THE RELATIONSHIP BETWEEN
ANCHORAGE AND ORTHODONTIC
TOOTH MOVEMENT

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INTRODUCTION

During the last several centuries various theories have been proposed to explain the biologic response of teeth subjected to various types of forces. These forces may result from occlusion, perioral musculature, muscles of mastication and tongue, tooth eruption or be induced by dental appliances.

Early in this century (1901)[1] the first histologic study of the osseous response of alveolar bone of dogs' teeth subjected to appliance forces was reported. This work was followed by another similar study in 1911[2]. Then, a lag exists in our literature until the 1930's[3]. This was followed by a flurry of controversy over rather minor points in the original papers. Essentially the early papers reported a response of alveolar bone to pressure as resorption on the leading side and bone apposition on the following or tension side. However, one problem in tooth movement is that of quantitating the relationship of force applied to the tooth and the resulting rate of tooth movement.

Various theories have been proposed to explain the tooth movement phenomena. Prior to histologic studies, Schwalbe and Flouren (1841) [2,3,4] proposed a pressure tension theory of resorption and apposition, similar to that in which we know today...Also, in this time period, Kingsley[5] (1880) believed that tooth movement was due to the elasticity, compressibility and extensibility of bone and that the alveolar process bends anterior to the moving tooth. Sandstedt[1] provided the first histologic evidence of pressure, tension and furthermore coined the term "undermining resorption" for occasionally observed marrow space osteoclastic activity adjacent to the pressure site. Oppenheim's (1911)[2] classic histologic study essentially substantiated the earlier work of Sandstedt, but also brought in many clinically empirical statements which were not proved by his experiments, though this paper was not critically reviewed until 1928 by Stallard[6]. Schwarz[3] in 1932 did a quantitative and histologic study using a range of forces from 3.5 grams to 67 grams on dog teeth and concluded that forces in the range of capillary blood pressure, "20 to 26 gm/cm^2" produced optimal tooth movement.

In more recent years Storey and Smith (1952)[7] have proposed an optimal force theory based on root surface area of posterior teeth resisting movement when retracting cuspids were subjected to an "optimal" force. Reitan (1957)[8] has probably conducted the largest number of histologic studies to date and proposed a resistence to movement due to "hyalinized" periodontal ligament when teeth are subjected to heavy force tooth movement mechanics. Tweed[9] utilized some of this histologic information to develop a theory of anchorage resistence based on the formation of osteoid immediately following tooth movement (tip-backs). Burstone (1962)[10] classifies tooth movement into an initial phase, lag phase and post-lag phase time period. Lastly, the work of Bien (1966)[11] suggests a hydrodynamic damping theory of tooth movement.

To date, none of these various theories have proven clinically applicable in that a given force value does not move a tooth at a predictable rate[12, 13].

The purpose of this study is to test the hypothesis of preparing posterior teeth to resist anterior movement by tipping the anchorage units distally prior to placing an anterior force upon them.

REVIEW OF LITERATURE

As of today, only three distinct theories can be identified which explain the mechanism of tooth movement.

The first is the theory of bone resorption and was first expounded by Schwalbe and Flouren [2,3,4] and stated that the alveolar bone is resorbed on the side of pressure while new bone is added on the opposite side of the stress. The second theory can be identified as the theory of bone elasticity as originated by Kingsley[5] and further elaborated upon by Farrar[14]. They stated that the movements of the teeth were the result of compressibility and flexibility of the alveolar bone. Recently, Bien[11] offered a third hypothesis where he stated that minute free gas bubbles which form in the interstitial tissues creating a favorable local climate for bone resorption. This may be called a hydrodynamic damping theory.

The first investigation of tissue changes in dental literature was a histologic study published by the Swedish investigator, Sandstedt, in 1901 in his book, "Nagra Bidrag Till Tandregleringens Teori"[1]. Later on (1904) Nordisk Tandlarkaretidskrift" published an article in German based on the same investigations[1a]. Sandstedt constructed a labial arch wire with which he moved the six maxillary incisors of a dog lingually by means of jackscrews. The forces used were not measured, nor were they constant. The histologic examination of the jaws at the end of this experiment revealed the presence of bone resorption on the side of the alveolar wall toward which the teeth had been moved, and the formation of new bone trabeculae arranged in the direction of force on the opposite side. Sandstedt was the first to use the term "undermining resorption" and the axis of rotation was found to be in the lower half of the root.

Ten years after Sandstedt's publication, Oppenheim[2] published a paper describing the histological appearance of the periodontal ligament under pressure. His findings led him to slightly different conclusions than those observations of Sandstedt. The reason for this diversity of interpretation may primarily consist in the fact that his experiments were performed on a different material, namely, deciduous teeth of young baboons. He observed resorption on the pressure side and bone building on the stress side. His sections showed bone building on the alveolar surface opposite the pressure area with the spicules of bone arranged parallel with the line of force. The spicules of bone on the stress area were also parallel with the line of force. He reported necrotic areas produced in the peridental membrane on the pressure side when heavy forces were used. No data concerning the exact magnitude of forces used or the rate of tooth movement was presented; however, on the basis of his findings, he stated that the tissue reaction during orthodontic movement implies transformation of the entire bone architecture. Thus he considered his findings as an "indubitable refutation of the pressure theory". He disagreed with the findings of Sandstedt in the fulcrum of rotation of the tooth, and he stated that the fulcrum was at the apex.

Later publications[15, 16] continued to deal with histologic interpretation of orthodontic tooth movement and Oppenheim introduced the following principles in orthodontic movement of teeth:

1. Excessive force applied to a tooth will bring about thrombosis in the periodontal membrane.
2. Damage of the periodontal membrane interferes with the production of osteoclasts, bone resorption and orthodontic tooth movement.
3. Excessive force applied intermittently which produces "jiggling" of the tooth is conducive to root resorption.

4. Teeth can be moved by gentle forces over great distances without root resorption.

He states that only nature can perform biologic tooth movement, such as during eruption and growth and in the physiologic mesial drift throughout life. No such biologic tooth movement can be obtained by means of orthodontic appliances; it is not possible to produce it artificially. In 1944[17] he still advocated the use of light forces for "physiologic tooth movement" and frequent rest periods are to be allowed.

In 1932 Schwarz[3] performed two experiments involving tooth movement in dogs and described the histologic picture. He was probably the first one who related the amount of force used and the reaction of the surrounding tissues (periodontal membrane, alveolar bone and root of the tooth). He made a quantitative evaluation of the orthodontic forces, which he divided into 4 degrees. Based in his observations, he stated "that biologically the most favorable treatment is that which works with forces not greater than the pressure in the blood capillaries. This pressure in man as well as in most mammalia is 15 to 20 mm. Hg. and it is about 20 to 26 grams for 1 sq. cm. surface", i.e., light continuous forces constitute the best principle for orthodontic treatment.

The first papers recording the results of human experiments were published by Grubrich in 1930 and by Herzberg in America in 1932[4]. The teeth commonly used in the investigation of tissue changes due to orthodontic treatment in man are premolars which were indicated for extraction in the orthodontic treatment plan. Herzberg[18] placed an orthodontic appliance and studied its surrounding tissues histologically. He found that adjacent to the tooth spicules of bone were formed on the tension side, and they were arranged parallel to the direction of the force.

In 1937 Stuteville[19] concluded from both human and dog experiments that the magnitude of an orthodontic force was not as important as the distance through which it was active in minimizing injuries to the dental unit. He also concluded that the important factors in the injuries caused by orthodontic force are:

a. The amount and type of force.
b. The distance through which the force is active.
c. The forces other than those exerted by the appliance[20].

Skillen and Reitan[21] in 1940 contributed further to our understanding of experimental rotation of teeth. Their work on dogs demonstrated compression and resorption during rotational tooth movement and they stated that the most important factor in tooth movement was the time of application. They found more rotation in five days with lesser force than in three days with greater force.

In 1950 Moyers[22] and Moyers and Bauer[23] stated "that the periodontal membrane acts as the tooth's natural shock absorber" and "the maintenance of good capillary function in the periodontal membrane is of prime importance to the orthodontist since an adequate nutrient blood supply is necessary to bring about the genesis of osteoclasts and osteoblasts". Finally, they recommended the use of light-intermittent forces.

About this time, many investigators made an attempt to measure more accurately orthodontic forces. In 1952 Storey and Smith[7,24,25] published their studies on the relationship of the rate of tooth movement to the force applied and reported very conslusive findings from their study made on five patients from 12 to 15 years of age involving the retraction of mandibular canines. Using precalibrated helical torsion springs to the cuspids and the second premolars and first molars as anchorage teeth, they obtained results which showed a marked difference in tooth movement between the light (175-300 gram) and heavy (400-600 gram) springs. From their results they concluded that there is a specific range of forces for optimal tooth movement, optimal referring to that force which produces the most rapid rate of tooth movement. This optimal force did not produce any discernible movement of the molar anchor unit during the period that these experiments were conducted. This force range for moving the canine distally extends from 150 to 200 grams. By increasing the force above this optimum range, the rate of the canine decreases and finally approaches zero. The maximum rate of mesial movement of the molar anchor unit occurred in the high range of force values, 300 to 500 grams. When the force was below 150 grams for the canine and below 300 grams for the molar, neither tooth moved appreciably. With values greater than 300 grams there was no appreciable movement of the canine and an appreciable movement of the molar anchor unit. In 1954 Storey[26] still stated that "the application of heavy orthodontic force will move anchor teeth as well as temporarily damaging the tissues surrounding the tooth".

From 1951 to 1964 Reitan[27,28,29,30] performed extensive experiments in tipping tooth movement in dogs and in humans. In 1957[29] he reported an experiment in which he applied a continuous force on maxillary first bicuspids of human subjects where measurements were made of the force applied and the distance the teeth moved. Tooth movement occurred for six to eight days and then ceased for two to four weeks. Reitan describes that this plateau as caused by the formation of a zone of hyalinization, a cell free area of PDM which is not removed by osteoclastic resorption. He theorizes that the bone removal must occur by the undermining resorption process which causes a delay in the tooth movement pattern. He stated that "osteoclasts will remove the bone around the cell free area. In this case bone resorption will continue for a few days more until the cell free area is completely undermined, then the tooth will suddenly move". He found that the average time required for elimination of this compressed area by "undermining resorption" varies from two to four weeks. He also indicates that "the duration of an indirect resorption process is influenced by the length of the root. The force exerted in a tipping movement performed with continuous forces will create compressed cell free areas in the periodontal membrane more frequently than in a bodily movement". He reported some estimated values for tooth movement as follows: 150-200 grams for continuous bodily movement of upper cuspids, 100-200 grams for lower cuspids, and 25 grams for extrusion of individual teeth.

In 1956 Begg[31] advocated the use of light forces for tooth movement and says that "the force found by Storey and Smith are most favorable for tooth movement, from the standpoints of rapidity and tissue tolerance". In his book[32] he stated, "I have been applying the principles of optimal and differential forces in my clinical practice since 1938".

Reitan[33] in 1962 proposed to investigate in humans if the stabilizing effect obtained by distal tipping of molars increases resistance against mesial movement (anchorage preparation) and also if this resistance should be caused by osteoid tissue formed on the mesial side of the roots during distal tipping. He concluded that "osteoid tissue created during distal tipping of anchor teeth cannot be considered a factor of any significance in stabilizing anchor teeth against mesial movement" and finally said that "calcified osteoid when subjected to pressure is more readily resorbed than old bone".

Other proponents of light optimal forces are Jarabak and Fizzell[34] based on the most effective pressures which they calibrated to be between 2 and 2.5 grams/cm^2 of projected root area. They arrived at these values using the clinical guides of pain, mobility and jaw reflex. From these figures they formulated a table of numerical force values for optimal tooth movement. However, these force values have never been substantiated by any other investigations or experimental designs.

About this time several investigators made an attempt to measure orthodontic forces more accurately and their experiments do not agree with the light and optimal force theories. Burstone[35,36] recognizes the extreme difficulty of correlating forces and tooth movement due to the great number of variables that can influence the recorded rate of tooth displacement. He classifies tooth movement into three phases. The initial phase is very rapid, lasting a few days, and represents the tooth displacement within the PDL. The lag phase next occurs with little or no movement. He considers this as possibly an indication of hyalinization. In the post-lag phase the tooth begins moving again. He concluded that "there are no gross differences in response between light and heavy forces if the absolute displacement is measured after two or three days or if the average rate is calculated for a longer period of time". In addition he states that over a long enough time interval, the average rate of movement for heavy continuous forces may be greater than those for lighter forces.

Bien and Ayers[37] used the upper central incisors of the rats in their experiments. Pressure was exerted on the periodontium exceeding capillary blood pressure. Upon sacrifice of the animal, the experiment was repeated. They found that the circulatory system plays a large part in the support of a tooth in its socket, or saying it differently, teeth are fluid-cushioned. They state that during mastication formation of gas bubbles takes place due to the application of force which is dampened by the squeeze film, the squeeze film being re-fed as the force is released. When prolonged forces such as orthodontic forces act on the tooth, they suggest that after the squeeze film is exhausted without replenishment that gas cavitation occurs past the constriction of the capillaries and small vessels where they are caught between the tightened periodontal fibers. They suggest that minute free gas bubbles form in the interstitial tissues resulting from gas diffusion through the walls of small vessels. They concluded that difficulties and failures in tooth movement result from the rate of application of forces to teeth rather than the magnitude of those forces. Based on the hydrodynamic nature of tooth support, they say that forces should be applied in a gradual manner on a tooth to be moved. The magnitude and direction of force application should be governed in each patient individually by clinical judgment and experience.

Tweed[38] states that "anchorage preparation in my opinion is the most important step in clinical orthodontics". To substantiate his mechanical approach to anchorage he proposes that by distal tipping of the posterior teeth, "like tent stakes in the ground" they become more stable and better able to resist forward displacement. Later he states that "Reitan concludes that this new calcified osteoid bundle bone does not enhance the resistance of the tooth to mesial movement when force is applied...does not make the necessity for anchorage preparation obsolete". Nevertheless, he concludes that anchorage preparation can be proved by a mechanical viewpoint rather than physiological.

In 1967 Andreasen and Johnson[39] reported an experiment where maxillary first molars were distally moved by cervical traction with eccentric headgear. Forces of 400 and 200 grams were applied on opposite sides of the same maxillary arch. The 400 gram force moved teeth an average of two and one-half times further than the 200 gram side.

Utley[40] in 1968 studied the distance and rate of tooth movement in cats using light (40-60 grams), medium (135-165 grams) and heavy (400-560 grams) forces. On rate of tooth movement he found great individual variation for forces of the same magnitude. Another observation was that tooth movement was the same on both sides of each animal regardless of the different forces applied on each side. Each animal showed its own rate of movement regardless of the magnitude of the orthodontic force applied.

Hixon et al[12] working in young boys and girls (12 to 15 years of age) who required removal of four first premolars and distal retraction of the canines could not find any data to support the theory of optimal force or differential force theory. They postulate that higher forces per unit root area increase the rate of biologic response and say that "the rapid tooth movement of the light forces appears to be the result of tipping which produces a high load at the alveolar crest". In 1970 Hixon et al[13] made a similar study and they state that it is almost impossible to move teeth without tipping due to the mechanical flexion inherent in all arch wires. They found large differences (two times greater) between patients with regard to root area, time of beginning tooth movement and rate of tooth movement. As in the previous study, they found that the higher forces tend to produce more rapid movement than lighter ones. They suggest that tip-back bends or angulated brackets minimize anchorage loss by overcoming the inherent flexion of the arch wires. Also, when the applied forces exceed 100 gm.

they classified two distinct phases of tooth movement:

1. An initial mechanical displacement of tissues, deformation of alveolar bone and compression of the PDL.
2. A delayed metabolic response of the connective tissue (bone resorption and tooth movement).

Baumrind[41] studied in rats the dimensional and metabolic changes incident to the movement of the maxillary first and second molars. He reported that according to the theories of Kingsley and Farrar, he found that alveolar bone deflects under load and that deflection can be produced by forces lower than those required to produce consequential changes in PDL width. This finding does not agree with the results of Bien and Ayers[37] where they say that tooth movement occurs only through changes within the PDL. He concludes that he may explain his "bone bending" hypothesis with the following examples:

1. The relative slowness of en masse movements and the relative rapidity of alignment of crowded anterior teeth.
2. The rapidity with which teeth can frequently be moved into an extraction area.

3. The relative rapidity of tooth movement in children in whom bone is less heavily calcified and more flexible than in adults.

Thus, it can be seen that there is no universal agreement among investigators regarding optimal force and rate of tooth movement.

MATERIAL AND METHODS

Nine patients were used in this study, six girls and three boys, caucasians, ranging from age 12 to age 15. They were selected because the correction of the malocclusion required the removal of all four first bicuspids and the retraction of the cuspids. Only the lower arch was utilized in order to not jeopardize the position of the maxillary molars for later orthodontic therapy. Each patient agreed to be available for records and appliance adjustments at least once a week for eight to ten consecutive weeks.

The cuspid retraction appliance was designed in an attempt to retract cuspids bodily and without rotation[42] (Figures 1-2). Bodily movement without rotation is desirable in a study of this type because theoretically it distributes forces uniformly along the root surfaces and the unknown force variables of tipping are eliminated. Coil springs (Unitek Pace Multicoil) of known force values were used in an effort to move the teeth with a somewhat uniform and controlled force. The springs were precalibrated on an Instron tensile testing instrument through a definite range of deflection. Force values ranged from 100 grams to 1,000 grams. The springs were then recalibrated after appliance removal to detect any degree of permanent deformation or set, which may have occurred during the experiment.

To provide reliable fixed radiologic landmarks for the measurement of tooth movement, three tantallium implants were placed in the maxilla and three in the mandible of each patient, one in each molar region and one in the midline[43].

The analysis of tooth movement was to be evaluated by a three-dimensional cephalometric technique[44]. However, mechanical failures with the x-ray machine halfway through treatment made it impractical to employ this technique. As a back up technique, open mouth head films had been taken at the beginning and at the end of the study. For these the headholder was rotated 25 degrees toward the film so that the posterior segment of each side of the arch was approximately parallel to the film[12]. Vertical .020 stainless steel tubes approximately 3 mm. long were soldered to the mesial of the cuspid and distal to the molar. These vertical tubes were used to hold .020 stainless steel posts when taking radiographs, so that tooth landmarks could be easily distinguished.

To determine whether a tooth had been moved by tipping or bodily translated, the first and last head films were superimposed on the implants. Criteria for selection were:

a. The midline and the molar implants (right or left in compliance with the side) in each quadrant should superimpose with 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.

To measure the friction in the tooth moving appliance, an apparatus was constructed to duplicate the situation that existed in the mouth when the appliance was cemented and activated[42]. Force values employed consisted of the average of the two coil spring force values minus the effect of vibrating friction.

Prior to construction of the tooth movement appliance, the lower first molar and the second bicuspid on one side were tipped back for a period of approximately 4 weeks using a standard edgewise appliance and a lever arm activated by an oblique vertical (triangular) elastic from the maxillary arch. When this tip-back was achieved, the tooth moving appliance was constructed and cemented to place.

One week following cementation of the appliance, the retraction springs were activated for a given force. At each one week interval appointment the springs were measured. If the length of the springs had decreased from the original or known force values (10% maximum) the springs were reactivated (elongated) to the original length.

Impressions of the arch segments were taken at each of the appointments for later reference and evaluation. The final records were taken and the appliances were removed in eight to ten weeks.

FINDINGS AND DISCUSSION

A total of 36 molars and cuspids were evaluated in this study and four patients with 8 molars and 2 cuspids showed bodily movement under rigid criteria. There was only one patient in which both sides moved bodily (molar and cuspid) and three patients in which only the molars moved bodily. These four cases represent a small sample compared to the 18 possible quadrants, but by the strict definition of bodily movement in this study it was felt that the data are valid as well as reliable. Our data from one patient (E) which showed bodily movement forward of the prepared anchorage quadrant were compared to a previous tooth movement study[13]. The criteria for selection of teeth in that study and ours were comparable (Figure 3).

It can be seen from Figure 3 that the molar unit moved at a more or less constant rate over the time period studied. Furthermore, the movement did not undergo a lag phase as did the cuspid retraction of Hixon[13] and the force used was lighter (100 grams) than their best represented cuspid retraction (301 grams). Our molar unit movement was greater than any of the comparable cuspid retraction movement.

The estimate of measurement error (0.2 mm.) is identical to the previous study of Hixon[13].

Figure 4 shows that patient A had no movement on the tipped-back side (right) and the left side moved 1.2 mm. In patient C no movement was seen. Patient B enjoyed equal movement on both sides and patient D showed a great deal of movement on the tipped-back side (1.8 mm.) and a very minor movement on the left side.

As can be noted, the displacement of the molar anchorage units show no patterns or tooth movement trends. There is no apparent relationship between force and the distance the teeth were displaced or between the forward displacement of the prepared anchorage unit and the within patient control, nonprepared side.

The findings of Reitan[8,27,28,29,30], Burstone[36] and Storey and Smith[7] cannot directly be compared with the findings in this study because they were observing the pattern of movements of tipped teeth. The initial movement (Figure 3) during the first week may be due to slight tipping and it might be due to compression of the PDL. Baumrind[41] suggests, however, that this initial movement is more due to deflection of bone. He states that in rat experiments the PDL under heavy tooth compression reduces only 5% in width and that deflection can be produced by forces lower than those required to produce a gross reduction in the width of the PDL. Baumrind did not observe hyalinized areas, which would suggest that the cell free areas (zones of hyalinization) of Sandstedt, Schwarz, Reitan and advocated by others cannot be supported by Baumrind's findings. The findings of this study do not agree with the Storey and Smith concepts that an increase of the force above the optimum range (150 to 200 grams) results in a decreased rate of tooth movement and will approach zero when the range of forces reaches 500 grams[7]. In our small sample no optimum range was apparent between the forces of 100 to 1000 grams.

The pattern of tooth movement studies in this investigation tends to disagree with Reitan's findings. Complete statistical evidence is lacking, but there is definitely a trend of a straight line accumulation of tooth movement of all time points studied. These findings tend to question many of the theorized concepts of tooth movement such as hyalinization, undermining resorption and capillary compression.

Additional research in this area is essential, both on the histological and clinical levels before any positive answers can be found. The answers will come only from an extensive examination of the problem with accurate records taken at the shortest intervals, i.e., daily if possible. Schwarz postulates that orthodontic forces should not exceed the capillary blood pressure (20 to 26 gms/cm^2). We have used forces over 1000 grams - 60 times the capillary blood pressure - and the tooth moved at the same rate, with the same lack of patient complaint as when we were using 20 to 26 gms/cm^2.

Also, in this study, there is no evidence to support the hydrodynamic theory of Bien[37]. He stated that the rate of application of forces causes more failures than the magnitude of those forces. In our study we had "good" movement when we applied sudden heavy forces instead of a gradual force increase on a tooth to be moved. We believe that when he used rat incisors (teeth of continuous eruption) he could not determine their real level. These facts bring us to the conclusion that Bien had little basis to construct his theory.

CONCLUSIONS

It would appear that no single force in different individuals will result in differential movement of prepared anchorage units. Furthermore, no range of forces was found which would show a trend toward the desirability of preparing anchorage units to resist cuspid retraction forces.

We can only conclude that individual variation in response to tooth movement is greater than the range of forces that we have studied.

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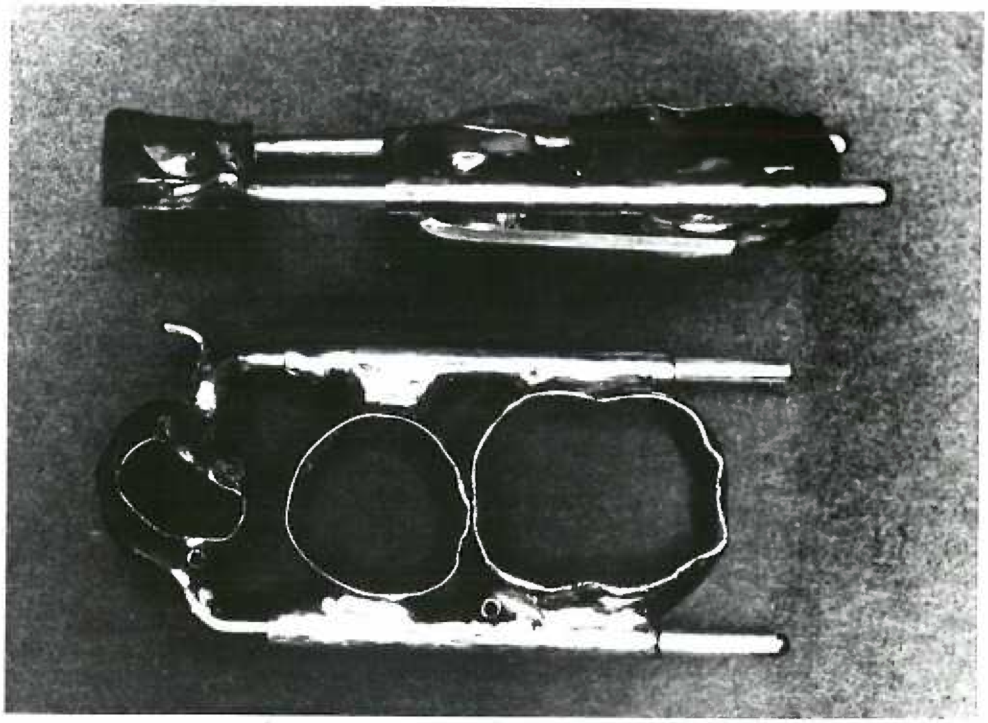

FIGURE 1

BUCCAL AND OCCLUSAL VIEWS OF APPLIANCES

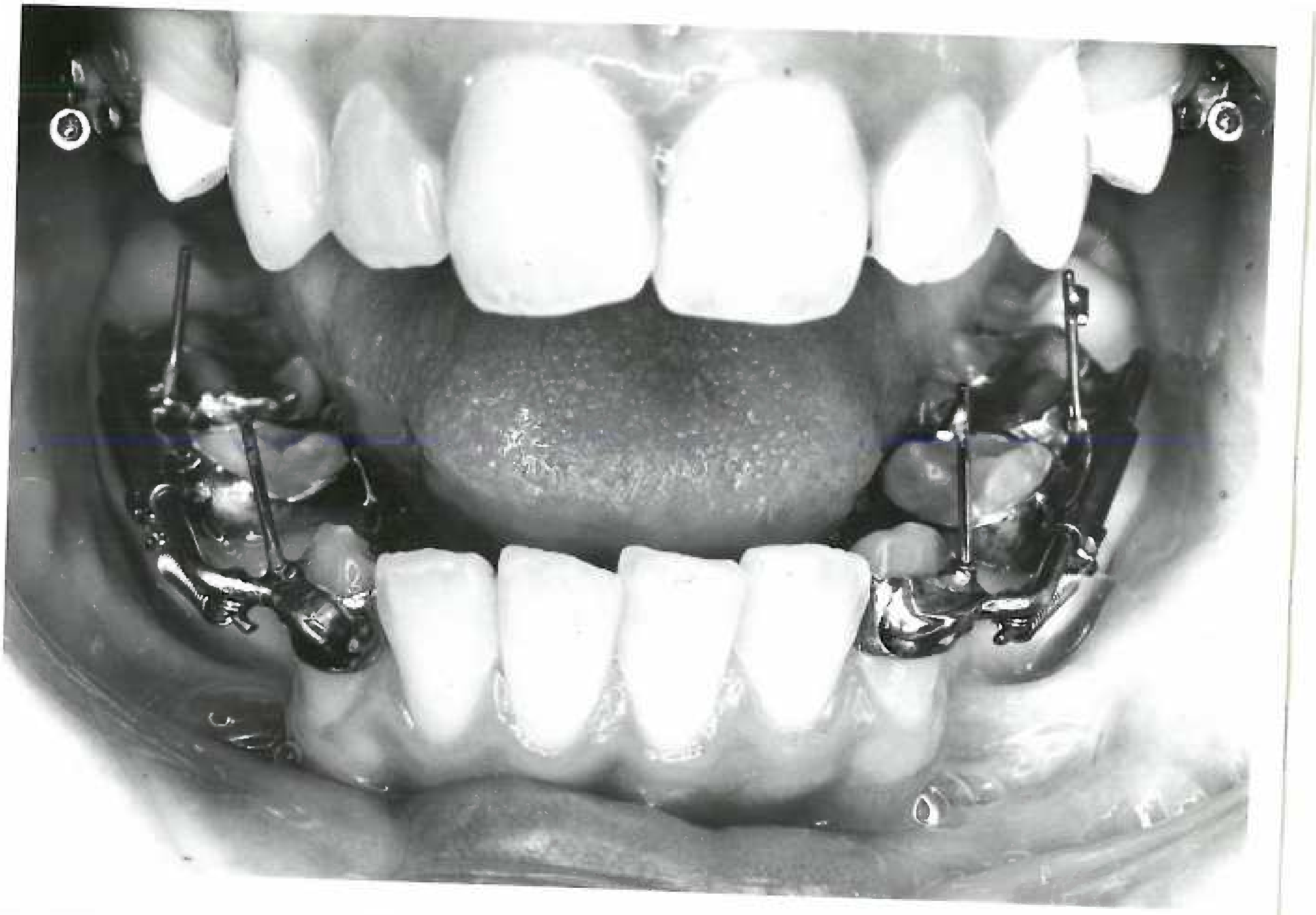

FIGURE 2

→ APPLIANCE CEMENTED ON MANDIBULAR TEETH

DISPLACEMENT OF MOLAR ANCHORAGE
UNIT (8 WEEKS)

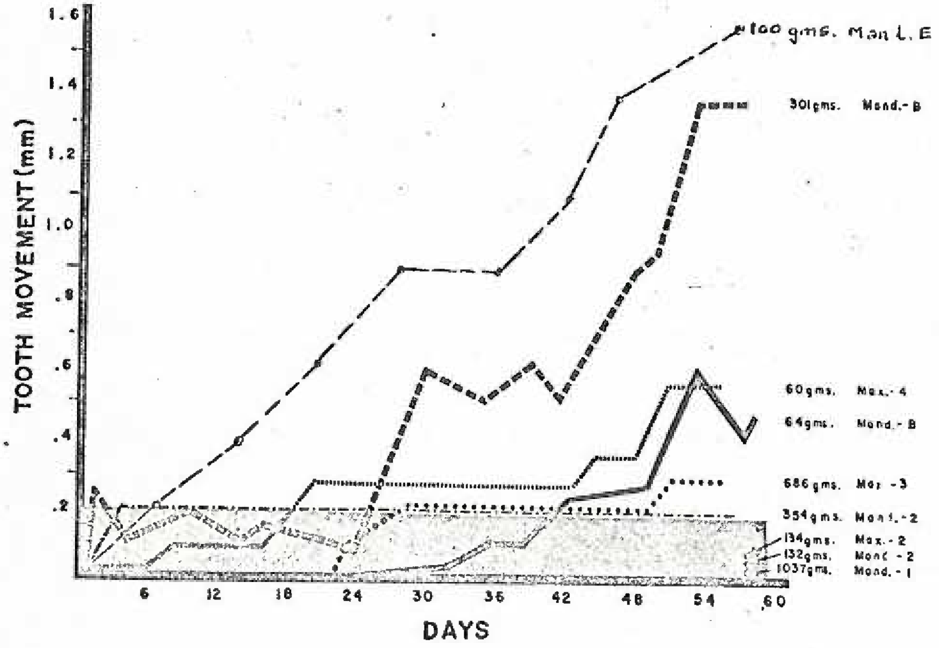

FIGURE 3 - MOLAR BODILY ANCHORAGE MOVEMENT
(PATIENT E - 100 GRAMS)
SUPERIMPOSED ON CUSPID
BODILY RETRACTION OF HIXON [13]

FORWARD MOLAR BODILY MOVEMENT

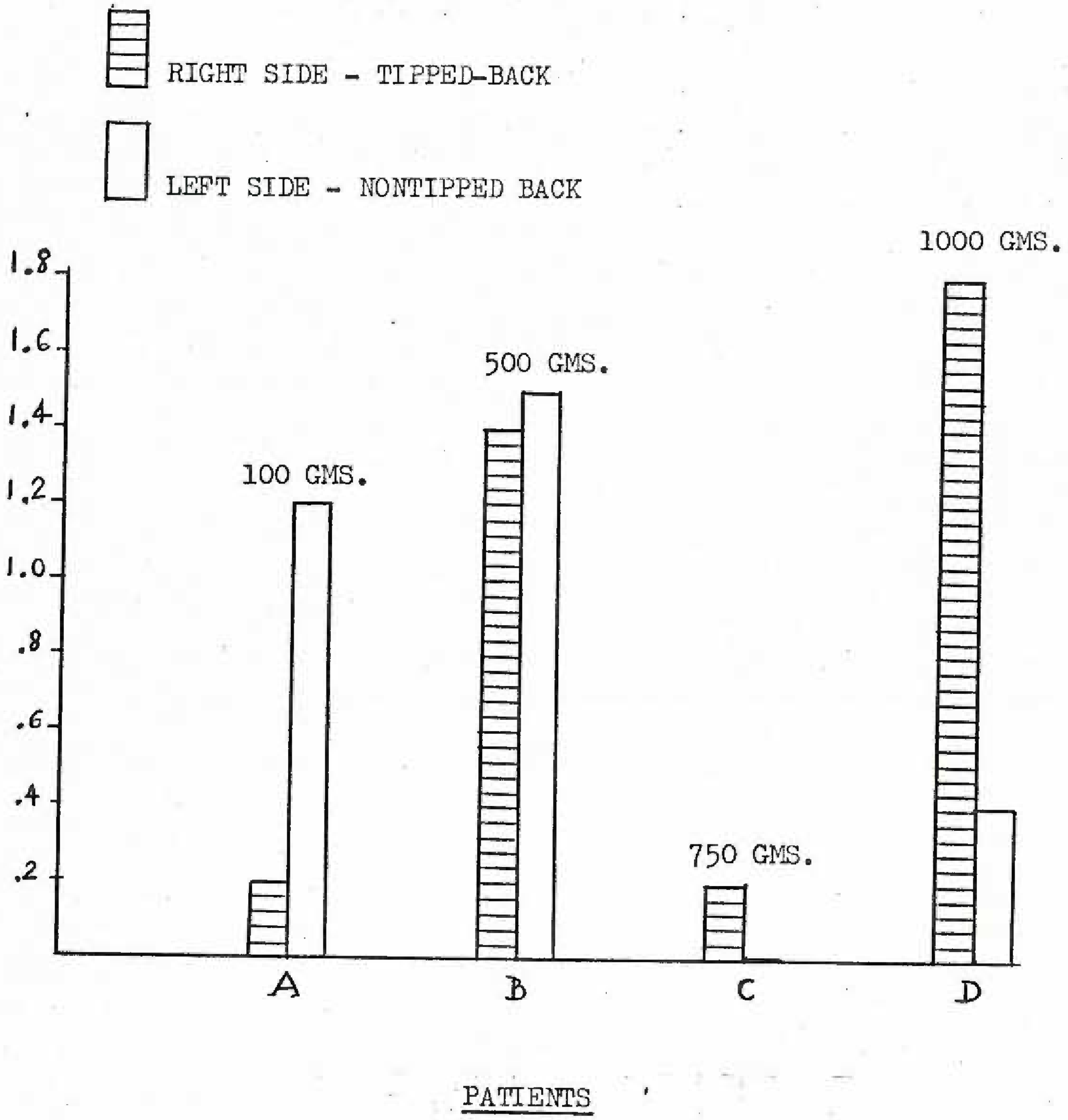

FIGURE 4: TOTAL DISPLACEMENT OF MOLAR ANCHORAGE UNITS IN FOUR PATIENTS OVER 56 DAY TIME PERIOD.