A STUDY OF RATE OF MOLAR MOVEMENT
AS RELATED TO FORCE

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TABLE OF CONTENTS

I. Introduction....................................page 1

II. Review of Literature....................................page 2

III. Material and Methods....................................page 8

IV. Findings....................................page 11

V. Discussion....................................page 13

VI. Conclusion and Summary....................................page 16

VII. Bibliography....................................page 17

VIII. Graphs....................................page 18-21

I. Introduction

The 1969 orthodontic class undertook to continue a study of tooth movement begun by the previous class[1]. In the preceding study some of the findings did not support three of the concepts currently employed in orthodontics, like the optimal force theory, the differential force theory and the plateauing of tooth movement.

The main objective in this part of the study is: a) to measure and record the rate of individual tooth movement (molars) for different forces, b) to test the differential force concept for bodily moved teeth, c) to measure the loss of "anchorage" when cuspids are retracted bodily.

When trying to formulate concepts about the cellular response of bone for a known force, it is essential to obtain bodily tooth movement. Then every square mm of root surface, on the pressure side, is pressed toward the bone surface with an equal force. If tipping and rotation occurs, as happened for most teeth in the 1968 study, the force distribution from the root surface against the bone is changing from one area of the root to the next. The actual force on a certain area of bone is then difficult to afirm.

In order to obviate factors like tipping and rotation, which are difficult to account for, an appliance was made to maximize the likelihood of bodily tooth movement.

Review of Literature

It is difficult to discuss rate of tooth movement, mm per unit of time, in a meaningful way, without taking the surrounding tissues into consideration. Therefore, some of the classic histology of tooth movement will be included in this review.

Celsus, about 2,000 years ago, knew that an external applied force was able to move a tooth.[2] Since that three theories have tried to explain why orthodontic tooth movement is possible. Two of them came about in the eighteenth century, Flourens (1841) pressure theory and the theory of Kingsley[3] that bone could be bent due to its elasticity and compressibility. The third theory is of recent date. Bien[4] explains the resorption as due to escape of oxygen on the pressure side which supposedly should stimulate resorption of bone.

Up to present time Flourens pressure theory has offered the best explanations to the understanding of the different events when a tooth is moved by orthodontic means.

Sandstedt[5], in 1904, was the first who systematically experimented on animals with orthodontic appliances and investigated the results histologically. In a three weeks experiment on dog he moved the maxillary central incisors three mm lingually by means of a labial bone. On the basis of his findings he was able to describe what has become the classic picture of histology of tooth movement: Resorption of bone on the pressure side by weak forces, and apposition of new bone on the old bone surface on the tension side for both strong and weak forces. He also coined the expression "undermining" resorption[5]. By the use of strong forces the PDL was compressed, at first, on the pressure side, and no resorption could take place, because the crushed area had become necrotic. But an active resorption took place from the neighboring marrow spaces of the alveolar bone. Not before all the necrotic material was removed could the tooth continue to move. The root surface was unchanged. The axis of rotation was thought to be in the lower half of the root.

Oppenheim[6-10], in 1911, reported findings after experiments on baboons which disagreed with those of Sandsedt. A large area of bone surrounding the tilted tooth was transformed into new spongious bone before resorption could take place on the pressure side and new bone was formed on the tension side. The newly formed bone trabeculae were in the direction of the pull. The axis of rotation was at the apex.

Schwarz[11], in 1932, and Gottlieb and Orban in 1931[12], experimenting on dogs report histologic findings similar to Sandsedt. Schwarz describes the "four biologic effects", and states that orthodontic forces should not exceed the capillary blood pressure (20 to 26 gr. per square cm root surface). Stuteville[13] claimed in 1938 that the magnitude of an orthodontic force was not as important as the distance through which it was active. The force should not be active for a great enough distance to obliterate the blood vessels in the PDL.

Reviewing the orthodontic literature on the relationship between force and rate of tooth movement one finds that not much information is available.

Storey and Smith[14] reported very conclusive findings from a study made on five patients. The mandibular cuspids were retracted with precalibrated helical torsion springs. Heavy (400 gr. to 600 gr.) and light (175 gr. to 300 gr.) forces were applied and adjusted weekly by comparing deflexion in the spring with the load deflection curve for that spring. The tooth movement was measured intraorally from a fixed reference point in the maxillary arch. On the basis of this experiment the "optimal" force by which the mandibular cuspids may be retracted, without forward movement of the anchor teeth, was found to be 150 to 200 gr. (on the average 0.75 mm per week). On the other hand, with forces in excess of 300 gr. the anchor teeth moved, but not the cuspids. All the cuspids, however, were moved by tipping, as evidenced from lateral head plates.

Burstone describes three phases[15] of tooth movement when the applied force is constant: 1) an initial phase, 2) a lag phase and 3) a post lag phase. The initial phase, which is characterized by a period of rapid tooth movement, is contributed to compression of the PDL. In the lag phase the tooth moves very little if any. A number of explanations could be postulated to explain this. Several investigators have suggested hyalinization.[5,6,11,16] Another explanation[15] might be that the lag period represents the time required for the thicker compact bone of the lamina dura to be resorbed, and hence the rate of tooth movement is reduced. Contradictory to an "optimal" force, Burstone[15] states: "...over a long time interval, the average rate of movement for heavy, continuous forces may be greater than those observed for lighter continuous forces." This observation does not support the observation of Storey and Smith, who found that with forces above 300 gr. the cuspids did not move, only the anchor teeth moved.

Burston, however, also reports findings,[16] where an "optimal force range" was observed. In a study with 22 patients the retraction of upper anterior teeth by tipping was observed to be optimal where forces of the magnitude 50-75 gr. were applied. The total amount of tooth movement during a 27 day period varied from 0 to 3.3 mm. The degree of movement was observed from lateral head plates.

Andreasen and Johnson[17] found support for the hypothesis that more force in a certain period of time gives more movement than a smaller force during the same time interval.

In their study of rate of tooth movement in 16 girls between the ages of eight to ten years using eccentric head gear (400 and 200 gr.) of the Kloehn type to the maxillary first permanent molars. On the average during the twelve week period, the teeth in the 400 gr. force group moved approximately two and one-half times as far as the teeth where a 200 gr. force was applied. No comment is given to whether the teeth were moved by tipping or by bodily movement.

The graph of rate of movement in their report[17] gives some support to the appealing thought that the relationship between force and rate of movement is a more linear one.

Reitan[18-29], with the most extensive experience in this field, has reported several well controlled experiments initially on dogs and later on humans. Teeth, to be extracted for orthodontic reasons, were first used in an experiment, and then extracted with a small area of the surrounding tissue (PDL and alveolar bone) for histologic studies.[19]

His findings revealed an initial period of tooth movement due to gradual compression of the PDL that may last from four to seven days, and a period of hyalinization[20] during which no movement took place. This phase may last from four or five days and up to two months or more in experimental animals that exhibit a high bone density (few marrow spaces). During the secondary period there is mainly direct resorption and the tooth will continue to move. Reitan states[28] that the initial hyalinization is difficult to avoid, but with proper force control it should be possible to avoid further hyalinization after the initial zone has been eliminated.

Resistance against tooth movement[26] may also be caused by the streching and displacement of the fibrous tissue, the free gingival fibers and the alveolar crest fibers, the transeptal fibers and the elastic fibers found among these supra crestal fibers.

Reitan describes further bodily movement as favorable[26] because the force is distributed over the whole side of the root, and there is less tendency to formation of compressed or cell free areas. Direct bone resorption takes place along the bone surface.

A recent publication by Utley[30] reported findings on cats. On rate of tooth movement he found great individual variation for forces of the same magnitude. This is in agreement with most authors. Another observation was that both right and left cuspid of the same animal moved equal distances, regardless of the different magnitudes of force delivered by the right and left appliance. Utley states: "Within the limits of this investigation it was demonstrated that the rate of cuspid tooth movement in young cats was not related to the magnitude of the orthodontic force delivered. Tooth movement was the result of a specialized activity of the investing alveolar bone which occurred in response to an applied force but was independent of the magnitude of that force." A similar statement in the orthodontic literature is unknown to the author.

Material and Methods

The present study was conducted on three females and three males in the age group twelve years ten months to fifteen years ten months. They included three class I crowding and three class II division 1 malocclusions.

The criteria for selection were: a) eruption of all permanent teeth except second and third molars, b) the necessity for extraction of the four first premolars for retraction of all four cuspids, as part of routine orthodontic treatment, c) the agreement of each patient to be available for records and appliance adjustment three times per week for eight consecutive weeks.

Tantalum implants, three in the maxilla and the mandible on the right side, and two in each jaw on the left side, provided fixed landmarks after the method of Björk[36].

For full description of the appliance used in this study, see Miller[31].

All four appliances were cemented in one appointment. After the teeth had settled for two weeks, right and left open mouth head films were taken with the head holder rotated 25 degrees toward the film so that the buccal segment of each arch was approximately parallel to the film. Head plates were taken: a) before the first activation b) after three days c) after four weeks d) then weekly to the end of the study. Sectional alginate impressions were taken of each quadrant: a) before each activation b) 45 minutes after the elastics were removed at the end of the study c) after three days.

The appliances were activated with elastics, see Odom[32], three times per week.

A force of approximately 300 gr. was applied to the two right quadrants, serving as controls. Varying forces from 100 to 1500 gr. were applied to the two left quadrants.

The space closure data (at the crown) were measured from the casts with a sharp pointed Boley gauge, between landmarks (a premade notch in the cuspid and molar band) on the cuspids and molars. Other landmarks were also used to test their reliability. The distances were measured to the nearest 0.1 mm. At least five measurements per quadrant were duplicated to determine measurement error.

To determine the type of movement, whether a tooth had moved by tipping or bodily, the first and last headfilm were superimposed on the implants. Criteria for selection were: a) all three implants (two on the left side) in each quadrant should superimpose within 0.2 mm. b) the movement of the crown and apex on the same tooth (separately measured from one of the implants) should agree within 0.2 mm c) the total space closure measured on casts and headfilms should agree within 0.5 mm.

Of the total number of 48 teeth, 16 cuspids and 3 molars could by the above mentioned criteria, be said to have moved bodily. Bodily movement is essential, because only then is the force evenly distributed along the root surface, and the bone cell response can be tested for a certain force. When tipping occurs, varying force magnitudes are applied to different areas of the bone surface, and the actual force applied to a certain area is unknown.

To be of value in this study of rate of molar movement in relation to force, only the molar should have moved (bodily), not the cuspid (upper molars discarded due to the head gear). To be able to test the concept of "differential force" either the cuspid or the molar or both of them may have moved bodily. All upper quadrants had to be discarded because of the use of head gear to conform to the requirements of orthodontic therapy for the patient.

IV. Findings

I. Rate (pattern) of movement

When the criteria established in materials and methods have been met, only one molar (plus second bicuspid) was found in which the anchor unit moved bodily and the cuspid did not move.

As described in materials and methods, the definition for bodily movement allowed for ± 0.2 mm tipping (S.E. measures on radiographs is 0.2 mm) In spite of the fact that molar movement plotted in Fig. 1 was measured from the casts (S.E. measures 0.078 mm), the transfer from the radiographs indicates that measured movement less than 0.2 mm could be tipping (compression of the PDL, bone bending and measurement error). Thus bodily movement cannot be said to have occurred until the fourteenth day. From that day forward the rate was more or less constant. It did not deviate from a straight line expanded to include 2 S.E. measures as derived from the casts.

II. Differential movement

The three quadrants that fulfilled the requirements and gave bodily movement of both cuspid and anchor unit are plotted in Fig. 2. The cuspid movement is plotted along the vertical axis, and the molar movement along the horizontal axis.

No distinct pattern is to be observed, only failure to conform to the concept of differential force as usually described.[33,34]

III. Loss of anchorage

In Fig. 3 are eight molars plotted. Three of these show bodily movement, and five molars (anchor units) had moved by tipping. Of six anchor units where forces up to 354 gr. had been applied, only one-half of them moved bodily. (Some of the molars when higher forces were applied, were discarded not only because of tipping, but also due to fifficulties whith the superimpositioning on the implants (see materials and methods)).

At least for this initial period of cuspid retraction it seems like less "anchorage" is lost when the anchor units are kept upright (moved bodily).

Fig. 4 contains the molar movement plotted in Fig. 3 plus the distance through which the canines have been retracted (in the same quadrant).

It should be noticed that all the canines in the graph were retracted bodily, where as the molars exhibited both tipping and bodily movement. No control is available (cuspids retracted by tipping), but it may be more desirable clinically to tip the cuspids back.

V. Discussion

It was mentioned in the findings why the rate of movement (pattern) for the bodily moved molar, could be a linear one. The findings of Reitan[20] and Burstone[15] cannot directly be compared with the findings in this study, because they were observing pattern of movements of tipped teeth. The initial movement (Fig. 1) during the first three days may be due to slight tipping. It might also be due to compression of the PDL. A recent study suggests, however, that this initial movement is more due to compressibility of bone[35]. Baumrind reports a maximum of five per cent compression of the PDL in spite of excessive forces in a study on rats. The teeth and their surrounding structures may respond differently in rats than in humans to an applied force, but to what extent, is so far not established. The study of Baumrind strongly implies that deflection of the investing alveolar bone can be produced by forces lower than those required to produce a gross reduction in the width of the PDL. Extending this thought one step further, this would imply that the cell free areas, or zones of hyalinization, first seen by Sandstedt[5], has been incorrectly interpreted. Baumrind did not observe hyalinized areas. The reason for this may be that his experimental animals were sacrificed before any zone of hyalinization could be produced (72 hours). Reitan[20] does not observe the hyalinized areas before the fourth to the seventh day. Baumrind has, however, very good evidence for the occurrence of alveolar bone deflection. Undermining resorption may then be interpreted as a remodeling process due to new zones of stress along the trabeculae in spongious alveolar bone.

(This may be particularly true in young individuals where the bones are less heavily calcified). The force applied to a tooth and transferred through the PDL to the investing bone, becomes a stimulus for altered biologic activity of cells lying purpendicular to the stress lines. The altered activity of these cells modifies the shape and internal organization of the bone to accommodate to the force upon it. This may be considered as an application of Wolff's law to the specific conditions of tooth movement by orthodontic means.

As regards continuous, bodily movement, disregarding the "initial phase" as measurement error, tipping, compression of the PDL and bone deflection, the individual difference in biologic response to applied force is not merely to be found along the mm scale (vertical axis in Fig. 1) but along the horizontal time axis. It is a matter of how soon the bone cells respond to the evenly distributed force from the root surface. The individual variation is thus dependent on the state, in which the bony tissue surrounding the tooth, is to be found. Bone, especially in young individuals, is not a static tissue, but one of continuous and rapid turnover of both the cellular and inorganic fractions.

The pattern in which a tooth moves is thus more dependent on the type of applied force, whether it causes the tooth to move bodily or by tipping. By tipping, the tissue response is in the "initial period" (Reitan[20] and Burstone[15]) of more mechanical nature (bending of bone). By bodily movement much higher forces are needed before this becomes a major factor.

One could theorize, that when teeth are moved by the application of heavier forces, two phenomena are involved to give higher rate of movement:

a) surface resorption (on the bone surface toward the PDL) and

b) resorption and apposition along the stress lines to accomodate to the deflection.

From this point of view it is understandable that some investigators[1,17,30] have failed to make observations that support the currently employed consepts of "differential force"[33,34] and "optimal force"[14]. A tooth will by bodily movement, to a certain degree also by tipping, until deflection of the archwire and friction between the bracket and archwire becomes a problem, move at a higher rate when higher forces are applied. As regards differential force, both teeth will move at a higher rate when higher forces are applied. The cuspid will move faster than the anchor unit because the force per unit area of root surface is higher. That some times only one of the two teeth moves (in the observed period of time) can be explained by the state of biologic activity in which the surrounding tissues of the two teeth are to be found.

VI. Conclusion and Summary.

a.) The most consistent observation in this study, is the great individual variation in response to applied force

b.) Because of this, no optimal force range could be observed for either molar or cuspid movement.

c.) Anchor units seem to move a greater distance (loss of anchorage) when tipped, than when moved bodily for a certain force.

d.) Initially cuspid crowns may be retracted easier when tipped back (no controls).

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Fig. 1

The Pattern of Molar Movement

(Bodily)

patient H.T.
lower left quadrant
force - 132 grams

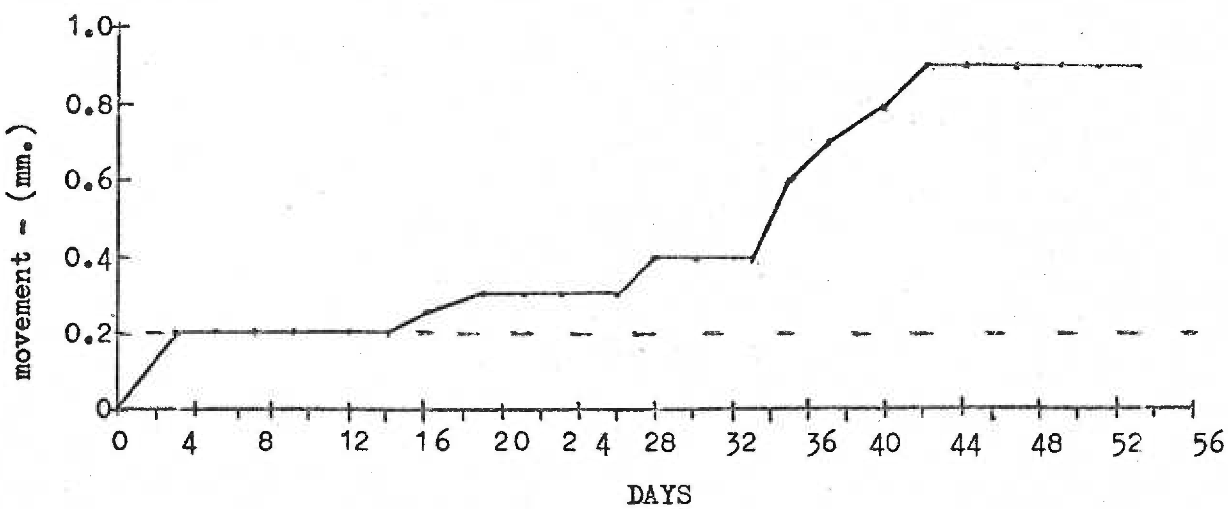
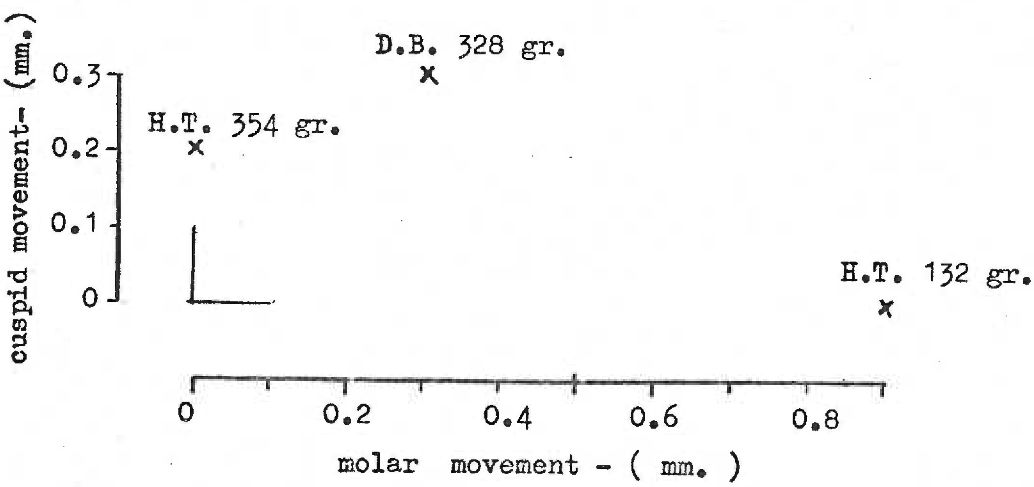


Fig. 2

" Differential Force "

Relationship Between Cuspid And Molar Movement

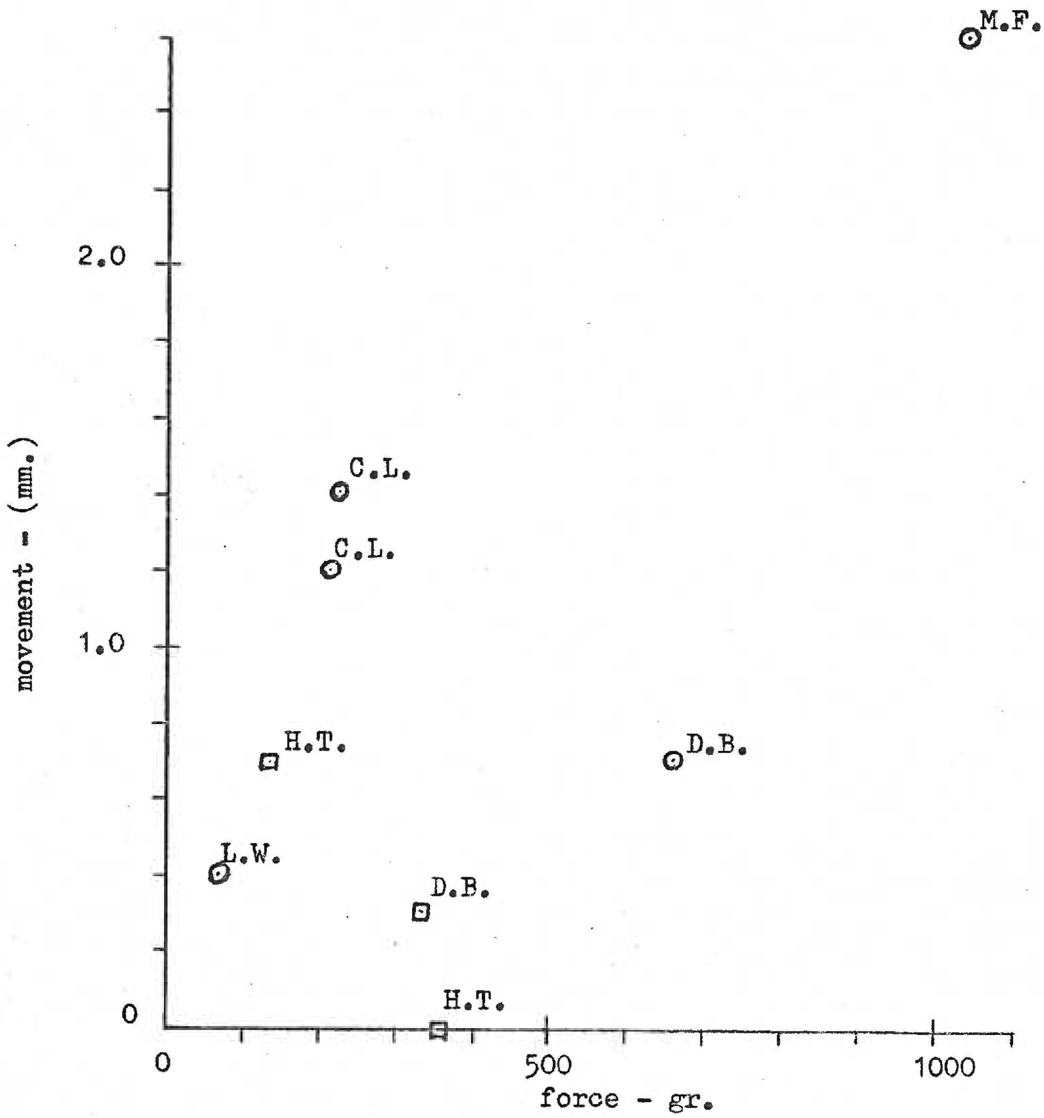


patient H.T.
force - 354 gr. lower right quadrant
force 132 gr. lower left quadrant

patient D.B.
force 328 gr. lower right quadrant

-Fig. 3

Molar Movement As Related To Force

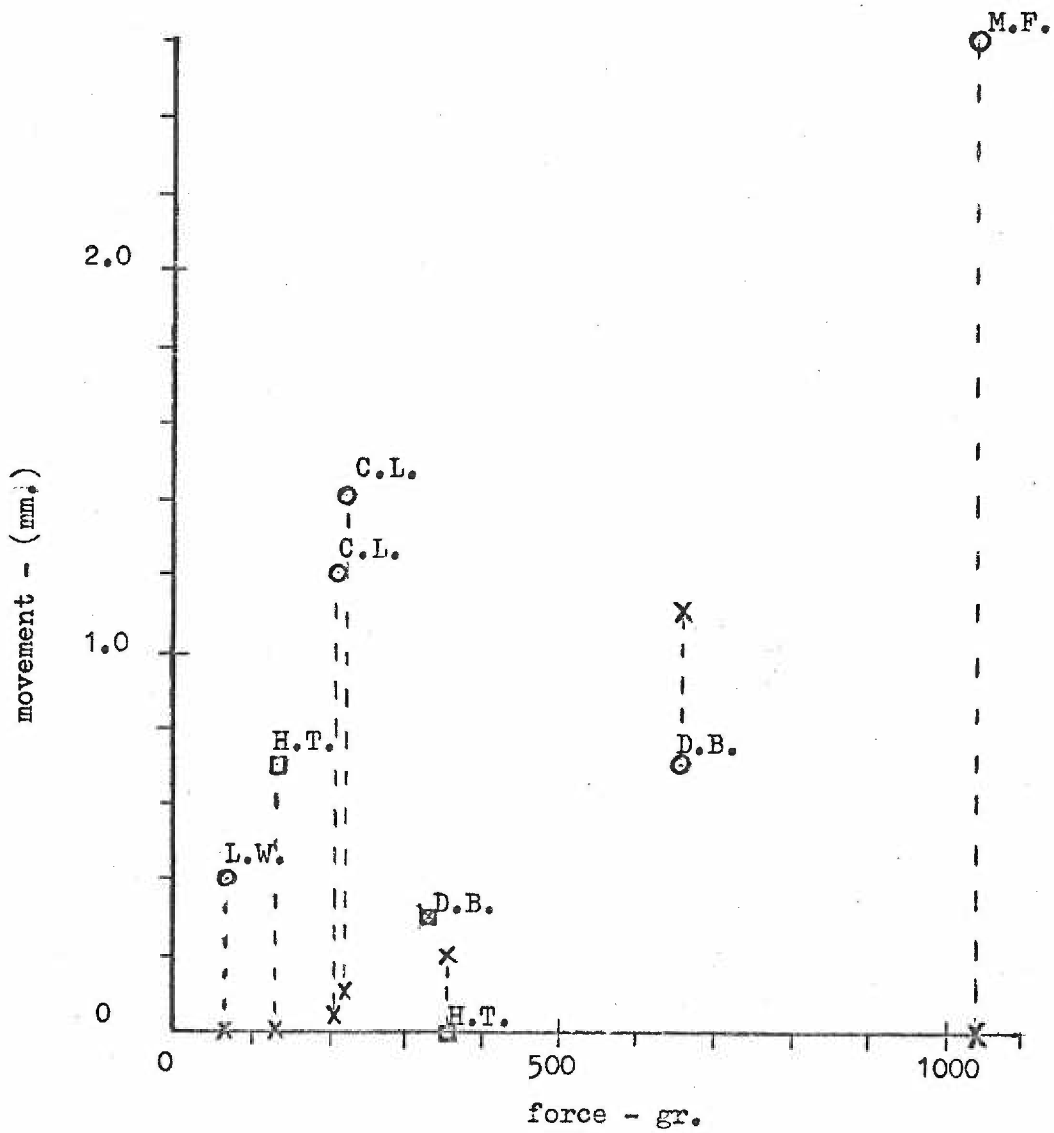


Bodily movement - □

Tipping - ⊙

Fig. 4

Cuspid And Molar Movement As Related To Force



Bodily movement of molars - □
Tipping of molars - o
Bodily movement of cuspids- X