A PRELIMINARY STUDY OF CONDYLAR MOVEMENTS IN MAN: characteristics of condylar movement in TMJ "closed lock".

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FIGURES AND TABLES

ABSTRACT

Farrar (1979) described that in chronic temporomandibular joint (TMJ) "closed lock", the range of jaw movement increases and the condylar movement is normal. The condylar path was studied in non-functional and functional jaw movements of the following subjects: 1) before-and-after occlusal splint therapy for a patient with TMJ "closed lock", 2) one subject with signs and symptoms of TMJ disorders, and 3) two subjects without signs or symptoms of TMJ disorders. Movements were recorded by means of an optoelectronic jaw tracking system (Metropoly, Jaws-3D) consisting of 3 cameras which register the position of 6 light-emitting diodes mounted on two target frames separately attached to the upper and the lower jaws. A computer produced plots of the condylar path in the sagittal, frontal and horizontal plane as well as the opening angle against the anterior condylar translation. Results indicated some variations in the relationship between condylar rotation and translation during jaw opening movement. Asymptomatic subjects had a linear relationship, but symptomatic subjects had a non-linear relationship. In the "closed lock" joint before the occlusal splint therapy, the movement occured mainly by rotation. After occlusal splint therapy, an increase of anterior condylar translation was found and the relationship between rotation and translation became more linear. This study supported a hypothesis of Farrar's (1979) that condylar movement in chronic TMJ "closed lock" is similar to that which could be expected in asymptomatic temporomandibular joints.

AUTHOR'S STATEMENT

This is to certify that the work presented was carried out by the candidate in the Department of Prosthetic Dentistry and has not been submitted for a higher degree at any other university or institution.

Yoshi-Nobu Shoji

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1. INTRODUCTION

1.1 <u>The condylar movements in chronic TMJ "closed lock"</u>

In 1971, Farrar hypothesized on the characteristics of condylar movement in reciprocal clicking of the temporomandibular joint (TMJ). The study of movements (i.e. disc displacement with reduction) has developed and some scientific evidence exists to support the hypothesis (Farrar, 1971; Nanthaviroj et al., 1976; Wilkes, 1987; Farrar and McCarty, 1979; Isberg-Holm and Ivarsson, 1980;Isberg-Holm, 1982; Isberg-Holm and Westesson,1982 (a) and (b); Eriksson and Westesson, 1983; Westesson, 1983; Ito et al., 1986; Palla et al., 1986; Ernst et al., 1987 (a) and (b); Mauderli et al., 1988; Merlini and Palla, 1988; Alsawaf et al., 1989) following recent developments in the field of medical engineering.

Farrar (1979) also hypothesized on the characteristics of the condylar movement in TMJ "closed lock": as locking becomes more chronic, the range of movement increases and the condylar path becomes normal.

It has been described that this is achieved by further anterior displacement and advanced deformation of the disc (Farrar 1979; McCarty, 1980(a) and (b); Westesson, 1984). Westesson (1984) claimed that increasing mouth opening in patients with anterior disc displacement without reduction should not automatically be regarded as a normalization of joint function.

In spite of numerous studies which focussed on the topic of TMJ clicking and locking (i.e. TMJ internal derangements), no objective assessment has been available to assess condylar movement in chronic TMJ "closed lock" (i.e. disc displacement without reduction).

1.2 The aims of the study

The aims of this study are:

(1) To develop a standardized manual for the use of an optoelectronic system for tracking TMJ displacement in six degrees of freedom and to apply it to subjects in order to explore its potential for studying condylar movements.

(2) To determine whether there are characteristic condylar movements in subjects with chronic TMJ "closed lock", with asymptomatic healthy subjects and symptomatic subjects as controls.

This will involve an analysis of a visual and numerical comparison of non-functional and functional condylar movement and the relationship between condylar rotation and translation during opening - closing jaw movement.

A comparison of the results will be completed to test the hypothesis:

(1) Normal condylar movements are seen in chronic TMJ "closed lock".

Further investigation of the results will clarify the following points in relation to the future use of recording techniques:

(1) Is it possible to classify different types of internal derangements?

(2) Is there any continuous progress in patients with TMJ internal derangements?

(3) Which factors will contribute the most to trigger TMJ internal derangements?

2. REVIEW OF THE LITERATURE

2.1 Arthrography

Nϕgaard (1944) was the first person to examine the technique of arthrographic examination of the TMJ. He reported that in the normal joint, the contrast medium injected into the lower joint cavity covered the condyle like a coat; this was not found in abnormal joints. Campbell (1965) reported that since Nϕgaard's study, arthrographic examination had not been developed for the field of TMJ dysfunction because of its clinical difficulty.

However, Farrar (1971) applied and revaluated arthrographic examination as a diagnostic procedure for TMJ dysfunction. He introduced the term "reciprocal clicking" to describe the condition in which there was an opening and closing click, and hypothesized characteristics of the condylar path in reciprocal clicking of the TMJ. He described that during jaw opening, the forward movement of the condyle is limited and displaced inferiorly, whilst in jaw closing, the condyle is usually displaced distally, in association with displacement of the disc.

Wilkes (1978) verified Farrar's hypothesis by using arthrography in conjunction with fluoroscopy. The specific role of anterior disc displacement in TMJ dysfunction was clarified, and was now described as "anterior disc displacement with reduction" and "anterior disc displacement without reduction". The examination of joint movement became more accurate and easier with fluorography.

Farrar and McCarty (1979) described the details of the condylar paths in TMJ reciprocal clicking, as follows: in the closed position, the disc is located in front of the condyle. When the opening click occurs, the disc snaps into its centered position and remains in contact relationship with the condyle throughout the remainder of the opening or the protrusive movement. During the retrusive condylar path, the disc remains in its centered position until the condyle approaches its starting position. Then the condyle moves downward slightly and the disc snaps forward and antero-medially, when the closing click occurs.

Arthrographic studies indicated that prior to the opening click the condyle was located behind the posterior ridge of the disc and after clicking in front of it (Wilkes, 1978; Farrar, 1979).

On the other hand, the findings by Toller (1974) did not support this explanation. He performed arthrography with 19 clicking subjects and reported that the condyle did not ride over any anterior or posterior ridge of disc structure in all cases. Thus, he suggested different mechanisms in the development of TMJ sounds. The aetiology and mechanism of TMJ sounds are debated (Nanthaviroj, 1976). It has been stated that the different mechanisms indicated different features of articular sounds (Klineberg, 1988).

Kiehn (1952) introduced the term "Internal derangement of temporomandibular joint" as a means of more correctly describing TMJ dysfunction.

Dolwick (1983) proposed that TMJ internal derangement is defined as an abnormal relationship of the articular disc to the condyle, in which the disc is usually displaced anteriorly.

Eriksson et al., (1983) described a definite difference in patients diagnosed as having anterior disc displacement with reduction, compared with those having displacement without reduction using clinical and radiological assessments. They reported that clinical assessment indicated clicking occurred in both groups. However it was more frequent in patients showing displacement with reduction, and radiologically for patients with displacement without reduction, the limitation of anterior condylar translation was more frequently exhibited at maximal opening.

Westesson (1983) extended the diagnostic technique by developing a technique for double-contrast arthrography. Iodine-contrast medium and air were injected into both joint compartments, thus the articular surfaces became coated with radiopaque contrast medium and the joint compartments expanded by air. The resulting arthrograms depicted the disc and the articular surfaces with enhanced definition.

A modern approach to conservative treatment of TMJ disorders is based on knowledge about the soft tissues of the joint (Westesson 1983). In this regard, it is reasonable that the use of TMJ arthrography has been increased.

A recently published magnetic resonance imaging (MRI) study (Katzberg et al., 1988) indicated that sideways and rotational displacement of the TMJ disc frequently occurred in up to about 25% of patients with internal derangement. By "sideways displacement" they implied that the disc was displaced medially or laterally without an anterior component to the displacement; rotational displacement implied a combination of anterior and medial or lateral displacement.

Liedberg et al. (1990) performed arthrography for the diagnosis of sideways and rotational displacements of the TMJ disc and concluded that arthrographic diagnosis of such disc displacements may be difficult. Further, they suggested that other diagnostic methods should be considered when these types of disc displacement were suspected.

Ash (1986) indicated that arthrography was often painful, time-consumming, and required sophisticated equipment as well as considerable experience in order to perform this displacement procedure.

2.2 Cineradiography

The cineradiographic technique was first described by Klatsky in 1939.

Serial recordings of the movements of the TMJ may be made by photographing a fluorescent screen on which the moving object is reproduced by roentgen radiation (McLeran et al., 1967). This method was termed cinefluorography (Berry et al., 1957).

Several studies (Lindholm 1957, Berry et al., 1957,) have described general observations of the functioning TMJ recorded by cinefluorographic techniques.

McLeran et al. (1967) first attempted to classify or categorize the patterns of jaw opening and closing movements of 35 clinically normal TMJs. It appeared, however, from the results of the study that there was a wide variation in individual movements.

Isberg-Holm et al. (1980) obtained a continuous radiographic registration of condylar movements in individuals with and without clicking. Cineradiography and fluoroscopy were used simultaneously, the film speed being 0.02 seconds per frame and the duration of each film being 7-10 seconds. In this way, it was possible to obtain a graphical representation of the condylar path during opening and closing movements. They reported that condylar movements were unsynchronized in clicking joints but were synchronized in normal subjects.

In 1982, Isberg-Holm carried out simultaneous registration of jaw movements and recordings of TMJ sounds using a video-film technique in combination with cineradiography and oscilloscopic sound registration. Lateral deviation of jaw movements in association with clicking during opening or closing and also jaw movements without lateral deviation in clicking patients were reported. In the latter, jaw movement was not influenced by the onset of clicking, and the condylar movement exhibited an irregularity simultaneously with the lateral jaw movement.

Isberg-Holm and Westesson (1982a) performed cineradiography in combination with arthrography on TMJ autopsy specimens with clicking. In this way, the movements of disc and condyle could be registered simultaneously in association with clicking and examined subsequently by dissection. They reported that on opening and closing, the condyle slipped over the posterior ridge of the disc in association with clicking which caused the sudden deviation in condylar path. The observation from the previous clinical study was confirmed in the autopsy specimens.

Further, these authors(Isberg-Holm and Westesson 1982b) developed high-speed cinematography for autopsy specimens with and without clicking, to permit close examination of clicking movements. They reported again that in joints without clicking, even and smooth movement of condyle and disc was observed whilst in joints with clicking, the rapid movement of disc and condyle in association with clicking was delineated. Thus, Farrar's hypothesis was verified by these cineradiographic studies.

In cineradiography, many of the problems caused by influencing chewing movements were eliminated, since there was no requirement of external connections. However, there are other problems: immobilization of the head was required, there was risk of tissue damage due to radiation, (Karlsson, 1979) analysis was time-consuming (Jemt, 1984) and slower camera speeds increased the risk of inaccuracy (Saxby et al., 1976).

2.3 Pantography

In 1934, McCollum demonstrated a recording apparatus which was called a "Gnathograph". This was the first instrument that was designed to accurately record the condylar path for more refined clinical work and was a marked advance on other instruments. It led to the need for the development of the fully adjustable articulator by Stuart (1959). Stuart indicated that most modern articulators could be made to reproduce simple opening-and-closing rotation, but not the protrusive and lateral movements; and we need to know the linear characteristics of the protrusive and lateral movements in order to make acceptable restorations. He developed the first fully adjustable articulator and established the procedure to transfer the record of physiological mandibular movements accurately from the patient to the apparatus. It made it possible to closely reproduce a patient's condylar and mandibular movements on the articulator that was called the gnathograph.

Many variations of this instrument have appeared over the years. Guichet (1967) developed the Denar Pantograph (Denar, Anaheim, California 92806, U.S.A.) as a more simplified version of the gnathograph and established the Stuart's value in clinical diagnosis.

Pantography was used to demonstrate the individual variations which exist in movements of the jaws of different subjects (Van Rensburg et al., 1974).

Roura et al. (1975) used pantography to observe mandibular movements on subjects with TMJ dysfunction and indicated that TMJ patients had non-reproducible border movements.

Clayton et al. (1976) indicated that there was a need for objective methods of detecting the presence or absence of TMJ dysfunction and proposed a Pantographic Reproducibility Index (PRI) to identify muscular and occlusal problems and for monitoring treatment.

Shields et al. (1978) reported a relationship between the reproducibility of the pantographic tracing and the degree of dysfunction using the Helkimo Index (Helkimo 1976) and reported that the mean reproducibility of the pantographic tracing decreases when the degree of dysfunction increases.

Beard et al. (1980) used the PRI to monitor the success of occlusal splint therapy and reported that occlusal splint therapy reduced TMJ symptoms and decreased PRI index scores. They confirmed that the PRI was an effective aid in detecting and monitoring the TMJ dysfunction symptom of muscle incoordination.

Studies of pantographic tracings of condylar movements have reported the ability to distinguish TMJ patients from normal subjects (Roura and Clayton 1975, Clayton et al. 1976, Shields et al. 1978, Beard 1980). However , at the present time, the claim that pantographic devices have diagnostic value for TMJ is not well supported by scientific evidence; TMJ dysfunction was diagnosed by the PRI score, even when there was a complete lack of clinical symptoms (Mohl et al, 1990).

Mongini (1980) examined the factors influencing the characteristics of pantographic tracings with radiographic examination of the condyle in conjunction with pantography. He reported that a straight tracing was associated with flattened condyles and a curved tracing with rounded condyles. Mongini et. al. (1982) evaluated the influence of anatomic and neuromuscular factors on pantographic tracings of mandibular border movements, and claimed that sudden deviations in the tracing may be observed in disc-condyle incoordinations.

Bates et al. (1986) described a simple procedure that was used at chairside to determine TMJ click positions.

The procedure uses the Quick-Set recorder (Whip-Mix Corporation, Louisville, Ky.) and the condylar movement path is recorded on graph paper in the sagittal plane. They reported that a "figure-of-eight shaped" condylar path occured in reciprocal clicking. This compared with a curved path in non-clicking joints.

Mauderli et al. (1988) recorded condylar movements by using a simplified condylar movement recorder, the SAM Axiograph (SAM Prazisionstechnik, Munich, West Germany). They identified six condylar movement patterns in clicking subjects and concluded that it was reasonable to assume that an anteriorly displaced disc with reduction was present when a "figure-of-eight pattern" was recorded.

Thus, these studies using pantography verified Farrar's hypothesis.

Van Rensburg et al. (1974) indicated that there was no differentiation between rotation or translation about the X, Y and Z axes in pantographic tracings, as it recorded the three dimensions of jaw movement in two planes. They claimed that the jaws could be regarded as bodies having six degrees of freedom of movement namely three rotations and three translations. Mongini (1984) proposed that a system with six degrees of freedom was required to study the complex functional movements of the jaw.

2.4 Jaw Tracking

Hickey et al. (1963) reported the first comprehensive study using cinephotography to monitor condylar movements. Pins were surgically inserted into the author's own TMJ condyle. Lights were attached to follow condylar movement. The lights, together with an incisal pointer, were photographed. A further development is using three synchronized cameras to replace the mirror system originally used to achieve three dimensional (3-D) registration of jaw movements.

In recent years technically advanced electronic systems(Gibbs et al., 1971; Van willigen,1979; Alsawaf et al., 1989) have been employed for the tracking of condylar movements.

Gibbs et al. (1971) developed the Replicator system which recorded jaw motion with the aid of two facebows attached to the upper and lower dental arches. Jaw movements were transmitted to recording equipment by six photoelectric transducers within the facebow system. The photocells transformed the displacement of the mandible into electrical signals, which were then stored on multichannel tape and connected to a computer. Computer analysis allowed measurment of the position of any point on the mandible, rather than a single point in the incisor area. They reported functional condylar movements in six degrees of freedom in asymptomatic subjects, and found that reproducible tracing were obtained for the opening paths, when the condyles move downward and forward and in the closing paths, when the condyles moved upward and rearward. The closing paths were found to be posterior and inferior to the opening paths. In chewing, both condyles began the opening immediately downward and forward; early in closing, the working side condyle moved upward and rearward and reached its terminal position at the most vertical rearward position before intercuspation. During the remainder of the stroke, the working side condyle moved medially and anteriorly to its closed position. The non-working side condyle moved upwards and laterally to its closed position (Gibbs et al., 1980).

Van Willigen (1979) reported condylar movements of five healthy subjects and five patients with unilateral or bilateral clicking joints. He developed an electronic pantograph consisting of two facebows which contained photoreceptors. By means of two movement scanners, the positions of the photoreceptors in the sagittal planes were determined bilaterally through optical electronics. In the clicking group he found that at the moment of clicking, clear deviations occured in the smooth movement pattern as found in the normal group. The registration of condylar movements in three dimensions was suggested for a deeper study of the mechanism of the clicking.

Mesqui and Palla (1985) developed an optoelectronical system for recording jaw movement. The system was constructed by three one-dimensional cameras which register the position of six light-emitting diodes mounted on two target frames attached to teeth of the upper and lower jaw. A computer produced plots of the condylar plane on line: This was called the Jaws-3D tracking system. They reported that it was non-invasive and did not in any way restrain the patient, restricting instrumentation to record movements of any point on the mandible (in six degrees of freedom).

Merlini and Palla (1988) reported that in subjects without signs or symptoms of TMJ disorders, jaw opening occurred by a combination of condylar translation and rotation, and the ratio was highly linear. However, in clicking joints with a sudden deviation of the condylar path at the position of clicking, the jaw movement started mostly by rotation. Thus, non-linear relationship between condylar rotation and translation existed.

Ito et al. (1986) examined the stability of the disc during chewing on the deranged and non-deranged sides for a patient with the reciprocal clicking and found that the disc was more likely to remain in place during chewing on the non-deranged side. They delineated a deviation of condylar movement during reciprocal clicking in the sagittal plane by means of the Replicator system. The lateral deviation during an opening click in the frontal view was also reported.

Alsawaf et al. (1989) examined the angles of condylar guidance in the sagittal plane during opening and closing movements in subjects with and without TMJ clicks, by means of the computerized Axiograph (GAMMA Institute U.S.A. Rochester, N.Y.). The tracings showed that deviations occurred in the condylar path during both the opening and closing clicks and demonstrated that the posterior part of the closing movement was inferior to the opening condylar path in subjects with clicking. They also concluded that there was no difference in condylar inclination between clicking and non-clicking subjects.

In these studies of jaw tracking the condylar movement again showed a "figure-of-eight pattern" during reciprocal clicking in the sagittal plane (Van Willigen, 1979; Ito et al., 1986; Alsawaf et al., 1989).

Consequently, the Replicator system allowed the measurement of the condylar movement in six degrees of freedom. However, some problems have been indicated: difficulty for clinical application in dentistry (Mesqui et al., 1985), and heavy weight of its clutch (Bates et al., 1975). Lewin et al., (1974) indicated that bulky clutches may change the masticatory pattern due to variations in the sensory feed-back system.

2.5 Summary

Recently, diagnostic devices in dentistry have made rapid progress thanks to the development of computer science. The efficiency of these devices is well established, however, additional factors need to be considered. These include easier clinical application to dentistry and physiological application in patients.

3. METHODS

One patient diagnosed with TMJ internal derangement, and three control subjects matched for age and sex were selected for the study.

3.1 Control Subjects

Three subjects from the Department of Prosthetic Dentistry of the University of Sydney were asked to participate in this investigation as control subjects. All subjects were male with an age range of 26 to 44 years (mean 35yrs). A summary of the control subjects is given in Table 3.1.

NAME	AGE	SEX	O'BITE (mm)	O'JET (mm)	NO. OF TEETH	JAW RELATIONSHIP
PH	44	M	2	2	28	class I
GM	34	M	1	1	28	class I
CP	26	M	5	3	28	class II

Table 3.1 Table showing the Age, Sex, Occlusal and Jaw Relationship of the Control Subjects.

Subject PH and CP had no clinical signs or history of TMJ disorders. Subject GM had a history of TMJ clicking, but no other symptoms such as myofascial pain or limited jaw movement. This subject had had no previous treatment, and was not seeking any treatment for clicking.

3.2 Dysfunction Subjects

A 16-year-old female patient with a history of TMJ locking was asked to participate in this investigation. The first series of two recordings was made before occlusal splint therapy and the second series six weeks after the initial recording.

3.2.1 Case History

The patient attended the Oro-Facial Pain Clinic at Westmead Hospital Dental Clinical School in March, 1991. She had had a history of left TMJoint "closed lock" during mouth-opening over the previous six months. During this time her chewing ability was strongly impaired and her chief complaint was difficulty in jaw opening.

The patient had undergone orthodontic treatment for an Angle Class II division 1 malocclusion for three years, and shortly after completion of orthodontic treatment, TMJ clicking on the LHS began and gradually became worse. The first episode of TMjoint locking was observed six months ago, and now joint clicking was no longer present.

The patient was a high school student and had a healthy appearance and showed no symptoms of any other illness.

3.2.2 Clinical Examination

An examination following the standardized procedure of the Oro-Facial Pain Clinic was carried out (See copy of completed form in Table 3.2.).

Occlusal examination disclosed that four bicuspid teeth had been extracted and there remained an Angle Class II division 2 occlusion with 5mm overbite and 3mm overjet (Fig. 3.1A, B and C).

The maximum jaw opening measured 18mm; lateral jaw movement to the right was 8mm, to the left 9mm and the protrusive movement was 10mm. Slight jaw deviation to the LHS was observed with jaw opening. The discrepancy between retruded position (RP) and intercuspal position (IP) was 1mm with an RP supracontact on the left maxillary and the left mandibular first bicuspid teeth.

Binding ...argin — No Writing

ORO — FACIAL PAIN AND DYSFUNCTION

CLINICAL EXAMINATION:

Date:	19.3.91		7.6.91							
1. T.M. JOINTS	R	L	R	L	R	L	R	L	R	L
Pain — lateral	–	–	–	–						
Pain — posterior	–	–	–	–						
Clicking	–	–	–	–						
Crepitation	–	–	–	–						
Limited movement	1	2	–	1						
? Subluxation	–	–	–	–						
Inflammation	–	–	–	–						
Score	1	2	0	1						

2. JAW MUSCLE PALPATION	R	L	R	L	R	L	R	L	R	L
Temporal ant.	–	–	–	–						
Temporal post	–	–	–	–						
Temporal tendon	–	–	–	–						
Masseter origin	–	–	–	–						
Masseter body	–	–	–	–						
Masseter insertion	–	–	–	–						
Masseter deep	–	–	–	–						
Pterygoid med.	–	–	–	–						
Pterygoid lat	1	2	–	–						
Digastric ant.	–	–	–	–						
Digastric post	–	–	–	–						
Sternomastoid origin	–	–	–	–						
Sternomastoid body	–	–	–	–						
Sternomastoid insertion	–	–	–	–						
Trapezius origin	–	–	–	–						
Trapezius insertion	–	–	–	–						
Tongue	–	–	–	–						
Submandibular gp.	–	–	–	–						
Score	1	2	0	0						
Total Score	2	4	0	1						

3. MANDIBULAR MOVEMENTS Opening Max. incisor dist. 2.1/3.1	mm 18	Pain localisation and degree	Clicking point mm Hard/Soft	Provocation test Pain/fatigue at bruxofacet location	Deviation open — close R L 5 0 mm 5	Deviation open — close R L 5 0 mm 5
Vertical overbite	5					
Horizontal overbite	3		Nil			
Max. laterotrusion R	8					
Max. laterotrusion L	9					
Max. protrusion	10					
Score pain						

Date:	7.6.91											
MANDIBULAR MOVEMENTS REASSESSMENT	mm	Pain	Click mm	mm	Pain	Click mm	mm	Pain	Click mm	mm	Pain	Click mm
Opening Max. incisor dist.	35		Nil									
Max laterotrusion R	8											
Max. laterotrusion L	9											
Max protrusion	10											
Score pain												

DR-10

Table 3.2 A copy of the form used in the examination.

Figure 3.1A The preoperative frontal view of subject EA in the intercuspal position.

Figure 3.1B The left side view of the diagnostic casts in the retruded position.

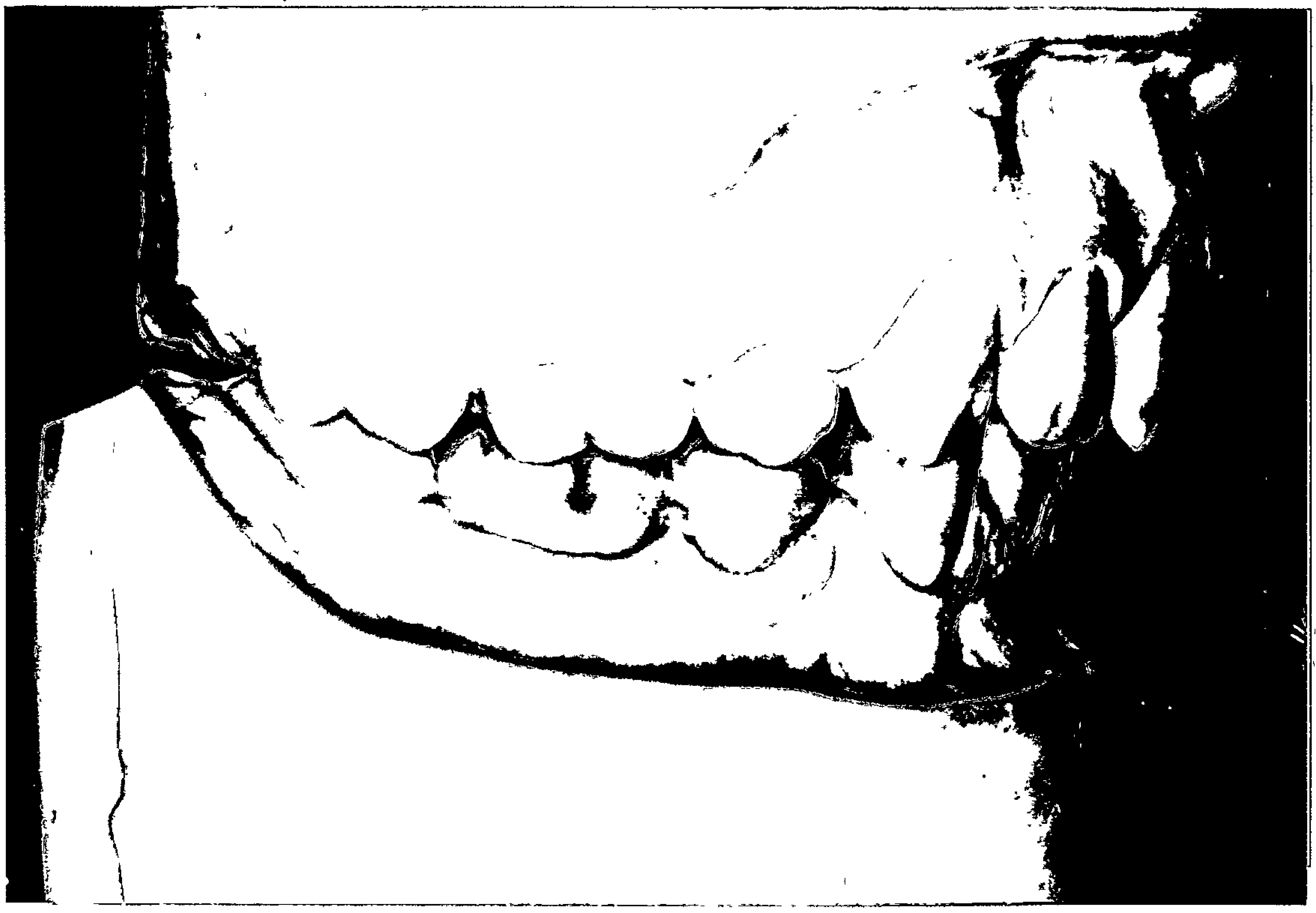


Figure 3.1C The right side view of the diagnostic casts articulated in the retruded position.

Auscultation with a stethoscope revealed no joint sounds and there was no joint tenderness to posterior and lateral palpation.

Clinical examination revealed tenderness to palpation in the left lateral pterygoid muscle and discomfort in the right lateral pterygoid muscle. No other muscles were tender to palpation.

Slight to moderate attritional tooth wear was evident on the maxillary central incisors and canines, and on the mandibular lateral incisors and canines.

3.2.3 Radiographic Examination

Transcranial radiographs suggested that the left condyle may have been displaced posteriorly (Fig. 3.2).

Figure 3.2A Transcranial radiograph shows the preoperative condition of the temporomandibular joint. (Left side closed).

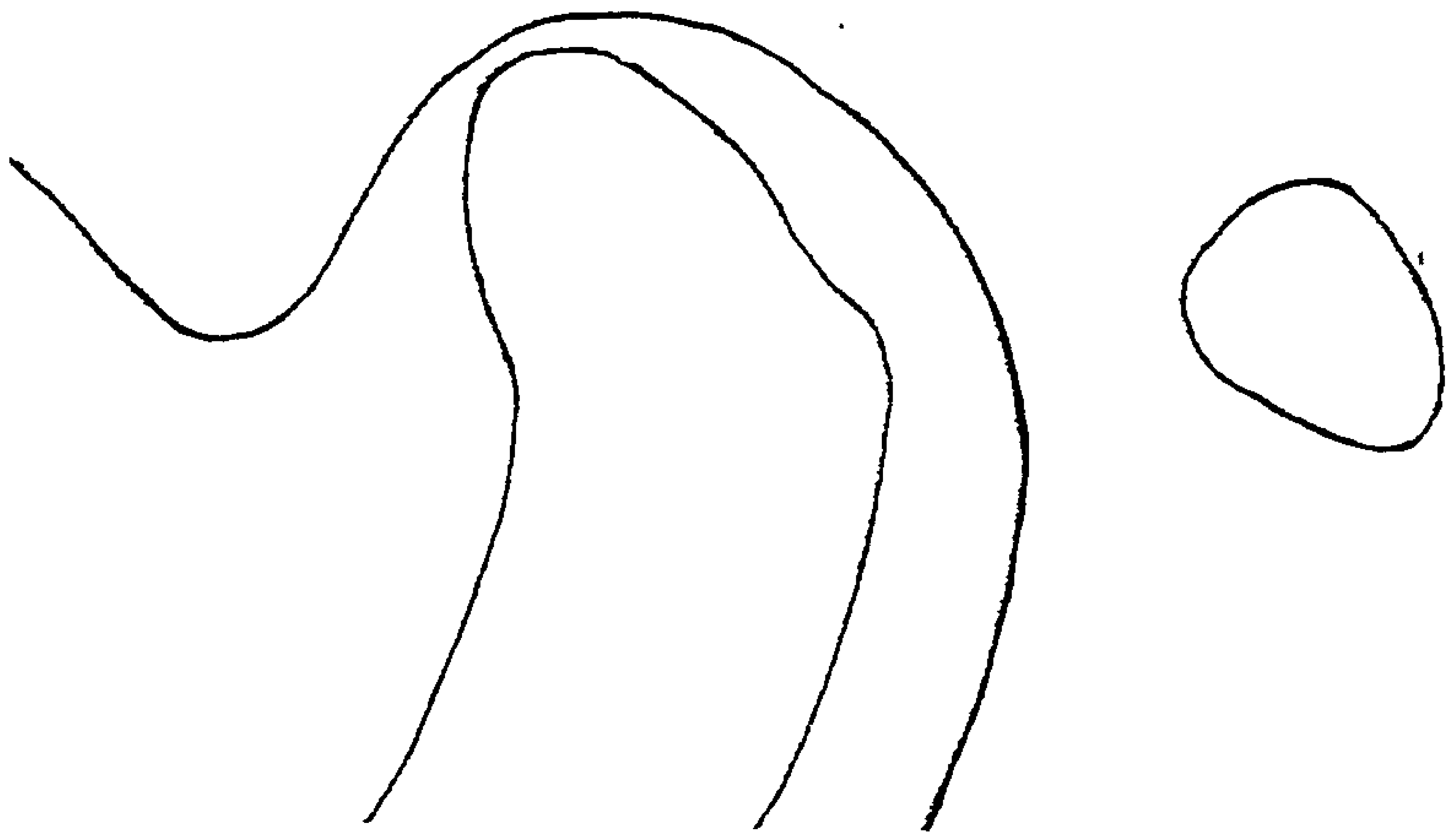


Figure 3.2B Diagrammatic representation of transcranial radiograph of the left temporomandibular joint.

Further, inferior joint space arthrography performed for left TMjoint revealed a well established disc displacement without reduction, but there was no evidence of perforation (Fig. 3.3).

Figure 3.3A Arthrogram of the inferior joint space of the left temporomandibular joint with jaw opening.

Figure 3.3B Diagrammatic representation of the left side inferior joint space arthrogram.

3.2.4 Treatment

Initial management of such internal derangement problems involves reversible therapy.

An upper flat plane occlusal splint (Ramfjord and Ash, 1966) was fitted which the patient was instructed to wear as often as possible during the day and especially at night while sleeping (Fig. 3.4). The splint was worn after the initial recording until the second recording, which was made after a period of six weeks. Instructions were given for the patient to eat a soft diet only.

Following the six-week splint therapy, the patient showed remarkable improvement - she reported less difficulty with jaw opening, the maximum range for jaw opening increased from 18 to 35mm, and a resolution of tenderness was apparent in the left lateral pterygoid muscle. See clinical examination assessment (Table 3.2).

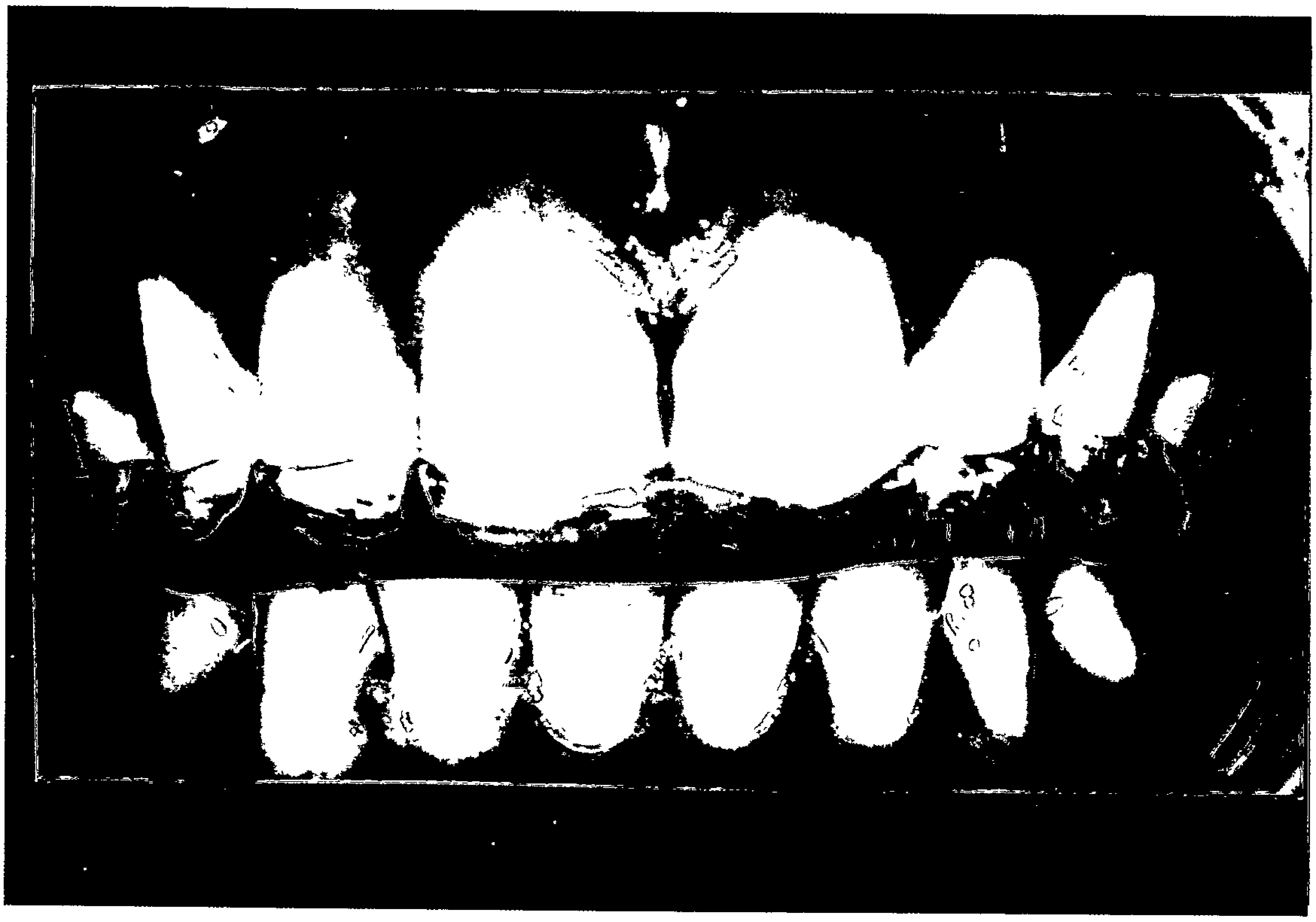


Figure 3.4 The maxillary occlusal splint fitted to the maxillary teeth with the jaw in intercuspal position.

3.3 Introduction of the Jaws-3D Tracking System

The system is an optoelectronic tracking system which allows the clinician to monitor on-line the three-dimensional motion of any point on the jaw.

The system was originally developed at the Dental Institute of the University of Zurich (Mesqui et al., 1985, 1986a, 1987b; Mesqui & Palla, 1985, 1987; Ernst et al., 1987a, 1987b; Earnst, 1988; Merlini et al., 1987; Merlini and Palla, 1988; Palla et al., 1986; Rohrer, 1988) and is now manufactured by METROPOLY AG in Zurich, Switzerland (Jaws-3D user's manual. METROPOLY AG 1990;1).

3.3.1 Design Criteria

The system has been designed to meet the following criteria: 1) there is no interference with jaw function;

2) there is no head movement restriction and no bulky instrumentation-weight of rod attaching light source is in the order of 4-5 grams;

3) it is non-invasive and allows natural tooth contact and normal lip contour;

4) it may be used by a clinician without technical support;

5) the software allows on-line and easily interpretable representation of the measured data;

6) the software allows off-line data collection for long time storage; and,

7) it is flexible and inexpensive to operate.

Thus, the system is acceptable to be used in a dental clinic, but is primarily a research tool.

3.3.2 Operating Principles

Several methods have been developed for the kinematic analysis of jaw movements (Kinzel and Gutowski, 1983). In the Jaws-3D system the mandible is considered to be a rigid body which moves relative to the upper jaw with six degrees of freedom. This can be expressed in the form of three rotations and three translations (Van Rensberg 1974).

Spoor (1980) claimed that the movement of a rigid body from a position 1 into another position 2 can be characterized by a translation vector and a rotation matrix, and if the spatial coordinates of the three non-linear reference points of the rigid body are known, it is possible to compute the spatial locations of this rigid body.

For this purpose a target frame containing three Light Emitting Diodes (LEDs) are fixed to the upper arch and the lower arch, and from these LED coordinates, the rotation and the translation of the head and the jaw are determined. Furthermore, it is possible to compute the coordinates of the arbitrary jaw point (Fig. 3.5).

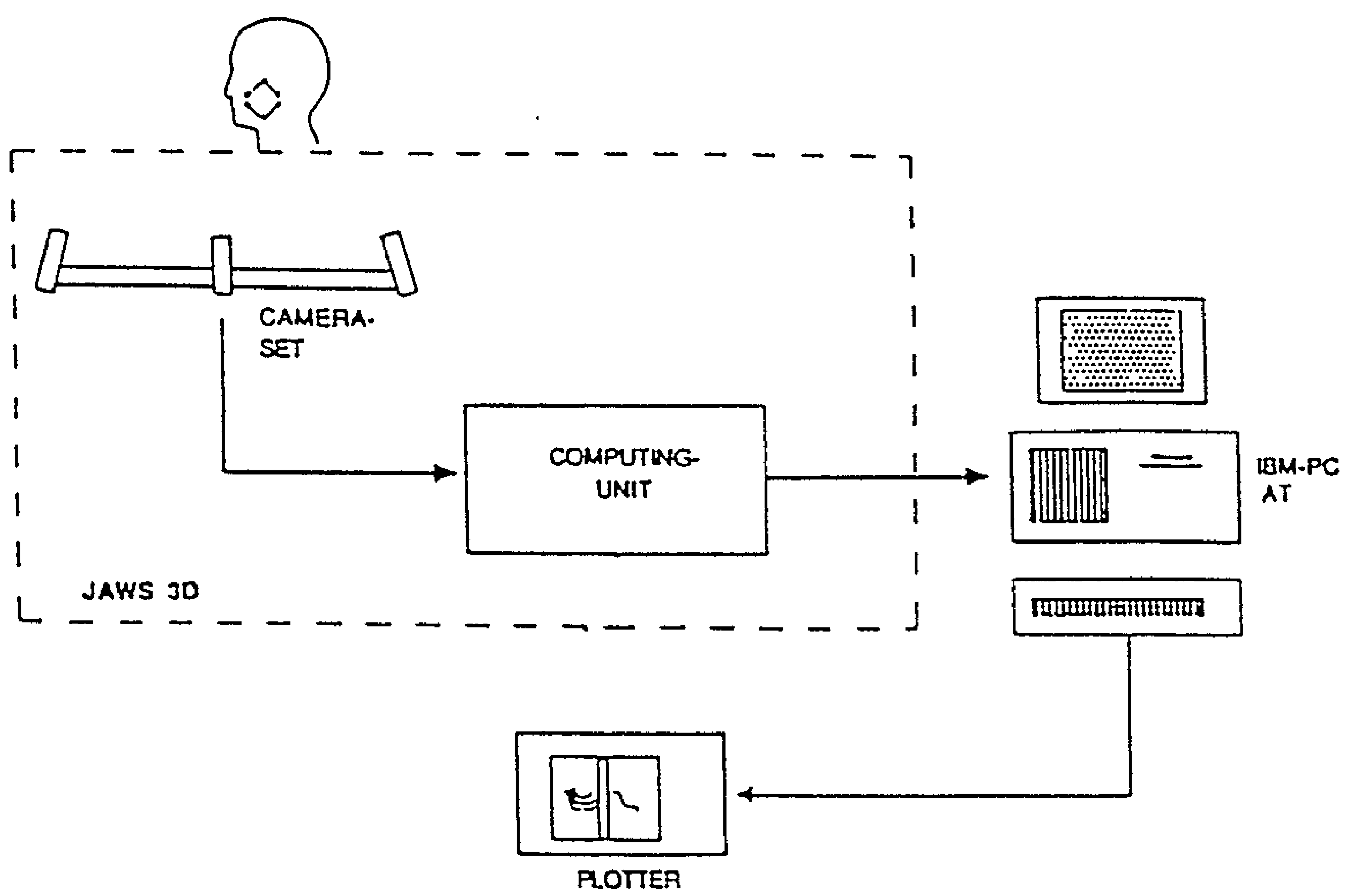


Figure 3.5 Diagram of the optoelectronic system Jaws-3D.

3.4 Subsystems

3.4.1 Target LEDs

The target frames each contain three LEDs (Fig 3.6) and the weight of the frame is only 2g. Each LED is fired cyclically every 2ms. The upper and lower target frames each define a coordinate system.

The upper coordinate is the reference coordinate which defines the anatomic plane and the movement of the head. The lower coordinate is the non-reference coordinate which defines the movements of the head and jaw.

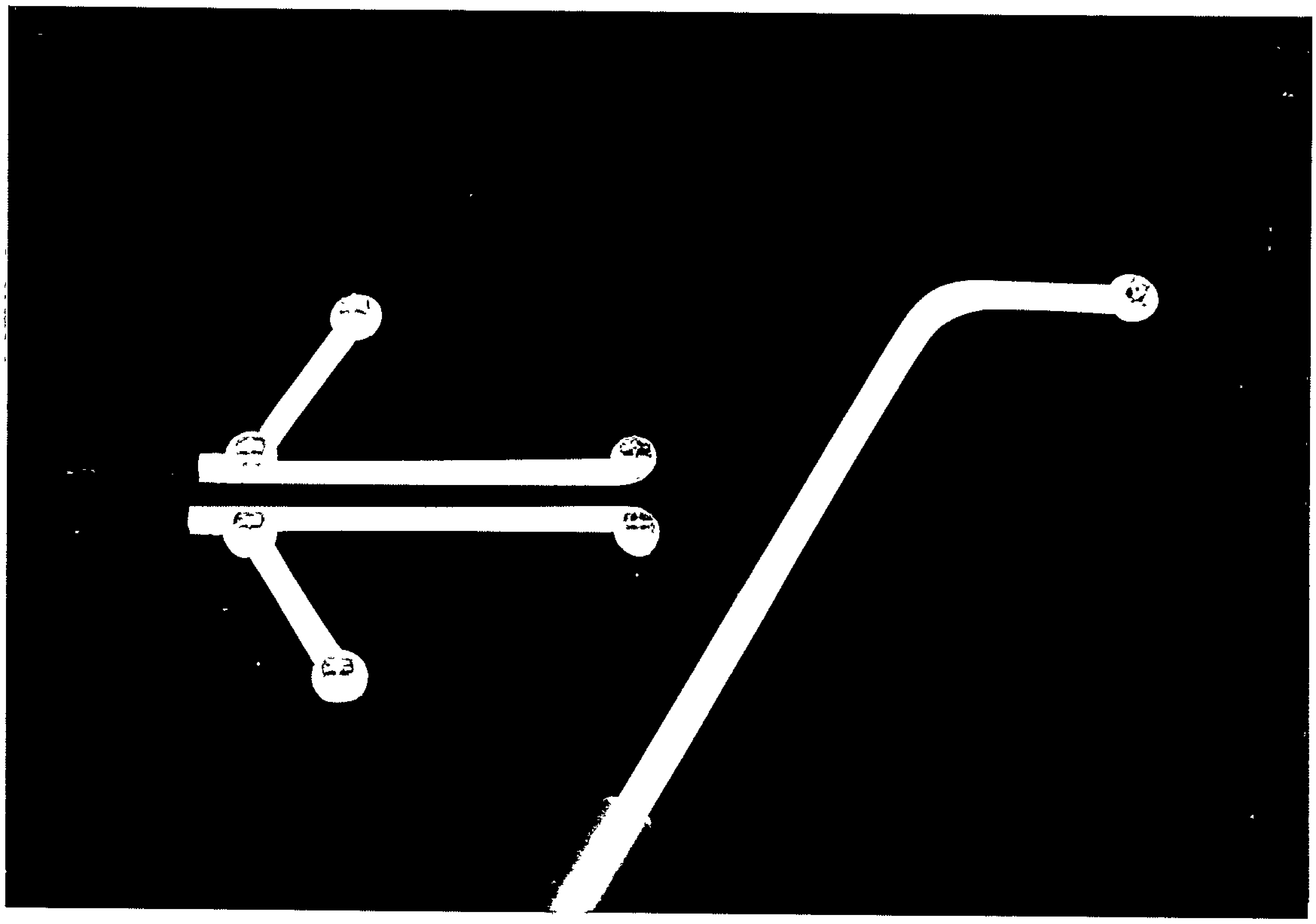


Figure 3.6 Upper and lower target frames, and the LED of the pointer.

3.4.2 Measurement System

The system consists of three single dimensional linear cameras with a cylindrical lens in each of them (Fig 3.7). The centre of the field of view is situated 35cm to the front of the cameras. The field of view is a slightly deformed cube with side-lengths of 14cm.

Three sensors deliver a video signal which is proportional to the incident light. The video signal is first digitized and fed to a reconstruction unit which computes the spatial location of the LEDs in less than 1ms.

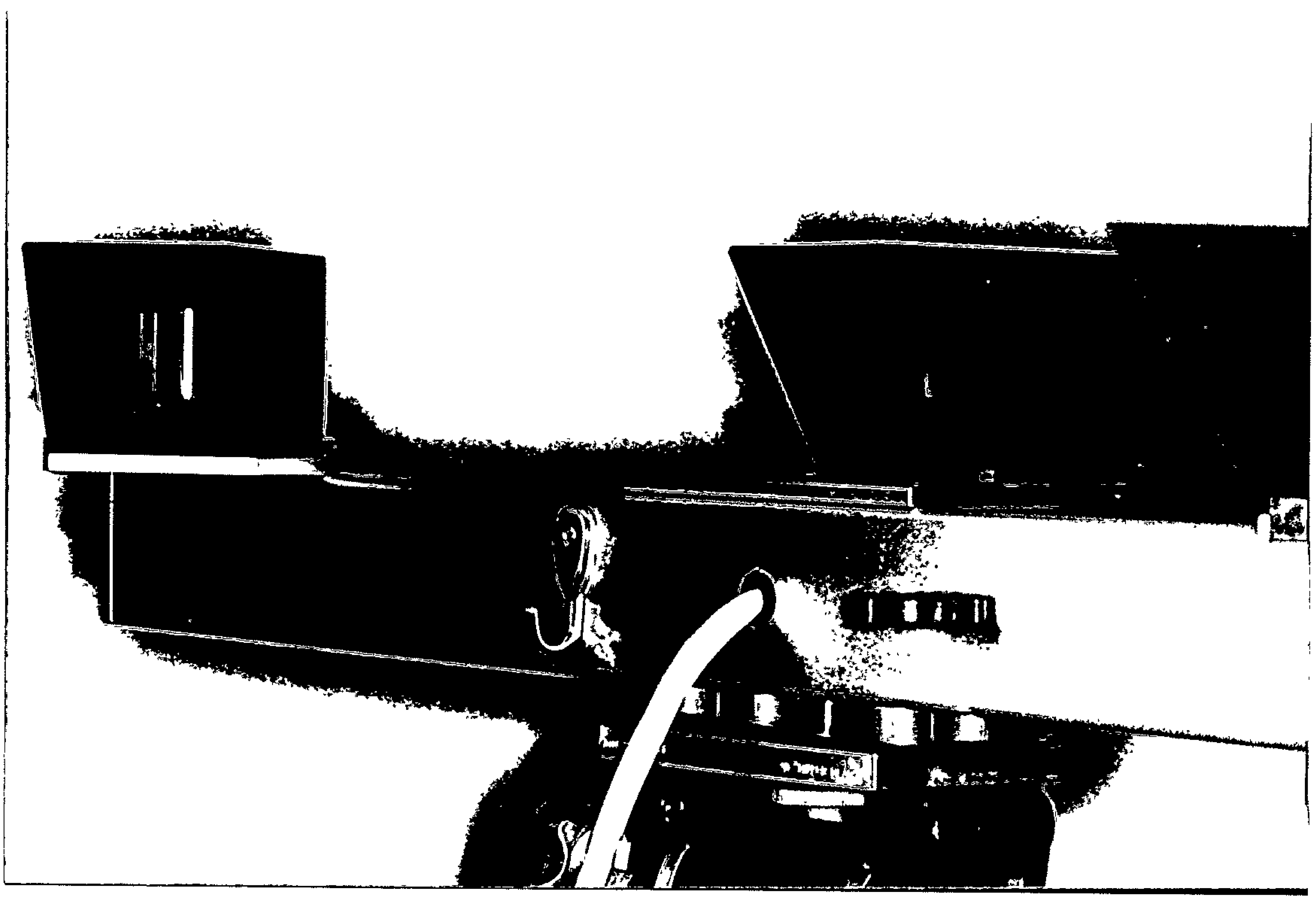


Figure 3.7 Three single dimensional linear cameras.

3.4.3 Computation Unit

The computation unit is designed around two modes:-

a) the normal mode

b) the preselection mode

a) The Normal mode.

The system first computes the spatial location describing head motion from the position of the LEDs of the upper frames. Next it computes the spatial location describing the combined motion of head and mandible from the position of the LEDs of the lower frame. By standard coordinate transformation techniques, the system subtracts the head motion from the combined head and mandible motions and can deduce any point of the mandible in a head-related coordinate system.

b) The Preselection mode.

A pointer with LED (Fig. 3.6) is used to preselect the point of interest on the mandible. The coordinates of the jaw point are determined with respect to a non-reference coordinate system of the lower target frame fixed on the mandible. Therefore, the system knows which points of the jaw should be tracked and one coordinate can be modified manually to be sure that the point is within the body.

3.4.4 Display Unit

The location of the jaw point is displayed on a three dimensional display unit and a printer which is linked to the system produces the trajectory of the jaw point. The system allows on-line observation of trajectory of the preselected point.

3.5 Pre-recording Preparation

3.5.1 Mounting Cast

The mid-sagittal and occlusal planes were chosen as a reference for the analysis of the condylar path. In order to fulfil these requirements, the maxillary cast was mounted in the Denar Mark II articulator (Denar, Anaheim, Cal, U.S.A.) using a custom made mounting plate and then the mandibular cast was articulated in maximum intercuspation.

3.5.2 Construction of Clutch

Cast metal clutches were fabricated by forming a pattern of Duralay resin (Reliance Rental Mfg, Col, Worth II., U.S.A.) and a soldering wire (Solder, RCS- 2 Arista Electronics, Australia) on the cast. The pattern was then placed in the mouth and the wire bent to fit lip morphology, in order not to impair lip function.

Before casting, the pattern was checked for interferences in centric occlusion, protrusion and laterotrusion on the cast.

The upper and lower target frames were fixed to a custom-made frame device which could place the target frames parallel to the mid-sagittal plane and perpendicular to the occlusal plane. Once the target frames were positioned, the pattern was adjusted to the frames after bending the soldering wire. The pattern was removed from the cast and invested (Kristbalite investment, Shohu, Japan).

3.5.3 Casting

The pattern was cast with a semiprecious metal (Novopal 3, Cendres & Metaux SA, Switzerland). The weight of the clutch including casting and attachment was measured with a balance. Its overall weight was about 7 grams. Thus the total weight of the clutch and target frame was less than 10 grams. After the casting, the upper and lower clutches were remounted on the articulator in order to check the position of the target frames.

3.6 Recording Technique

The recordings of the patient were carried out before the commencement of the occlusal splint therapy, and again after six weeks, when she had a resolution of her clinical symptoms.

3.6.1 Recording Procedure

Two metallic clutches were attached with composite resin(SYSTEM 1 + ,ORMCO, California, USA) to the buccal tooth surfaces in the canine-bicuspid region in the upper and lower arch (Fig. 3.9), ipsilaterally to the TMjoint to be studied. Two target frames, each carrying three light emitting diodes (LEDs) were connected to the clutches that were designed to enter the mouth and be unobstructive.

The upper and lower target frames were connected by custom-made attachments.

The condylar point to be recorded was palpated laterally to the condylar pole and identified, and a point 15mm medial to the skin surface (Merlini & Palla, 1988) was selected as the approximate centre of the condyle based an anatomical data concerning condyle size.

Figure 3.8 Metallic clutches attached to the buccal teeth surfaces in the upper and lower arch.

Figure 3.9 The upper and lower target frames attached to the upper and lower dental arch by custom-made metallic clutch.

3.6.2 Experimental Procedure

Subjects sat in an upright position in a chair during the recording and were asked to perform the following jaw movements:

1) single maximum opening and closing movement;

2) a sequence of five consecutive opening and closing movements;

3) chewing movements with a softened chewing gum on the right and then on the left side;

4) protrusive slide-edge to edge;

5) lateral slide to the right and then to the left;

Each subject performed a series of trial movement sequences under operator instruction to become accustomed to the requirements of each procedure. All procedures were performed at a rate that was comfortable for the subject and in a quite relaxed atmosphere that was temperature-controlled.

3.6.3 Data Processing

The jaw motion data were recorded on a floppy disc with a personal computer (APC N, NEC Corporation, Tokyo, Japan). The three dimensional condylar trajectory was reconstructed and the graphic display of the trajectory in three planes was provided and printed.

The computer produced plots of the opening angle (OA) versus the anterior condylar translation (AT). The OA which was used as a measure of condylar rotation was calculated by computing the instantaneous angle between the bases of the upper and lower triangular target frames. This angle could be considered as the angle produced by the jaw in relation to the head-related reference plane.

The anterior condylar translation was calculated as the distance between the projection of the begining and the end of the condylar path on the horizontal plane. Therefore, it was not the actual length of the condylar path.

3.6.4 Data Analysis

The condylar trajectories in the sagittal, horizontal and frontal planes were examined visually. The ratio between OA and AT in TMJoint during opening and closing movements were plotted and examined. Student T-test was performed for analysis of range of movement with the three parameters:

1) the lateral range of movement,
2) the antero-posterior range of movement,
3) the vertical range of movement,

across three groups of chewing movements:

1) 3 subjects in the control group,
2) patient EA in the chronic stage of "closed lock",
3) patient EA in the acute stage of "closed lock".

3.6.5 Statistics

All parameters were presented as mean ($\bar{x}$) values with the additional standard deviation (S.D). The data were compared statistically by Student T-test at the 0.01 significance level.

3.7 Determination of Errors

A preliminary test was performed to determine the errors of the Jaws-3D tracking system.

3.7.1 Accuracy

In order to study the actual representation of the three-dimensional movement pattern, a calibrated device which could repeat that movement was fabricated (Fig. 3.10). The three planes (x, y, z) of movement at the point of w (0.0.0), was to be analyzed within the 10mm range. The movement accuracy was to be determined by comparing the actual movement as indicated by the calibrated device, with the analyzed movement. The actual distance of the movement was measured by a dial gauge (Baty, J.E. BATY & CO. LTE. SUSSEX, UK) and the analyzed distance of the movement was provided with the analyzing programme of the system.

A personal computer was used to provide a means of statistically analyzing all of the data using the "SAS" programme (SAS Institute Inc, SAS circle, Cary, NC).

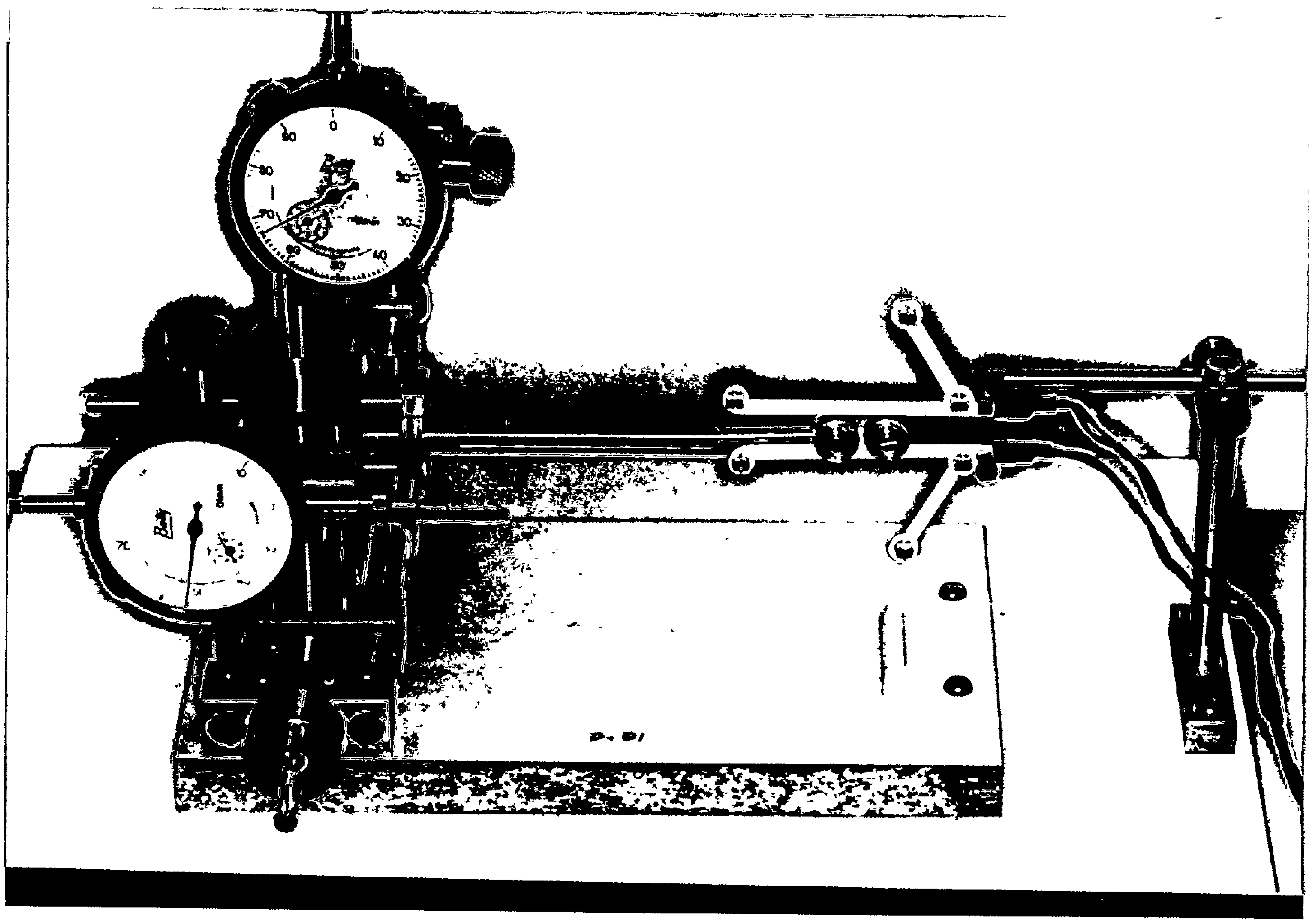


Figure 3.10 Three dimensional positioning device for calibration of the Jaws-3D tracking system.

3.7.2 Stability

In order to study the stability of the system, recordings were made in a motionless state when the LEDs were fixed to the calibrated device. It was repeated ten times for a duration of twenty seconds.

3.7.3 Accuracy of the Angle

In order to study the actual representation of the angle between the bases of the upper and lower triangular target frames, a calibrated device which could repeat that angle was fabricated (Fig. 3.11). The opening movement at the point of w(0,0,0) was to be analyzed within the range of a 10 degrees angle. The angle accuracy was to be determined by comparing the actual angle as indicated by the calibrated device, with the analyzed angle.

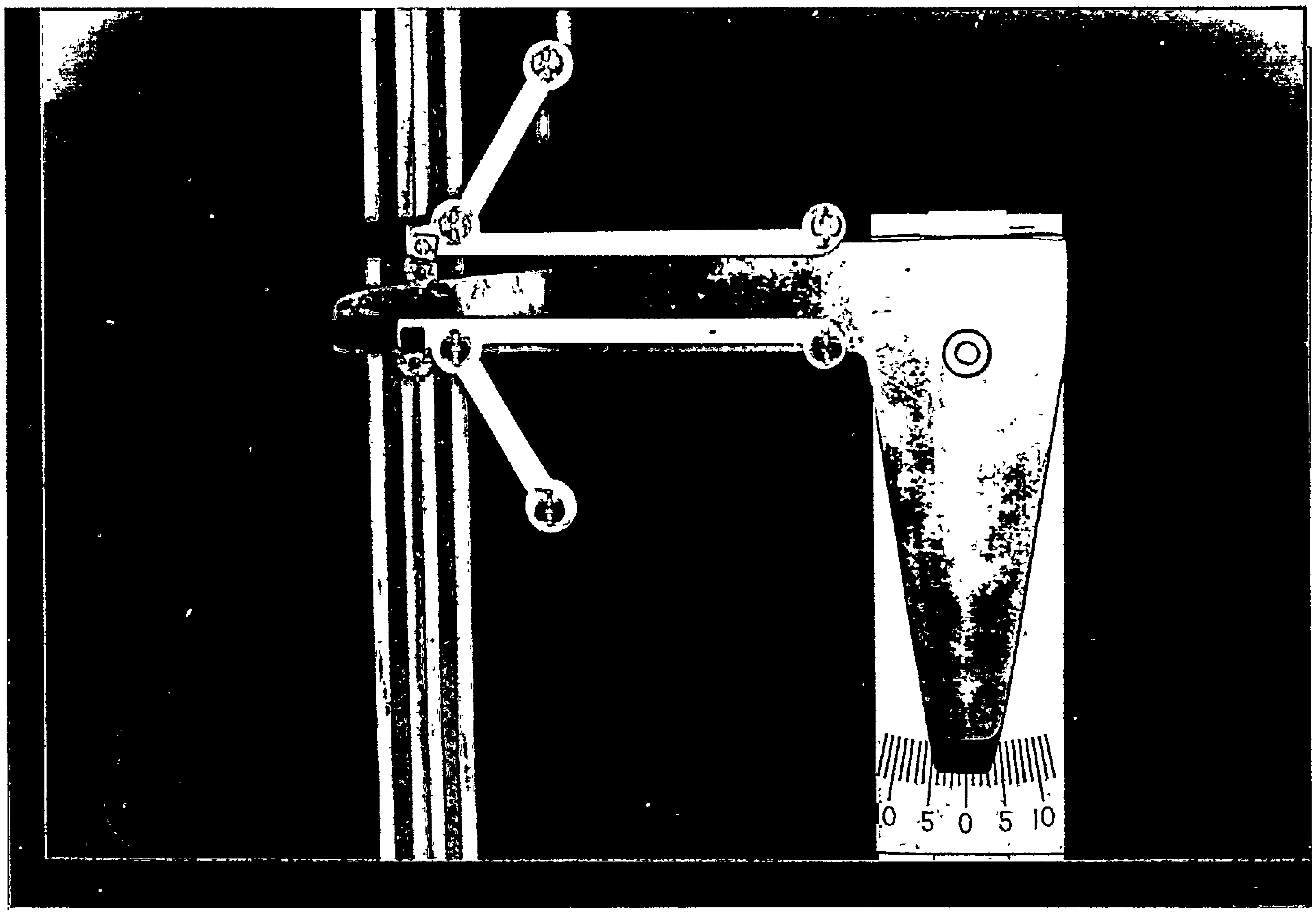


Figure 3.11 Positioning device for the calibration of the opening angle of the Jaws-3D tracking system.

3.8 Errors of the System

3.8.1 Accuracy

The error of the system was less than 0.2mm (Fig. 3.12) of the entire measured area of 10mm, when the LEDs were moved parallel and perpendicularly to the detector surface. The mean values, minimum and maximum range, and also standard deviations for each point of the entire measured area of 10mm were calculated (Appendix 1).

3.8.2 Stability

The drift of the system was less than 0.2mm during

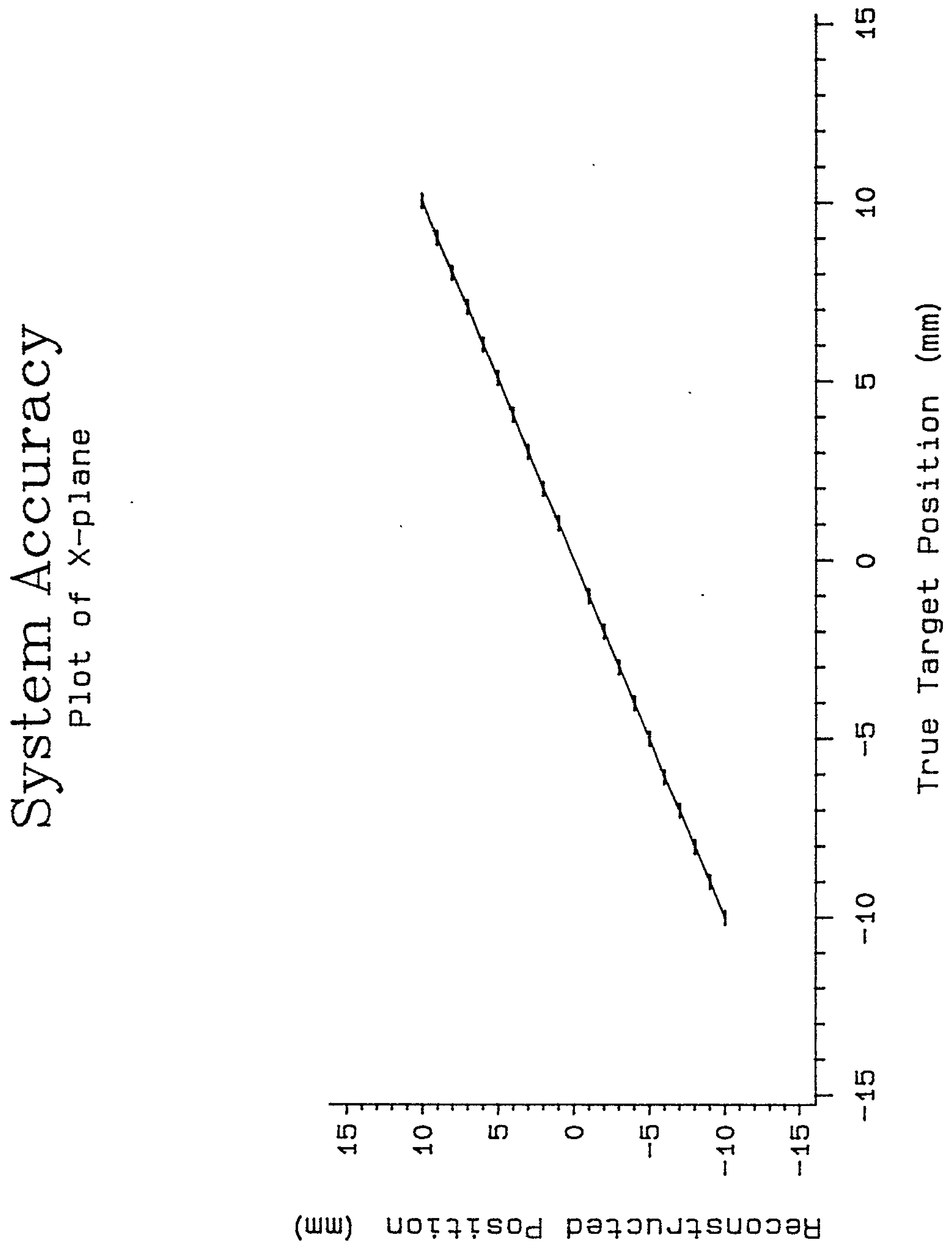


Figure 3.12A Accuracy assessment in X-plane (antero-posterior).

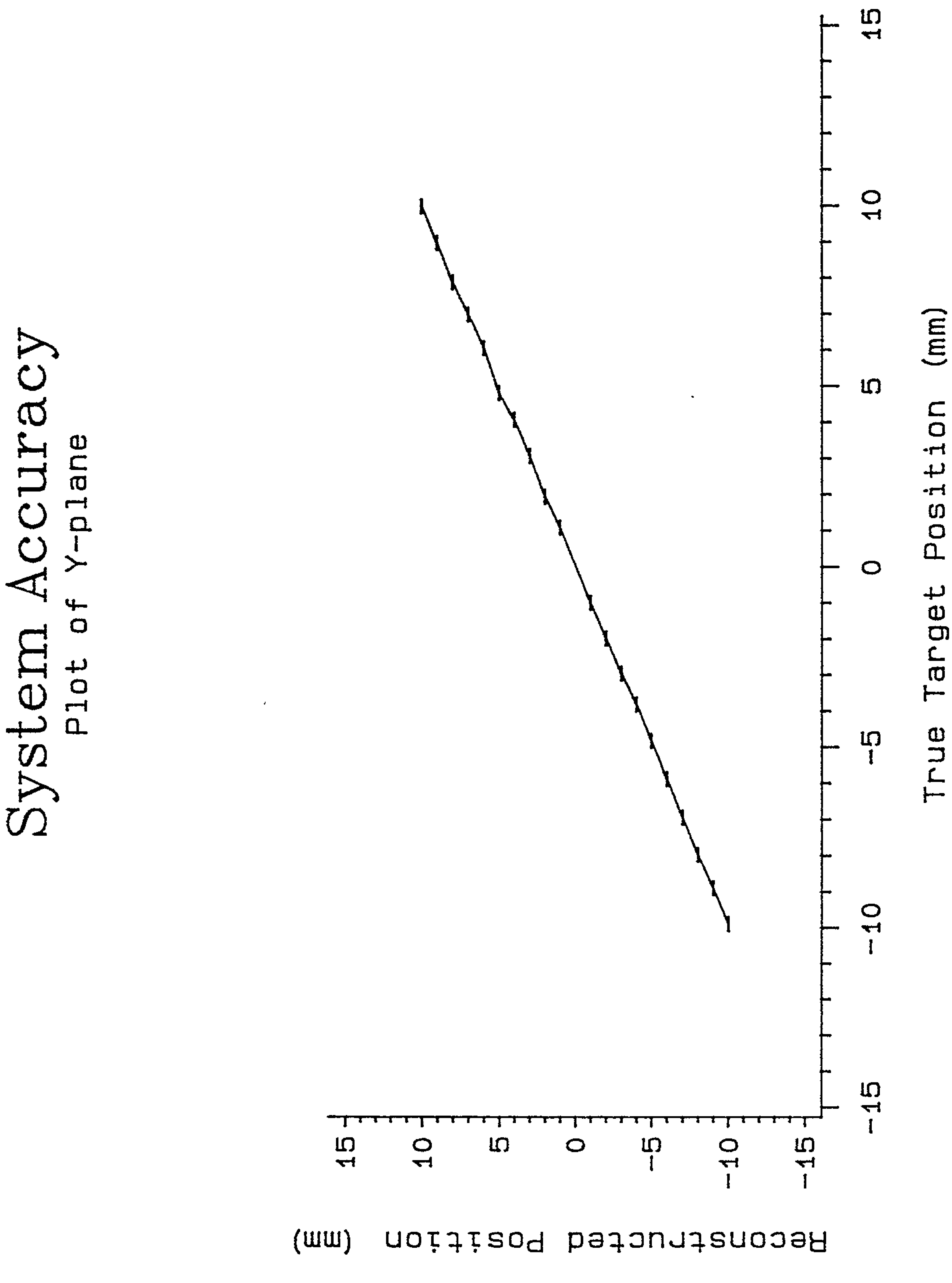


Figure 3.12B Accuracy assessment in Y-plane (lateral).

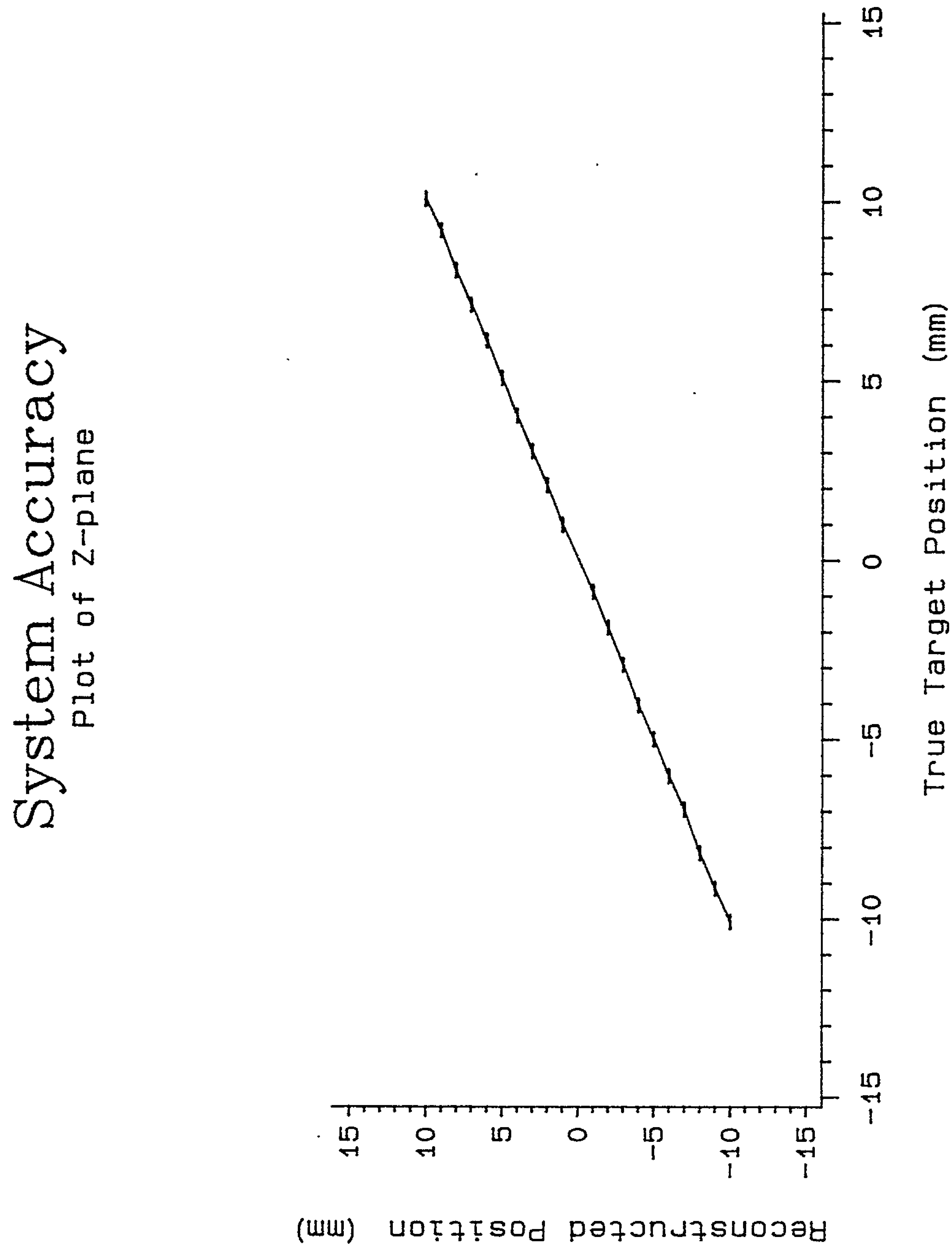


Figure 3.12C Accuracy assessment in Z-plane (vertical).

the maximum duration of 20 seconds in each of the three planes (Table 3.3).

3.8.3 Opening Angle

The error of the opening angle of the system was approximately 5% of the entire measured angle of 10 degrees when the lower target frame was rotated (Table 3.4).

	x	y	z
session 1	—	—	0.1
2	-0.1	-0.1	0.1
3	—	—	—
4	—	—	-0.1
5	—	-0.1	0.1
6	—	-0.1	-0.1
7	—	—	-0.1
8	—	-0.1	0.1
9	—	-0.1	0.2
10	-0.1	-0.2	—

Table 3.3 Stability assessment (mm).

session 1	9.6
2	9.5
3	9.8
4	9.5
5	9.6
6	9.6
7	9.8
8	9.7
9	9.2
10	9.3

x: 9.5 (SD: ±0.19)

Table 3.4 Accuracy of angle (degree)

4. RESULTS

Condylar movements showed variations depending on the TMjoint condition. TMjoints were divided into four types:-

1) acute stage of "closed lock" - before the occlusal splint therapy.
2) chronic stage of "closed lock" - after the occlusal splint therapy.
3) symptomatic stage (control group).
4) asymptomatic stage (control group).

4.1 <u>Non-functional movement</u>

In the acute stage, consecutive opening and closing movements showed steeper and straight i.e. less curved condylar paths in the sagittal plane (Fig. 4.1). A single opening and closing movement showed non-reproducible paths in the sagittal plane (Fig. 4.2).

In the chronic stage, a decreased vertical translation and an increased anterior translation were found in the frontal and horizontal planes. As a result the sagittal view showed curved condylar paths (Fig. 4.3). A single opening and closing movement showed a more reproducible path in the chronic stage (Fig. 4.4).

In control subjects, some variations were observed. Well superimposed condylar paths were found in all three planes with the subject PH (Fig. 4.5A). A single open and close movement showed reproducible paths in this asymptomatic subject (Fig. 4.6), similar to that observed in the chronic stage. Figure 4.5B shows the characteristic condylar movement of subject CP. In this asymptomatic subject, the opening movement ended by a lateral movement, and condylar paths were not superimposed. Figure 4.5C shows a variation in condylar path trajectories in the opening and closing movement of the symptomatic subject GM.

Figure 4.7 shows lateral voluntary movements of the condyle in the acute stage. An excessive distal and lateral excursion of the condyle was observed during movements to the LHS (i.e. ipsilateral side).

Figure 4.8 shows that the distal and lateral excursion of the condyle found in the acute stage (Fig. 4.7) decreased in the chronic stage of subject EA.

Figure 4.9 shows the movements of the lower incisor point in the same lateral voluntary movements represented in Figure 4.7 and 4.8. The most lateral position of the movement (*) in the acute stage (Fig. 4.9a) was less reproducible when compared with tracings in the chronic stage (Fig. 4.9b).

Figure 4.10 shows the protrusive movements of the condyles. In the acute stage protrusion started with a characteristic downward movement (Fig. 4.10a) that disappeared in the chronic stage (Fig. 4.10b). The protrusive movement in the chronic stage became a straight forward-and-downward movement, similar to that observed in the asymptomatic stage(Fig. 4.10c).

4.2 Rotation versus Translation

The plot of anterior condylar translation versus the opening angle is represented in Figure 4.11.
In Figure 4.11a, the opening movement in the acute stage began mainly by translation; however, the translatory movement was obviously restricted in the latter half of the movements, as movement was possible for a distance of 9.0mm only.

Figure 4.11b represents tracings made in the chronic stage, where a greatly increased translatory movement over the entire range of motion was observed.
Thus, the ratio between the opening angle and translation became more linear than that of the acute stage.

In the asymptomatic stage, the ratio between the opening angle and translation was highly linear with the subject PH (Fig. 4.12a).

Figure 4.12b represents tracking made with the subject CP. It shows that the opening movement ended mainly by rotation.

Figure 4.12c represents trackings made with the subject GM. It shows that there were obvious deflections during opening.

Closing movements started mainly by rotation, and movement was possible for a distance of 17.0mm.

4.3 Functional Movement

In the acute stage, the working side condyle showed an obvious distraction during the closing movement. The opening (red lines) and closing (blue lines) paths of the working side condyle were clearly distinguishable and at the end of the closing movement, the working side condyle was positioned posteriorly, superiorly and laterally when compared with the intercuspal position (IP) (Fig. 13c).

In the chronic stage, however, well superimposed paths were seen in both the working and non-working side condyle (Fig. 14). Further, an increase of anterior condylar translation was found on both working and non-working side condyles (Fig. 14a and 14b).

In the asymptomatic stage, the working and non-working side condyle showed superimposed condylar paths with the subject PH (Fig. 4.15 A)

Figure 4.15 B shows the condylar paths of ten chewing movements with the subject CP. It shows distraction of the working side condyle in the beginning of the closing movement.

Figure 4.15C shows the condylar paths of chewing movements with the subject GM in the symptomatic stage. It shows unstable paths of the working and non-working side condyles in the whole chewing movements.

Figure 4.16a shows a characteristic immediate side shift (ISS) of the non-working side condyle in the acute stage. However, ISS of the non-working side condyle disappeared in the chronic stage (Fig. 4.16b). ISS was found mainly at the end of the closing movement as a pure lateral movement. (Fig. 4.17).

Figure 4.18 and 4.19 represent separate temporal displays in the sagittal plane during chewing. The rhythm of condyle movement path was particulary unstable in the acute stage (Figs. 4.18a and 19a). In the chronic stage, a more stable rhythm of condyle movement during chewing was found and antero-posterior translation during chewing movements increased (Figs. 4.18b and 19b). In the asymptomatic stage, the condyle rhythm during chewing appeared to show stable and constant antero-posterior translation (Figs. 4.18c and 19c).

Table 4.1 shows the assessment of ten chewing strokes with the working side condyles in the three groups.

	1		2		3	
	3 Control Subjects		Pat. EA Chronic "closed lock"		Pat. EA Acute "closed lock"	
	AV	SD	AV	SD	AV	SD
#1. The lateral range of movement.	1.40	0.47	1.49	0.83	1.10	0.44
#2. The ant-posterior range of movement.	5.37	2.05	4.58	2.26	* 2.90	0.90
#3. The vertical range of movement.	4.15	0.83	4.25	1.25	4.05	0.58

* P<0.01

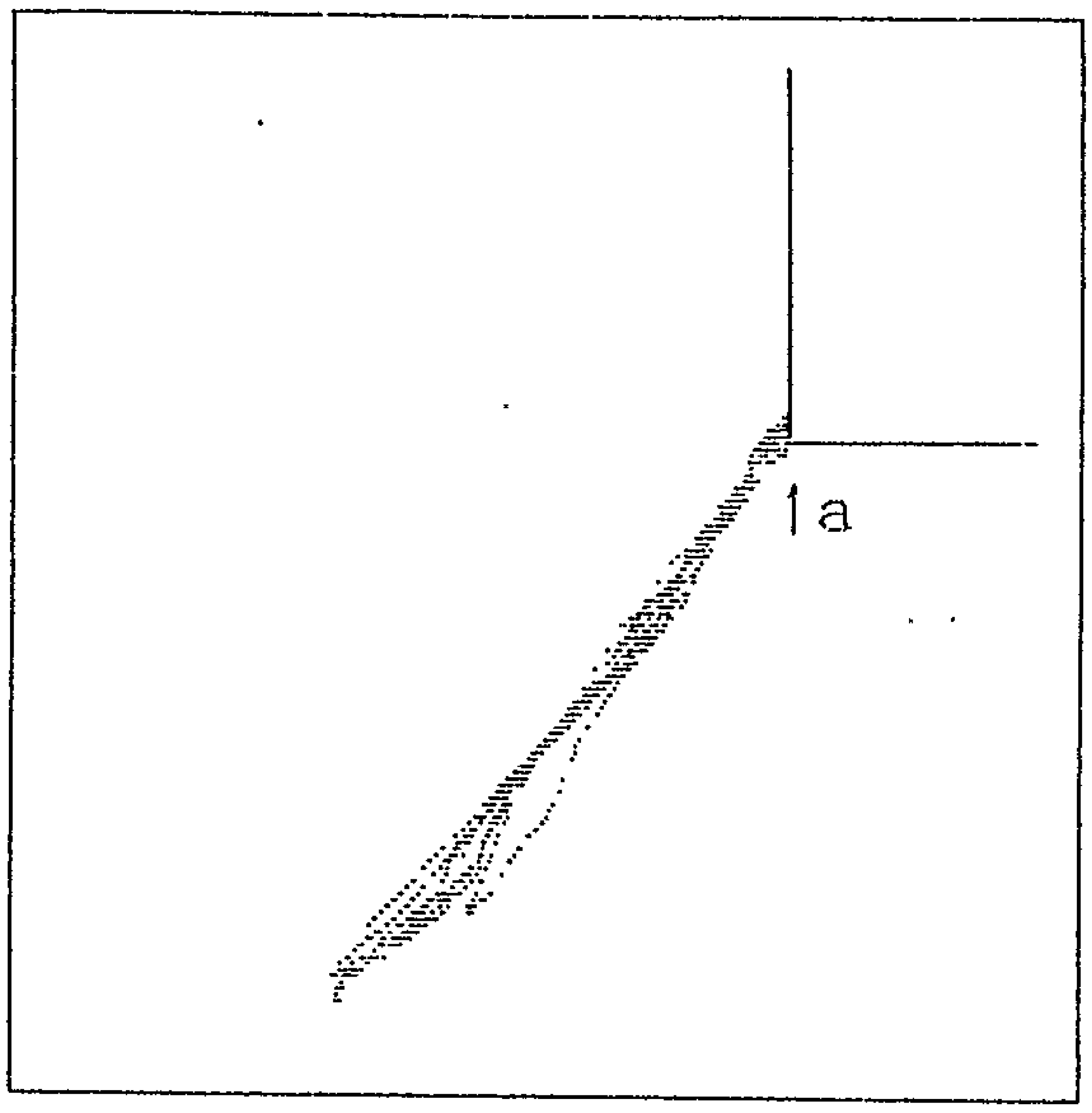
Table 4.1 Student T-test was made for three different parameters of measurement (AV = Average; SD = Standard Deviation).

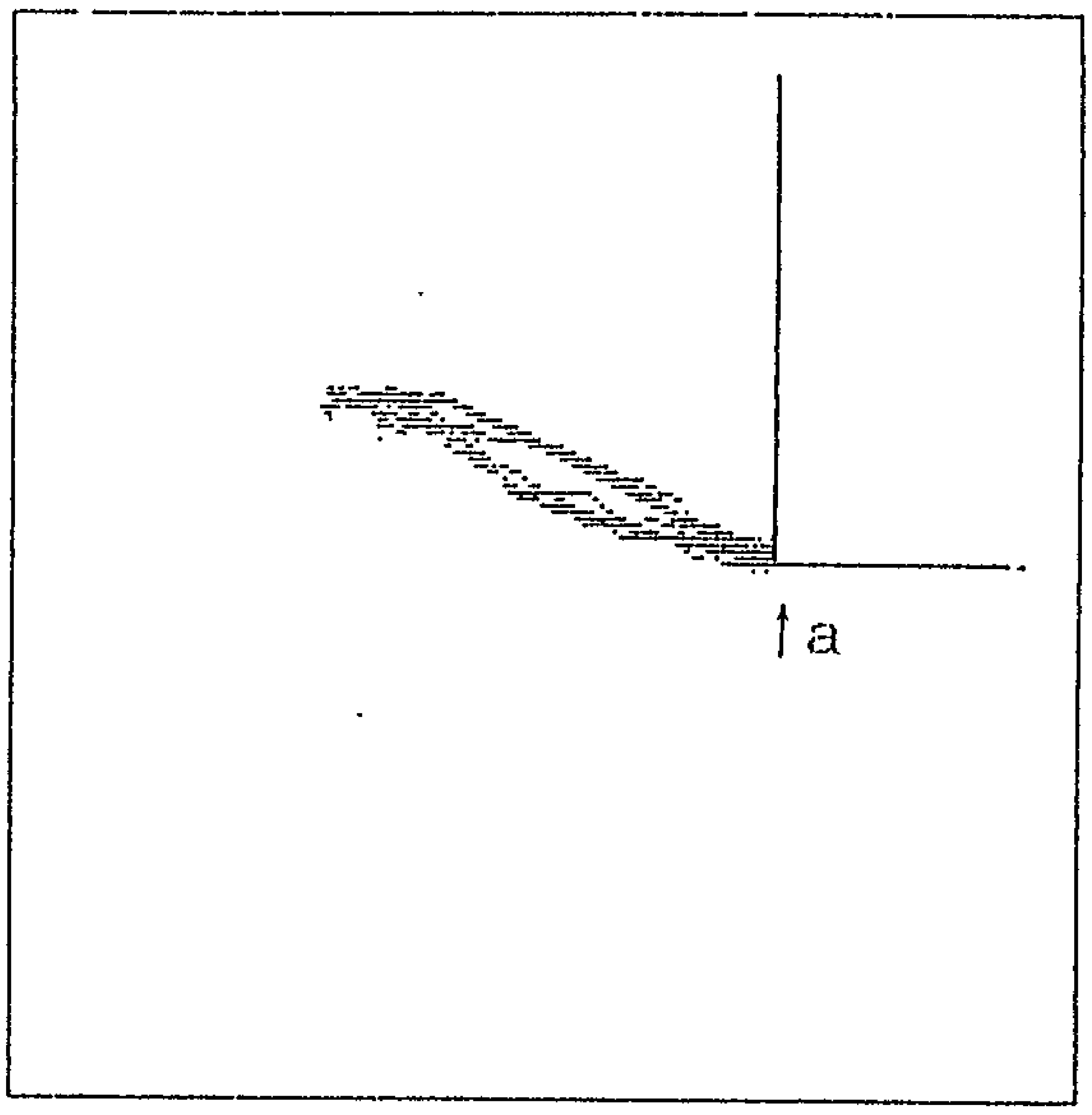
Two of the relationship tested were significant at the 1% level: the antero-posterior range of movement parameter #2 (Table 4.1) increased from 2.90 to 4.58 mm in the chronic stage of the patient EA. There was no statistical significance between control subjects and the patient EA in the chronic stage.

SAGITTAL PLANE

HORIZONTAL PLANE

medial

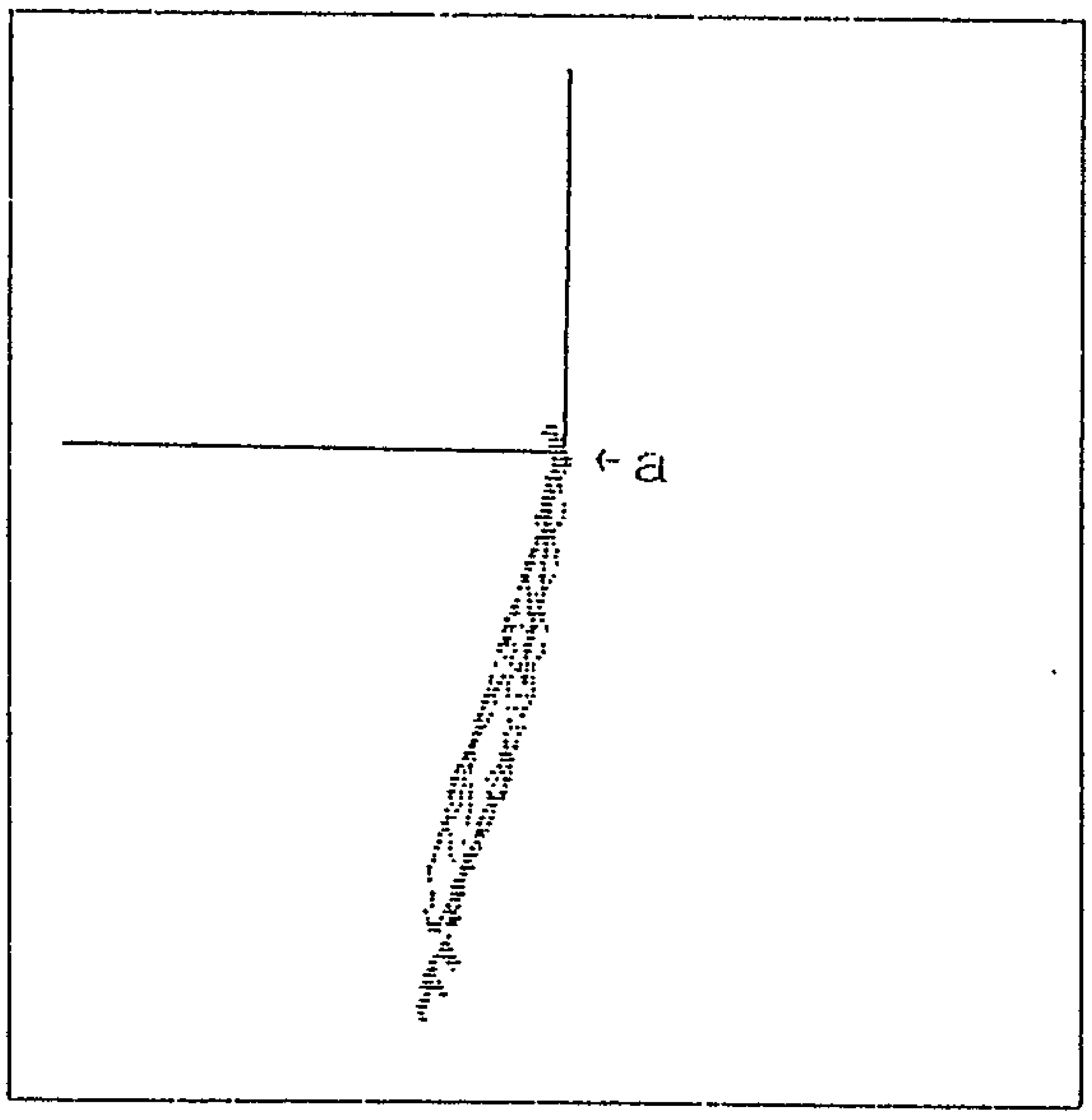




front back

lateral

FRONTAL PLANE



right left

Date: 23/04/91

Subject: EA

Jaw point: tmj-L

Scale: 5 mm

Figure 4.1 Plot of the condylar path in the three planes for the acute stage: patient EA - five open and close movements are superimposed. All movements start and finish at "a". It can be seen that sagittal translation is approximately 9.0mm, vertical movement is approximately 12.0mm, and lateral movement is approximately 3.0mm.

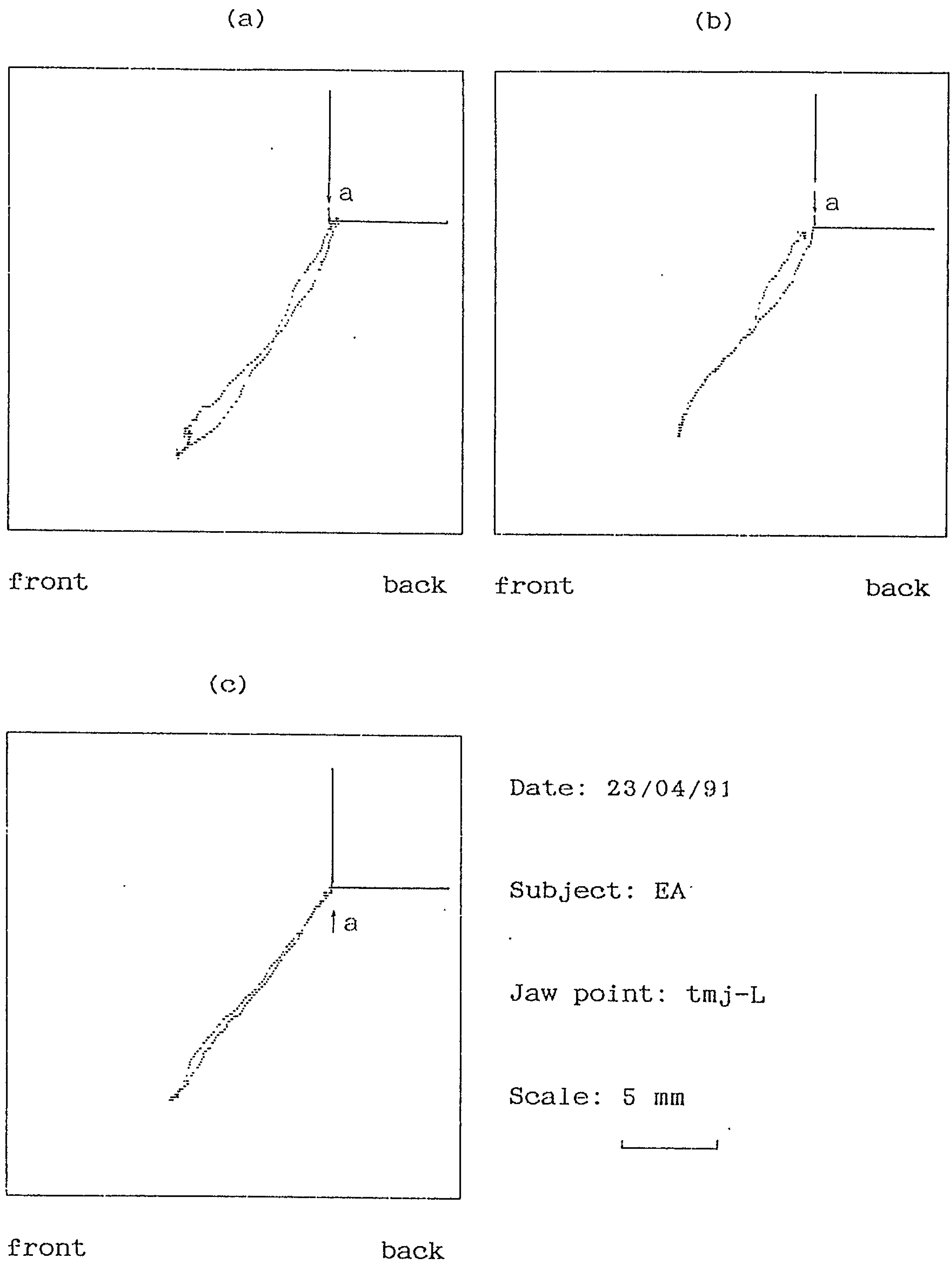


Figure 4.2 Individual trajectories for condylar paths of three single opening and closing movements for the acute stage: Patient EA. All movements start and finish at "a".

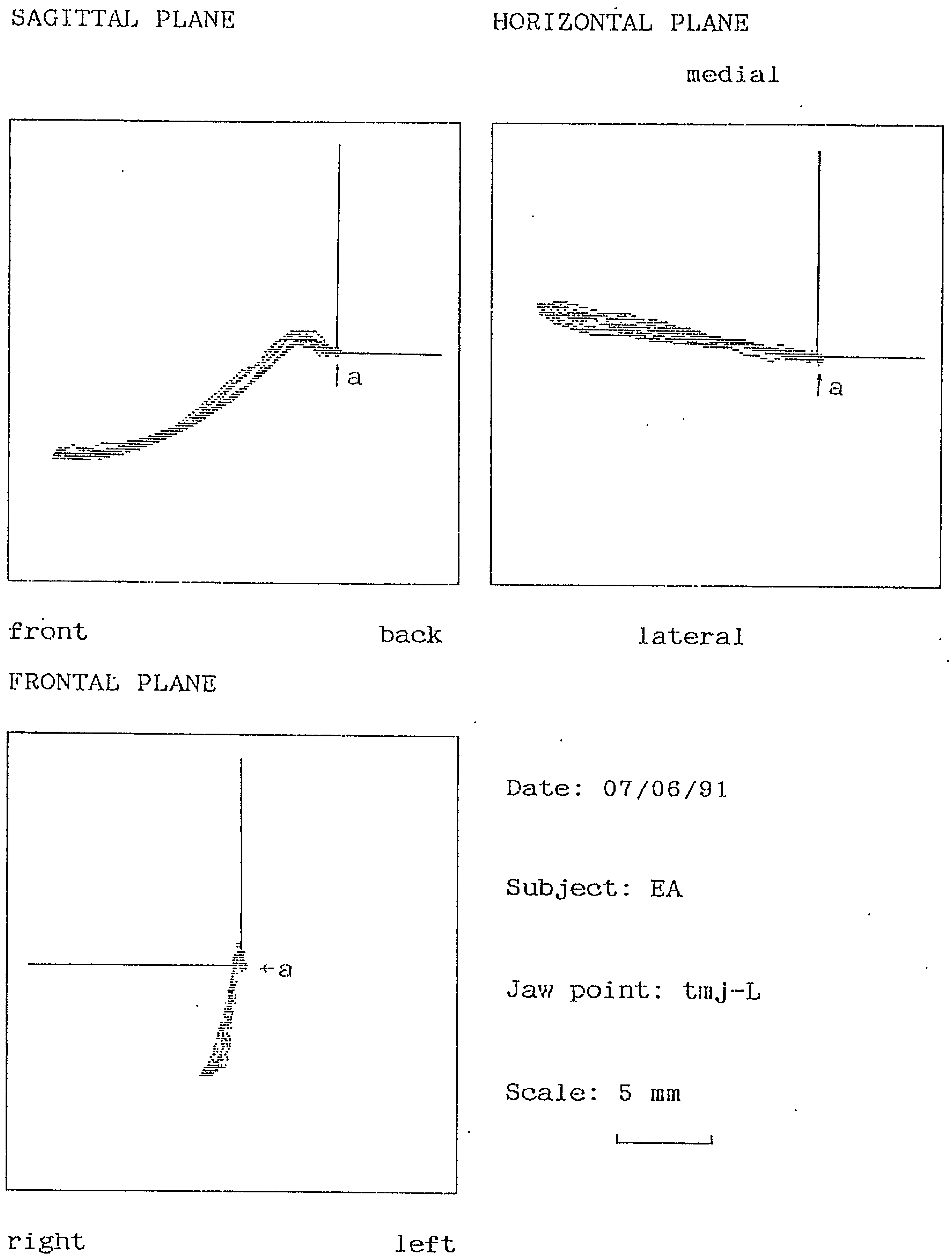


Figure 4.3 Plot of the condylar path in the three planes for the chronic stage of the patient EA - five open-close movements are superimposed. All movements start and finish at "a". It can be seen that sagittal translation is approximately 14.0mm, vertical movement is aproximately 6.0mm, and lateral movement is approximately 2.0mm.

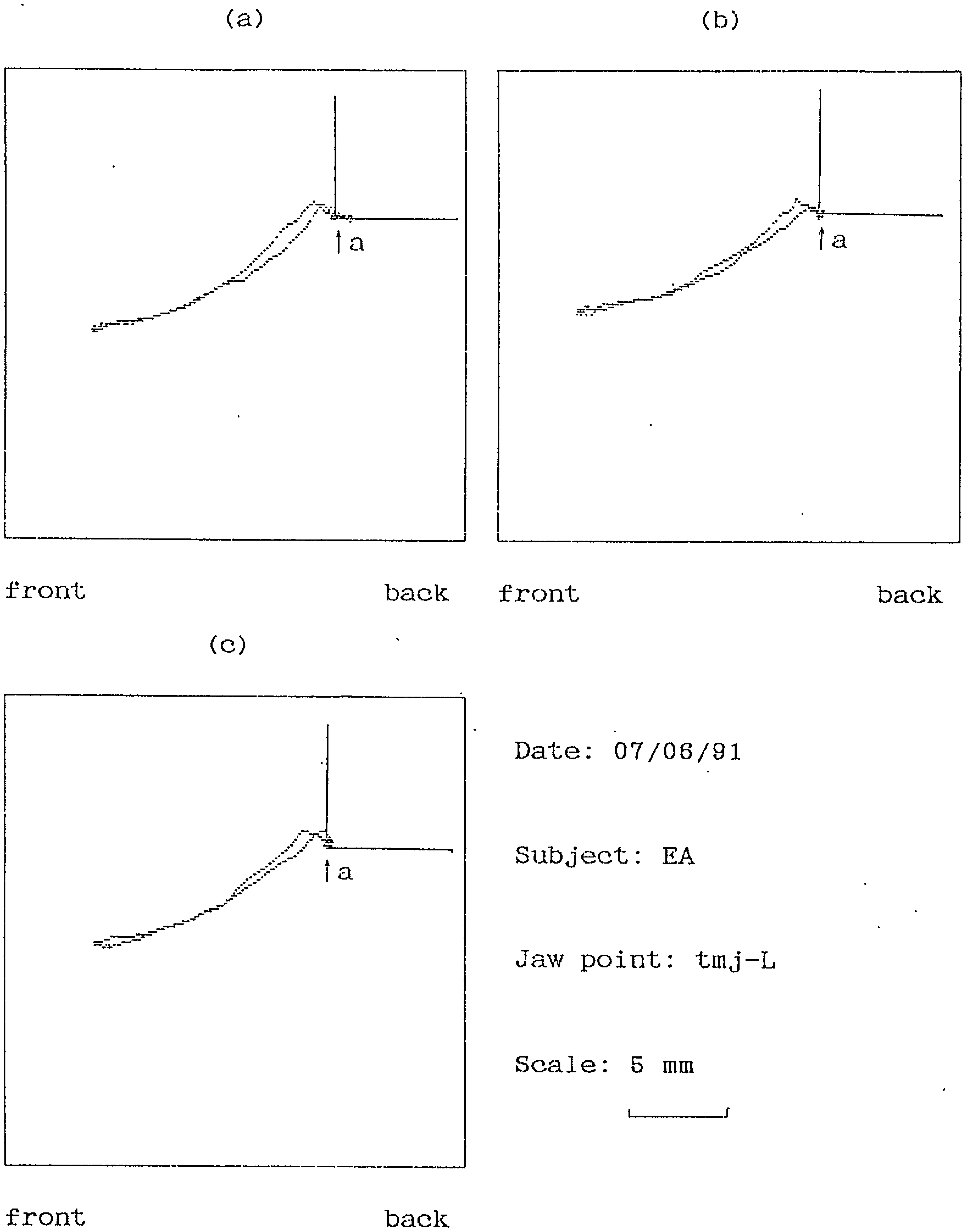
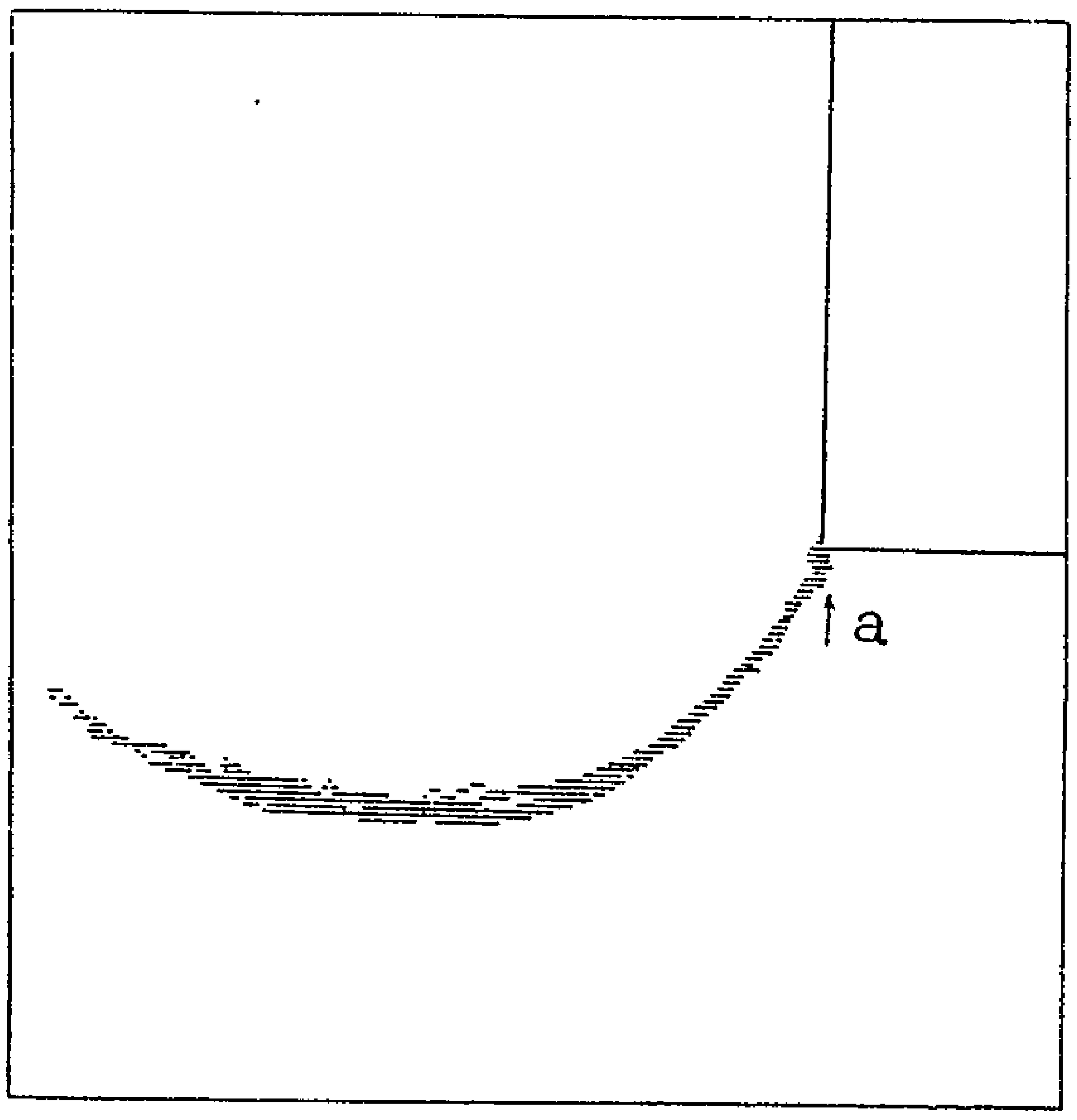


Figure 4.4 Individual trajectories of condylar paths of three single open-close movements for the chronic stage: Patient EA. All movements start and finish at "a".

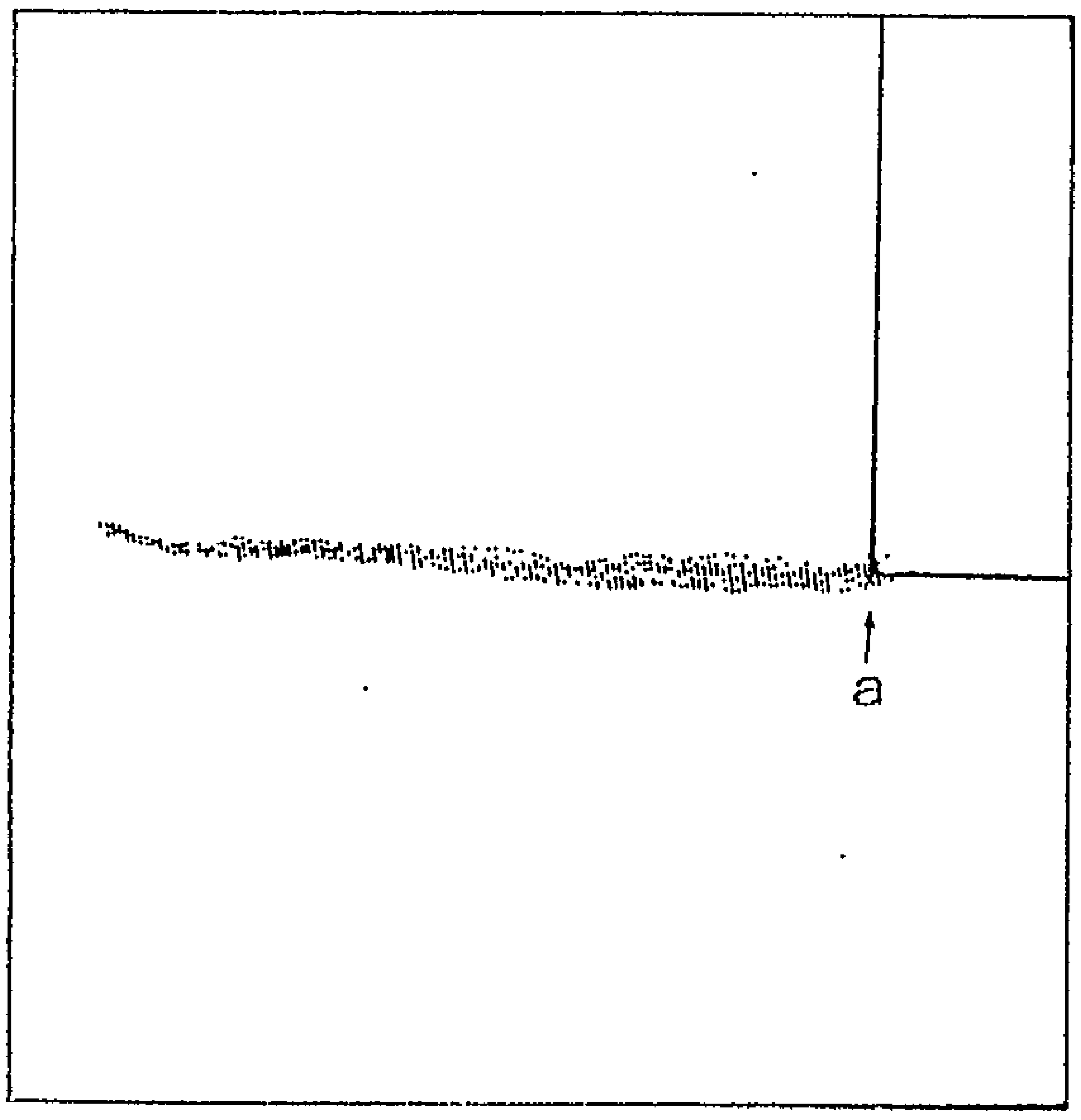
SAGITTAL PLANE



front back

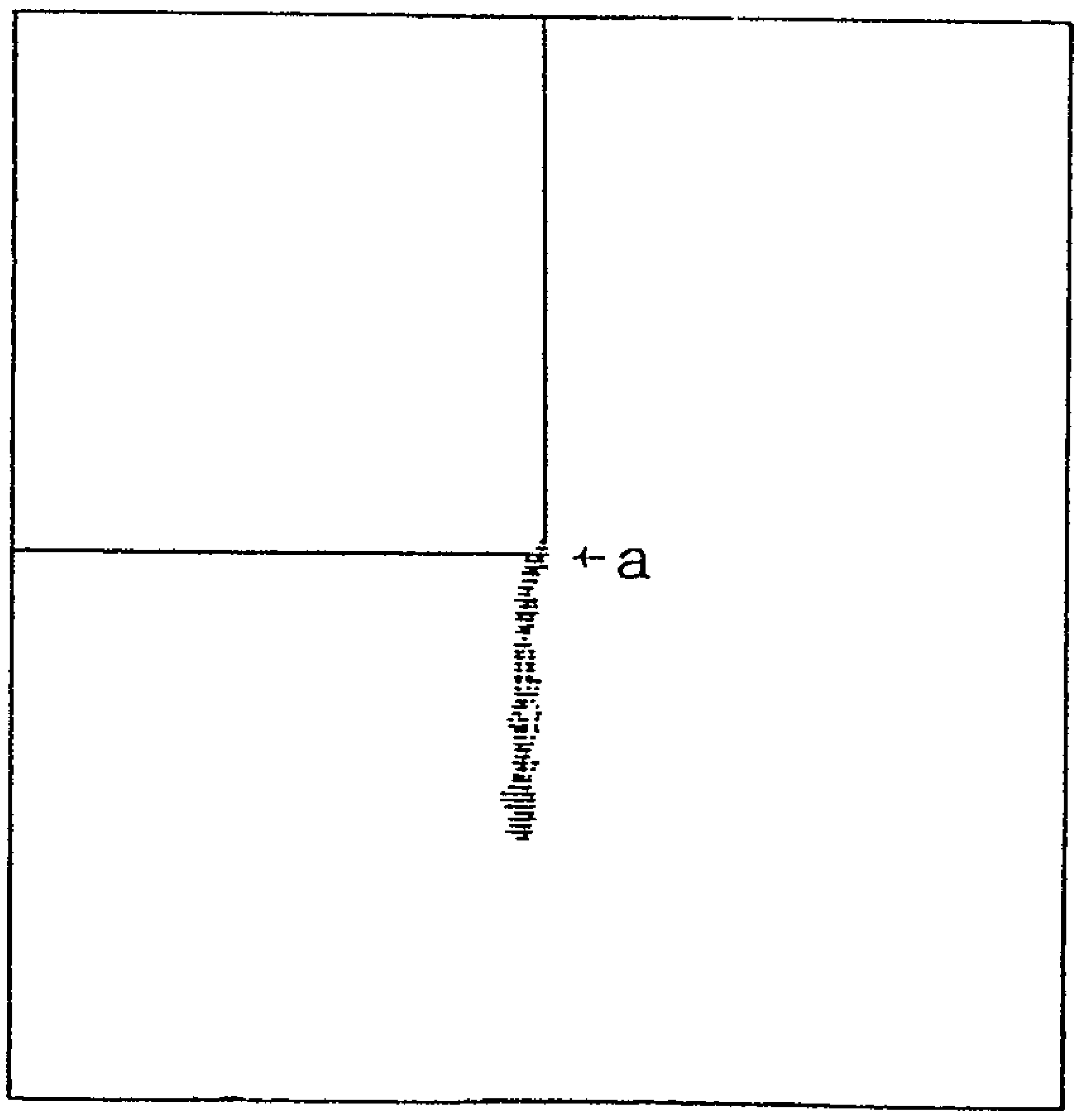
HORIZONTAL PLANE

medial



lateral

FRONTAL PLANE



right left

Date: 30/05/91

Subject: PH

Jaw point: tmj-L

Scale: 5 mm

Figure 4.5A Plot of the condylar path in the three planes for the asymptomatic stage: Subject PH. Five opening and closing movements are superimposed. All movements start and finish at "a". It can be seen that sagittal translation is approximately 15.0mm, vertical movement is approximately 6.0mm, and lateral movement is approximately 1.0mm.

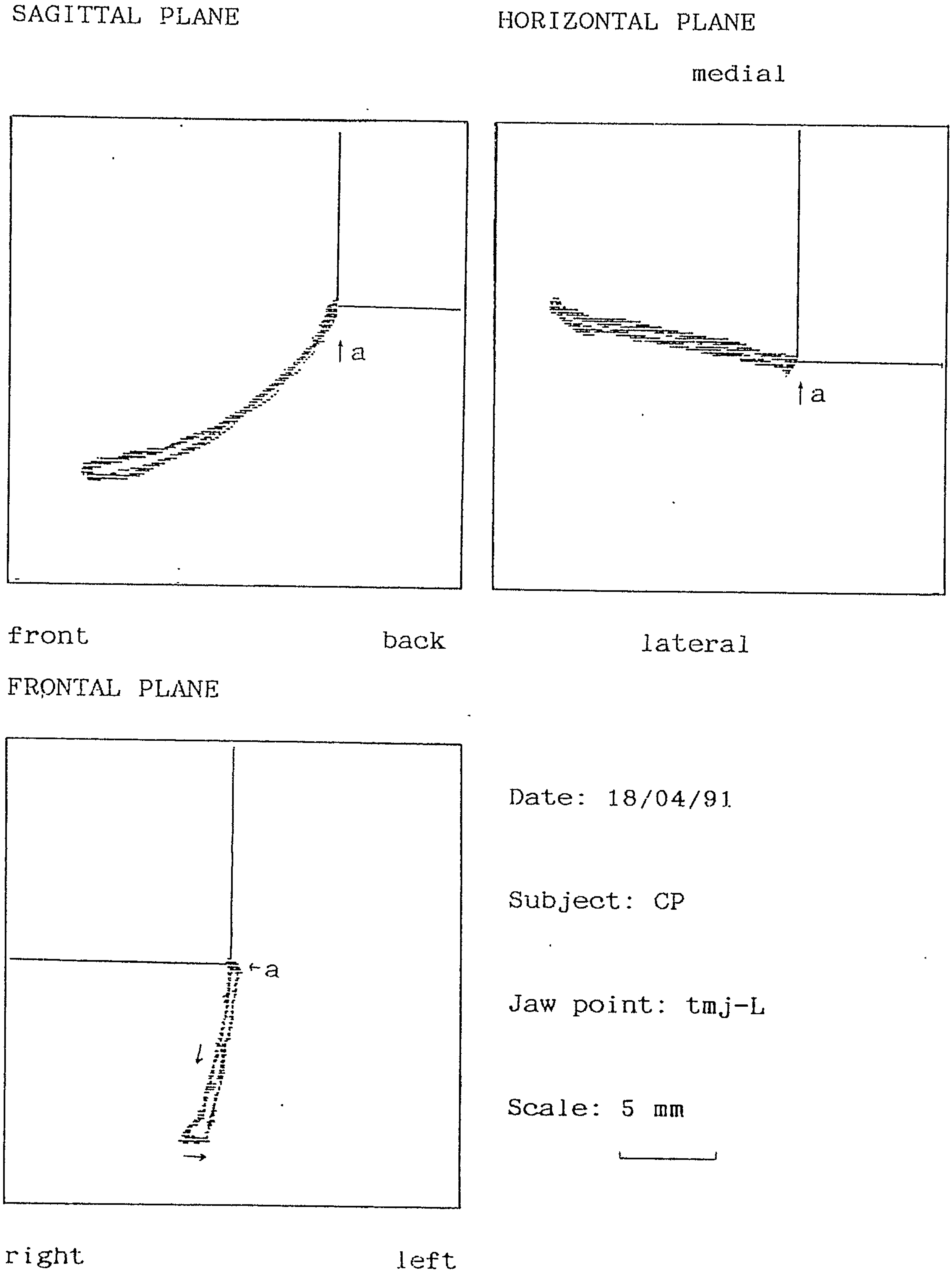


Figure 4.5B Plot of the condylar path in the three planes for the asymptomatic stage: Subject CP. Five opening and closing movements are superimposed. All movements start and finish at "a". It can be seen that sagittal translation is approximately 12.0mm, vertical movement is approximately 9.0mm, and lateral movement is approximately 3.0mm.

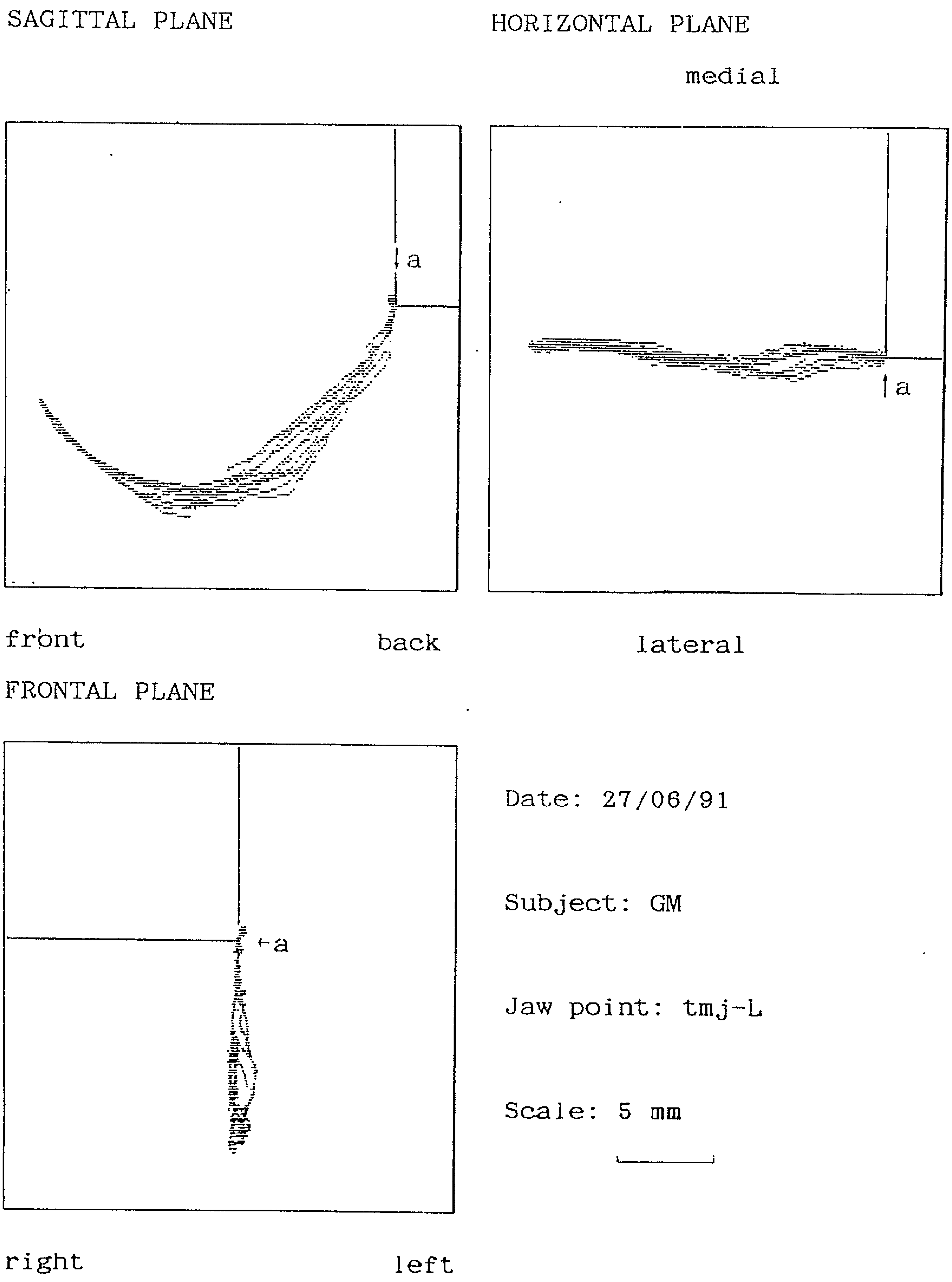


Figure 4.5C Plot of the condylar path in the three planes for the symptomatic stage: Subject GM. Five opening and closing movements are superimposed. All movements start and finish at "a". It can be seen that sagittal translation is approximately 17.0mm, vertical movement is approximately 11.0mm, and lateral movement is approximately 1.0mm.

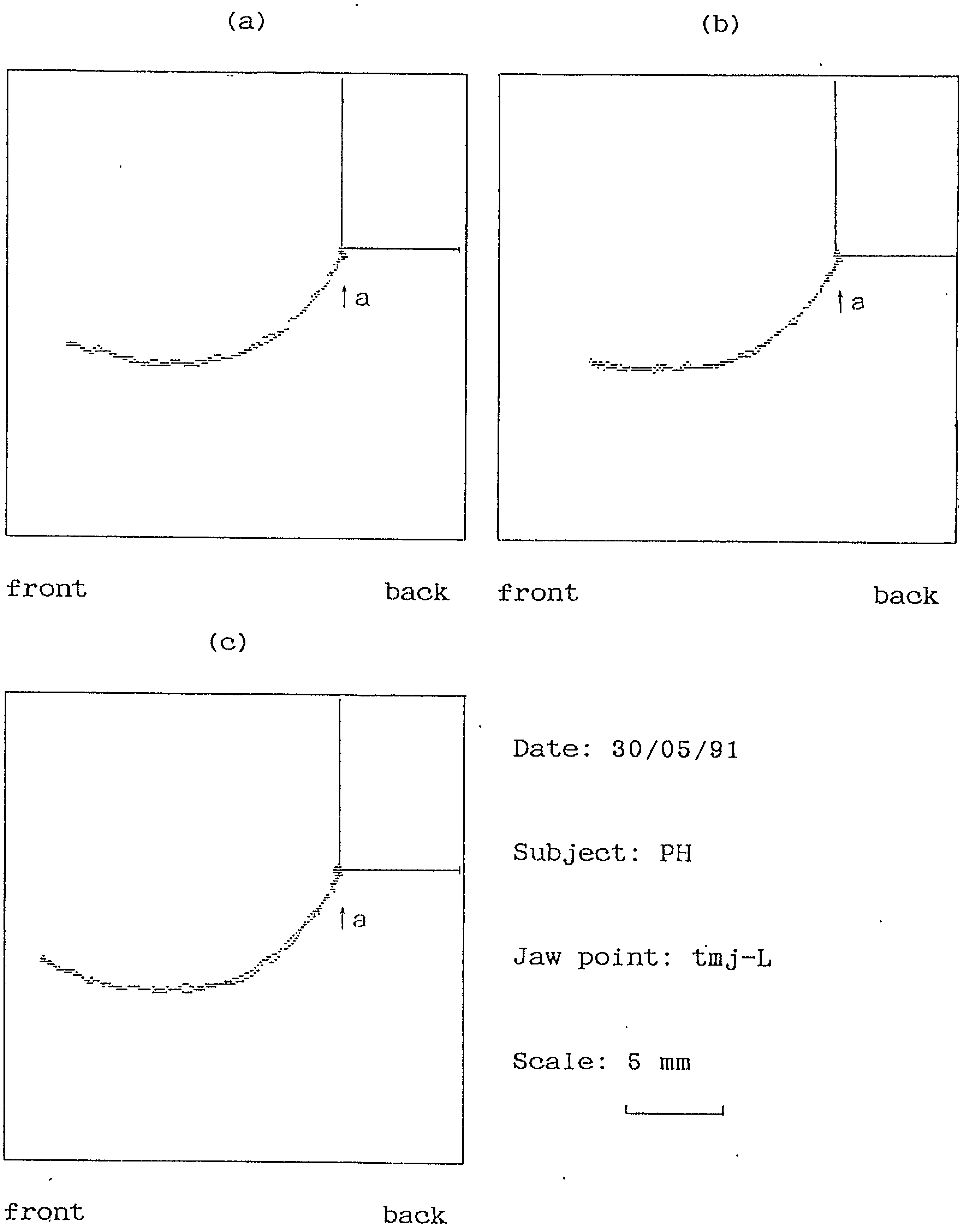


Figure 4.6 Individual trajectories of condylar path for three single open-close movements for the asymptomatic stage: Subject PH. All movements start and finish at "a".

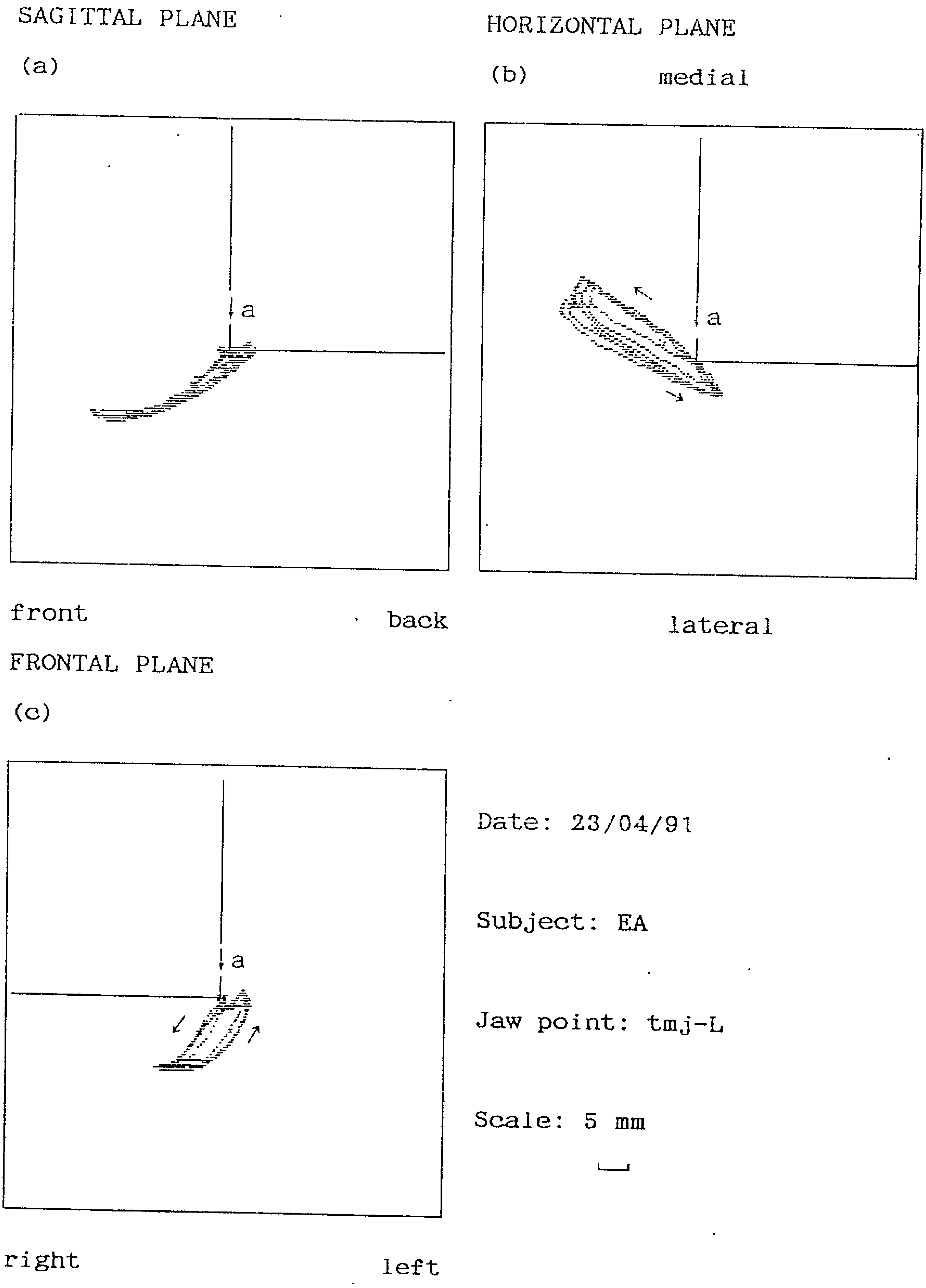


Figure 4.7 Plot of five voluntary lateral movements of the condyle in the acute stage. All movements start and finish at "a".

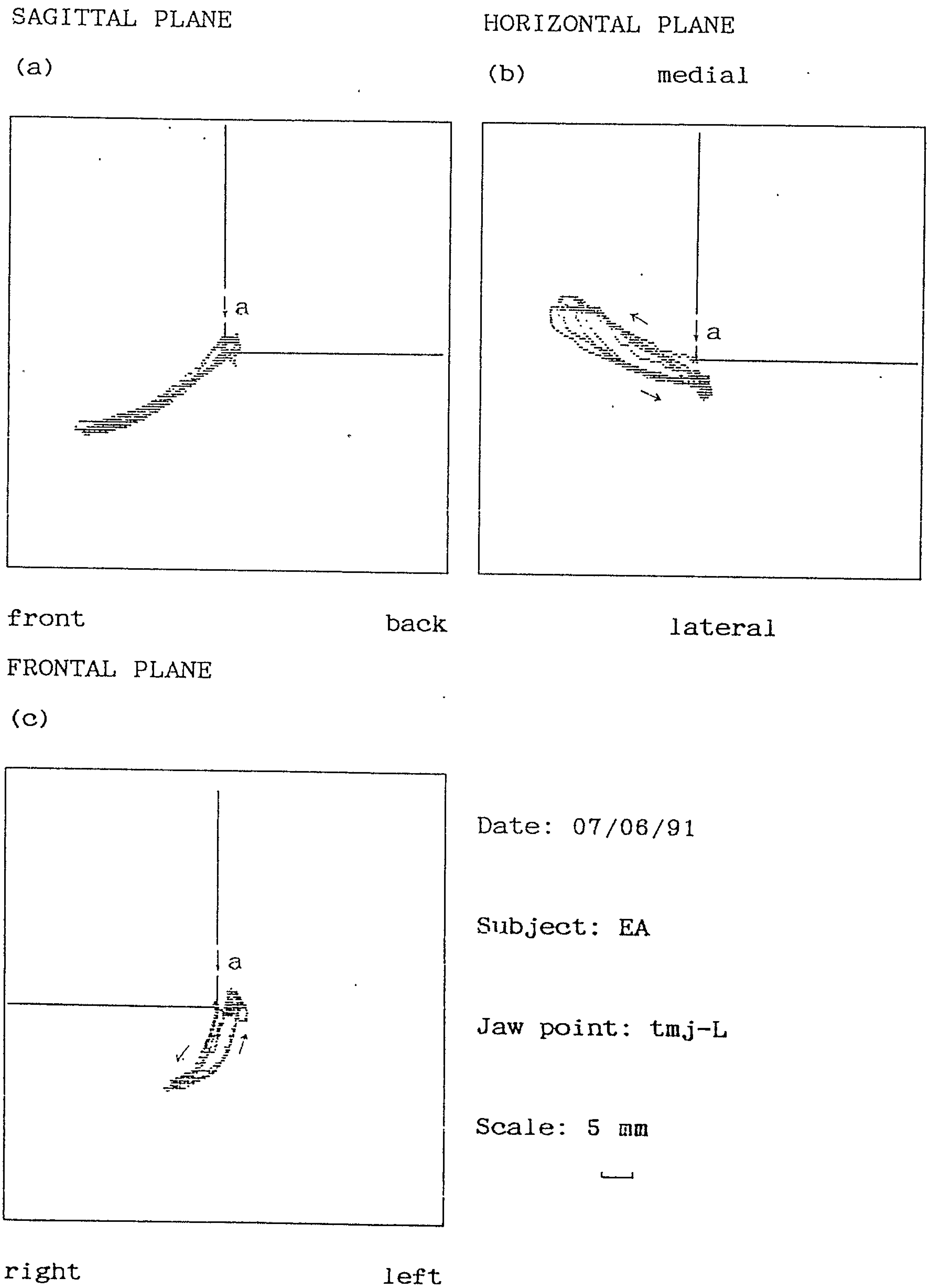


Figure 4.8 Plot of five voluntary lateral movements of the condyle in the chronic stage. All movements start and finish at "a".

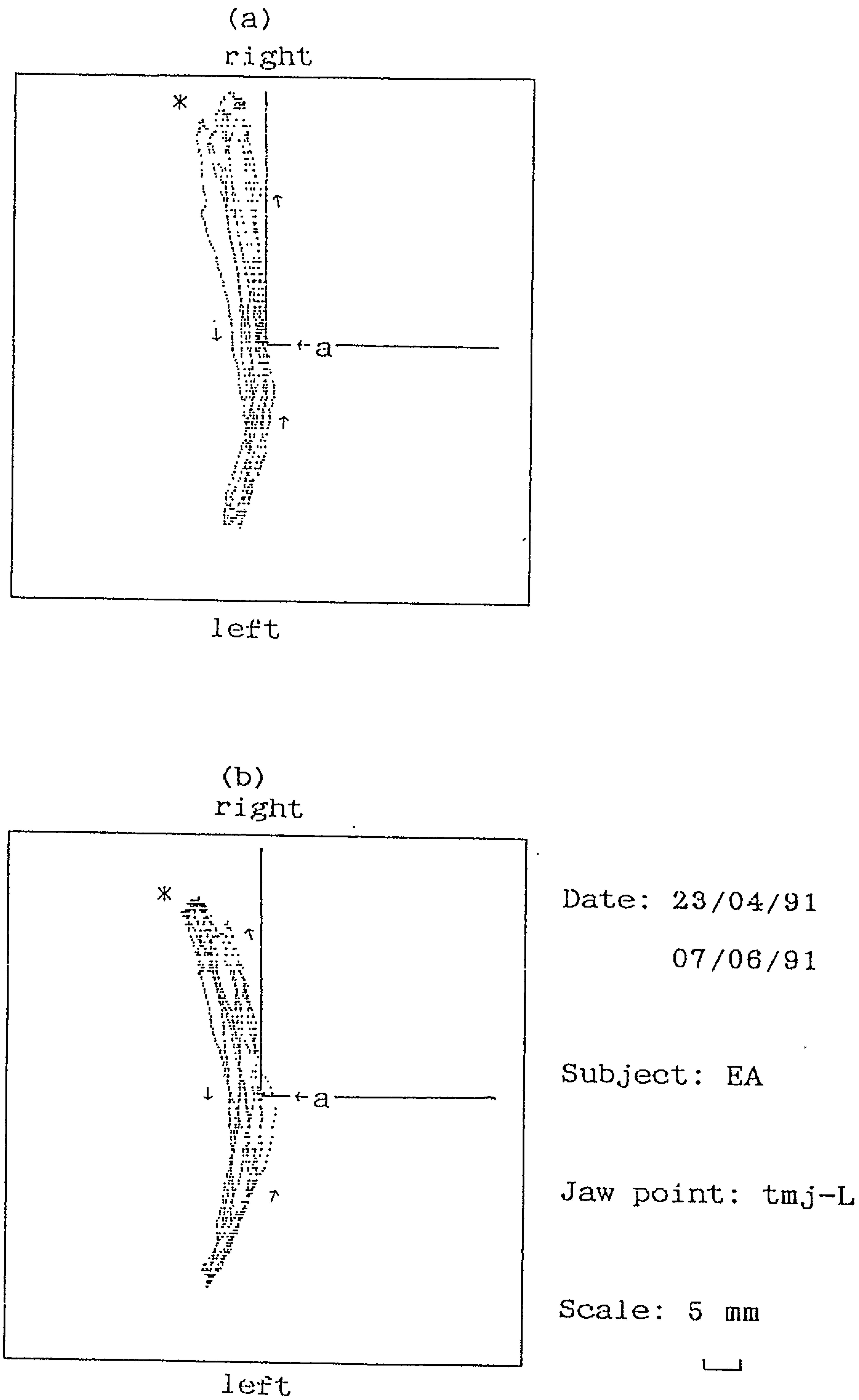


Figure 4.9 Plot of five lateral voluntary movements of the lower incisor point in the horizontal view for; (a) the acute stage, and (b) the chronic stage. All movements start and finish at "a".

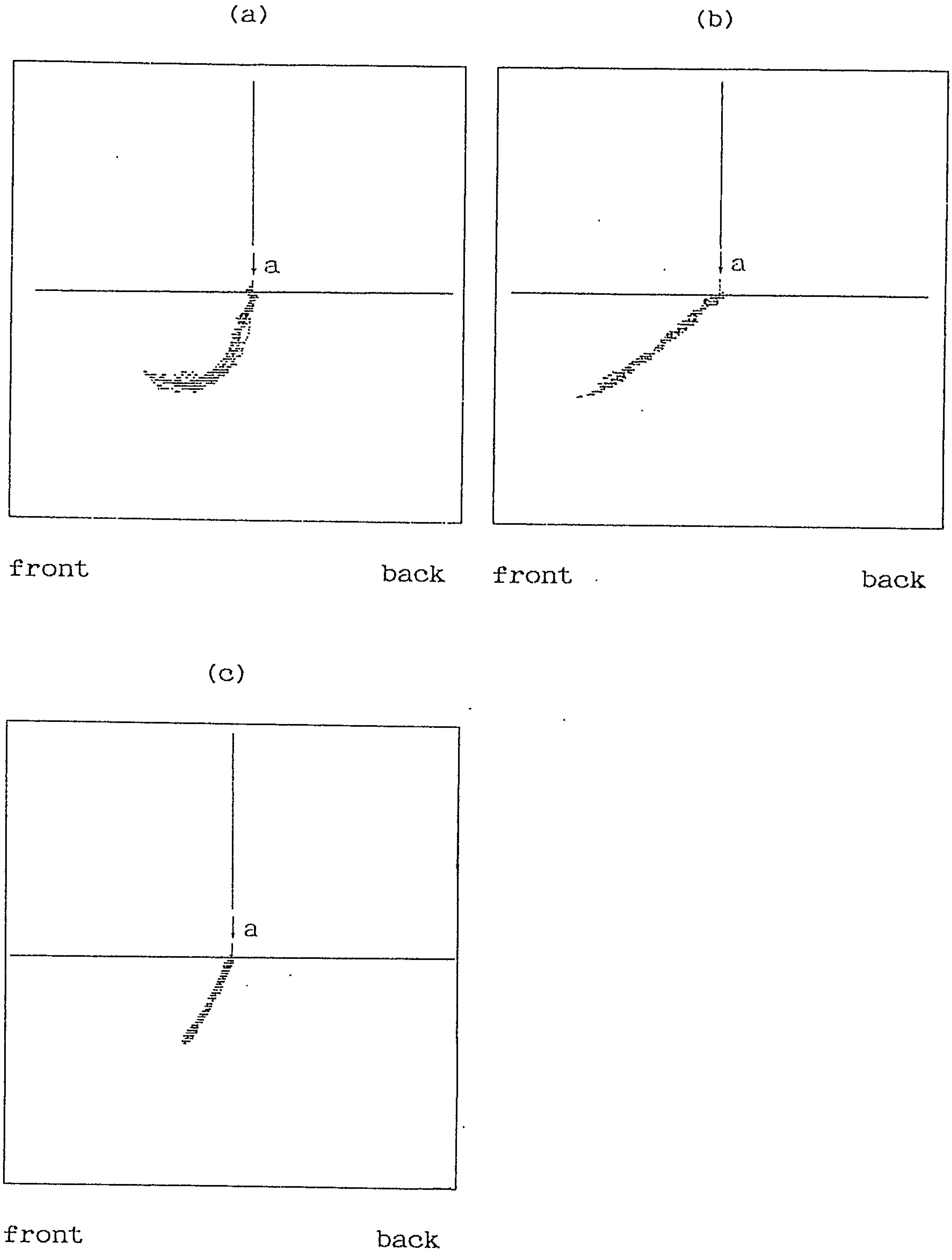


Figure 4.10 Plot of five protrusive movements of the LHS condyle without tooth contact in the 45° rotated sagittal view for (a) acute stage (patient EA): forward movements are seen following initial downward movements of the condyle, (b) chronic stage (patient EA): the condyle shows straight forward-downward movements, and (c) asymptomatic stage (subject PH): the condyle shows straight forward-downward movements. All movements start and finish at "a".

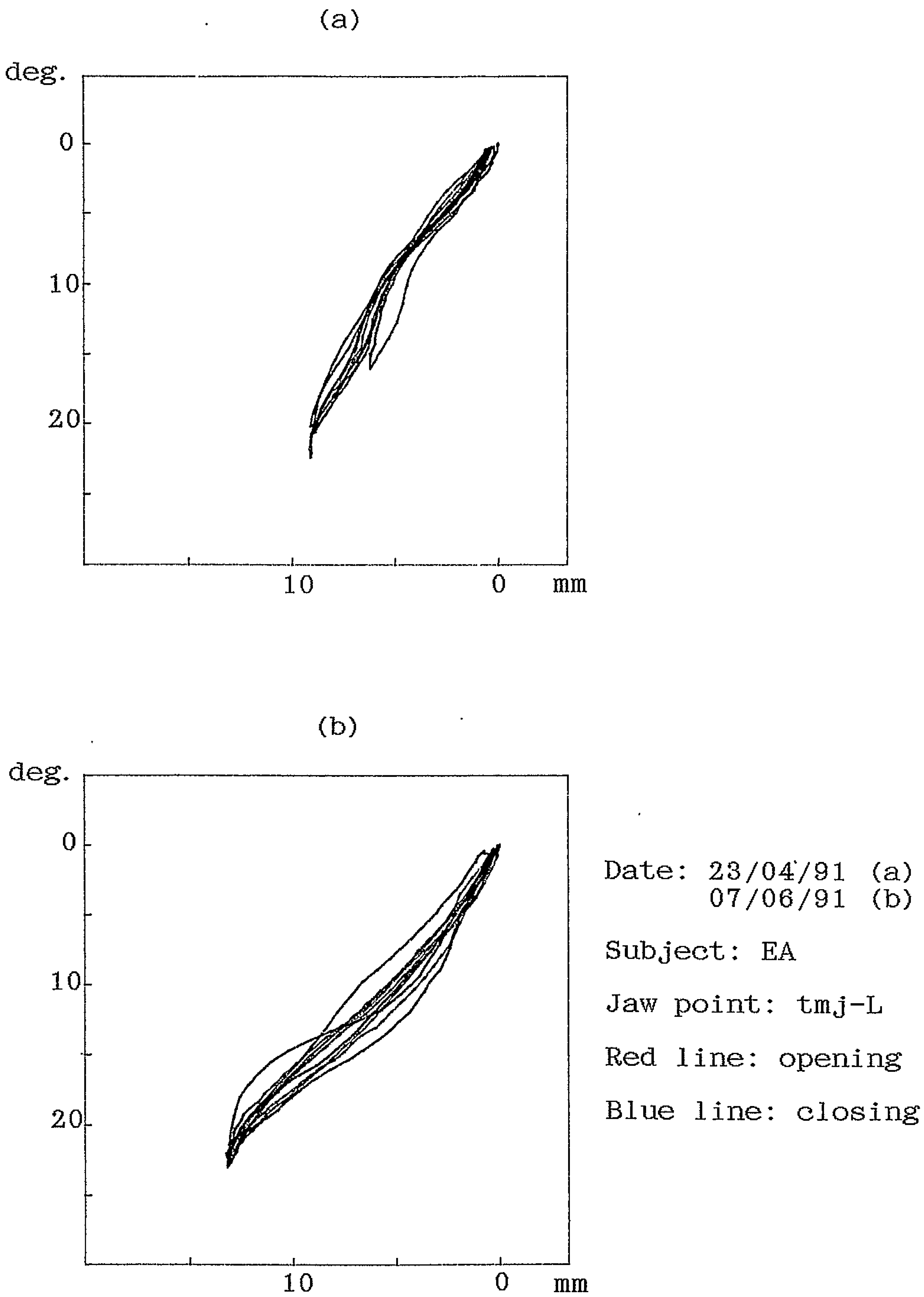


Figure 4.11 Plot of the anterior condylar translation versus opening angle for: (a) acute stage: Max. ant. translation = 9.0mm, End Angle = 22.0°, (b) chronic stage: Max. ant. translation = 14.0mm, End Angle = 22.0°. Five opening and closing movements are superimposed.

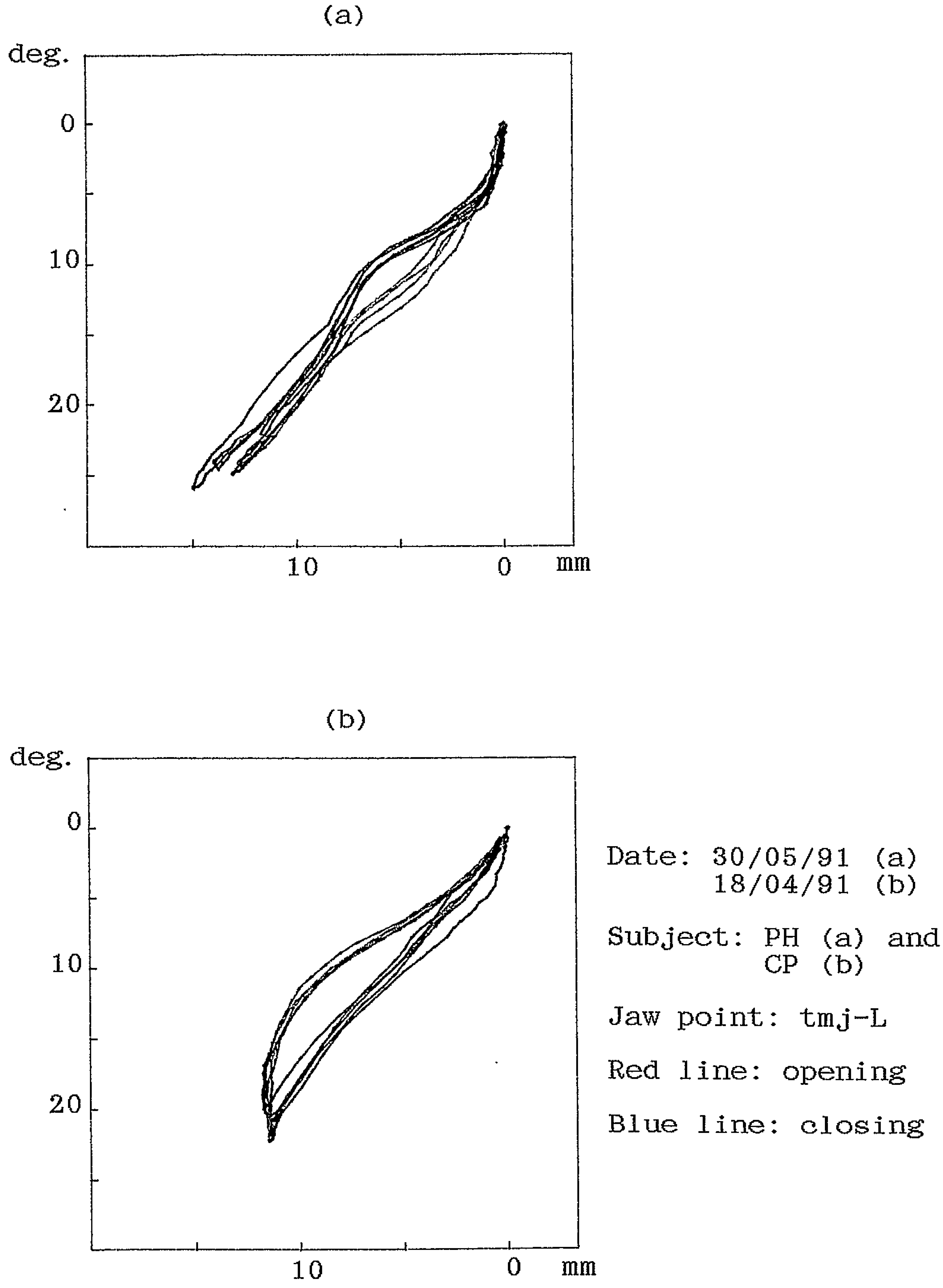


Figure 4.12 Plot of the anterior condylar translation versus opening angle for asymptomatic stage: (a) subject PH; Max. ant. translation = 15.0mm, End Angle = 26.0°, (b) subject CP; Max. ant. translation = 12.0mm, End Angle = 21.0°.

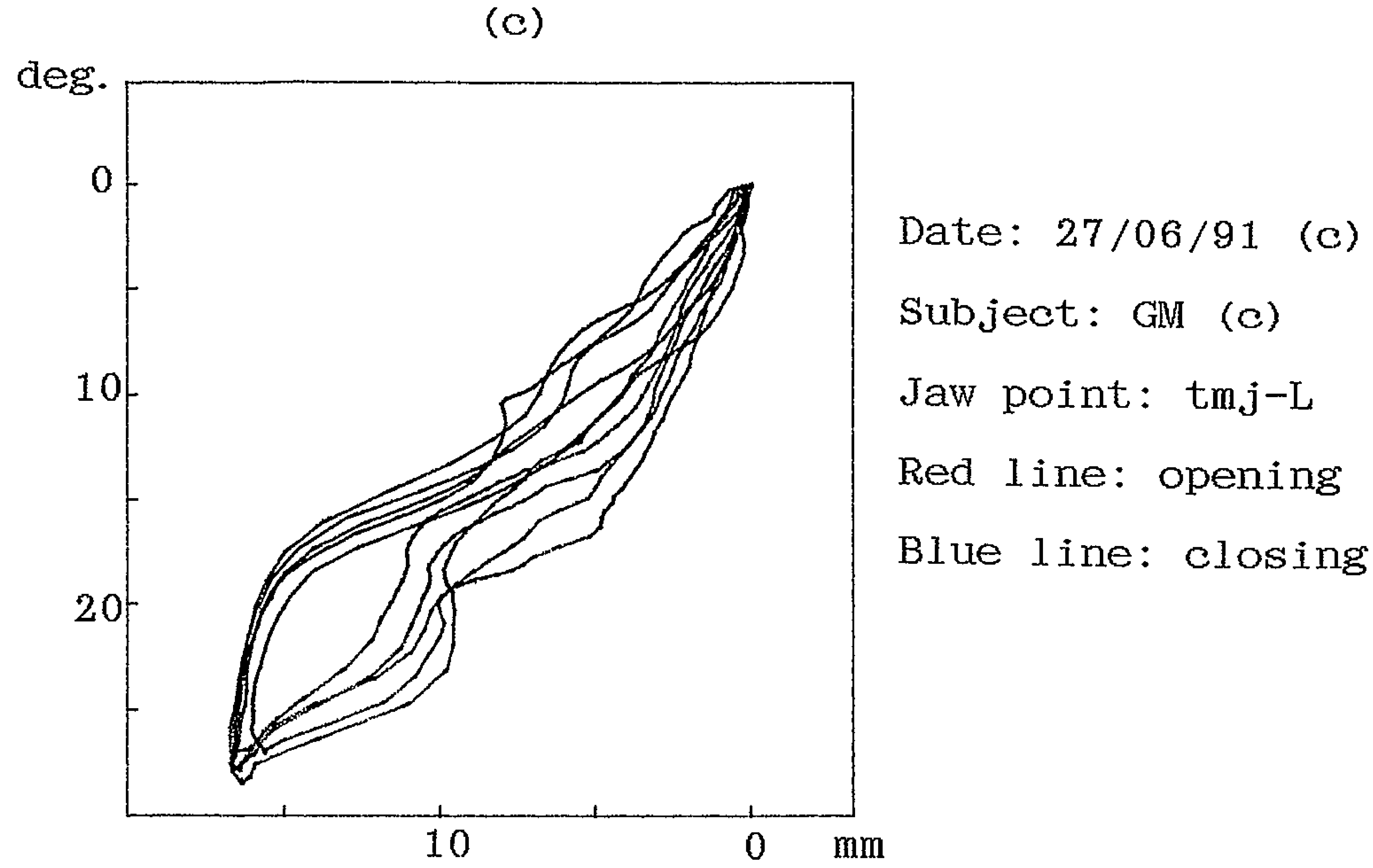
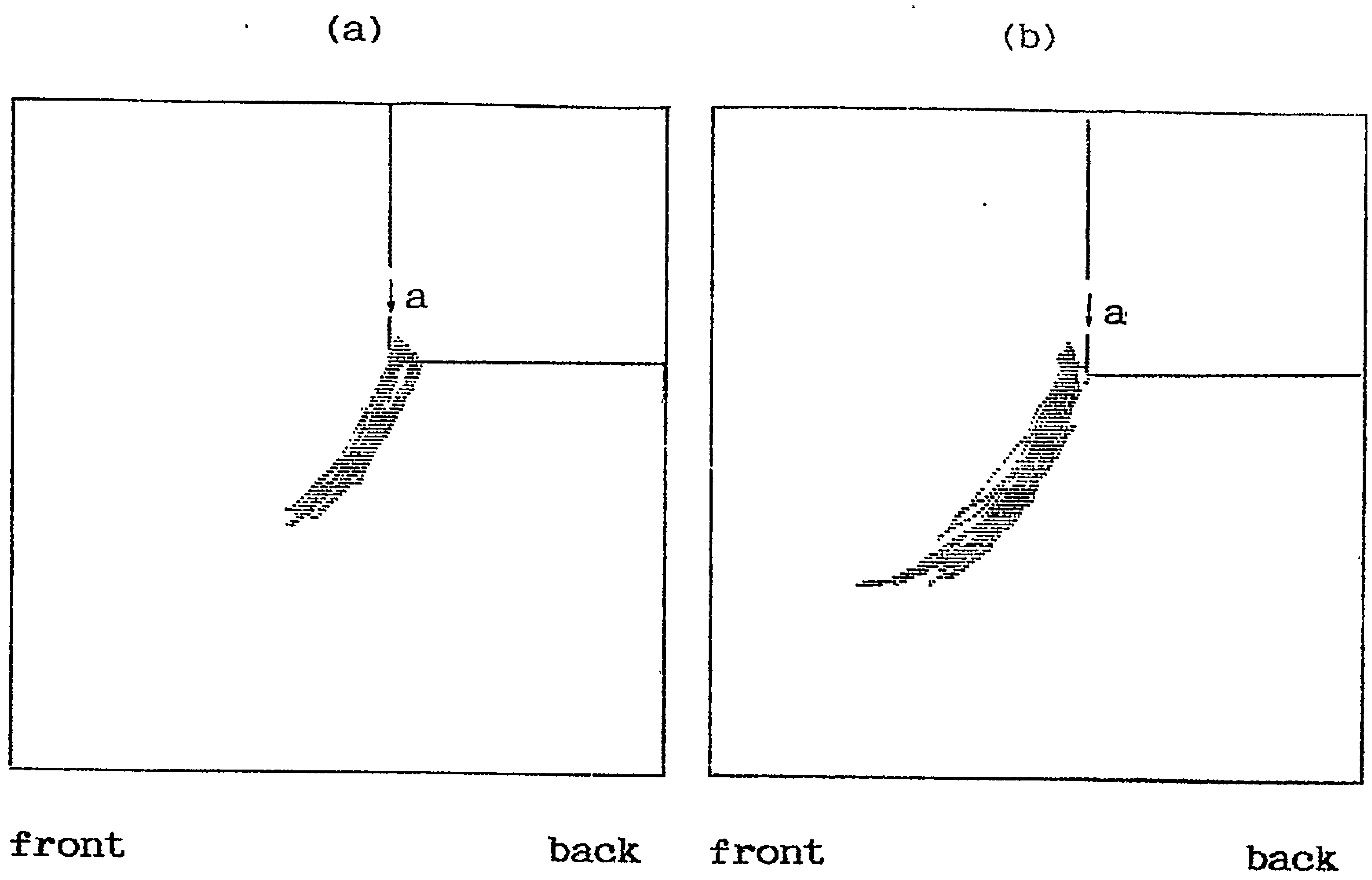
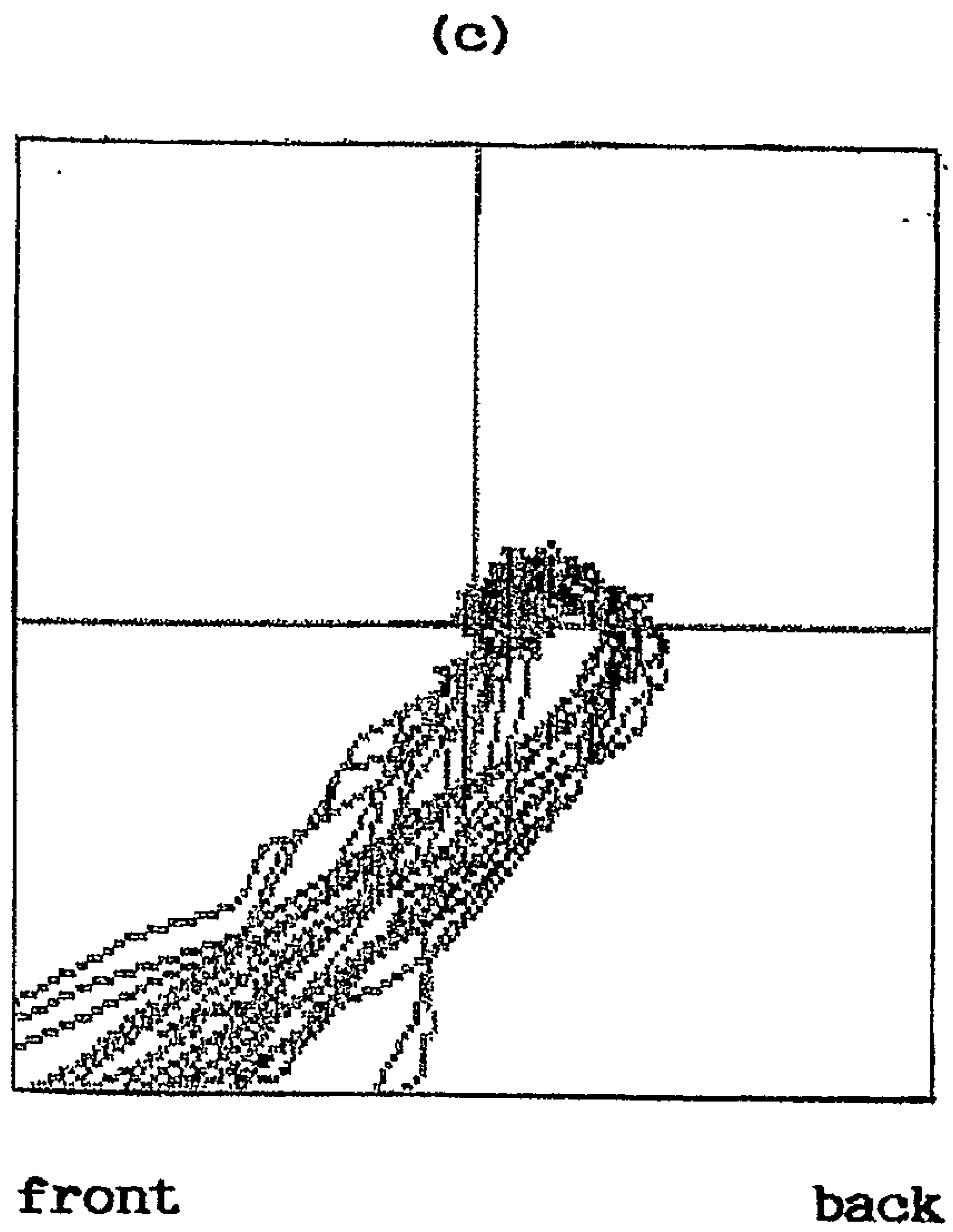


Figure 4.12 Plot of the anterior condylar translation versus opening angle for symptomatic stage: (c) subject GM; Max. ant. translation = 17.0mm, End Angle = 28.0°.





Date: 23/04/91

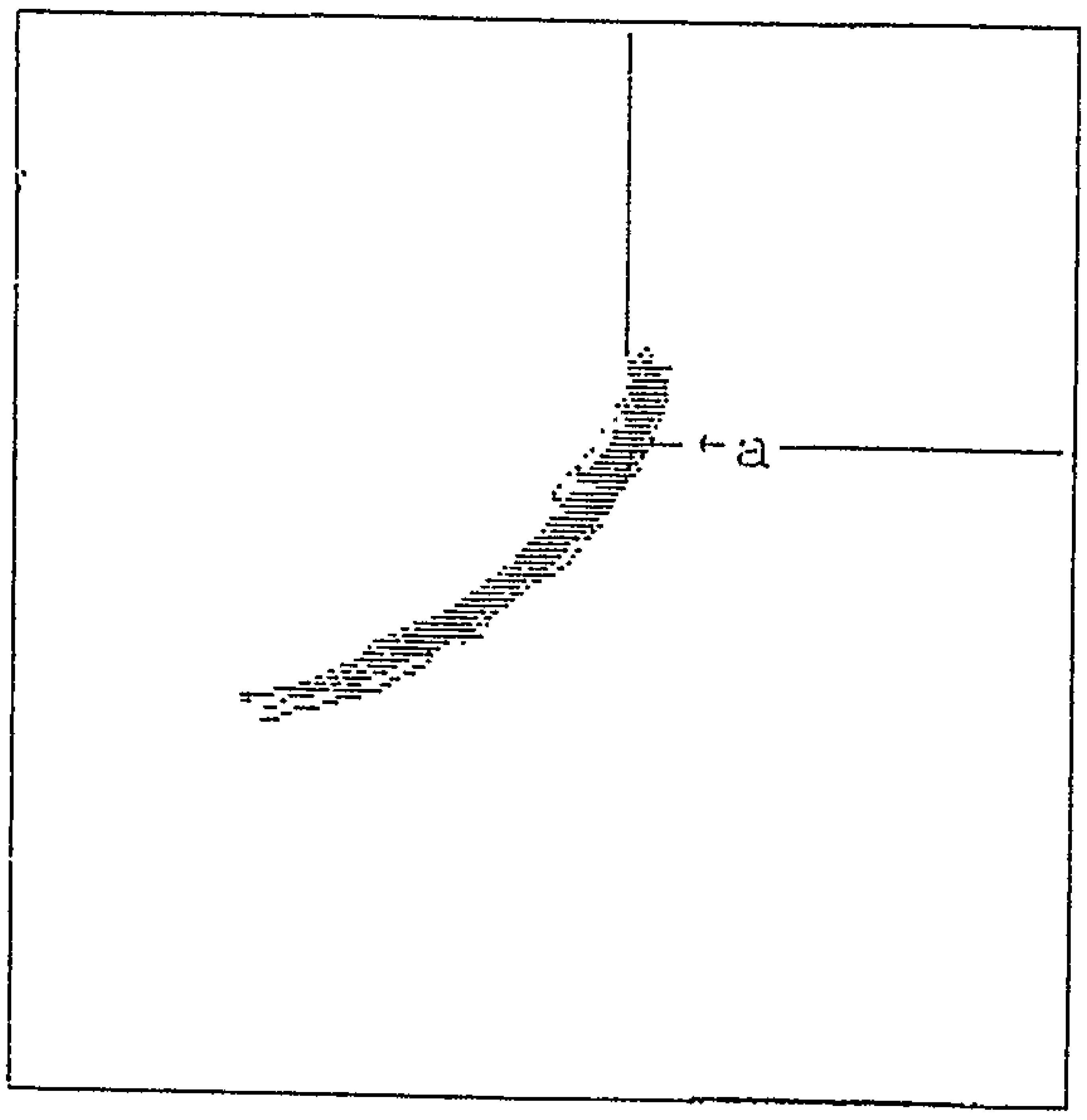
Subject: EA

Jaw point: tmj-L

Scale: 5 mm

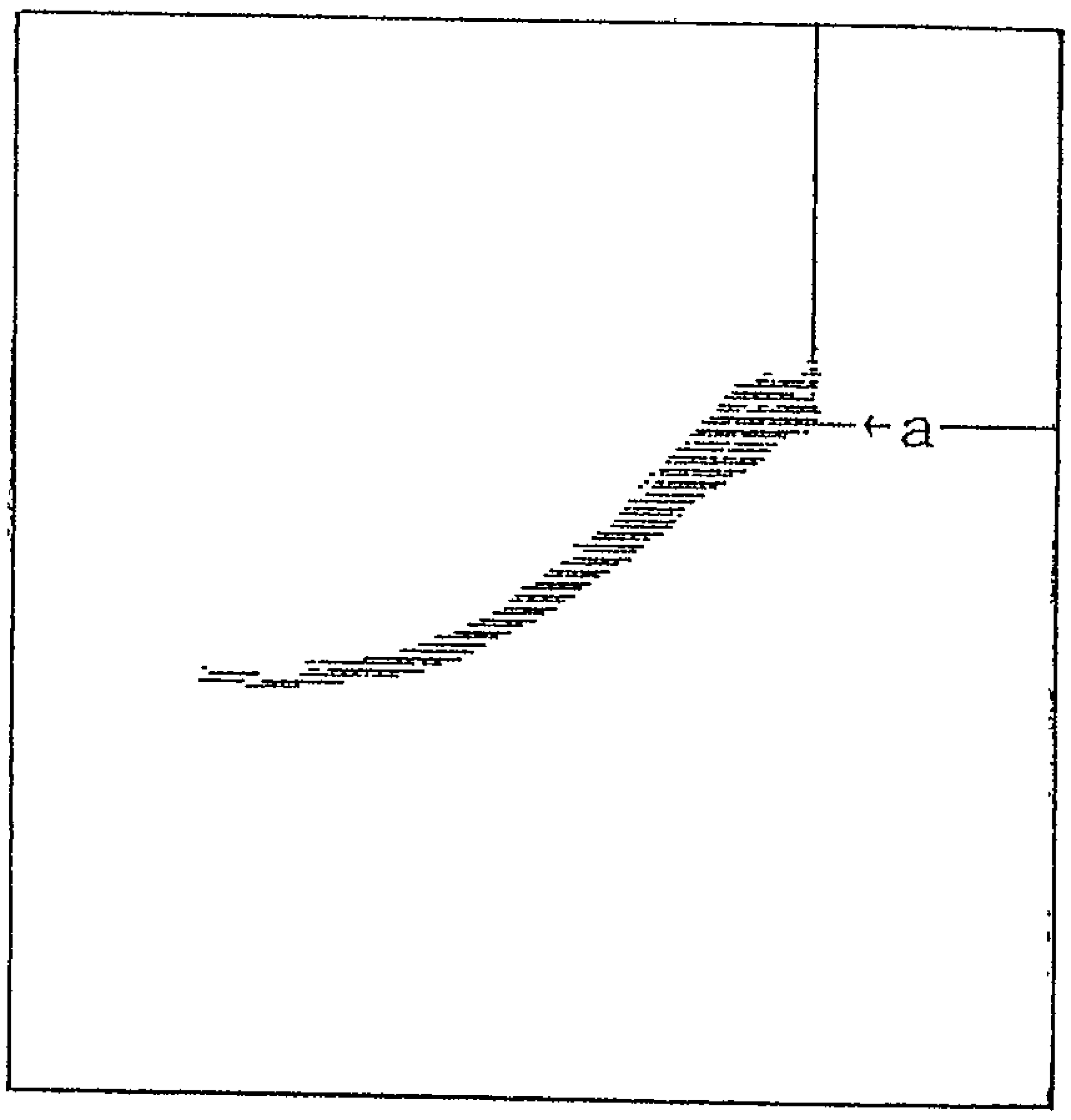
Figure 4.13 Plot of the sagittal view of ten chewing (gum) movements of the patient EA in the acute stage for (a) working side condyle and (b) non-working side condyle. (c) the condylar movement on the working side is reproduced in the 45° rotated sagittal view in magnification 9x. Red line: opening movement, Blue line: closing movement. All movement start and finish at "a".

(a)



front back

(b)



Date: 07/06/91

Subject: EA

Jaw point: tmj-L

Scale: 5 mm

front back

Figure 4.14 Plot of the sagittal view of ten chewing movements of the patient EA in the chronic stage for; (a) working side condyle and (b) non-working side condyle. All movements start and finish at "a".

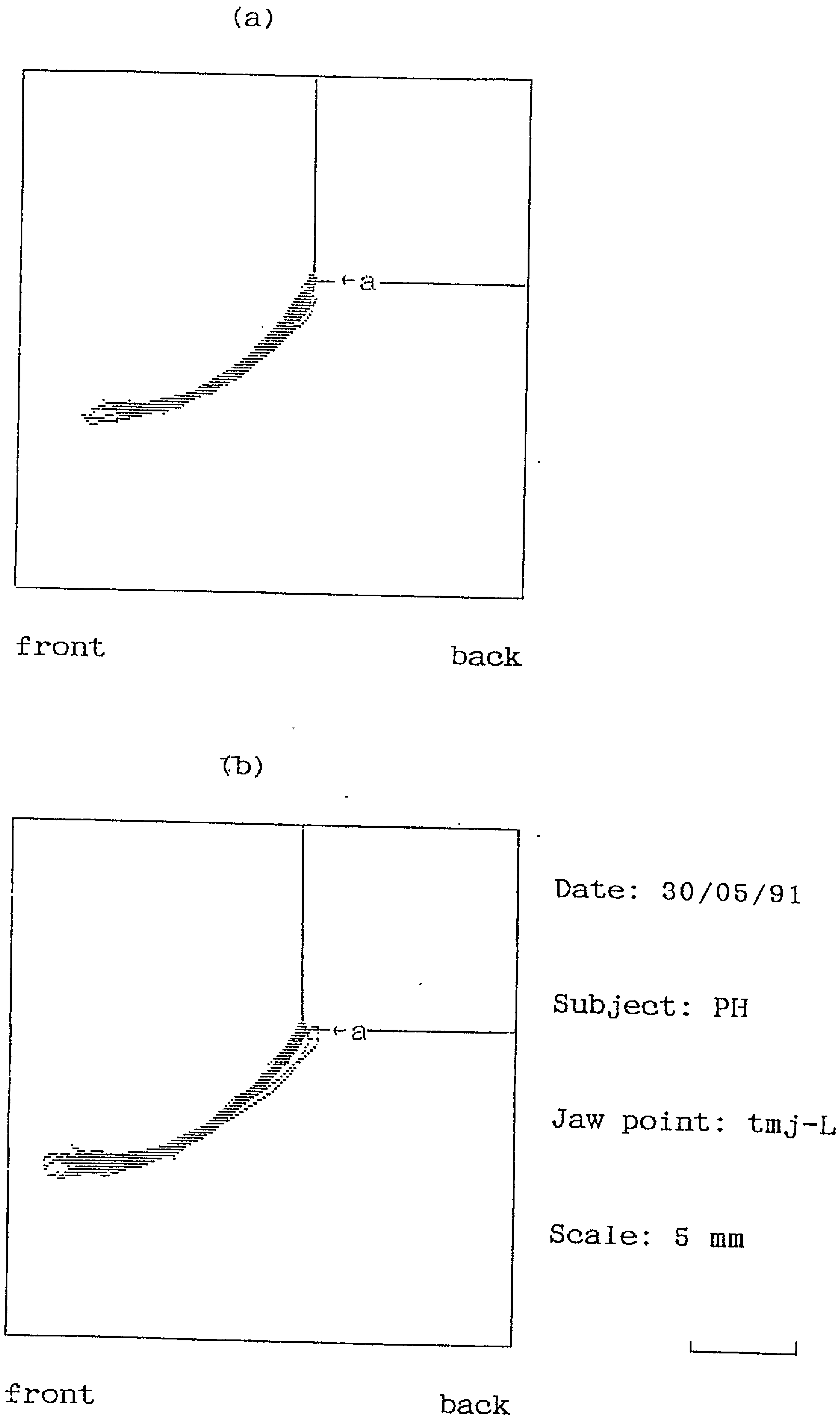


Figure 4.15 A Plot of the sagittal view of ten chewing movements of the subject PH in the asymptomatic stage for; (a) working side condyle and (b) non-working side condyle. All movements start and finish at "a".

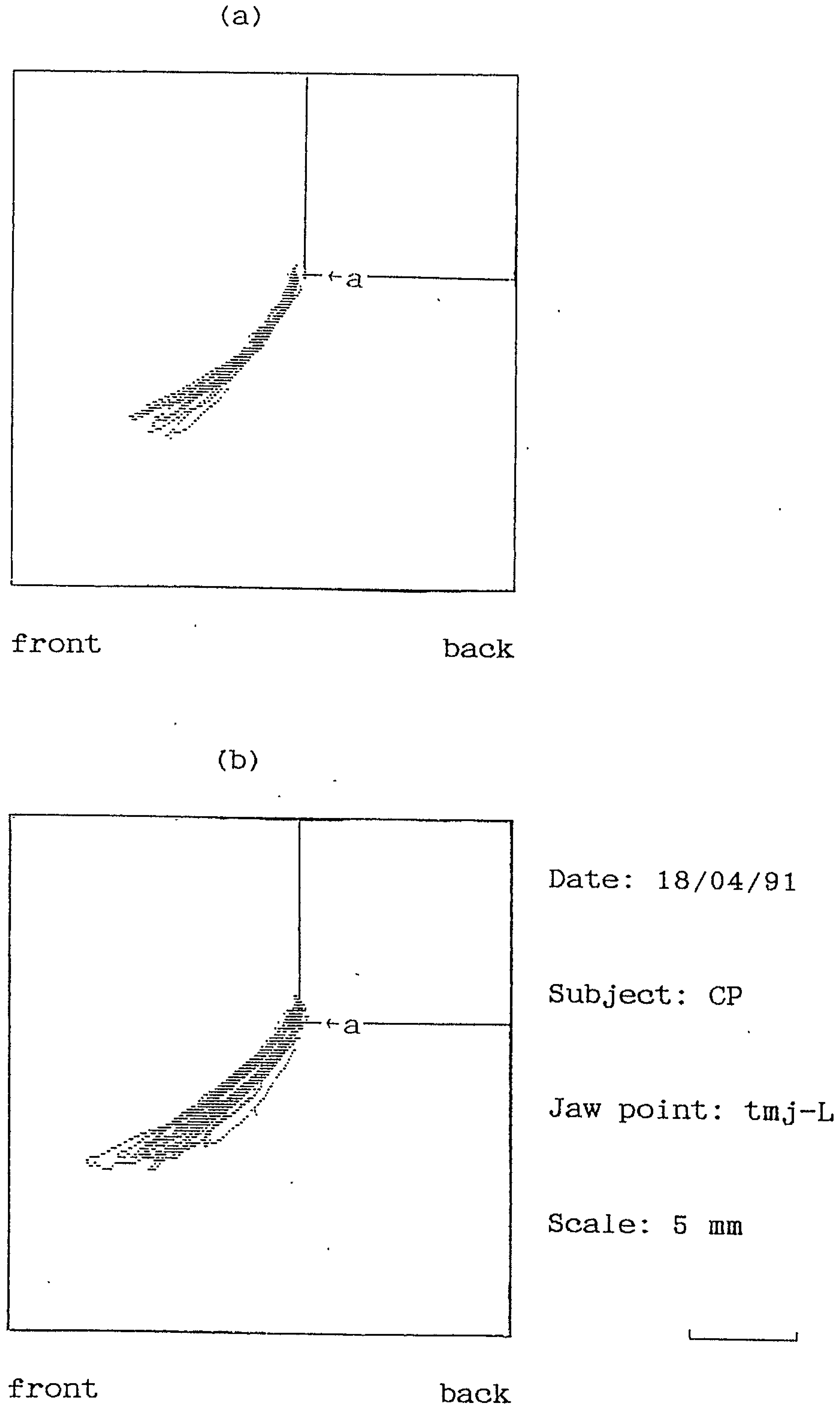


Figure 4.15 B Plot of the sagittal view of ten chewing movements of the subject CP in the asymptomatic stage for; (a) working side condyle and (b) non-working side condyle. All movements start and finish at "a".

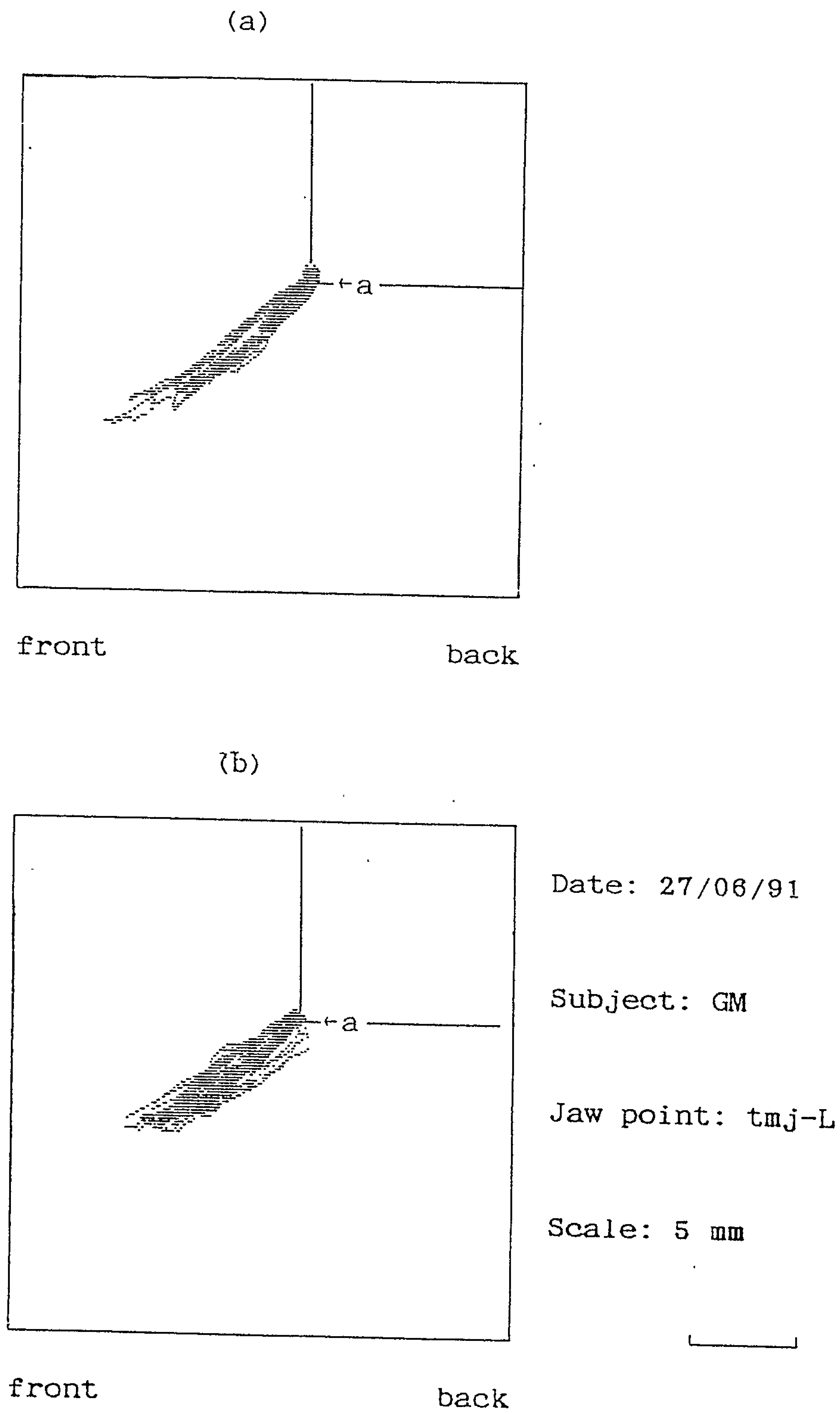
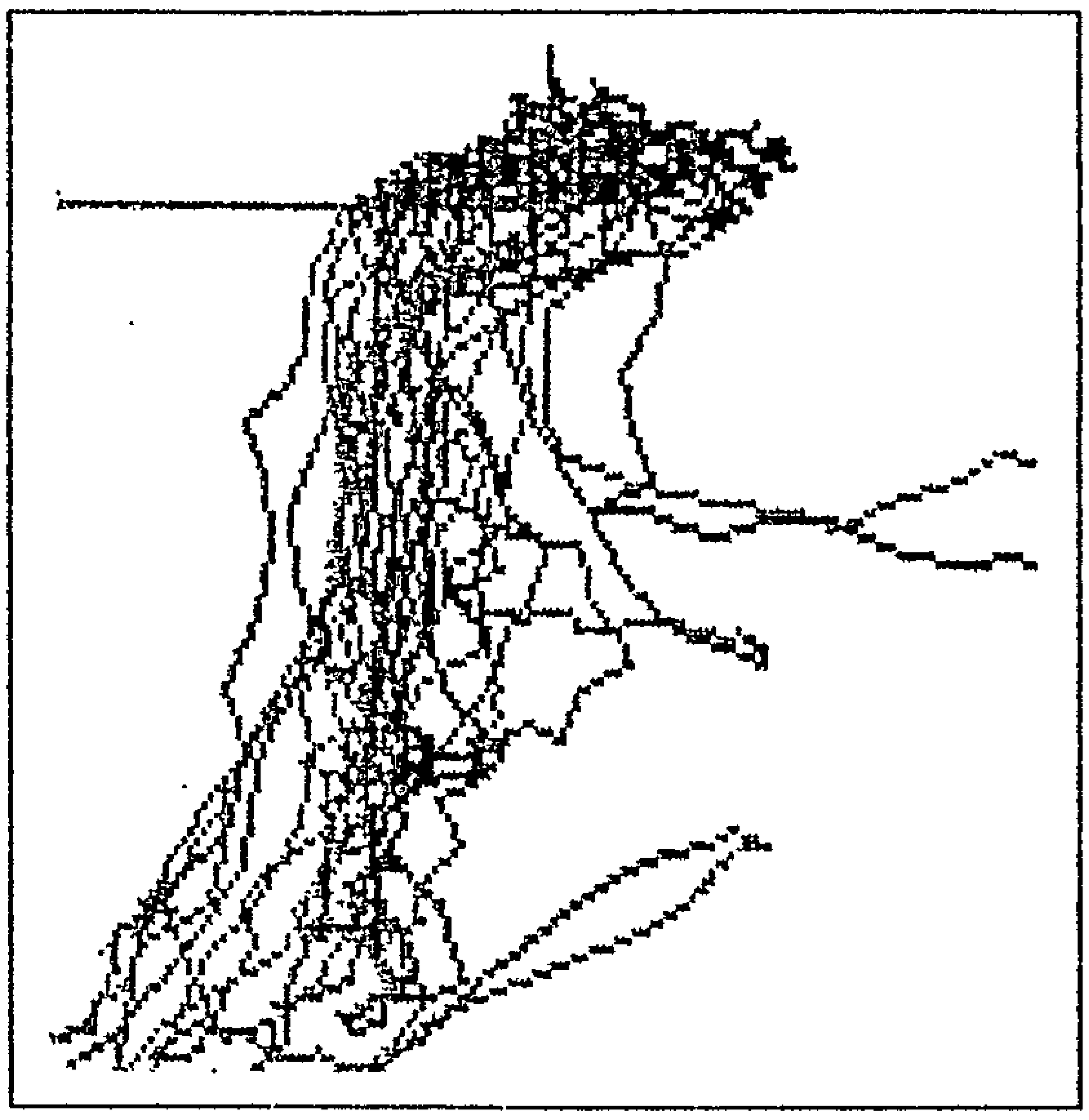


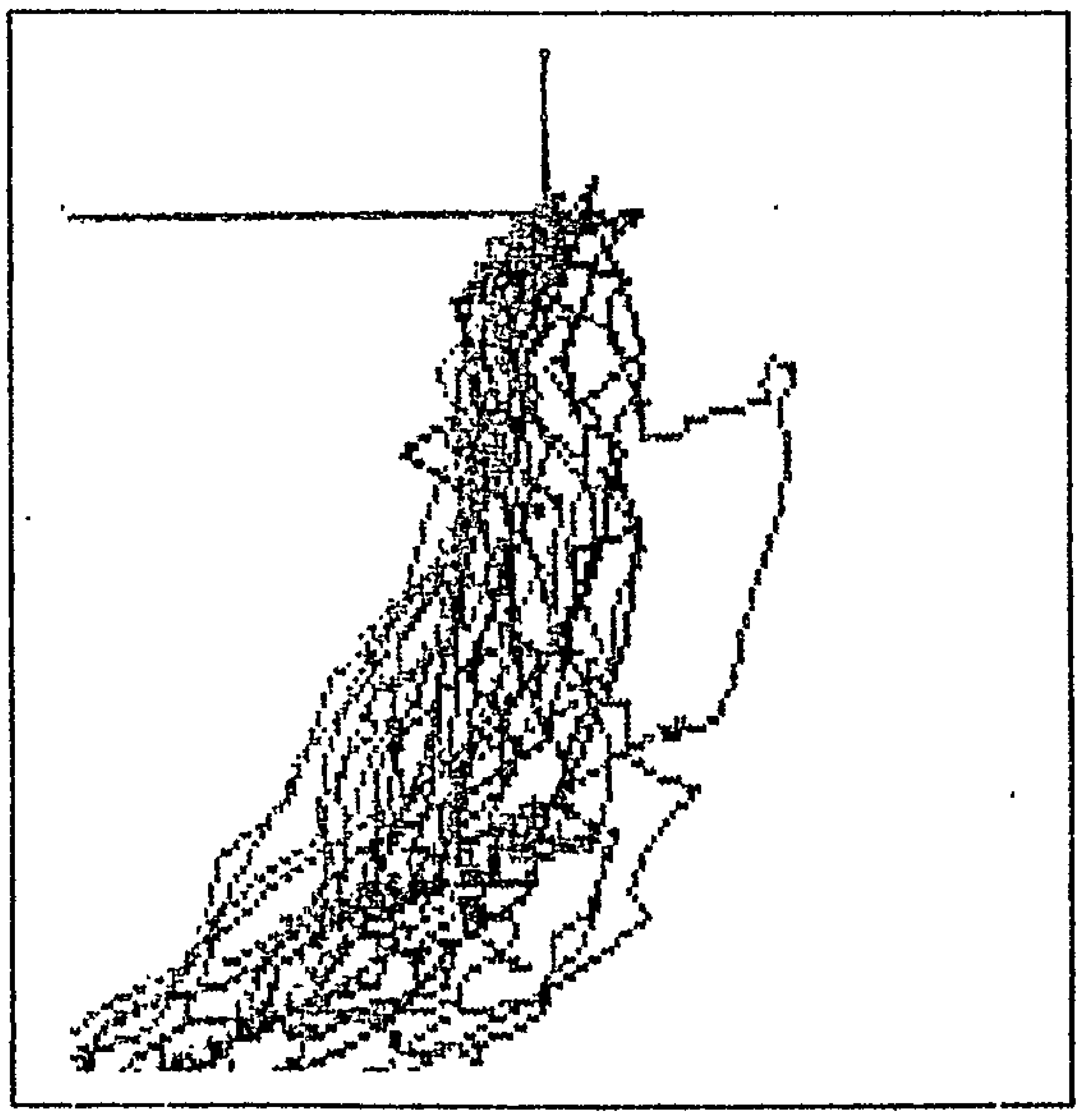
Figure 4.15C Plot of the sagittal view of ten chewing movements of the subject GM in the asymptomatic stage for (a) working side condyle and (b) non-working side condyle. All movements start and finish at "a".

(a)



right left

(b)



right left

Date: 23/04/91(a)

07/06/91(b)

Subject: EA

Jaw point: tmj-L

Scale: 5 mm

Figure 4.16 Plot of the movement of non-working side condyle in the frontal view for (a) acute stage and (b) chronic stage. Ten chewing movements are reproduced in magnification 9x. Red line: opening movement. Blue line: closing movement.

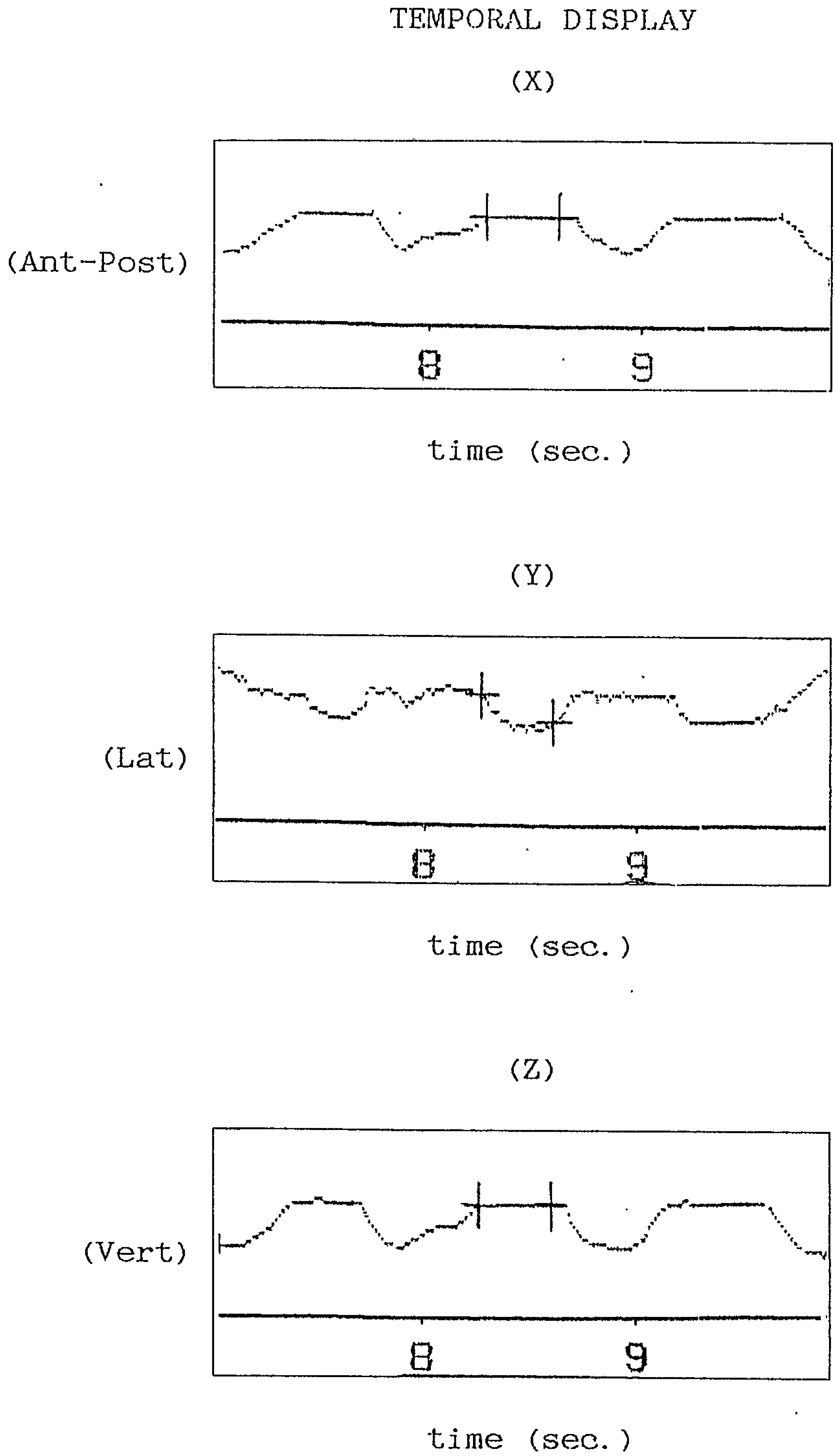
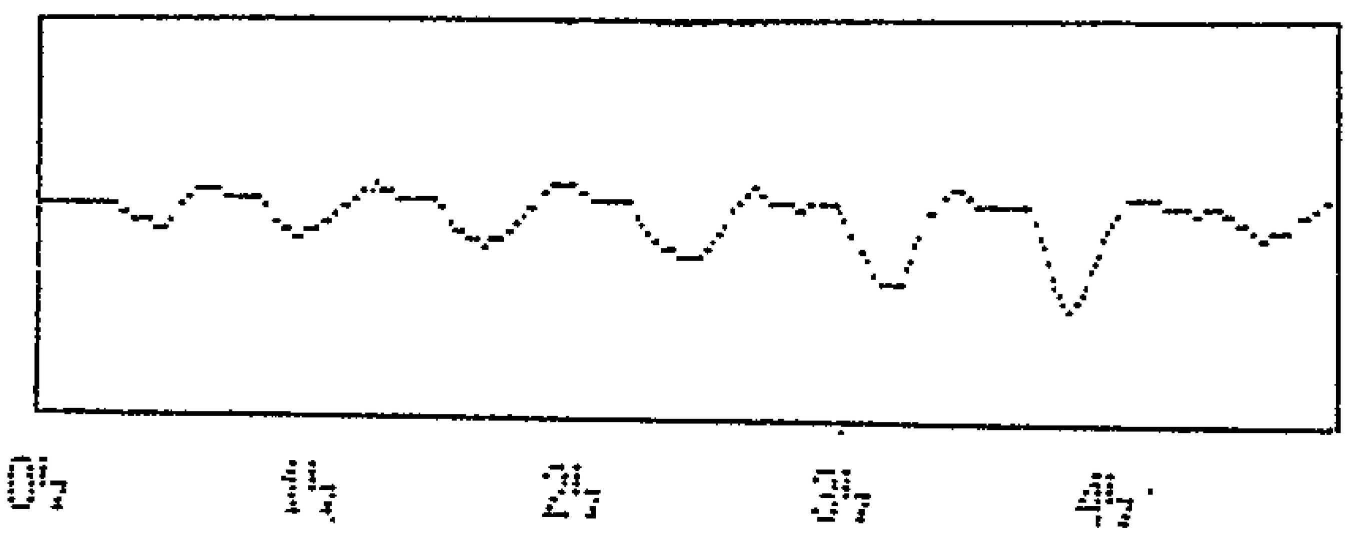


Figure 4.17 Plot of the X, Y and Z-planes against time in ten chewing movements. The movements of the non-working side condyle for the acute stage of patient EA. All movements examined start and finish at "+" with a duration of 0.34 sec.

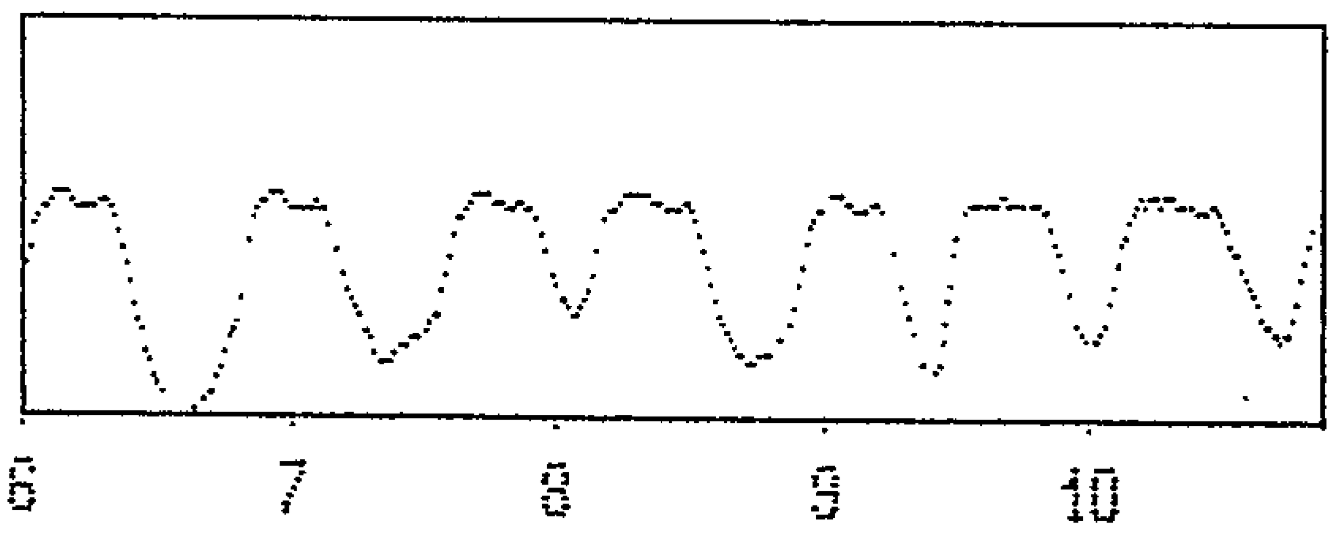
TEMPORAL DISPLAY-WORKING SIDE

(a)



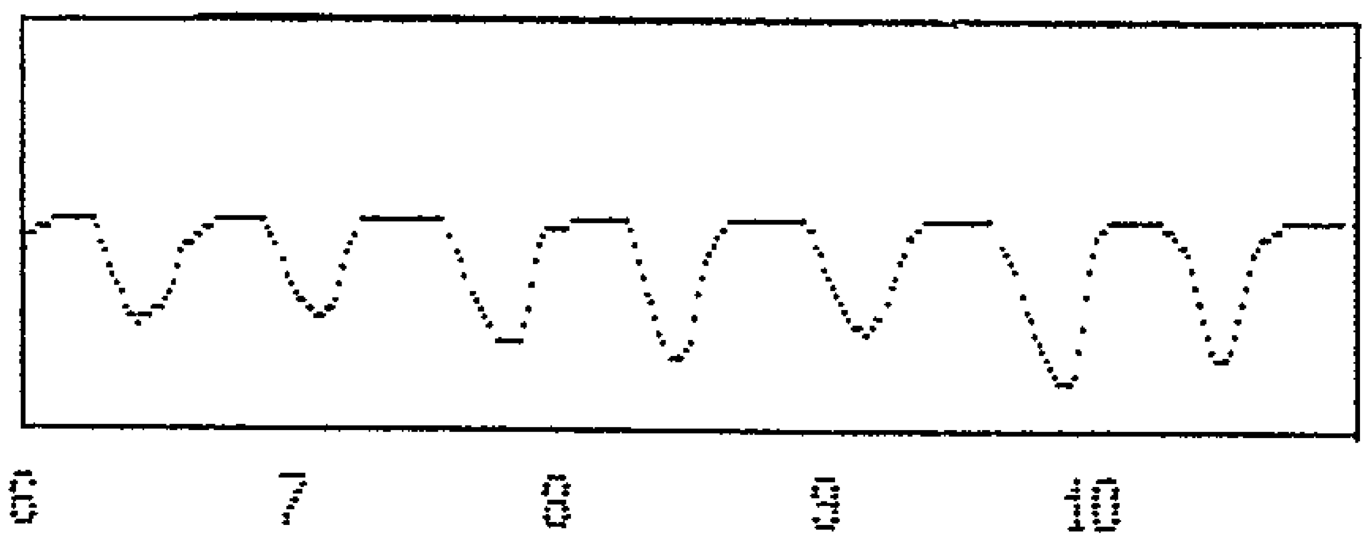
time (sec.)

(b)



time (sec.)

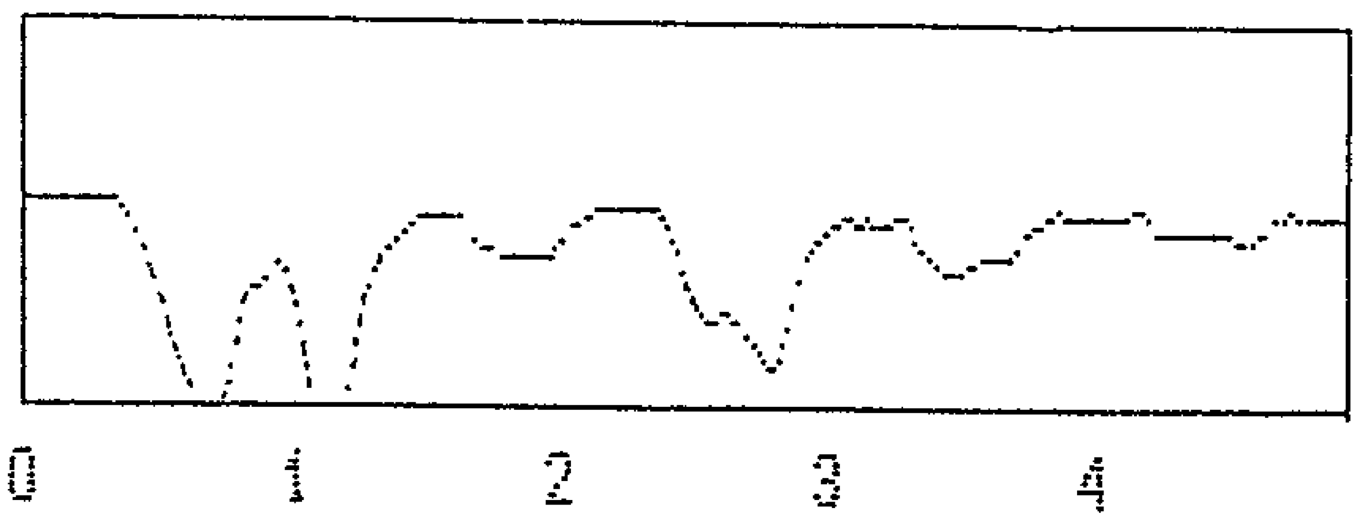
(c)



time (sec.)

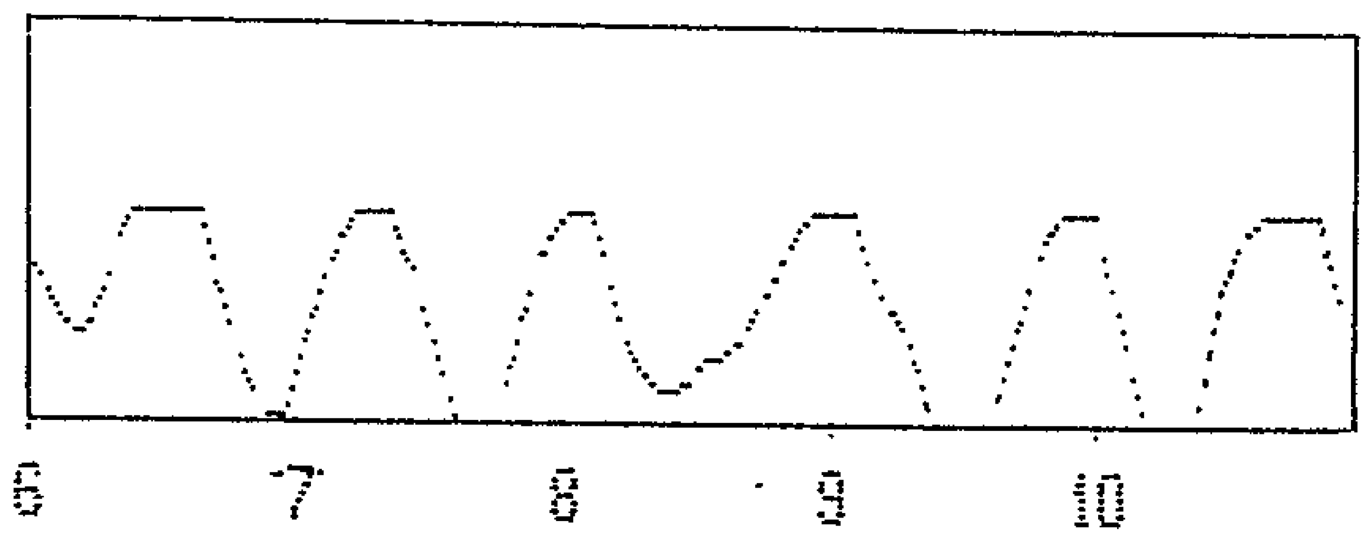
Figure 4.18 Plot of the X-plane against time in ten chewing movements. The movements of the working side condyle for; (a) acute stage (EA) (b) chronic stage (EA) and (c) asymptomatic stage (PH).

(a)



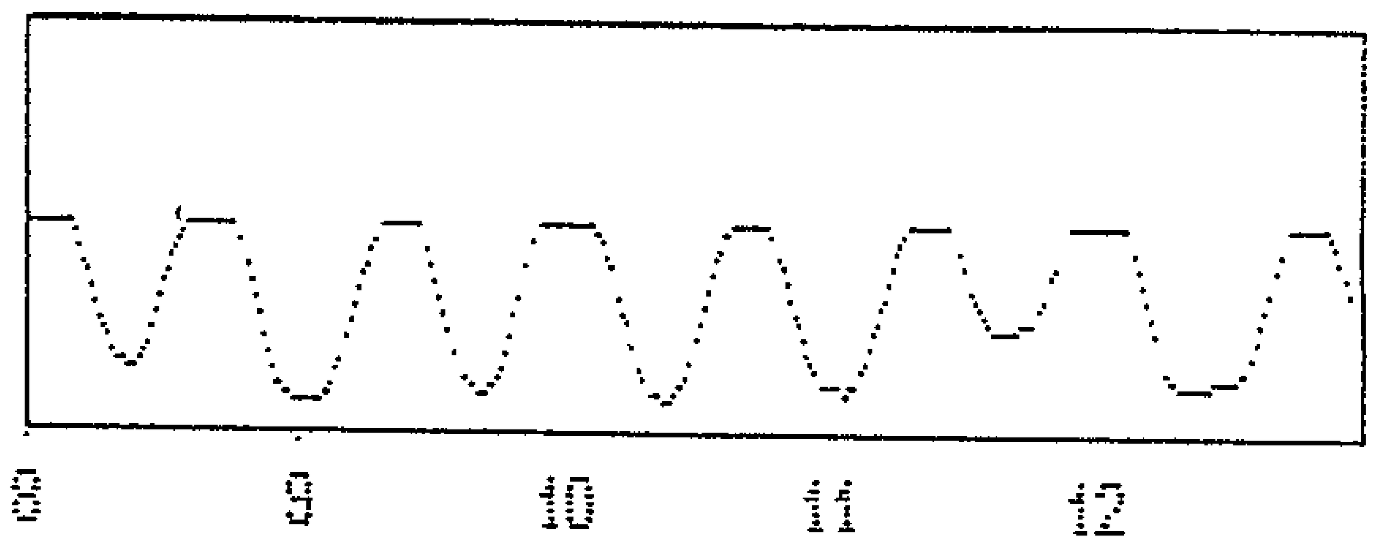
time (sec.)

(b)



time (sec.)

(c)



time (sec.)

Figure 4.19 Plot of the X-plane against time in ten chewing movements. The movements of the non-working side condyle for; (a) acute stage (EA) (b) chronic stage (EA) and (c) asymptomatic stage (PH).

5. Discussion

5.1 Accuracy of Jaws-3D tracking system

The accuracy of the system was tested on a device. In the present study the error of the system was less than 0.2mm in the entire range of 10mm (Appendix 1), which is similar to the result of 0.1mm obtained by Mesqui et al. (1986a).

It has been indicated that the error of computation of one point from the LED coordinates increases with the distance of the point to be recorded from the target frames (Woltring et al., 1985). Therefore, in this study, the placement of the target frames was chosen laterally and nearest to the points of the condyle (Fig. 3.10).

The level of the electronic noise is an important factor that limits the spatial resolution (Faulkner, 1990). The system had a drift of less than 0.2mm during a 20 second period (Table 3.2). This result is equivalent to the efficiency of a previously developed jaw tracking system such as that of Selspot system 0.14~0.2mm (Jemt, 1984).

There is also the possibility of vibration of the connecting rod when the teeth contact (Faulkner, 1990). A clutch made of rigid semi-precious metal and cast in one piece was constructed to minimize this.

The attachment which connects the target frame to the connecting rod should be fine and strong. This is very important for thc analysis of accuracy of opening angle, since the target frame could rotate following the opening and closing jaw movement if it is not strong. The error of the reconstruction of the opening angle was a mean of 5% in a range of 10 degrees. A further refinement of the small fine attachment will be required for future investigations.

Consequently, the determination of errors confirmed both qualitatively and quantitatively the validity of the Jaws-3D tracking system as a precise representation of jaw movement at the condyle point.

Since the Gnathograph of McCollum (1939) many devices to study condylar movement have been developed, and some limitations and constraints have been described in these systems:

1) the invasion and head restriction of the photographic or radiographic techniques (Karlsson, 1979; Ash, 1986),

2) the reconstruction of the movement path in two dimensions by the pantographic technique (Van Rensberg et al., 1974; Mongini, 1982), and

3) constraints induced by clutches of previous jaw tracking systems (Bates et al., 1975; Faulkner, 1990).

The Jaws-3D tracking system attempted to monitor condylar movement without any invasion in six degrees of freedom. This was first investigated by the Case Gnathic Replicator System (Gibbs et al., 1971). The system used in this study made the clutch including LEDs very much lighter. This would not bias the system as much as the previous system did.

5.2 Results of Orthodontic Treatment and their Influences

Patient EA had had three-years of fullband orthodontic treatment for Angle class II division 1 malocclusion a year before the onset of current TMJ treatment.

The influence of orthodontic treatment on the function of the stomatognathic system is not clear (Thilander, 1986). It was hypothesized that if a loss of posterior support and incisal interference occurred during the retentive phase of orthodontic treatment (Fig. 5.1), the condyle might retrude with anterior displacement of the disc (McCarty, 1980).

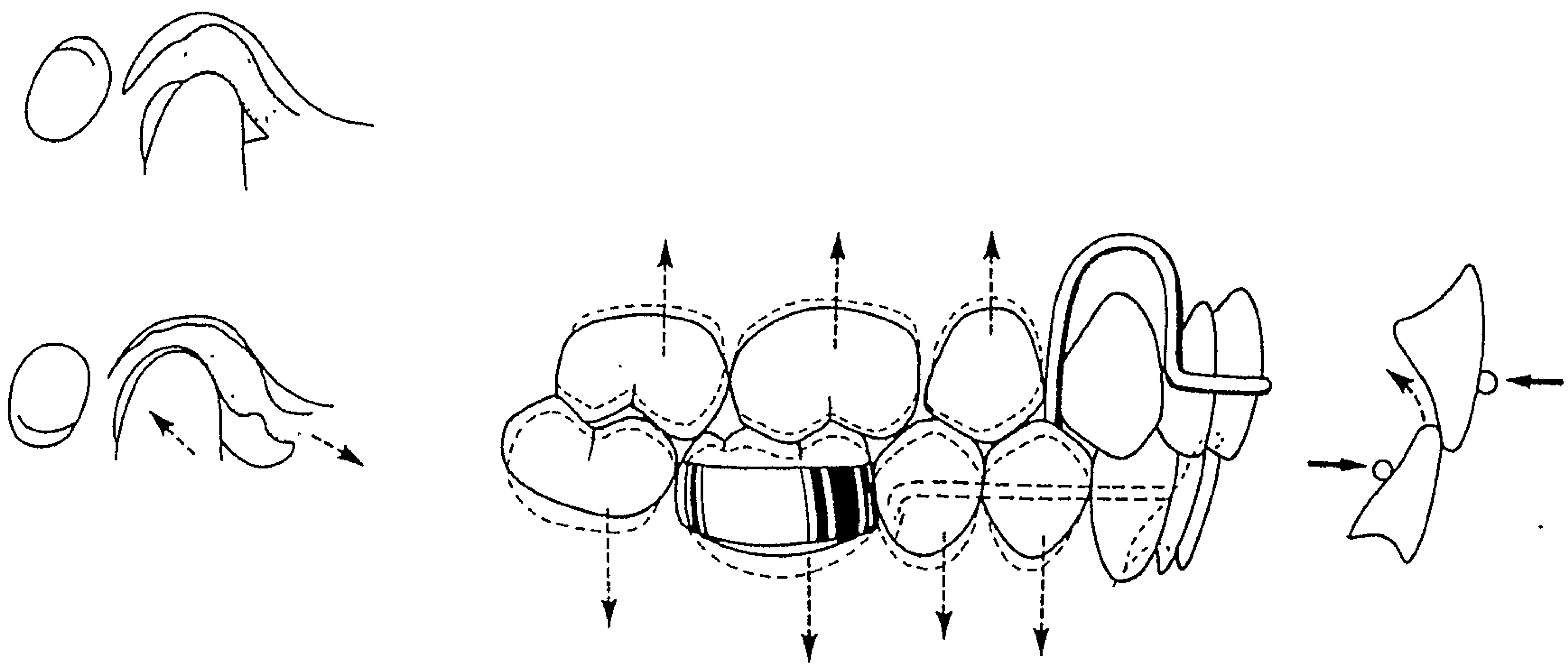


Figure 5.1 Diagrammatic representation of a loss of posterior support and incisal interferences occurred during the retentive phase of orthodontic treatment (from McCarty, 1980).

Bakke (1980) studied the influence of the occlusal contact on jaw muscle EMG and reported that during retrusion, strong activity in the posterior temporal muscles tended to decrease, when the number of posterior teeth contacts increased. Thus, when the loss of posterior teeth contacts occurs, it seems that activity of the posterior temporal muscles could become stronger. This reflex effect increases the activity of the posterior temporal muscles, and this may be one of the possible etiologic factors in TMJ internal derangements.

Further, in the case of a steep incisor relationship such as with deep-overbite, the jaw movement to avoid incisal "interferences" might be a cause of muscle fatigue in the jaw closing muscles with this wedging action of incisor teeth (Lee, 1982). This directs the jaw along a more retruded closing paths. In this way the condyles become more distally placed (retruded) at the IP, which may predispose the subject to interarticular disc displacement (Klineberg, 1988).

It has been reported that in the treatment of the adult Angle classⅡ deep-overbite patient, it is necessary to use a splint placed between the posterior teeth to support the jaw at the tentative increased vertical dimension and to free the anterior teeth for easier orthodontic manipulation (Lee and Gregory, 1971). This would consequently be of benefit to jaw muscle activity.

It seems that in the case of orthodontic treatment for Angle class Ⅱ malocclusion, a reflex change in neuromuscular coordination would develop, provoking derangement in the stomatognathic system. It is of significance, therefore, that orthodontists are aware of TMJ disorders, and the implications of their treatment on TMJ function both before and during treatment (Thilander, 1986).

5.3 Non-functional Movement of the Condyle

5.3.1 Steeper condylar path

It has been claimed that condylar path in TMJ "closed lock" is steeper with restricted anterior translation (Farrar, 1979; McCarty, 1980). Further, in the chronic stage of TMJ "closed lock" (Fig. 5.2), the condylar path will have resolution of restricted anterior translation and the condylar movement becomes normal (Farrar, 1979).

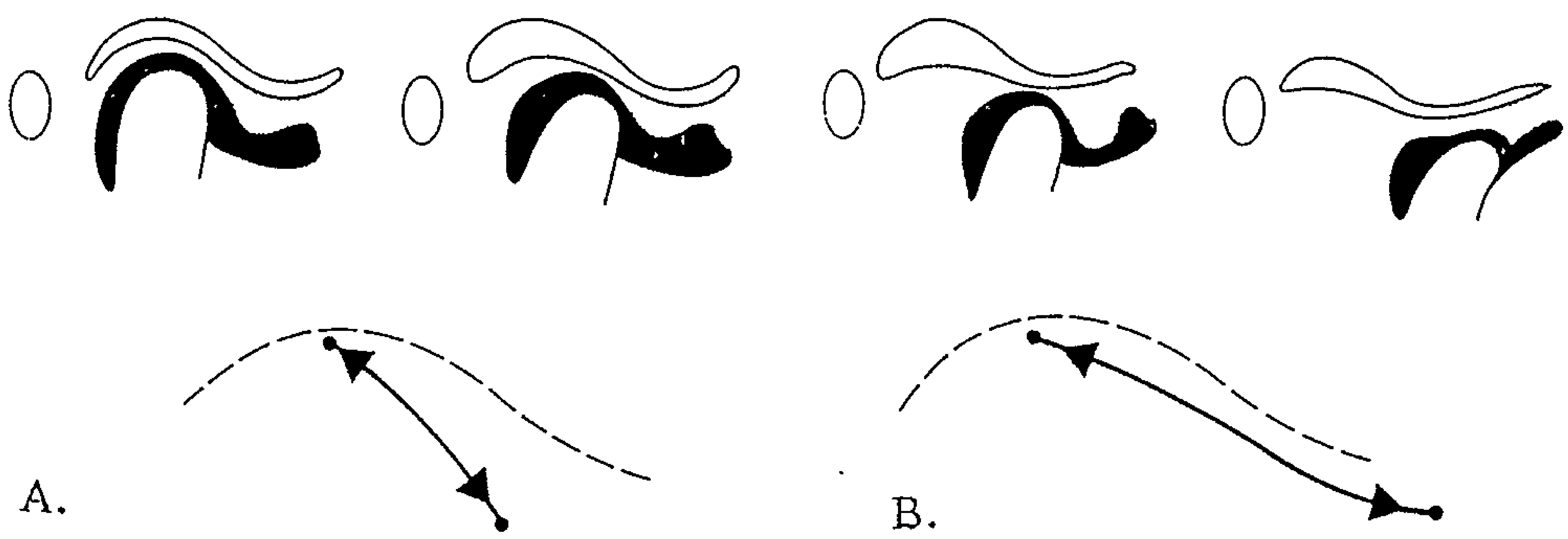


Figure 5.2 Diagrammatic representation of arthrographic correlation with condylar movement. A. Acute stage of TMJ "closed lock". B. Chronic stage of TMJ "closed lock" (from Farrar, 1979).

The present study confirms this hypothesis. That is the steeper condylar paths recorded during consecutive opening and closing movements in the acute stage (Fig. 4.1), are altered to condylar paths with increased anterior translation and decreased vertical displacement (Fig. 4.3). This is similar to that in asymptomatic subjects (Fig. 4.5A). The condylar movement could be restricted by the antero-medially displaced disc which becomes a functional obstacle (Isberg-Holm and Westesson, 1982a). Mahan et al., (1983) stated that if a disc has been displaced anteriorly, contraction of the lower head of lateral pterygoid tends to displace the condyle downward as well as forward during protrusion. This facilitates the passage of the condyle over the thick posterior band of the disc. Figure 4.10a shows the initial downward movement of the condyle during protrusion in the acute stage, in contrast to the straight forward and downward movements in the chronic and asymptomatic stage (Fig. 4.10b and c).

It has been claimed that a pure rotation of the jaw is usually limited to a jaw opening of about 15mm before the opening is stopped, (Fig.5.3) since the condyle-disc assembly pivots against the ligament and must translate forward to permit further opening (Dawson, 1989). If this further translation is restricted, the condyle tends to move downwards which may keep the floor of the mouth from hinging back causing an interference with the airway, (Dawson, 1989) to maintain an adequate opening range of jaw motion inter-incisally.

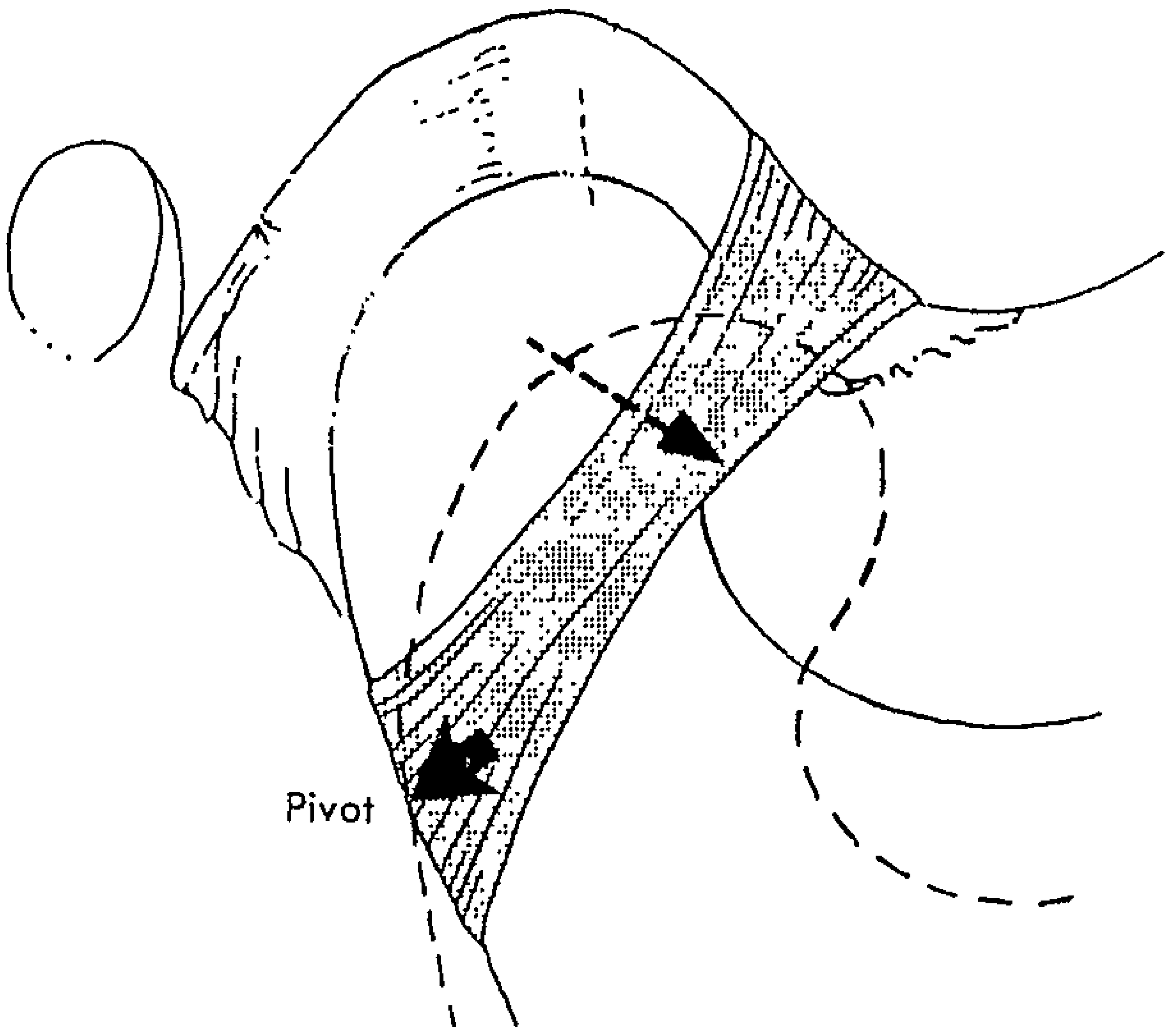


Figure 5.3 Diagrammatic representation of the hypothesis that lateral ligament of the temporomandibular joint, designed to prevent the mandible from opening too far on a pure hinge rotation at the uppermost position. The ligament reaches its full length at about 15 to 20mm of jaw opening, at which point it becomes a pivot that initiates a forward translation of the rotating condyle. This requires the mandible to move forward to reduce the possibility of airway obstruction during full opening (from Dawson, 1989).

5.3.2 Distalization of condyle

During lateral voluntary movement, a distalized movement of the condyle on the ipsilateral side that was observed in the acute stage decreased in the chronic stage (Figs. 4.7 and 4.8). Federic (1974) claimed that the magnitude of distalization of the mandible is influenced by postural position of the patient and the amount of pressure applied to the jaw. In this study, the patient performed voluntary lateral movement in the upright position. It would be reasonable, therefore, to compare alterations between the two stages (i.e. acute and chronic - see Figs. 4.7 and 4.8).

It has been suggested (Dawson, 1989) that the direct ipsilateral excursions of the jaw may cause disc displacement, since such distalizing functional movement tends to force the lateral pole backward (see Fig. 5.4). Consequently, the compromised joint capsule can be the source of the instability of the condyle (Solberg, 1986).

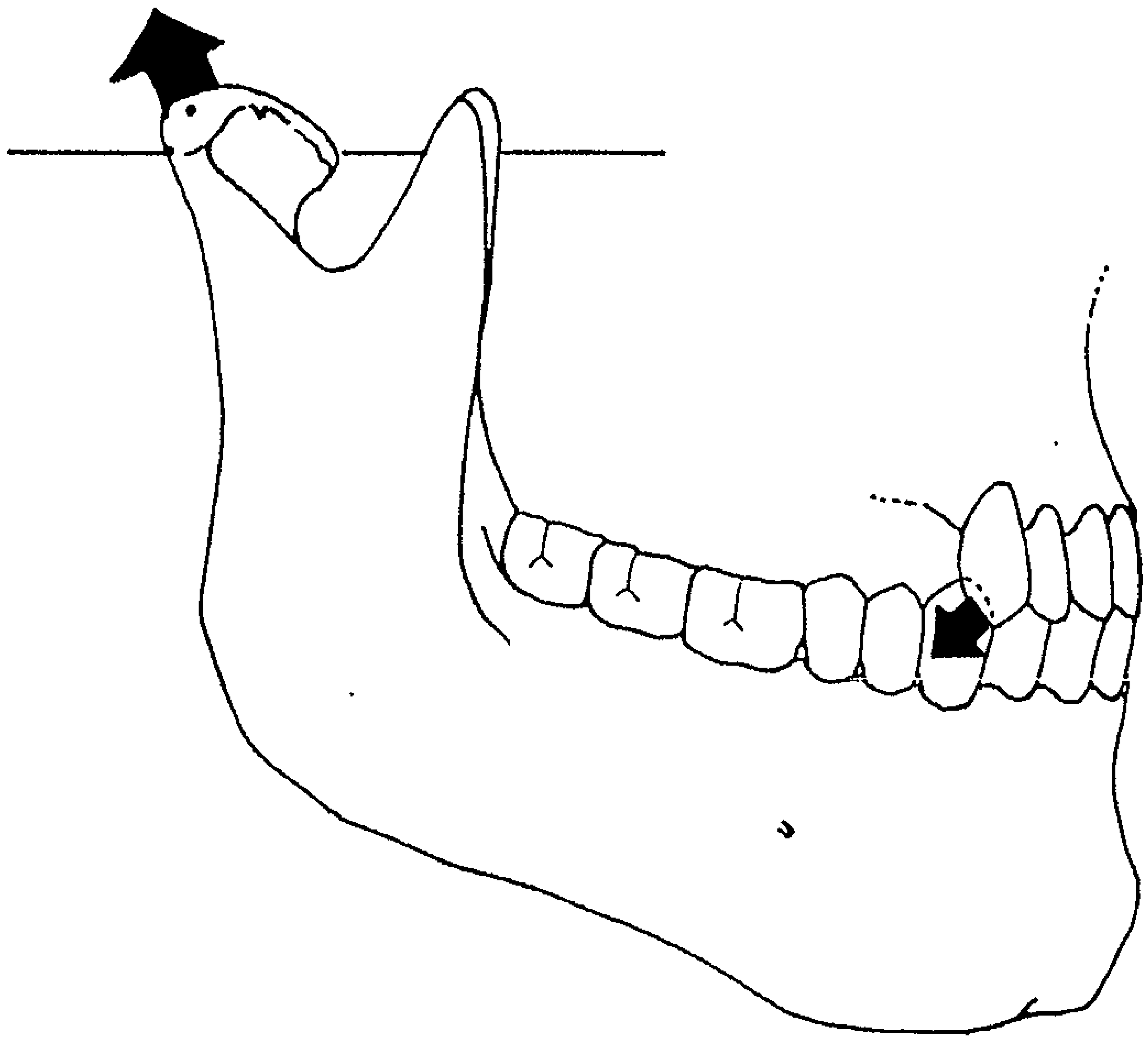


Figure 5.4 Diagrammatic representation of distalizing functional tooth inclines which tend to force the lateral TMJ pole posteriorly and stretch lateral discal ligament (from Dawson, 1989).

5.3.3 Lateral TMJ ligament

The articular capsule is a thin fibrous membrane, but the lateral surface is strenghened by the lateral ligament. This arises from the tubercle on the temporal bone and runs downwards and backwards to the neck of the condyle below the lateral pole (Rees, 1954). It has two paths (Fig. 5.5A), a horizontal band and an oblique band (Griffin and Hawthorn et al., 1975; Klineberg, 1988).

It has been claimed that the capsule and ligament prevent excessive forward, backward and lateral dislocation of the condyle (Kawamura, 1968). However, the role of the lateral ligament may have other functions also:

1) to restrict posterior condylar movement (Arstad, 1959,),

2) to restrict downward dislocation (Sicher and DuBrul, 1970), and

3) to restrict lateral dislocation (Griffin and Hawthorn et al., 1975).

In the present study, the distalized movement of the condyle decreased in the chronic stage (Figs. 4.7 and 4.8) with a resolution of excessive vertical displacement (Figs. 4.1 and 4.3). Therefore, these proposed roles for the lateral ligament appear to be combined in our data leading to dislocation of the condyle.

Wilkinson (1988) reported that the continuous band of tissue runnning from the anterior rim of the condyle to the roof of the infratemporal fossa was observed under the microscopic examination of sagittal histologic sections of TMJ. Further, the foot of the anterior part of the disc blends with the superior surface of this band. Posteriorly, the disc attaches to it by loose connective tissue;however, medially and laterally the disc is not connected with the capsule at all (Choukas and Sicher, 1960). This relationship between the disc and lateral ligaments agrees with that suggested by Ohmura (1984) in his study of 50 TMjoint specimens. It was claimed (Mahan and Kreitziger, 1977) that the disc is attached firmly to the lateral and medial poles of the condyle by the lateral and medial discal ligaments (Fig. 5.5B).

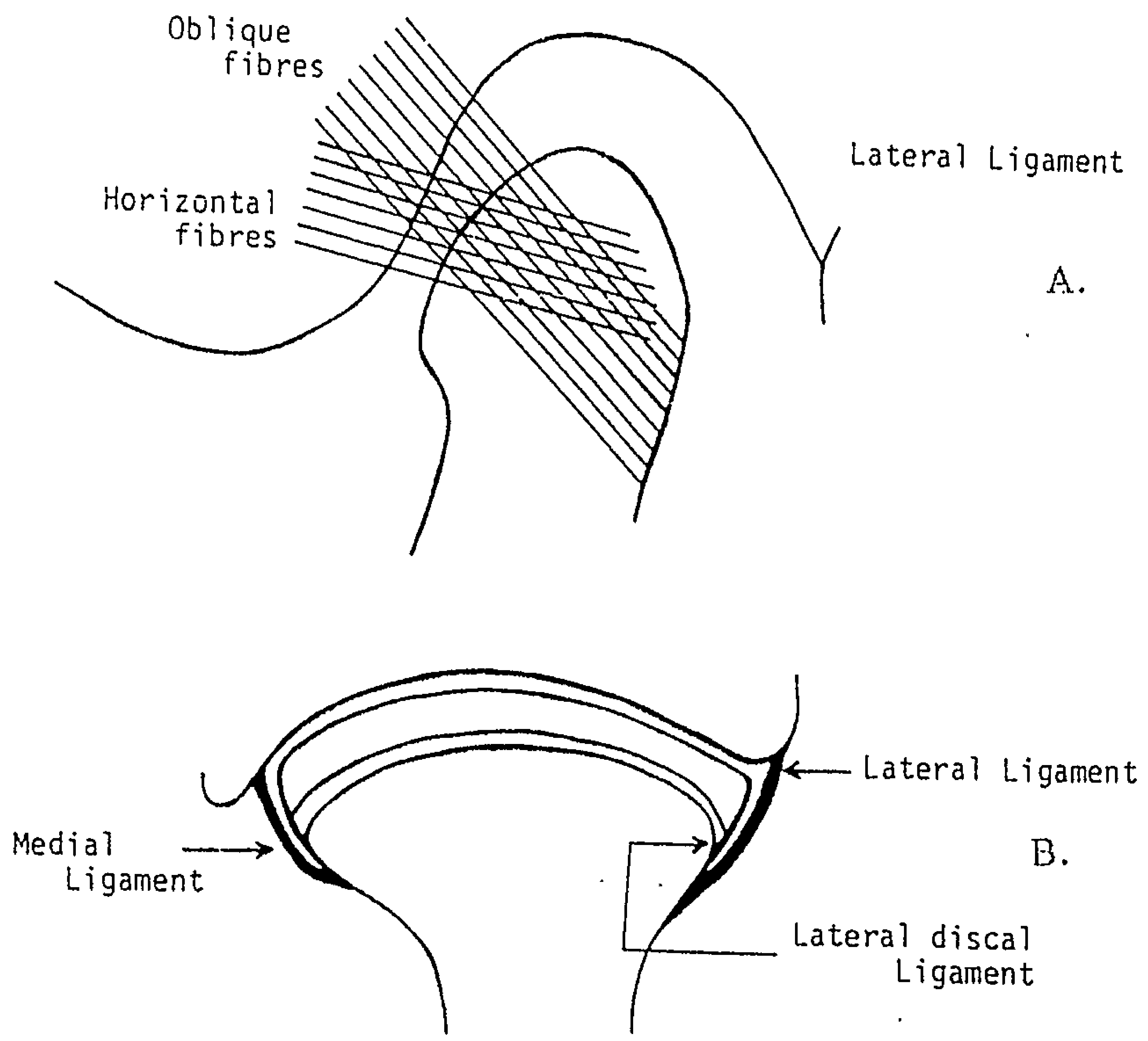


Figure 5.5 Diagrammatic representation of primary and accessory ligaments of the temporomandibular joint:
A. Lateral ligaments
The outer obligue band of fibres extends from the articular tubercle to the neck of the condyle. The inner more horizontal band of fibres extends from the articular tubercle to the interaticular disc and to the lateral pole of the condyle.
B. Relationship of medial and lateral capsular ligaments with medial and lateral discal ligaments. The latter ensure that the interarticular disc is firmly attached to the medial and lateral condylar poles allowing rotation within the lower joint compartment. Translation occurs in the upper joint compartment and synchronous movement of disc condyles is facilitated by presence of the discal ligaments (from Klineberg, 1986).

When the lateral discal ligament is stretched or torn, the disc rotates more anteromedially since the condyle causes it to stretch during attempted translation in the inferior joint space instead of the superior joint space(Moses, 1991).

5.3.4 <u>The Reproducibility of Non-functional Condylar Movement</u>

In a single opening and closing movement, the condyle in the acute stage showed non-reproducible paths in contrast to the reproducible paths in the chronic and asymptomatic stages. Ernst (1988) reported by using the optoelectronic tracking system developed by Metropoly (Naegelistr. 8, 8044 Zurich, Switzerland), that a single opening and closing movement is not reproducible in the clicking joint.

It has been claimed that the reproducibility of the condylar movement as assessed mainly by pantograph (Clayton et al., 1976; Shields et al., 1978; Beard et al., 1980) can be a parameter (e.g.PRI) with which to detect TMJ dysfunction. However, the diagnostic value of the reproducibility of this condylar movement is debated. Mohl et al., (1990) indicated that the diagnostic value of the PRI is not well supported by scientific evidence. Firstly, there are known exceptions to their findings, and secondly, the sample size was always too small. Comprehensive statistical analysis is required in future studies to assess the diagnostic value of this pantographic assessment method.

5.4 Rotation and Translation

5.4.1 Ratio between condylar rotation and translation

Merlini and Palla (1988) using the optoelectronic tracking system developed by Metropoly, showed a linear relationship between condylar rotation and translation during opening and closing movement in healthy TMJoints. They also reported that in clicking joints with a pronounced irregularity of condylar path with clicking, the opening movement started mostly by rotation and the closing movement ended generally with a pronounced rotation.

The present study indicated that in the asymptomatic stage, subject PH showed a linear relationship between the condylar rotation and translation over the entire range of jaw opening (Fig. 4.12a). In the case of subject CP, jaw closing movement showed a linear relationship, but jaw opening movement ended mostly by rotation (Fig. 4.12b). Figure 4.5B (also from subject CP) shows lateral displacement of the condyle in the end of jaw opening movement. During this displacement, therefore anterior translation of the condyle could be restricted producing some rotatory movement.

The subject GM with symptoms of TMJ dysfunction showed a pronounced hesitation of the anterior condylar translation in the middle of jaw opening (Fig. 4.12c). Subject GM had an excessive anterior translation and the hesitation in movement represented a downward displacement immediately before the change of direction of movement from downward to upward during jaw opening (Fig. 5.6). This hesitation may have occurred when the condyle rode over the posterior thick band of the disc whilst passing over the summit of the articular eminence.

Merlini and Palla (1988) reported similar findings in 3 of 10 healthy subjects, and they described that these three subjects had a larger mouth opening than the others. It was reported that the condyles often reach a position far beyond the articular eminence in maximal opening and that this should not be taken as a sign of chronic subluxation or TMJ hypermobility as described by Brown (1975).

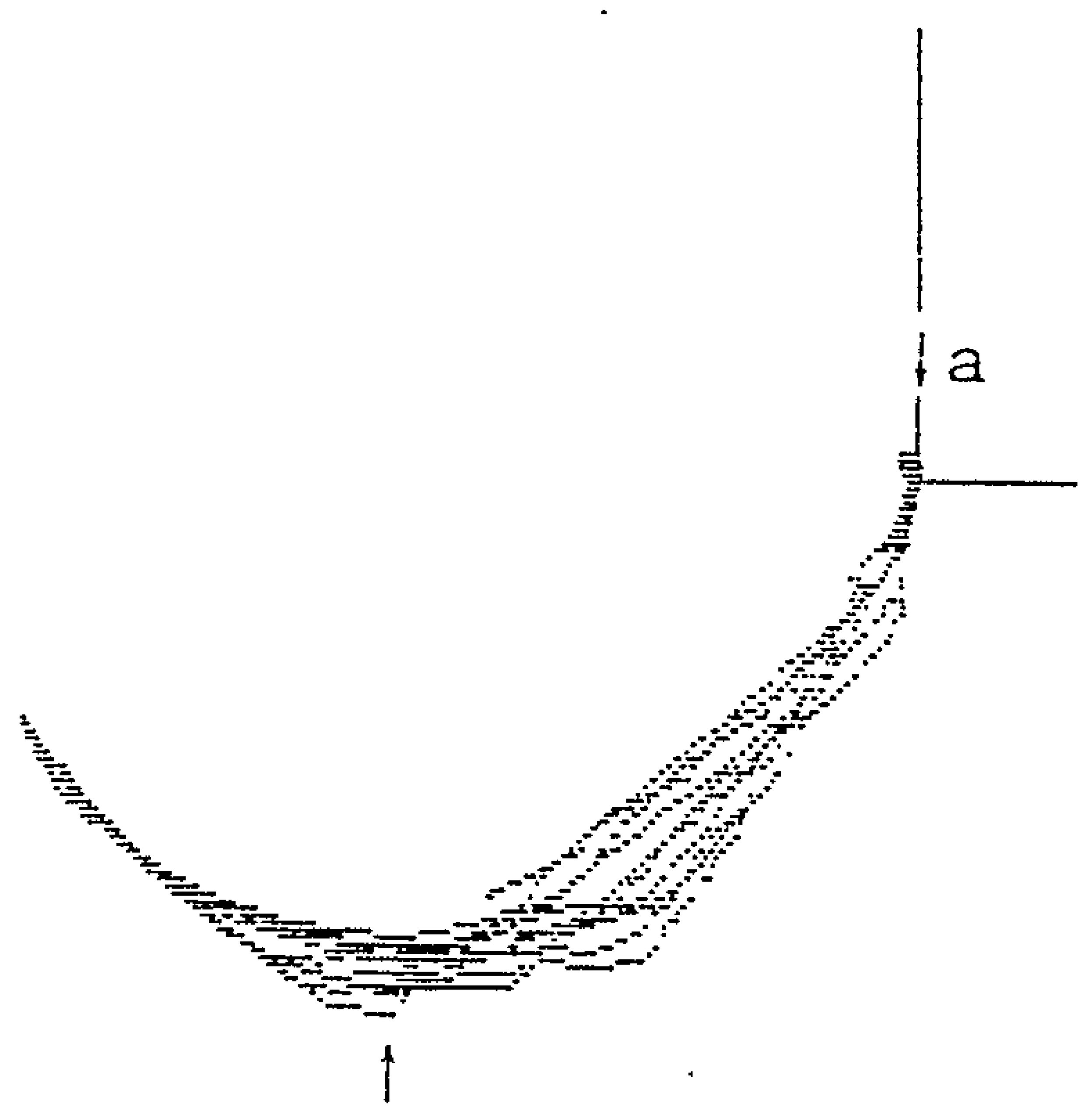


Figure 5.6 Plot of the condylar path in the sagittal plane for the subject GM. Five opening and closing movements are superimposed. All movements start and finish at "a". Arrow indicates downward displacement occurred just before the change of that direction of movement from downward to upward during jaw opening.

Gysi (1910) stated that in any movement of the jaw, the condyle moved around its centre of rotation, the hinge axis, which was thought to be located somewhere in the body of the condyle (McCollum, 1960). This apparent centre of action is not constant; its position depends on the amount of combined components during forward-and-downward movement and hinge axis opening.

The combined movement components are translatory and rotatory. The translation of the axes is made by sliding actions in the disco-temporal joints (i.e. the superior joint space), and the pure opening-and-closing rotation movements occur in the disco-mandibular joints (i.e. the inferior joint space, Stuart, 1959). A wide mouth opening is produced by both rotation and translation of the condyle (Stuart, 1959; Posselt, 1962).

5.4.2 <u>Influences to condylar rotation and translation</u>

There are two main factors which may trigger dyskinetic movements of the condyle in jaw opening: one is discoordination of jaw muscles and the other is derangements in TMJ.

In the present study, patient EA had tenderness due to palpation on the left lateral pterygoid muscle in the acute stage (Table 3.2). There was associated restricted anterior condylar translation with some rotatory movement, since the opening angle clearly increased in the latter half of the movements (Fig. 4.11a). The discoordination of jaw muscles, and particularly the lateral pterygoid, may have affected the relationship between the rotation and translation components of jaw movment.

The lower head of the lateral pterygoid mainly pulls the condyle forward and downwards (Kawamura, 1968). It has been reported that during maximum protrusion, it is more active than the digastric muscles whilst the activity of the temporal muscle is negligible (Møller, 1967).

If the disc has been displaced anteriorly, it could be a functional obstacle for anterior translation of the condyle (Isberg-Holm and Westesson, 1982). The contraction of the lower head of the lateral pterygoid tends to displace the condyle downwards which facilitates the riding of the condyle over the thick posterior band of the disc (Mahan et al., 1983). If this contraction in the lower head of the muscle is prolonged, activation of peripheral mechanoreceptors, could contribute to reflex muscle hyperactivity (Klineberg, 1986). Such a response (Travel, 1960) may cause pain in the muscles. The cause is uncertain and may be associated with accumulation of metabolic end products, and blood flow restriction due to interference with venous drainage by sustained muscle activity (Møller et al., 1979). Further, the reduced muscle activity of the lateral pterygoid decreases anterior translation of the condyle.

After the resolution of muscle tenderness of the left lateral pterygoid (Table 3.2), condylar movement of patient EA showed an improvement in restricted anterior translation (Fig. 4.11b). The relationship between condylar rotation and translation became near linear with almost the same opening angle as the one in the acute stage (Fig. 4.11a). This finding suggests that the discoordination of this muscle was a major cause of restriction of anterior condylar translation.

As the disc slowly displaces forward and medially, movement within the superior joint space generally becomes minimal and the inferior joint space begins to act as the translatory compartment for the "wide-open" mouth position (Moses and Topper, 1991). This functional change in the TMJ, may cause imbalance of the ratio between condylar rotation and translation.

Furthermore, immobility of the disc has been claimed to be a factor of restricted TMJ mobility (Toller, 1976). Such immobility infers that there are fibrous adhesions in the superior joint space. Arthroscopic examination of the superior joint space has revealed that there are often pathological adhesions present (Murakami et al., 1986; Moses, 1989). Fibrous adhesions in the superior joint space would lead to restricted condylar translation since the superior joint compartment would not then allow the translatory movement.

It has been reported that lavage of the superior joint space helped eliminate the joint pain and improved restricted jaw mobility, but it was unsuccessful in the lower joint space (Murakami et al., 1987). Therefore, the normal function of the superior joint compartment could be important for the linear relationship between condylar translation and rotation.

5.5 Functional Condylar Movement

5.5.1 Condylar movements on working and non-working side

Chewing movement is produced by the different movements of the working side and non-working side condyles. This finding was firstly reported by Gibbs et al., (1971). In the present study, similar findings were shown:

1) distraction of the condyle in the closing paths existed on the working side, and

2) as the teeth reached their IP, the working side condyle moved anteriorly and medially to its terminal position, in contrast to the non-working side condyle which moved directly posteriorly and superiorly to reach its terminal position (Fig. 4.13).

The anterior component of movement of the working side condyle during final closure had been reported by Hickey et al., (1963) and comfirmed by the replicator system with an average of 0.3mm (Gibbs, Lundeen, Mahan et al., 1980). The present study did not provide a numerical estimate, but revealed a similar movement of the working side condyle during final closure in the TMJ even without disc in position (Fig. 4.13c).

5.5.2 Rhythm of chewing cycle

In this study, the patient EA showed that the rhythm of the chewing cycle became more stable after occlusal splint therapy (Fig. 4.18 and 19). Previous studies of chewing movements (Ahlgren 1966; Jemt, 1984)have indicated variations in the shape, size and speed of the movement path. It has been reported that the lack of rhythm within each chewing cycle and also from cycle to cycle was the most constant feature in patients with TMJ symptoms such as clicking or pain (Stohler and Ash, 1985). Changes in chewing cycle can be due to causes other than purely local ones such as occlusal disharmony (Atkinson and Shepherd, 1961).

The rhythm of the chewing movement is known to be pre-programmed by the central pattern generator (Dellow and Lund, 1971) in the brain stem associated with peripheral afferent inputs from receptors in the articular (Klineberg, 1971), periodontal (Hannam and Matthews, 1969), mucosal (Thexton, 1973) and periosteal (Sadaka, 1972) tissues (Klineberg, 1986). Therefore, changes in the rhythm of chewing movement suggest that reflex changes occurred during the occlusal splint therapy.

5.5.3 Efficacy of occlusal splint

Occlusal splints provide the possibility for spatial change in jaw position (Klineberg, 1986) with even tooth contact and an increase of vertical dimension of occlusion (VDO).

The TMJ capsule is richly innervated and sensory information detected by joint receptors is conveyed mainly along the afferent fibres in the auriculo-temporal nerve (Klineberg, 1971) to the central nervous system. It has been stated that the TMJ may provide several important sensory functions which includes the signalling of joint position and pain, and probably, the initiation of reflex movements (Miles, 1978).

Klineberg (1980) studied functional envelopes of jaw movements by monitoring spatial changes of the lower incisor teeth, recorded before and during unilateral and bilateral anesthesia of the temporomandibular (TM) articular capsule, and reported subsequent variations in the size and shape of the envelope of function. This study shows an interaction between joint afferents and the moto neurons of jaw muscles.

Although muscle coordination is controlled predominantlly from higher centres (Klineberg, 1980), it was noted that permanent joint damage can make jaw mobility and opening limited (Miles, 1978).

The change in the spatial jaw position could cause changes in articular capsular tension in TMJ which could eventually contribute to the overall reflex changes in coordinated jaw muscle activity (Klineberg, 1986). Further, reflex changes in jaw muscles may alter the overall programming of the rhythm of chewing cycle (Fig. 4.18 and 19). A stabilized overall rhythm of jaw movement could indirectly indicate a return to normal tonicity and smooth reciprocal activity of the muscles that govern mandibular movements (Sessle, 1974; Ow et al., 1988).

The relationship between VDO and TMJ disorders is debated. Costen (1934) concluded from clinical observations made on 11 patients that mandibular overclosure caused posterior displacement of the condyles. He stated that the pressure caused by posterior displaced condyles resulted in headaches, sinus pain, earache, tinnitus, stuffy sensation in the ears, burning tongue and metallic taste. ; a group of symptoms that became known as " Costen's syndrome".

However, other causes of this syndrome as opposed to Costen's hypothesis suggested on anatomical grounds by Sicher (1954) and on clinical grounds by Schwartz (1959). The latter indicated that psychological factors play a significant role in this syndrome.

Conflicting results have been reported on the effect of an increase in VDO on masticatory muscles: not only is there an increase of tenderness due to palpation in all masticatory muscles (Christensen, 1970), but there is also a decrease in masticatory muscle activity (Manns et al., 1983). The different responses obtained with an increase in VDO may relate to different study methods. It was reported that severe responses occurred when the occlusal appliance used did not cover the dentition completely (Gianelly, 1970;Sergle, 1975).

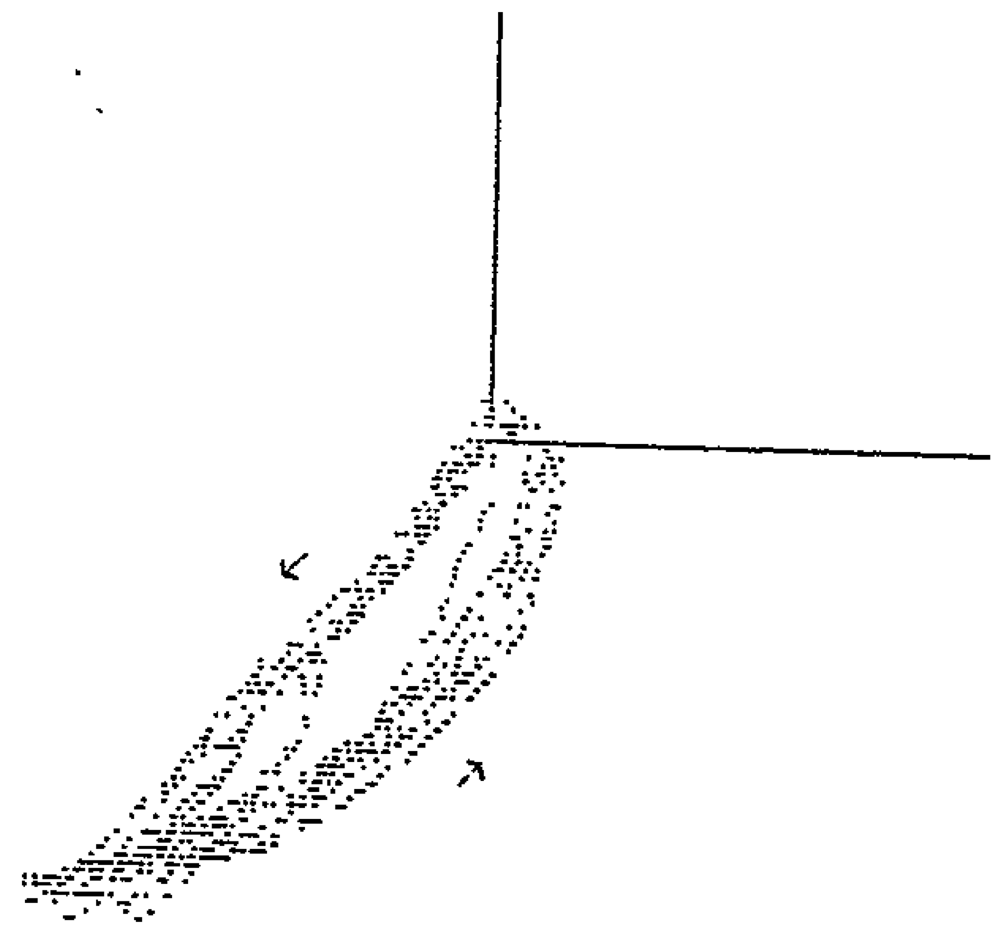
Maximum occlusal force was observed in the position of mandibular opening (Mackenna and Turker, 1983; Boucher et al., 1959). It seems that greater forces that promote closure are produced as the vertical dimension is further increased (Nakamura et al., 1988). However, the relationship between the maximum occlusal forces and muscle activity at that moment is not obvious.

Individual adaptive capacity for comfort in VDO is unknown (Rivera-Morales and Mohl, 1991); however, Tryde et al. (1977) revealed the existence of a comfort and discomfort zone of the masticatory system under well established artificial laboratory conditions. The fact of the existence of the comfort zone may be the reason why the occlusal splint causes sensorimotor change due to an increase of VDO with even tooth contacts.

Therefore, it seems that the occlusal splint may have allowed reprogramming of muscle coordination (Klineberg, 1986) and resolution of muscle dysfunction (Clark et al., 1979) with the patient EA in the present study. Further, it could have resulted in a protrusive movement (Fig. 4.10b) produced by maximum condylar translation plus minimum rotation (Stuart, 1959), opening movement produced by a near linear relationship between condylar translation and rotation (Merlini and Palla, 1988; Fig. 4.11b) and a chewing cycle which was produced by more stable rhythm than the one in the acute stage (Fig. 4.18 and 19).

5.5.4 <u>Condylar movement during chewing</u>

The chewing strokes could be adaptive to the food being chewed. Jankelson et al., (1953) investigated incision using the cinefluorographic technique. They reported that with soft food, the mandible moved forward and teeth grasped the food in the protrusive position, then sheared the food. When the mandibular teeth contacted the food, retrusion of the mandible began without interruption, but it was interrupted when resistant food was encountered. Figure 5.7 shows the chewing movement of the condyle with "Wine Gum". The distraction of the condyle during the closing movement is clearly seen with this resistant food, with the closing path inferior to the opening path.



Scale: 5mm

Figure 5.7 Plot of the sagittal of ten chewing movements with "Wine Gum" of the subject NS, who is not included in the present study. The condylar movement on the working side is reproduced in the sagittal view. The distraction of the working side condyle is clearly seen.

The distraction of the condyle during chewing movement was first reported by Gibbs and Lundeen (1982). The factors that maintain a functional relation between the disc and condyle during condylar translation has been examined. In the healthy TMjoint, the biconcave shape of the disc tends to centre it on the condyle when the condyle is loaded toward the eminence (Dawson, 1989).

Mahan (1980) described that there is an interaction between the upper layer of the posterior attachment and the upper head of the lateral pterygoid acting upon the disc to keep it functionally related to the condyle during jaw opening and closing movement, and further, this interaction will fail, if the tight attachment of the disc to the condyle is stretched or torn. If the condyle has an excessive distraction during chewing, the discal ligaments (Fig. 5.5B) could be stretched or torn, and subsequently may cause disc-condyle discoordination.

With the non-working side condyle in the acute stage of "closed lock", the characteristic side shift movements were reflected as a straight, laterally directed tracing mainly within the end of closing movement (Fig. 4.16a). However, these side shifts disappeared in the chronic stage of "closed lock" (Fig. 4.16b).

The Bennett movement is a bodily side shift of the mandible that occurs during lateral movements (Okeson, 1985). Guichet (1969) classified the side shift occurring in the initial 4mm of lateral movement as:

1) progressive side shift,
2) immediate side shift,
3) early side shift,

in relation to its ratio. It has been stated that the immediate side shift (ISS) can be evaluated easily on the non-working side condyle (Simonet and Clayton, 1981; Mongini, 1984) and it can be a pure straight lateral side shift (Guichet, 1969). In this study, the findings seen in Figure 4.16 and 17 agree with these statements. It was reported that the average ISS was 0.75mm in healthy subjects (Lundeen et al., 1978).

The basic mechanism of chewing relates to the placement of the bolus and muscle coordination, occurrence of regular tooth contact and neural control (Ahlgren, 1966; Mφller, 1974). In the present study, the position of the bolus (i.e chewing gum) was known and no irreversible occlusal alterations were provided with the patient EA.

It has been demonstrated that lateral movements of the mandible are brought by ipsilateral contraction of the temporal muscle and contralateral contractions of the lateral and medial pterygoid muscles with the suprahyoid muscle (Kawamura, 1968). EMG studies revealed that the posterior temporal muscle acts as antagonists with the lateral pterygoid (Fig. 5.8; Mφller, 1974). Dawson (1989) reported that during jaw movement, the coordination of muscle function depends on precise timing between antagonist muscles. Jarabak (1956) observed that temporal muscle hyperactivity appeared to occur simultaneously with functional disturbance in TMJ, and proposed that hyperactivity occurring in the temporal muscles could upset the reciprocal timing between the temporal and lateral pterygoid muscles.

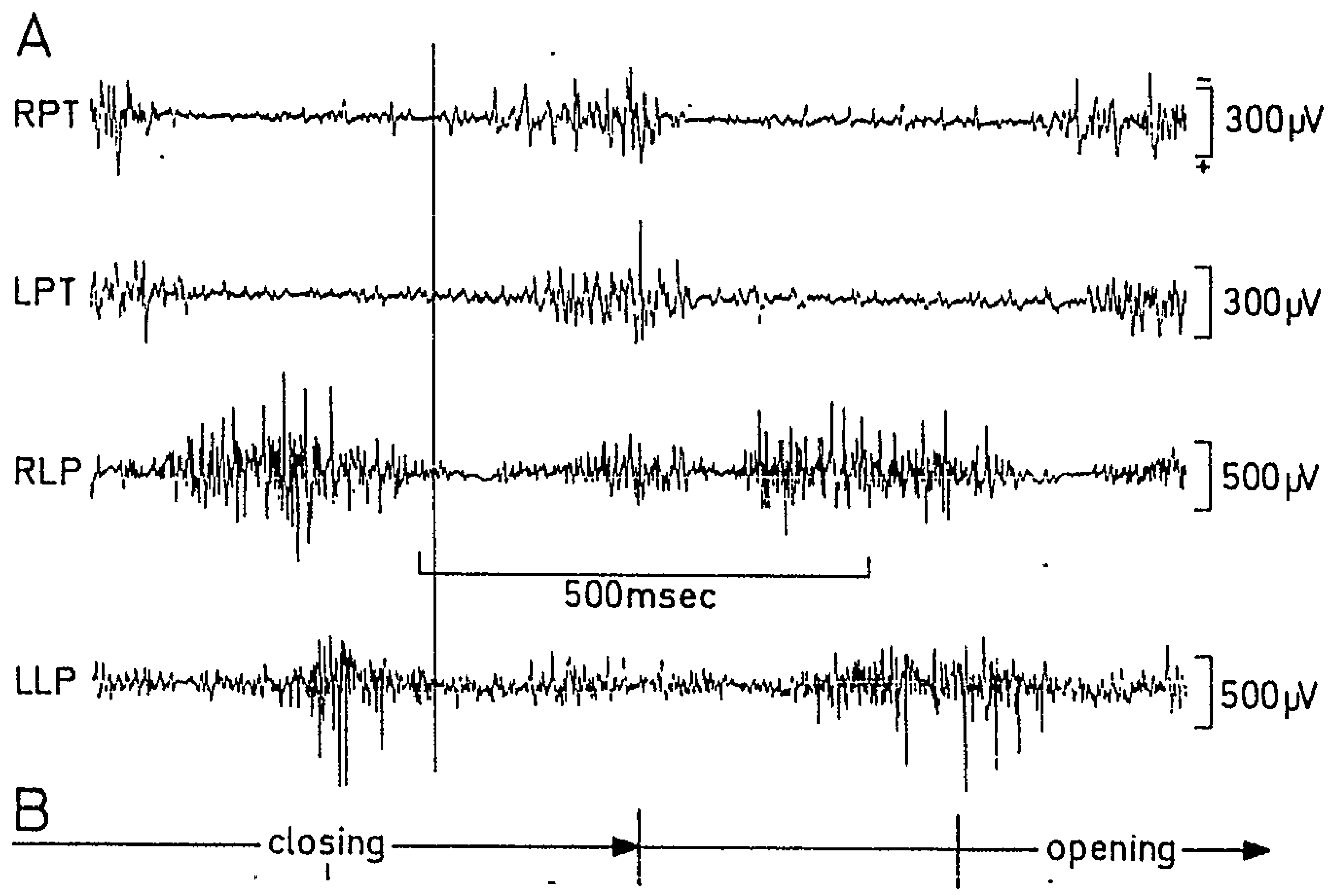


Figure 5.8 Action of the lateral pterygoid muscles and their antagonism with the posterior temporal muscles in the closing phase and the initial opening phase during a right-sided chewing stroke. EMG activity in the right (RPT) and left (LPT) posterior temporal and lateral pterygoid muscles (RLP, LLP) (modified from Møller, 1974).

Simonet and Clayton (1981) proposed that neuromuscular coordination is an important component in registering the lateral side shift of the mandible. They observed that the voluntary Bennett movement is always within the borders of the induced movement and TMJ dysfunction related muscle hyperactivity affects the amount of Bennett movement recorded by the pantograph.

Changes in range of condylar movements during chewing also occurred. The range of the patient EA in the acute stage of "closed lock" was statistically significant in parameter # 2 (Table 4.1). It has been reported that rehabilitation of the occlusion with its associated reduction in muscle soreness affected the chewing pattern mainly at the lower incisor point (Gibbs and Fujimoto, 1982). In this study, similar findings were revealed at the condyle point between before and after the occlusal splint therapy. The present study does not show variability of response of different patients to the occlussal splint therapy. Further study will be required on this topic for the diagnostic value of condylar movements during chewing.

Therefore, the alteration of the working and non-working side condylar movements in the chronic stage of "closed lock" suggests that changes in neuromuscular coordination may have occurred during occlusal splint therapy. The results of this study encourage the involvement of an EMG assessment in conjunction with this tracking system for future research.

5.6 Lateral Pterygoid Muscle

The patient EA had tenderness of the lateral pterygoid muscle and discomfort on the right lateral pterygoid in the acute stage of "closed lock." Clinically, these symptoms were resolved during occlusal splint therapy (Table. 3.2).

The lateral pterygoid consists of an upper and a lower head. The upper and lower head demonstrated nearly reciprocal EMG activity (Fig. 5.9) (Kamiyama, 1961; McNamara, 1973; Mahan et al., 1983). Thus, the upper head was active during jaw closing, retrusion and ipsilateral movements; in contrast, the lower head was active during jaw opening, protrusion and contralateral movements (kamiyama, 1961).

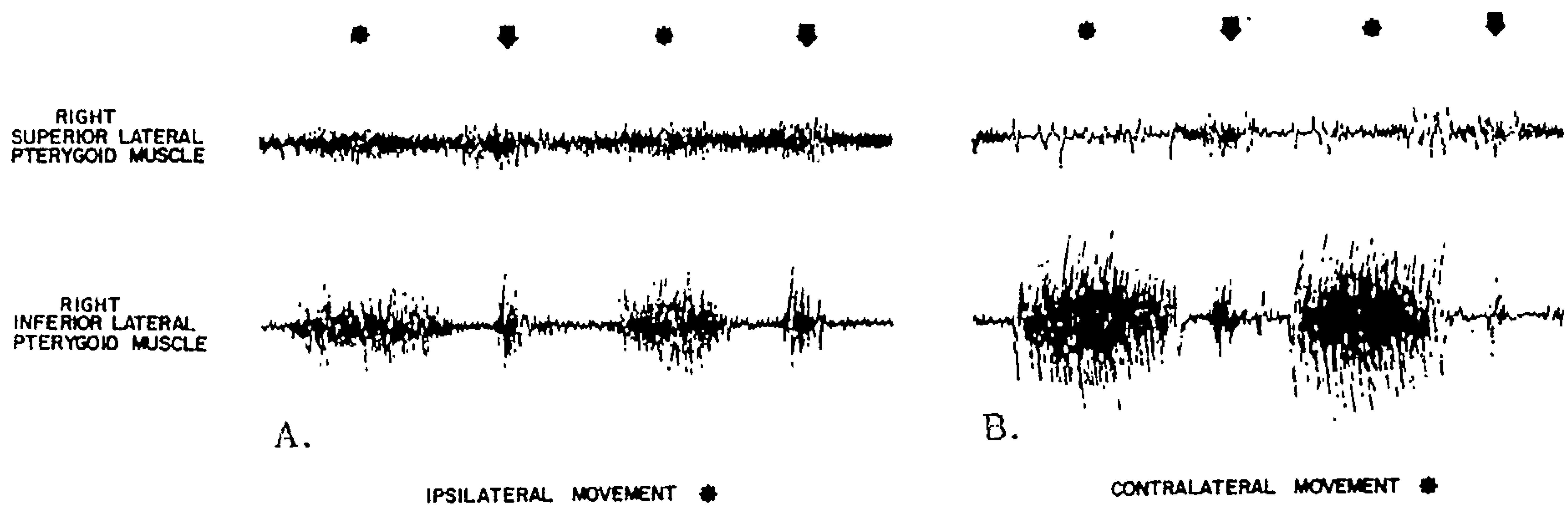


Figure 5.9 A and B. EMG activity of right lateral pterygoid muscles during standardized mandibular movements.
A. Performing ipsilateral movements (asterisk) with teeth parted and returned to an intercuspal clenching position (arrow).
B. Performing contralateral movements (asterisk) with teeth parted and returned to an intercuspal clenching position (arrow) (from Mahan et al., 1983).

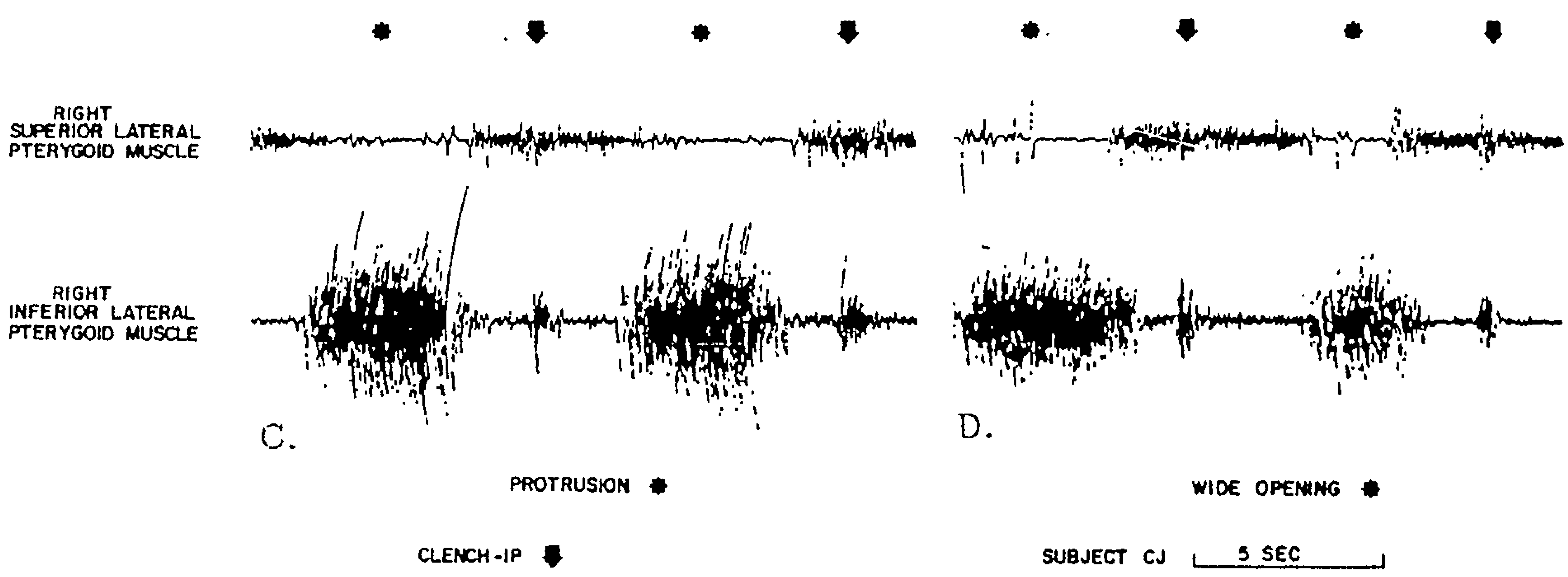


Figure 5.9 C and D. EMG activity of right lateral pterygoid muscles during standardized mandibular movements.
C. Performing protrusive movements (asterisk) with teeth parted and returned to an intercuspal clenching position (arrow).
D. Opening wide (asterisk) and returning to an intercuspal clenching position (arrow). Activity is reciprocal during movement (from Mahan et al., 1983).

It has been proposed that anterior disc displacement could be caused by hyperactivity of the upper head of lateral pterygoid (Shore, 1959). However, Mahan et al., (1983) claimed that dysfunction of the upper head could be a result of prolonged disc displacement, not its cause, since the most majority of fibres of the upper head insert into the condylar fovea. Opinions regarding the insertion of the upper head are divided (Rees, 1954; Thilander, 1964; DuBrul, 1980; Meyenberg et al., 1980; Ramfjord and Ash, 1983; Wilkinson, 1988; Wilkinson and Chan, 1989).

Meyenberg et al., (1980) reported that there was an insertion of the upper head into the condylar fovea with 40% of their 25 human cadaver joints and in the other 60%, there was an insertion of the most superior cranial layer of the upper head to the disc-capsule complex.

Wilkinson (1988) studied 26 human cadaver joints and reported that in 70% of the joints the superior head had two insertions: the major insertion was directly into the condylar fovea and a smaller accessary insertion was fused to the capsule under the foot of the disc.

Wilkinson and Chan (1989) studied 5 human cadaver joints under the dissecting microscope and reported that the fibres of the anterior joint capsule extended from the condyle to the surface of the articular fossa; however, under the foot of the disc they blended with and became indistinguishable from disc fibres. Further, they stated that no muscle fibres were seen passing through the capsule to enter into the disc. In these studies, the functional activity of the fibres of upper head did not move the disc forward independently.

Wherever the insertion of lateral pterygoid upper head, synchrony is important for smooth condyle-disc movement since the upper head is responsible for stabilizing the disc and condyle during jaw closing (McNamara, 1973). An alteration in the mutual timing of translatory movements of the condyle and disc, derived from reflex integration of the upper and lower head may lead to condyle-disc discoordination (Klineberg, 1986).

5.7 Progress of TMJ Internal Derangement

Patient EA had a progressive nature of symptoms of TMJ internal derangement (see- 3.1).

Lundh et al., (1987) suggested that reciprocal clicking does not usually progress to locking. The course of arthropathy of 70 patients with reciprocal clicking i.e. disc displacement with reduction was followed by clinical examinations during a 3-year period (Lundh et al., 1987). The results showed that locking developed in only 6 patients (9%).

However, the current arthrographic study reported that about 20% of 61 patients with disc displacement with reduction progressed to locking during the 6-month period. Also this study suggested that the assessing of the configuration of the disc (e.g. convex or concave) is significant in relation to the progress of internal derangements (Westesson and Lundh, 1989).

It has been suggested that there is a correlation between a large anterior recess of the inferior joint space and disc displacement (Farrar and McCarty, 1979). Westesson and Lundh (1989) indicated that the depth of the anterior recess of the inferior joint space revealed in arthrography may be associated with the configuration of the disc.

Recently an arthrographic study of 40 subjects with asymptomatic joints was performed in order to obtain more information about the anatomy of the clinically normal TMJ in relation to the dimension and configuration of joint spaces (Westesson et al, 1989). The results showed a large variation of the dimensions of the joint spaces and the position of the disc in relation to the condyle. Thus, it was concluded that the size or configuration of the anterior recess of the lower joint space could not be regarded as a reliable indicator of the position of the disc.

Further, the study of disc deformation was performed in 58 randomly selected autopsy specimens of TMjoints (Westesson et al., 1985). The results showed that disc deformation was frequently found in anteriorly displaced discs (77%), non-reduction of the disc was associated with disc deformation and reduction of the disc was associated with biconcave configuration.

Therefore, it seems that condylar movement could be affected by the configuration of the displaced disc. However, a great veriation in the degree and extent of disc deformation between different joints and also between different mediolateral parts of the same joint were revealed (Westesson et al., 1985).

A recent MR imaging study with coronal images showed that sideways and/or rotational displacement of the disc was observed in up to 26% of 61 joints in patients with internal derangement (Katzberg et al., 1988).

Arthrography was performed in 40 asymptomatic joints and it was reported that 15% of these joints were radiographically abnormal, having dislacement of the disc. Further, all but one of the joints showed normalization of disc position during opening (Westesson et al., 1989).

The results suggest that a study of conventional two-dimensional images is limited in assessing the position and configuration of the disc regarding the condyle since the disc clearly changes shape and moves medially or laterally as well as anteriorly during function.

Therefore, it seems that only limited information is available about the progress of internal derangements in relation to complex TMJ mechanism. Improved imaging systems coupled with digitized data and three-dimensional manipulation could provide for extension of the method which quantify three dimensional dynamics of TMJ function (Price, 1990).

5.8 Anatomical Reduction and Physiological Adaptation of TMJ

The patient had a progressive TMJ internal derangement with restricted jaw motion, but without any severe pain in the TMjoint.

TMJ internal derangement is managed with non-surgical treatments (Westesson et al., 1991):

1) an occlusal splint, and

2) mandibular manipulation technique.

However, the patient who underwent conservative treatment without success would be a candidate for surgical intervention (Eriksson, 1985).

Occlusal splint therapy usually has two kinds of treatment modalities in the management of TMJ internal derangement:

1) a flat plane occlusal splint (Ramfjord and Ash, 1983), and

2) a mandibular repositioning splint (Farrar, 1971).

The former is mainly used for the neuromuscular component of masticatory disorders and the latter may be beneficial for the correction of anatomical relationships of structures within the TMJ, with anteriorly displaced discs (Anderson et al., 1985).

The available literature on the topic shows that the success rate of the anterior repositioning splint (AR-splint) treatment is quite discouraging (Mauderli et al., 1988). Some studies demonstrated a high degree of success of the AR-splint treatment (Anderson et al., 1985;

Williamson and Sheffield, 1987; Lund et al., 1985), whereas Moloney and Howard (1986) reported a 36% success rate of 241 patients using the AR-splint during the 3-year follow up. Okesson (1988) reported that 75% of patients were satisfied with the AR-splint treatment during the two -and-half-year follow up, but 66% of the patients had a recurrence of TMJ clicking. He claimed that the symptoms must be evaluated not only for joint sounds, but for pain related to joint sounds as well. Therefore, success rates could change if the criteria for success are altered (Moloney and Howard, 1986). It was indicated that too little is known about AR-splint therapy in:

1) prognosis of TMJ internal derangement,
2) factors determining the need for further treatment, and
3) long-term results of therapy (Wabeke et al., 1989).

Mandibular manipulation technique is widely used not only to release closed locking of TMJ (Farrar, 1978), but also to help differential diagnosis (Solberg, 1986).

Segami et al. (1990) examined preoperative and postoperative arthrograms with 30 closed lock joints for which sucessful mandibular manipulation was carried out. They reported that all the joints had remarkably improved clinical symptoms and joint mobility, whereas only three joints revealed complete reduction of its structure. They indicated that the relationship between the position of the disc and the functional repair of the joint is unknown.

It has been reported that the articular disc is not in a normal position in a number of patients who had no symptoms and had a good clinical course using arthrography (Segami et al, 1990) and/or magnetic resonance images (MRI) (Montgomery et al., 1989; Gabler et al., 1989; Moses and Topper, 1991). This may suggest that the clinical success of treatment for TMJ internal derangement does not occur as a result of disc repositioning or recapturing (Gabler et al., 1989). It has been reported that the frequency of disc displacement was 12% among 95 young TMJ autopsies (Hansson et al., 1983). These findings suggest that disc displacement would be a consequence rather than the cause of previous histologic events (Hansson, 1986).

It has been widely accepted that if the condyle is off the disc, pressure loads the condyle directly onto the vascular innervated tissue in the posterior attachment. In such circumstances compression of the nociceptive plexus in the posterior articular adipose tissues (Wyke, 1976) may evoke acute pain at the site (Klineberg, 1988). Further, McCarty (1988) claimed that the internal derangement is the precursor of degenerative joint disease. On the other hand, results of the course of arthropathy for six years in 119 patients with TMJ pain and erosion of the condyle demonstrated by transpharyngeal radiographs showed a resolution of all TMJ symptoms but crepitation, resulting practically always in freedom from pain and most often in freedom from symptoms (Rasmussen, 1981).

Documentation of the histologic changes in TMJ soft tissue in association with internal derangement is limited (Isacsson et al., 1986). Wide variation in histologic appearance was reported by light microscopic findings among 26 specimens, some of which indicated that the tissue was undergoing adaptive changes without significant inflammation (Hall et al., 1984). Isacsson et al., (1986), after surgical examinations, reported that disc-like-appearance of the posterior attachment had undergone adaptive change characterized by connective tissue hyalinization.

The posterior attachment of the disc usually revealed two types of tissue change:

1) hyalinized connective tissue, and

2) non-hyalinized alteration showing inflammation.

Further investigation is expected to develop a more objective description of the histologic appearance of the posterior attachment (Hall et al., 1984).

Therefore, the evidence to date shows no obvious relationship between occurrence of symptoms and disc displacement. It seems that treatment should be directed toward normalization of physiological TMJ function rather than its anatomical reduction (Moses and Topper, 1991) when the patient has no severe pain. Further, reversible treatment should first be attempted.

6. SUMMARY

It has been shown that clinical judgement alone cannot be used to assess the abnormality of TMJoint since arthrographic examination revealed that 15% of the subjects with asymptomatic joints had radiographically abnormal displacement of the disc (Westesson et al., 1989). Further, it has been suggested that a study of conventional two-dimensional images is limited in assessing the position and configuration of the disc regarding the condyle, since the disc clearly changes shape and moves medially or laterally as well as anteriorly during function (Westesson et al., 1985; Katzberg et al., 1988; Westesson et al., 1989).

Therefore, an improved imaging system would be required to obtain more accurate information about complex TMJ mechanism. It has been claimed, however, that at the present time the diagnostic value of jaw tracking devices for temporomandibular disorders is not well supported by the scientific evidence (Mohl et al., 1990).

In this preliminary study, the Jaws-3D (Metropoly AG, Naegelistr. 8, 8044 Zurich, Switzerland) tracking system showed some parameters of measurement for distinguishing the patient with TMJ disorders from healthy subjects.

Although there are a few limitations to this study, the comparison between the condylar movement in chronic TMJ "closed lock", asymptomatic and symptomatic TMjoints supported a hypothesis of Farrar's (1979) that is, the condylar movement in chronic TMJ "closed lock" is similar to that which could be expected in asymptomatic temporomandibular joints.

7. CONCLUSIONS

1. Occlusal splint therapy clearly changed the condylar movement in TMJ "closed lock" with a resolution of muscle tenderness. Changes were seen in non-functional condylar movement, relationship between condylar rotation and translation and functional condylar movement.

2. The decision to select an appropriate treatment of TMJ internal derangement should be based upon the results of the occlusal splint therapy.

3. It was suggested that the distalization and distraction of the condyle could be detrimental factors in TMJ internal derangement, and these displacements may be related to the discoordination of the muscles.

4. The recording of three dimensional condylar movements and the relationship between condylar rotation and translation may have a diagnostic value in patients with TMJ dysfunction. Future studies need to include numerous subjects.

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9. APPENDICES

	Min	Max	Mean	SD	Set Val
forward	0.975	1.079	1.023	0.022	1.000
	1.957	2.028	1.991	0.016	2.000
	2.990	3.061	3.026	0.018	3.000
	3.998	4.154	4.070	0.030	4.000
	5.077	5.148	5.107	0.018	5.000
	6.006	6.090	6.041	0.024	6.000
	7.059	7.143	7.099	0.016	7.000
	8.015	8.099	8.057	0.013	8.000
	8.996	9.080	9.044	0.014	9.000
	10.036	10.121	10.084	0.020	10.000

	Min	Max	Mean	SD	Set Val
backwards	-1.073	-0.988	-1.023	0.017	-1.000
	-2.060	-1.983	-2.013	0.019	-2.000
	-3.081	-2.990	-3.022	0.020	-3.000
	-4.069	-3.998	-4.031	0.012	-4.000
	-5.063	-4.986	-5.023	0.015	-5.000
	-6.156	-6.065	-6.110	0.019	-6.000
	-7.079	-6.994	-7.036	0.019	-7.000
	-8.106	-8.008	-8.064	0.011	-8.000
	-9.094	-9.03	-9.045	0.021	-9.000
	-10.107	-10.023	-10.064	0.020	-10.000

Appendix 1A. Lists with numerical values of the X-plane for the reconstructed value versus the setvalue.

	Min	Max	Mean	SD	Set Val
right	-1.092	-0.929	-1.002	0.046	-1.000
	-2.060	-1.853	-1.994	0.044	-2.000
	-3.074	-2.867	-2.972	0.047	-3.000
	-3.952	-3.757	-3.828	0.043	-4.000
	-4.940	-4.700	-4.849	0.052	-5.000
	-6.006	-5.811	-5.905	0.049	-6.000
	-7.065	-6.897	-6.978	0.037	-7.000
	-8.080	-7.937	-8.016	0.033	-8.000
	-9.100	-8.814	-8.949	0.052	-9.000
	-10.055	-9.783	-9.937	0.059	-10.000

	Min	Max	Mean	SD	Set Val
left	0.904	1.216	1.086	0.060	1.000
	1.853	2.035	1.945	0.044	2.000
	2.945	3.217	3.077	0.055	3.000
	3.978	4.186	4.077	0.049	4.000
	4.700	4.953	4.822	0.049	5.000
	5.980	6.194	6.070	0.043	6.000
	6.819	7.098	7.002	0.053	7.000
	7.787	8.053	8.904	0.065	8.000
	8.840	9.087	8.997	0.054	9.000
	9.867	10.114	10.013	0.049	10.000

Appendix 1B. Lists with numerical values of the Y-plane for the reconstructed value versus the setvalue.

	Min	Max	Mean	SD	Set Val
upward	-0.968	-0.774	-0.887	0.029	-1.000
	-1.937	-1.807	-1.880	0.033	-2.000
	-3.016	-2.860	-2.921	0.039	-3.000
	-4.101	-4.010	-4.057	0.019	-4.000
	-5.103	-4.921	-5.007	0.031	-5.000
	-6.143	-5.967	-6.038	0.037	-6.000
	-7.079	-6.884	-6.980	0.034	-7.000
	-8.294	-8.112	-8.197	0.038	-8.000
	-9.282	-9.048	-9.191	0.037	-9.000
	-10.055	-9.997	-10.125	0.041	-10.000

	Min	Max	Mean	SD	Set Val
downward	0.897	1.144	0.997	0.039	1.000
	2.008	2.291	2.104	0.038	2.000
	2.983	3.179	3.059	0.039	3.000
	3.952	4.179	4.052	0.054	4.000
	5.005	5.213	5.109	0.053	5.000
	6.045	6.227	6.151	0.036	6.000
	7.072	7.241	7.158	0.031	7.000
	8.008	8.268	8.121	0.046	8.000
	9.145	9.412	9.252	0.058	9.000
	9.990	10.251	10.116	0.054	10.000

Appendix 1C. Lists with numerical values of the Z-plane for the reconstructed value versus the setvalue.