A Radiographic Study of Tooth Movement Determined by the Changes Seen in the Periodontal Space of the Mandibular Molar Teeth During Anchorage Preparation with Light Forces

Jesse Patrick Gantt
Loyola University Chicago

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A RADIOGRAPHIC STUDY OF TOOTH MOVEMENT
DETERMINED BY THE CHANGES SEEN IN
THE PERIODONTAL SPACE OF THE
MANDIBULAR MOLAR TEETH DURING
ANCHORAGE PREPARATION
WITH LIGHT FORCES

by

Jesse Patrick Gantt, Jr.

A Thesis Submitted to the Faculty of the Graduate School
of Loyola University in Partial Fulfillment of
the Requirement for the Degree of
Master of Science

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Jesse Patrick Gantt, Jr. was born in El Paso, Texas, on October 25, 1930. The elementary school education was received in Texas. In June of 1940 his family moved to Long Beach, California. After graduating from Woodrow Wilson High School in 1947, he studied for two years at Long Beach City College. In June, 1951, the Bachelor of Arts degree was conferred on him by the University of California at Los Angeles, California. From 1951 to 1952, he was a graduate student at the University of California at Los Angeles. The study of dentistry leading to the degree of Doctor of Dental Surgery was successfully completed in 1956 at Loyola University, New Orleans, Louisiana. From 1956 to 1958 he served as a commissioned officer on active duty with the United States Navy Reserve. The author began his graduate studies in June of 1958 at Loyola University, Chicago, Illinois.
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"No man is an island unto himself...."

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CHAPTER I

INTRODUCTION

A. Introductory remarks and statement of the problem.

As orthodontics has grown through the years, the trend of thinking has shifted from purely mechanical considerations to a fuller concept which places significance on the biologic principles involved in orthodontic tooth movements. Presently we think of orthodontics as being a biomechanical science.

Biologic and histologic studies have shown that the cellular activity of bone surrounding teeth moved orthodontically is directly related to the amount of force employed.

It has been shown that a heavy orthodontic force results in cessation of cellular activity in the immediate vicinity of the pressure side of the tooth, often causing necrosis. The bone changes occurring under such circumstances are predominantly due to undermining resorption, because this necrotic bone must be removed before the tooth will move in the direction of the force. Further, it has been demonstrated that there is an optimum range of force within which the movement tends to be more physiologic in nature.
The presence of a cribriform plate of bone and a periodontal space surrounding each tooth has been adequately ascertained histologically. With the advent of the x-ray in dental diagnosis, these areas received considerable clinical importance, since they were readily identifiable. Under ordinary conditions a dental radiograph shows wider cribriform plate on the distal root surfaces of the teeth because of the physiologic mesial migration of teeth. The width of the periodontal space and of the cribriform plate can be increased or decreased in orthodontic tooth movements depending upon the direction in which a tooth is being moved, and is constantly being remodeled to suit the functional requirements. The present study was designed to investigate the direction of tooth movement on the basis of direct radiographic appraisal of the change in these areas around the mandibular molar teeth.

Progressive thinking in orthodontics has been to correlate the biologic findings with the existing knowledge of mechanical therapy creating the science of biomechanics. Lately, new technics employing smaller diameter, highly resilient, round arch wires have been developed to produce tooth movements more in keeping with our biologic knowledge. This has made it possible to hasten or catalyze the biologic processes associated with the physiology of tooth movement and thus achieve our orthodontic objectives in far shorter time than heretofore possible.
Sound orthodontic mechanics dictate stability of anchor teeth.

Investigations designed to study the position of anchor teeth during orthodontic treatment have been reported previously (Tweed, 1956; Brodie, Downs, Goldstein, and Myer, 1938; Stoner, Lindquist and others 1956; Graber, 1954). Previous studies utilized the principle of superposition of lateral cephalometric tracings. These methods related the anchor teeth to certain cephalometric and craniometric landmarks, and measured their respective positions during the course of the tooth movements. It becomes exceedingly difficult to get an accurate picture of what is happening to the teeth and the surrounding tissues because of the error in tracing and the difficult visualization of the dentition from cephalometric x-rays, in addition to the factor of growth.

This investigation proposes an analysis of the radiographic changes in the periodontal space and cribiform plate surrounding the mandibular anchor teeth in patients under orthodontic treatment, because it is believed this method will be more accurate and consequently more useful. It is the belief of this investigator that these areas are useful as a radiographic barometer of tissue activity and are direct indicators of the direction and type of tooth movement taking place at any precise time.
CHAPTER II
REVIEW OF THE LITERATURE

Sandstedt (1904, 1905) (in experiments of tipping the incisors
lingually by means of a threaded arch wire and constantly and gradually
tightening the nuts at the end of the wire each day for three weeks) arrived
at the following results: (1) On the side of pull with both weak and strong
forces, a deposition of bone takes place on the old alveolar wall. The
newly formed bone spicules follow the direction of the strained periodontal
fibers (Figure 1). One can distinguish precisely the limit between the
newly formed bone and the old alveolar bone histologically; the latter is
not changed. (2) On the side of pressure the old alveolar bone is
equally resorbed by weak forces. The surface of the tooth root it self
remains intact. By these fundamental findings Sandstedt was the first
to ratify the pressure theory of Flourens, which also involved the ortho-
donitic movement of teeth. (3) By strong forces the periodontal soft
tissue is compressed at first on the side of pressure and cannot resorb
the old alveolar bone, because it is deprived of its vitality. Instead of
this, an active resorption soon begins in the neighboring marrow spaces
of the alveolar bone; the bone and the compressed soft tissue in the
(Reproduced from Schwarzs: International Journal Orthodontics, 1932)

FIGURE 1

THE RESULT OF A STRONG TILTING FORCE

As the result of a strong tilting force (pp) applied to a tooth, all gradations of the force are exerted in different zones of the root surface. With a strong force the tilt axis, O, lies about in the middle of the root. There are two regions of pressure (vertically shaded) and two regions of pull horizontally shaded, lying diametrically opposite each other. The greatest force acts in the zones 1 and 5 (margin and apex); a much smaller one acts in the zones 2 and 4 (nearer the center), no force at all in the zone 3 (center of the root).
FIGURE 2

TIPPING OF A MOVED TOOTH

Figure 2A. Sandstedt (1904 and 1905) states that the tooth moves by the force, $P$, and tilts around an axis, $O$, lying a little apically from the center of the root. By this means two regions of pressure and pull arise, lying diametrically opposite. In the regions of pressure the old alveolar bone is resorbed (jagged line); in the regions of pull new bone is added (horizontal shading). Gray shading shows alveolar bone without transformation.

Figure 2B. Oppenheim (1911 and 1928) states that the tooth moved by the force, $P$, tilts around an axis, $O$, lying on the apex. Therefore, there is only one side of pressure, and one side of pull. On both sides, the alveolar bone opens into a transitional spongy bone, whose elements are arranged vertically to the surface of the tooth (horizontal shading). On the side of pull, this newly formed transitional bone is resorbed (jagged line). On the side of pull new bone is added. Gray shading shows the old untransformed alveolar bone at a greater distance from the moved tooth.
region of the greatest pressure are removed. When all the necrotic material is removed, the tooth assumes at one pull a new position.

Sandstedt called this process the **undermining resorption**.

According to Gottlieb and Orban (1931):

The physiologic width of the periodontal membrane is that width which it attains when the tooth is in function. Biologic width is the width of the periodontal membrane of a tooth not in function.

The physiologic width of the periodontal membrane they found to be greater than the biologic width.

It is only when the pressure applied on the tooth causes the width of the periodontal membrane to become less than the biologic width would be if the tooth were out of function, that resorption of the adjacent hard bone takes place through activation of the periodontal fibers. Resorption depends not only on the amount of pressure applied, but also on the amount of compression produced on the periodontal membrane.

Gottlieb (1943) says:

The theoretical ideal of tooth movement is the compression of the periodontal membrane to such a degree that it can perform frontal resorption of the bone and furnish place for further tooth movement, without damaging the connective tissue of that periodontal membrane.

The chief difference between Sandstedt's findings and those of Oppenheim appears in the following statement: "The lamellae of the compact alveolar bone become opened out as the result of weak forces by the influence of pressure and pull on both sides of the moved tooth; and the bone transforms itself into a transitional spongiosa, the elements
of which are arranged in the direction of force.

Oppenheim's conclusions are shown in Figure 2B. The tooth tilts, as Angle says, from the apex. The horizontally shaded parts are transformed alveolar bone, both on the side of pressure and on the side of pull. On both sides of the moved tooth the alveolar bone is transformed over a wide area around the tooth. The elements of the new bone are arranged on both sides in the direction of force. The newly formed alveolar bone on the side of pressure is resorbed along the jagged line.

The difference lies in the fact that Oppenheim described this old alveolar bone as a newly formed bone, set vertically to the direction of pressure, because the free ends were surrounded by thick osteoid borders.

Schwarz (1932) states that strong force affects different teeth with different and varying intensity. The movement of a single tooth by a strong tilting force must also produce all degrees of biologic effects from the strongest to the weakest. The pressure of the tooth acting against the alveolus decreases as it approaches the axis of rotation, where the force is zero.

Moyers (1950) feels that rather than speak of what one appliance or another can do in the way of moving teeth, perhaps, it would be more correct to speak of what the periodontal membrane will allow one appliance to achieve and what it will not permit another. His article deals with
physiologic limitations and the tissue responsible for them.

The periodontal membrane, situated as it is between the root and the alveolar bone, acts as the tooth's natural shock absorber. The principal fibers serve as suspensory ligaments allowing the tooth to move a small, but perceptible, amount during biting and mastication. More important for the orthodontist, this membrane is made up of the connective tissue from which are generated the cells that make tooth movements possible. Little is known about this generative process, but both osteoclasts and osteoblasts have their origin in connective tissue and so without these transient osseous cellular elements the speciality of orthodontics would not exist.

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. The blood supply of the periodontal membrane arises from three sources; (1) periapical vessels found in the medullary bone, (2) vessels which feed the periodontal membrane from the gingival mucosa and periosteum, and (3) vessels which enter the membrane from the alveolar wall. There is, of course, much anastomosing of the vessels. The orthodontic significance of this anastomosing is that if one of the sources of blood is cut off the remaining vessels can still bring about repair and regeneration.
When an orthodontic force presses the tooth against the periodontal membrane, even the lightest force, will show compression, and it will show a straightening of the fibers on the opposite side of the tooth. When vessels are caught between fibers thus being stretched they assume an oval appearance. This straining of the periodontal fibers is the initiating mechanism for the realignment of the alveolar trabeculae, a condition called transitional bone by Oppenheim. On the pressure side there is a greater tendency to lessen the blood flow. Actually very little force is required to bring about actual stasis in the periodontal vessels. When stasis occurs, and it happens often with most orthodontic appliances, it means that a portion of the membrane undergoes strangulation, necrosis and regeneration before actual tooth movement will be started. (Moyers)

This is the general picture in the membrane before the resorptive and depository processes have begun. However, the picture varies with the manner of force application and the way in which the tooth is to be moved.

Tipping a tooth endangers its blood supply; however, the reason permanent damage is not done is due to the rich anastamosing of the vessels. The membrane is crushed at the alveolar crest on one side and just above the apex of the root on the opposite side unless the very lightest pressures are used.

Bodily movement presents a different problem. This is the
simultaneous movement of the crown and apex of the root in the same direction. When true bodily movement is undertaken all three sources of blood supply for the periodontal membrane are cut off on the side of pressure, and a lessening of the rate of blood flow in the tension side. The danger of real damage is greater since all the possibilities of collateral circulation are removed. The clinical response is much slower because a larger region of regeneration must be undertaken before movement can begin. While bodily movement may often be more desired from a mechanical viewpoint, it is difficult to attain physiologically. The appliances designed to move teeth bodily are the most difficult to use in a gentle manner. When a force acting parallel to the long axis of the tooth is applied the entire surface area of the periodontal membrane is compressed against the bone. It will have to be regenerated in its entirety and resorption must take place over the entire alveolus before movements can be realized. (Moyers)

No single factor limits and controls the orthodontic therapy so much as the physiologic response of the periodontal membrane to induced pressures and strains. It determines whether tooth movement is possible or not, at what rate and manner and, to some extent, whether the tooth will retain its new position.
Moyers (1950) states, and it is basic knowledge, that:

All tooth movements can be described as being (1) tipping, (2) intrusions, (3) extrusions, (4) bodily movements, (5) rotational movements, or (6) combinations of these (Figure 3). While we speak loosely of what one appliance will do and what another is unable to achieve, we would be more correct to speak of what the periodontal membrane will allow one appliance to do and what it denies another."

The periodontal membrane is involved in those bone alterations in two ways: (1) periodontal fibers continue into the alveolar bone and thus forces brought against the tooth are transmitted through the periodontal membrane to the alveolus; (2) the transient osseous cellular elements which alter the trabecular framework of the alveolus may find their origin in the periodontal membrane.

Several factors affect the initiation of this process of change in the periodontal membrane and bone incident to the placement of an activated appliance. First there is the amount of force, its sheer weight in grams or ounces; second is the distance the force is active; and third, the length of time the force is applied. Since the capillary blood pressure is approximately 25 gm/square cm., any force in excess of this amount is certain to diminish periodontal blood flow. The average thickness of the periodontal membrane in the human being is in the neighborhood of 0.2mm.; therefore, forces active over a greater distance will interrupt the blood flow.
FIGURE 3
FOUR TYPES OF TOOTH MOVEMENT
An excessive force directed parallel to the long axis of the tooth (bodily movement) will compress the entire periodontal membrane against the encircling bone. Almost total membrane regeneration must take place, and with greatly diminished blood flow if osseous changes are to occur.

As expected, the reverse is true when teeth are being moved gently. As long as a very light force is applied, the essential periodontal changes will appear quickly and bone transformations will occur readily. Increasing the force often causes such a stretching and compression of the fibers that periodontal blood flow is once more impeded.

Histologic studies do not confirm the use of the phrase "physiologic tooth movement" when referring to modern orthodontic appliances. Regardless of how the movement might be classified, the periodontal membrane knows nothing of number or shape of arch wires; it simply reacts biologically to weight of force application, distance of force application, and duration of time the force is active. Round wire appliances can effect tipping movements easily, provided the ordinary rules of light force application over a short distance are observed. Histologic sections do not bear out the claim that the light application of round wire mechanics will result in bodily movement of teeth.

(According to Moyers).
It is possible with the edgewise mechanism to demonstrate actual true bodily movement of teeth in the histologic sections. But it is also true that measurements of the forces inherent within this appliance as it is ordinarily used are completely beyond the limits of periodontal tolerance physiologically. When the edgewise mechanism is used the osseous response appears quite sometime after it might if a lighter action were used. Experimental data show that root resorptions are caused more easily with the edgewise appliance and the pin and tube appliance than any others tested. From a practical standpoint, these studies seem to indicate that all the movements possible should be carried out with light round arches first.

The study by Zander and Muhlemann (1956) was done to determine the effect on the periodontal structures not only of mechanically induced stresses but of this effect combined with that which might be produced by systemic stresses such as hypoxia, gravitational forces, explosive decompression, and others. Quantitative evaluations: the intra-alveolar displacement of roots through the applied lingual-labial force was evaluated by measurements of the widths of the labial and lingual marginal periodontal membrane. The measurement of width was difficult to standardize because the teeth studied had not always completely erupted. The ratio obtained by dividing the labial membrane width by the lingual
membrane width (labiolingual periodontal membrane width index) was chosen empirically as the criterion and is referred to as "marginal index."

Results: The marginal indices of teeth not subjected to dental traumatism are, on the average, slightly smaller than unity. In the absence of dental traumatism the application of the systemic stresses studied was not associated with an appreciable change of median marginal index.

A marked reduction of the median marginal index appears to be a characteristic of the type of dental traumatism applied in this investigation. The question as to whether or not the superstition of systemic and dental traumatisms is associated with a further reduction of median marginal index cannot be decided with certainty, in view of the limited sample size.

The changes of the periodontal membrane width were not significantly different whether twenty or forty grams, during one or two days, were applied. There were no differences due to different ages of the monkeys. In teeth seven days under local mechanical stress, a trend toward the lowest indices was found. Qualitative Periodontal Tissue Changes: The qualitative tissue changes associated with the application of local mechanical forces to the crowns were necrosis, degeneration, circulatory disturbances, osteoclasia, and formation of new bone. The periodontal tissue changes were most pronounced in the marginal and apical pressure zones and marginal tension zones of the periodontal
membrane. Pressure and tension zones occur because of the tipping of the roots within the alveolus (Figure 3).

The forces necrotizing the periodontal membrane sometimes squeeze the necrotic material through the nutrient canals into the adjacent bone marrow spaces, thus producing what could be called a "periodontal hernia." This was found to be true at the labio-marginal pressure region.

On the tension side the tissue damage was less pronounced. It consisted mainly of degenerative changes, hyalinization of the connective tissue and hemorrhage. Osteoclasia; osteoclastic activity was regularly found in pressure zones of all the animals. If pressure led to necrosis of the periodontal membrane, the osteoclasts were seen only at the border of the necrotic segment where the tissues did not lose their vitality. The osteoclasts undermined the alveolar bone that was opposite the necrotic area. Only in rare instances did osteoclastic resorption of the root cementum occur.

New bone formation: New bone formation occurred on the inner bony side in tension zones and on the outer alveolar side of pressure zones. The osteoblasts were found at the alveolar bone surface and also oriented parallel to the future Sharpey fibers. New bone formation would be found when the local stresses had been applied for forty-eight hours. It was
very definite after seven days.

It was established that the monkeys subjected to orthodontic tooth displacement exhibit a narrowing of the periodontal membrane on the side toward which a tooth is being moved. If the marginal index is being employed as the criterion of effect, a reduction of this index will ensue.

Concerning force values and mode of application of force to move teeth at the most favorable rate, and with least tissue damage and pain, Storey and Smith (1952) remark that the question of whether there is an optimum force that will give the best results has not been answered up to the present; nor has the question of whether force should be applied continuously or intermittently been answered. These writers used the edgewise mechanism for experiments with wire spring forces of varying values to move canine teeth distally. First permanent molars, together with second premolars, were used as anchorage for the springs to move canines distally into the first premolar extraction spaces.

Their results showed that a similar behavior of the teeth occurred in all cases studied. They found that there is an optimum range of force values that should be used to produce a maximum rate of movement of the canine. This optimum 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 movement of the canine decreases and finally approaches zero. Also, with an increase of force, appreciable movement of the molar anchor unit appears to be consistent with the behavior of the canine tooth, since the ratio of area of contact of teeth with bone in the canine and molar anchor unit, is approximately 3:8. 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 300 grams for the molar anchor unit, neither tooth moved appreciably. When heavy springs were first activated, very little or no movement of the canine occurred. Instead, the molar anchor unit moved in a very marked fashion until the force exerted by the spring had decreased to the range of 200 to 300 grams. This means that the canines were acting as anchor teeth, and the so-called molar anchor teeth were the teeth being moved. With values greater than 300 grams, there is no appreciable movement of the canine and an appreciable movement of the molar anchor unit.

Although the work of these investigators was purely experimental, and their findings were not applied by them for full treatment of cases with fixed appliances, they state that their experiments have already yielded sufficient evidence to be used as a basis for future designing of fixed appliances suitable for universal tooth movement.
The tentative explanation given by Storey and Smith for the different rates of movement of canines and molars, under heavy forces, is that the behavior conforms to the concept of undermining resorption, as presented by Sandstedt, and later supported by Schwarz.

The forces found by Smith and Storey (1952) to be most favorable for tooth movement from the standpoint of rapidity and tissue tolerance, are much lower than those exerted by the edgewise arch wire. They found that there is no evidence for the claims of earlier investigators that there is no value for the forces which will bring about tooth movement without causing some damage to the tissues. When investigating this question of tissue damage, neither Oppenheim nor Gottlieb gave accurate values for the forces used.

Halderson, Johns, and Moyers (1953) state:

In many instances the force exerted by the edgewise arch wire is of the very high value of over two pounds, or approximately 900 grams, which causes a pathogenic tissue response.

Clinicians using the edgewise mechanism have learned that to start their cases with a series of light round wires is to facilitate the movement of teeth. This is sound therapy for two reasons: (1) it takes as much advantage of tipping movements as is possible and (2) it utilizes forces much lighter than are possible with a standard edgewise wire.

Reitan (1957) has shown that one of the first signs of orthodontic forces exceeding two hundred grams is that of the lack of cellular activity
which is later followed by hyalinization in the periodontal ligament. Therefore, in retracting canine teeth, if excessive forces are applied we can expect an impairment in, if not a complete cessation of cellular activity responsible for direct alveolar resorption and, thereby, a lack of canine movement. What may happen, on the other hand, is that this force which prevents direct resorption and distal movement at the site of the canine can, when distributed over the greater root surface area of the teeth in the anchorage unit, permit forward movement of these teeth through direct resorption since the forces are now within the physiologic limits necessary for movement of these teeth. In essence, this amounts to placing a lighter force on the teeth in the anchorage unit than upon the canines and the bone response here begins within twenty-four to thirty-six hours while the lengthy procedure of undermining resorption in the area distal to the canine teeth will require a considerable amount of time. This explains anchorage breakdown during the retraction of canine teeth. The opposite of this occurs -- the anchorage unit is stable -- when canines are retracted using light forces.

A number of researchers, among them Stuteville (1937 and 1938), Sichcr and Weinmann (1955), Reitan (1951 and 1956), Wentz, Jarabak and Orban (1958), concur and have shown that the physiology of the periodontium and the cellular activity of the periodontal bone itself are affected in
different ways depending upon the types and/or degrees of orthodontic forces which may be selected and used to control the movement of teeth.

The picture of the bone activity which occurs in the areas which surround teeth moved orthodontically can be attributed, in general, to the degree of stimulation of the normal physiology of the periodontium. This degree of stimulation of the normal periodontal physiology is affected by the intensity, magnitude, and duration of the forces used to control the movement of teeth. (Jarabak 1959).

Wentz, Jarabak and Orban (1958) showed in their experiment that undermining resorption which was induced through tooth jiggling, created by the forces of traumatic occlusion, (a cycle of crushing, undermining resorption, repair, and heavy activation again) produces a large periodontal space containing hyalinized connective tissue and osteoid tissue on both sides of the tooth which is poorly organized. The larger the periodontal space becomes (due to more jiggling), consequently the more osteoid and more hyalinized tissue is created. As this process is continued, these teeth become more and more mobile.

Osteoid tissue is not bone and, therefore, cannot be expected to, and does not, respond to these forces in its pattern of activity as does bone. (Jarabak 1959).

There is an implication in the foregoing material that there is now a need for an appliance that will deliver sufficiently light force and at the same time, accomplish universal tooth movements throughout treatment.

Steiner (1953) in considering the question of arch wire force,
believes that any tooth movement might be accomplished with one adjustment if the arch wire were to be reduced sufficiently in size. This, he feels, has been proven by all who have used 0.018 inch or even 0.022 inch round steel arch wire in competition with heavier ones. He states that the edgewise appliance principles may be applied someday by using an arch wire of extremely elastic metal of a diameter which may be only a small fraction of that of the cross section of the present ones. Steiner also points out that to gain much tooth movement, whether it be rotation, torquing, or mesial or distal tipping, a great deal of force must be applied to distort the short rigid section of the edgewise arch wire enough to accomplish power delivery.

The purpose of the article by Begg (1956) is to describe a technic for the application of optimum forces for tooth movement using stainless steel round arch wire 0.016 inch in diameter.

Begg points out that the use of thin round steel arch wire raises the standard of results, as it eliminates the excessively high forces that are exerted by rectangular arch wire; also, active treatment time is greatly reduced. He feels that the orthodontic force values that are used cause least discomfort to patients, least loosening of the teeth, and least damage to tooth investing tissues, while at the same time they are also the forces that move teeth the most rapidly and are the most easily applied and
controlled forces.

In this technic, advantage is taken of the principle that for moving anterior teeth with small root surface area, relatively light arch wire and rubber ligature forces produce the most rapid movement with the least disturbance to tooth-investing tissues. At the same time, these light forces leave the larger-rooted, posterior anchor teeth almost stationary. Conversely, relatively large forces cause the anterior teeth to resist the pressure, so that the anterior teeth can be made to operate as anchor teeth, as they then move only very slowly, while with this large force the posterior teeth, the so-called anchor teeth, move very rapidly.

Values are given in grams for the appropriate forces for accomplishing differential tooth movement. It is possible to utilize extraction spaces more fully to move either the upper, the lower, or both dental arches further forward or backward in the jaws while closing extraction spaces due to the application of the principles of differential force. The use of differential orthodontic forces makes it possible to carry out simultaneously, and with much greater efficiency, the various groups of tooth movements, such as opening up deep incisor overbites, aligning crowded teeth, closing extraction spaces, correcting anteroposterior occlusal malrelations of all teeth, and bringing down impacted teeth with hooks cemented into them. When all groups of tooth movement are
carried out simultaneously with differential forces, each group movement reciprocally aids all other group movements so that they are all more successful and more easily accomplished. Furthermore, because the employment of differential forces in a reciprocal manner makes it possible to move teeth more completely to required positions without also moving anchor teeth, it is unnecessary to carry out the well-known preliminary operation in Class I and Class II cases of putting treatment into reverse with Class III intermaxillary elastics, fortified by extra-oral anchorage, in order to prevent Class II intermaxillary elastics from causing mandibular anchorage failure. Extra-oral anchorage, in the form of high-pull headgear, may be required in the treatment of deep overbite cases with this technic.

The order of procedure of treatment of any cases with this technic differs in several respects from that with the edgewise mechanism. An important difference is that, from the beginning and throughout treatment with this technic, movements of all teeth are simultaneously set in motion along the shortest, most direct paths to the positions the teeth will occupy at completion of treatment. Elaborate precautions are necessary to prevent mandibular anchorage failure when the orthodox edgewise technic is used. Tooth movements are put in reverse by using Class III intermaxillary elastics for a time during treatment by the edgewise technic.
This careful preparation to prevent mandibular anchorage failure is unnecessary when using the thin round arch wire because optimum orthodontic forces are exerted by it.

Prevention of Mandibular Anchorage Failure -- When small diameter round arch wire technic is used, mandibular anchorage failure, even in the most pronounced Class II cases with bimaxillary protrusion and tooth crowding, does not occur, even if such procedures as distal driving canine teeth into extraction spaces and wearing of Class II elastics are carried out simultaneously.

Advantages of using differential force -- An important advantage of the employment of differential force is that it is possible, while closing extraction spaces, to place all the teeth in the dental arch either slightly further forward or back in the jaw, by appropriate variation of the force from space-closing elastics. Of course, this can be done to an extent only within the limits of the sites of the extraction spaces.

The usefulness of x-ray as well as the microscope has been long valued in the observation and diagnosis of the normal as well as the pathologic dental picture. Now, it is common practice for dental examinations and periodic caries check-ups to begin with intra-oral radiographs. Unfortunately, it is quite uncommon for the orthodontist to take or ever refer to intra-oral x-rays once the treatment has been
initiated. It is unfortunate, in my opinion, because the orthodontist is overlooking a fine indicator of treatment progress in the intra-oral radiograph. I would now like to develop the literature as it pertains to the radiographic picture of the teeth in their bony environment and in particular the cribiform plate.

Teleroentgenography, as discussed briefly by Schwarz (1957), is a comparatively new technic which, unfortunately, is hardly used in dentistry. In contrast to the customary roentgenographic technics, in teleroentgenography the x-ray tube is placed at a distance of about six feet from the plate to obtain parallelism of rays and to avoid distortions.

Teleroentgenography aids the diagnosis in instances of malocclusions, fractures of the teeth and jaws, periodontal disease, and in locating foreign bodies and impacted teeth. It may be used in the following instances: (1) when dis-proportions exist between the teeth and their apical bases; (2) when tooth extractions for orthodontic purposes seem indicated and a clear diagnosis is not obtainable by interpretation of roentgenograms taken by the usual means, and where severe deformations exist, and the comparison with the standard profile appears to be necessary to obtain proper compensation.

In films or pictures taken by teleroentgenography, the parallelism of the rays is secured, and distortions, impairing the correct interpretations,
are avoided.

Elf enbaum (1958) feels that bodily or tipping movement of a tooth under orthodontic influences is exhibited radiographically by resorption of the cribiform plate in areas in which pressure is being exerted and an apposition of the cortical bone in the areas of tension. In this manner the cribiform plate will appear thicker in the areas of tension and thinner in the areas of pressure. After the orthodontic treatment has been completed the cribiform plate regains its normal appearance. When a tooth is being tipped the center of rotation may be readily determined by noting the proportion of increase in the width of cribiform plate in the tension areas. Bodily movements are demonstrated by an even thickened cribiform plate in the tension area. A tooth which has been tipped into an edentulous area by occlusion shows the cribiform plate to be thickened on the side toward which the tooth is being tipped. The bone trabeculations are arranged at right angles to the new and heavier cribiform plate, thus, reinforcing it like the timbers in a mine shaft. This picture differs from one in which there is a reduction in the thickness of cribiform plate caused by root pressure when a tooth is being moved orthodontically.

The orthodontic appearance of the cribiform plate has been repeatedly described as an "even thin white line surrounding the tooth root." This description would lead one to believe that this line is found
characteristically surrounding every normal tooth root.

Updegrave (1958) did not find this to be so regardless of the technic used.

It is the exception rather than the rule to see a root completely outlined with a thin clear-cut, uniform radiopaque line. Even in radiographs of single-rooted teeth, made with various technics, the cribriform plate cannot always be seen in its entirety.

The visualization of the cribriform plate is affected by the individually distinctive patterns of both cancellous and cortical bone overlying the roots of the teeth. It may be observed that the cribriform plate is seen more clearly outlining the roots of the anterior teeth in the mandible. This is due to the thinness and close proximity of the cortical plates to the single roots which leave little room for cancellous bone. The shape of the roots themselves also influences the clarity of cribriform plate visualization. A root with broad labio-lingual or bucco-lingual diameter and blunt apex is most favorably formed to show the outline of the cribriform plate throughout its complete length. The cribriform plate often can be traced on the lateral surfaces of the root but is lost as the apex is approached since the greatest bucco-lingual width of the cribriform plate is located at the cervical region, this portion appears more radiopaque than the apical portion. The result is a blending of the apical portion into the adjacent cancellous bone and a loss of detail in the area (Figure 4).

Another contradiction to the "even white line" is the apparent lack of
FIGURE 4
COMPARATIVE THICKNESSES OF THE BUCCO-LINGUAL WIDTH OF THE CRIBRIFORM PLATE AT THE CERVICAL AND APICAL PORTIONS OF THE ROOT
uniformity of width. Since bone responds to physiologic forces (internal structures adapting to functional stresses), it is logical to expect evidence of this to be recorded in bone that surrounds the teeth so closely.

Histologic evidence shows that in tooth movement the bony wall of the alveolus is resorbed in the direction in which the tooth is moving, and new bone is formed on the wall under traction. Thickening of any portion of the cribriform plate of fully developed, non-pathologic teeth could therefore be a clue to stress being exerted in that direction.

Shanks and Kerley (1951) have stated:

The reason the lamina dura is seen in a radiograph and can be distinguished from the surrounding alveolus is that the bone of which it consists is denser and therefore more radiopaque than the surrounding structures.

Goldman, Millsap and Brenman (1957) believe that this is not the reason the alveolar bone proper (lamina dura) shows as a thin radiopaque line, but that it is due instead to the shape of the tooth socket. The tooth socket being oblong, the rays are not passing through just a single width of the alveolar bone proper, but through many times its width. This also explains why the inferior border of the mandible shows up as a radiopaque band. The outer cortical plate and the inner cortical plate join in a curvature so that the rays are passing through much more cortical bone at this curvature than in the middle of the tooth. Actually,
both reasons are significant in the visual establishment of the cribriform plate radiographically.
CHAPTER III
MATERIALS AND METHODS

A. Subjects Investigated

Twenty four children, being treated by the five graduate orthodontic students in the class beginning June 1959 at Loyola University School of Dentistry, were used in this investigation. The group of children was composed of thirteen females and eleven males. The distribution of the material by age is presented in Table I. The patients were selected for use in this study because they were all being treated by the light forces technic. Another reason for their selection was that they were all started in their courses of treatment by the graduate students in the Orthodontic Department of Loyola University School of Dentistry, and their records could be made simultaneously from the time immediately prior to the placement of the arch wires to the completion of the preparation of the mandibular anchorage units. Four intra-oral roentgenograms were taken on each patient for a total of ninety-two.
### TABLE I

**DISTRIBUTION OF THE MATERIAL BY AGE**

<table>
<thead>
<tr>
<th>AGE (years)</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>1</td>
</tr>
</tbody>
</table>

Mean 12.22
Total 24
B. Methods of Study

The methods used to obtain data for this study were from two sources as follows: (1) A lateral cephalometric headplate was made for each patient using the Universal Cephalometrix apparatus (Figure 5); (2) A headspanner for headpositioning and orientation, constructed by F. W. Steiner of Chicago, Illinois, was adapted and attached to the crossbar of the Universal Cephalometrix apparatus (Figure 6). This headspanner (Gantt) was located and made secure in a position thirty inches from the focal spot of the x-ray machine. This distance is one-half the fixed distance (sixty inches) from the focal spot of the x-ray machine to the Universal headpositioner (Wehmer) (Figure 7). The reason for attaching another headpositioner to the crossbar at a distance of thirty inches from the x-ray machine was to reduce the amount of time of radiation the patient must receive in order to expose an intra-oral x-ray film adequately. Also, by moving the headpositioner one-half of the preset fixed distance closer to the x-ray machine, the intra-oral x-ray could be taken using virtually parallel rays to minimize the factors of enlargement and distortion. The use of a headpositioner was a necessity in order to prevent distortion errors by movements of the patient's head, and to allow the operator to replace the patient into the headpositioner in the same spatial relation to the x-ray machine each successive time a
FIGURE 5

THE UNIVERSAL CEPHALOMETRIX APPARATUS
FIGURE 6
THE HEADSPANNER
(GANTT)
record was taken.

An adapter (Figure 3) was constructed to attach the second head-positioner to the transverse bar of the Universal apparatus. This adapter consists of the following parts: (i) a vertical arm with a sleeve which fits over the horizontal bar of the head-holding apparatus; (ii) an arm on which two sleeves were mounted which allowed the arms to move in and out of their respective sleeves on the apparatus; and (iii) a sleeve on the vertical arm of the adapter which fitted into the horizontal bar and was too accurate. When rotated and the lock nuts tightened, gave the sleeve a very close tolerance fit.

This headspanner (Gaunt) (Figure 4), when fixed at a set distance from the x-ray machine, may be adjusted in two planes of space. It may be raised or lowered on the vertical arm by an adjustment of the thumb screw, and it may be moved in or out horizontally on the horizontal arm. Attached to the vertical bar is a millimeter scale which enables the operator to determine the amount of vertical distance desired to move this head-positioning device vertically with relation to the x-ray machine. This vertical distance was previously determined for each subject from his

**FIGURE 7**

**THE HEADSPANNER AND THE UNIVERSAL HEADPOSITIONER**

*WEHMER*
record was taken.

An adapter (Figure 8) was constructed to attach the second head-positioner to the transverse bar of the Universal apparatus. This adapter consists of the following parts; (1) a vertical arm with a sleeve which fits over the horizontal transverse bar of the Universal cephalometric apparatus; (2) a horizontal arm with a sleeve which fits over the vertical arm of the adapter and is attached to it at a right angle. These two sleeves were secured in position by large thumb screws which allowed the arms to be fully adjustable. It was noted that the fit of the sleeves on their respective arms to which they were clamped was loose and not too accurate. Therefore, the sleeves were drilled and tapped and outfitted with set screws and lock nuts. These set screws, when adjusted and the lock nuts tightened, gave the sleeves a very close tolerance fit.

This headspanner (Gantt) (Figure 6), when fixed at a set distance from the x-ray machine, may be adjusted in two planes of space. It may be raised or lowered on the vertical arm by an adjustment of the thumb screw, and it may be moved in or out horizontally on the horizontal arm. Attached to the vertical bar is a millimeter scale which enables the operator to determine the amount of vertical distance desired to move this headpositioning device vertically with relation to the x-ray machine. This vertical distance was previously determined for each subject from his
lateral cephalometric survey also be moved in and out in a horizontal projection of the headpost. The horizontal arm of the headpost was also equipped with a millimeter scale with movements to be measured as fits the subject.

The two arm posts were splayed and marked with lead indicators in order to have an index by which they could be aligned with a point from which to start. It was necessary to align the two arm posts so that the central x-ray would pass directly through the indicated area as on the two lead indicators exacted in space. The arm rods were aligned as shown in Figure 9.

In order to do this, it was necessary to remove the entire assembly between each patient. In the position each time a vertical and horizontal adjustment was necessary, and the anterior arch must be adjusted for the different coordinate distances which were derived for each patient from the headplate tracing (previously described). A test was conducted in order to establish the successive accuracy of the ability to disassemble and
lateral cephalometric headplate. The headspanner may also be moved in and out in a horizontal plane. The thumb screw on the horizontal projection of the headspanner allows it to be moved freely in and out on the horizontal arm of the adapter. This horizontal arm is also equipped with a millimeter scale which allows horizontal adjustment movements to be measured as fits the requirements of the individual subject.

The two ear posts of the head fixation device were slotted and marked with lead indicators in their respective centers in order to have an index by which they could be aligned. To have a zero point from which to start, it was necessary to align the two ear posts so that the central x-ray would pass directly through their centers and super-impose the two lead indicators exactly in the horizontal and vertical planes of space. The ear rods were aligned and their super-imposition recorded (Figure 9).

In order to obtain lateral cephalometric headplates, it was necessary to remove the headspanner from the adapter assembly between each patient. It was also necessary to adjust the vertical and horizontal position each time a subject was recorded. The vertical and horizontal adjustments were necessary because the headspanner must be adjusted for the different coordinate distances which were derived for each patient from the headplate tracing (previously described). A test was conducted in order to establish the successive accuracy of the ability to disassemble and
FIGURE 9

SUPERIMPOSITION OF THE EAR RODS
C. Tracing

A headplate was taken of the subject's teeth in centric occlusion. These headplates, which included the Frankfort horizontal plane, were mounted on an anchor unit that moved itself along with the change in the patient's position. A line was drawn parallel to the central incisor and distal most surfaces of the lower second and upper first molar teeth. It was desirable to pass through the center of each of these teeth.

A vertical coordinate was drawn down from the center of the ear rod perpendicular to the Frankfort horizontal plane at the level of the vertical center of the anchor teeth. From a point made in the center of this second area a horizontal coordinate was drawn connecting this point with the termination of the line representing the vertical coordinate. This line was constructed parallel to the Frankfort horizontal plane. The length of these two lines was measured for each.
reassemble the head-fixator on the adapter assembly so that the ear rod indicators were accurately superimposed upon each other. Eight successive radiographs were taken, one after each reassembly of the apparatus, with the x-ray film taped to the far ear post. An indication of the accuracy of this test of the apparatus is demonstrated in Table II.

C. Tracing Technic

A headplate was taken of each subject with the subject's teeth in centric occlusion. A tracing was made for each in these headplates which included the Frankfort Horizontal Plane and the teeth in the mandibular anchorage unit (Figure 11). Since this study concerns itself with the change in the periodontal space adjacent to the mesial and distal root surfaces of the mesial and distal roots of the mandibular first molar teeth, it was desirable to adjust the headspanner so that the central x-ray would pass through the center of the area of the mandibular first molar tooth. A vertical coordinate was drawn down from the center of the ear rod perpendicular to the Frankfort Horizontal Plane to the level of the vertical center of the anchor teeth. From a point made in the center of this molar area a horizontal coordinate was drawn connecting this point with the termination of the line representing the vertical coordinate. This line was constructed parallel to the Frankfort Horizontal Plane. The length of these two lines was measured in millimeters and recorded for each
## Table II

### Test for Accuracy of Apparatus

<table>
<thead>
<tr>
<th>Picture No.</th>
<th>Distance between Centers in mm.</th>
<th>$d^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>$d$</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3.8</td>
<td>14.44</td>
</tr>
<tr>
<td>1</td>
<td>2.1</td>
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<td>6</td>
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<td>7.29</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>20.7</td>
</tr>
</tbody>
</table>

\[
(d)^2 = 428.49
\]

\[
\frac{(d)^2}{N} = 53.561 - C.F.
\]

\[
d^2 - C.F. = 3.809
\]

\[
N - 1 - 7
\]

\[
3.809 - 7 - .5441
\]

\[
-.5441 = .737631
\]

95% Level \[2.365 \times .737631 = 1.744497315\]

Magnification \[5.5 \times 1.7445 = 5.5 \times 0.317\]

Circle of Confusion \[0.317 \text{ mm.}\]
FIGURE 11

A LATERAL HEADPLATE TRACING
subject were made of the distances vertically and horizontally to which the headspanner must be adjusted. These distances were attained by moving the thumb screws of the vertical and horizontal arms which were previously described. The adjustments were initiated from the horizontal and vertical "zero" points which were arrived at in centering and superimposing the two ear rod indicators. Thereby, the head positioner can be adjusted for each subject in order to allow the central x-ray to pass through the center of the area of the mandibular anchorage unit. In this manner the error of distortion is minimized.

The radiographic film used in taking the cephalometric lateral head records for this part of the study was 8 X 10 inch high speed, blue brand, Kodak Medical Film. Each cassette was equipped with a Du Pont high speed intensifying screen to eliminate some secondary radiation and to provide greater contrast. The machine setting for each exposure was 87 K.V.P. and 25 M.A. Exposure time was one-half second for the lateral head roentgenogram. The radiographic film used for the intra-oral records for this study was Du Pont code d-1, double coated dental x-ray film. The machine setting was the same as mentioned previously. The exposure time was two and one-half seconds for each intra-oral roentgenogram.

D. Measurements -- A guide to the change which occurred in the width
FIGURE 12

A LATERAL HEADPLATE TRACING WITH
HORIZONTAL AND VERTICAL CO-ORDINATE LINES
the periodontal space.

The headspanner was adjusted and the subject placed in the apparatus. Two individual radiographs of each (the left and the right mandibular anchorage units) were taken prior to the placement of the arch wires. At the completion of anchorage preparation, the headspanner was adjusted to the previously established positions for each subject and another set of four radiographs was taken. These radiographs were then developed at the same time as a group in order to provide uniformity in developing technic. This was done first with the entire group of radiographs taken prior to the initiation of treatment, and then the same procedure was done in the same manner with the entire group of radiographs taken seventy-six days after the initiation of treatment for each subject.

The radiographs taken on each subject consisted of two series:

1) Two radiographs were taken of the mandibular anchor unit on the right side. The first film was marked 1. A replicate film, marked 1A, was taken (as stated previously) to provide a check of accuracy and to provide a larger number of readings to minimize error. Another set of two films was taken for the right side of the arch seventy-six days later and marked 1B (the original) of the follow-up records and 1C (the replicate of it).

2) The second series of films was taken of the left mandibular anchor unit
of the subjects. The procedure was the same as in the preceding series.

One film marked 2 (the original and another marked 2A (the replicate) were taken prior to placement of arch wires. Seventy-six days later two more films were taken of the left side and marked 2B (the initial follow-up) and 2C (the replicate of it). These eight films constituted the records for each patient.

The original film in each series was then transilluminated on a tracing table, and under a stationary three power magnifying lens it was marked in the following manner. A fine pointed needle was used to make a small perforation in the film in four areas. These marks were made just inside the surface adjacent to the periodontal space on the root portion of the molar tooth represented on the radiograph. They were labelled A (marginal area of mesial surface of mesial root), B (apical area of mesial surface of mesial root), C (marginal area of distal surface of distal root), and D (apical area of distal surface of distal root) (Figure 13). These areas were selected on each original film for each subject and were marked at a place adjacent to each marginal and apical area where the periodontal space was clearly distinguishable. This original film, thus marked, was then superimposed over each of the three other films individually in that series. The perforation marks were then transferred to each of the other films by pressing the fine needle through the
FIGURE 13

AREAS AT WHICH CHANGE

IN PERIODONTAL SPACE WAS EVALUATED
perforations and into the underlying film. Thus it was possible to compare very nearly the same areas of the periodontal space on each of the four films in the series. This was done on each of the one hundred and eighty-four films taken in this study (Figure 14).

The films were then bound as slides and projected on a plain white posterboard screen at a fixed distance from the screen. The distance from projector to screen was established and maintained throughout the observation period. The magnification of the projected image was twenty times that of the original film. This distance was obtained by projecting a slide of a line two millimeters in length on the screen and adjusting the distance from screen to projector until the line measured forty millimeters. Thus a magnification factor of 20:1 was obtained.

The slide projector used was a Kodak Cavalcade with a Kodak Projection Ektanar Lens, 5 inch, f12.8. (Courtesy of Dr. J. F. Jarabak).

A technique was devised to compare the change in the width of the periodontal space on the mesial and distal of these anchor molar teeth. A strip of plain white paper one inch wide and ten inches long was divided lengthwise into four boxes or section (A, B, C, D), each corresponding to one of the four areas marked on the radiographs (previously described). In each section a vertical straight line was drawn and labelled as a reference line (Figure 15). The slide of film Number 1 was then projected
FIRST ARCH WIRE PLACED

76 DAYS LATER

DUPLICATES

FIGURE 14

INITIAL AND FOLLOW-UP RADIOGRAPHS

AND THEIR DUPLICATES
FIGURE 15

REFERENCE STRIP
onto the screen and the white paper strip was interposed and placed against the screen. The reference line in box A was superimposed over the image of the outer border of the cementum adjacent to the mark which was made on the film representing point A (marginal area of the mesial surface of the mesial root). The width of the periodontal space was then estimated for this area; and then a short vertical line representing this distance was drawn with a sharp red pencil on the white paper strip parallel to the reference line. This procedure was followed for points B, C, and D on the same paper strip (Figures 16, 17, 18 and 19). (Figure 20 shows graphically the same areas A, B, C, and D for the second film series.) The next x-ray slide, Number 18, the record taken at the end of the anchorage preparation period, was projected. Using the same white paper strip, the same procedure was followed, except this time a short blue vertical line drawn parallel to the reference line was used to indicate the estimated width of the periodontal space on this follow-up, post anchorage x-ray (Figure 21, 22, 23, and 24). Thus, the difference between the red and blue pencil lines represented the change that had taken place in the periodontal space of these teeth during the anchorage preparation period. If the blue line fell between the red line and the reference line, the space was evaluated as a decrease in width, if the blue line fell outside the red line, the space was evaluated as an increase in width. Thus, by
FIGURE 16

INITIAL EVALUATION OF AREA A
FIGURE 17

INITIAL EVALUATION OF AREA B
FIGURE 18

INITIAL EVALUATION OF AREA C
FIGURE 19

INITIAL EVALUATION OF AREA D
FIGURE 26

AREAS A, B, C, D, ON FOLLOW-UP ERG:

AT THE END OF ANCHORAGE PREPARATION
FIGURE 21

EVALUATION OF AREA A

AFTER ANCHORAGE PREPARATION
FIGURE 22

EVALUATION OF AREA B

AFTER ANCHORAGE PREPARATION
FIGURE 23

EVALUATION OF AREA C

AFTER ANCHORAGE PREPARATION
FIGURE 24

EVALUATION OF AREA D

AFTER ANCHORAGE PREPARATION
weighing the proportionate amount of change and the direction of such change, it was possible to determine the direction and the relative degree of movement of the molar teeth being investigated. This procedure was done for each of the one hundred and eighty-four films. The descriptive evaluation of the direction and type of movement which the teeth underwent was then calculated. The films were again projected for study purposes and the evaluation of the type and direction of movement was checked out by visual evaluation of the films. The calculated descriptions were substantiated by the visual examination in each instance. Additional information which was gained from the visual interpretation of the radiographs was amended to and correlated with the descriptions which had been calculated.

E. Appliance Design.

Each of the subjects was fully banded using angulated brackets on the bands. The brackets were angulated from horizontal in order to give the teeth a distal tip-back when a straight wire was fitted into the bracket boxes (Figure 25, Courtesy of Dr. Joseph R. Jarabak).

In this study only those subjects were used who were treated with light, highly resilient, round arch wires. The entire group of twenty-three subjects was treated employing initial arch wires of .016 inch diameter Elgiloy Semi-spring wire. Prior to their insertion, all the arch wires
were tempered to spring hardness after having been first fashioned individually for each subject. Eleven of these subjects were treated with differential forces arch wires fashioned from the type of wire mentioned above (Loyola University Light Differential Forces technic). This type of arch wire employs bent in vertical helical loops in the anterior segment of the arch; bent in hooks located against the mesial surface of the canine brackets; and straight posterior segments extending distally through the buccal segments of the dental arch. These straight posterior segments are slightly curved in the horizontal plane of space to provide some arch form. (Figure 26), shows a typical helical loop arch. These subjects treated with helical loop arches were also required to wear rubber elastics. These elastics are made of latex rubber (rubber dam material) and are 1/4 inch in diameter. They are of two types: (A) Light 1/4 inch elastics, which exert an average pull of two ounces, and (B) Heavy 1/4 inch elastics which exert an average pull of three to four ounces. These averages are obtained when the elastics are stretched a distance of about 1 and 1/4 inches. This is the average distance from the distal of the mandibular first molar tooth to the hook on the arch wire mesial to the mandibular canine tooth.

These patients wore the elastics in the following manner on each side of the mouth: (A) One 1/4 inch light elastic worn from the end of the arch wire on the buccal surface of the first molar tooth to the bent in hook
ARTISTIC ALIGNMENT OF ANTERIOR TEETH

MESIO-DISTAL BRACKET ANGULATION

MAXILLA

MANDIBLE

FIGURE 25
BRACKET ANGULATION FOR THE ANTERIOR AND POSTERIOR PARTS OF THE MOUTH
FIGURE 26

A TYPICAL HELICAL LOOP ARCH

LOYOLA UNIVERSITY LIGHT WIRE DIFFERENTIAL TECHNIC
located mesial to the canine bracket: (B) One 1/4 inch light elastic worn from a hook located on the lingual surface of the band on the mandibular first molar tooth to the bent-in hook located mesial to the canine bracket (Same as above); (C) One 1/4 inch light elastic worn buccally from the lower to the upper arch as a triangle having its base on the upper arch and its apex on the lower arch. This elastic worn in a triangular fashion is attached from the end of the upper arch wire on the first molar to a ligature wire hook (pigtail) on the upper second premolar tooth and then down to a similar ligature wire hook on the lower second premolar tooth. Those cases in which a helical loop differential forces arch was employed in the upper arch as well as in the lower required one additional 1/4 inch light elastic to be worn from the lower molar lingual hook to the bent-in hook on the upper arch wire located mesial to the canine bracket. (Figure 27 shows a subject with arch wires ligated into place and elastics in position).

Anchorage was established on eight of the subjects with the use of headgear force. The arch wires used were of the same dimensions, however, no bends were incorporated into these arch wires other than the general configuration of the arch and a slight curve in the posterior segments to conform to the general arch form. (Figure 28 demonstrates a typical arch wire of the type described). There were two sections of
FIGURE 28

IDEAL ARCH WIRE WITH NO ATTACHMENTS
.010 open coil spring placed on the wire to advance two sliding hooks (Figure 29). The distal end of the section of open coil spring was placed against the bracket of the first premolar tooth and the hook was advanced by the coil to a position mesial to the canine tooth. In these cases the canine bands on the mandibular canine teeth were removed in order to allow the hook to be advanced a greater distance without any interference from the bracket on the canine band. The headgear hooks were attached bilaterally to the sliding hooks in the mouth, and these hooks on the headgear were attached extraorally to the material from which the headgear was constructed by means of "X" type Orthospec elastics. (Figure 30 shows an example of the headgear, the manner in which it is worn, and the way in which the hooks are attached from it to the mouth). In these cases also, light 1/4 inch elastics are worn in the same triangular manner as previously described.

Finally, the remaining four subjects were treated during this period of anchorage preparation using the same type of .016 inch diameter round Elgiloy wire as was used in all of the arches for the other subjects. The arch wires placed in these subjects were simply fashioned to the shape of an ideal arch, individualized for arch width and form for each subject; tempered, and inserted. These arch wires carried no attachments or bent in vertical helical loops or hooks (Figure 31). These arch wires were
FIGURE 29
ARCH WIRE WITH ATTACHMENTS FOR USE
WITH HEADGEAR TO THE LOWER ARCH
FIGURE 30

THE ATTACHMENT OF A HEADGEAR TO THE LOWER ARCH
used to effect minor tooth movements in an otherwise well shaped lower dental arch. In those cases where light elastics were applied in the previously described triangular fashion.

A brief explanation is due concerning the three types of arches just described. All of the arch wires are described (the helical, helix, and straight) in each of the four diameters. However, due to the discrepancy in the use of the first primary anchorages and the discrepancy between the mandibular anchorage units and the direction and type of tooth movement accomplished by the arch wires and the elastic forces used in the initial phases of the treatment, i.e., anchorage preparation. Headgear therapy was used in the preparation of the anchor units in those cases in which the malocclusion was not sufficiently severe to require the extraction of permanent teeth. The headgear force in the buccal segments of the mandibular arch was used to upright and tip these teeth distally. In this manner the amount of space needed to align and upright the mandibular

FIGURE 31

AN IDEAL ARCH WIRE
used to affect minor tooth movements in an otherwise well shaped lower dental arch. In these cases 1/4 inch light elastics were applied in the previously described triangular fashion.

A brief explanation is due concerning the three types of arches just described and their application in the treatment of the patients. All of the arch wires used on these subjects were constructed from .016 inch diameter round Elgiloy wire. The first type of arch wire described (the helical loop differential forces arch) was used in those eleven cases which, due to the discrepancy of arch length available to tooth size and/or the discrepancy in the relation of arch to arch, required the extraction of four first premolar teeth. The differential forces arch was employed to accomplish several different types of tooth movement simultaneously. However, in this study we are concerned with the preparation of the mandibular anchorage units and the direction and type of tooth movement accomplished by the arch wires and the elastic forces used in the initial phases of the treatment, i.e.: anchorage preparation. Headgear therapy was used in the preparation of the anchor units in those cases in which the malocclusion was not sufficiently severe to require the extraction of permanent teeth. The headgear force to the buccal segments of the mandibular arch was used to upright and tip these teeth distally. In this manner the amount of space needed to align and upright the mandibular
incisors over their apical bases was obtained. The ideal arch wires used in the initial phases of the treatment of the remaining subjects were employed to prepare only the anchorage necessary for minor tooth movements and bracket alignment and, as in all of the cases, to establish a more favorable vertical dimension. This was the purpose of these ideal arch wires in otherwise well situated mandibular dental arches.
CHAPTER IV
EXPERIMENTAL RESULTS

The records in this study were appraised with regard to the change in the width of periodontal space which occurred during the seventy-six day treatment interval. This was the period in which anchorage was being prepared in the mandibular arch of each subject by the use of the appliances described in the foregoing chapter. As previously stated in the chapter on Methods and Materials, the change was evaluated in four areas of the periodontal space of the mandibular first molar teeth. Those areas were: (A) Marginal area of mesial surface of mesial root, (B) Apical area of mesial surface of mesial root, (C) Marginal area of distal surface of distal root, and (D) Apical area of distal surface of distal root (Figure 13). A description of the types of tooth movement was made for each molar tooth involved in the study. These changes were appraised by evaluating the increase, decrease, or no appreciable movement (as was sometimes the case) at each of these four areas of the roots of the molar teeth. The films were projected again for study purposes, and the calculated evaluation of the type and direction of tooth movement was checked out by and correlated with a visual evaluation of the films.
In the undertaking of this study ninety-six records of the direction of tooth movements were made as demonstrated in Figures 14 - 23. It was very interesting and encouraging to discover the significant correlation that was obtained between the original record and the duplicate of it. Thirty-six of the forty-eight sets of original and duplicate records were in complete agreement as to the direction of the movement which occurred at all four areas where tooth movement was observed. Twelve sets of these records did not agree completely as to the direction of movement, however, eleven of the twelve sets of records did agree upon the direction of movement at three of the four positions of observation. Only one set of records disagreed on the direction of movement at two of the four positions of observation.

The types of tooth movements observed could be divided into two main groups. These groups are (1) Bodily Movements, and (2) Tipping Movements. The bodily movements which were observed occurred in a mesial direction, a distal direction, or as an elevation of the tooth. The tipping movements were sub-divided according to (A) The location of the axis of the tipping movement, (B) The direction of the tipping movement (mesial or distal), and (C) A jiggling movement (tooth rocking mesially and distally). Some of the observations, however, demonstrated no apparent movement.
Table III shows (by percentages) the types of tooth movements and their sub-divisions which were observed for (1) The entire group of light wire subjects (2) The subjects treated initially with Differential Forces Arches, (3) The subjects treated initially with Headgear, and (4) The subjects treated initially with Leveling Arches.

A series of four bar graphs were constructed to present a graphic picture of the results obtained in this study. These graphs illustrate the number of occurrences which were produced by a particular type or sub-type of tooth movement throughout the study. (Figure 32 shows the results of the study as they pertain to the entire group of light wire Treatment subjects). (Figure 33 shows the results of the study as they pertain to the subjects who were treated initially with the Differential Forces Arches). (Figure 34 shows the results of the study as they pertain to the subjects who were treated initially with Headgear). (Figure 35 shows the results of this study as they pertain to the subjects who were treated initially with Leveling Arches).

It can be readily seen from these graphs that certain types of movements were demonstrated most frequently by the greatest number of the dental units under consideration.
In each of the bar graphs under the heading of Tooth Movements, the columns are represented as follows:

A. Bodily Movements

Column

1. Bodily Mesial Movement
2. Bodily Distal Movement
3. Tooth Elevated

B. Tipping Movements

Column

4. Axis of tipping in apical third of root
5. Axis of tipping in middle third of root
6. Crown Tipping distally
7. Crown Tipping mesially
8. Jiggling
9. No Apparent movement

In Graph Number I (All light wire subjects) columns 3, 4, 5, and 6, were found to contain the largest number of occurrences. Column 2 and 7 showed the least number of occurrences. In Graph Number II types 3, 4, 5, and 6 were also the largest columns represented. Column 2, 7, and 8 showed minimum occurrences. Graph Number III demonstrates that the number of occurrences of tooth movements most commonly fell into
columns 1, 3, 4, 5, and 6. Columns 2 and 8 showed only minimum occurrences, and columns 7 and 9 showed no occurrences at all. In Graph Number IV, Columns 3, 4, 5, and 6 contained the highest number of occurrences with columns 1, 8, and 9 showing minimum occurrences. In this graph, columns 2 and 7 showed that no interpretable occurrences were recorded.

Referring to Table III again, it is interesting to note that the total was divided into 37.4% Bodily Movements, 48.1% Tipping Movements, and 14.5% No Apparent movements for All Light Wire Subjects. Regarding the Differential Forces Subjects, 39.8% showed Bodily Movements, 36.5% showed Tipping Movements and 22.7% showed No Apparent Movement. For the Headgear Subjects 37.4% showed Bodily Movements, 62.6% showed Tipping Movements, and 0% showed No Apparent Movement. Finally, concerning the Leveling Arch Subjects, 30.0% showed Bodily Movements, 50.0% showed Tipping Movements, and 20.0% showed no Apparent Movement.

It was necessary to perform an accuracy check upon one's ability to determine from the radiographs the various types and sub-types of tooth movements. To accomplish this, two groups of four observers each (orthodontic graduate students) were selected without having any previous knowledge of what they would be asked to do. These observer
groups were asked to view the original and the follow-up films which were shown simultaneously. They were asked to determine the various types of tooth movements which they could discern by visual comparison of points A, B, C, D, which existed on each set of films. They were then shown the set of duplicate films which corresponded with the original films which had been shown first. This enabled them to either confirm or reject their original decisions as to the movements.

Both groups concurred with each other and with the author in nearly every instance as to the types of movements demonstrated radiographically. This test was done merely to verify the decisions of the author as to the types of movements which could be demonstrated by these sets of films. It was previously explained that the author also compared and checked the calculated findings with the visual interpretations.

These are the numerical and graphic representations of the results which were obtained in this study.
## Table III

**Observations of Tooth Movements**

(Values Expressed in Percentages)

<table>
<thead>
<tr>
<th>Bodily Movements</th>
<th>All Light Wire Subjects</th>
<th>Differential Forces Subjects</th>
<th>Headgear Subjects</th>
<th>Leveling Arch Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bodily Mesial Movement</td>
<td>31.2</td>
<td>31.8</td>
<td>31.2</td>
<td>30.0</td>
</tr>
<tr>
<td>Bodily Distal Movement</td>
<td>6.2</td>
<td>9.0</td>
<td>6.2</td>
<td>0</td>
</tr>
<tr>
<td>Tooth Elevated</td>
<td>75.0</td>
<td>68.2</td>
<td>87.5</td>
<td>70.0</td>
</tr>
<tr>
<td>Tipping Movements</td>
<td>48.1</td>
<td>36.5</td>
<td>62.6</td>
<td>50.0</td>
</tr>
<tr>
<td>Axis of Tipping in Apical third of root</td>
<td>55.2</td>
<td>56.8</td>
<td>55.7</td>
<td>50.0</td>
</tr>
<tr>
<td>Axis of Tipping in Middle third of root</td>
<td>44.8</td>
<td>43.2</td>
<td>44.3</td>
<td>50.0</td>
</tr>
<tr>
<td>Crown tipping Distally</td>
<td>72.0</td>
<td>57.0</td>
<td>93.7</td>
<td>70.0</td>
</tr>
<tr>
<td>Crown tipping Mesially</td>
<td>4.2</td>
<td>9.0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jiggling</td>
<td>9.3</td>
<td>11.3</td>
<td>6.3</td>
<td>10.0</td>
</tr>
<tr>
<td>No Apparent Movement</td>
<td>14.5</td>
<td>22.7</td>
<td>0</td>
<td>20.0</td>
</tr>
</tbody>
</table>
ALL LIGHT WIRE SUBJECTS

NUMBER OF OCCURRENCES

TOOTH MOVEMENTS

FIGURE 32

BAR GRAPH 1
DIFFERENTIAL FORCES SUBJECTS

FIGURE 33
BAR GRAPH II
HEADGEAR SUBJECTS

NUMBER OF OCCURRENCES

10

5

0

1 2 3 4 5 6 7 8 9

TOOTH MOVEMENTS

FIGURE 34

BAR GRAPH III
LEVELING ARCH SUBJECTS

NUMBER OF OCCURRENCES

10

5

0

1 2 3 4 5 6 7 8 9

TOOTH MOVEMENTS

FIGURE 35

BAR GRAPH I V
CHAPTER V
DISCUSSION

The prime consideration an orthodontist has for his patients is the achievement of his treatment goals which are naturally individualized and limited by genetic composition and physical development of the patient. To establish these goals for treatment is one thing; to achieve them through the application of mechanical principles may be an entirely different proposition. Quite naturally, men in this field have been trying to develop technics which will allow them to realize these treatment goals as fully as possible without jeopardizing the health of the biologic structures with which they are dealing. To aid and facilitate treatment, diagnostic aids such as radiography have been developed and utilized. Naturally, in order to realize treatment goals and to fulfill obligations to the patient, it is vitally important to the orthodontist to be able to control and regulate tooth movements as easily and rapidly as possible. To accomplish this, the accurate knowledge as to the direction and type of tooth movement obtained from the application of various mechanical techniques is essential.

This study has attempted to contribute some information regarding the type of tooth movement obtained through the application of a mechanical technic which was formulated with specific consideration given to the
According to Sandstedt (1905), the tooth tilts about an axis that lies near the middle of the root when a strong force is applied to it (he does not give the amount of force which he applied). This tilting produces two areas of pressure and two areas of tension of the root surface of the tooth. These areas are located diametrically opposite. Oppenheim's conclusions (1911, 1928), which were summarized previously in Figure 2B, show that the tooth, subjected to a pressure, tilts from its apex thereby having only one side of pressure and one side of tension. Schwarz (1932) approaches the problem with the statement to the effect that strong force affects different teeth with different and varying intensity. As the biologic and physiologic aspects of tooth movement become more apparent the feeling of Moyers (1950), that rather than speak of what one appliance or another can do in the movement of teeth, it would be more correct to speak of what the periodontal membrane will or will not permit an appliance to achieve, is very sound. However, it could be better stated that it is the amount of force delivered by the appliance to the periodontal membrane that regulates the degree and type of tooth movement.

Storey and Smith (1952) have taken just such a concept into account in the designing of light resilient loop springs to move certain teeth while leaving their anchor teeth undisturbed. The term that has been adapted to
describe the application of reciprocal forces which will move some teeth
and leave others to resist this force undisturbed, has been called
"Differential Forces." An arch wire such as that shown in Figure 26
has been designed to utilize these principles. Storey and Smith (1952)
demonstrated Sandstedt's theory of undermining resorption with the
application of heavy and light springs, and further demonstrated that there
exists an optimum range of force for the movement of teeth. When this
optimum range of force is exceeded the process of undermining resorption
(Sandstedt) impedes the desired tooth movement.

In designing this experiment, the desire was to be able to determine
the type and direction of movement which occurred in the mandibular
resistance units when the mandibular canine teeth were retracted into the
extraction sites of the first premolar teeth. A study and evaluation of the
change which occurred in the periodontal ligament space of the mandibular
first molar teeth, as determined from intra-oral radiographs, presented
the data from which an evaluation of the tooth movement was made. The
method of obtaining the intra-oral radiographs was explained in detail in
the chapter on Methods and Materials. In addition, it was desired to
develop a technic for taking intra-oral radiographs which could be compared
with other radiographs taken with the same equipment of the same area at
various stages in the treatment of patients, without fear of drawing
erroneous conclusions which might be produced by distortions.

Intra-oral radiographs are invaluable to dentists and if the author can judge from the experimental results obtained in this study, they may be just as valuable to the orthodontist by allowing him to determine if the application of the forces which he is using will permit the accomplishment of the goals which he set forth in planning the treatment of his patients.

It was desirable to use a headholder to stabilize and orient the subjects to the central x-ray, and to use a fixed x-ray source in order to eliminate, as much as possible, the change in width of the periodontal ligament space which can be obtained by an alteration of the angulation of the x-ray machine cone or by rotation of the subject's head. Naturally, some error exists in the consistency of film placement, and in the adjustment of the apparatus, and in the placement of the subject in the apparatus. However, the accuracy of the apparatus was adequate (see Table II), and an honest attempt was made to minimize the other errors inherent in such a study. The use of duplications (not double films) in such taking of the intra-oral radiographs was another method of checking the type and direction of tooth movements which could have been judged erroneously from the original radiographs. The duplicate records agreed completely with the original records in thirty-six of the forty-eight records; and eleven of the twelve records, which did not agree completely
with the original records, did agree with them on three of the four areas of observation. This appears to be very good substantiating evidence for the accuracy of the experimental technic.

In considering the entire group of subjects treated with light (.016 inch diameter) round arch wires it was found that the types of tooth movements which were demonstrated by the highest percentage of the anchor teeth were: Type 1 (Bodily Mesial movement), Type 3 (Tooth Elevated), sub-Type 4 (Axis of Tipping in the Apical Third of Root), sub-Type 5 (Axis of Tipping in Middle Third of Root), and sub-Type 6 (Crown Tipping Distally). Sub-Type 8 (Jiggling) and Type 9 (No Apparent Movement) were also found to occur commonly enough to be of significance. These results for all of the subjects treated show that at least two-thirds of the mandibular first premolar tooth extraction site may be used in distal driving mandibular canine teeth if it is desirable to do so. An explanation of the mesial movement of some of these anchor teeth can best be explained when the subgroups of treated subjects are discussed individually.

The results achieved in obtaining the initial phase in the treatment of subjects with Differential Forces Arches is summarized as follows:
The types of tooth movements which were demonstrated by the highest percentage of anchor teeth for this sub-group were Type 1 (Bodily Mesial Movement), Type 3 (Tooth Elevated), sub-Type 6 (Crown Tipping Distally,)
Type 4 (Axis of Tipping in Apical Third of Root), sub-Type 5 (Axis of Tipping in Middle Third of Root), and Type 7 (No Apparent Movement) in that order. This pattern is practically the same as the one for the entire group of subjects. The Bodily Mesial Movement indicates that in those cases which demonstrated this type of movement, the forces exceeded the maximum amount of the optimum range of force which is from 150 to 200 gms. This is the optimum range of force for moving the mandibular canine tooth distally. If the maximum of this range is exceeded the canine tooth will cease to move distally and will act as an anchor tooth until the bone on the distal wall of the canine socket has been resorbed through the process of undermining resorption. In the meantime, the anchor unit will be moved mesially by the reciprocal action of the elastics until the force has diminished and the optimum range of force is again reached.

The fact that the teeth show Bodily Mesial Movement is an indication that they are resisting this mesial movement in the most stubborn manner. The accomplishment of a bodily movement (i.e.: the crown and root moving simultaneously in the same direction at the same rate of speed), is the most difficult to accomplish especially when it involves a large molar tooth. If a molar tooth resists a force and the result of this resistance is movement in a bodily fashion, it is acting as an excellent anchor tooth. Naturally, in some of these cases it was
recognized that the entire amount of arch length created by the extraction of permanent teeth would not be needed to align the mandibular anterior teeth and to place them over their apical base. In these cases the elastic force was increased in order to accomplish a greater number of steps in the treatment more efficiently and more rapidly.

An important consideration in these cases is that of patient cooperation. It is not uncommon for some of these patients to become confused as to the placement of the elastics, and in the wearing and changing of them. The wearing of the headgear, as well, is difficult to manage. These are factors over which the clinician has no assurance of control.

There are, of course, the differences between individuals as to the rapidity of movement and the progress which they make, however the overall picture shows the types of movements to be very nearly the same for the majority of the subjects in this group as compared with the total group.

In this group of subjects treated with Differential Forces Arches in the initial period, it was shown that Type 2 (Cephalic Distal Movement), sub-Type 7 (Crown Tipping Mesially) and sub-Type 8 (Jiggling) show the least number of occurrences. The instances of mesial tipping of the crown and the distal root apex being elevated higher than the mesial root
apex were found to be due to the wearing of a heavy 1/4 inch latex
elastic from the distal end of the lower arch wire (at the distal of the
mandibular molar tube) to a hook mesial to the maxillary canine tooth in
the process of retracting it. This fact in conjunction with the absence
of the important elastic worn in a triangular fashion (described previously
in the chapter on Methods and Materials) were responsible for the
elevation of the distal of the mandibular first molar and the mesial
tipping. These movements were also accentuated by the intramaxillary
elastics on the lower arch (from lower first molar to mesial of lower
canine).

In considering the next sub-group (that of the subjects who were
initially treated with a headgear to the lower arch) the general picture is
the same as that of the Differential Forces Subjects. These subjects
were handled without the extraction of permanent dental units. The
pressure was brought to bear against the mandibular first premolar tooth,
and the crowns of the teeth were tipped distally by transmission of the
force, through the contacts, to the other teeth in the buccal segments. It
is interesting to note that Type 2 (Bodily Distal Movement), and Type 8
(Jiggling) show only minimal occurrences, and that sub-Type 7 (Crown
Tipping Mesially) and Type 9 (No Apparent Movement) demonstrated no
occurrences whatsoever. Some of these subjects wore their headgear
appliances almost continuously while others wore them only spasmodically. This factor of patient cooperation is one of the greatest difficulties with this type of therapy. In those instances in which the crown of the teeth tipped distally and their roots tipped mesially to a considerable extent, it can be deduced that the headgear force was of too great a magnitude. This resulted in raising the axis of tipping to the middle area of the root or even higher.

The Third sub-group (that of the Leveling Arch subjects) shows the highest percentage of occurrences fall into Type 3 (Tooth Elevated), sub-Type 4 (Axis of Tipping in Apical Third of Root), sub-Type 5 (Axis of Tipping in Middle Third of Root) and sub-Type 6 (Crown Tipping Distally). It is also interesting to observe that Type 2 (Bodily Distal Movement) and Type 7 (Crown Tipping Mesially) had no occurrences. These subjects wore no elastics other than those worn in a triangular manner to elevate the molar and premolar teeth and thus increase the vertical dimension.

Another important consideration concerns itself with the very evident factor of the distal tipping of the crowns of these teeth. This factor has been mentioned previously, however, it deserves to be discussed at this time. The chief reason for this type of movement is that the brackets had been angulated to produce tip-backs (see Figure 25). This virtually insures that the crown of a tooth treated with this type of
bracket will tip distally as a result when a straight arch wire is placed in these brackets.

The significance in this instance is that even with a mesial force upon the molars from the elastics, these teeth were elevated and tipped distally through the medium of bracket angulation. The molar teeth were left virtually undisturbed in many instances with respect to mesial drift.

One important consideration that can be brought out which may or may not have been evident from the experimental procedure, the data, or the results, is the fact that the areas under investigation in this study which were represented in the intra oral radiographs do not present the type of data which is of an exact measurable nature. This is to say, that, to be able to give the amount a tooth moved during a given period of time from intra oral radiographic evidence, is not possible. However, the fact remains that evidence for type, direction, and relative amount of tooth movement, is as readily accessible to the practitioner as it is to the teacher and can be very useful in guiding treatment to a successful conclusion.

It is hoped that this study may help to point out the value of intra oral radiographs to the orthodontist as an important adjunct to the other diagnostic and treatment progress tools at his disposal.
CHAPTER VI
SUMMARY AND CONCLUSIONS

I. Summary

A. The subjects investigated in this study were twenty-four children being treated by the five graduate orthodontic students in the class beginning June 1959 at Loyola University School of Dentistry.

B. An adjustable headpositioning apparatus and a stationary x-ray source were necessary to standardize the technic of taking intra oral radiographs and to minimize the errors of distortion which could be produced.

C. The data for determining the type of tooth movements were obtained by evaluating the relative amounts of change which occurred in the width of the periodontal space adjacent to marginal and apical areas of the mesial and distal root surfaces of mandibular first molar teeth.

D. The entire group of subjects demonstrated fourteen categories of tooth movements listed according to their type and direction of movement.
The Types of Movements found were:

A. Bodily Movements
   1. Bodily Mesial Movement
   2. Bodily Distal Movement
   3. Tooth Elevated

B. Tipping Movements
   1. Axis of Tipping in Apical Third of Root
   2. Axis of Tipping in Middle Third of Root
   3. Crown Tipping Distally
   4. Crown Tipping Mesially
   5. Jigging

C. No Apparent Movement

E. All the lightwire subjects showed five main types of movements which were: (1) Type 3 (Tooth Elevated), (2) sub Type 6 (Crown Tipping Distally), (3) sub Type 4 (Axis of tipping in Apical Third of Root), (4) sub Type 5 (Axis of Tipping in Middle Third of Root), (5) Type 1 (Bodily Mesial Movement). Type 2 (Bodily Distal Movement) and sub Types 7 (Crown Tipping Mesially) Type 8 (Jigging) and Type 9 (No Apparent Movement) all showed minimal occurrences.
F. The Differential Forces Subjects demonstrated principally the same types of movements.

G. The Headgear subjects showed virtually the same pattern as did the entire group with the exceptions that Type 7 (Crown Tipping Mesially), and Type 9 (No Apparent Movement) show no occurrences at all.

H. The Leveling Arch Subjects showed an almost equal number of occurrences in each of five types of movement (Types 1, 3, and sub-Types 4, 5, and 6). It is interesting to note that all of the other types of movement occurred in minimal numbers and there were no occurrences at all in Type 2 (Bodily Distal Movement) and Type 7 (Crown Tipping Mesially).
II. Conclusion

In considering the entire group of light wire subjects, it was generally found that the tipping type of movements exceeded the bodily type of movements considerably. The most common occurrences through the entire group of movements were (1) Elevation of the Tooth, and (2) Distal Tipping of the Crown of the tooth. It was also noted that the axis of tipping of the tooth occurred more commonly in the apical third of the root than it did in the middle third of the root.

A similar pattern may be noted for each of the sub groups of treatment (Differential Forces, Headgear, and Leveling Arch Subjects). One distinction that the sub group treated initially with Differential Forces Arches demonstrated, is the fact that a considerable number of occurrences is shown in Column 9 (No Apparent Movement) whereas in the other treatment sub groups no occurrences or minimal occurrences of this movement are demonstrated. This is interesting in the light of the knowledge that two and sometimes three, two ounce elastics were exerting a mesial force on these anchor units.

Bodily Distal movement did occur to some extent with the Headgear subjects, however, this observation was far outweighed by the occurrences of distal tipping of the crown. The axis of this tipping occurred with these subjects in the middle third of the root nearly as often as it did in the apical third of the root.
The factor of mesial tipping of the crown did not occur at all in either the Headgear or the Leveling Arch sub groups, and quite naturally enough the Leveling Arch sub group demonstrated no occurrences of bodily distal movement.

It must be stated that the occurrence of distal tipping was both intentional and desirable. This movement was created through the medium of the angulated bracket (described in detail in the chapter on Methods and Materials).
BIBLIOGRAPHY


Jarabak, J. R. Personal communication.


APPENDIX I

DIFFERENTIAL FORCES SUBJECT

FIRST ARCH WIRE PLACED

76 DAYS LATER

DUPLICATES
APPENDIX III

DIFFERENTIAL FORCES SUBJECT

FIRST ARCH WIRE PLACED
FIRST ARCH WIRE PLACED

76 DAYS LATER
76 DAYS LATER

DUPLICATES
APPENDIX IV
HEADGEAR SUBJECT

FIRST ARCH WIRE PLACED

76 DAYS LATER

DUPLICATES
APPENDIX VI

DIFFERENTIAL FORCES SUBJECT

FIRST ARCH WIRE PLACED

76 DAYS LATER

DUPLICATES
The thesis submitted by Dr. J. Patrick Gantt, Jr., has been read and approved by four members of the Departments of Anatomy and Oral Anatomy.

The final copies have been examined by the Director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

[date]

Signature of Advisor