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GRADUATE STUDIES

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CHANGES IN SYNOVIAL FLUID PRESSURE DUE TO ALTERED MANDIBULAR POSITIONS

Abstract

by

DENNIS M. WARD

The synovial organ has long been investigated in joints other than the temporomandibular. Its responsibilities include nutrition and lubrication to the articular surfaces. The pressure of the synovial fluid has been measured in both long bone joints and recently the temporomandibular joint. Both have been shown to be negative relative to the atmosphere. It is conceivable that changes in mandibular position could have marked effects on the relative pressure of the synovial fluid.

This study is designed to measure the synovial fluid pressure in the growing animal, uninhibited by mechanical intervention and by changing the mandibular position. Various functional parameters are investigated including mastication, lateral movements and opening and closing of the mandible.

The resting synovial fluid pressure was found to be subatmospheric in the unaltered TMJ. By functionally positioning the mandible forward there was a marked rise in pressure with a gradual stabilization and return to the base line level. With a

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Submitted in partial fulfillment of the requirements for the Degree of Master of Science in Dentistry

Department of Orthodontics

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retruding appliance in place the synovial fluid pressure increased substantially and failed to return to a subatmospheric level during the duration of the experiment.

The fluctuation in synovial fluid pressure could have biologic implications in deference to its role in nutrition and lubrication. Elevated pressures could be responsible for local ischemic changes, and decreased lubrication with increased friction to the articular surfaces.

Synovial fluid may be the medium by which pressure changes, due to altered mandibular position, are translated to joint surfaces.

The findings are summarized as follows:

1. The resting synovial fluid pressure was negative relative to the atmosphere in all six joints. The mean value was -3.9 mm of Hg.

2. Pressure increased during operator manipulated jaw positions, returning to the baseline when the jaw was released.

3. There was a marked increase in pressure when a protruding appliance was placed. This pressure gradually returned to the baseline. The return is attributed to joint compliance and absorption of fluid.

4. There was a substantial rise in pressure when a retruding appliance was placed. The pressure never returned to the baseline.

5. Mastication produced a marked pressure change. The pressure changes appeared cyclical.

6. Possible relations between fluid pressure and pathology and growth and development are discussed.

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DEDICATED

TO

My wife, Meigan, who made the last six years possible through her love, compassion and understanding. To my children, Erin, Matt and Katie, for being my escape and reminding me how much fun it is to be a child.

IN MEMORIUM

To my father, James Matthew Ward, who died October 9, 1982 with dignitiy and grace. Thank you.

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# INTRODUCTION

Currently the temporomandibular joint (TMJ) is attracting the increased interest of researchers and clinicians. Dentists, both general practitioners and specialists, have begun to stress the importance of and responsibility for maintaining a healthy joint articulation. The complex nature of the etiology of the TMJ diseases is becoming more appreciated. Treatment thus far has involved a largely symptomatic approach, because a gap exists regarding biologic understanding of basic TMJ physiology and applied treatment rationale based on it. Krough-Poulsen (1980) points out that:

> . . .although our understanding of the symptoms of the TMJ diseases and the type of patient involved is vast, we must attain full competence of the problem before a true resolution to the enigma can be obtained.

Synovial fluid hydrostatic pressure relationships have been well researched for other joints, most notably the knee. The synovia's role in both function and pathology has been documented and studied in detail.

Until recently, however, TMJ synovial physiology has been largely neglected as an area of active research in the dental field (Roth, 1982). In deference to its role in both nutrition and lubrication of the articular surfaces, disruption of the normal physiology of the synovial organ may indeed have biologic implica-

tions concerning growth and pathologic responses within the joint and surrounding structures.

The objectives of this study are:

1. To establish a baseline record of synovial fluid pressure in a growing experimental animal model by means of a surgically placed catheter.

2. To measure synovial fluid pressure changes under various forms of mechanotherapy.

3. To correlate the physiological responses with craniofacial growth and development.

# LITERATURE REVIEW

## Synovial Physiology

### Normal Synovial Fluid

Synovial fluid is a clear, yellow, viscous fluid which does not clot (Bauer and Ropes, 1940). The earliest known mention of it is credited to Paracalus (1449-1541), who described the presence of a viscous fluid in the articular cavities. This substance was eventually found to be a diasylate of blood containing protein (see Bauer and Ropes, 1940; McCarty, 1980).

The protein component was identified as hyaluronic acid (Toller, 1961; McCarty, 1980). Gardner (1950), in a chemical analysis described it as a form of interstitial connective tissue fluid to which hyaluronic acid had been added.

Synovial fluid functions as the source of nourishment to the articular surfaces (Bauer et al., 1940; Toller, 1961). It also is the lubricant which provides for efficient function of the joint (Toller, 1961).

Toller (1961), stated that the viscosity of the synovial fluid is directly related to its lubricating quality. The capacity of a joint to function smoothly lies in its ability to change from a state of non-movement or "solid lubrication" to a state of fluid lubrication. The viscosity of the lubricant is directly responsible for the joint's ability to effect that change (Toller, 1961).

## Intra-Articular Pressure

The joint cavity, like other "space" containing organs, conforms to a pressure volume relationship in a manner similar to a rubber balloon (McCarty, 1980). The fibrous capsule, like the walls of a balloon are subjected to a variable force exerted on its lining surfaces by the fluid medium. Guyton (1971), explains that in a biologic medium there exists three types of pressure: fluid, solid and total tissue pressure. The intra-articular pressure of a joint cavity is then the amount of pressure the synovial fluid exerts on the fibrous capsule.

The intra-articular pressure of the resting knee joint has been found to be subatmospheric (Guyton, 1963; Reeves, 1966; Levick, 1978). Not until recently (Roth, 1982) has interstial fluid pressure of the TMJ been investigated, and it was also observed to be subatmospheric.

During periods of exercise or in the presence long bone and TMJ joint effusions, the state of fluid hydrostatic pressure can be reversed, with positive readings recorded (Ekholm and Norback, 1951; Jayson and Dixon, 1980; Roth, 1982).

## Pathophysiology Associated with Synovial Fluid Pressure

Pathological relationships between joints and synovial fluid pressure changes have been noted for long bone joints. As early

as 1840, Robert Adams suggested chronic effusion and high intra-articular pressures were responsible for the formation of popliteal cysts in arthritic joints.

Ekholm and Norback (1951), showed that in exercising rabbit knee joints high positive pressure was present and may cause local ischemic changes of articular surfaces. They also found that fluctuation in synovial fluid pressure correlated with alterations in the shape of the surface cells of the articular cartilages.

In a series of reports, Jayson and Dixon (1970), found consistently higher synovial fluid pressure in patients afflicted with rheumatoid arthritis. They also suggest that the increased pressure could interfere with circulation to and from the synovial membrane. Caughey (1965) also found higher intra-articular pressures in patients suffering from chronic knee problems. Geilberger (1982) monitored synovial fluid pressure in patients with hip problems and consistently found pressures higher than normal.

Richman et al. (1981) found an inverse relationship between oxygen tension and synovial fluid volume. Intra-articular pressure was shown to play a major role in the oxygen tension level of synovial fluid. This increased pressure may shunt blood from capillary beds throughout the joint with subsequent hypoxia.

In a series of studies, Oberg and Carlson et al., 1966, 1967), concluded that disturbances in the normal physiology of the synovial membrane and synovial fluid can be etiologic to morphologic degenerative changes in the articular cartilage of the temporomandibular joint.

Finally, Roth (1982), showed that synovial fluid pressure in the pig TMJ was, as with other joints, subatmospheric and that during function fluctuations in the pressure occur.

## Technique

Over the years, there have been many techniques used to measure various body fluid pressures. The technique used in the present study was developed by Schollander (1968) and later employed by many other investigators to determine pressure changes under various physiologic conditions.

Schollander discovered that by inserting a catheter plugged with a cotton wick into specific sites he could easily and accurately measure fluid pressure in that site. Various locations in both botanical and animal models were analyzed. He established that these pressures are subatmospheric.

Snashall (1971), repeated Schollanders work and also recorded subatmospheric pressures. Taking the technique one step further, using human beings, he recorded subatmospheric pressures in the subcutaneous tissues of the human hand.

Hargens (1977) used the technique to monitor fluid pressure in the calf's of patients suffering from "compartment syndrome". This is a syndrome found in patients with chronic muscular pain. A buildup of interstial fluid pressure occurs within the muscle. Mubarek (1978) refined the technique, substuting dexon suture for the cotton wick. He measured intramuscular pressures in the anterolateral fascial compartments of the canine leg.

Investigators have also used the technique to investigate intra-articular pressures. Levick (1977) and Geilberger (1980) measured pressures in the knee and hip respectively.

In 1982, using a technique similar to that of Murabek, Roth implanted a "wick catheter" in a pig temporomandibular joint and monitored changes in synovial fluid pressure levels. His procedure allowed for the monitoring of post-surgical pressures over an extended period of time.

## MATERIALS AND METHODS

### Animal Model

Selection of animal species for this experimental investigation took into account several anatomical, functional and behavioral requirements. The joint should be essentially comparable to the human temporomandibular joint in both form and function. The joint cavity should also be large enough to allow surgical placement of a catheter. Finally, the animal should have a relatively rapid rate of growth and development so that craniofacial growth effects of the experimental procedure could be monitored. The juvenile monkey, rat and rabbit, although meeting basic form and function requirements, would not allow for surgical insertion of the catheter due to the small joint size. A large breed of dog has a joint cavity of acceptable size, and is easily trained, but its masticatory apparatus does not allow for a range of lateral movements.

Large herbivores (cattle, sheep, or pigs) were felt to be appropriately suited to the investigation. Of these species, the domestic pig (Sus scrofa domesticus) was chosen because of its very rapid growth rate, wide range of TMJ movements, adequate joint size in a species having body size appropriate for laboratory housing.

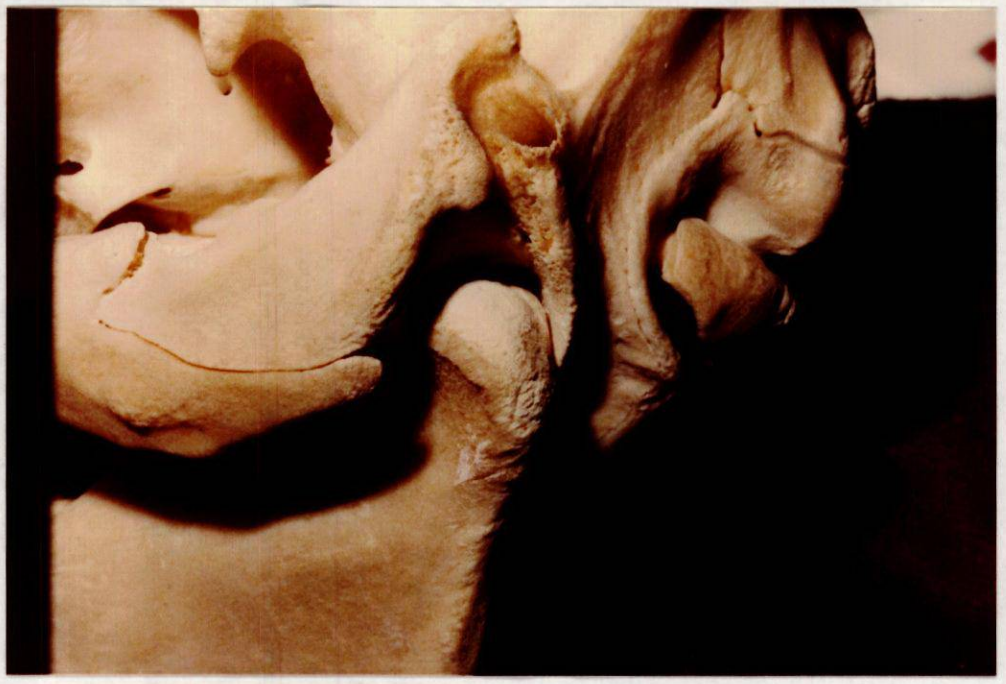
The TMJ of the pig, although not dissimilar to man in basic form and function, also has certain unique anatomical differences. Its jaws are long and robust. The dentition is set in two parallel rows and are approximately isognathic. There are three pairs of procumbent lower incisors in a transverse row across the mandibular symphysis. The upper incisors are larger than their mandibular counterparts and converge toward the midline.

Each glenoid fossa is located above the plane of occlusion. Its surface is convex anteroposteriorly and concave mediolaterally. There are virtually no osseous restraints that could serve to severely constrain movements (Herring and Sapino, 1973).

The mandibular condyle is short superoinferiorly and is trigonal in shape when viewed from the superior aspect (Figure 1). The mandibular ramus is almost perpendicular in its relationship to the corpus. It is broad and flat allowing for a greater insertion area of the large masseter. There is no post-glenoid process, but a backstop is formed by a tough fibrocartilaginous part of the capsule that attaches to a protuberance behind the articular surface of the condyle.

The masseter, zygomaticomandibularis, and temporal muscles all have unique anatomical relationships to the joint capsule and serve as landmarks for its location.

Figure 1



The masseter is the largest of the adductor muscles. It originates as an aponeurosis arising directly from the ventral edge of the zygomatic arch. Its insertion covers the entire ventral surface of the mandibular angle.

The zygomaticomandibularis originates from the zygomatic process. Its posterior part is continuous with the joint capsule. Anteriorly it is continuous with the temporalis and masseter muscles.

The temporalis is a relatively short muscle arising from the medial surface of the zygomatic arch and the temporal fossa. The insertion is into a large aponeurosis coursing anterior to the TMJ and covering the coronoid process of the mandible.

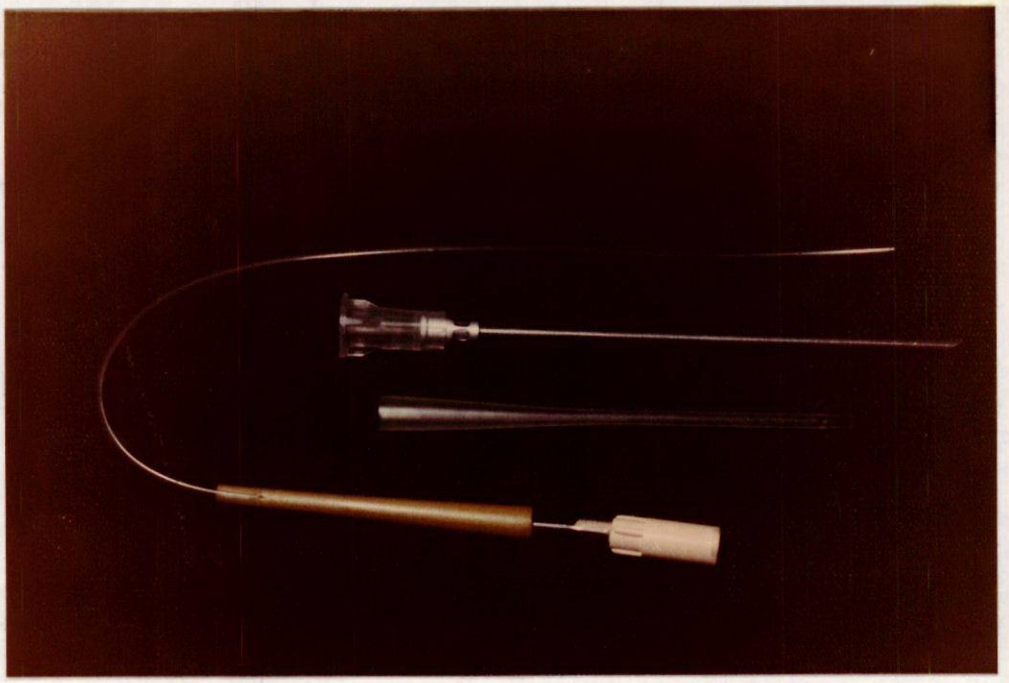
## The Wick Catheter

The wick catheter contains one four centimeter cord of No. 1 dexon absorbable suture tied centrally to a 40 cm length of 6-0 nylon monofilament (Figure 2). The monofilament's free end was passed through PE-90 tubing and fitted with a 21 guage luer stub adapter. The dexon fibers were pulled one centimeter into the catheter leaving approximately 2 mm exposed. This allows fluid pressure only to be monitored, as the free end of the wick prevents tissue impingement against the catheter's opening.

## Surgical Placement of the Catheter

Approximately 25 to 30 pound weenling pigs were fasted

Figure 2



24 hours prior to the procedure. Ketamine (5 mg/lb) and acepromazine (0.5 mg/lb) were injected intramuscularly for sedation. The animals were then fitted with a nose cone and given a maximum dose of halothane until completely relaxed. They were maintained on 0.5 to 1.5% halothane during the procedure. To dry oral secretions, atropine was given at 1 cc/30 lb intramuscularly.

The location of the condyle is at the intersection of a line drawn tangent to the infraorbital rim and one bisecting the long axis of the external auditory meatus. An incision was made posteriorly along the zygomatic arch from the infraorbital rim and then inferiorly along a line drawn from the long axis of the meatus. The skin was reflected and a careful dissection through the fatty tissue was undertaken. The zygomaticomandibularis and temporalis muscles were identified and used as landmarks for locating the capsule. The capsule was palpated and superficial tissue carefully dissected free.

Placement of the wick was facilitated by placing a 20 guage 1.5" IV catheter into the superolateral aspect of the joint. The metal portion of the catheter kit was then retracted leaving the plastic outer catheter in place. The wick catheter was attached to the transducer and recorder and calibrated. The wick was introduced through the plastic outer catheter, the later then retracted, leaving the wick in place. Lastly, cyanoacrylate

was placed around the insertion site to eliminate leakage. A pressure measurement was taken at that time.

For post-operative pressure measurements the catheter had to be anchored to the surrounding tissues. To accomplish this polyethylene "dumbells" were fabricated, slipped over the catheter and sutured to the surrounding tissues. The dumbells were fashioned from PE-90 tubing cut into 6 mm lengths and flamed at both ends producing the required shape. One dumbell was placed adjacent to the capsule and sutured in place, 1.0 cm from the previous one. A second dumbell was placed and also sutured. Dumbells were placed 1.0 cm apart until the overlying skin was reached.

The catheter, if allowed to exit the animal directly lateral to the capsule, could be easily removed. Using blunt dissection a "tunnel" was made from the capsule to the posterior aspect of the ear. The catheter was passed athrough this tunnel and anchored just distal to the ear. Excess tubing was removed and the catheter plugged with 0.030 stainless steel wire stops.

## Radiographic Procedures

Immediately post-operatively 1.5 cc of renograafin was injected into the wick catheter, and a temporomandibular arthrogram was taken. Upon completion, the fluid was asiprated and replaced with heparinized saline. The catheter was again stopped with 0.030 stainless steel wire.

Next, a lateral radiograph was taken of the animal's head in maximum intercuspation. The film to object distance was standardized for each animal.

## Appliance

The TMJ pressure effect of both a mandibular propulsing appliance and a mandibular retruding appliance was determined. The mandibular propulsor was an anterior incline plane fashioned from cold cure acrylic. The appliance was fitted to the animal and bonded to the mandibular incisors.

To fabricate the retruding appliance 0.050 wire was adapted circumfrentially to the mandibular incisors. Two "wings", also 0.050, were soldered to the base wire at the lip line. These two wings exited the mouth laterally and provided hooks to which a straight pull headgear was attached. Cold cure acrylic was applied to the wire base. The appliance was fitted and bonded to the mandibular incisors. A straight pull headgear was fabricated and attached to the wings of the appliance. Sixteen ounces of distal force was applied bilaterally.

## Measurement of Synovial Fluid Pressure

Fourteen days following the initial placement of the catheter, fluid pressure was again monitored. It was felt that 14 days would allow sufficient time for any inflammation or infection resulting from the surgical procedure to manifest itself.

Pressure recordings were monitored daily for a period of three weeks. To record the pressure the animal had to be stabilized in a "chute". The chute stabilized the animal's body yet allowed for free movement of the head. The 0.030 stop was removed and replaced with the 21 gauge luer stub adapter. A fluid filled connector tube was attached to the catheter and recordings were made under varying masticatory conditions.

The wick catheter was connected to a P23D6 Statham pressure transducer. The transducer output was fed into a Gould-Statham amplifier and recorded on a Gould-Statham 220 two-channel chart recorder.

Wick response was checked by application of digital pressure to the capsule of the TMJ. Because of the relatively small bore of the intravenous catheter, insertion of the wick was possible without resultant hemorrhage.

# RESULTS

## Synovial Fluid Pressure in Resting Position

After wick catheters were surgically placed in six temporomandibular joints of three animals, synovial fluid pressures were recorded. The resting synovial fluid pressures were all subatmospheric (Figure 3). The average resting synovial fluid pressure was -3.9 mm of Hg. The range was -2.5 mm Hg to -5.5 mm of Hg. To verify proper functioning of the wick catheter several experiments were performed on the surgically exposed joint just after insertion. Following catheter calibration the capsule was subjected to finger pressure, with a subsequent rise in pressure noted. Second normal saline was infused into the joint via the catheter and again a rise in pressure was noted. Finally, fluid was withdrawn from the joint with a resultant drop in pressure.

## Relationship Between Synovial Fluid Pressure and Jaw Position

Each animal was subjected to various operator manipulated jaw positions. Fluid pressure was measured while the animal's jaws were sequentially opened and closed. In animal I (Figure 4), there was an initial drop in pressure (-3 mm Hg to -3.5 mm Hg) when the jaws were opened, followed by a rise to 0.5 mm Hg and a slow return to -3 mm Hg. When the jaw was closed there

Figure 3 shows the resting synovial fluid pressure of Aminals 1, 2 and 3, at the time the catheter was surgically placed.

Figure 3

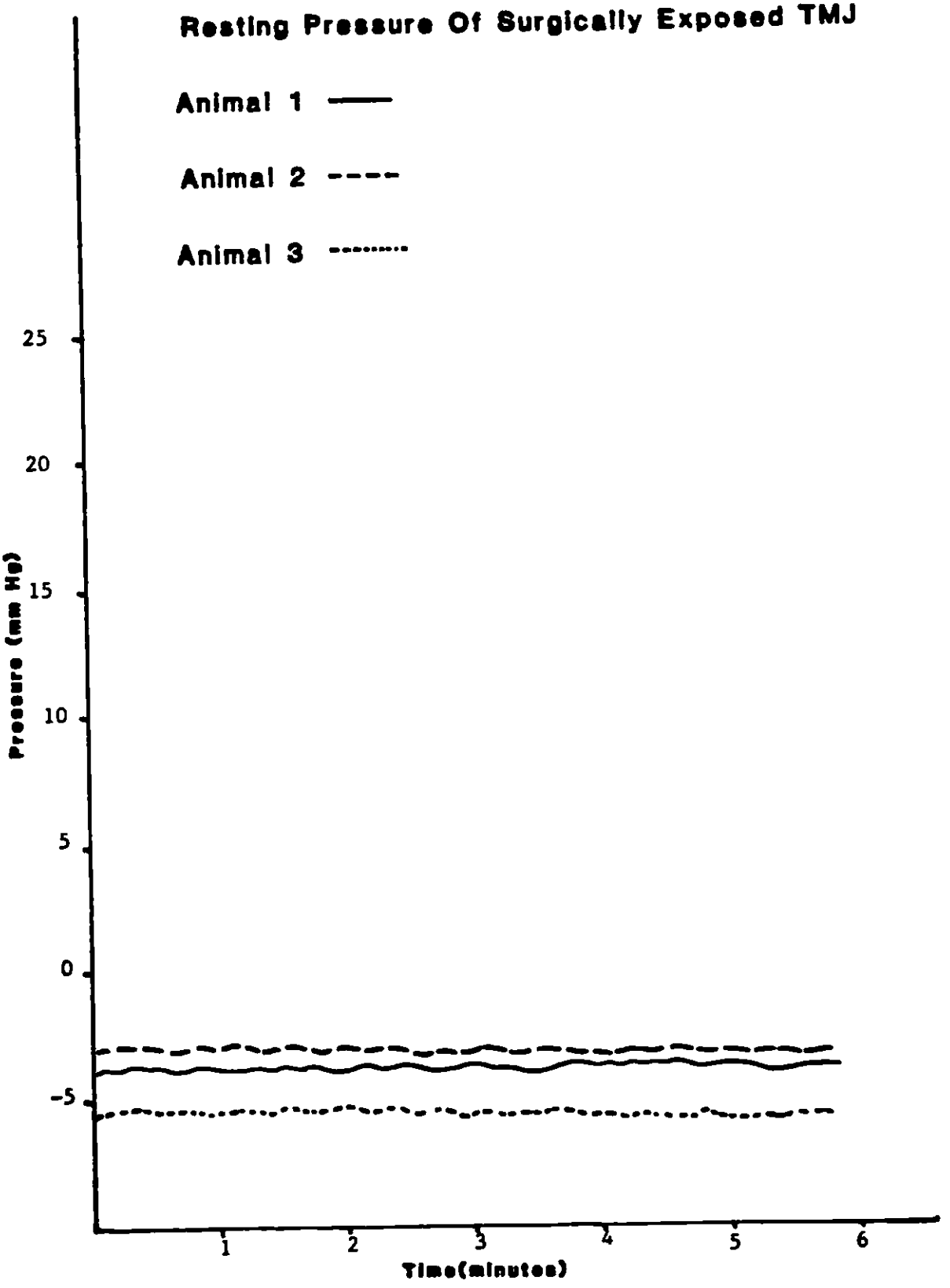
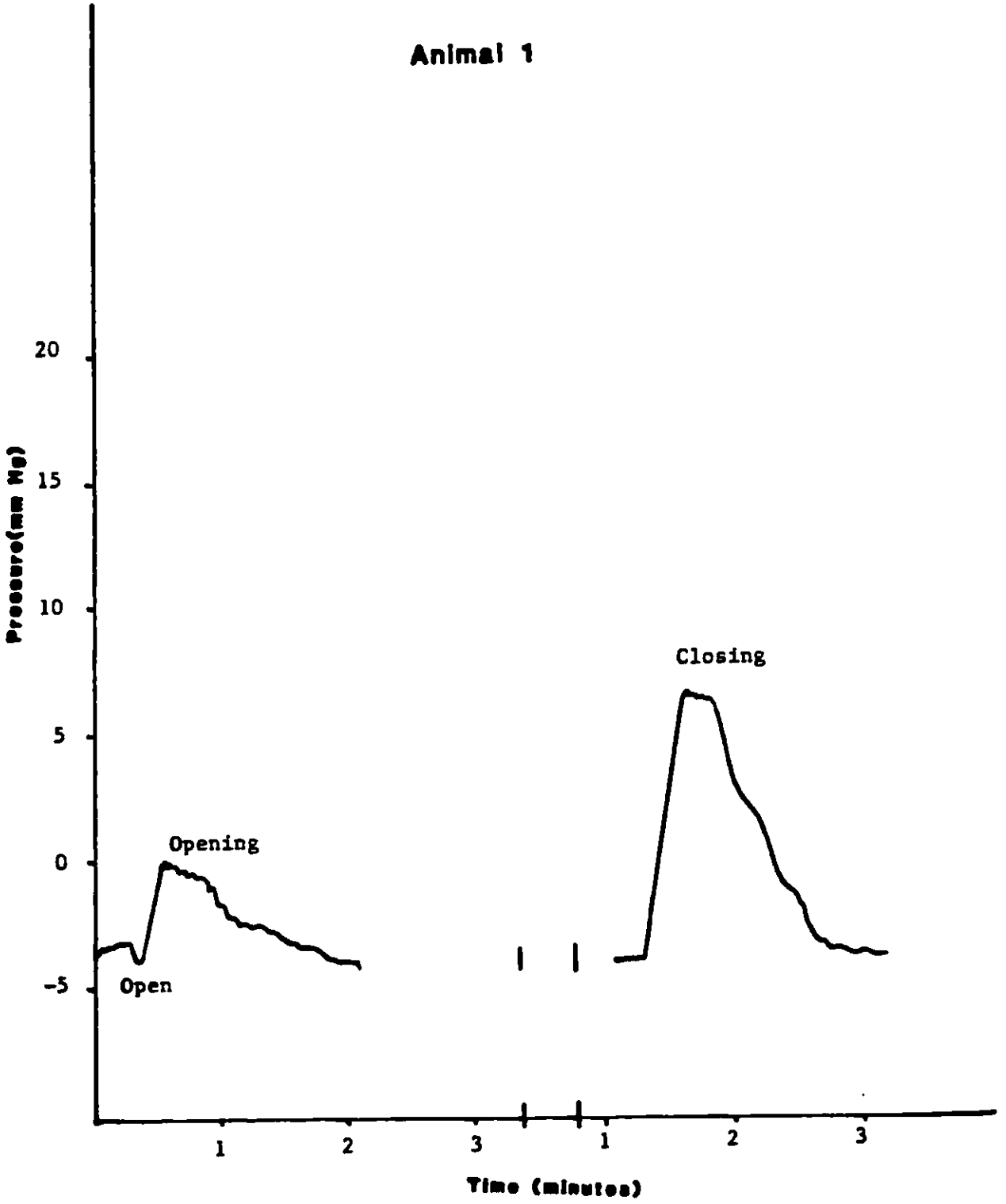

Resting Pressure Of Surgically Exposed TMJ
Animal 1
Animal 2
Animal 3
25
20
15
10
5
0
-5
Pressure (mm Hg)
1
2
3
4
5
6
Time(minutes)

Figure 4 shows the synovial fluid pressure response to operator assisted opening and closing. An initial drop in pressure as the jaw is protruded upon opening is presented.

Figure 4

**Pressure Response To Opening and Closing**



was an immediate increase to 6 mm of Hg followed by a return to normal. The second animal, wearing the inclined plane, showed a similar response to the alternate opening and closing manipulation (Figure 5). The third animal, wearing the retruding appliance, also had a similar pattern in fluid pressure response, but at a much higher level (Figure 6).

In the next experiment, synovial fluid pressure changes were monitored while the jaw was held in a lateral position. In animals I and II similar patterns were observed (Figures 7 and 8). The pressure changed from a negative at rest to a positive reading very quickly, followed by a slow degradation to the baseline. The third animal showed a pattern that was dissimilar to the others in that the extent of the change between the baseline and the peak pressures was much shallower (Figure 9).

Finally, the working and balancing side pressures were recorded in all three animals. Again animals I and II showed similar patterns (Figures 10 and 11). The third animal presented a markedly different pattern as seen in Figure 12.

## Synovial Fluid Pressure in Relation to Altered Mandibular Position

The catheters were placed in 8 week old weanling pigs. The 1st animal was allowed to grow and develop without mechanical interference. Synovial fluid pressures were recorded every second day during mastication for a period of six weeks. The

Figure 5 illustrates the synovial fluid pressure response to operator assisted opening and closing while wearing a protruding appliance. A similar pattern to Animal 1 is evident.

Figure 5

**Pressure Response To Opening and Closing**

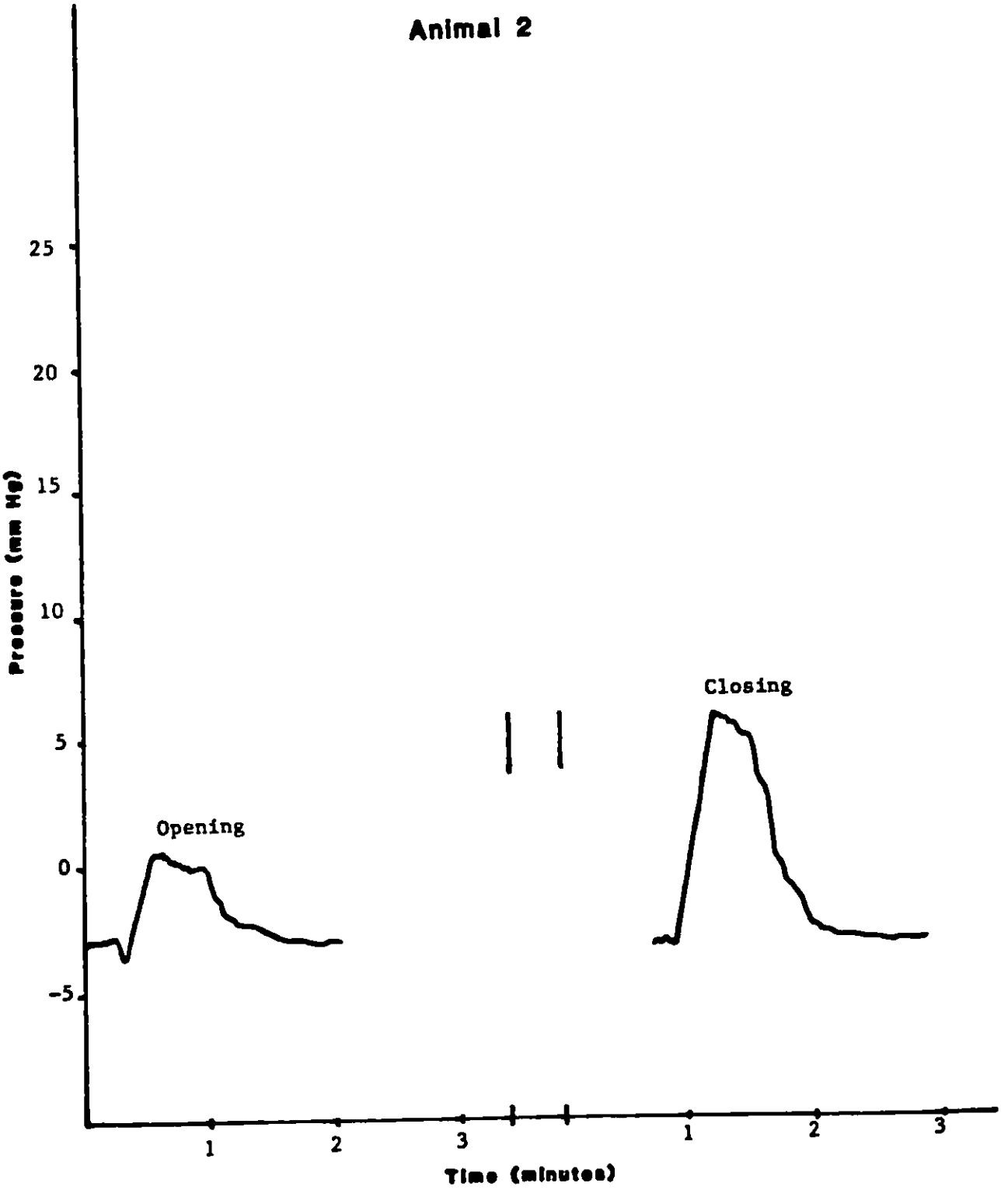


Figure 6 illustrates the synovial fluid pressure response to opening and closing while wearing a retruding appliance. The pattern is similar but, at a much higher pressure.

Figure 6

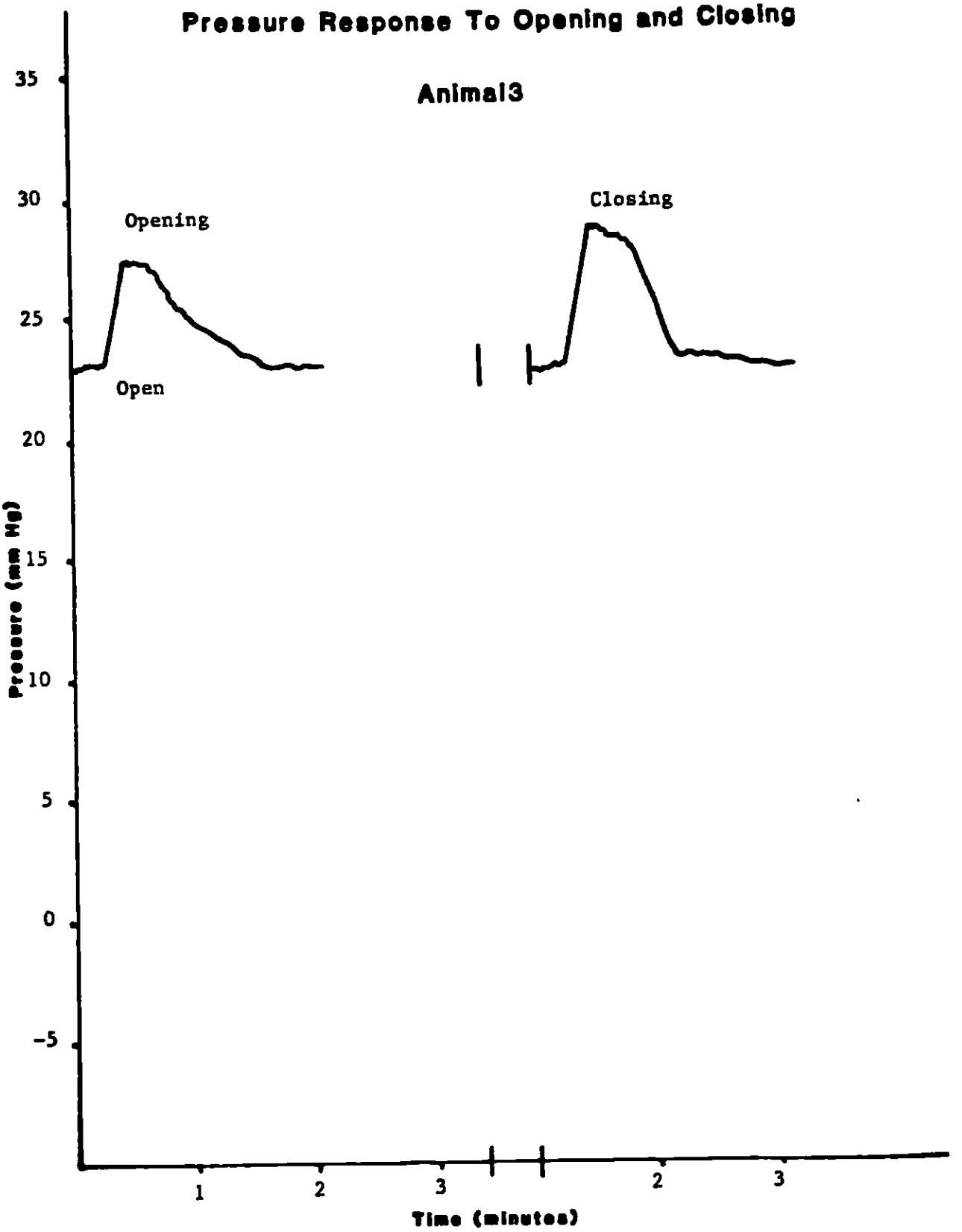

Pressure Response To Opening and Closing
Animal3
Opening
Closing
Open
35
30
25
20
15
10
5
0
-5
Pressure (mm Hg)
1
2
3
2
3
Time (minutes)

Figure 7 illustrates the synovial fluid pressure response to an operator manipulated lateral movement. An initial increase in pressure is followed by a slow degradation when the jaw is released.

Figure 7

**Pressure Response To Operator**

**Manipulated Lateral Movement**

**Animal 1**

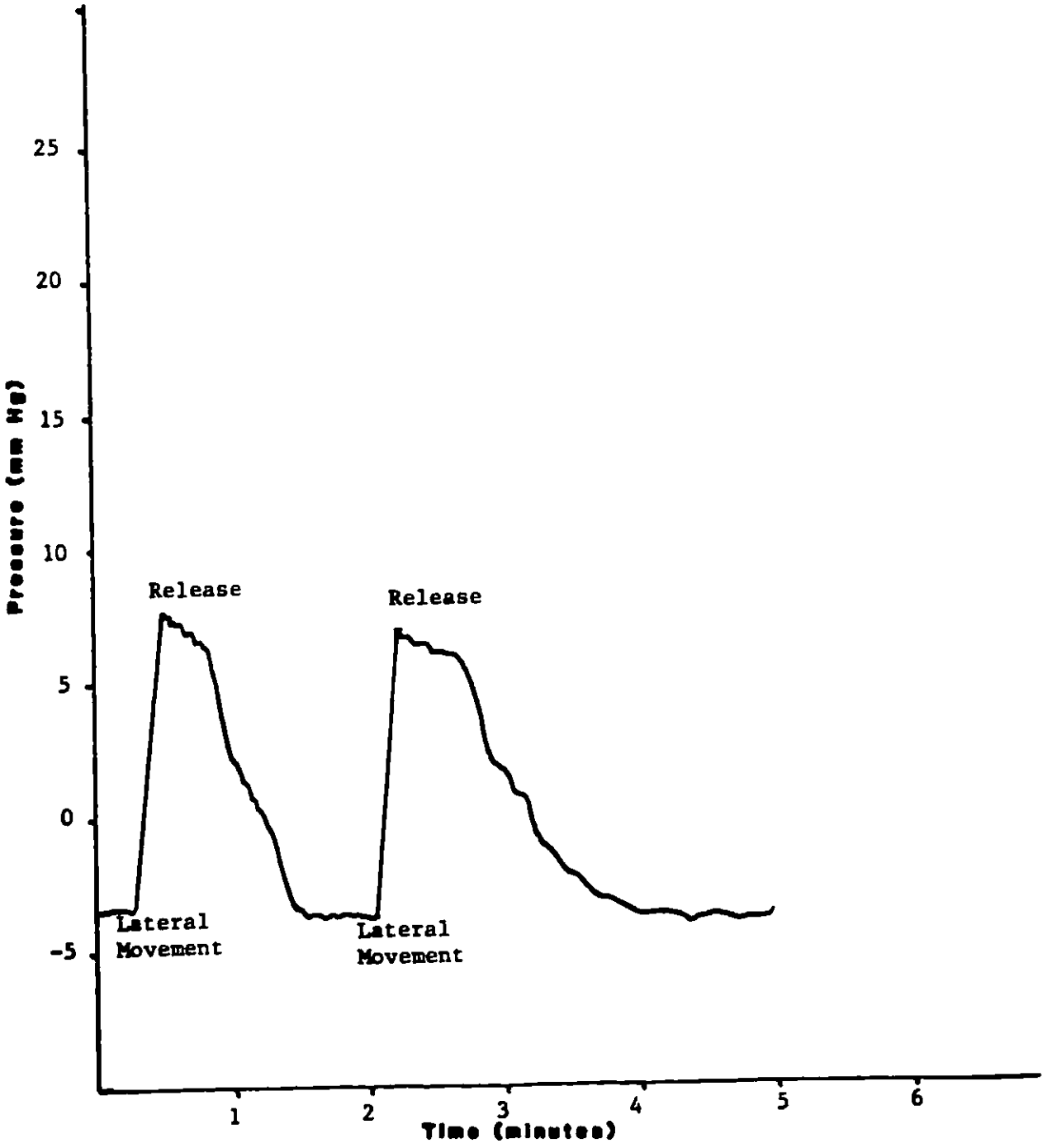


Figure 8 illustrates the synovial fluid pressure response to an operator manipulated lateral movement while wearing a protruding appliance. A similar pattern to Animal 1 is presented.

Figure 8

**Pressure Response To Operator**

**Manipulated Lateral Movement**

**Animal 2**

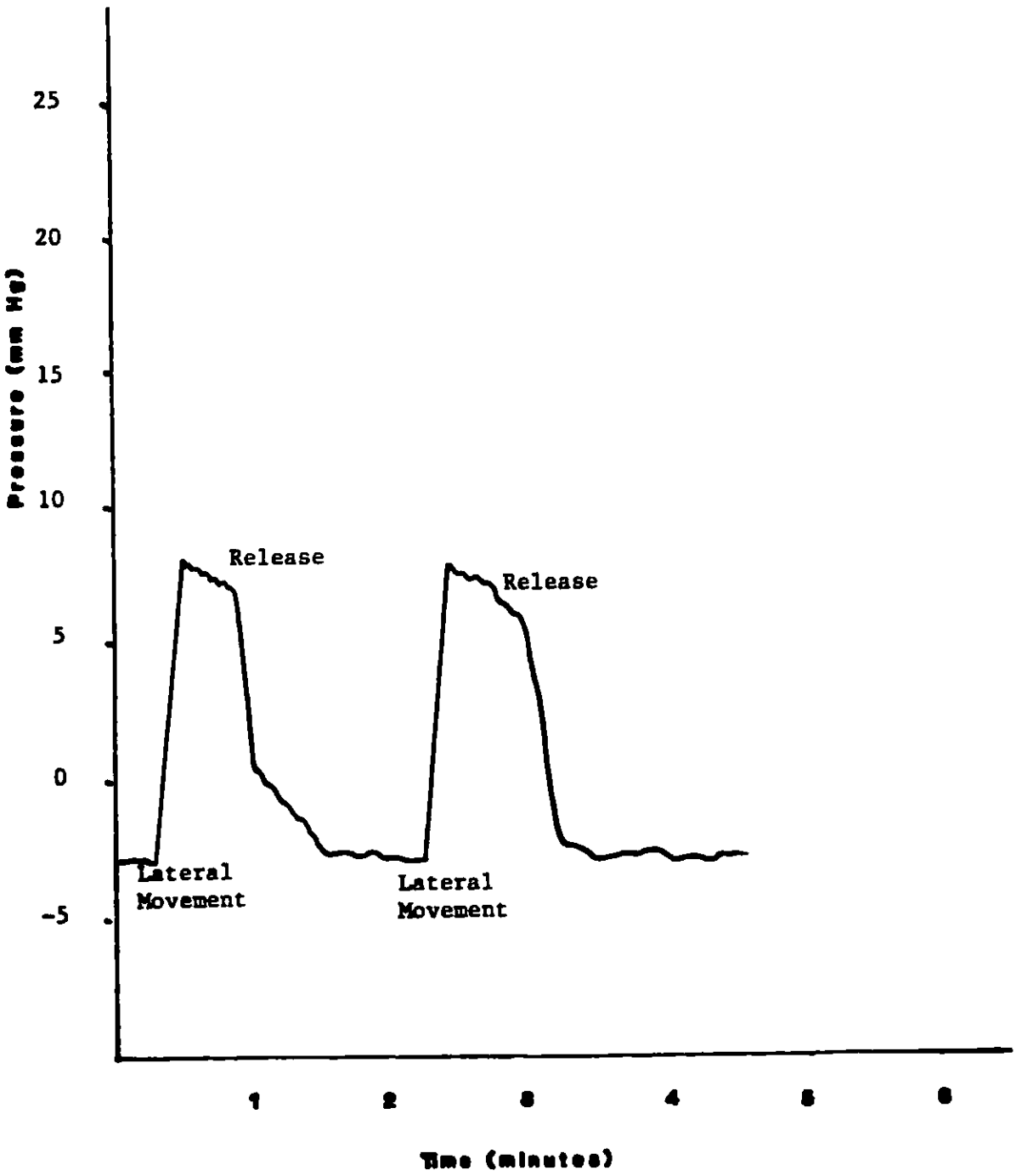


Figure 9 illustrates the synovial fluid pressure response to an operator manipulated lateral movement while wearing a retruding appliance. The pattern is similar to Animals 1 and 2 but at a much higher pressure.

Figure 9

**Pressure Response To Operator Manipulated Lateral Movement**

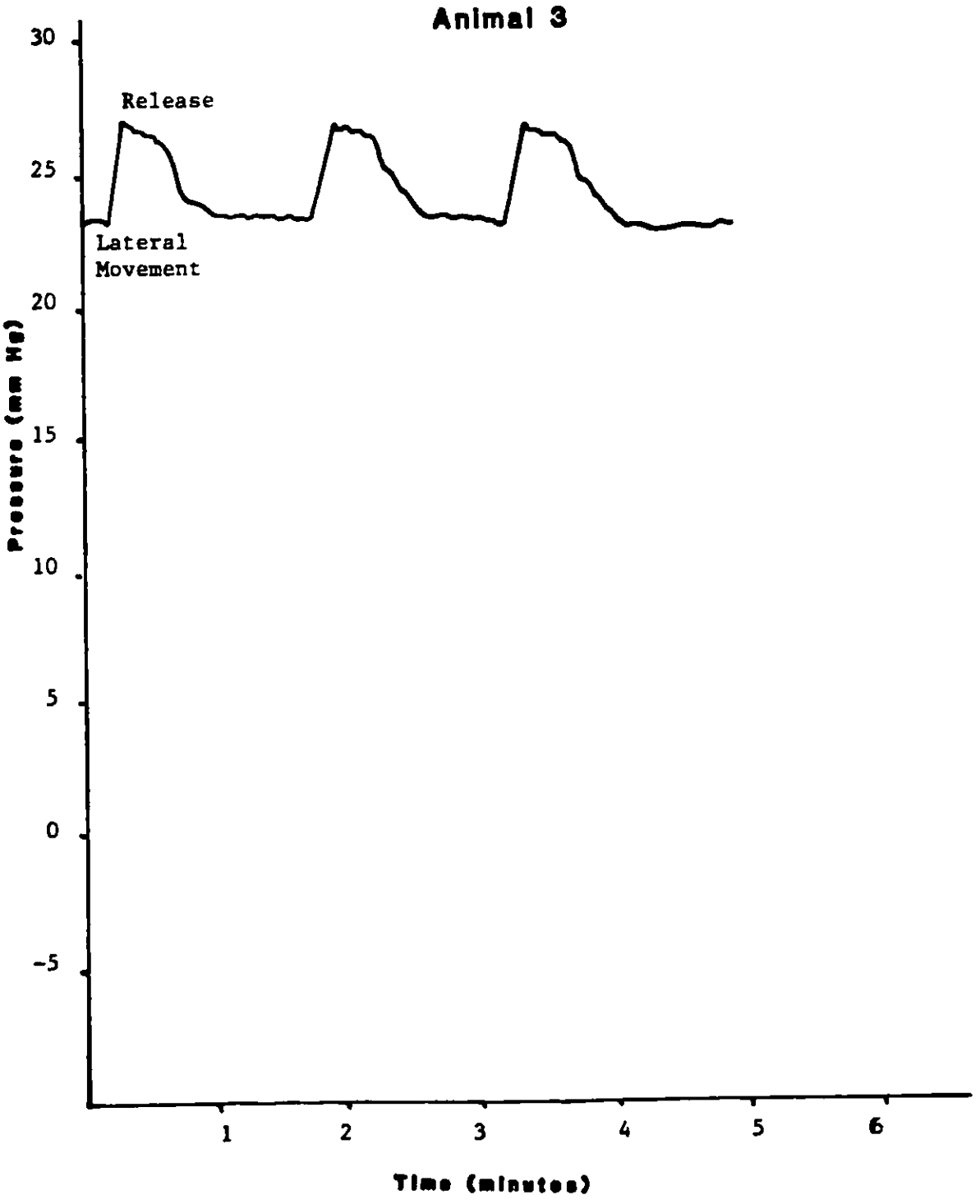


Figure 10 illustrates the synovial fluid pressure response on the balancing and working TMJs of Animal 1. An initial increase is followed by a slow degradation when the jaw is released.

Figure 10

**Pressure Response To Working and Balancing Side Shifts**

**Animal 1**

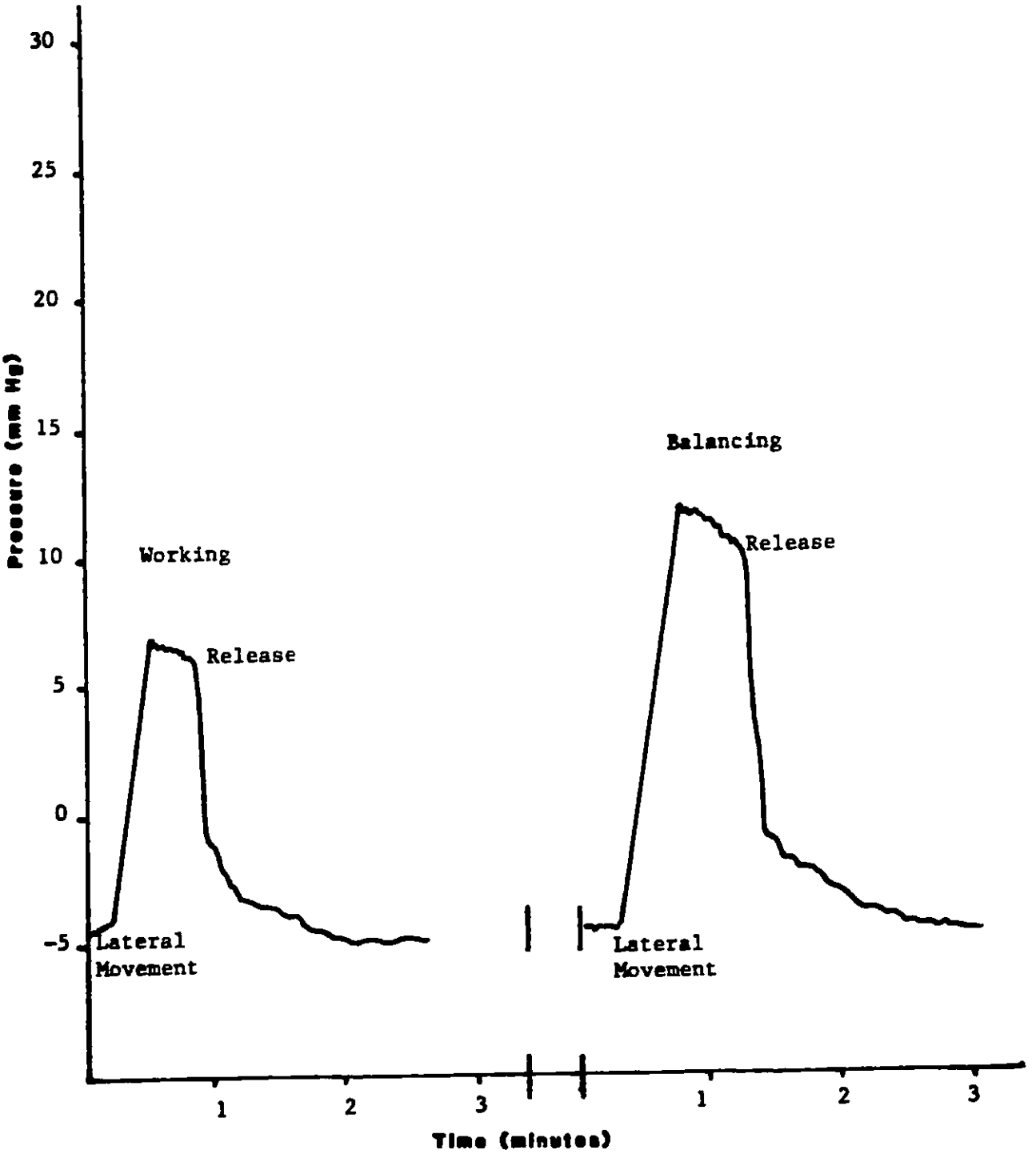


Figure 11 illustrates the synovial fluid pressure response of the working and balancing side TMJs of Animal 2. A similar response to Animal 1 is illustrated.

Figure 11

**Pressure Response To Working and Balancing Side Shifts**

**Animal 2**

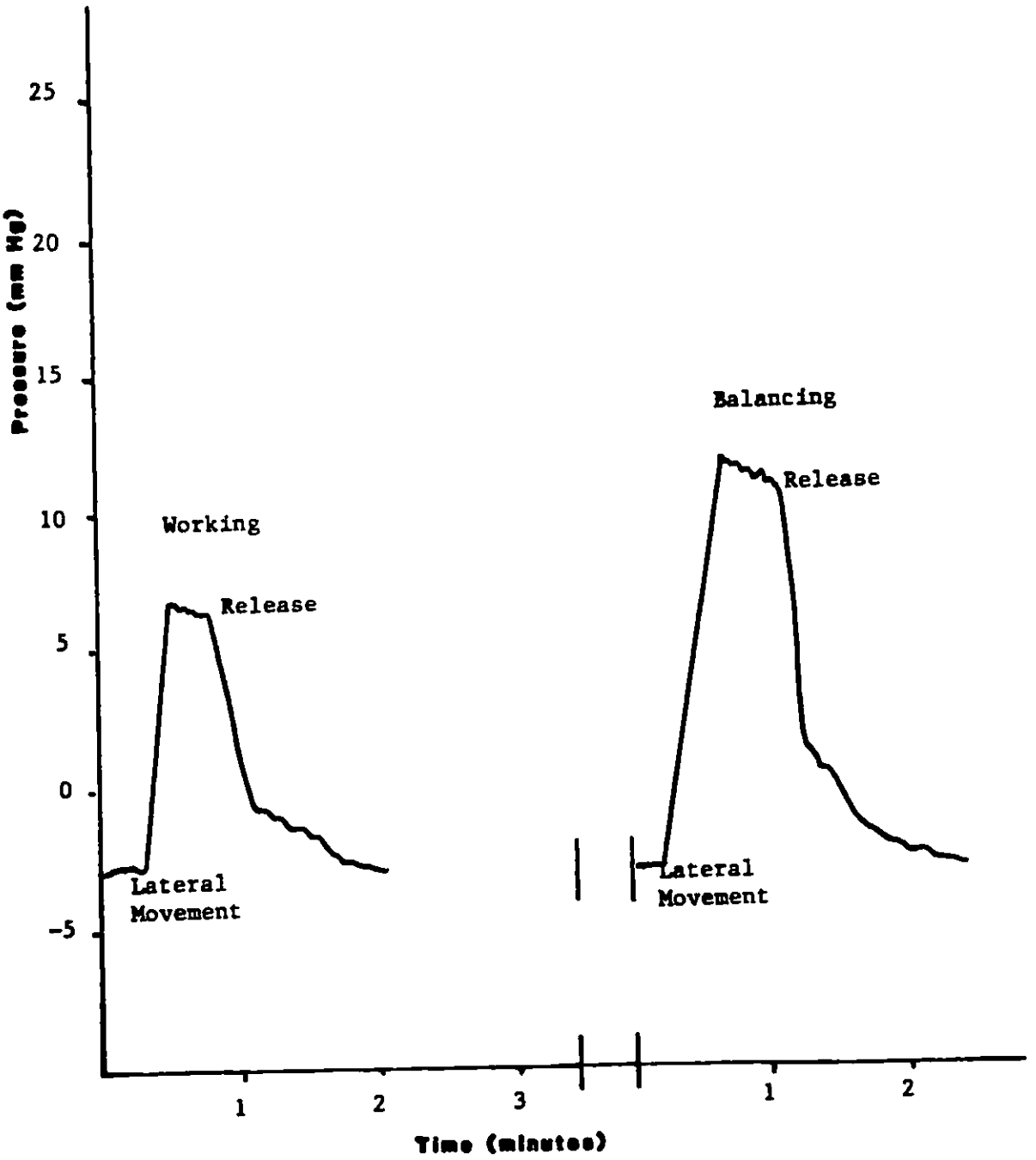
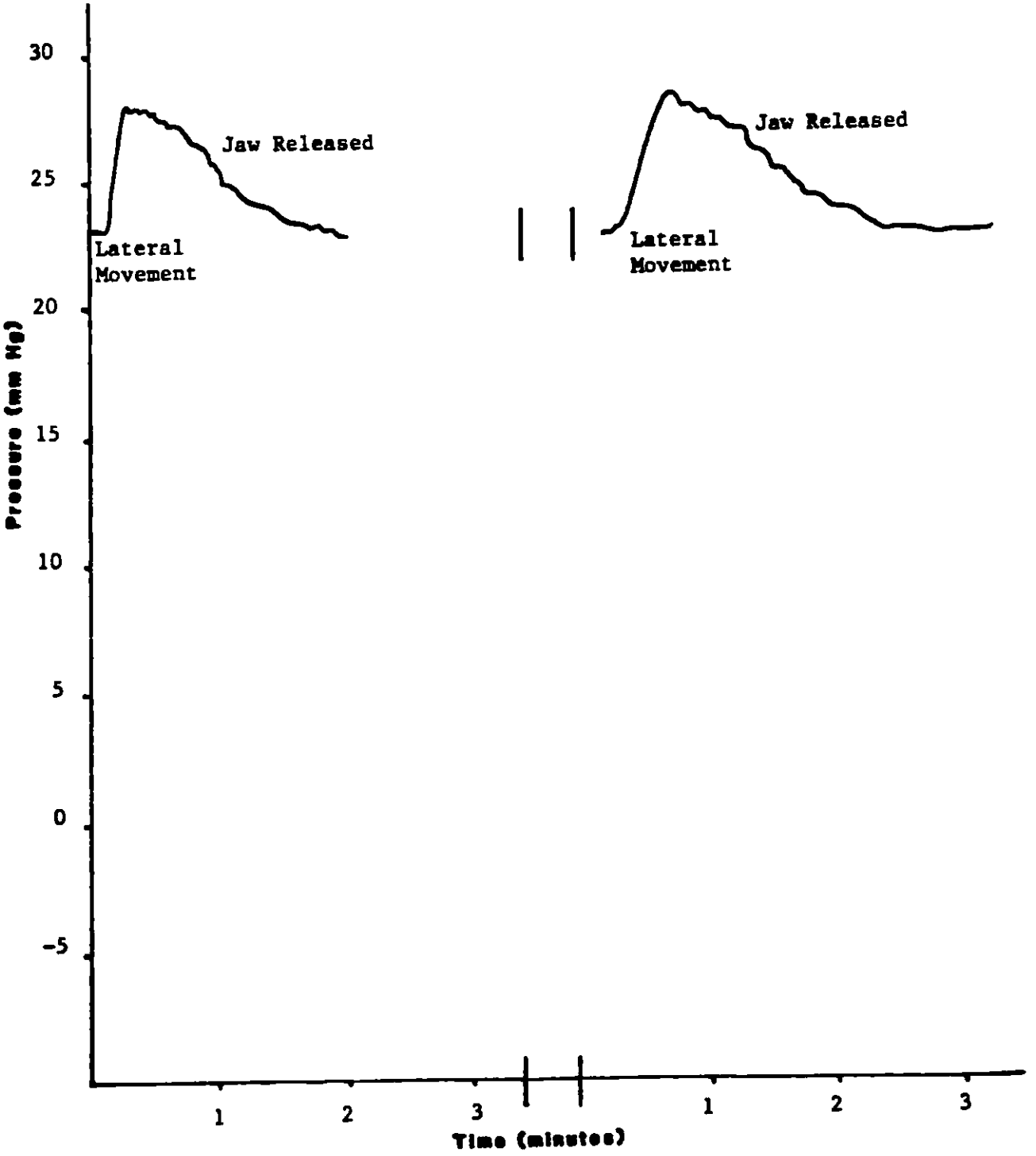


Figure 12 illustrates the synovial fluid pressure response of the working and balancing side TMJs of Animal 3. The animal, wearing a retruding appliance, responded at a much higher level.

Figure 12

**Pressure Response To Working andBalancing Side Shifts**

**Animal3**



average chewing cycle is represented in Figure 13. At the start of the cycle an immediate drop in pressure was noted (-3 mm Hg to -4 mm Hg), followed by a rapid increase in pressure to a peak of 17 mm Hg. After the animal had swallowed a bolus of food there was a gradual decrease in pressure until the baseline value was restored.

At 14 weeks of age the second animal received an inclined plane appliance, bonded to the lower incisors, in order to functionally position the mandible forward (Figure 14). Again, fluid pressure was monitored. When the appliance was placed, there was an immediate drop in fluid pressure (-3 mm Hg to -4 mm Hg), followed by a gradual increase to 10 mm of Hg (Figure 15). A very slow degradation to the original level occurred over a one hour and 40 minute period.

The animals' masticatory cycle was also monitored for TMJ pressure for four weeks following appliance placement. Pressure recordings were monitored every second day (Figure 16).

Animal III also received an appliance at the age of 14 weeks. This appliance was designed to cause a distal placement of the mandible (Figure 17). The immediate fluid pressure went from -5 mm Hg to a peak value of 35 mm of Hg very rapidly (Figure 18). A slow degradation of pressure occurred over a 2 hour period to 23 mm of Hg. Repeated measurements showed that the fluid pressure remained relatively constant at 23 mm Hg thereafter.

Figure 13 illustrates the synovial fluid pressure response to mastication of Animal 1. The initial drop in pressure corresponds to the animal's protrusive movement. Next a rise in pressure as the animal begins to masticate is followed by a degradation to the baseline after the bolus is swallowed.

Figure 13

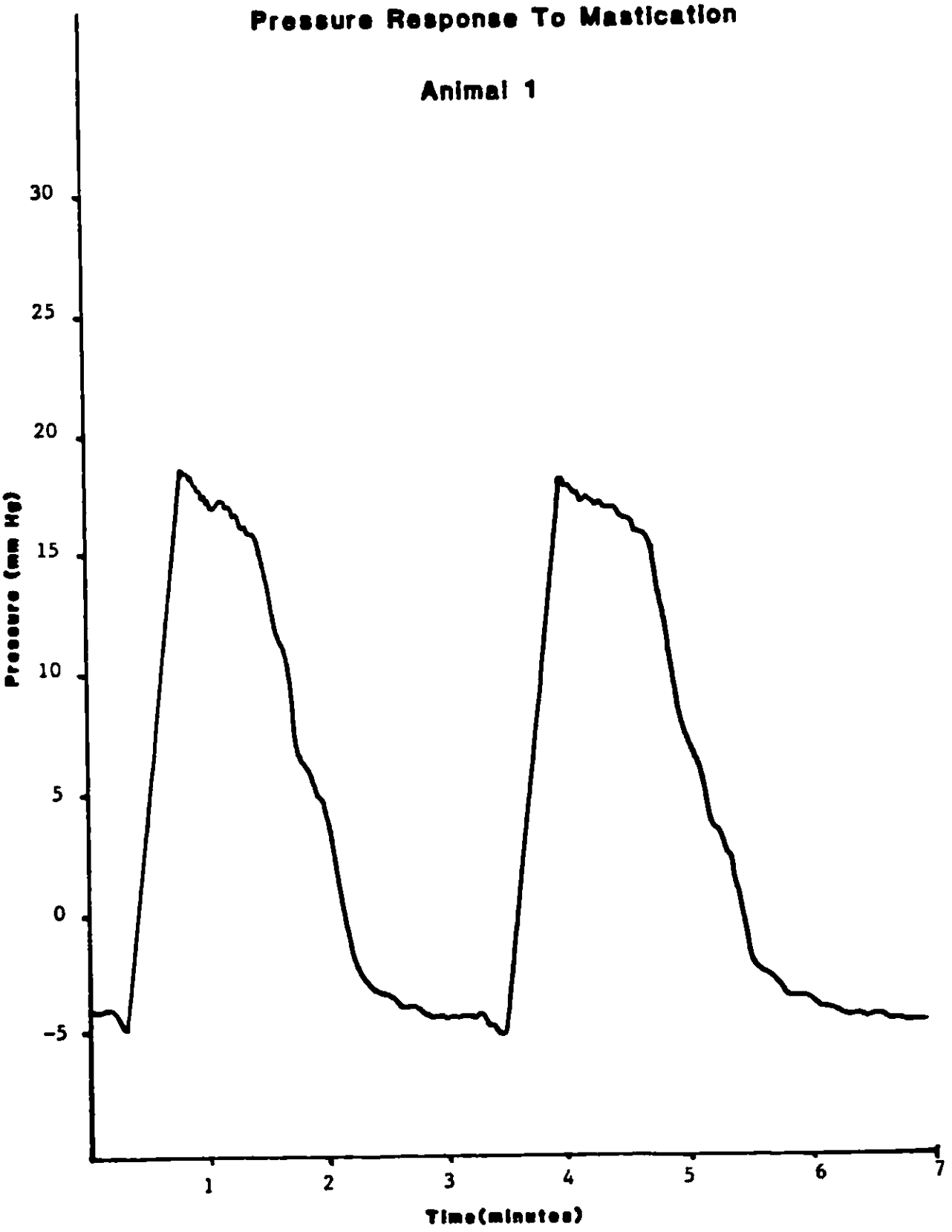
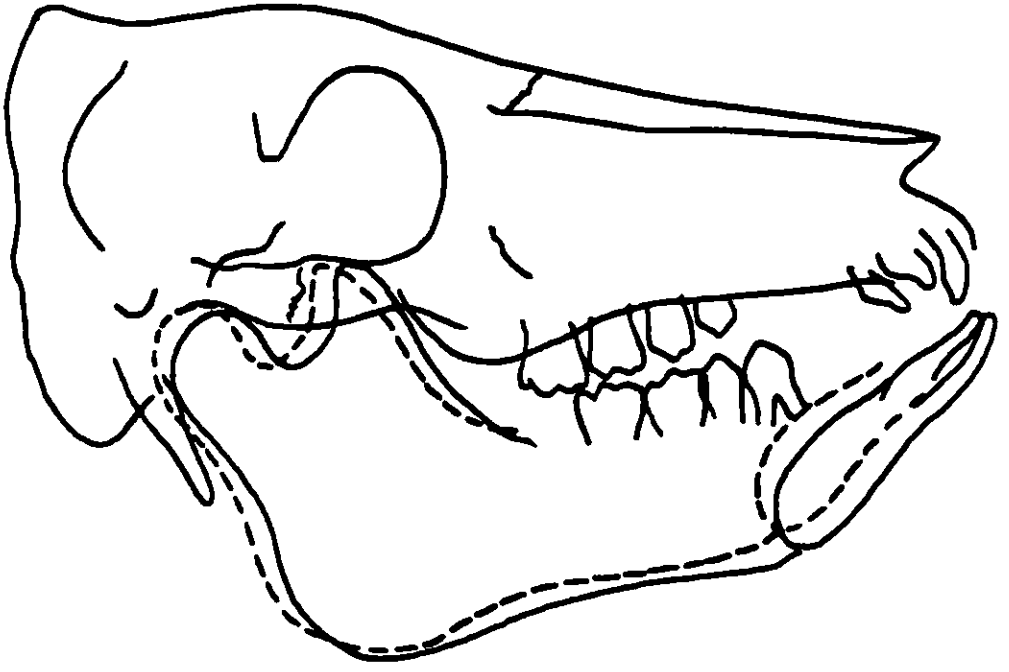

Pressure Response To Mastication
Animal 1
Pressure (mm Hg)
30
25
20
15
10
5
0
-5
1
2
3
4
5
6
7
Time(minutes)

Figure 14 illustrates the animal wearing a mandibular protruding appliance. The tracings are superimposed on the sella-nasion plane.

Figure 14

**Mandible Positioned Forward**

**Animal 2**



**Normal Position ----**

**Retruded ——**

Figure 15 illustrates the synovial fluid pressure response when the protruding appliance was placed and the animals mandible was closed.

Figure 15

**Pressure Response To An Inclined Plane**

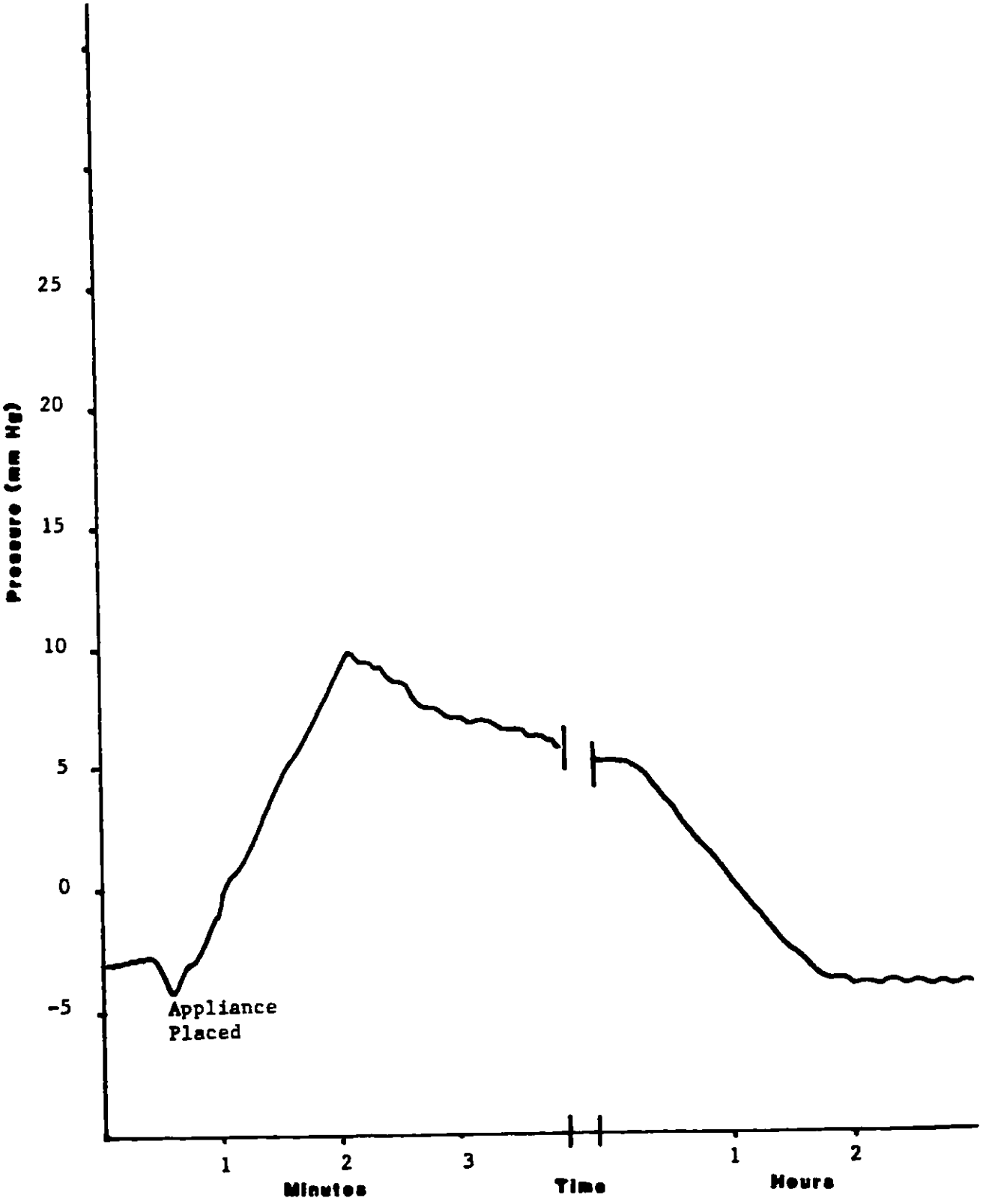


Figure 16 illustrates the synovial fluid pressure response to mastication while wearing a protruding appliance. A similar pattern to Animal 1 is presented.

Figure 16

**Pressure Response To Mastication**

**Animal 2**

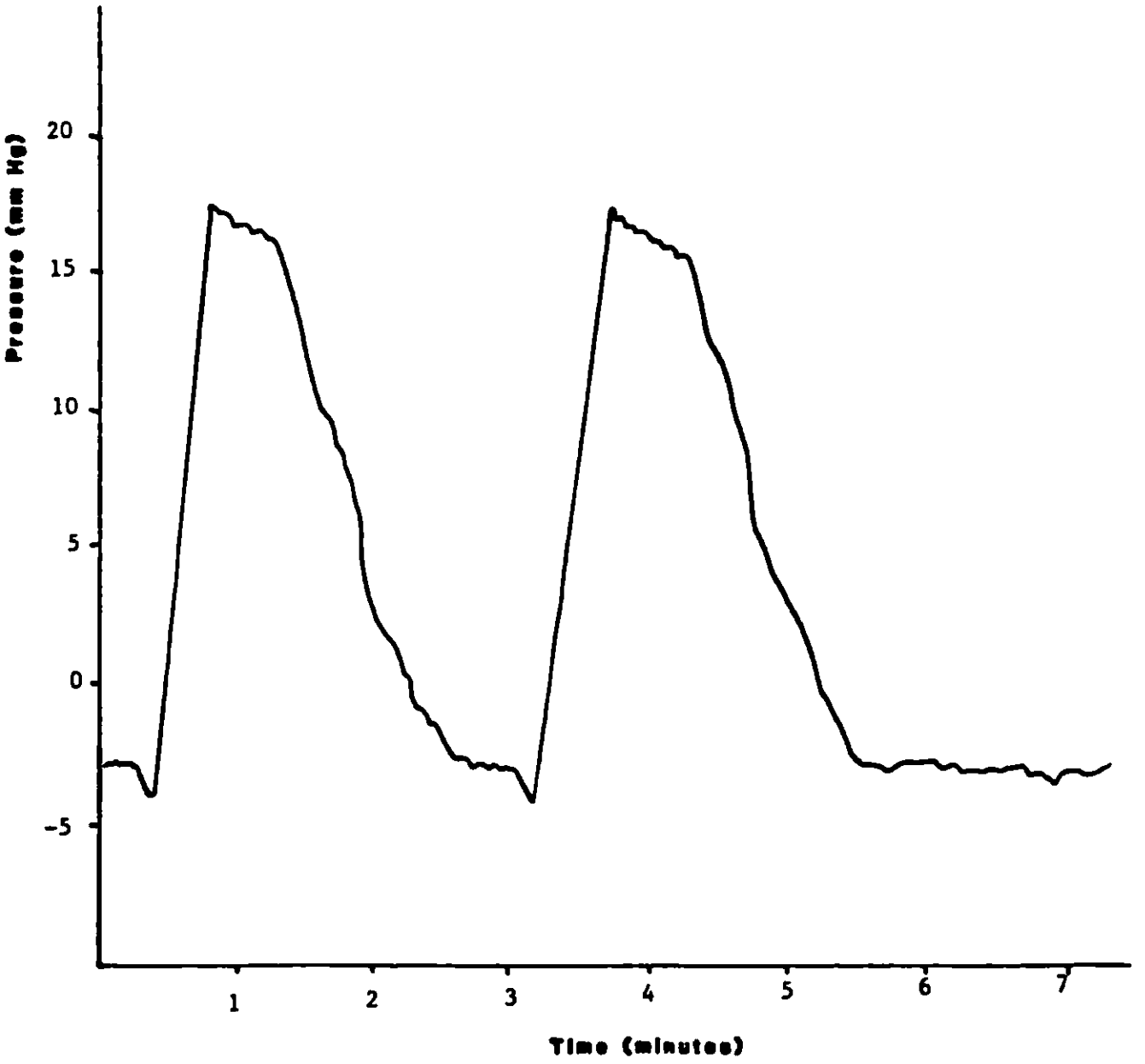
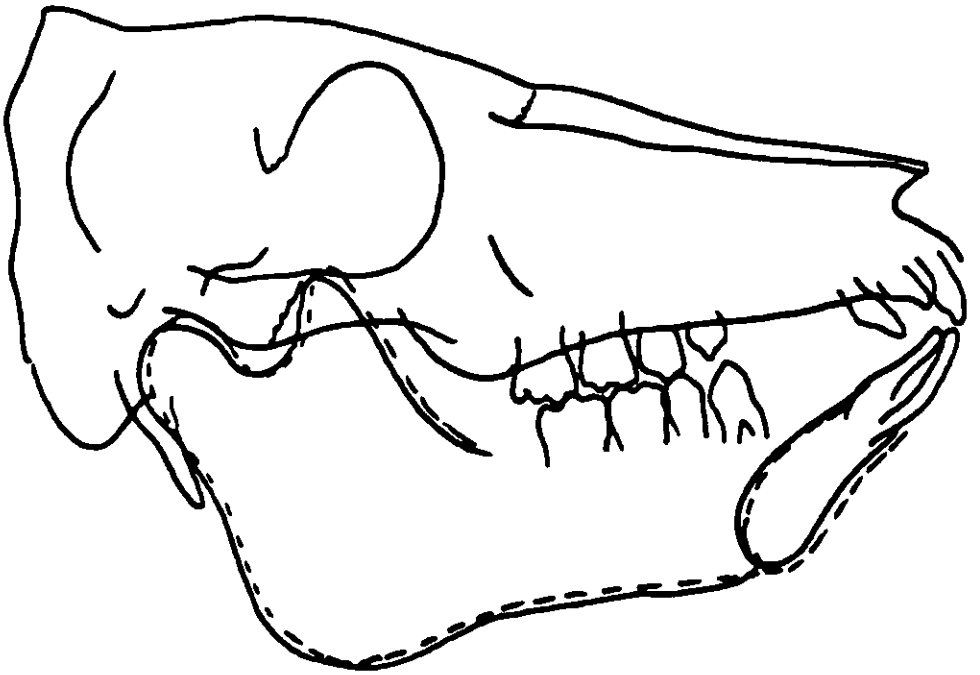


Figure 17 illustrates the animal wearing a retruding appliance. The tracings are superimposed on sella-nasion.

Figure 17

**Mandible Positioned Backward**

**Animal 3**

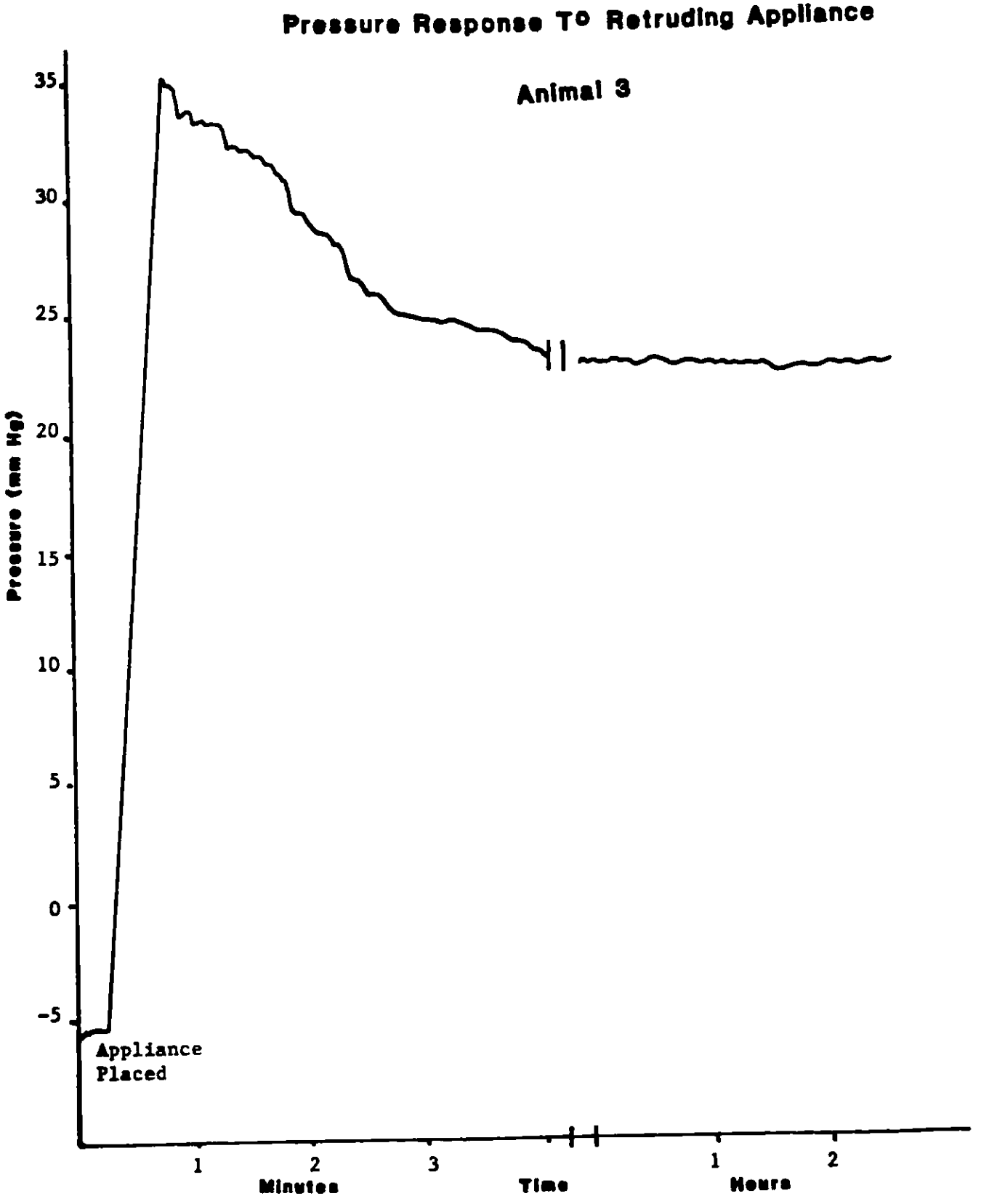


**Normal Position----**

**Retruded ——**

Figure 18 illustrates the synovial fluid pressure response when the protruding appliance was placed and the animals mandible was closed.

Figure 18


Pressure Response To Retruding Appliance
Animal 3
Pressure (mm Hg)
35
30
25
20
15
10
5
0
-5
Appliance
Placed
1
2
3
Minutes
Time
1
2
Hours

The masticatory cycle of animal III was monitored in the same manner as the previous two (Figure 19) There was a drop in fluid pressure as occurred in animals I and II. The fluid pressure went from 23 mm of Hg to a peak value of 35 mm of Hg and then slowly degraded back to 23 mm of Hg.

Finally, to determine if the synovial fluid pressure changed during successive periods of growth and development cephalometric radiographs were taken at 8 weeks, 14 weeks (time of appliance insertion) and at 20 weeks (Figure 20). Although there was a great deal of growth the synovial fluid pressure remained relatively constant, and the experimentally induced variations had essentially the same results.

Table I illustrates the mandibular growth changes that occurred during the experimental procedure. The mandible was measured from condylion to pogonion (Co-Pg), and from gnathion to pogonion (G-Pg). The animal wearing the mandibular protruding appliance showed a relative increase in the Co-Pg measurement (185 mm). The animal wearing the mandibular retruding appliance showed a relative decrease in the Co-Pg measurement (170 mm).

Figure 19 illustrates the synovial fluid pressure response to mastication while wearing a protruding appliance. The pressure response is at a much higher level than Animals 1 and 2.

Figure 19

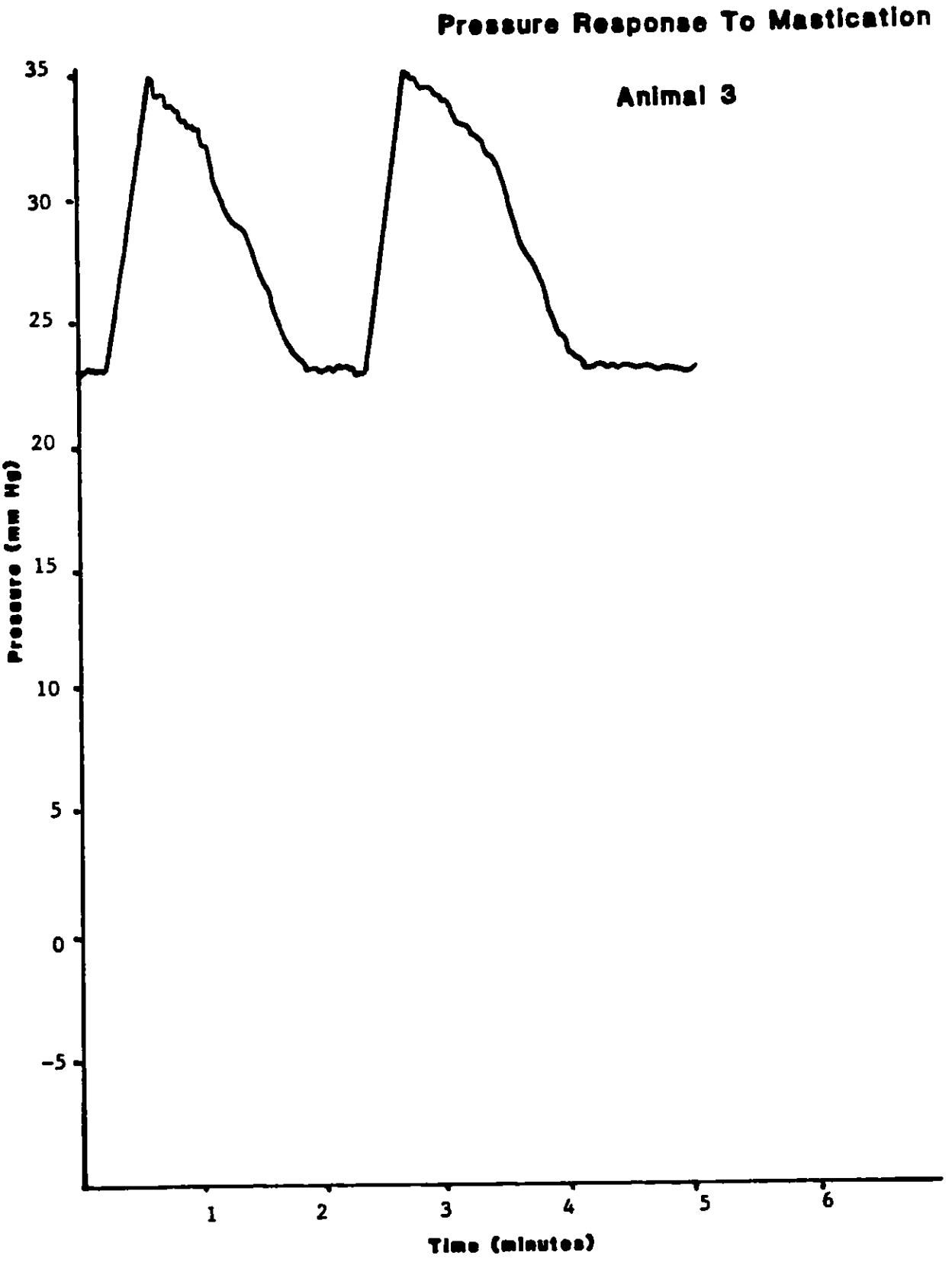

Pressure Response To Mastication
Animal 3
35
30
25
20
15
10
5
0
-5
Pressure (mm Hg)
1
2
3
4
5
6
Time (minutes)

Figure 20 illustrates the resting synovial fluid pressure of Animals 1, 2 and 3 prior to appliance placement and for 7 weeks after appliance placement.

Figure 20

**Resting Synovial Fluid Pressure In The Growing Animal**

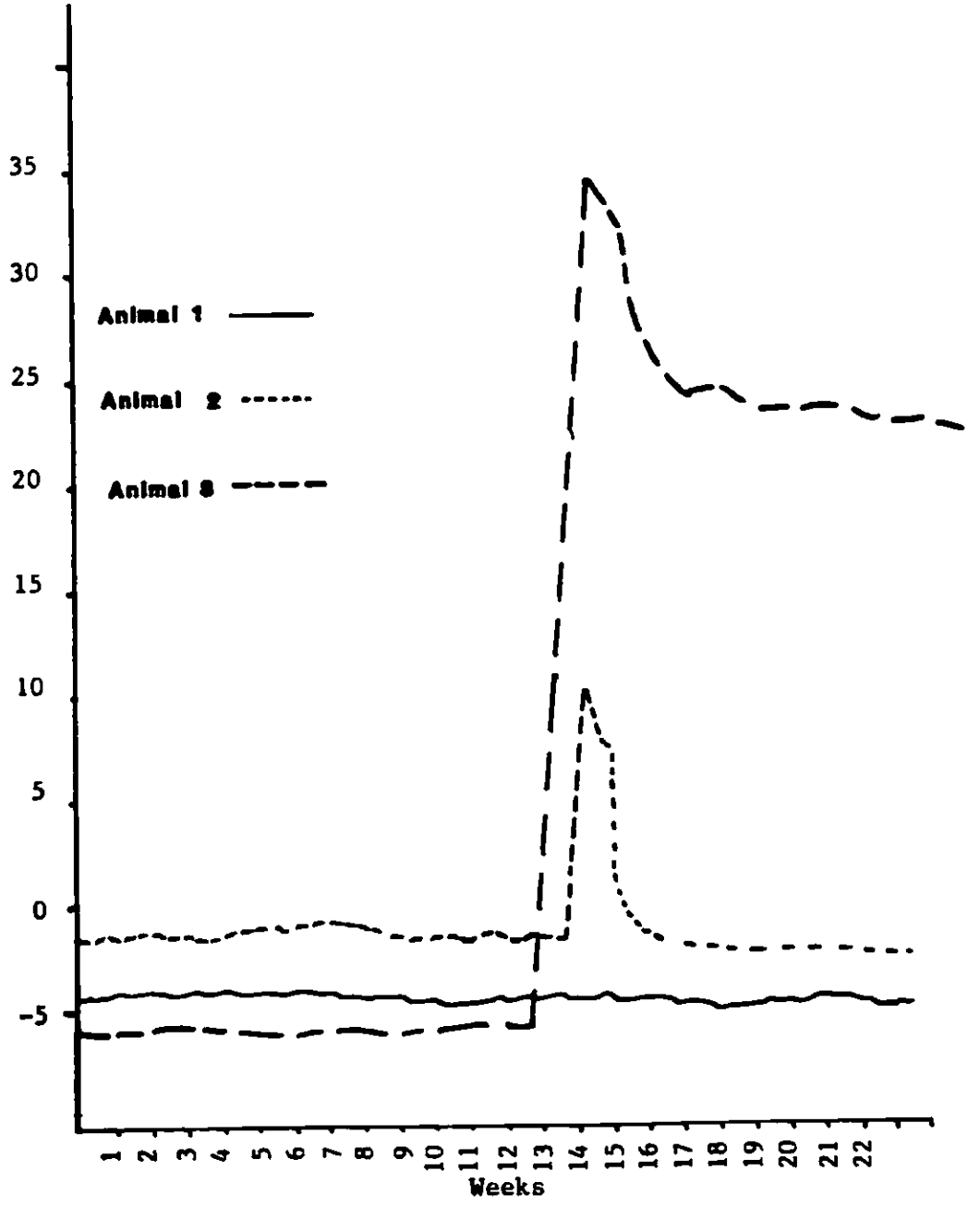


TABLE I

GROWTH CHANGES OF THE MANDIBLE

| Animal | Measure-ment | 8 Weeks | 14 Weeks | 20 Weeks |
|---|---|---|---|---|
| 1 | Co-Pg | 120 mm | 137 mm | 178 mm |
| | G-Pg | 86 mm | 97 mm | 136 mm |
| 2 | Co-Pg | 118 mm | 135 mm | 185 mm |
| | G-Pg | 88 mm | 93 mm | 134 mm |
| 3 | Co-Pg | 122 mm | 139 mm | 170 mm |
| | G-Pg | 87 mm | 95 mm | 133 mm |

# DISCUSSION

Recordings of the synovial fluid pressure of the pig TMJ were found to be consistent with the subatmospheric measurements recorded in other jaws. The mean values of the resting TMJ are comparable with those obtained by Roth (-3.8 cm Hg; pig, 1982), Reeves (-4.0 cm Hg; rabbit and human knee; 1966), Levick (-4.6 cm Hg, rabbit knee, 1976) and Muller (-4.9 cm Hg; dog and human knee, 1929).

## Validity of Wick Technique

Caughey and Bywaters (1963) suggested that the subatmospheric nature of the measurements obtained are possibly artifactual, caused by obstruction of the catheter. The construction of the wick type of catheter, however, precludes such blockage. The exposed dexon fibers act as a buffer to prevent mechanical blockage of the catheter.

The validity of the wick method has been tested by both Scholander (1968) and Snashall (1971). The wick was firmly attached to a piece of filter paper, wetted with 0.9% saline, by means of a weight. The filter paper was then dipped into a beaker of 0.9% saline from various heights. The wick method measured accurately the hydrostatic pressure of the fluid in the filter paper. Varying the weight from 0.5 to 3.0 kg did not affect the recorded pressure.

## Negative Interstitial Pressures

The synovial cavity can be regarded as an interstial compartment with a viscous diasylate of blood sandwiched between the interface of two tissue surfaces. Controversy regarding the significance or meaning of negative versus positive pressures in interstitial fluid has arisen because of confusion regarding the types of tissue pressure that can exist.

Considering several simple physical principles, there occurs at least three types of pressures operative within tissues. If the lining surfaces of a blood vessel is considered as a model, wherever fluids are in contact with this surface there exists pressure caused by kinetic impact of the fluid molecules on the surface. Where solids contact the surface, force is applied at the contact points between the two surfaces. Therefore, there exists an interstial type of fluid pressure where fluid contacts a given surface, and a solid tissue type of pressure where the solids meet. The third type of pressure then is the sum of these two, representing the total tissue pressure of a regional system.

The physiologic significance of interstial fluid pressures is principally for activation of fluid movement through pores and tissue spaces. By definition, solid tissue pressure cannot have similar effects because these are pressures exerted by solid contact points. That is, tissue to tissue contacts causing pressure on each other.

Another function of the fluid pressure is to contribute to the functional performance of cellular systems. For instance, if atmospheric pressure is 0 mm of Hg, the solid tissue pressure exerted between two contiguous cells would then be a positive value. The fluid pressure would have to be an equal but opposite negative value and the sum of the two would then equal zero.

In the TMJ joint a negative synovial fluid pressure may contribute to the maintenance of the functional integrity of the joint organ. Maintenance of the negative pressures may serve to balance the powerful tissue to tissue pressures exerted by the overlying musculature. The negative pressures may also serve to cause passive movement of fluid and solute materials into the synovial cavity to maintain its lubrication and nutritional function.

## Jaw Movements and Fluid Pressure Changes

In both operator manipulated and natural masticatory movements of the mandible, there were concomitant rises in the synovial fluid hydrostatic pressure with subsequent degradation to the baseline level. Three possible reasons are suggested for this. First, deformation of the capsule could cause a displacement flow of the synovial fluid with regional increases in fluid pressure. Secondly, deformation of the capsule itself during function could result in a decrease in the potential space of the synovial cavity and therefore a relative increase in pressure. Lastly, an increase in the volume of the fluid could also elicit a

more positive recording. It is most likely that fluid pressure changes are a combination of all of these factors.

It is also noted that after a peak volume was reached a degradation to the baseline level of fluid pressure occurred. This could be due to a decrease in fluid volume, that is, fluid is removed from the cavity in response to the altered pressure gradient or by an increase in tissue compliance (capsular rigidity). Both circumstances may exist synergistically. To determine if this were true Levick (1978) removed the synovial fluid from rabbit knee joints and replaced it with a light grade paraffin oil which is not absorbable. The pressure levels in the flexed joints declined with time but the rate was twice as rapid for the synovial fluid filled joint as compared with the paraffin filled joint. This would suggest that both fluid extravation and capsular compliance are operational. The tissue compliance occurs over a slower period of time as evidenced by the oil containing joint.

## Synovial Fluid Pressure and Mastication

The phylogenic lineages of pigs and man have been divergent since the early beginnings of their respective groups (Herring, 1976). There are nevertheless, structural analogies in their TMJ patterns and masticatory actions. Similarities have been observed in tooth form as well as mandibular configuration and muscular anatomy (Scheman, 1967). Resemblances have usually been ascribed to the specialized nature of their diets.

The masticatory cycle of the pig, as described by Herring (1973), begins with a protrusion of the mandible and a scooping of food with a protruded lower lip. The food particles are held in the front of the mouth for a moment and then picked up by the tongue. This process is repeated several times, then the food mass is transferred to the back of the mouth. During this transfer the jaws are held wide apart. Chewing is rapid with approximately three complete masticatory cycles per second. Each cycle consists of jaw movements in all planes of space and involves an opening movement, a closing movement and a transverse or longitudinal movement with the jaws in closed position.

The synovial apparatus, as with other "hollow" organs, conforms to a pressure-volume relationship of a rubber balloon (McCarty, 1980). The slight drop in fluid pressure as the animal opens may be explained by the initial protrusive movement of the mandible. As the condyle moves forward, releasing the magnitude of compression forces exerted on the TMJ capsule, it causes a slight decrease in synovial pressure. As the cycle progresses a rise in pressure ensues due to distortion of the capsule and displacement of the synovial fluid. A return to the baseline level occurs at the completion of the cycle.

## Pressure Changes with Mandibular Repositioning Appliances

An appliance placed on the mandibular dentition to cause

the animal to functionally protrude his lower jaw produces a change in the resting synovial fluid pressure. The initial drop and then rise in pressure in the masticating animal is similar to the pattern of alteration seen in the normal chewing cycle. However, a much slower degradation to the baseline followed. The long delay in reaching the original resting pressure appeared to reflect the length of time necessary for the TMJ complex to adjust to a functionally protruded position. Once joint compliance was obtained, normal recordings were observed for resting and mastication.

An appliance designed to position the animal's mandible in a retrusive position had marked effects on the synovial fluid pressure. The marked rise in fluid pressure and the sustained elevated pressure would indicate a lack of ability of the joint to adjust to such functional demands with a restoration of the pressure level to the normal resting value. The elevated pressures are probably due to a reduction in the potential space of the synovium and a decrease in the ability of the capsule to comply. These elevated pressures likely have pathologic ramifications as well as a modifying effect on the growth process.

## Pressure Changes and Pathology

The synovial apparatus is responsible for lubrication and nutrition of the articular tissues in non-vascular areas. The rich

vascularity of the synovial membrane itself is one of its significant features. The synovial membrane behaves according to the laws of a semipermeable membrane (Bauer et al., 1940). Rates of diffusion through it are markedly influenced by joint motion. Acute and chronic changes in its basic physiologic behavior can have biologic effects underlying pathologic responses within the joint.

It is conceivable that during periods of excessive and chronic muscular activity a pressure gradient would cause an increase in the fluid volume of the synovium and a subsequent increase in pressure. A sustained increase in pressure could cause a local ischemia to the articular surfaces with ensuing cell death.

The second function of synovial fluid is to provide lubrication to the joint surfaces. The property of lubrication is dependent on the viscosity of the fluid which in turn is directly related to the mucin content. The synovial mucin is hyaluronic acid. During periods of muscle activity it has been shown that there is an increase in fluid volume and therefore pressure. As the intra-articular pressure increases the viscosity of the synovial fluid falls. This presumably impairs the lubricating ability of the fluid, subjecting the joint to a more abrasive action than normal. Jones (1936) showed that dry articular cartilages exhibited approximately 14 times as great a coefficient of friction as those surfaces lubricated with joint fluid.

## Synovial Fluid Pressure and Growth and Development

The role of the condyle in the growth and development of the mandible has long been investigated and reviewed. In deference to its role in nutrition and lubrication of the joint, alterations in synovial physiology could conceivably have effects on the growth and development of the condyle.

Mandibular growth was first described by John Hunter (1771) as occurring in a predominatly posterior direction, toward its articulation. Humphrey (1864) likewise showed that the jaws grow backwards by using metal rings placed on the jaws of pigs. Later, Brodie emphasized the importance of the condyle as a "growth center" which brought about the forward and downward growth of the mandible (Enlow and Harris, 1964). Moss' introduction of his functional matrix concept brought yet another way of thinking and describing mandibular growth.

Currently, the condyle is thought of as more than a "master center". It is involved in the adaptations of the mandible to changing local environmental conditions. It is responsible for the fine growth adjustments that ensure an efficient occlusion.

As clinical orthodontists we use many different therapeutic means in the hopes of altering facial growth and development. However, the underlying control methods are still clouded and in need of further research. Orthodontic and orthopedic

effects on condylar growth have been investigated by many researchers. Charlier (1968) demonstrated experimentally that appropriate orthopedic appliances may modulate the rate and the amount of condylar cartilage growth in young rats. Demonstrating that the condylar cartilage responds in a basically different manner from epiphyseal and other primary cartilages to local extrinsic factors. Likewise Petrovic (1973) found in a 4 week treatment of the rat mandible with a postnatal hyperpropulsor a highly significant lengthening of the mandible occurred.

Folke and Stallard (1966) showed that distal placement of the mandible showed changes in cellular physiology and morphology of the condyle.

Research in other joints (Trueta and Amato, 1960) showed that increases in pressure caused a decrease in the nutritional supply by decreasing the blood flow to the articular surfaces.

For years craniofacial biologists have been postulating theories as to the mode of condylar growth. All these theories involve a discussion of pressure in one way or another. For years the pressure-tension argument was the prevailing theory. That is, the growing condyle pushed against its articulation thrusting the mandible forward. Then came a conceptual revolution of sorts in the theory of the functional matrix. Central again to this theory was pressure. Here it was the "pressure release" which contributed the stimulation to the growing condyle.

The "pressure" though has never been well defined. Is it a fluid pressure, a tissue pressure, or a combination? Synovial fluid may be the medium which translates the "message" from the hyperpropulsed mandible to the growing articular surface.

The drastic increase in synovial fluid pressure when the mandible was held in a retrusive position could no doubt have an effect on the condylar growth and development. Elevated pressures could cause local ischemic changes and subsequent alterations in cellular development.

The fact that the pressure "normalized" with a protrusive positioning appliance gives an indication as to the compliability of the TMJ. That is, the increase in pressure reflects the overall increase in total tissue pressure of the joint. Its subsequent return to normal indicates an ability within the tissues to adapt to a regional change.

Further research as to the biochemical and histologic responses of the tissues concomitant with alterations in synovial fluid pressure is necessary for a further understanding of condylar growth and development.

## SUMMARY AND CONCLUSIONS

Synovial physiology, in particular synovial fluid pressure, has been investigated in many long bone joints. Not until recently has it been investigated in the temporomandibular joint. Its physiologic responsibilities include nutrition and lubrication to the articular surfaces. Changes in fluid pressure to positive values have been shown in long bone joints to be concomitant with pathological alterations of the articular surfaces.

The purpose of this study was to determine if synovial fluid pressures changed during altered mandibular position. Various functional parameters were also monitored to determine their effect on the fluid pressure.

The anumal used was the domestic pig, Sus scrofa domesticus. Using the "wick" technique six TMJ capsules were investigated. Pressure was monitored in the growing animal uninhibited by mechanical alteration and in animals with both a retruding and protruding appliance.

The findings are summarized as follows:

1. The resting synovial fluid pressure was negative relative to the atmosphere in all six joints. The mean value was -3.9 mm of Hg.
2. Pressure increased during operator manipulated jaw positions, returning to the baseline when the jaw was released.

3. There was a marked increase in pressure when a protruding appliance was placed. This pressure gradually returned to the baseline. The return is attributed to joint compliance and absorption of fluid.

4. There was a substantial rise in pressure when a retruding appliance was placed. The pressure never returned to the baseline.

5. Mastication produced a marked pressure change. The pressure changes appeared to be cyclical.

6. Possible relations between fluid pressure and pathology and growth and development were discussed.

## LITERATURE CITED


Bauer, W., M.W. Ropes and H. Waine: The physiology of articular structures. Physiol. Rev. 20: 273-312, 1940.

Caughey, D.E. and E.G.L. Bywaters: Joint fluid pressure in chronic knee effusions. Ann. Rheum. Dis., 22: 106-109, 1965.

Charlier, J.P., A. Petrovic and J. Herrmann-Stutemann: Determinisme de la croissance mandibulaire: effets de l'hyperpropulsion et de l'hormone somatotrope sur la croissance condylienne de jeunes rats. L'Orthodont. Franc. 39: 567-579, 1968.

Ekholm, R. and B. Norback: On the relationship between articular changes and function. Acta Odont. Scand., 21: 81-98, 1951.

Enlow, D.H. and D.B. Harris: A study of the postnatal growth of the human mandible. Am. J. Orthod., 50: 25-50, 1964.

Folke, L.E. and R.E. Stallard: Condylar adaptation to a change in intermaxillary relationship. J. Periodont. Res., 1: 79-89, 1966.

Gardner, E.: Physiology of movable joints. Physiol. Rev., 30: 127-176, 1950.

Geilberger, W.: Personal communication. University Hospitals, Cleveland, Ohio, 1982.

Guyton, A.C., H.J. Granger and A.E. Taylor: Interstial fluid pressure. Physiol. Rev., 51: 428-558, 1971.

Hargens, A.R., S.J. Mubarak, C.A. Owen, L.P. Garetto and W.H. Akeson: Interstial fluid pressure in muscle and compartment syndromes in man. Microvas. Res., 14: 1-10, 1977.

Herring, S.W. and R.P. Scapino: Physiology of feeding in miniature pigs. J. Morph., 141: 427-460, 1973.

Herring, S.W.: The dynamics of mastication in pigs. Arch. Oral Biol., 21: 473-480, 1976.

Humphrey, G.: On the growth of the jaw. Trans. Cambridge Phil. Soc., 1864.

Hunter, John: The Natural History of the Human Teeth, Explaining their Structure, Use, Formation, Growth and Disease. J. Johnson. 1971.

Jayson, M.I.V. and A. St. J. Dixon: Intra-articular pressure in rheumatoid arthritis of the knee. I. Pressure changes during passive joint distension. Ann. Rheum. Dis., 29: 261-265, 1970a.

Jayson, M.I.V. and A. St. J. Dixon: Intra-articular pressure in rheumatoid arthritis of the knee. II. Pressure changes during passive joint use. Ann. Rheum. Dis., 29: 401-408, 1970b.

Jayson, M.I.V. and A. St. J. Dixon: Intra-articular pressure in rheumatoid arthritis of the knee. III. Effect of intra-articular pressure on blood circulation to the synovium. Ann. Rheum. Dis., 29: 266-268, 1970c.

Krough-Poulsen, W.G.: From occlusion theory to oral physiotherapy. In: Temporomandibular Joint Problems Biologic Diagnosis and Treatment, W.K. Solberg and G.T. Clark, eds., Quintessance Publishing Co., Inc. pp. 15-19. 1980.

Levick, J.R.: Fluid transport across synovial tissue in vivo. J. Physiol., 275: 83, 1978.

McCarty, D.J.: The physiology of teh normal synovium. In: The Joints and Synovial Fluid II. Leon Sokoloff ed., Academic Press, pp. 294-312, 1980.

Mubarak, S.J., C.A. Owen, A.R. Hargens, L.P. Garetto and W.H. Akeson: Acute compartment syndromes: Diagnosis and treatment with the aid of the wick catheter. J. Bone Joint Surg., 60-A: 1091-1095, 1978.

Muller, W.: Uber den negativen luftdruck in gelenkraum. Dt 2 Chir, 218: 395-401, 1929.

Oberg, T., G.E. Carlsson and T. Ekberg: Microradiographic study of the mandibular disc in the guinea pig. Acta Odont. Scand., 24: 63, 1966.

Oberg, T., G.E. Carlsson and T. Ekberg: Morphological changes in the mandibular joint disk in temporomandibular joint pain dysfunction syndrome. Acta Odont. Scand., 52: 56-71, 1967.

Petrovic, A., N. Gasson and C. Ovdet: Growth hormone, postural mandibular hyperpropulsion and condylar prechondroblast proliferation in rat. Tenth Annual Meeting of the Int'l. Assoc. Dent. Res., Continental Div., Strassbourg, 1973a.

Reeves, B.: Negative pressure in knee joints. Nature (London), 212: 1046, 1966.

Richman, A.I., E.Y. Su and G. Ho, Jr.: Reciprocal relationship of synovial fluid volume and oxygen tension. Arth. and Rheum., 24: 701-705, 1981.

Roth, T.E.: Synovial fluid determination in the temporomandibular joint. Unpublished Masters Thesis, Case Western Reserve University, 1982.

Scheman, R.P.: Anthropoid comparisons of the anatomy of the external pterygoid muscles of the fetal and adult domestic pig. J. Dent. Res., 46: 1337-1343, 1967.

Scholander, P.F., A.R. Hargens and S.L. Miller: Negative pressure in interstial fluid in animals. Science, 161: 321-328, 1968.

Snashall, P.D., J. Lucas, A. Guz and M.A. Floyer: Measurement of interstial "fluid" pressure by means of a cotton wick in man and animals; an analysis of the origin of the pressure. Clin. Sci., 41: 35-53, 1971.

Toller, P.A.: The synovial apparatus and temporomandibular joint function. Brit. Dent. J., 111: 355-362, 1961.

Truetta, J. and V.P. Amato: The vascular contribution to osteogenesis. III. Changes in the growth cartilage caused by experimentally induced ischemia. J. Bone Jt. Surg., 43B: 571-587, 1960.