border movements of the mandible.

The natural relationship of opposing canine teeth with regard to the effect on the lateral mandibular translation was investigated by Preiskel[23]. However, no significant correlation could be shown.

Aull[24] in a pantographic study, partially concerned with the Bennett movement, demonstrated the concept of "timing" in laterotrusion, which was later simplified by Guichet[25], who introduced the terms "immediate" and "progressive side-shift". The timing factor in laterotrusion was later shown to be of prime importance as it determined the moment and period of the lateral condylar translation and affected significantly the movement ratio between the working condyle and the working-side teeth[26].

Granger[27,28], as an advocator of the modern gnathological school, introduced a new aspect into the discussion. As muscle contraction on the working side is associated with laterotrusion, he defined the Bennett movement as the "power movement" of the mandible. Similar statements were made by Cohen[29], who equally emphasized its importance during masticatory function. Granger explains the occurrence of the Bennett movement by the differentiation of two functionally different temporomandibular joint compartments separated by a cartilagenous disque. The lower compartment contains the center of rotation whereas the upper compartment allows translational gliding; the Bennett movement occurs in the upper gliding compartment. This interpretation stands in sharp constrast to Vincelli's[30] concept, who completely denies any pure lateral sideshift due to anatomical restrictions. Consequently, observations of immediate side shift have to be judged as a pathological situation. Koeck[31], based on a recent study of 40 patients with the Denar system, raised a similar question about the pathological nature of the Bennett movement, as 70 % of the patients tested, exhibiting some degree of initial lateral movement, experienced also increased sensitivity to pain at the side of increased laterotrusion. The restriction of the initial Bennett movement by occlusal features could thus be of therapeutical value in the reconstruction of the dentition. Later evaluation of the initial Bennett movement in the restored patient could give further evidence of its pathophysiology.

Another explanation of the Bennett movement is theorized by De Pietro[32], who accounts basicly three influencing factors for the translatory movement: the asymmetry of the medial surface of the condylar element, the degree of deviation of the medial aspect of the condyle from the horizontal axis, and the position of the vertical and sagittal centers in the condylar element. These theories were partially confirmed by Steinhilber[33], who found the anatomical shape of the condyle in combination with the medially directed pull of the external pterygoid muscle responsible for the laterotrusion of the working condyle. Mahan[34] also refers to the shape of the condyle and its congruent counterpart - the approximating surface of the glenoid fossa, - as the factor which directly affects the nature of the Bennett shift, in particular its downward or upward component.

Based on electromyographic investigations, Sicher[35] considered that muscle action and in particular the time--lag between the contraction of the external pterygoid and the contralateral temporalis muscles accounted for the formation of the Bennett movement. The ipsilateral external pterygoid muscle was found not to increase its activity during lateral jaw movements and therefore not to oppose the Bennett movement[36]. As electromyographic measurements, however, do not differentiate between isotonic and isometric contraction and are extremely difficult to obtain from the external pterygoid muscles, conclusions drawn from these findings are at least questionable. The explanation of the neurophysiologic aspects related to the Bennett movement is still in its initial phase[37-39].

In addition to his statements about the Bennett movement, Sicher[40] rejects any attempts to study mandibular movements by means of anatomical assessments on dry skulls. According to his judgement only the centric occlusion position in the dead imitates the position of the mandible in the living. In spite of his statement anatomical assessments made up an important part in the investigation of the Bennett movement. Continuing the work of early investigators[1,2,3,6,7,8,9,11,12], Landa[41] more recently studied the Bennett movement on dry skulls by the observation of wear facets on the teeth. He concluded that the Bennett movement was more an illusion than a fact. In the second part of his publication he tried to disprove the scientific value of Bennett's investigation[42]. Similar statements were made by Brotman[43] who believed that Bennett's observations were an effect of optical illusions. Mills[44], however, studying occlusal wear facets in various mammalian species found significant correlations between the wear facet pattern and condylar laterotrusion.

Page[45-47], as the advocator of transographics, a new concept of mandibular kinematics introduced during the 1950's, did not relate the Bennett movement to lateral jaw movement but to the vertical opening and closing movement. As the concept of transographics is based on the assumption that there is one separate hinge axis for each condyle, which are parallel to one another and perpendicular to the opening movement the Bennett movement has to be a component of the vertical instead of the lateral movement. The asymmetrical jaw, with regard to the law of mechanics, cannot open and close on an arc lying in the sagittal plane alone. "The divergence of centers and radii force a collateral transverse movement to accompany the opening and closing"[45] which explains the occurrence of the Bennett movement.

Special attention in the study of human mandibular movement was given to the functional or masticatory aspect and its relation to the border movement. Based on recent investigations by Clayton, Kotowicz and Zahler[48] and Dewe-Mathews[49] it appears to be well-substantiated that in the absence of tooth interferences mandibular function is performed from centric relation and in harmony with the border tracings recorded by a pantograph. Posselt's[50] studies of "the physiology of occlusion and rehabilitation" led to the definition and visualisation of mandibular border movements, which is still accepted today[51]. "Border movements are dictated by the tautness of the ligaments of the joint capsules, with the proviso that muscles of mastication reflexly protect the temporomandibular joints before the mechanical limitation of the ligaments is reached. The three-dimensional space circumscribed by border movements of a given point of the mandible is called the movement space or space envelope". The limiting function of the temporomandibular ligaments could be documented by Posselt[52] and Posselt and Thilander[53], who showed that general anaesthesia or local capsular injection of Xylocaine did not alter the border path in the horizontal plane. Independent experiments by Boucher and Jacoby[54] and Mc Millen[55] who graphically recorded border movements outside the mouth from conscious subjects and repeated the same experiment during a stage of general anaesthesia, revealed more posterior border positions and wider lateral border movements for the anaesthesized patients. Thus they concluded, that the muscles are the limiting factor of the border movements. Their findings could be somewhat confirmed by Lundeen and Wirth[26] who reported on rather high immediate side shift values for premedicated patients.

The role of the Bennett movement as a section of the border movement and its relation and significance to functional movements was further investigated by several investigators. Where Hildebrand[56] merely stated its occurrence during masticatory movements, Kurth[57] observed generally a lesser amount of laterotrusion during mastication than during the unrestricted lateral glide. These findings could be emphasized by Hickey et al.[58], who measured a lateral condylar shift of 0.3 mm during functional movements in comparison to a shift of 4 mm during maximal lateral movements with the teeth out of contact. Both values were obtained for the locally anaesthesized patient. The significant increase of the Bennett movement could thus partly be explained by the increase of the vertical dimension during mouth opening; the same phenomenon as already observed by Bennett[10] in his original investigations. Gibbs et al.[59] investigated the functional movements of the mandible by means of the Case Gnathic Replicator, which is basicly a self-contained electronic articulator. As this instrument is supposed to simulate exactly the true functional mandibular movements every motion can be observed as executed by the patient. As during the final part of the closing stroke the working condyle moved medially to is centric occlusion position, the presence of the Bennett movement during mastication could be confirmed. The average translation was found to be around 0.4 mm. Loeb[60] recently reported on further improvements of the Case Gnathic Replicator by the use of a television screen which allowed "an immediate visualisation of mandibular movements from a point inside the condyle as it's functioning". With regard to the studies of mastication and their observations of the Bennett movement, Granger's[28] statement about the immutability of the Bennett movement independent from the degree of mouth opening should be presented, This statement was challenged by Preiskel[61] who used a new recording system based on the echo-sound principle of ultrasonic waves. This instrumentation allowed tooth guided movements from centric occlusion without any foreign intraoral influences. As the mouth opening was increased by cuspid overlays of increasing thicknesses, which did not alter the vertical dimension in centric occlusion, generally increasing amounts of working condylar translation were recorded.

Preiskel's[61] findings stand in contrast to the understanding of the border movement as a reproducible and immutable process of mandibular motion. In an articulator and patient study by Clayton, Kotowicz, and Myers[62] it was shown that the recording of functional mandibular movements by pantographic means would require the "zeroing" of the instrument, i.e. the styli and tracing tables have to be positioned, so that during mouth opening on the terminal hinge axis the stylus tips remain on a stationary point. As these modifications and requirements could be established for pantographic recordings on the anterior horizontal plates, absolute reproducibility could be obtained for up to 3 mm of mouth opening. Although no zeroing could be done for lateral jaw movements this inaccuracy did not seem to affect the reproducibility of the tracings.

The concept of immutability of the Bennett movement stands thus in contrast to the findings of Bennett's own observations and more recent investigations by Hickey and Preiskel, in particular. Further research seems to be indicated to strive for a more precise explanation of the Bennett movement.

MATERIAL AND METHODS

The clinical part of this investigation was preceded by an articulator study. The mechanical concept of "zeroing"[62] the posterior horizontal table and vertical stylus unit of a pantograph could thus be evaluated during lateral movements at different levels of vertical dimension and at different degrees of simulated lateral cuspal guidance. At the same time the discriminative capabilities of the pantographic system could be determined.

A. Articulator Study

The Stuart Gnathological Computer* served as the articulator. The intercondylar distance was set at 100 mm and the condylar inclination adjusted to 35^{o} degrees[63], while the rear and top wall settings were kept at zero. The original side shift guide wings were adjusted to 8,5^{o} degrees; if, however, exchanged for the customized guide wings, the Bennett angle was increased to 17.5^{o} degrees[13]. A set of P.K. Thomas casts was centered and attached to the upper and lower member of the articulator in accordance with the average angulation between the axis-orbital plane and the plane of occlusion[64] and the Bonwill-triangle (Figure 1). Labial clutches, using the precision key part of the pre-

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* see Appendices: List of Materials and Manufacturers

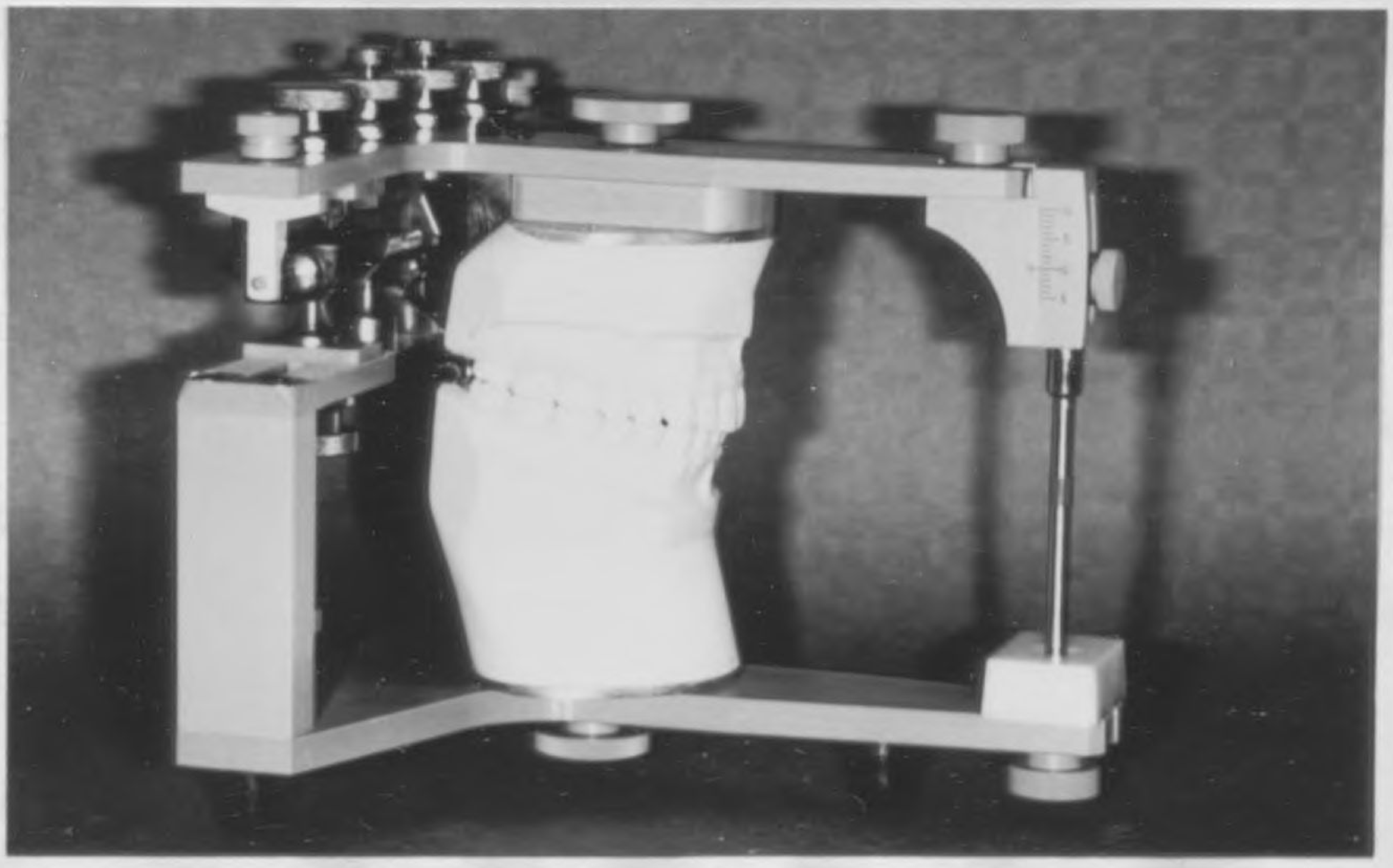

Figure 1. P.K. Thomas casts centered and mounted on Stuart Gnathological Computer.

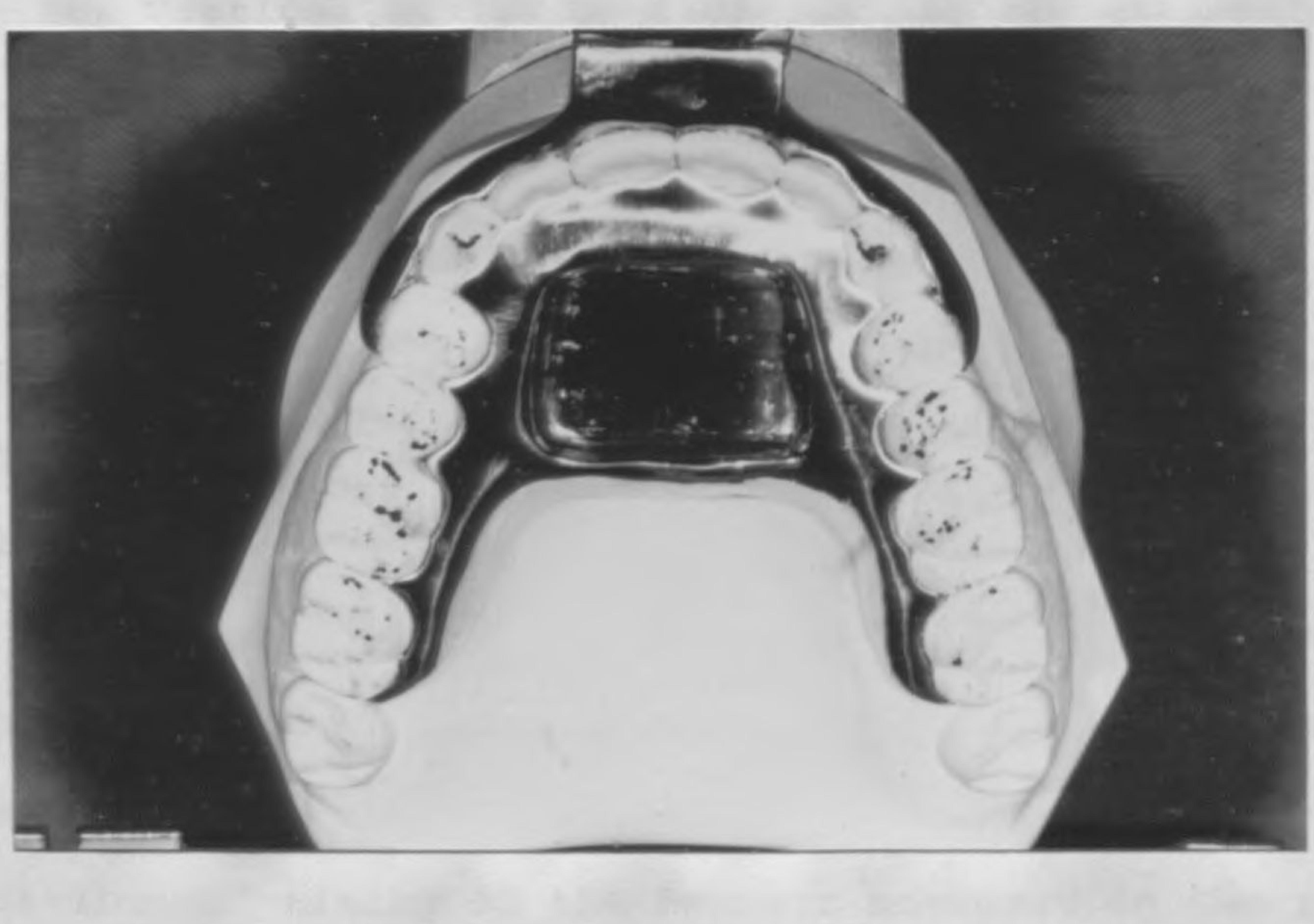

Figure 2. Maxillary labial clutch and bearing plate.

fabricated Denar clutch system and a bearing plate and pin assembly with provision for interchangeable bearing surfaces were waxed to the stone casts and processed in Ticonium. The labial clutches as well as the bearing plate and pin assembly (Figures 2 and 3), which were attached to the stone casts by Space Age Glue, did not interfere with the centric occlusion position nor with tooth-guided lateral movements.

A modified Denar pantograph, featuring only the posterior horizontal tables, attached over a hinge to the micro-adjustable side arms, was connected to the mandibular labial clutch, while the maxillary clutch supported the regular Denar pantographic side arm units (Figure 4). The posterior table-stylus unit was "zeroed" on the articulator as such that the vertical stylus contacted the horizontal table on the extension of the articulator's hinge axis, with the table parallel to the upper member of the articulator (axis--orbital plane) and the stylus perpendicular to the table (Figure 5). During the opening and closing movement on the hinge axis the stylus tip remained stationary on the writing table.

The side shift guide wings of the articulator were either used as supplied by the manufacturer or customized by grinding and adding of Duralay acrylic to allow for a "distributed" timing of the Bennett movement on the right side and an "early" timing on the left side. The movement

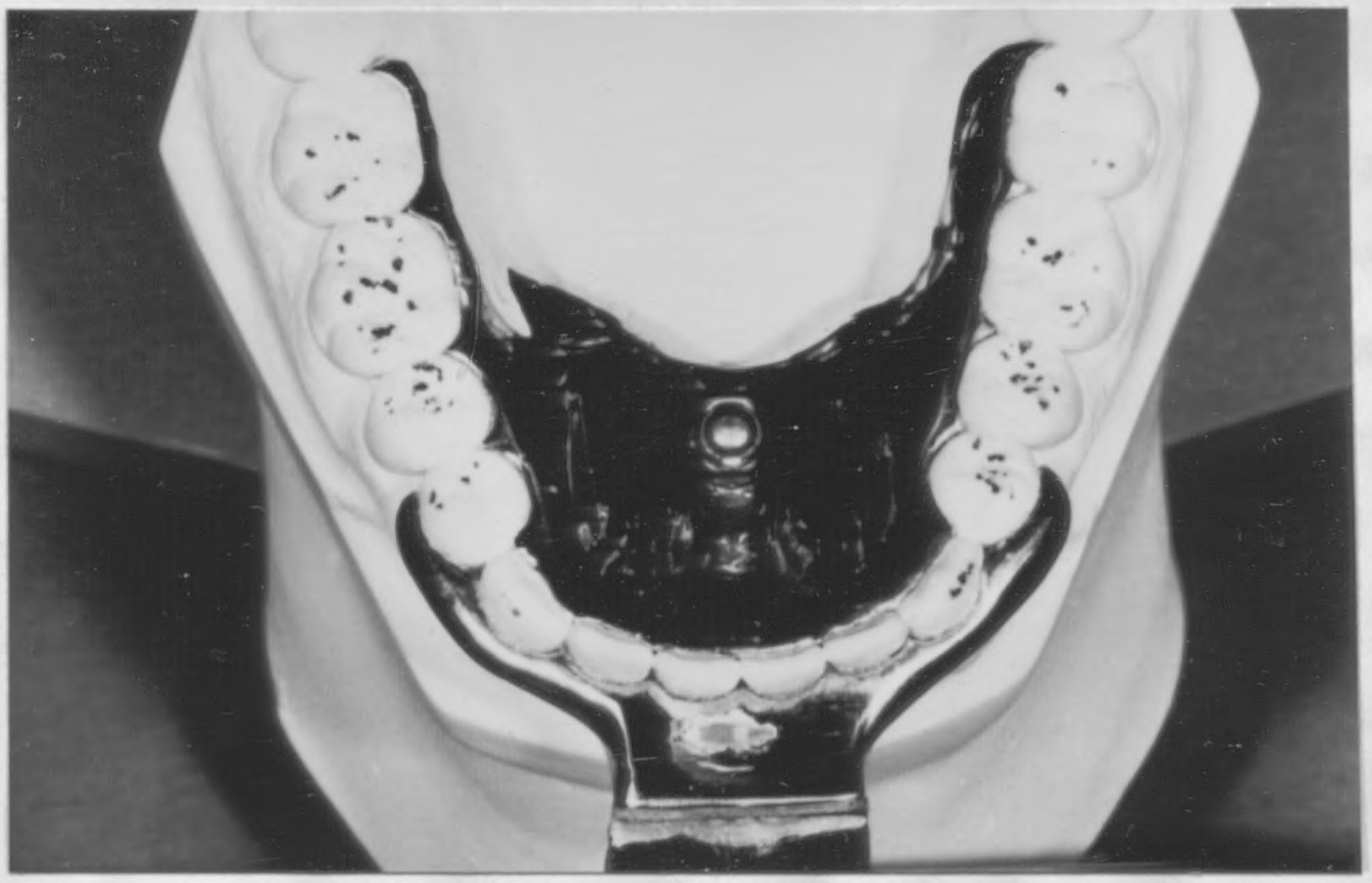

Figure 3. Mandibular labial clutch and bearing pin unit.

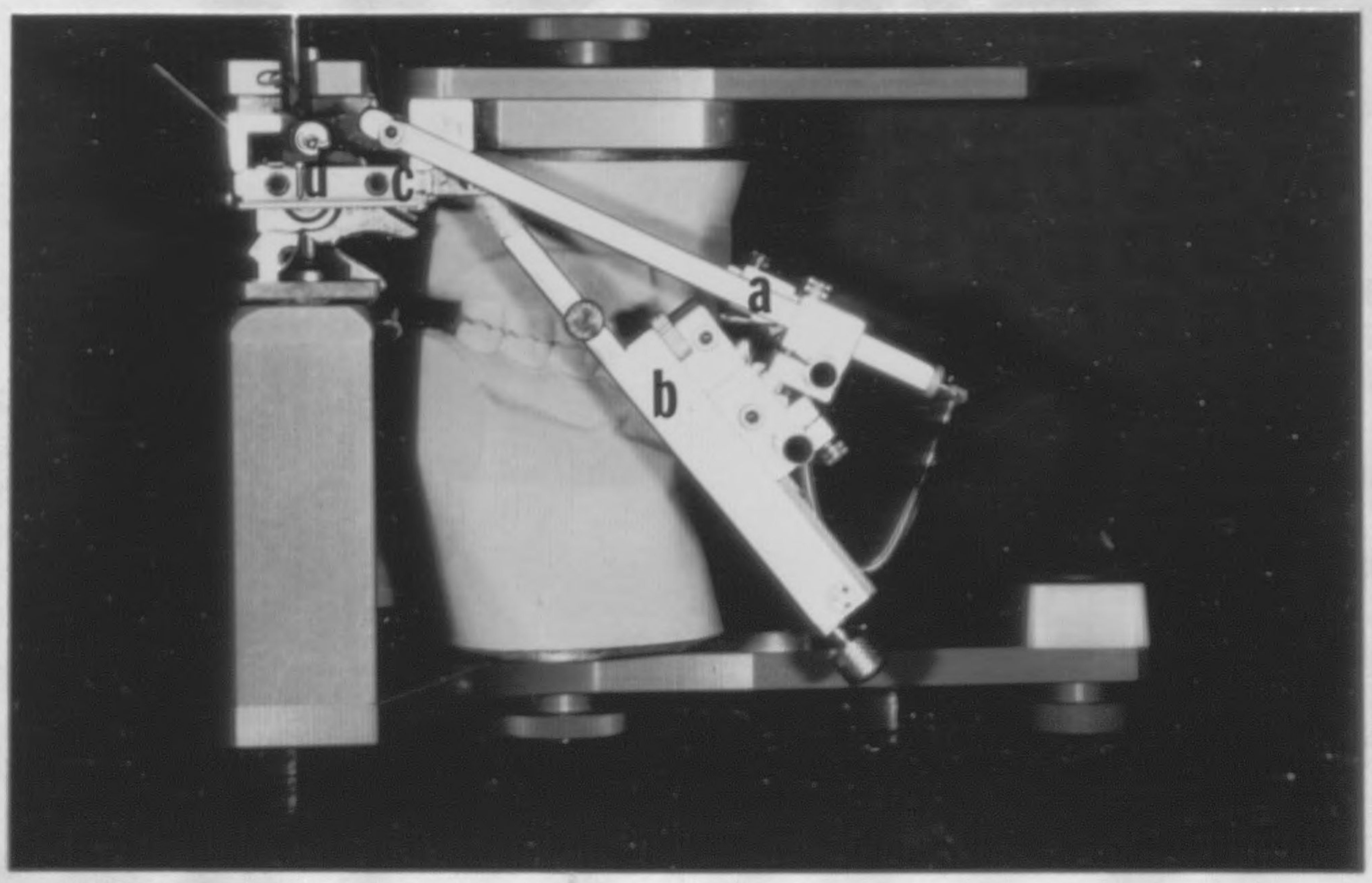

Figure 4. Modified Denar pantograph connected to labial clutches.
a maxillary side-arm
b mandibular side-arm
c recording table
d stylus

pattern for the "distributed" and "early" timing of the Bennett movement was previously established by the pantographic tracings of the Denar pantograph-articulator system, using the appropriate prefabricated fossa side shift inserts. The tracings were then transferred to the modified pantograph connected to the Stuart Gnathological Computer, and the guide wings were customized to follow the tracings.

The maxillary bearing plate was designed to allow for the exchange of different Ticonium bearing surfaces of increasing angulation (30^o, 45^o, 55^o, and 70^o degrees), which could be cemented with Temp-bond to a corresponding cavity of the bearing plate (Figure 6).

Lateral movements of the articulator were performed at different levels of vertical dimension and the tracings were recorded on Sanborn pressure sensitive chart paper. A set of controlled tracings, with no change of settings, was secured first, to provide a zero-unit for later comparisons with the experimental tracings. The increase of vertical dimension was either attained by extending the length of the bearing screw, using the bearing surface # 1 (30^o degrees), thus providing 0.5, 2.0, and 4.0 mm clearance at the cuspid edge-to--edge position, or by interchanging the bearing surfaces of increasing angulation (# 1 to # 4), keeping the length of the bearing screw constant.

In order to gain more information about the influence of

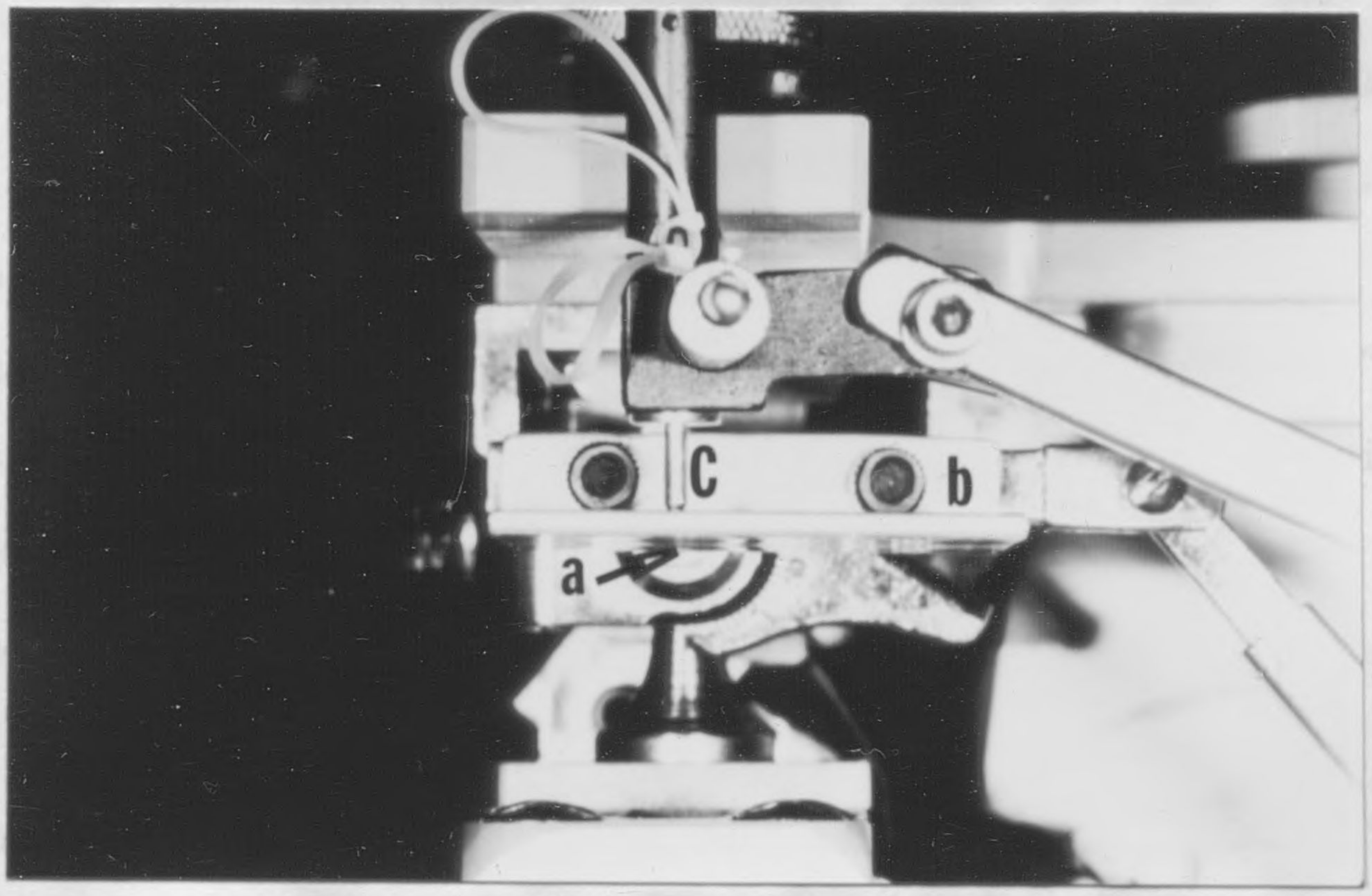

Figure 5. Posterior table-stylus unit zeroed to the extension of the articulator's hinge axis.
a hinge axis of articulator
b recording table
c stylus

Figure 6. Four bearing surface inserts of increasing angulation.

the table and stylus position on the reproducibility of the tracings, further sets of recordings were obtained with the table tilted 15° degrees backward (right side) or the stylus tilted 15° degrees forward (left side), still "zeroed" on the extension of the hinge axis. A fourth set of tracings was finally recorded for different unzeroed positions of the table-stylus unit (Figures 7 and 8).

The width and - if present - the number of lines were measured at the approximate midpoints of the first and second half of the balancing tail of the tracings. A Bausch and Lomb magnifying reticle, which was divided into 0.10 mm increments and allowed an interpolation to the 0.05 mm level, was used for this purpose (Figure 9).

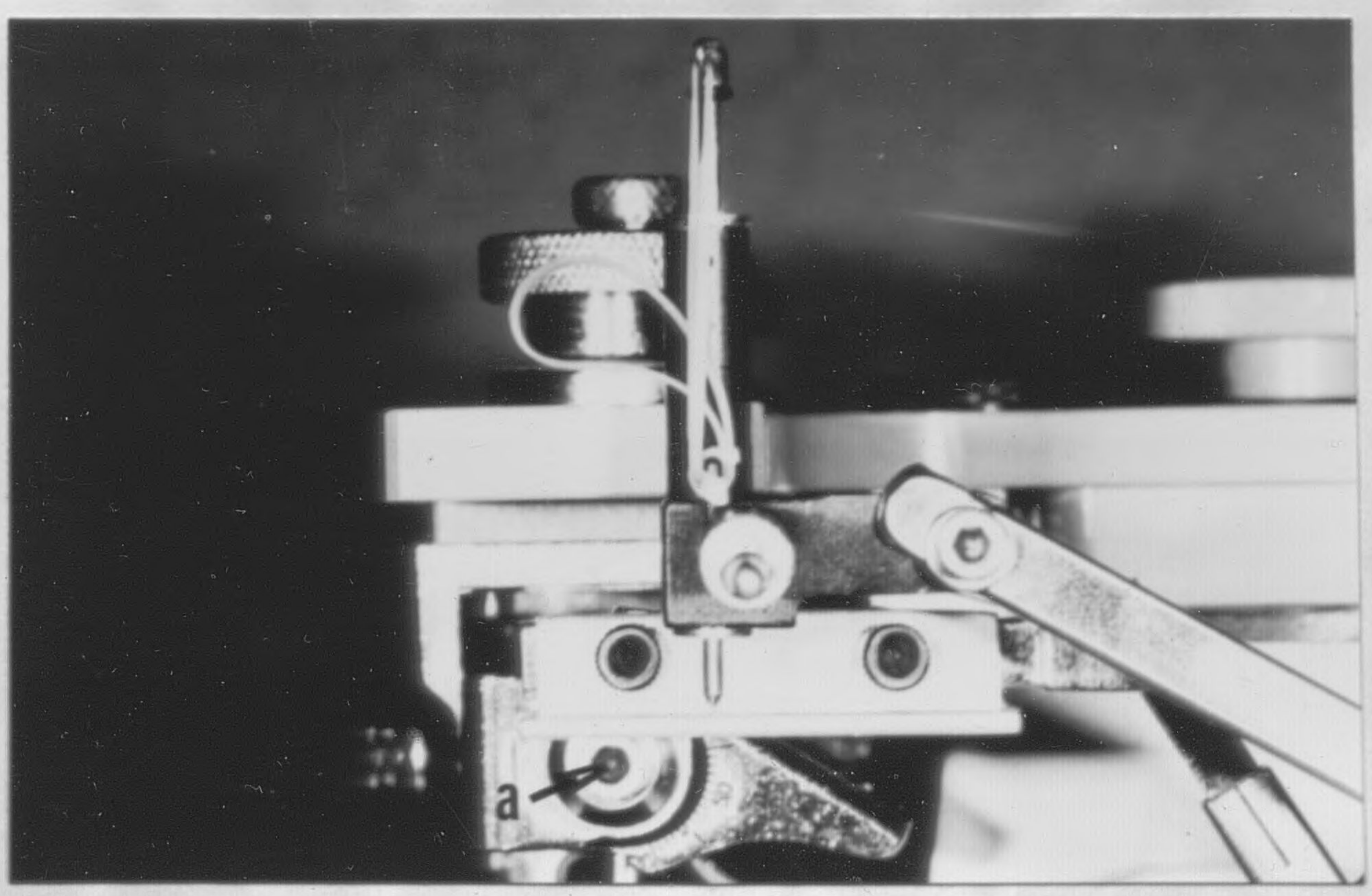

Figure 7. Non-zeroed posterior table-stylus unit. Upward and forward displacement.
a hinge axis of articulator

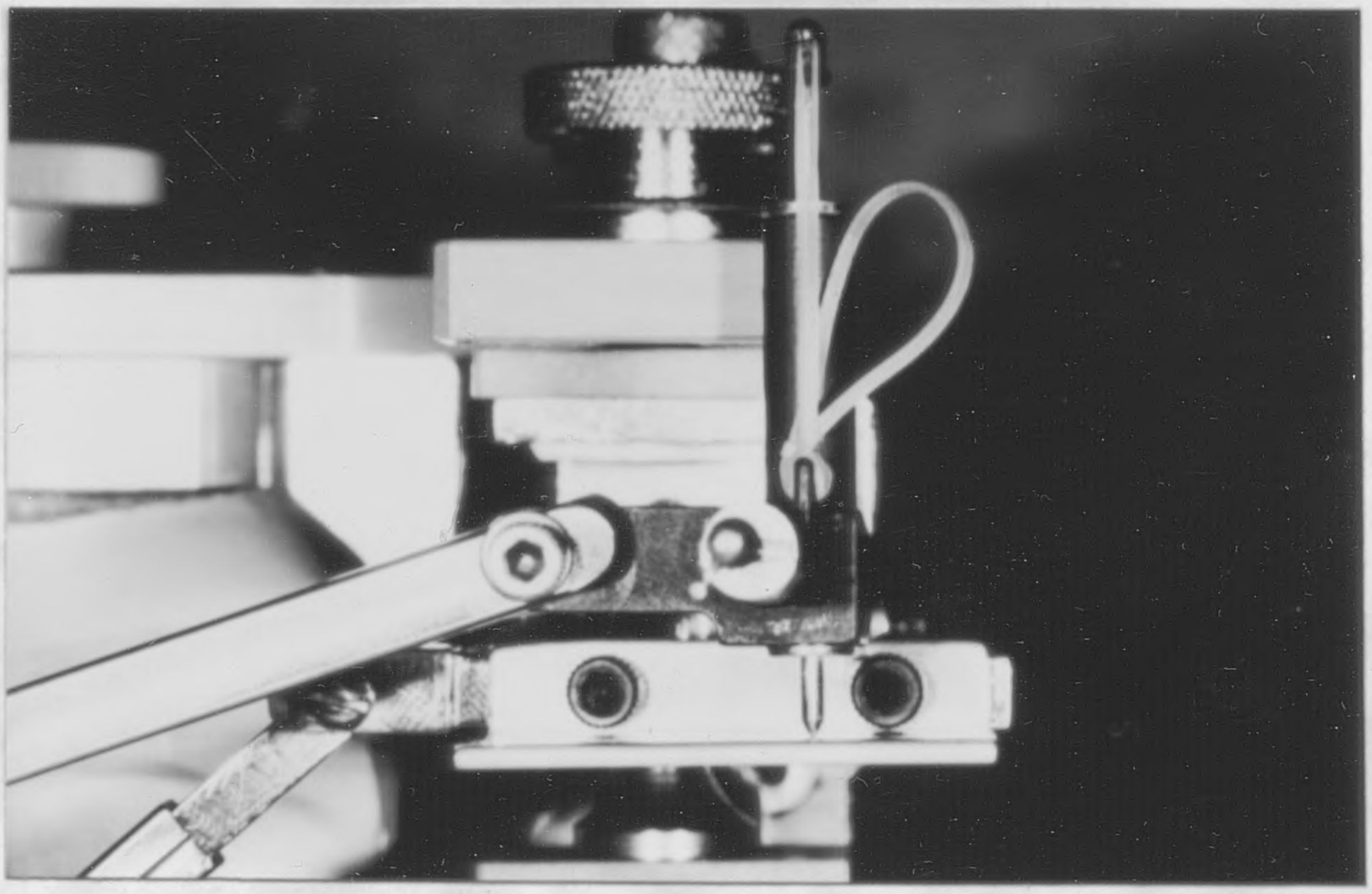

Figure 8. Non-zeroed posterior table-stylus unit.
Downward and backward displacement.

Figure 9. 7 x Magnifying reticle.

B. Patient Study

1. Patient description

Four patients, - three females, one male -, of record from the School of Dentistry of The University of Michigan were included in the clinical part of the investigation. The patients' ages ranged from 21 to 64 years.

Two patients (# 1 and # 2) were referred from the Department of Occlusion presenting either clinical evidence of bruxism and/or mild anamnestic and clinical symptoms of neuro-muscular dysfunction. One patient (# 3) was accepted directly by the Crown and Bridge Department for the treatment of temporomandibular joint dysfunction. The fourth patient (# 4) had just completed the restorative phase of his dental treatment in the Crown and Bridge Department. All patients presented with complete natural or restored dentitions, irrespective of the presence or absence of the third molars.

A thorough intra- and extraoral examination in combination with a full mouth x-ray status was obtained for each subject. For the subjects # 1, 2, and 3 a short history of temporomandibular joint dysfunction was recorded, with clinical signs of light to moderate bruxism and a discrepancy between centric relation and centric occlusion. Subject # 4 revealed no pathological symptoms with regard to the intra- and extraoral structures and the neuromuscular system. No subjectively noticeable slide between centric relation and centric occlusion could be recorded.

A diagnostic pantographic survey, evaluated by means of the PR-Index[65] (Pantographic Reproducibility Index)*, provided further evidence of the patients' neuromuscular co-ordination.

2. Treatment of temporomandibular joint dysfunction

A treatment of the symptoms of temporomandibular joint dysfunction was initiated for the subjects #1, 2 and 3 with a bite-splint therapy, followed by an occlusal adjustment. The objective was to create a stable contact position in centric relation as well as in centric occlusion, and to allow for interference-free lateral excursions. The final occlusal equilibration was checked by two staff members of the Crown and Bridge and/or Occlusion Department. When anamnestic and clinical examination revealed a substantial reduction or alleviation of the pretreatment symptoms, a second diagnostic pantographic survey was performed in an attempt to correllate the anamnestic and clinical findings with the PR-Index.

3. Preparation of experimental phase

At the end of the dento-neuromuscular treatment, which had to provide good evidence of neuromuscular coordination, new Jeltrate alginate impressions (2 max., 2 mand.) were taken for each patient and poured with improved Velmix Stone. The

*Index-Scores provided by Dr. J.A. Clayton maxillo-facial relation was secured by means of the Quick--Mount face-bow and the maxillary cast was mounted on the Whip-Mix Articulator. The patient's centric relation was recorded by a metal-reinforced Swiss denture wax check--bite and the mandibular cast was mounted according to the established relation of the centric relation record. The condylar guidance and Bennett angle were set to average values of 35^{o} degrees, respectively 12^{o} degrees[63]. Any instability in the centric relation contact position, - which may arise by the use of an arbitrary hinge axis -, was adjusted on the stone casts.

In a similar manner as for the articulator study individual labial clutches and a bearing plate-pin assembly were fabricated for each subject. The labial clutches, using again the precision key part of the prefabricated Denar clutch system, were directly processed on the stone casts with cold-curing Formatray acrylic. The bearing plate--and-pin assembly, using the same interchangeable Ticonium bearing surfaces, now with a precision-machined undersurface*, was waxed and checked for accurate center-position of the bearing screw contacting the bearing surface. It was then processed in Lucitone heat-curing acrylic and finished in the Laboratory (Figure 10).

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*machined by Mr. P. Hallaway and staff, U of M, Physics Department, Ann Arbor, Michigan.

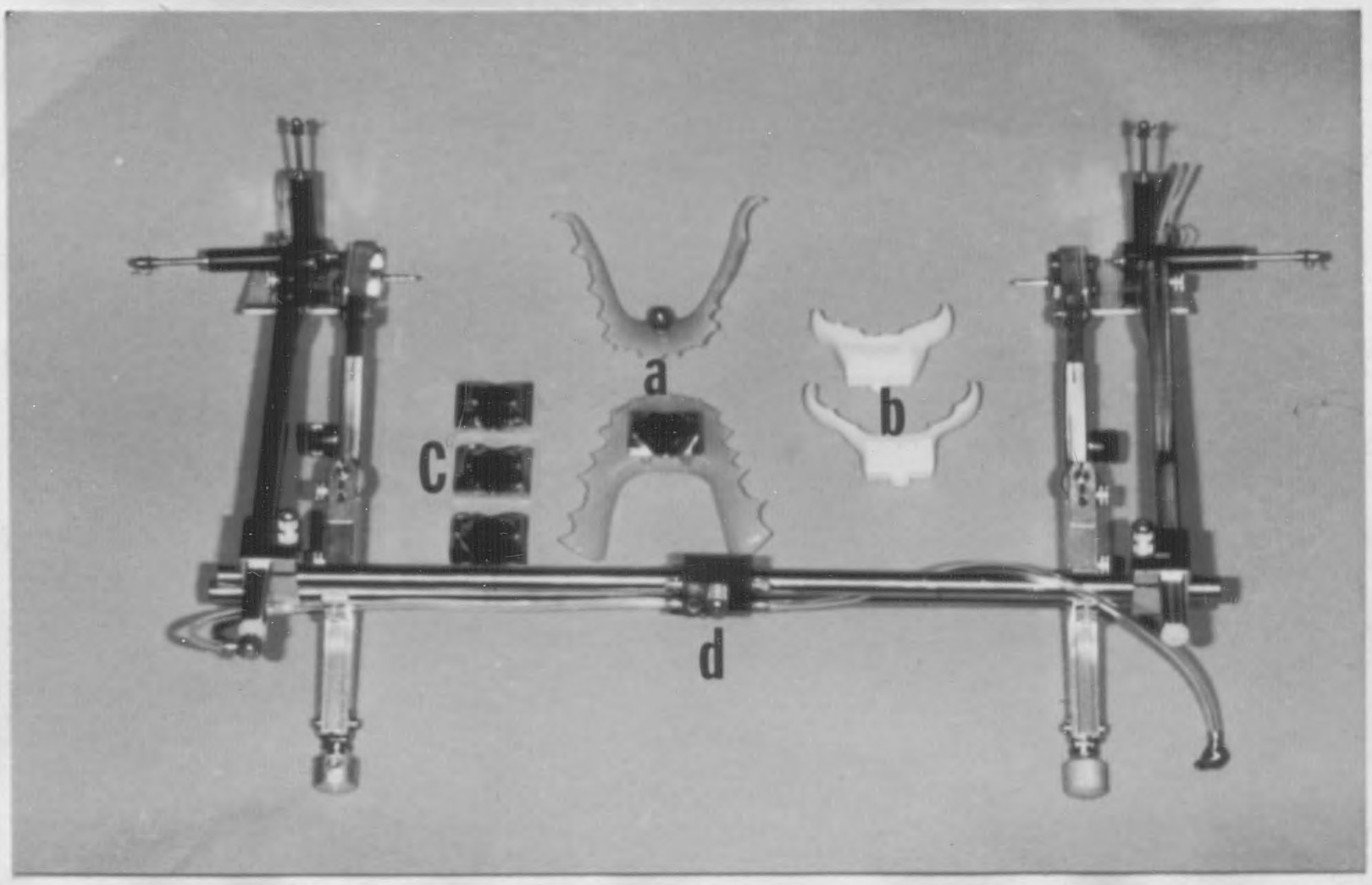

Figure 10. Instrumentation for patient study.
a bearing plate-and-pin assembly
b labial clutches
c bearing surface inserts
d maxillary and mandibular pantographic face-bows

4. Experimental phase

During the next appointment the patient's terminal hinge axis was recorded, following the instructions as outlined in the Denar Teaching Atlas[25]. The posterior reference points were permanently marked with mercuric sulfide in alcoholic solution, if the experimental recordings could not be performed or had to be interrupted during the same appointment. After recording the posterior and anterior reference points, thus establishing the axis-orbital plane, the labial clutches and the bearing plate and pin assembly were tried in the patient's mouth and adjusted, if necessary. The bearing plate and pin assembly should fit tightly without creating tension in the patient's mouth, engaging into the lingual interproximal spaces and under the greatest circumference of the teeth. The stability was checked by moving through the lateral excursions on the different bearing surfaces, which also had to fit tightly without rocking movement into the corresponding cavity of the bearing plate (Figures 11 and 12).

The labial surfaces of the anterior teeth were washed with CPC, rinsed, dried, and the acrylic clutches were cemented with Durelon (Figure 13). A final check was performed to control for interference-free centric occlusion and lateral excursions.

The upper and lower member of the modified pantograph was then connected to the labial clutches, and the posterior table and stylus units were carefully zeroed by visual means to the extension of the terminal hinge axis (Figure 14). The posterior horizontal table was adjusted on the axis-orbital plane with the stylus contacting in a right angle (Figure 15).

All sets of tracings were performed under light chin-point guidance using the same recording paper as for the articulator study. Two first sets of tracings were executed

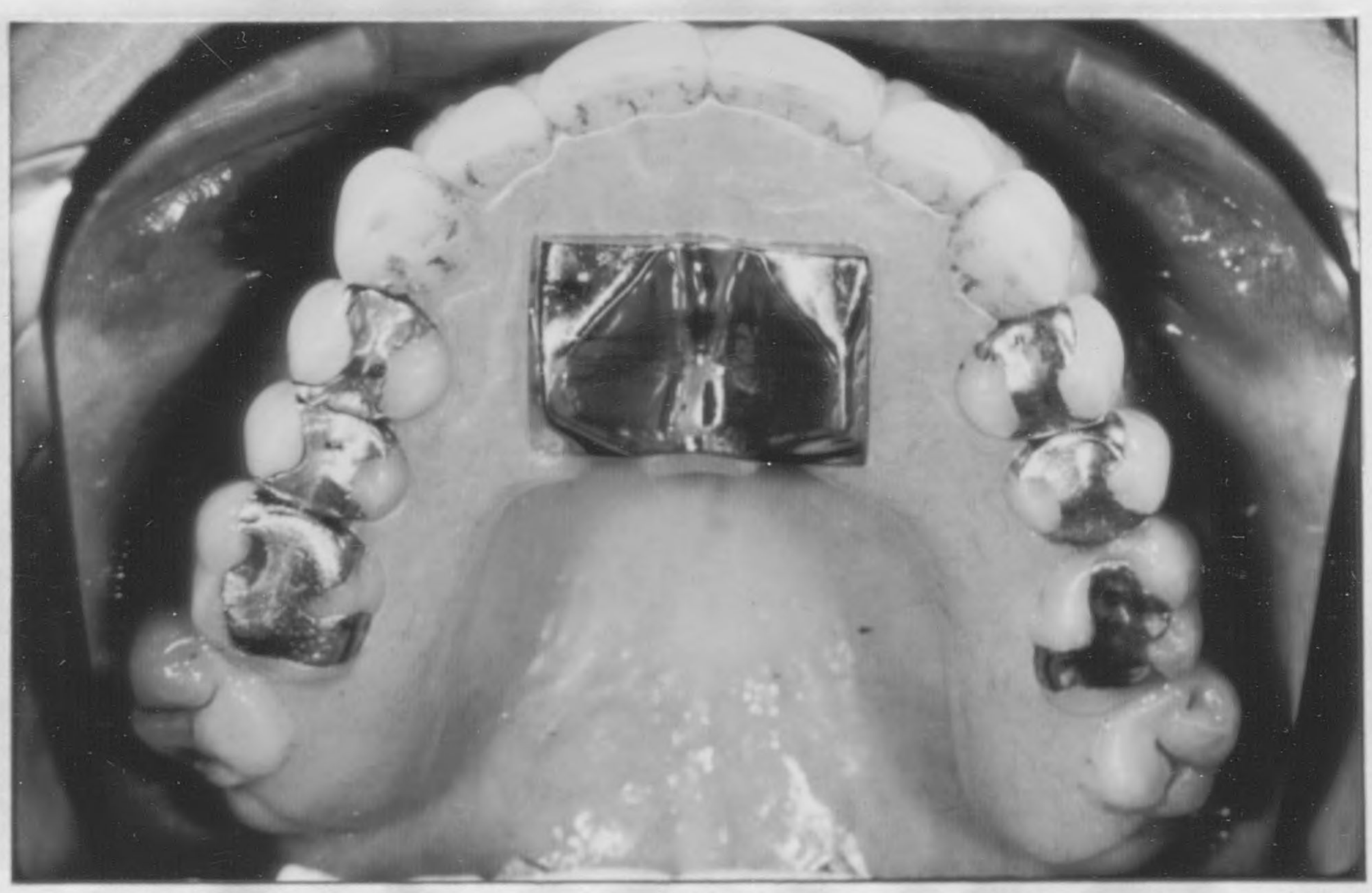

Figure 11. Maxillary bearing plate with bearing surface insert.

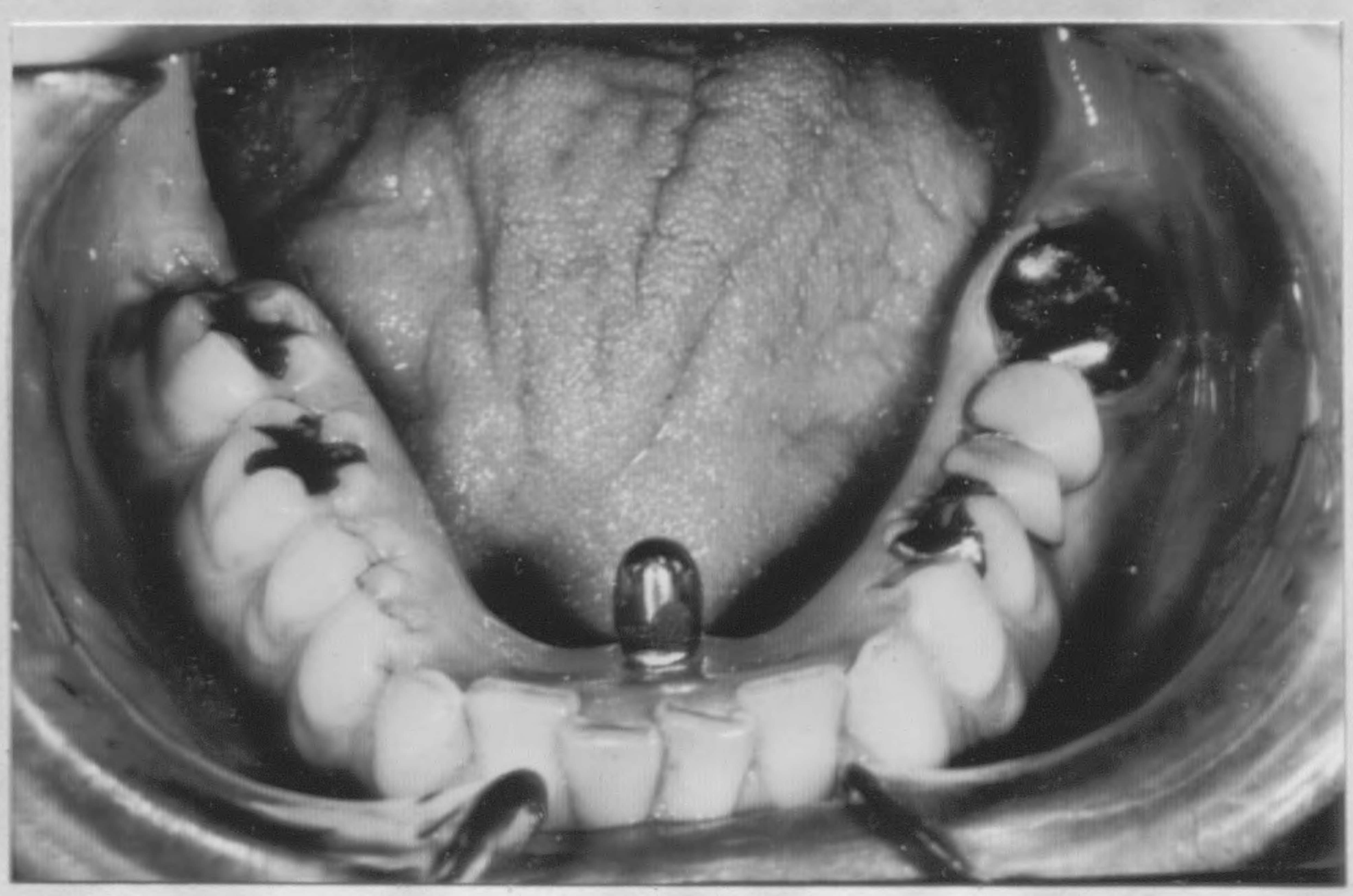

Figure 12. Mandibular bearing pin unit.

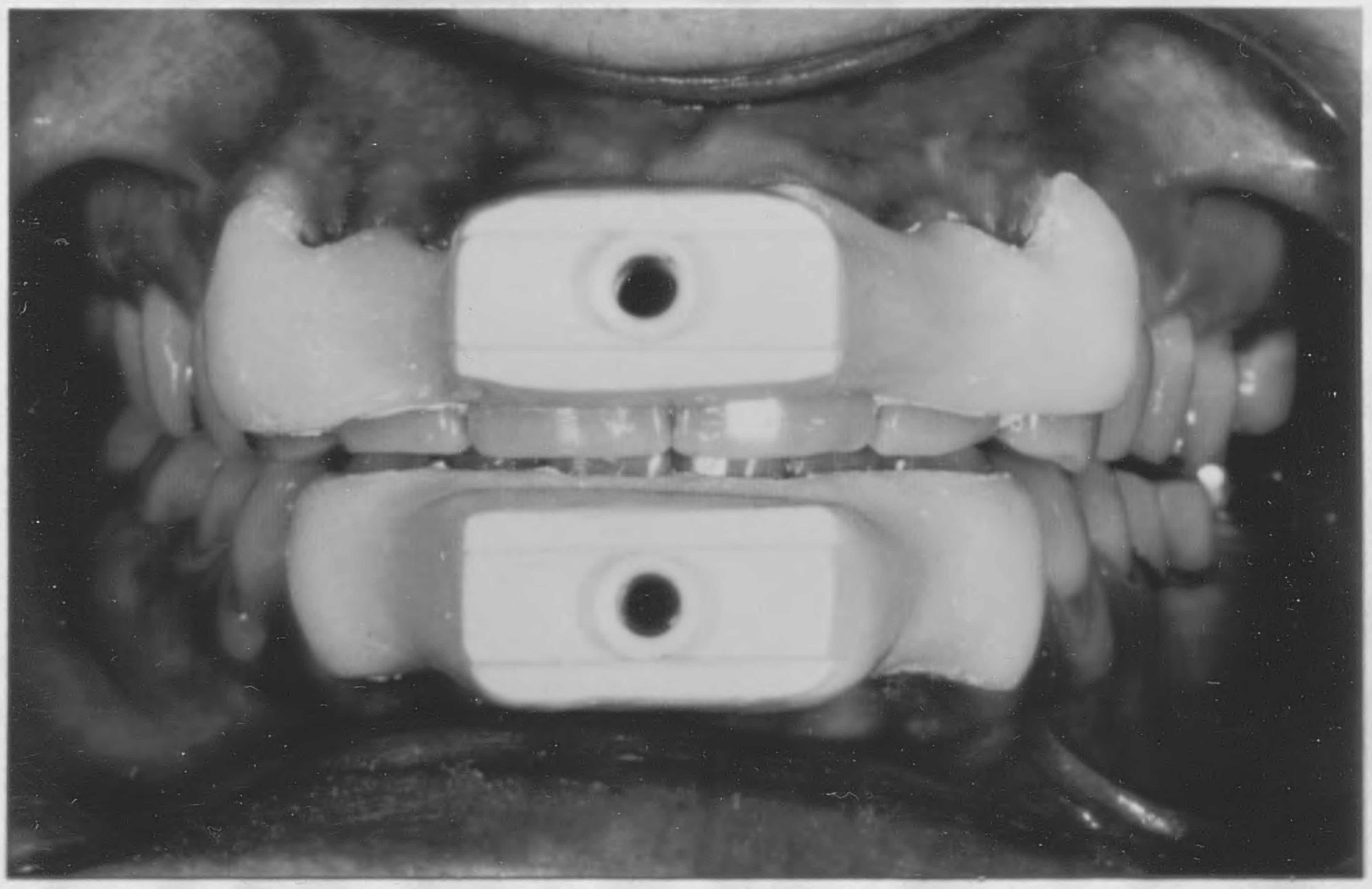

Figure 13. Cemented labial clutches.

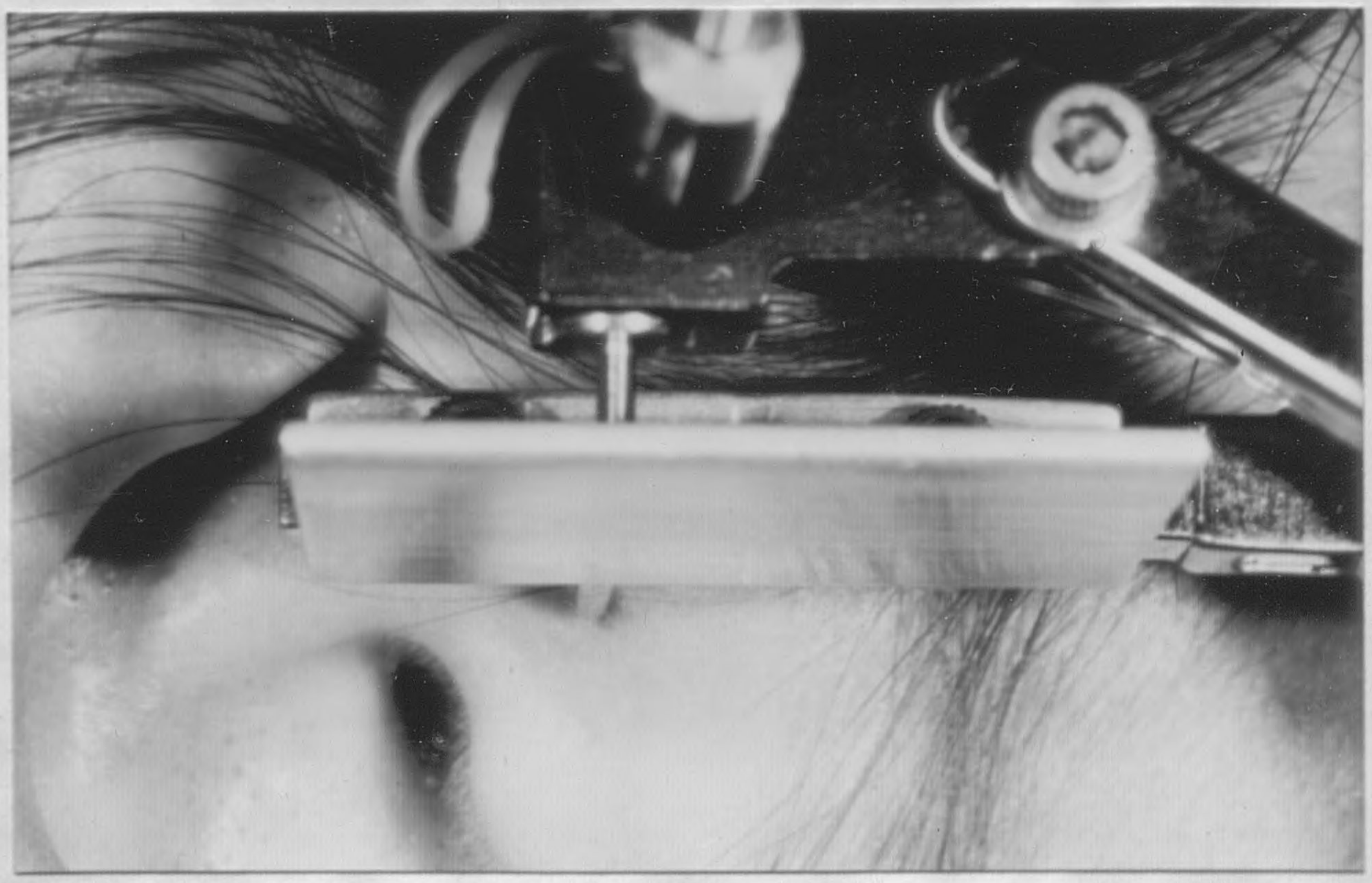

Figure 14. Zeroed posterior table-stylus unit.

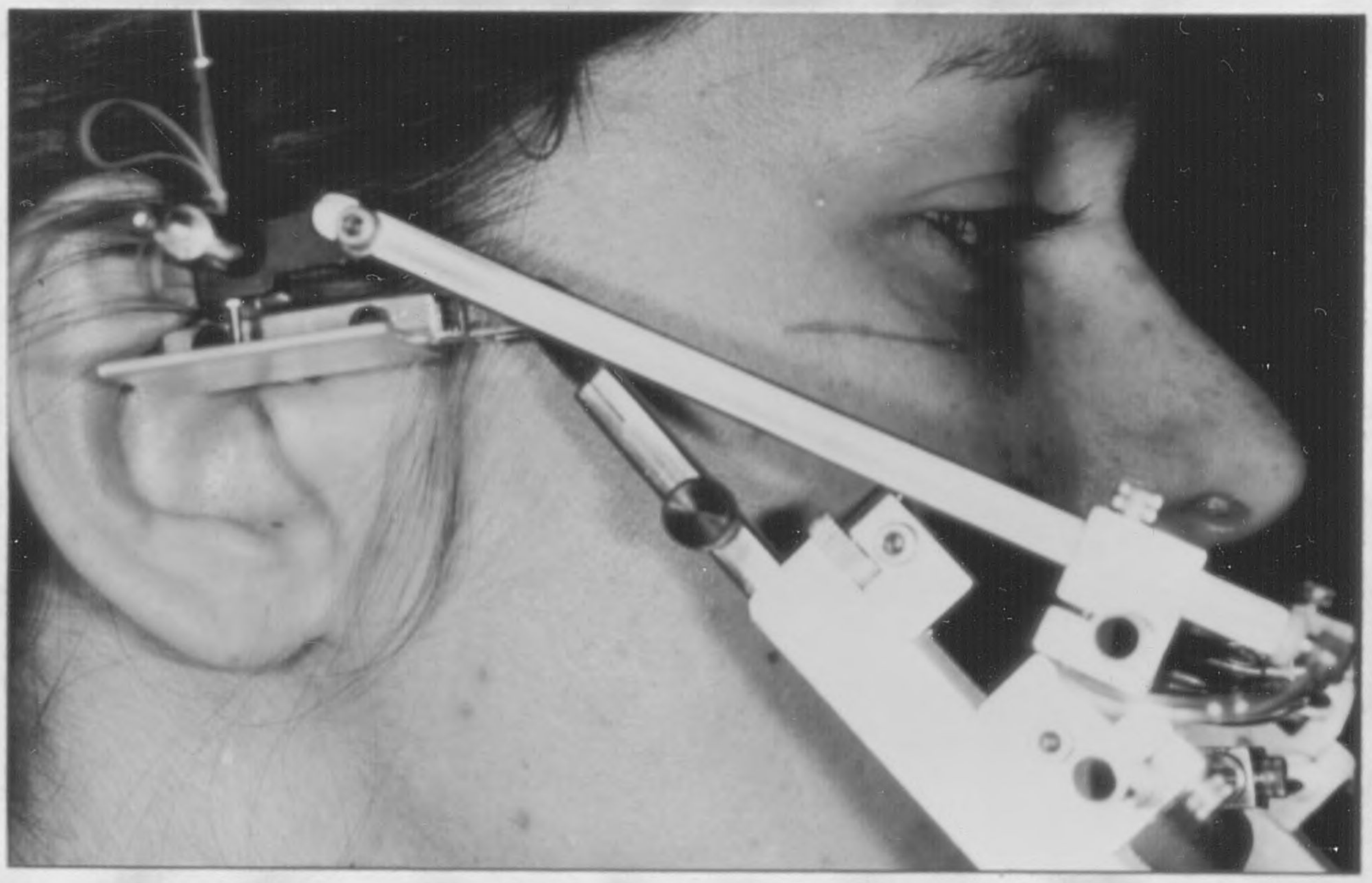

Figure 15. Modified Denar pantograph connected to the labial clutches.

five times with tooth guidance or with the bearing screw contacting insert # 1 on the same recording paper to provide control sets for later comparisons. A third set of tracings was then recorded comparing the tooth-guided lateral excursion with the lateral mandibular movements on inclines of increasing angulation (inserts # 1 to # 4). A fourth set compared the tracings recorded at different levels of mouth opening, provided by the extension of the bearing screw contacting the bearing surface insert # 1. The approximate clearance at the cuspid edge-to-edge position was determined at 0.5, 2.0, 3.0, and 5.0 mm. Each tooth-guided lateral excursion stopped at the cuspid edge-to-edge position, while the bearing surface-bearing screw excursions were limited by the extension of the inclined bearing surface.

In the case that the experimental tracings revealed different condylar pathways for the different conditions, a one-to-one check, using one insert against the next one, or checking one level of vertical dimension against the following, was secured, the patient's cooperation provided.

The tracings were measured and evaluated following the same guide-lines as described for the articulator study.

RESULTS

A. Articulator Study

The articulator study was designed as a pilot project to provide the basis for a better evaluation of the patient study.

A set of pantographic tracings under controlled conditions secured from the movements of the articulator--pantograph unit, without changing any modalities of the system, served as the guide line for later comparisons with the experimental tracings. A differentiation was made between the number of tracings superimposed versus the single tracing. Control sets were recorded for the movements following the original (BA) and customized (BG) side shift guide wings. The tracings were classified with regard to the width, and, if present, the number of lines.

No appreciable difference could be found for the use of the different side shift guide wings under controlled conditions. While the width of the single tracing generally centered around 0.10 mm, there seemed to be a tendency for the superimposed tracings to enlarge in width (Table 1), with the highest numerical value at 0.25 mm, allowing even a discrimination of seperate lines approaching the final phase of the lateral movement*. The width of the superimposed

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* for actual values see Appendices

experimental tracings averaged between 0.10 and 0.25 mm (Table II), irrespective of the changes introduced into the system. Rarely, a discrimination could be made between single lines, if present, however, near the end of the recorded balancing tail. The results did not provide any information about the increased or decreased degree of reproducibility with regard to the experimental pantographic set-up.

While the accidental error introduced into the experiment under controlled conditions totaled 0.15 mm, the values for the experimental conditions were distributed over a range of 0.20 mm.

Table I

Average line-width (mm) - Controlled conditions

	BA (Bennett Angle)	BG (Bennett Guide)
Single tracing	0.100	0.100
Triple tracing	0.125	
Quadruple tracing		0.135

Table II

Average line-width (mm) - Experimental conditions

a) Change of vertical dimension (insert # 1)

	BA	distr. BG	early
horiz. table - axis-orbital plane	0.175	0.200	0.175
horiz. table - 15^{o} degrees backward	0.250	0.200	
vertical stylus - 15^{o} degrees forward	0.200		0.100
table-stylus units non-zeroed	0.163	0.150	0.150

b) Change of lateral guidance (inserts # 1,2,3,4)

	BA	distr. BG	early
horiz. table - axis-orbital plane	o,138	0.125	0.100
horiz. table - 15^{o} degrees backward	0.150	0.150	
vertical stylus - 15^{o} degrees forward	0.100		0.200
table stylus units non-zeroed	0.188	0.250	0.200

B. Patient Study

1. Comparison of pre- and post treatment PRI-Scores (Table III)

Subject # 1 revealed a slight improvement in Index-Scores from 14 to 5 points, while for subject # 2 similar values could be recorded for the pre- and post-treatment phases. All scores, however, were considered reproducible. For subject # 3 the pre-treatment PRI-Scores of 36 respectively 32 points, categorized as moderate non-reproducible, could be improved by bite splint therapy and occlusal adjustment to a PRI-Score of 9. Subject # 3 could thus be considered as fully reproducible after completion of the treatment period. Subject # 4 underwent no special treatment of temporomandibular joint dysfunction. The PRI-Scores of 26 and 18 points classified subject # 4, however, under the category of slight temporomandibular dysfunction.

Table III

Pre- and post-treatment PRI-Scores (points on a scale of 144)

	Pre	Post
Subject # 1	14	9;5
Subject # 2	6	8;7
Subject # 3	36;32	9;9
Subject # 4	no treatment	26;18

2. Experimental phase

Similar to the design of the articulator study two sets of pantographic tracings under controlled conditions were first secured from each subject to assess the state of reproducibility during lateral mandibular movements and to receive a pattern of base-values for later comparisons.

In the average slightly higher values for the control as well as for the experimental tracings were obtained during the patient study when compared to the articulator study. While for the control tracings of the articulator study the line-width for the superimposed tracings averaged 0.15 mm, this value was increased to 0.20 mm for the first three subjects of the patient study, who showed to be reproducible with regard to their PRJ-Scores. No appreciable difference was found between the tooth-guided and bearing--surface guided control tracings, nor between the start and termination of the lateral movement. For subject # 4 the average line-width of the control tracings measured 0.30 mm (Table IV).

Table IV

Average line-width (mm) - Controlled conditions

subjects	#1,2,3	#1	#2	#3	#4
tooth-guided (5x)	0.192	0.175	0.175	0.225	0.313
insert # 1 (5x)	0.200	0.225	0.213	0.163	0.288

During the experimental phase, changing the level of vertical dimension, subject # 1 showed comparable reproducibility with regard to the tracings under controlled conditions, while the change of lateral guidance increased the line-width by up to 100 % to 0,40 mm for the right lateral movement.

Subject # 2 averaged less reproducibility for both experimental settings, when compared to the control tracings, with slightly higher values for the change of lateral guidance.

Subject # 3 revealed only a minimal decrease of reproducibility for the experimental changes of the level of vertical dimension, while the different angulations of the bearing surfaces introduced a more significant change in the recorded tracings. For both experiments the highest values were obtained during the final phase of the lateral movements. Although a one-to-one check, using tooth-guidance versus insert # 1, followed by checking one insert against the next one, was secured for subject # 3, the inconsistency of the results did not provide a more detailed information about the "timing" of the irreproducibility.

Subject # 4, despite of classifying slightly non-reproducible with regard to the PRI-scores, presented fairly reproducible for the two control settings. During the experimental phase only the recorded movements with changing levels of vertical dimension did reveal a satisfactory degree of consistency, as far as a common centric relation position was concerned. Here only the initial phase of the right lateral movement showed a higher amount of irreproducibility when compared to the control tracings, No regular tracings could be obtained for the experimental change of lateral guidance, nor could a one-to-one check be performed (Table V).

Table V

Average line-width (mm) - Experimental conditions

a) Change of vertical dimension (insert #1)

	Right side	Left side
Subject # 1	0,200	0.175
Subject # 2	0.266	0.310
Subject # 3	0.250	0.200
Subject # 4	0.250	0.500

b) Change of lateral guidance (tooth-guidance, inserts #1,2,3,4)

	Right side	Left side
Subject # 1	0,275	0.400
Subject # 2	0.300	0.317
Subject # 3	0,450	0.475
Subject # 4	-	-

A comparison between the values obtained during the articulator study and the patient study revealed only a slight increase of the controlled values for the patient study (subject # 1,2,3), while a more significant change could be observed for the experimental values. The change of lateral guidance introduced a higher amount of irreproducibility than the changes of the level of vertical dimension for the first three subjects (Table VI). Their accidental error under controlled conditions totaled o.2 mm.

Table VI

Average line-width (mm)

Comparison between articulator and patient movements

	Articulator	Patient (Subj.#1,2,3)
Controlled condition	0.150	0.196
Experimental condition		
a) change of vertical dimension	0.180	0.233
b) change of lateral guidance	0.158	0.370

DISCUSSION

Multiple explanations for the occurrence of the Bennett movement were given by various researchers. No definite statement, however, could yet be presented. The etiologic "proof", as theorized by De Pietro[32], Steinhilber[33] and Mahan[34], appears to be one of the more valid explanations. It just makes sense to think of the joints' asymmetrical osseous formations - among other anatomical influences - as one of the main causes responsible for the occurrence of the Bennett movement. Assuming the validity of this conception it further appears logical to say that any rotaional movement of the condyles, depending on the level of vertical dimension during lateral mandibular movements, could affect to some degree the amount and direction of the translatory movement. The approximating surfaces of the condyle and the glenoid fossa are constantly changing their relation to each other, thus introducing by their asymmetrical contact pattern a constant change of laterotrusion. Based on these considerations different tracings on the pantograph's "zeroed" posterior table-stylus units could be expected for the recording of the lateral jaw movement at changing levels of vertical dimension. Furthermore, refering to Preiskel's[61] clinical investigation of the Bennett movement, an increased amount of translations and a different pattern of lateral mandibular movement could be anticipated introducing a change in lateral cuspal guidance.

As it was possible to zeroe the posterior table-stylus units only for the rotational opening and closing movement and the straight outward lateral movement on the extension of the terminal hinge axis, an articulator project was designed to determine the mechanical error introduced by the stylus-table position during the recording of lateral movements. Later comparison with the recordings of the clinical subjects should then facilitate the differentiation between changes in condylar movement and the pure mechanical error. Although a mechanical error had to be expected for the unzeroed condition during the experimental lateral movements, the accidental error introduced under controlled conditions was almost identical compared to the variations observed under experimental conditions. The pantographic system - as used for this study - did thus not allow for a valid discrimination of the differences. Neither a change of the table or stylus position, nor the shifting of the table--stylus units to an off-zero position did affect the reproducibility of the recordings. The alignment of the table--stylus unit to the extension of the terminal hinge axis did therefore seem to be of minor importance. It may, however, be interesting to find out, how far the articulator--pantograph system can be unzeroed to pantographically demonstrate a significant difference in the recorded tracings.

Based on the results of the articulator study the attempt was made to copy the procedural pattern as closely as possible during the patient study. It was decided to align the posterior horizontal table with the axis-orbital plane to provide a definite reproducible reference position, and the subject's terminal hinge axis was recorded for the same reasons. The level of tooth contact/guidance was included as the starting level for the experimental recordings to evaluate the influence of tooth-guidance with regard to the timing of the Bennett movement. The inclusion of the occlusal level implied a stable relation in the retruded contact position to assure valid comparisons with the subsequently recorded tracings at an increased level of vertical dimension, starting from centric relation. As a stable retruded contact position without any slide in centric and without lateral interferences is rarely found in natural dentitions, an occlusal adjustment procedure was likely to be performed on the chosen subjects. As the occlusal adjustment, however, will not be performed for prophylactic reasons, all subjects (exept # 4) had to reveal some symptoms of temporomandibular joint dysfunction to justify the equilibration procedures, which would then hopefully lead to their alleviation. It is assumed by the author, that the fact of having some degree of anamnestic and clinical signs of temporomandibular joint dysfunction has influenced the outcome of the experimental recordings as this group of patients appears to be more susceptive to any change introduced into the oral environment. This assumption is made despite of the fact that all subjects, undergoing bite-plane and occlusal adjustment therapy prior to the experimental section of the investigation, presented reproducible according to the Pantographic Reproducibility Index. Furthermore anamnestic and clinical symptoms at the end of the treatment period were either totally alleviated or largely reduced for all subjects. Although no conclusive evidence is gained from these observations, the results seem to strengthen the validity of the bite-plane and occlusal adjustment therapy for the treatment of temporo-mandibular joint dysfunction.

The results obtained from the experimental phase should be interpreted and evaluated in the light of the potential errors inherent in an investigation involving human subjects. Not only the accidental error introduced by the operator and the instrumentation but also the variability within the human subject itself should be taken into consideration. Surprisingly, however, the accidental error for the experiments under controlled conditions remained for the first three subjects in the same range as for the articulator study, while subject # 4 presented a slightly increased variability, somewhat expected with regard to the PRI-Scores. Subject # 4 was yet included into the clinical part of the investigation, because of the unusual pattern of "exaggerated" early timing presented during laterotrusion. Despite of the slightly increased accidental error under controlled conditions, the numerical values could be used as a base-value for the comparison with the results obtained under experimental conditions.

Considering the graphically interpreted timing of the Bennett movement for the subjects # 1, 2, and 3 only insignificant variations seemed to be evident within the subject (right - left) or between the subjects, all presenting a timing between straight progressive and slightly distributed. The different values for the left and right sides under experimental conditions did thus not correlate to any special pattern in the timing of the Bennett movement.

The evaluation of the pantographic tracings, introducing a change of vertical dimension under constant lateral guidance, did indicate almost no change in the amount and direction of the Bennett movement for the subjects # 1, 2, and 3, while for subject # 4 the movement pattern changed slightly during the initial phase of the right lateral movement. The latter result should, however, be interpreted with regard to the accidental error presented under controlled conditions.

Modifying the experimental conditions by changing the angle of lateral guidance, all subjects showed a rather significant change of the recorded lateral movements. For the subjects # 1 and 2 the change of laterotrusion was equally distributed through all phases while subject # 3 presented the greatest changes towards the final phase of the lateral movement. Subject # 4 revealed to be nonreproducible in the centric relation position, which did not allow for a valid interpretation of the tracings. This condition seemed to be strongly influenced by the increased tension and fatigue near the end of the experimental session. All subjects demonstrated increased difficulty to execute smooth lateral movements with increasing angulation of the bearing surfaces, which may have especially contributed to the rather large variation within the repeated experimental recordings for subject # 2. Although no correlation could be established between the timing pattern of the Bennett movement and the amount of change introduced by the different experimental conditions, definite differences could be observed between the right and left lateral movements for certain subjects under certain conditions[13,34].

The comparison between tooth-guided and bearing-surface guided recordings did not provide enough information about the proprioceptive influence of the teeth with regard to the pattern of laterotrusion. The increased numerical values related to the change of lateral guidance, may, however, be refered to this modality of the experimental setting, which could be somewhat confirmed - using the one-to-one check - for the initial phase of the right lateral movement of subject # 3.

Comparing both experimental conditions the change of lateral guidance affected the condylar movement pattern to a higher degree than the pure increase of vertical dimension. The change, however, averaged 0.174 mm when compared to the values under controlled conditions and 0.221 mm when compared to the values obtained from the articulator study under similar experimental conditions.

Despite the fact that no infering statement can be based on the results of only four experimental subjects, the observations seem to indicate that the immutability of the Bennett movement has at least to be questioned. In a comparison to studies with similar scientific objectives[10,58], in particular to Preiskel's[61] clinical investigation, the documented increase of the lateral shift of the working condyle due to the change of lateral guidance, could not be confirmed to the same extent by this investigation. While Preiskel reported on a mean increase of the Bennett movement of 1.00 mm using cuspid overlays to open the vertical dimension approximately 2.00 mm at the cuspid edge-to-edge position, the change in laterotrusion remained within

0.20 mm for the subjects investigated in this study. Here again it is unknown in how far the experimental design did affect the outcome of the recorded differences. Preiskel's work, however, is open to criticism because of the mechanical design of his project, as the ultrasonic device was graduated using a flat surface, but finally used for the parabolic condylar surface during rotation. For further research its basic conception may yet promise increased scientific significance once the graduation for a parabolic surface can be accomplished.

The results of the present investigation seem to accord better with the accidental findings of Clayton, Kotowicz, and Myers'[62] study demonstrating good reproducibility of posterior pantographic tracings for up to 3.00 mm of mouth opening.

Finally it has to be questioned if the pantographic system represents the adequate instrumentation for an investigation with this scientific objective. Another question-mark has to be set behind the clinical significance of the changes reported in this investigation.Further research is needed to cover this aspect of the "immutability" of the Bennett movement.

A noteworthy observation, somewhat outside the scope of this investigation should not be omitted. By graphical interpretation of the recorded tracing under tooth-guidance no significant difference in the movement pattern could be detected for subject # 4 when compared to the bearing--surface guided recordings. The restorative treatment, including the restoration of the left maxillary cuspid, was performed on a fully adjustable Denar D 5 A Articulator programmed to the recorded pantographic tracings. The lingual contour, however, did not provide the often emphasized freedom for an "interference-free" execution of the left lateral movement. This condition did not seem to affect the amount and direction of the Bennett movement, nor did it seem to create any pathological changes in the patient's masticatory system. This observation disaccords with the statements made by Lucia[21], Kahn[22], and other gnathologists, favors, however, Preiskel's[23] findings studying the relation between the shape of the canine teeth and lateral condylar tranlation. At the same time it may raise the question about the significance of the Bennett movement in restorative dentistry as already pointed out by Koeck[31].

SUMMARY

The Bennett movement, introduced into the discussion of mandibular movements by Bennett in 1908, has created more confusion than beneficence to the understanding of the condylar movement pattern. Conflicting opinions concerning the immutability of the Bennett movement are stated in today's literature.

This investigation tried to evaluate by pantographic means the concept of immutability of the Bennett movement under experimental conditions. By modifying the guidance pattern of a customized bearing pin and plate assembly different levels of vertical dimension and changing degrees of lateral guidance were analyzed with regard to their affect on pantographic reproducibility.

A study utilizing an articulator was performed to determine the reproducibility of pantographic tracings, which represented different timings of the Bennett movement as recorded on "zeroed" horizontal condylar tracing tables. It demonstrated the limitations of the discriminative capabilities of the pantographic system.

As the outcome of the articulator study revealed almost total reproducibility of the pantographic tracings under experimental conditions, an attempt was made to copy the procedural pattern as closely as possible during the clini-

nical investigation. The pantographic reproducibility of the lateral condylar border movements under controlled and experimental conditions were recorded and evaluated. In four subjects a bite-plane was made and an occlusal adjustment therapy was performed prior to the experimental phase of the investigation. The success of treatment was graded by means of the Pantographic Reproducibility Index.

The results of the pre-experimental treatment affirmed the validity of bite-plane and occlusal adjustment therapy for the treatment of temporomandibular joint dysfunction. The results seem to indicate that the absolute immutability of the Bennett movement does not exist.

Data obtained indicated that the change of lateral guidance affected the condylar movement pattern to a higher degree than the pure increase of vertical dimension. The average change in laterotrusion remained within 0.20 mm for the subjects investigated in this study.

Further research is needed to determine the clinical significance of these findings and to analyze the nature of the Bennett movement.

CONCLUSIONS

Allowing for the limited number of clinical subjects under investigation the following conclusions can be drawn:

1. Satisfactory reproducibility of pantographic tracings at different levels of vertical dimension is obtained utilizing the concept of "zeroing" the pantograph's posterior horizontal table and stylus units during lateral border movements. The articulator study revealed the limited discriminative capabilities of the pantographic system, as used in this study.

2. The concept of absolute immutability of the Bennett movement as recorded by pantographic tracings is not valid.

3. An increase of lateral guidance affects the condylar movement pattern to a higher degree than does an opening of the vertical dimension.

4. The clinical significance of the observed changes in laterotrusion under experimental conditions needs further investigation.

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APPENDICES

APPENDIX I (i)

LIST OF MATERIALS AND MANUFACTURERS

1. Stuart Gnathological Computer.
   C.E. Stuart, Gnathological Instruments, Ventura, Ca.

2. P.K. Thomas casts.
   Columbia Dentoform Corp., New York, N.Y.

3. Denar Pantograph System.
   Denar Corp., Anaheim, Ca.

4. Ticonium.
   Ticonium Company, Albany, N.Y.

5. Space Age Glue.
   Weldbond, Newark, N.J.

6. Duralay.
   Reliance Dental Mfg., Chicago, Ill.

7. Denar D 5 A Articulator.
   Denar Corp., Anaheim, Ca.

8. Temp-bond.
   Kerr Manufacturing Co., Romulus, Mi.

9. Sanborn Perma EKG recording paper.
   Graphic controls, Inc., Farmington, Mi.

10. Bausch and Lomb, 7 x reticle magnifier.
    National Camera, Inc., Anglewood, Col.

11. Jeltrate.
    The L.D. Caulk Company, Milford, Del.

12. Velmix-Stone.
    Kerr Manufacturing Co., Romulus, Mi.

13. Quick-Mount face bow.
    Whip-Mix Corp., Louisville, Ky.

14. Whip-Mix Articulator
    Whip-Mix Corp., Louisville, Ky.

APPENDIX I (i)

15. Swiss denture wax.
    Swissdent. Corp., Los Angeles, Ca.

16. Formatray.
    Kerr Manufacturing Co., Romulus, Mi.

17. Lucitone.
    The L.D. Caulk Company, Milford, Del.

18. CPC.
    Lorvic Corp., St. Louis, Ma.

19. Durelon.
    ESPE, Seefeld/Oberbayern, W. Germany.

APPENDIX II

Articulator Study

BA = Bennett Angle (original side shift guide wing)

BG = Bennett Guide (customized side shift guide wing)

s = start of lateral movement

t = termination of lateral movement

(i) Table VII

AVERAGE LINE-WIDTH (mm) - CONTROLLED CONDITIONS

BA (insert #1)	Right side		Left side		
1x	(s) 0.10	(t) 0.10	0.15	(t) 0.10	3x
3x	0.15	0.10	0.10	0.10	1x

BG (insert #1)	Right side (distributed)		Left side (early)		
1x	0.10	0.10	0.10	0.10	1x
4x	0.15	0.10	0.20	0.25(3)*	4x

* number of lines ( ).

APPENDIX II

(ii) Table VIII

(mm) AVERAGE LINE-WIDTH - EXPERIMENTAL CONDITIONS

a) Change of vertical dimension (insert #1); 0.5, 2.0, 4.0 mm clearance at cuspid edge-to-edge position.

BA	Right side		Left side		
(1) horiz. table - axis-orbital plane	0.20	0.15			
(2) horiz. table - 15° degrees backward	0.25	0.25			
(3) vert. stylus - 15° degrees forward			0.20	0.20	(2)
(4) table-stylus units non zeroed	0.15	0.15	0.15	0.20	

BG	Right side (distr.)		Left side (early)		
(1) horiz. table - axis-orbital plane	0.20	0.20	0.20	0.15	
(2) horiz. table - 15° degrees backward	0.20	0.20			
(3) vert. stylus - 15° degrees forward			0.10	0.10	
(4) table-stylus units non zeroed	0.20	0.10	0.20	0.10	

b) Change of lateral guidance (inserts #1,2,3,4).

BA	Right side		Left side		
(1) horiz. table - axis-orbital plane	0.20	0.15	0.10	0.10	
(2) horiz. table - 15° degrees backward	0.15	0.15			
(3) vert. stylus - 15° degrees forward			0.10	0.10	
(4) table-stylus units non zeroed	0.20	0.10	0.25	0.20	

BG	Right side (distr.)		Left side (early)		
(1) horiz. table - axis-orbital plane	0.15	0.10	0.10	0.10	
(2) horiz. table - 15° degrees backward	0.15	0.15			
(3) vert. stylus - 15° degrees fprward			0.15	0.25	(2)
(4) table-stylus units non zeroed	0.30	0.20	0.20	0.20	

APPENDIX II

Patient Study

Subject #1

(iii) Table IX

(mm) AVERAGE LINE-WIDTH - CONTROLLED CONDITIONS

	Right side		Left side		
a) tooth-guided (5x)	0.20	0.15	0.15	0.20	(2)
b) insert #1 (5x)	0.20	0.20	0.20	0.30	(2)

(0.5 mm clearance at cuspid edge-to-edge position)

(iv) Table X

(mm) AVERAGE LINE-WIDTH - EXPERIMENTAL CONDITIONS

a) Change of vertical dimension: insert #1, 0.5, 2.0, 3.0, 5.0 mm clearance at cuspid edge-to-edge position.

Right side		Left side	
0.20	0.20	0.20	0.15

b) Change of lateral guidance: tooth-guidance, inserts #1,2, 3,4.

Right side		Left side	
0.25	0.30	0.40	0.40

Subject #2

(v) Table XI

(mm). AVERAGE LINE-WIDTH - CONTROLLED CONDITIONS

	Right side		Left side	
a) tooth-guided (5x)	0.20	0.15	0.20	0.15
b) insert #1 (5x)	0.20	0.20	0.25	0.20

APPENDIX II

(vi) Table XII

AVERAGE LINE-WIDTH (mm) - EXPERIMENTAL CONDITIONS

a) Change of vertical dimension

Right side		Left side	
0.35(2)	0.35(2)	0.40(2)	0.40(2)
0.20(2)	0.20(2)	0.40	0.40(2)
0.30(2)	0.20	0.15	0.10

b) Change of lateral guidance

Right side		Left side	
0.40	0.30	0.35	0.30
0.35(2)	0.30(2)	0.45(2)	0.40(3)
0.30	0.15	0.20(2)	0.20(2)

Subject #3

(vii) Table XIII

AVERAGE LINE-WIDTH (mm) - CONTROLLED CONDITIONS

	Right side		Left side	
a) tooth-guided (5x)	0.20	0.25	0.20	0.25(2)
b) insert #1 (5x)	0.20	0.20	0.15	0.10*

*flaring 6 mm from C.R.

APPENDIX II

(viii) Table XIV

AVERAGE LINE-WIDTH (mm) - EXPERIMENTAL CONDITIONS

a) Change of vertical dimension

	Right side		Left side	
	0.25	0.25	0.15	0.25*(2)

*flaring 4 mm from C.R.

b) Change of lateral guidance

	Right side		Left side	
	0.30	0.50(3)	0.50(3)	0.50(3)
	0.40	0.60(3)	0.30	0.60(4)
tooth-guidance vs. insert #1	0.20	0.30(2)	0.40(2)	0.10
insert #1 vs. #2	0.20	0.30(2)	0.10	0.20(2)
insert #2 vs. #3	0.25	0.20	0.20	0.35(2)
insert #3 vs. #4	o.25	0.15	0.20	0.10

Subject #4

(ix) Table XV

AVERAGE LINE-WIDTH (mm) - CONTROLLED CONDITIONS

	Right side		Left side	
a) tooth-guided (5x)	0.40	0.25	0.30	0.30
b) insert #1 (5x)	0.30	0.20	0.50(2)	0.15

APPENDIX II

(x) Table XVI

AVERAGE LINE-WIDTH (mm) - EXPERIMENTAL CONDITIONS

a) Change of vertical dimension

Right side		Left side	
0.20(2)	0.30(2)	0.70(2)	0.30(2)

b) Change of lateral guidance

multiple centric relation positions

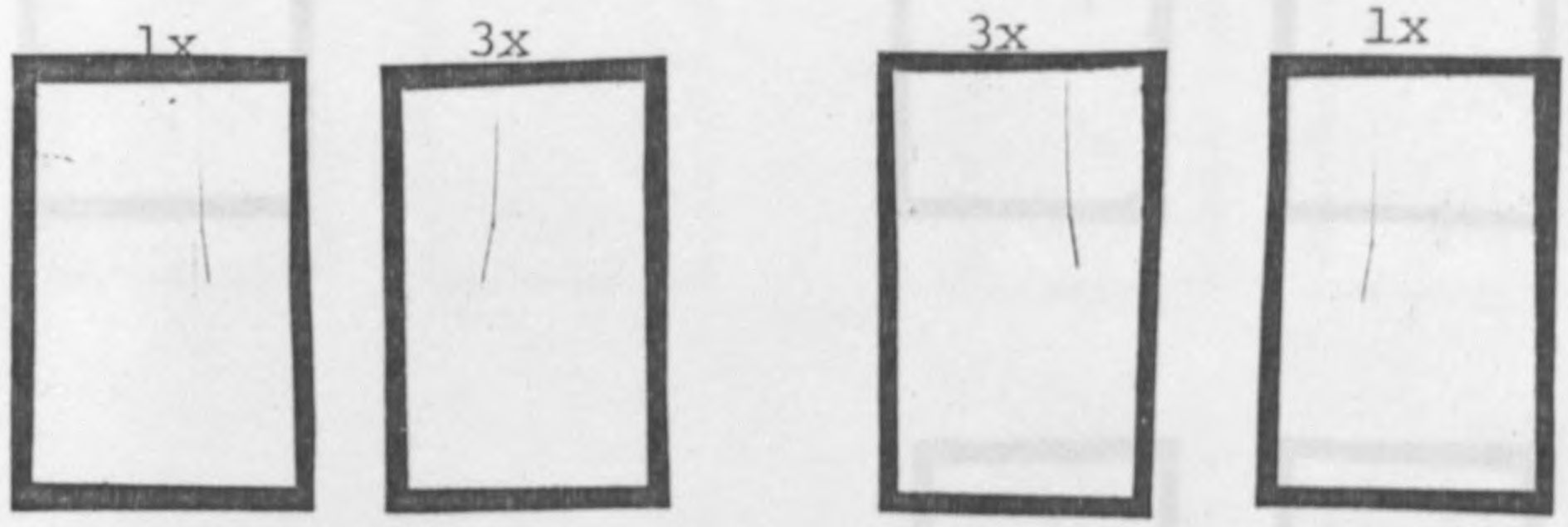
Appendix III

(i)

Articulator Study Controlled Conditions

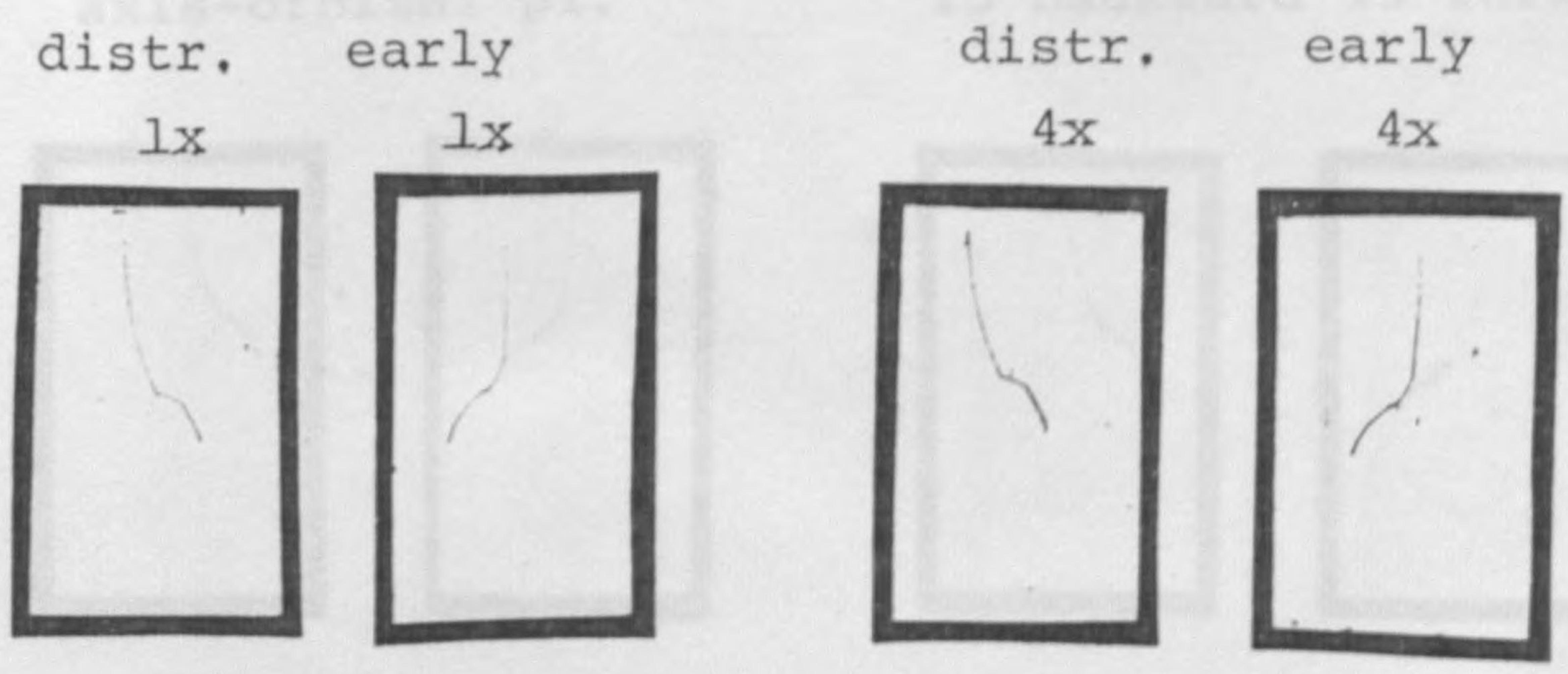
BA = Bennett Angle

a horiz. table - axis-orbit. plane



BG = Bennett Guide

a horiz. table - axis-orbit. plane



Appendix III (i)

Experimental Conditions - Increase of vert. dimension

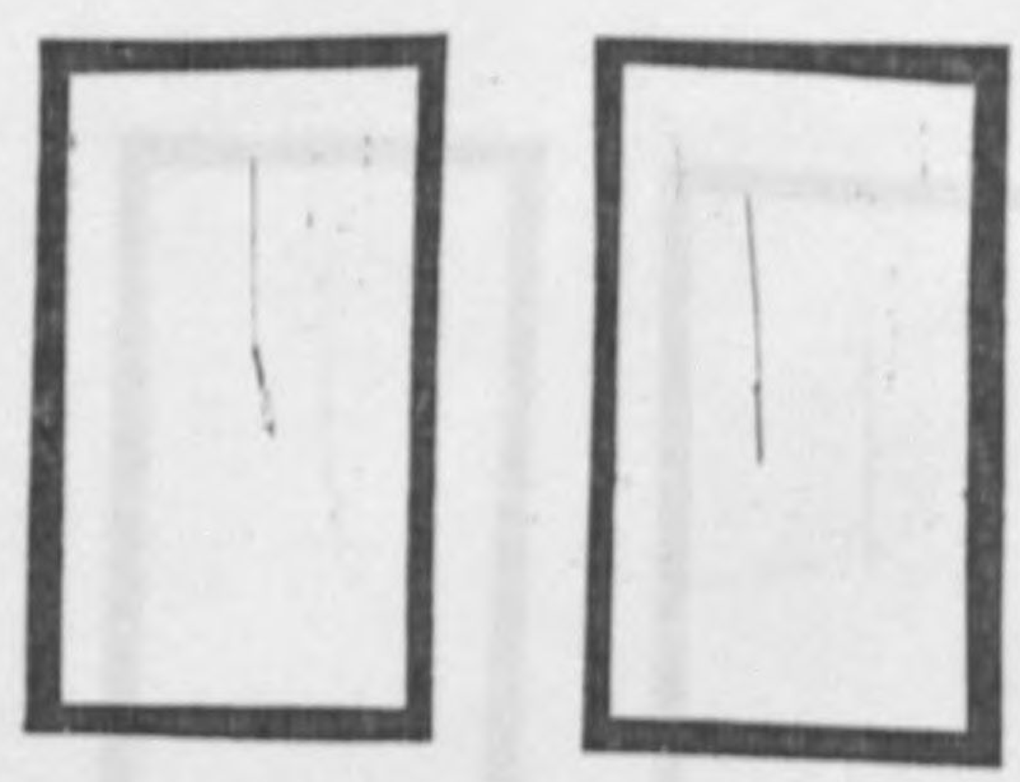
BA

a horiz. table - axis-orbital pl.

b table 15° backward

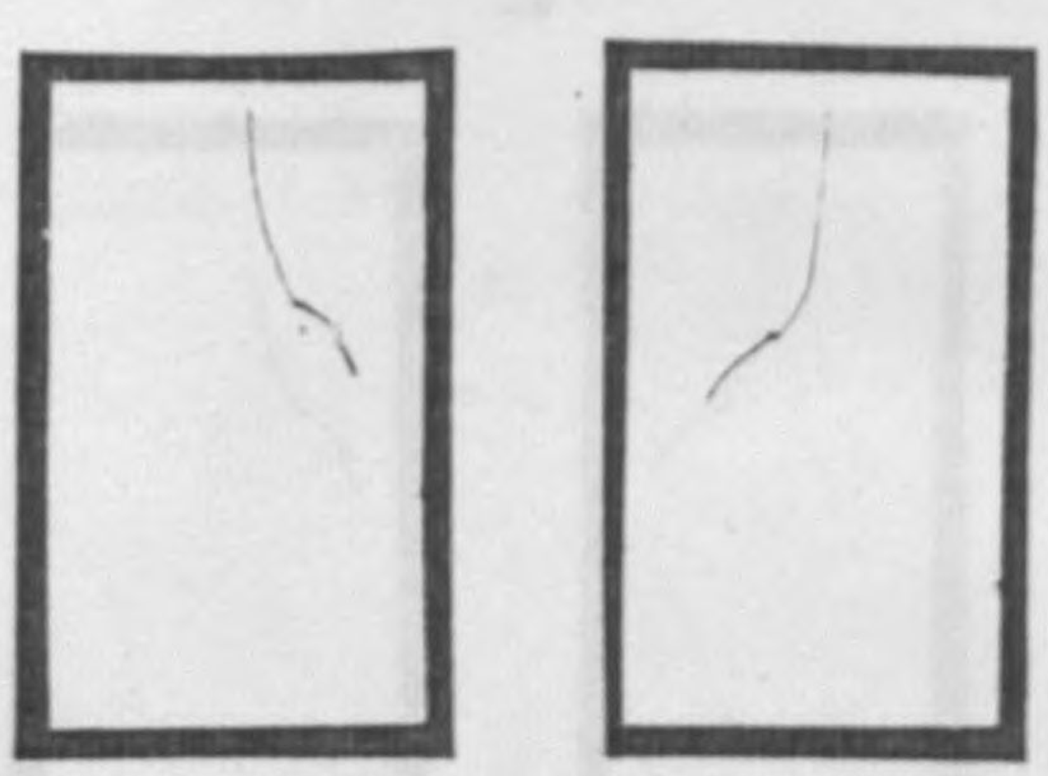
c stylus 15° forward

d non-zeroed



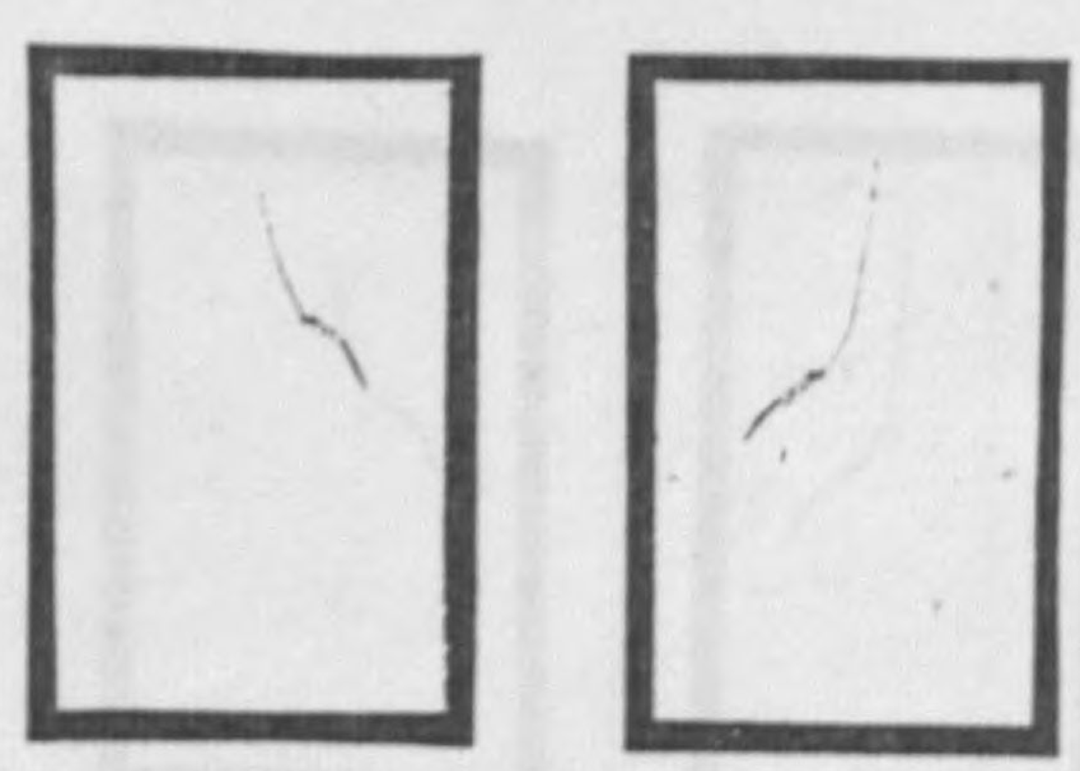
BG

a horiz. table - axis-orbital pl.

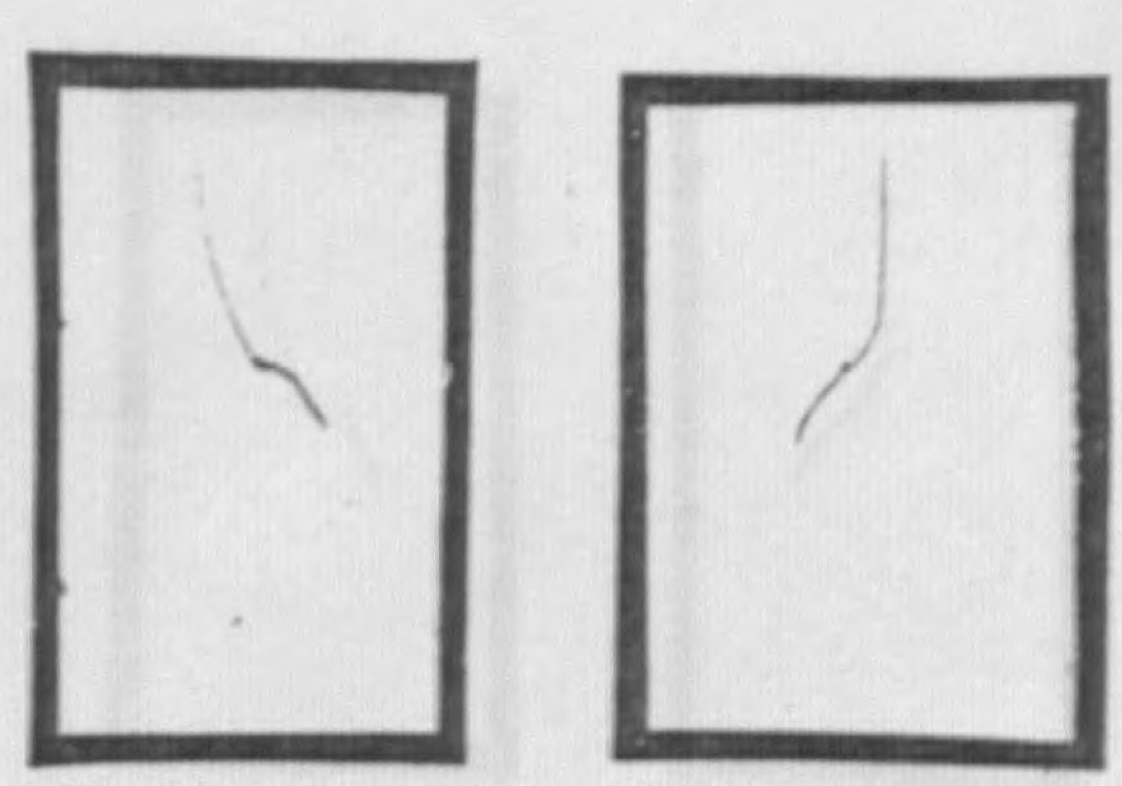


b table 15° backward

c stylus 15° forward



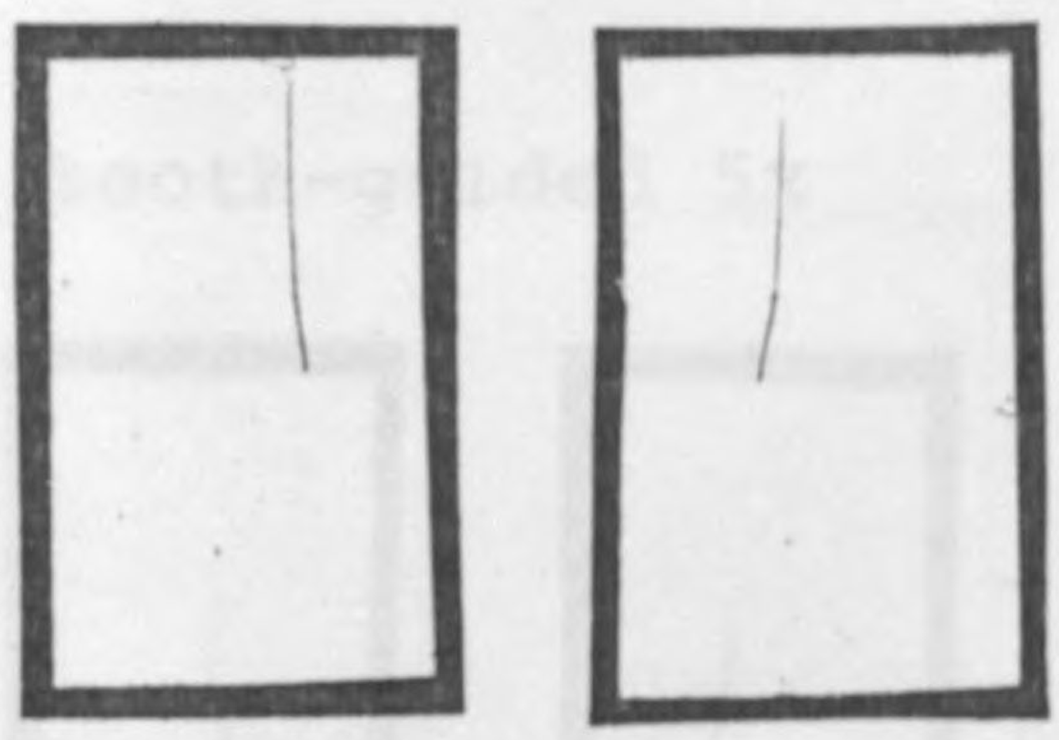
d non-zeroed

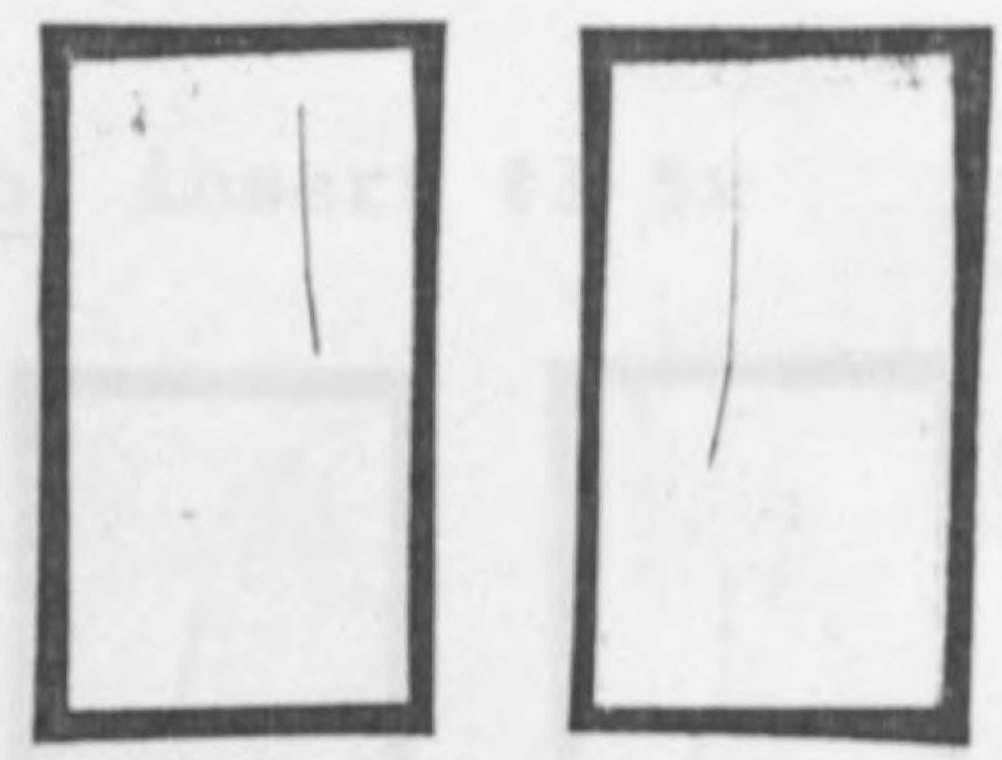


Appendix III (i)

Experimental Conditions - Increase of lateral guidance

BA a b c





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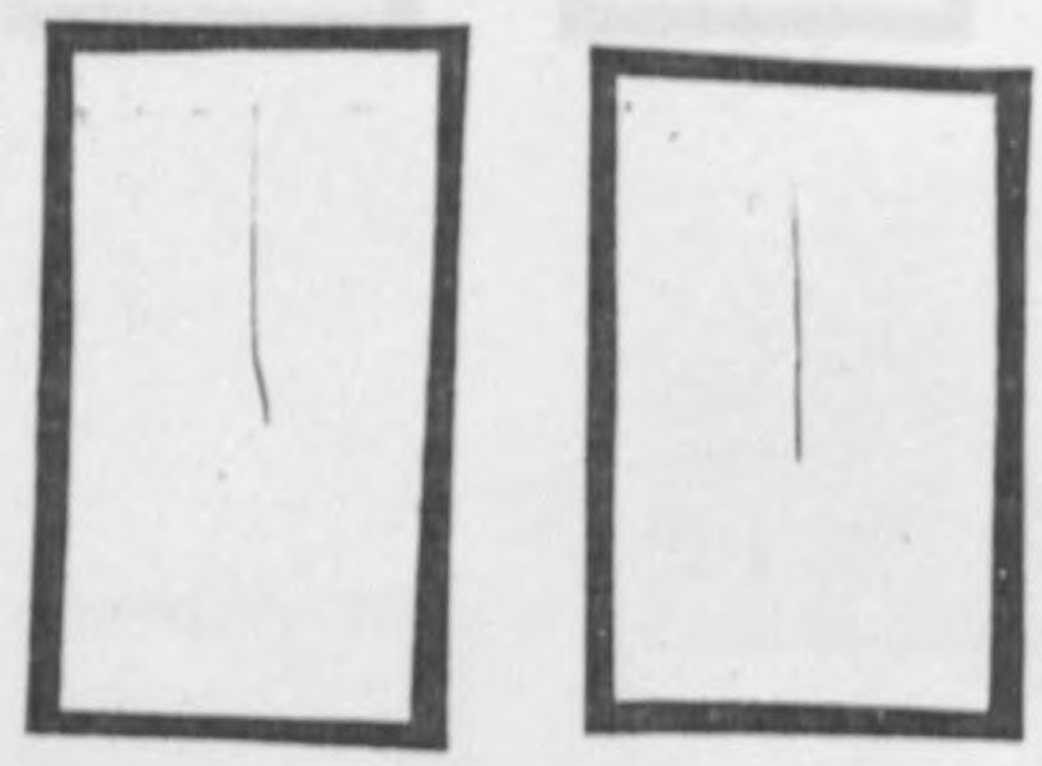
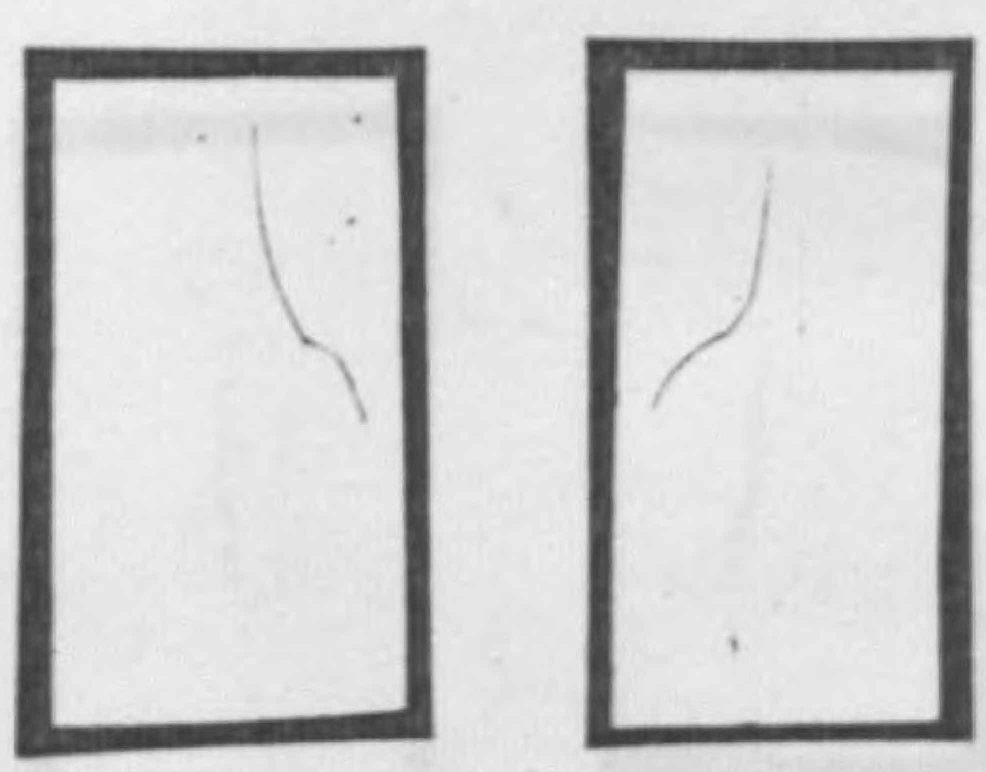
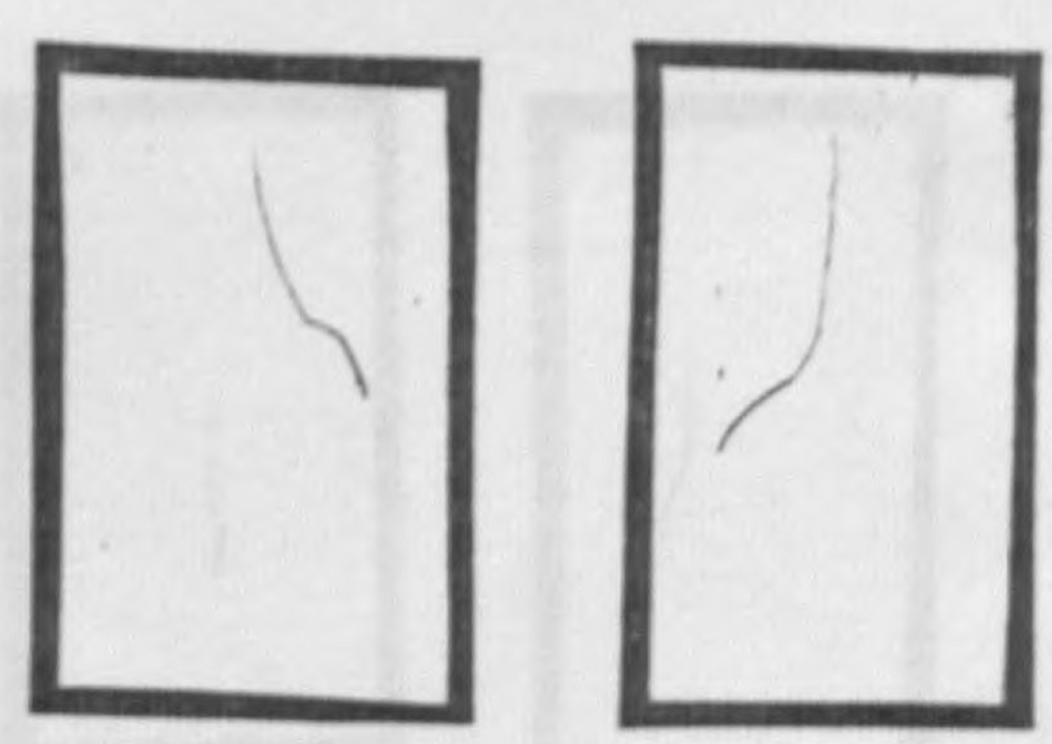


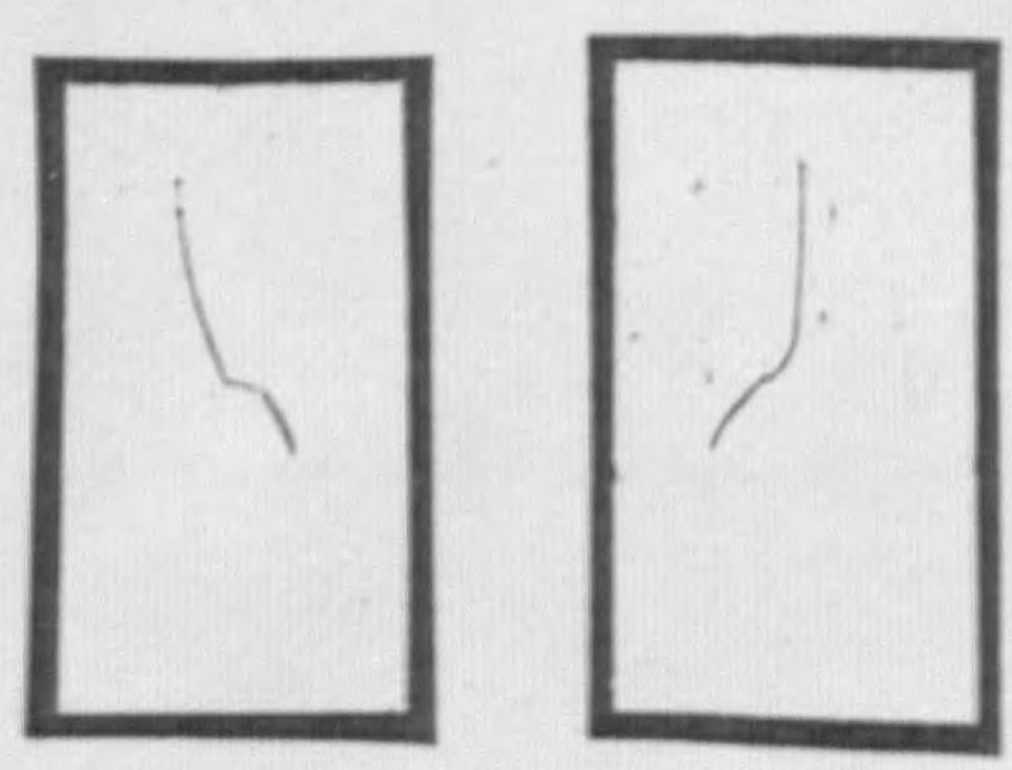
BG

a b c





d



Appendix III

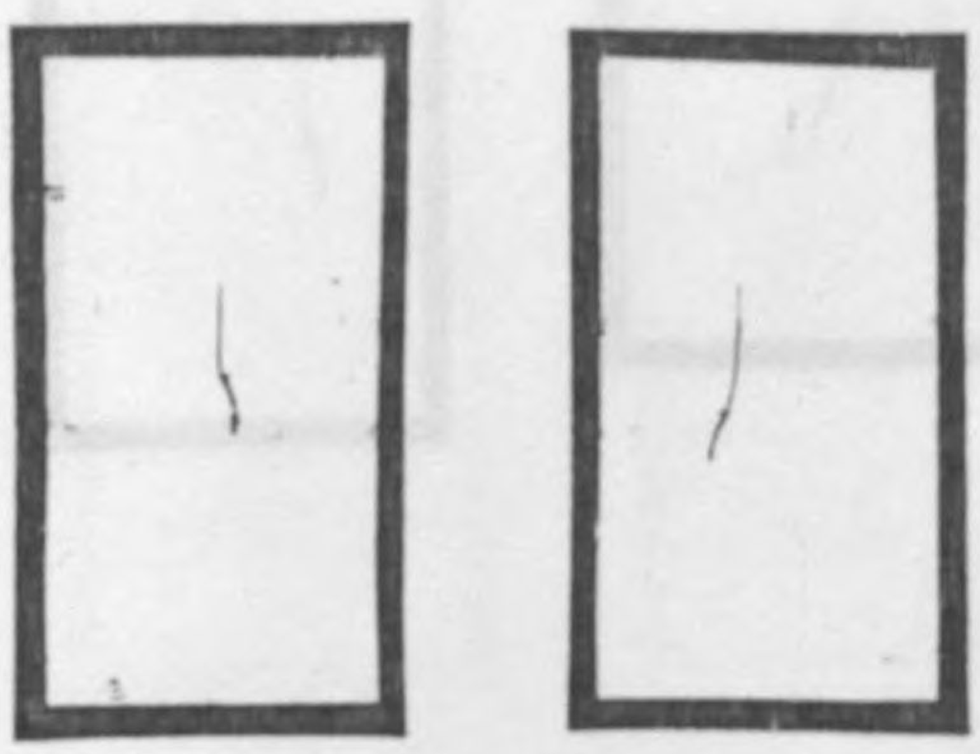
(ii)

Patient Study

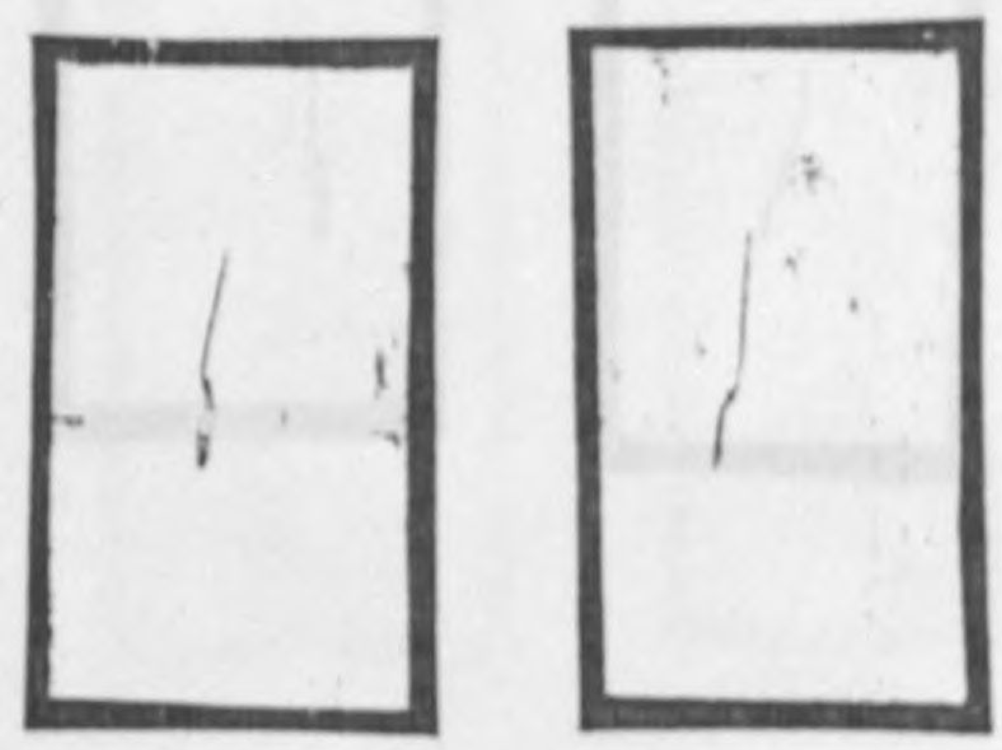
Subject # 1

Controlled Conditions

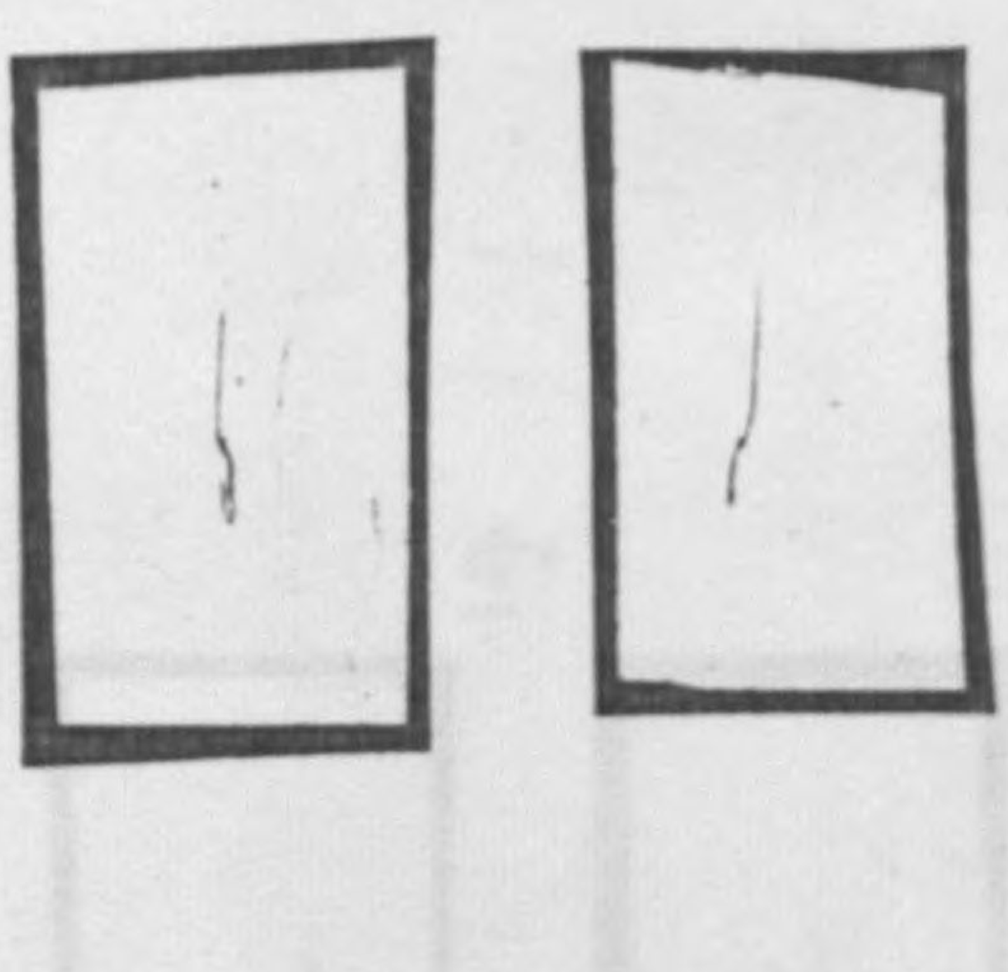
a tooth-guided 5x



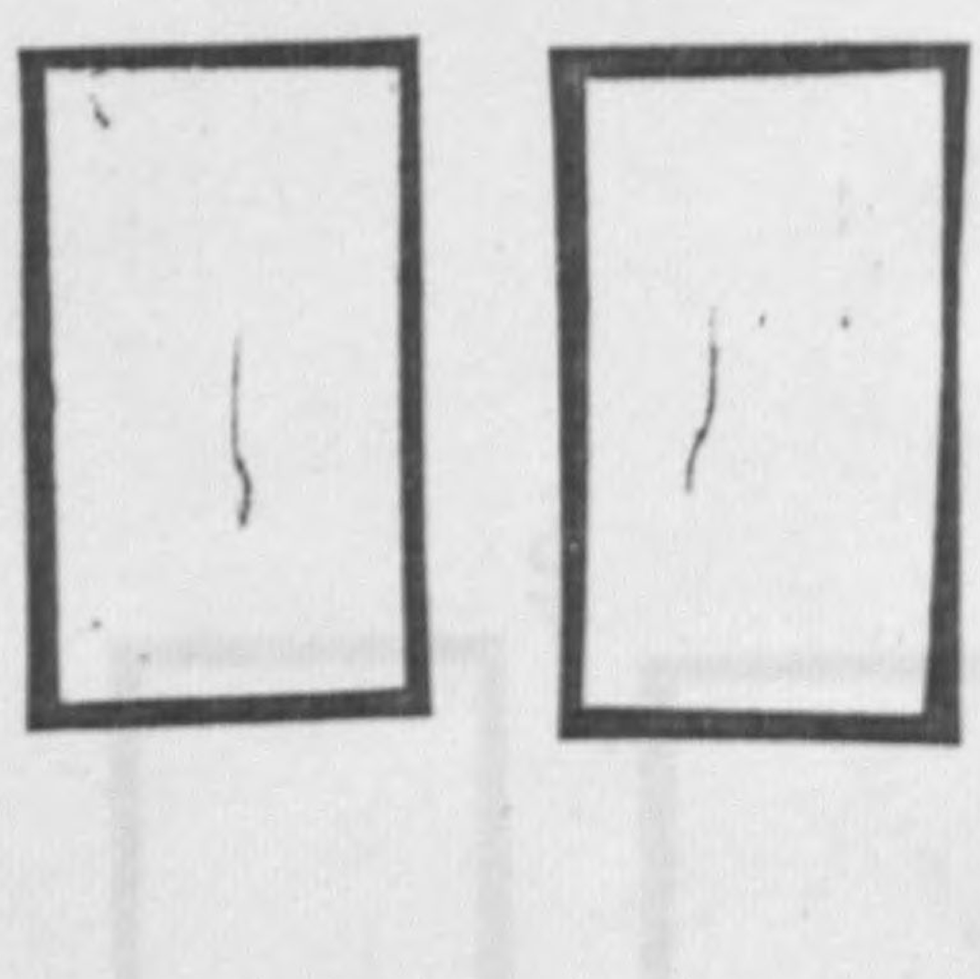
b insert #1 5x



c Increase of vert.dim.

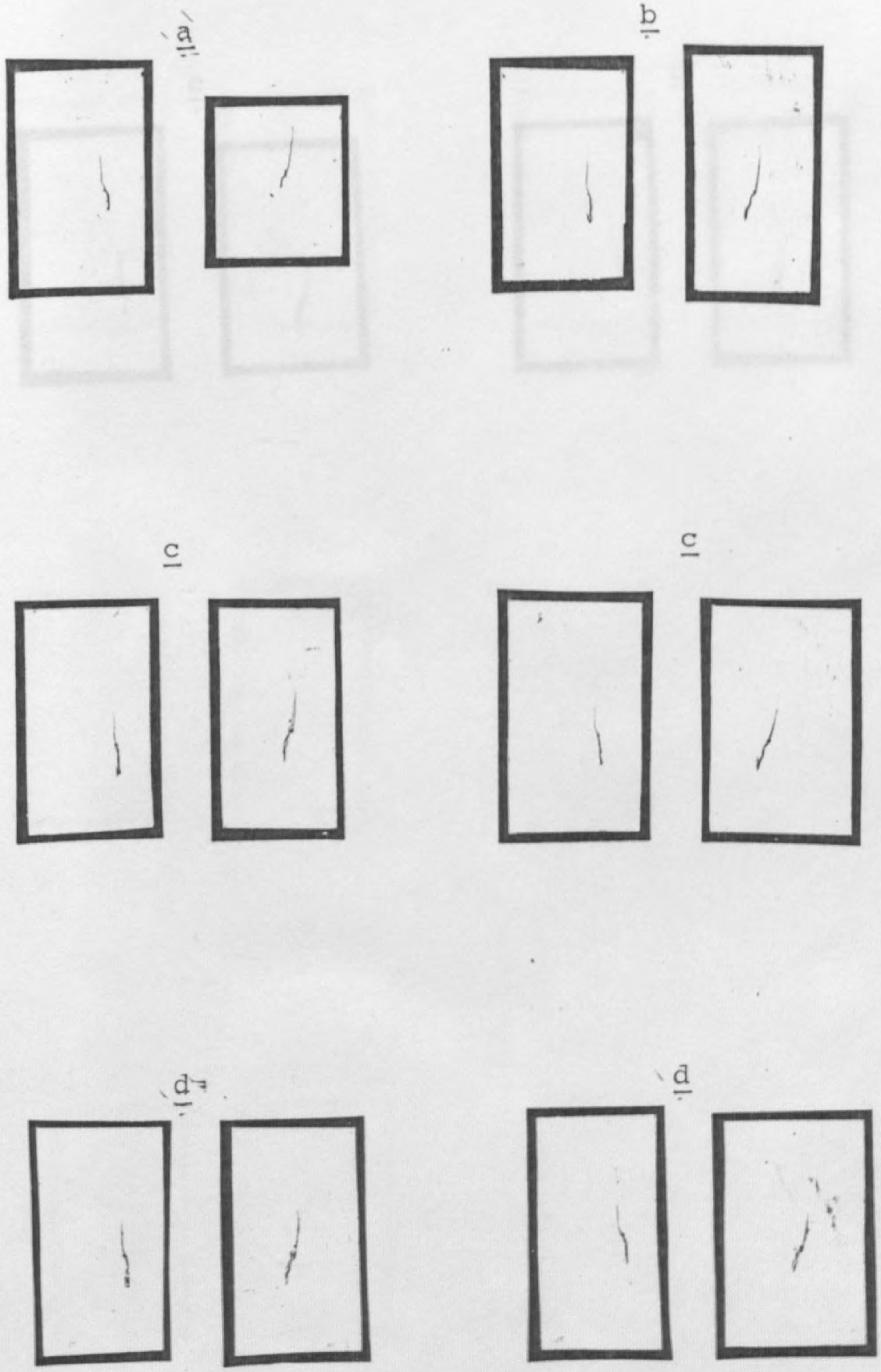


d Increase of lat.guid.



Appendix III (ii)

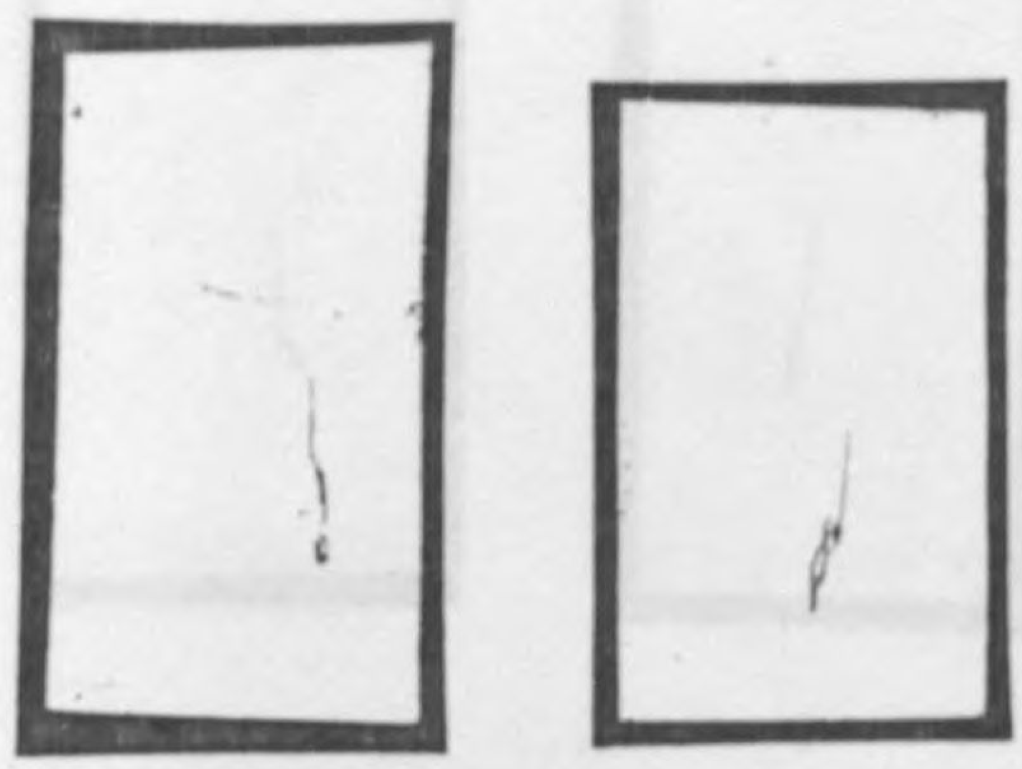
Subject # 2



Appendix III (ii)

Subject # 2

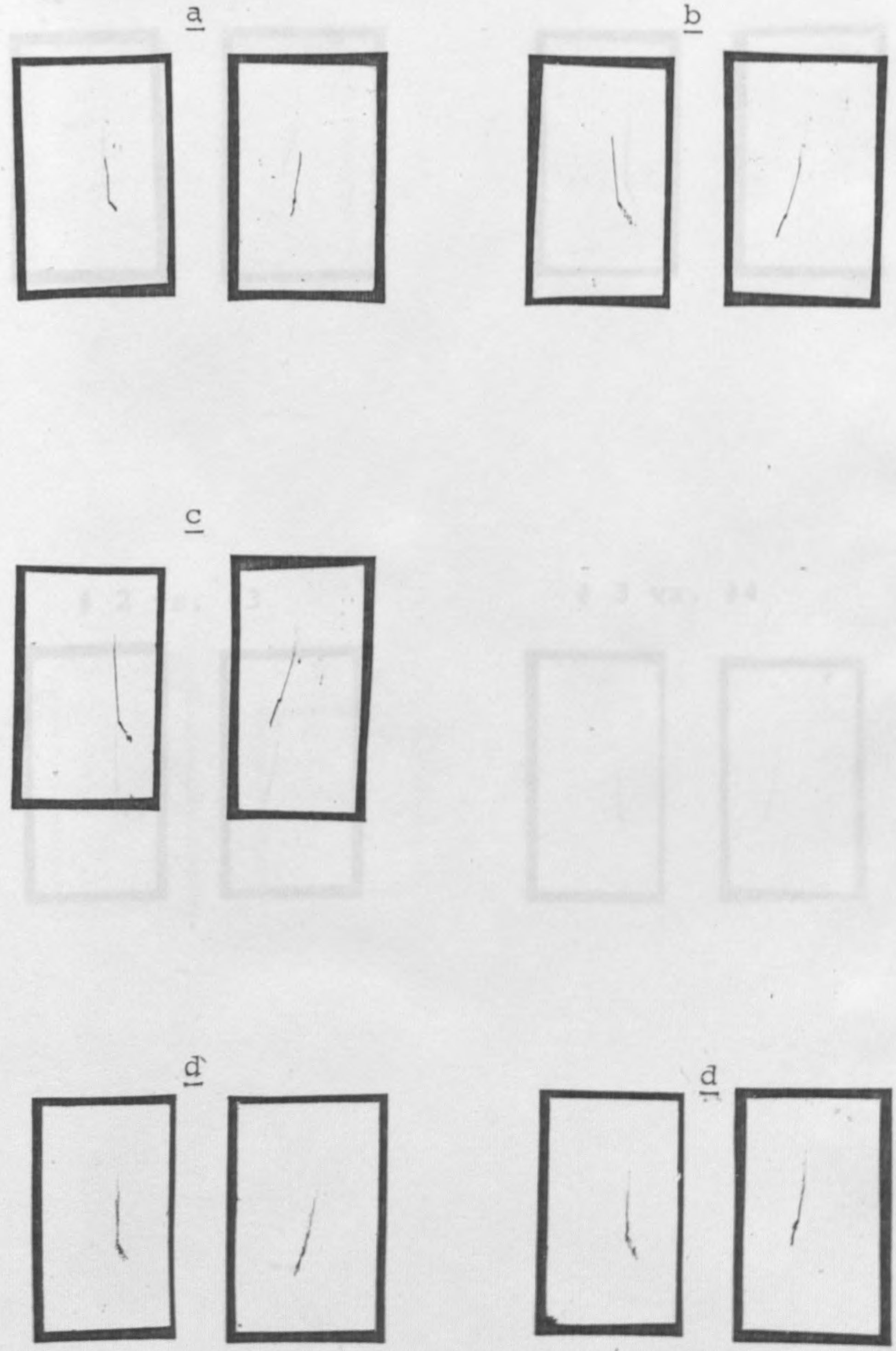
c



d

Appendix III (ii)

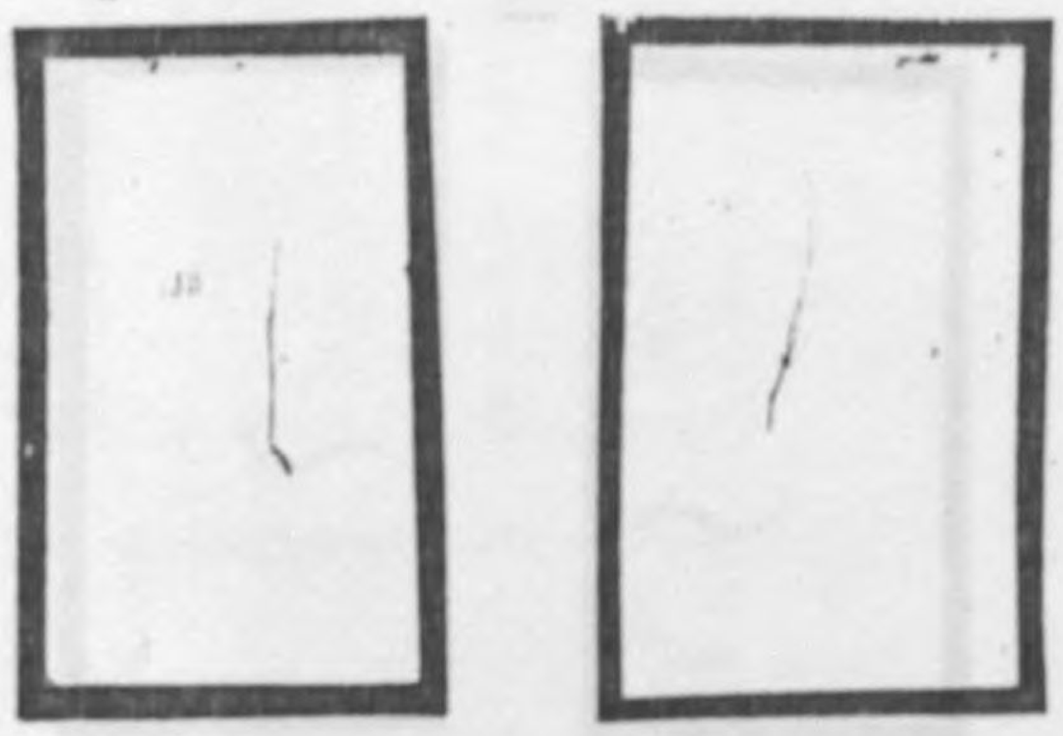
Subject # 3



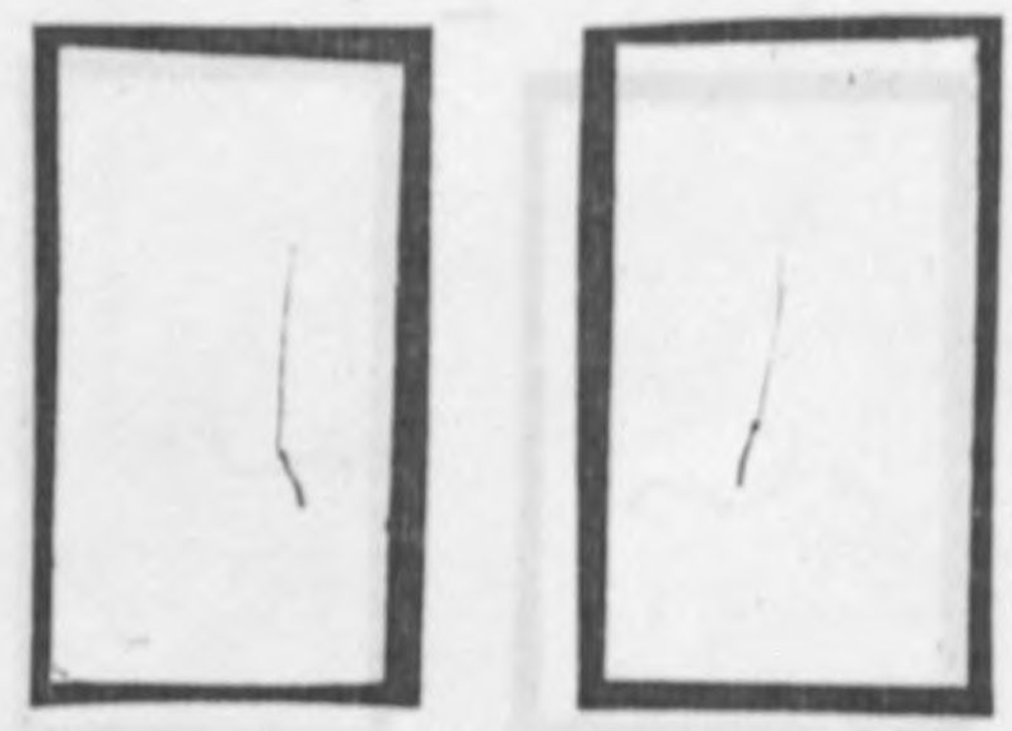
Appendix III (ii)

Subject # 3

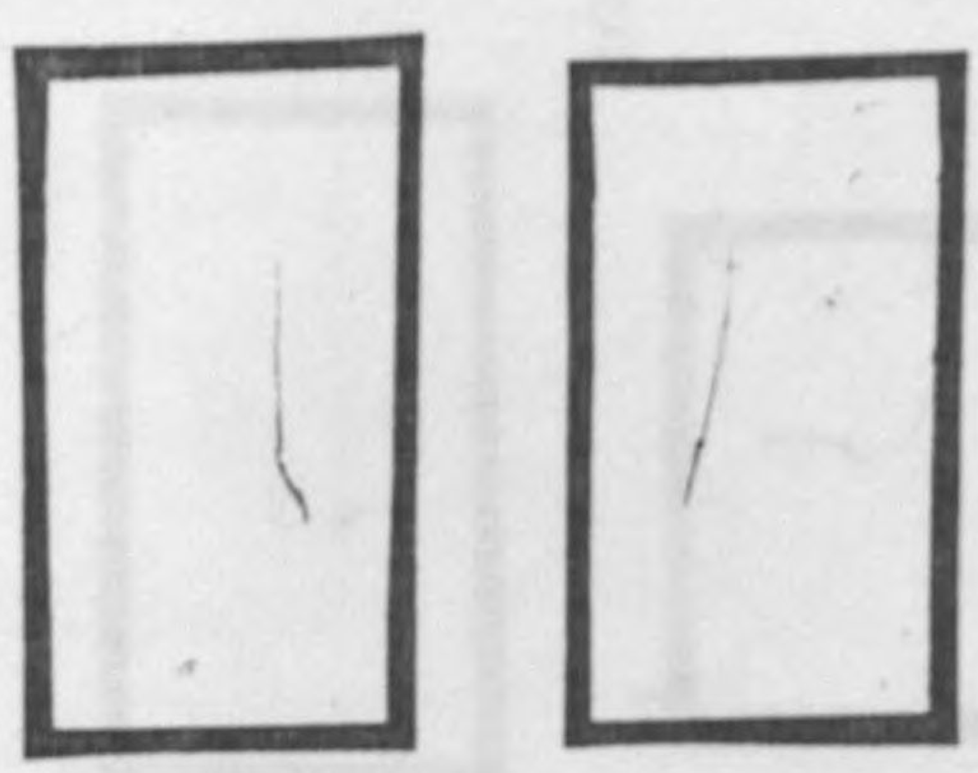
Tooth guidance vs. insert # 1



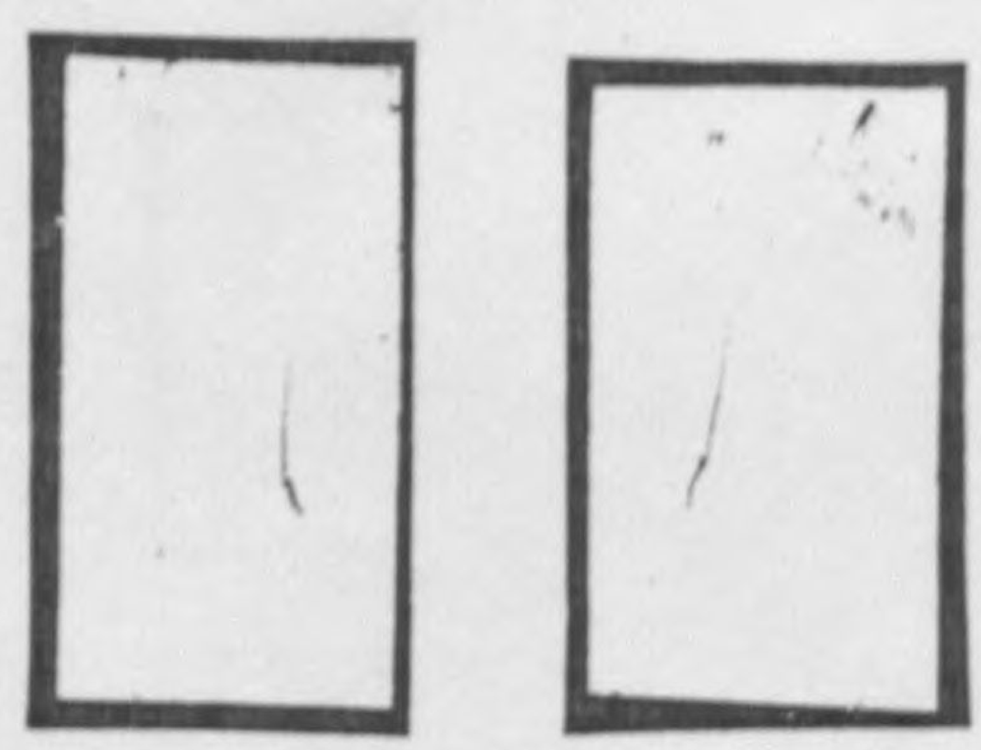
1 vs. # 2



2 vs. #3

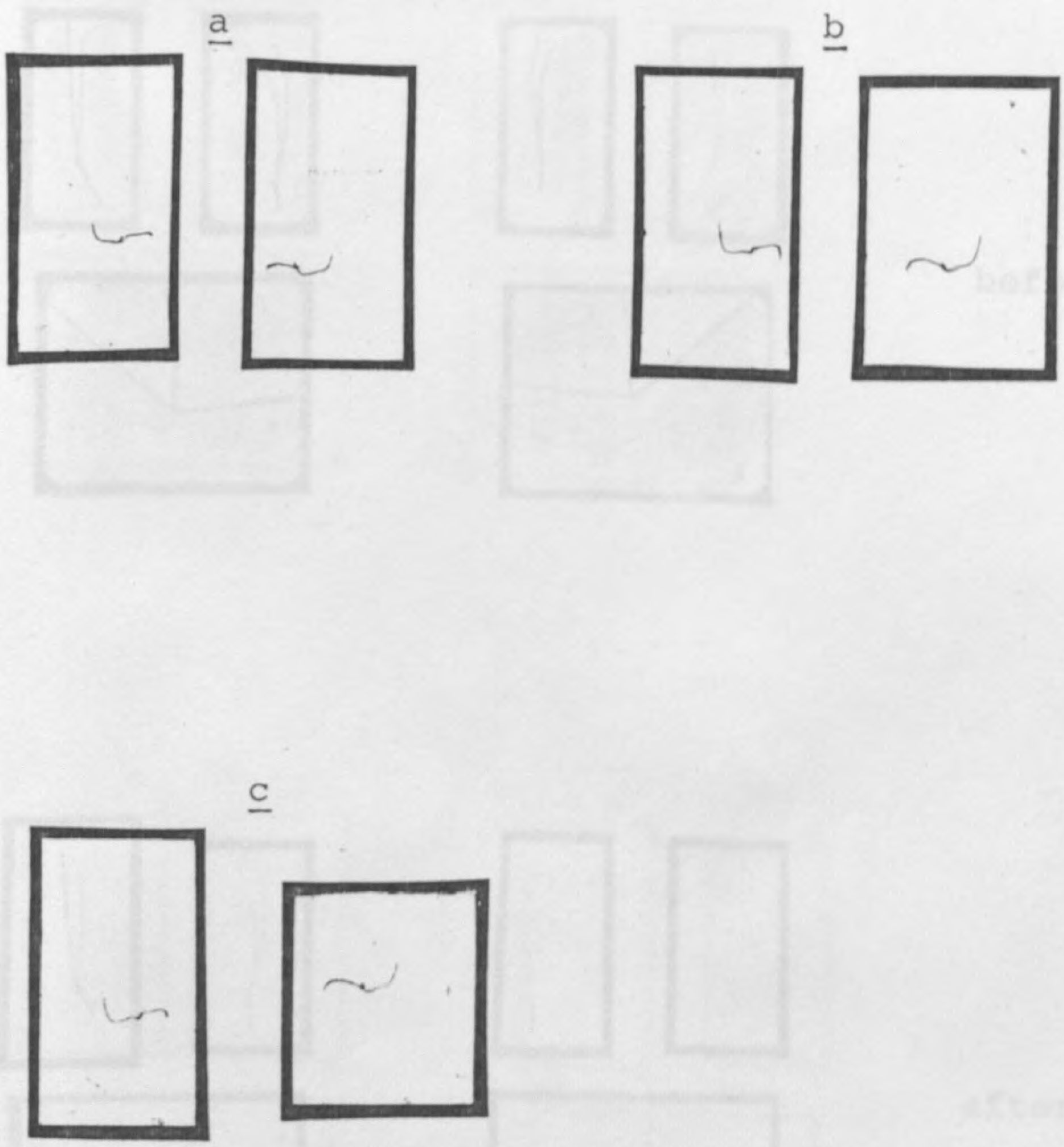


3 vs. #4



Appendix III (ii)

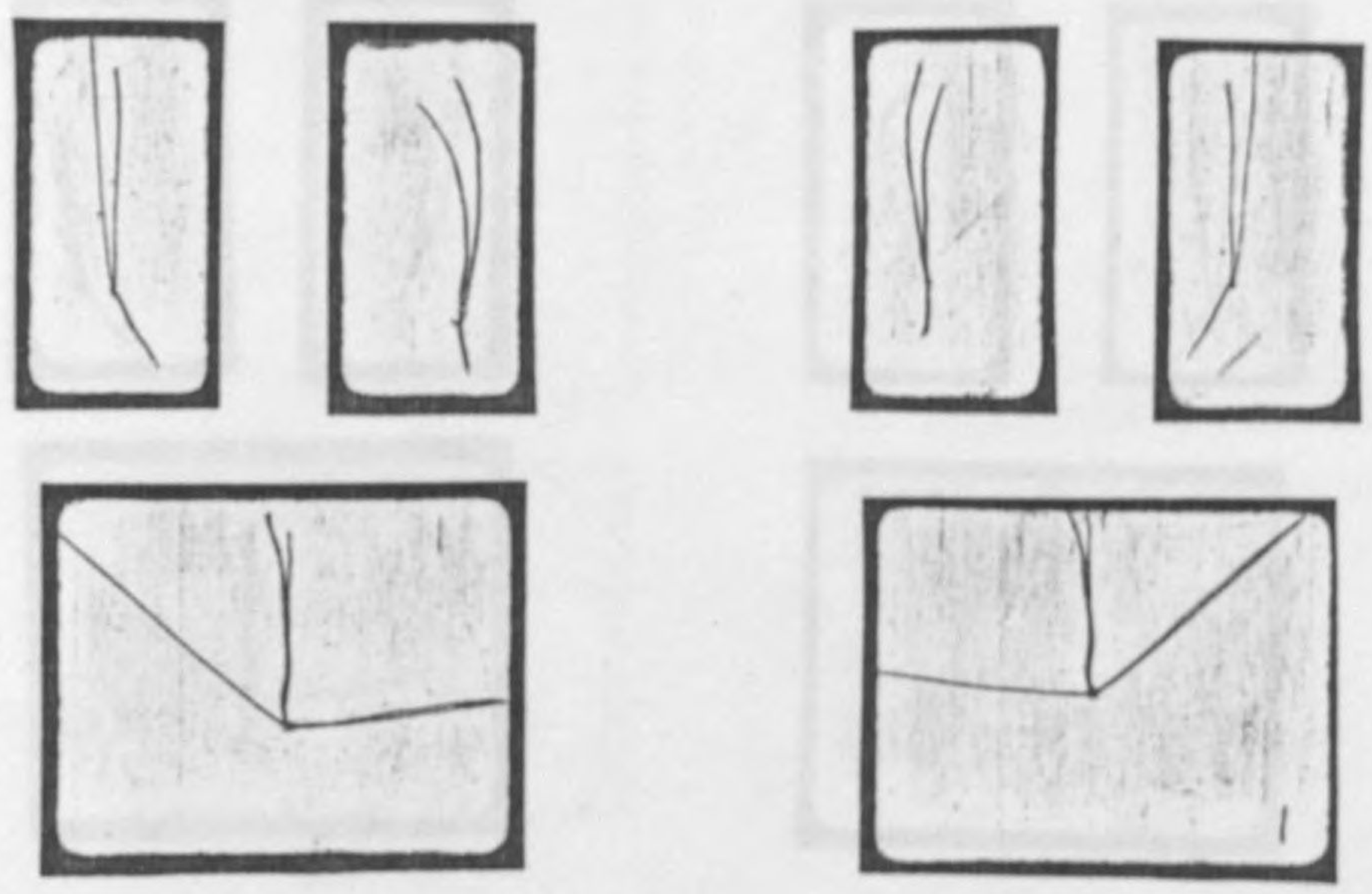
Subject # 4



Appendix III

(iii)

Diagnostic pantographic surveys Subject # 1



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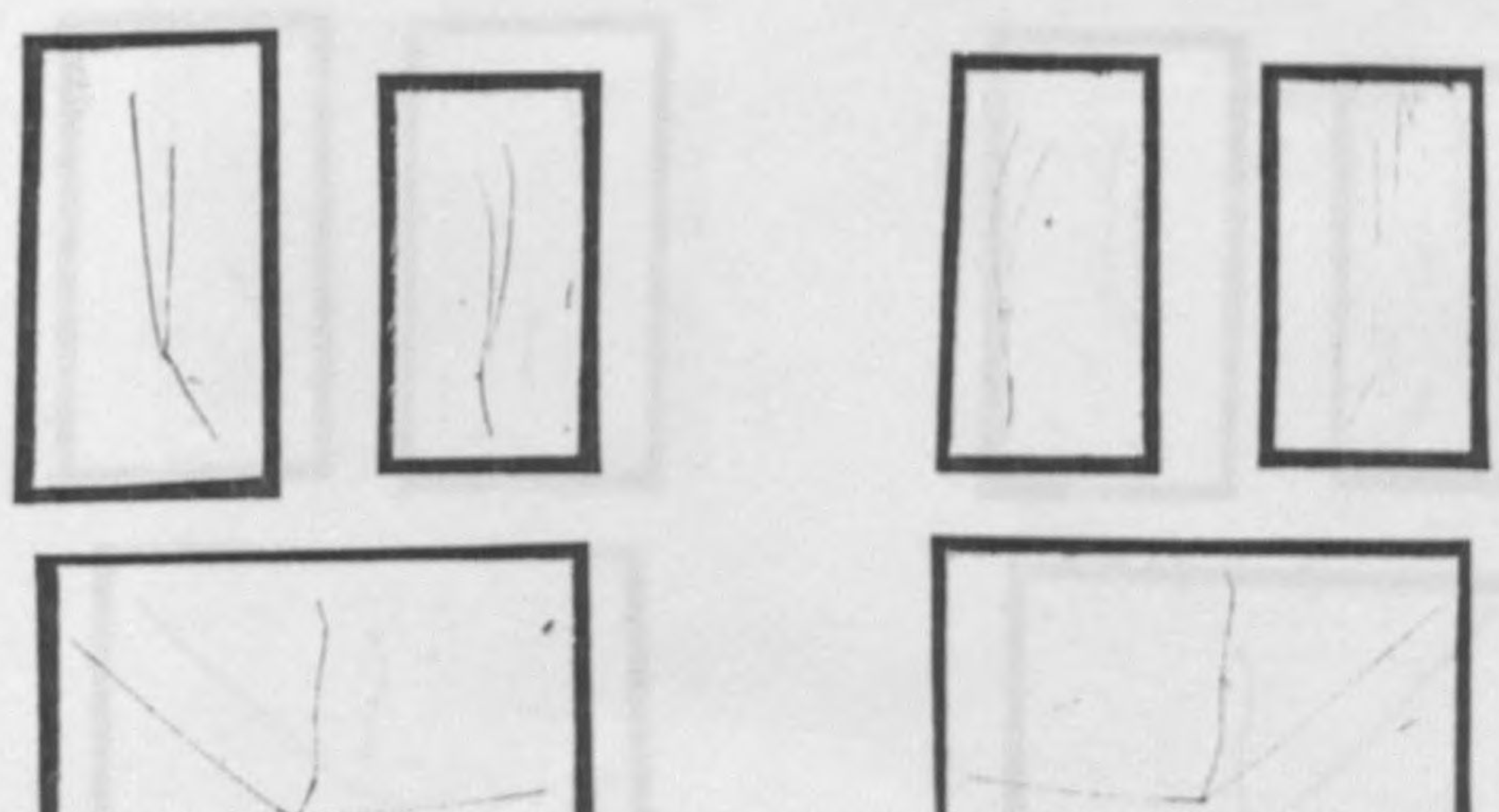

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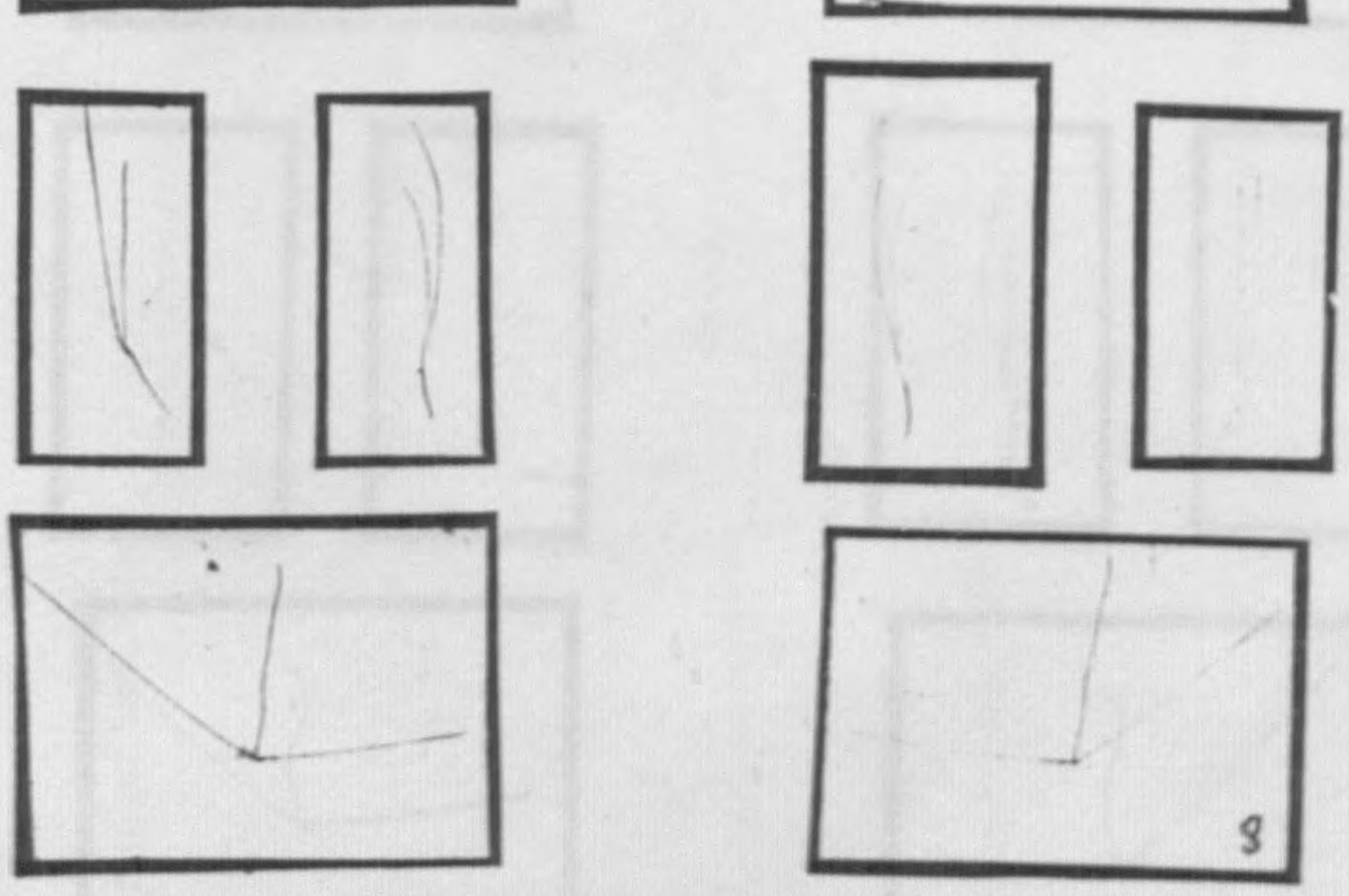
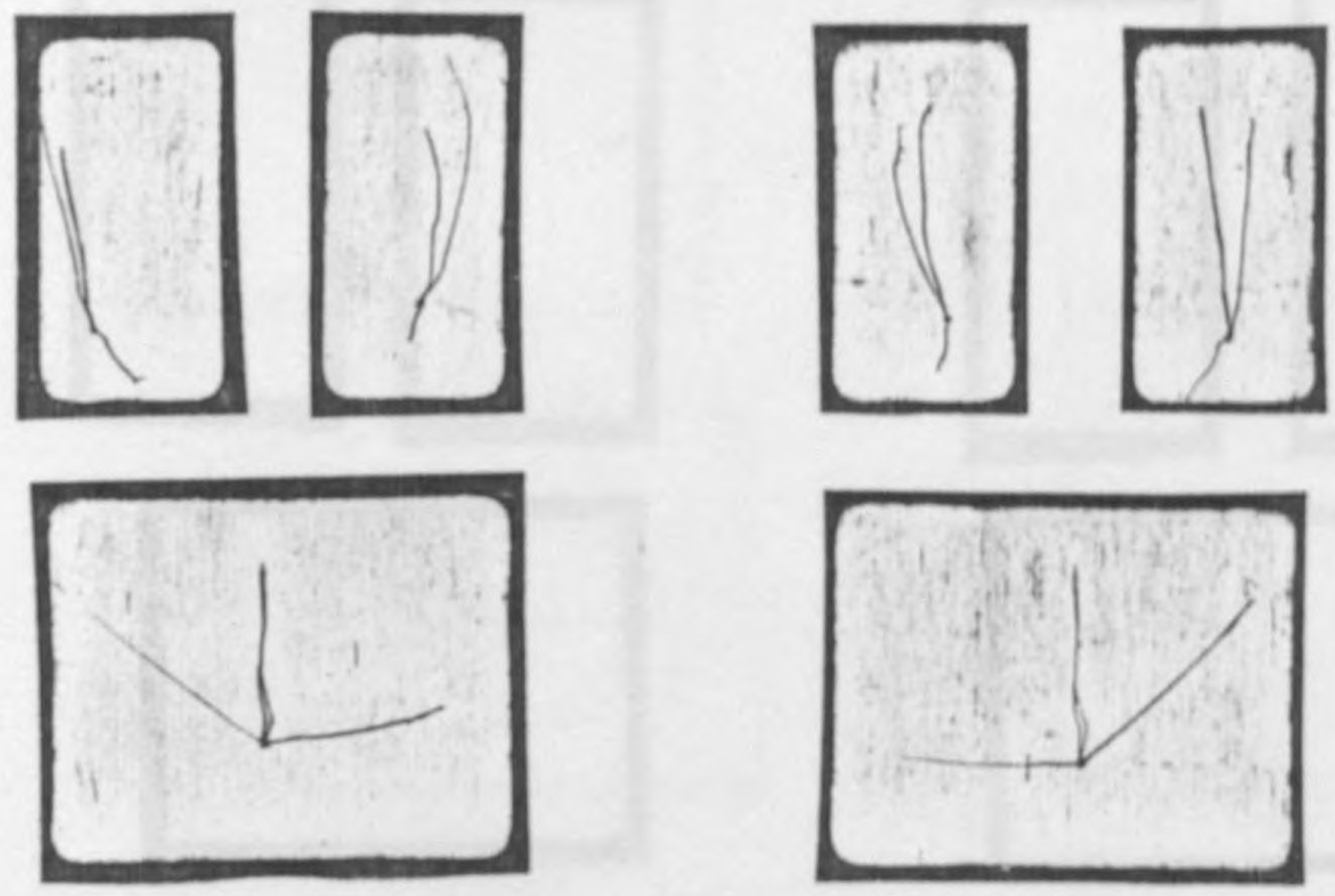


after

Appendix III (iii)

Subject # 2



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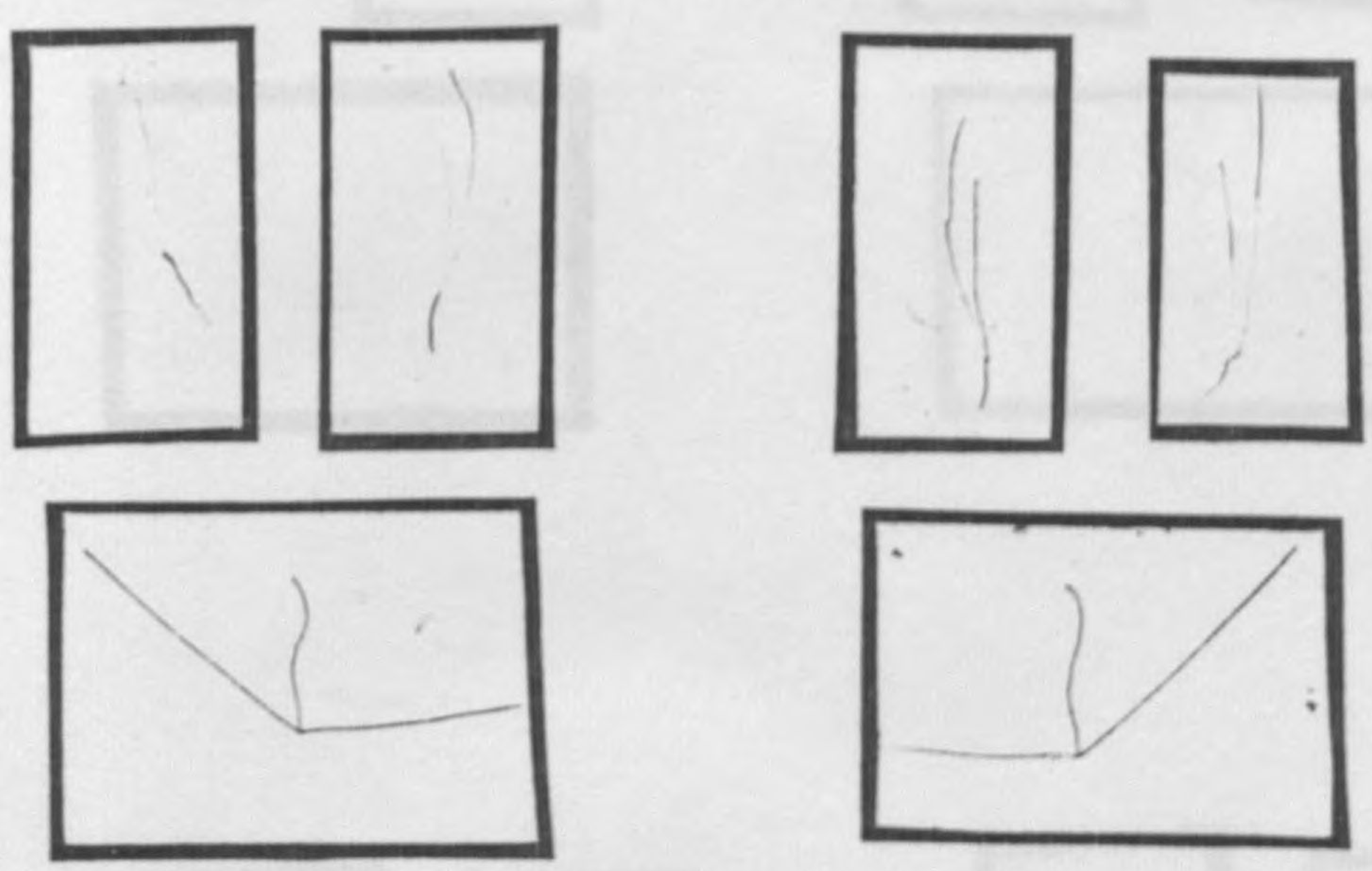

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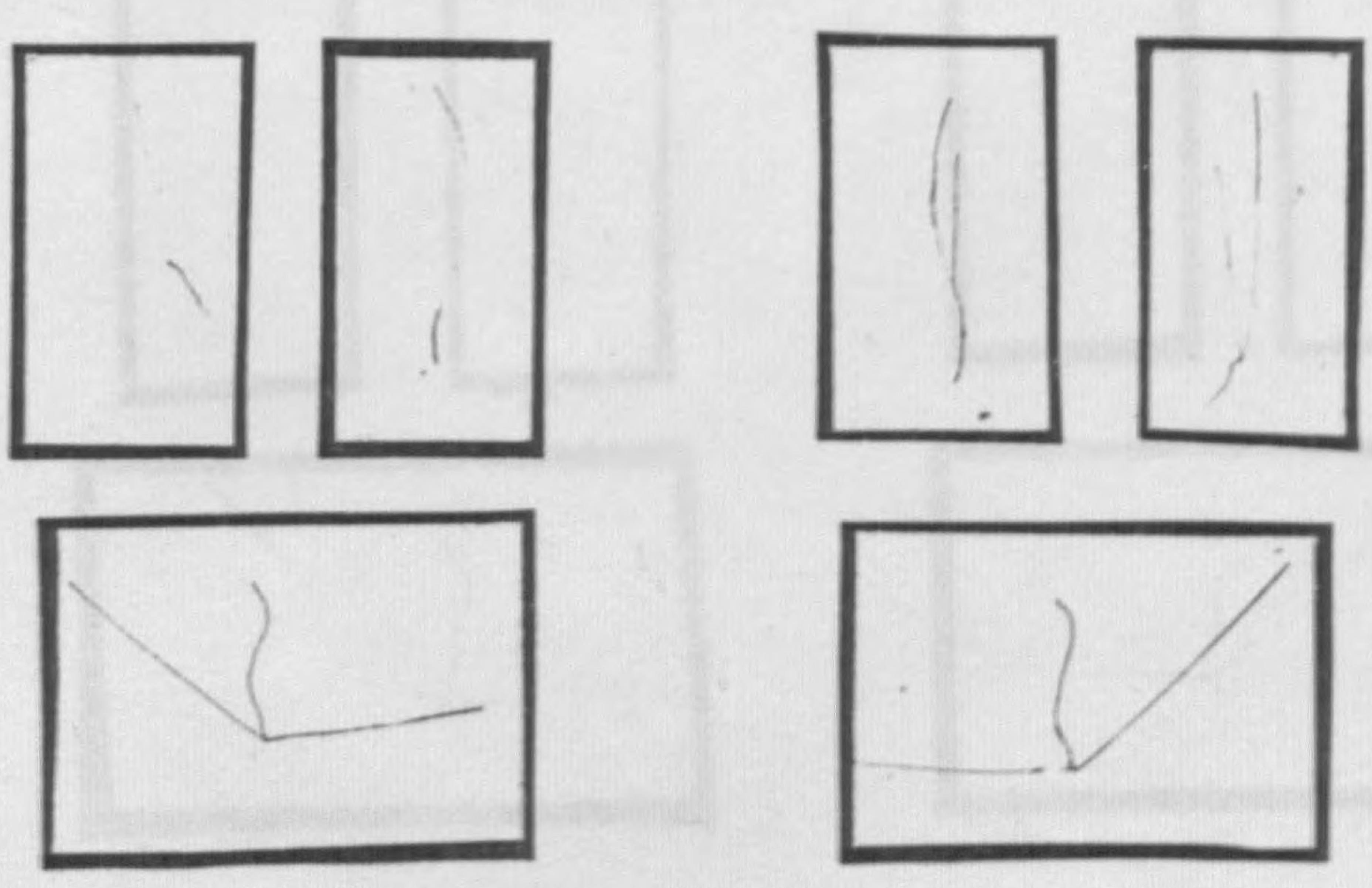

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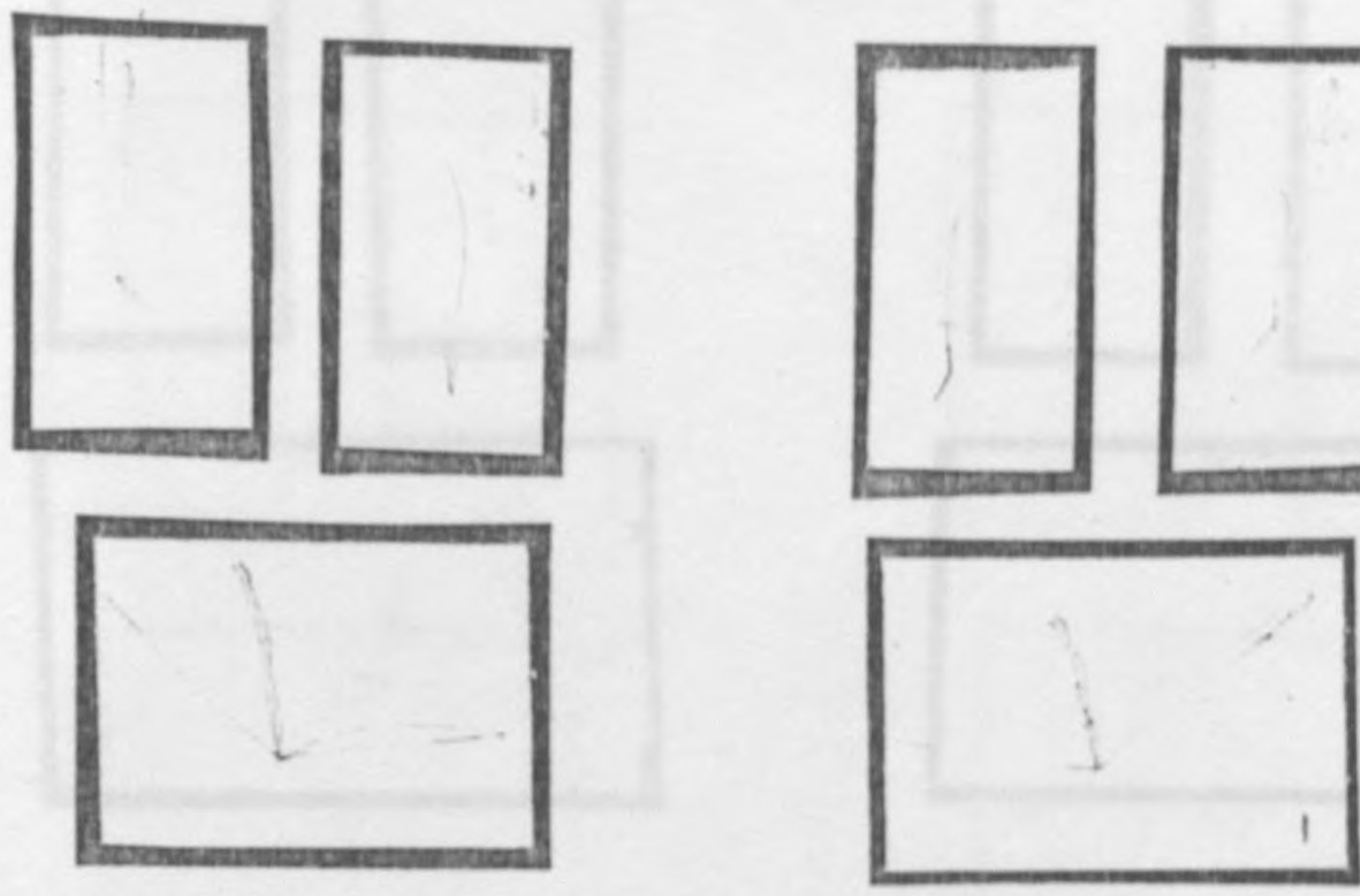
Appendix III (iii)

Subject # 3



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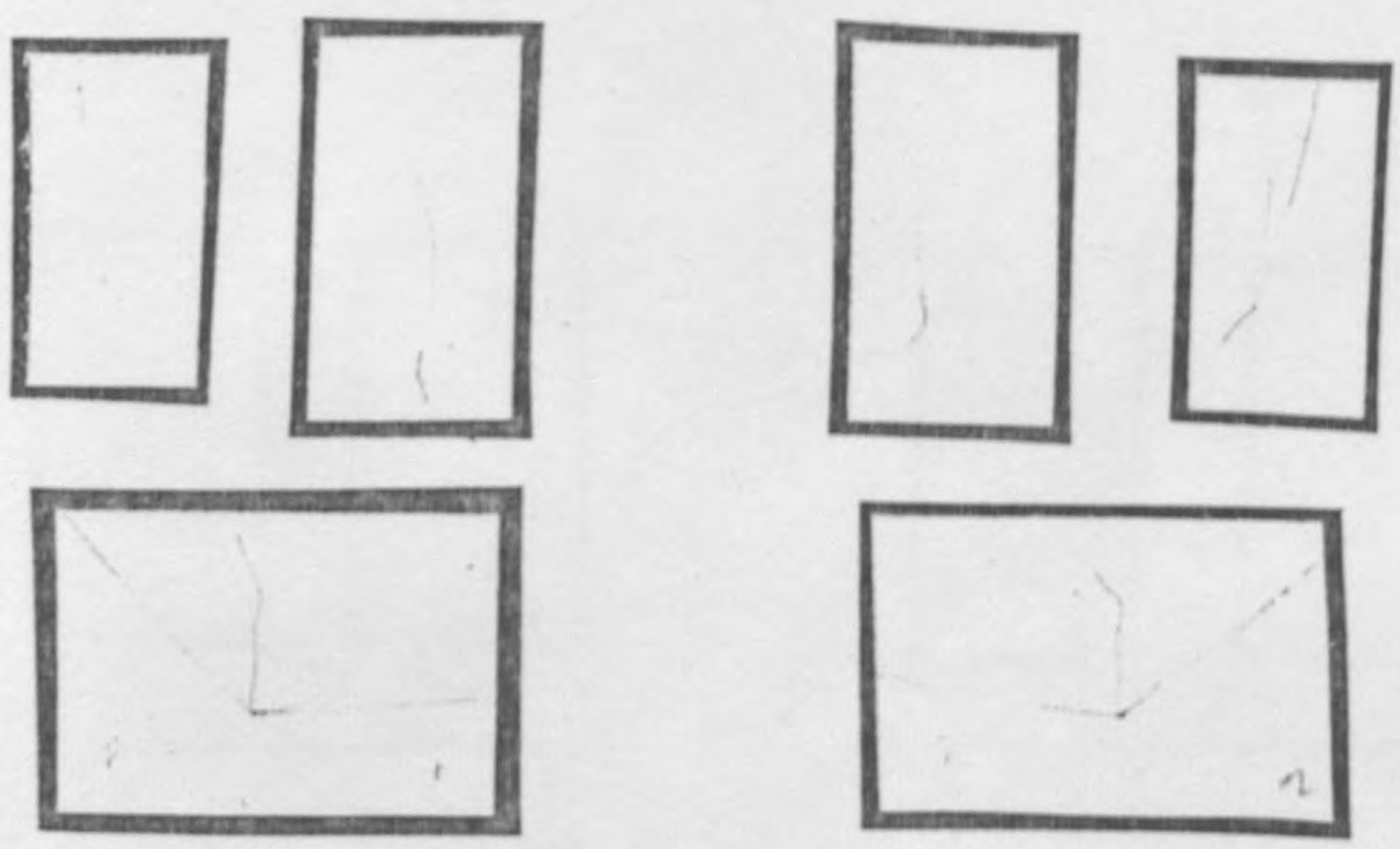

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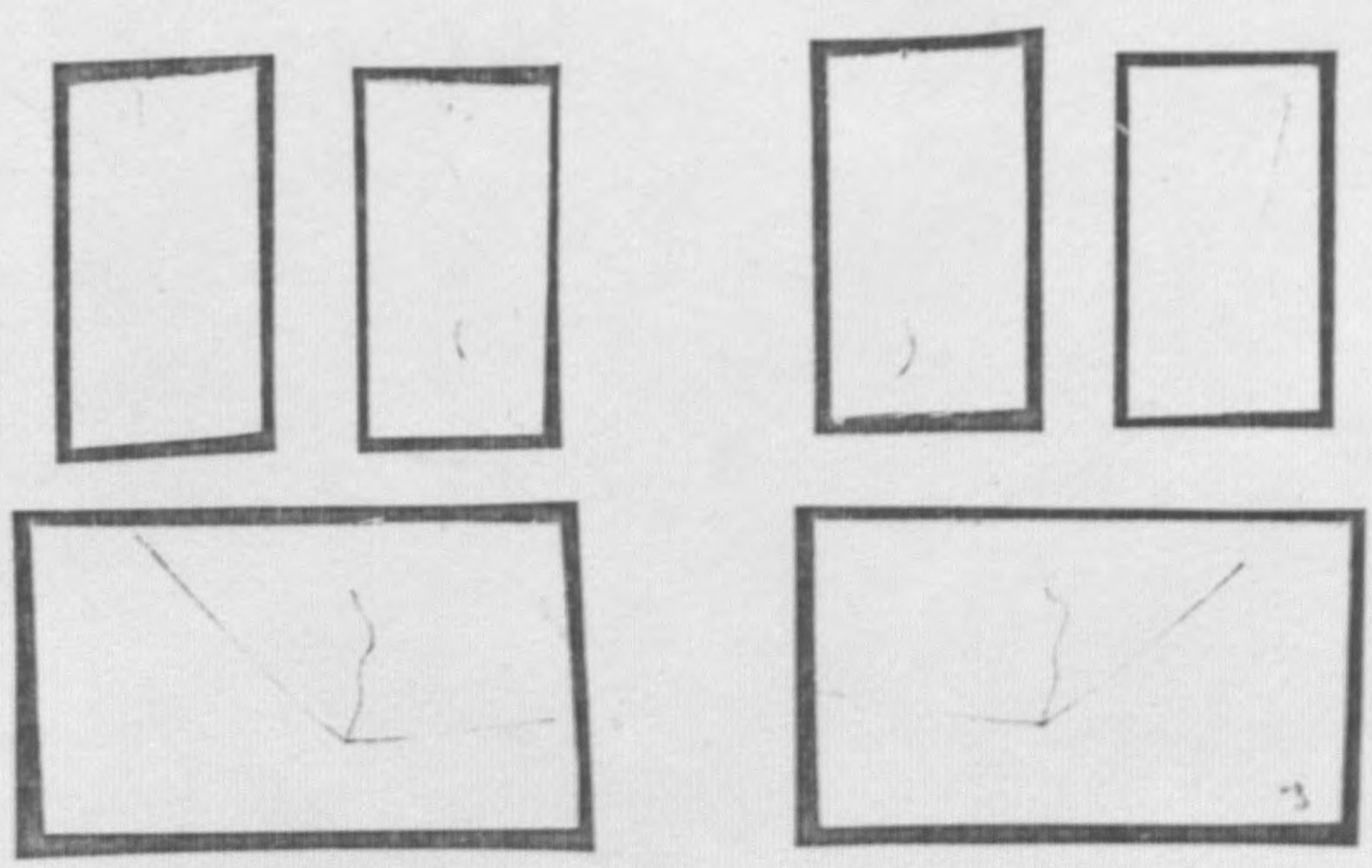

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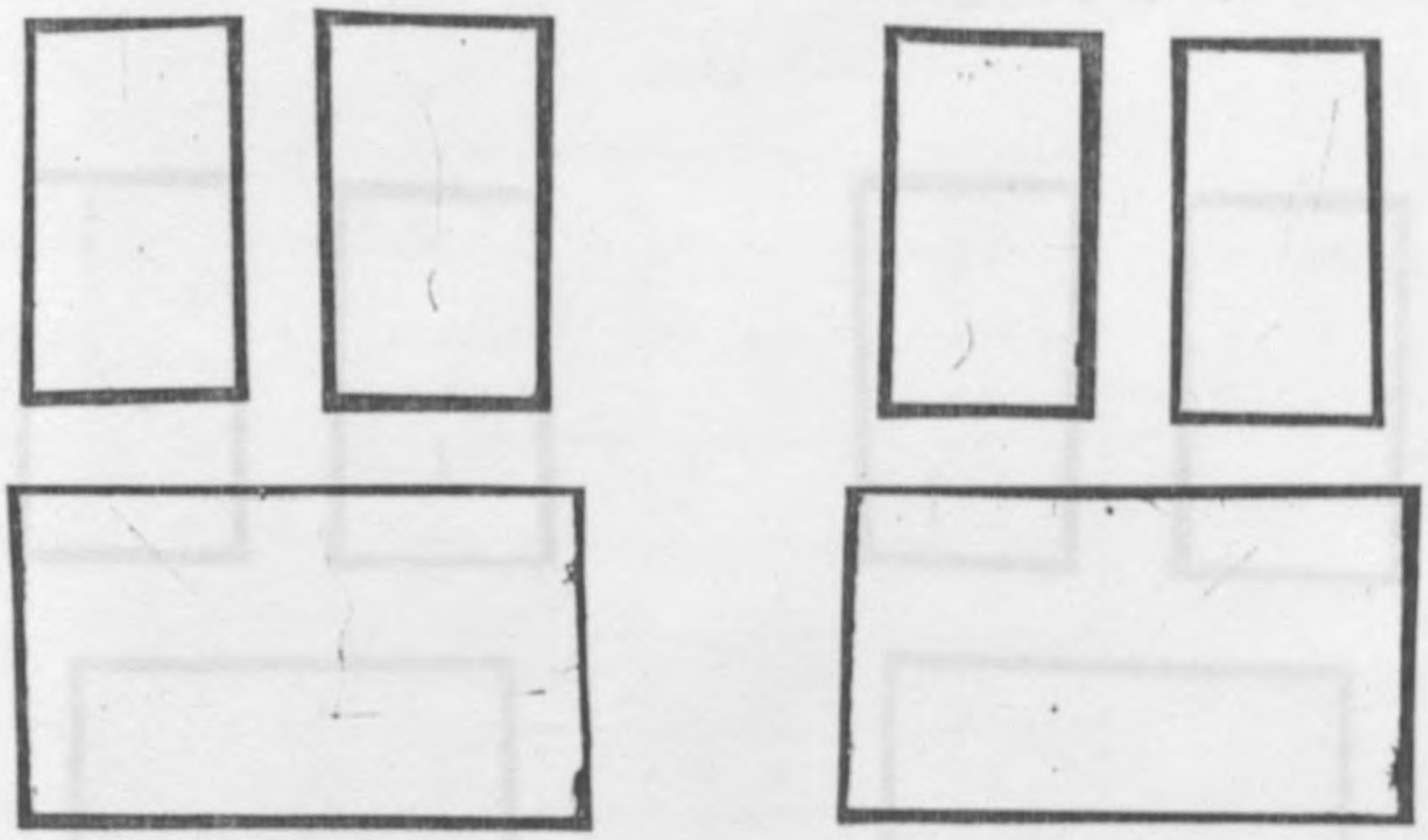
Appendix III (iii)

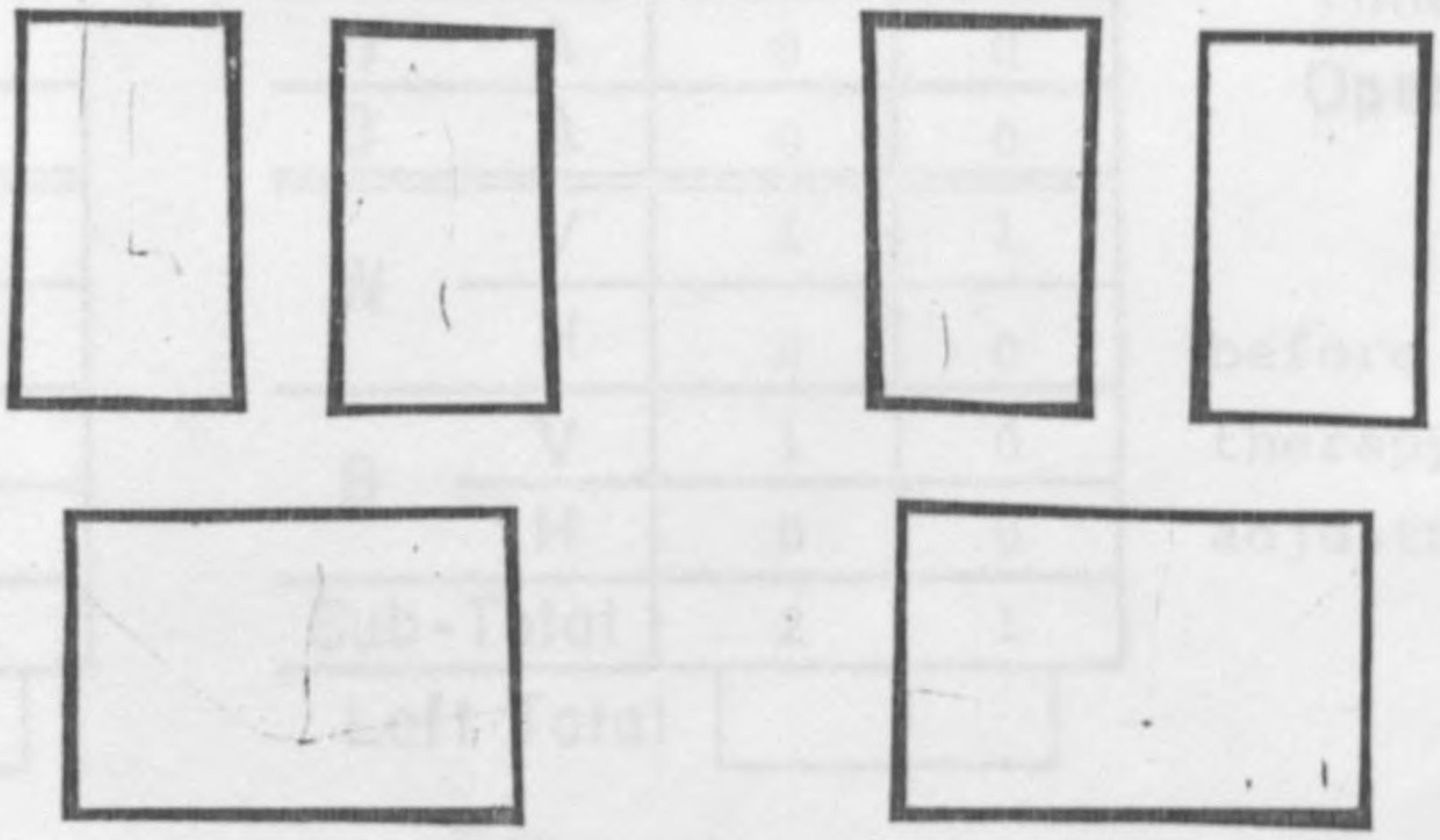
Subject # 3



after

Appendix III (iii)

Subject # 4



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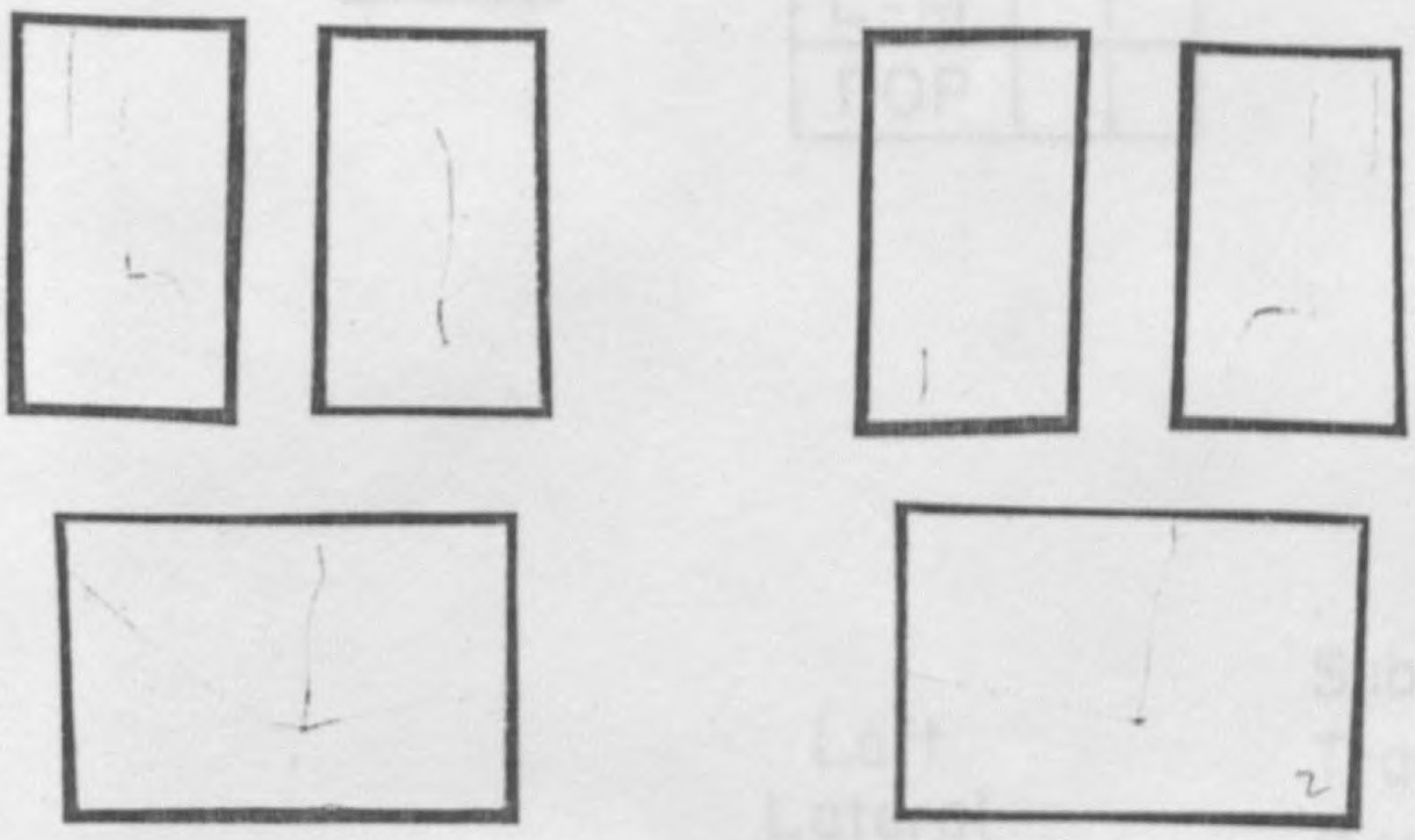

after

Appendix IV

PRI-Scores

Subject # 1
Tracing No. before (#1
Date 8/12/76
Time
Operator Kitschenber

		Right Lateral		Left Lateral	
W	A	2	2	0	0
B	A	2	2	0	0
W	V	1	1	1	1
	H	0	0	0	0
B	V	1	0	1	0
	H	0	0	0	0
Sub-Total		6	5	2	1
Right Total / Left Total		11		3	

(before bite-splint therapy and occlusal adjustment)

Total: 14

	R	L
M-C		
L-M		
POP		

Subject # 1
Tracing No. after (#2
Date 1/12/77
Time
Operator Kitschenber

		Right Lateral		Left Lateral	
W	A	1	o	1	0
B	A	0	0	1	0
W	V	0	0	0	0
	H	1	0	0	0
B	V	0	0	3	0
	H	0	0	1	1
Sub-Total		2	0	6	1
Right Total / Left Total		2		7	

(after bite-splint therapy and occlusal adjustment)

Total: 9

	R	L
M-C		
L-M		
POP		

Appendix IV

Subject # 1
Tracing No. after (#3)
Date 1/12/77
Time
Operator Kitschenber

(after bite-splint therapy and occlusal adjustment)

		Right Lateral		Left Lateral	
W	A	1	0	1	0
B	A	0	0	0	0
W	V	0	0	0	0
W	H	1	0	0	0
B	V	0	0	1	0
B	H	0	0	0	1
Sub-Total		2	0	2	1

Right Total: 2

Left Total: 3

Total: 5

	R	L
M-C		
L-M		
POP		

Subject
Tracing No.
Date
Time
Operator

		Right Lateral		Left Lateral	
W	A				
B	A				
W	V				
W	H				
B	V				
B	H				
Sub-Total					

Right Total

Left Total

Total

	R	L
M-C		
L-M		
POP		

Appendix IV

Subject # 2
Tracing No. before (#
Date 8/5/76
Time
Operator Kitschenber

		Right Lateral		Left Lateral	
W	A	0	1	1	0
B	A	1	1	0	0
W	V	0	0	0	0
	H	0	0	0	0
B	V	0	1	0	0
	H	1	0	0	0
Sub-Total		2	3	1	0
Right Total / Left Total		5		1	

(before bite-splint therapy and occlusal adjustment)

Total: 6

	R	L
M-C		
L-M		
POP		

Subject # 2
Tracing No. after (#2
Date 10/18/76
Time
Operator Kitschenber

		Right Lateral		Left Lateral	
W	A	0	1	1	0
B	A	0	1	0	0
W	V	0	0	0	0
	H	1	0	1	0
B	V	0	1	0	0
	H	0	1	0	1
Sub-Total		1	4	2	1
Right Total / Left Total		5		3	

(after bite-splint therapy and occlusal adjustment)

Total: 8

	R	L	
M-C	x		
L-M			
POP		x	orbiting

Appendix IV

Subject # 2
Tracing No. after (#3
Date 10/18/76
Time
Operator Kitschenber

		Right Lateral		Left Lateral	
W	A	0	1	1	0
B	A	0	1	0	0
W	V	0	0	0	0
W	H	0	0	0	0
B	V	2	0	0	0
B	H	0	1	0	1
Sub-Total		2	3	1	1
Right Total / Left Total		5		2	

(after bite-splint therapy and occlusal adjustment)

Total: 7

	R	L
M-C	x	
L-M		
POP		

Subject
Tracing No.
Date
Time
Operator

		Right Lateral		Left Lateral	
W	A				
B	A				
W	V				
W	H				
B	V				
B	H				
Sub-Total					
Right Total / Left Total					

Total:

	R	L
M-C		
L-M		
POP		

Appendix IV

Subject # 3
Tracing No. before (#1
Date 11/12/76
Time
Operator Kitschenber

(before bite-splint therapy and occlusal adjustment)

Right Lateral

W	A	3	3
B	A	3	3
W	V	2	2
	H	2	6
B	V	2	2
	H	1	3
Sub-Total		13	19
Right Total		32	

Left Lateral

W	A	1	0
B	A	0	1
W	V	0	1
	H	1	0
B	V	0	0
	H	0	0
Sub-Total		2	2
Left Total		4	

Total: 36

	R	L
M-C		
L-M		
POP		

Subject # 3
Tracing No. before (#
Date 11/12/76
Time
Operator Kitschenber

Right Lateral

W	A	6	2
B	A	3	2
W	V	1	1
	H	3	2
B	V	1	1
	H	1	2
Sub-Total		15	10
Right Total		25	

Left Lateral

W	A	1	0
B	A	0	1
W	V	0	0
	H	1	0
B	V	0	2
	H	0	1
Sub-Total		2	4
Left Total		6	

Total: 31

	R	L
M-C		
L-M		
POP		

Appendix IV

Subject # 3
Tracing No. after (#3
Date
Time
Operator Kitschenber

(after bite-splint therapy and occlusal adjustment)

		Right Lateral		Left Lateral	
W	A	1	0	1	0
B	A	0	1	0	1
W	V	0	0	0	0
W	H	0	1	1	0
B	V	0	0	1	0
B	H	0	1	0	1
Sub-Total		1	3	3	2

Right Total: 4

Left Total: 5

Total: 9

	R	L
M-C		
L-M		
POP		

Subject # 3
Tracing No. after (#4
Date
Time
Operator Kitschenber

		Right Lateral		Left Lateral	
W	A	1	0	1	0
B	A	1	1	0	1
W	V	0	0	0	0
W	H	1	0	1	0
B	V	0	0	0	0
B	H	0	1	0	1
Sub-Total		3	2	2	2

Right Total: 5

Left Total: 4

Total: 9

	R	L
M-C		
L-M		
POP		

Appendix IV

Subject # 4
Tracing No. 1
Date 12/7/76
Time
Operator Kitschenber

(after reconstruction)

Right Lateral

W	A	1	0
B	A	1	0
W	V	3	3
W	H	2	1
B	V	2	2
B	H	1	1
Sub-Total		10	7
Right Total		17	

Left Lateral

W	A	1	0
B	A	1	1
W	V	0	0
W	H	2	1
B	V	1	0
B	H	1	1
Sub-Total		6	3
Left Total		9	

Total: 26

	R	L
M-C		
L-M		
POP		

Subject # 4
Tracing No. 2
Date 12/7/76
Time
Operator Kitschenber

(after reconstruction)

Right Lateral

W	A	1	0
B	A	1	1
W	V	0	0
W	H	0	1
B	V	1	0
B	H	0	1
Sub-Total		3	3
Right Total		6	

Left Lateral

W	A	0	1
B	A	1	1
W	V	0	0
W	H	1	1
B	V	2	2
B	H	2	1
Sub-Total		6	6
Left Total		12	

Total: 18

	R	L
M-C		
L-M		
POP		

APPENDIX V (i)

CONSENT FORM

Consent form for participation in study of recording mandibular motion and its relationship to different degrees of mouth opening.

Date ______________________________

I understand that this study involves an occlusal adjustment, if clinically indicated. This procedure may require the wearing of a plastic removable bite splint for a period of 4 to 6 weeks. The recording of the movement patterns of the jaw with a pantographic device will precede and follow the occlusal adjustment procedures.

I am aware that this study may involve 6 to 8 appointments. At the end of this study I will be given the adjusted bite splint.

I understand that the occlusal adjustment procedures, if improperly executed, may cause temporomandibular disturbances, such as tmj-pain, muscle spasms and/or bruxism, and that the pantographic recording sessions may cause tender muscles and T.M.J., which, however, is rare and minimal.

The occlusal adjustment will be directly beneficial to myself as the indicated clinical symptoms should be subsequently reduced or completely alleviated. If by my own inability the occlusal adjustment cannot be completed during the assigned appointment sessions I agree to have the adjustment procedure continued under the supervision of another dentist.

The pantographic part of this investigation should lead to the development of improved treatment techniques. This phase will be beneficial to myself regarding diagnostic information about the condition of the masticatory system and possible presence of tmj-involvement.

I have been offered the opportunity for further discussion of the clinical procedures with Dr. Kitschenberg.

During the study, I consent to the taking of photographs to be used solely for teaching purposes as educational material, and for publication in scientific journals.

I hereby voluntarily give my permission to be a participant in the above study and understand the possible effect and unpredictable side effects that may occur.

______________________________ ______________________

Patient's signature Date

______________________________ ______________________

Witness Date