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

Kenneth LeRoy Kemp
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A ROENTGENOGRAPHIC STUDY OF TOOTH MOVEMENT DETERMINED BY THE CHANGES SEEN IN THE PERIODONTAL SPACE OF THE MANDIBULAR MOLAR TEETH DURING ANCHORAGE PREPARATION AND SPACE CONSOLIDATION WITH LIGHT FORCES

by

Kenneth LeRoy Kemp, 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

June

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ABOUT THE AUTHOR

Kenneth LeRoy Kemp, Jr., was born in Fredericksburg, Pennsylvania, on May 30, 1933. The elementary school education was received in Pennsylvania. In September of 1947 his family moved to Huntingdon, Tennessee. After graduating from Huntingdon High School in 1951, he studied for two years at Memphis State University, Memphis, Tennessee. The study of dentistry leading to a degree of Doctor of Dental Surgery was successfully completed in 1956 at the University of Tennessee, Memphis, Tennessee. He then served as a commissioned officer on active duty with the United States Navy Reserve from 1956 to 1958. The author began his graduate studies in June of 1959 at Loyola University, Chicago, Illinois.
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"The very spring and root of honesty and virtue lie in the felicity of lightening on good education."

... Plutarch

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CHAPTER I
INTRODUCTION

A. Introductory remarks

In recent years the trend of orthodontic thinking has changed from purely mechanical considerations to fuller concepts, placing more significance on the biologic principles involved in orthodontic tooth movements. Orthodontics is now thought of as a bio-mechanical science.

Orthodontic tooth movement depends upon bone resorption and bone formation stimulated by properly regulated pressure and tension. It has been shown that excessive orthodontic forces result in cessation of cellular activity in the periodontal membrane on the pressure side of the tooth, often causing necrosis. This excessive pressure diminishes blood circulation to such an extent that the only way the necrotic bone can be removed is by undermining resorption in order to allow the tooth to move in the direction of force. Furthermore, it has been demonstrated that there is an optimum range of force within which the movement tends to be more physiologic in nature.

The correlation of the biologic findings with the existing knowledge of sound mechanical therapy has created the
science of bio-mechanics. New techniques, employing light forces with highly resilient arch wires, have been developed to produce tooth movements more in keeping with our biologic knowledge. This has made it possible to accelerate the biologic processes associated with the physiology of tooth movement thus achieving orthodontic objectives in far shorter time than heretofore possible.

Investigations designed to study the position of anchor teeth during orthodontic treatment have been reported previously by numerous investigators. These studies utilized the principle of super-position of lateral cephalometric tracings which related the anchor teeth to certain cephalometric and craniometric landmarks. An attempt was then made to measure the respective positions of the anchor teeth during the course of treatment thus affording predictions of anchor stability. It has become exceedingly difficult to ascertain what is happening to the anchor teeth and the surrounding tissues because of the difficult visualization of the dentition from cephalometric radiographs due to super-position of left and right sides, errors in tracing techniques and distortion due to the diverging roentgen rays.

B. Statement of the problem

With the advent of the roentgen ray in dental diagnosis, the supportive tissues of the teeth received
considerable clinical significance, since they were readily identifiable. 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. The present study was designed to investigate the direction of tooth movement on the basis of direct roentgenographic appraisal of the changes in these areas around the mandibular molar teeth. It is partially a continuation of a previous study performed by Gantt (1960).

This investigation proposes an analysis of the roentgenographic changes in the periodontal space and cribriform plate surrounding the mandibular anchor teeth in patients at various periods of orthodontic treatment. It is believed that this method will more accurately display those areas of tissue activity which demonstrate the direction and type of tooth movement taking place at any precise time. It is hoped that this study will help to point out the value of intra-oral roentgenograms to the orthodontist as an important adjunct to the other diagnostic and treatment progress tools at his disposal.
CHAPTER II

REVIEW OF THE LITERATURE

Sandstedt (1904, 1905) was among the earlier investigators to employ histological techniques to examine orthodontic tooth movement. His experiments involved tipping dogs' incisors lingually by means of threaded arch wires tightened with nuts each day for three weeks. His conclusions were as follows:

(1) A deposition of new bone took place on the tension side (labial) along the old alveolar wall. The newly formed bone spicules followed the direction of the strained periodontal fibers. (2) The old alveolar bone on the pressure side was equally resorbed by weak forces. The surface of tooth root itself remained intact. (3) The periodontal soft tissue, with strong forces, was compressed at first on the pressure side preventing the old alveolar bone from resorbing because of the deprivation of its vital blood supply. Instead, an active resorption soon began in the neighboring marrow spaces of the alveolar bone working back toward the tooth and removing the intervening compressed (necrotic) hard and soft tissues. When all of this necrotic material was removed the tooth assumed a new position in one movement. Sandstedt called this the process of undermining resorption.
Oppenheim (1911 and 1928) was the first to employ a primate (baboon) for his studies of tooth movement. He applied a spring arch with ligatures for a period of forty days, leaving one-half of the jaw as a control. The movements, however, were performed on deciduous teeth.

Oppenheim's findings differed sharply from those of Sandstedt. Oppenheim maintained that the lamellae of the compact alveolar bone opened up as the result of weak forces by the influence of tension and pressure on both sides of the moved tooth; and that the bone transformed itself into a transitional spongiosa, the elements of which were arranged in the direction of force. The difference lay in the fact that Oppenheim described this old alveolar bone as newly formed bone, set vertically to the direction of pressure, because the free ends were surrounded by thick osteoid borders.

Oppenheim stated, as a result of his findings, that as a general rule, mild application of forces administered over long periods of time constituted the best orthodontic treatment. The normal reaction of the bone was lacking with the application of strong forces due to tearing of the periodontal fibers and thrombosis.

Johnson, Appleton and Rittershofer conducted their research in 1925 on two Macaque Rhesus monkeys, using the labio-lingual technique. The experiment, lasting for twenty-
six days in one animal and forty days in the other, demonstrated resorption and deformation of the root at the apex.

Johnson et al mentioned the amount of pressure sufficient to move a tooth as between one or two ounces. They described the movement of the incisor labially as a tipping action and showed that the apex moved in an opposite direction (lingually) to that of the crown. This was contrary to what Oppenheim had said. Oppenheim stated that the tooth under the influence of the orthodontic force moved like a single-arm lever, the apex of the root acting as the fulcrum point. Johnson differed by showing specimens in his experiments that the moved tooth acted like a two-armed lever and that the fulcrum was in about the middle of the root.

According to Gottlieb and Orban (1931) the physiologic width of the periodontal membrane was that width attained while the tooth was in function. The biologic width was that width of the periodontal membrane attained when the tooth was not in function. They found the physiologic width of the periodontal membrane to be greater than the biologic width. The adjacent hard bone was resorbed when the pressure applied to the tooth caused the width of the periodontal membrane to become less than the biologic width (if the tooth were out of function).

Schwarz (1932) stated that strong forces affect
different teeth with varying intensity. The movement of a
tooth by a strong tipping force also produced all degrees of
biologic reaction from the strongest to the weakest. The
pressure of the tooth acting against the alveolus decreased
as it approached the axis of rotation where the force was zero.

Gable (1945) presented two theories of periodontal
support; the fiber support theory and the theory of the incomp-
ressible membrane. Gable showed preference to the incomp-
ressible membrane theory concurring with the previous inves-
tigations performed by Synge (1933) and still later by
Hay (1939).

Gable saw that tissue filled the spaces between the
periodontal fibers and that this tissue was composed largely
of fluid outside of that in the blood circulatory system.
This fluid could not pass from one part of this space to
another because of its being impeded by solids also occupying
the space.

Synge pointed out that according to the fiber sup-
port theory the movement of the tooth should be in proportion
to the thickness of the membrane but with the theory of the
incompressible membrane, tooth movement would vary as the cube
of the membrane thickness.

Rather than assuming the membrane to be entirely
incompressible, Synge later considered the possibility of a
compressible membrane and May performed calculations using the actual figures expressing the compressibility of water.

May also investigated the pressures in various portions of the membrane surrounding the conical root of the maxillary incisor tooth being subjected to forces applied at different angles to the linguo-incisal edge. He found that even relatively small loads produced areas of ischemia of parts of the periodontal membrane. The capillary blood pressure was taken as 23 gm/cm, which was the average given by Schwarz.

The calculation of the location of the center of rotation under a transverse load was similar to that found earlier by Kronfeld (1931).

Schroff (1953) claimed the periodontal membrane to be composed of a loose fibrous connective tissue imbedded in a viscous tissue fluid. He further stated that the forces of occlusion were transmitted to the bone in two modes: first, as pressure due to the fluid content of the periodontal membrane and, second, as tension due to the collagen fibers.

It has been stated by Kronfeld (1949) that these pressure effects are rapidly dissipated due to the expulsion of fluid by way of the adjacent marrow spaces and vascular channels and, that the mechanism is similar to a "hydraulic and snubber shock absorber system".
Shroff, however, pointed out that to regard periodontal tissue fluid as a "simple fluid subservient to the ordinary laws of hydrostatics" was erroneous. He maintained this fluid to be quite viscous and, moreover, to be confined by a complex meshwork of fine and course collagenous fibers and cells. Applied pressure was not dissipated quite so rapidly as supposed and such pressure would not be equally transmitted in all directions as with simple liquids.

Huettner and Whitman (1956) added enormously to the understanding of what heavy forces do to the supporting tissues of the teeth undergoing orthodontic therapy. They treated experimentally nine Macaque Rhesus monkeys with the edgewise technique, while another was used for a control.

Several of the monkeys treated had had four first premolars extracted and the canine teeth were retracted into the extraction sites. It was found that in every one of the animals used there was always a distal movement of the anterior segment and at the same time there was a mesial movement of the posterior segments which were used for resistance.

They found histologically that "tip back" bends were the most damaging orthodontic movement and that torquing was the second most damaging. The so-called "tip back" bends did not prevent mesial movement of the posterior segments but did produce the most severe root resorption. They also found
that tipping the molar teeth in a distal axial inclination did not enhance their resistance to forward movement.

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. The intra-alveolar displacement of roots through the applied labio-lingual 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 (labio-lingual periodontal membrane width index) was chosen empirically as the criterion and referred to as the "marginal index".

Storey and Smith (1952) remarked that the question of whether there was an optimum force to move teeth that would give the best results had not been answered up to that time; nor had the question been answered of whether a force should be applied continuously or intermittently. These writers used the edgewise mechanism for experiments with wire spring forces of varying values to move canine teeth distally. The first permanent molars, together with second premolars, were used
as anchorage for the springs to move canines distally into the first premolar extraction sites.

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 discernable movement of the molar anchor units during the period that these experiments were conducted. This force range for moving the canine distally extends from 150 to 200 grams. The rate of movement of the canine decreased and finally approached zero by increasing the force above this optimum range. Also, with an increase of force, appreciable movement of the molar anchor unit appeared to be consistent with the behavior of the canine tooth, since the ratio of root surface areas between the canine and molar anchor unit was approximately 3:8. The maximum rate of mesial movement of the molar anchor unit occurred during application of 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 meant that
the canine was acting as the anchor tooth and the so-called molar anchor unit was being moved. There was no appreciable movement of the canine with values greater than 300 grams but rather the movement occurred in the molar anchor unit.

The tentative explanation given by Storey and Smith for different rates of movement of canines and anchor units, under heavy forces, was that the behavior conforms to the concept of undermining resorption, as previously presented by Sandstedt, and later supported by Schwarz.

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

Halderson, Johns, and Moyers (1933) claimed that in many instances the force exerted by the edgewise arch is over two pounds causing pathogenic tissue responses.

Reitan (1957) has shown that one of the first signs of orthodontic forces exceeding 200 grams is that of the lack of cellular activity which later is followed by hyalinization
in the periodontal membrane. Therefore, in retracting canine teeth, if excessive forces are applied we can expect cessation of cellular activity necessary for direct alveolar resorption resulting in a lack of canine movement. On the other hand, 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 anchor 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 anchor unit than upon the canine. The bone response in this case begins within twenty-four to thirty-six hours while the lengthy procedure of undermining resorption in the area adjacent to the canine teeth requires a greater amount of time. This explains anchorage slippage during the retraction of canine teeth. However, the anchorage unit is more stable when the canines are retracted by using light forces.

Wentz, Jarabak and Orban (1956) showed in their experiment that undermining resorption (induced through tooth jiggling created by the forces of traumatic occlusion) produced a larger periodontal space containing hyalinized connective tissue and osteoid tissue on both sides of the tooth. The larger the periodontal space became, the more osteoid and
hyalinized tissue was seen. These teeth became more and more mobile as this process continued.

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

The purpose of an article by Begg (1956) was to describe a technique for the application of optimum forces for tooth movement using stainless steel round arch wire 0.016 inch in diameter. Begg pointed out that the use of thin round steel arch wire raised the standard of results, as it eliminated the excessive high forces that were exerted by rectangular arch wire; also, active treatment time was greatly reduced. He maintained that these orthodontic force values caused least discomfort to patients, least loosening of the teeth, and least damage to the tooth-investing tissues, while at the same time they also moved teeth the most rapidly and were the most easily applied and controlled forces.

In this technique, advantage is taken of the principle that for moving anterior teeth with small root surface areas, 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 movement, while with this
large force, the posterior teeth move more rapidly.

The use of differential orthodontic forces makes it
possible to carry out simultaneously, and with much greater
efficiency, the various groups of tooth movement. Furthermore,
because the employment of differential forces in a reciprocal
manner makes it possible to move teeth more readily to their
required positions without also moving anchor teeth, it is
unnecessary to carry out the well-known preliminary operation
of "setting up anchorage" by putting treatment into reverse
in order to later prevent mandibular anchorage failure. 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.

Moyers (1950) stated that rather than speak of what
one appliance or another could or could not do in the way of
moving teeth, it was more correct to speak of what the perio-
donital membrane would allow one appliance to achieve and what
it would not permit another. His article dealt with the
physiologic limitations and the tissue responsible for them.
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 nourish 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 hindered the remaining vessels are still able to bring about repair and regeneration.

No single factor limits and controls the orthodontic therapy so much as the physiological response of the periodontal membrane to induced pressure strains. It determines whether tooth movement is possible or not, at which rate and manner and, to some extent, whether the tooth will retain its new position.

The periodontal membrane is involved in 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 osteous cellular elements which alter the trabecular framework of the alveolus may find their
origins in the periodontal membrane.

Histological studies do not confirm the use of the phrase "physiological 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 (Jarabak, 1960).

The usefulness of the roentgen 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 roentgenograms. Unfortunately, it is quite uncommon for the orthodontist to take or ever refer to intra-oral roentgenograms once the treatment has been initiated. This is unfortunate because the orthodontist is overlooking a fine indicator of treatment progress in the intra-oral roentgenogram (Jarabak, 1960).

Teleroentgenography, as discussed briefly by Schwarz (1957), is a comparatively new technique which, unfortunately, is hardly used in dentistry. In contrast to the customary
roentgenographic techniques, in teleroentgenography the roentgen ray tube is placed at a distance of about six feet from the plate to obtain parallelism of rays thus avoiding distortions.

The roentgenographic appearance of the cribriform 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 technique 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 a
broad bucco-lingual diameter and a blunt apex is most favorably formed to show the outline of the cribiform plate throughout its complete length. The cribiform 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 cribiform 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 this area. Another contradiction to the "even white line" is the apparent lack of 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 the 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 cribiform plate of fully developed, non-pathologic teeth, could be a clue to stress being exerted in that direction.

In 1953 Storey evaluated roentgenographically the results of his previous investigation which had been performed with Smith. Intra-oral roentgenograms had been taken at regular time intervals (14, 35, 59, 84 days) of the moved
canine teeth. There was a significant difference in the appearance of the bone laid down on the tension side after the application of various degrees of force. The bone was dense with light forces and the trabeculae were oriented in the direction of the applied force. With heavy forces the bone laid down was less dense and could be differentiated from the cribiform plate because the trabeculae were not oriented in the direction of the applied force. Using forces either below or above the optimum range caused the rate of tooth movement to decrease.

Storey showed many roentgenograms of the canine teeth but failed to show any of the molar anchor units. It is not known whether roentgenograms of the anchor units were taken but surely they could have enhanced his findings significantly. Teleroentgenological techniques were used in the author's study contrasted with the routine intra-oral roentgenographic (short cone) technique used by Storey in his investigation.

Massler (1954) reported on roentgenographic changes seen in the cribiform plate during various types of tooth movement. He studied one thousand full mouth roentgenograms, under magnification, of patients having been treated by orthodontics. His findings showed that during tooth movement the cribiform plate became distinctly wider and more radiopaque
on the side of tension and disappeared on the side of pressure. The periodontal space, at the same time, became wider on the side of tension and very narrow on the side of pressure. Changes in the cribiform plate revealed the type of tooth movement that occurred (tipped or bodily and in which direction). Buccal and lingual movements, however, could not be analyzed with certainty.

The cribiform plate, which had previously been resorbed, was filled in with bone during retention (the previous area of pressure had now become the site of new bone formation). He showed histologically that the newly formed bone, which was deposited during tooth movement, was fibrous in nature, and that this fibrous bone soon became organized into lamellated bone. The newly formed fibrous bone appeared thick and radiopaque in the roentgenogram and when it re-organized into lamellar bone the roentgenogram showed it to be thinner and much less radiopaque.

Massler stated that newly calcified bone was more radiopaque in any part of the body that could be observed roentgenographically, and that the thickness and degree of radiopacity of the cribiform plate in the roentgenogram indicated the area and the amount of new bone formation and therefore, also the direction and amount of tooth movement.

Hemley (1955) in an article attempted to apply the
clinical significance of tissue changes incidental to tooth movement. Hemley presented no new material but merely reviewed the literature which had dealt with tissue reaction in the past. He intended to interpret this material and findings in order to develop a rationale for the application of biologic principles to clinical practice.

He stated that when a pressure force was exerted on bone with an orthodontic appliance the force did not act directly on the bone at the site of pressure, but rather was exerted on the periodontal membrane. This caused a compression of the periodontal membrane on the pressure side resulting in a narrowing of the tissue and vessels in that area concomittantly with blood stasis. He went on to state that it was possible to note the change of the periodontal space to environmental alterations through the study of roentgenograms of patients who were undergoing orthodontic therapy.

Elfenbaum (1958) stated 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 the cribiform plate in the tension areas. Bodily movements are demonstrated by an even thickened cribiform plate in the tension area. There is a reduction in the thickness of the cribiform plate caused by root pressure when a tooth is being moved orthodontically. Allenbaum further stated that in single rooted teeth the center of rotation was located within the root and that in a molar the fulcrum was located in the bone septum between the roots.

Gantt (1960) studied roentgenographically the molar anchor units of patients being treated orthodontically with light forces and concluded that the most common movements were elevation and distal tipping of the tooth. He also found that the axis of rotation was most commonly found to be in the apical third of the root.

Jarabak (1960) demonstrated by means of intra-oral roentgenograms that during anchorage preparation the mandibular molars changed from a mesially inclined position to an upright venue with the fulcrum located near the apices of the distal roots. He also presented intra-oral roentgenographic evidence that resorption and apposition of bone approximated physiological balance when the differential forces technique was employed. This was substantiated by observing that the periodontal space remained small during treatment.
CHAPTER III
METHODS AND MATERIALS

A. Subjects for investigation

Seventeen children with malocclusions (neutroocclusion or distocclusion) requiring orthodontic therapy were used in this investigation. The sample was made up of nine females and eight males. The distribution of material by age is presented in Table 1. The patients selected for subjects in this study were all treated by the graduate students in the Orthodontic Department of Loyola University School of Dentistry utilizing the principles of the Light Wire Technique. Their records were taken simultaneously from the time immediately prior to orthodontic treatment, again during mandibular anchorage preparation (a clinical term meaning the uprighting of the mandibular molar and premolar teeth), and twice during the space consolidation (closure of spaces). Sixteen intra-oral roentgenograms were taken on each subject for a total of 272.

The subjects were divided into those with malocclusions which required extraction of four first premolar teeth, and those with malocclusions which did not require extraction
TABLE I

DISTRIBUTION OF THE SUBJECTS BY AGE

<table>
<thead>
<tr>
<th>AGE (years)</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>4</td>
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<tr>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
</tr>
</tbody>
</table>

Mean 12.05 Total 17
of teeth. Nine subjects with malocclusions which required extraction of teeth were treated with differential forces derived from vertical spring appliances. Five subjects with malocclusions which did not require extraction of teeth were treated with extra-oral forces from cervical headgear. An exception to this rule, however, was a group of three subjects treated with leveling arch wires in the mandibular arch. The orthodontic appliances will be elaborated upon under a later heading.

B. Methods of study

The methods used to obtain data for this study were from two sources as follows: (1) a lateral cephalometric roentgenogram was made for each subject using the Universal Cephalometrix apparatus (Figure 1); (2) a headpositioner for orientation of the head, constructed by P. W. Steiner of Chicago, Illinois, was adapted (Gantt) and attached to the crossbar of the Universal Cephalometrix apparatus in a position thirty inches from the focal point of the roentgen ray tube (Figure 2). This distance was one-half the fixed distance (sixty inches) from the focal point of the roentgen ray tube to the Universal cephalostadt (Figure 1). The reason for attaching the Steiner headpositioner to the crossbar at a distance of thirty inches from the roentgen ray tube was to reduce the amount of radiation time the subject had to
FIGURE 1

THE UNIVERSAL CEPHALOMETRIX APPARATUS
FIGURE 2

SUBJECT PLACED IN HEADPOSITIONER
receive in order to adequately expose the intra-oral roentgenograms. This virtually eliminated the factors of enlargement and distortion due to the parallel rays. The use of a headpositioner was a necessity in order to prevent distortion errors due to movements of the subject's head, and to allow the operator to replace the subject into the headpositioner in the same spatial relation to the roentgen ray tube each successive time a record was taken.

An adapter (Figure 3) was constructed to attach the Steiner headpositioner to the transverse bar of the Universal apparatus. This adapter consisted of the following parts: (1) A vertical arm which was attached to the horizontal transverse bar of the Universal cephalometric apparatus; (2) A horizontal arm with a sleeve which fit over the vertical arm of the adapter and was attached to it at a right angle. The Steiner headpositioner also had a sleeve which fit over the horizontal arm of the adapter. These two sleeves were secured in a position by large thumb screws which allowed the arms to be fully adjustable. The sleeves were drilled and tapped and outfitted with set screws and lock nuts which gave the sleeves a very close tolerance fit.

The Steiner headpositioner, when fixed at a set distance from the roentgen ray tube was adjustable in two planes of space. It could either be raised or lowered on
FIGURE 3

HEADPOSITIONER WITH ADAPTER
the vertical arm or moved in or out on the horizontal arm by adjustment of the thumb screws. Attached to the vertical bar was a millimeter scale which enabled the operator to determine the amount of vertical distance desired to move the headpositioner with relation to the roentgen ray tube. This vertical distance had been previously determined for each subject from lateral cephalometric roentgenography. The horizontal arm also was equipped with a millimeter scale which allowed horizontal movements to be measured as required by the individual subject.

The two ear posts of the Steiner headpositioner were slotted and marked with lead indicators in their respective centers in order to have an index by which they could be aligned. It was necessary to align the two ear posts so that the central roentgen ray would pass directly through their centers, thus super-posing the two lead indicators exactly in the horizontal and vertical planes of space. The ear rods were aligned and their super-position recorded. (Figure 4)

In order to obtain lateral cephalometric roentgenograms, it was necessary to remove the Steiner headpositioner from the adapter assembly between each subject. It was also necessary to adjust the vertical and horizontal position each time a record was taken. The vertical and horizontal adjustments were necessary because the headpositioner had to be
Figure 4

Super-Position of the Ear Rods
adjusted for the different coordinate distances which were derived for each subject from the cephalometric tracings. A test was conducted in order to establish accuracy of the operator's ability to successively disassemble and reassemble the headpositioner on the adapter so that the ear rod indicators were always super-posed upon each other. Eight successive radiographs were taken, one after each reassembly of the apparatus, with the intra-oral roentgenogram taped to the distant ear post. An indication of the accuracy of this test of the apparatus is demonstrated in Table II.

Naturally, some error existed in the consistancy of film placement and in the adjustment of the apparatus, and in placement of the subject in the headpositioner. However, the accuracy of the apparatus was adequate, and an honest attempt was made to minimize the other errors inherent in this study.

C. Tracing Technique

A cephalometric roentgenogram was taken of each subject with the teeth in median occlusion. A tracing was made for each of these headplates which included the Frankfort Horizontal Plane and the teeth in the mandibular anchorage unit (Figure 5). Since this study was concerned with the change in width of the periodontal membrane adjacent to the mesial and distal root surfaces of the mandibular first molar
### TABLE II

**TEST FOR ACCURACY OF APPARATUS**  
(after Gantt)

<table>
<thead>
<tr>
<th>Picture No.</th>
<th>Distance between Centers in mm.</th>
<th>$d^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3.6</td>
<td>14.44</td>
</tr>
<tr>
<td>1</td>
<td>2.1</td>
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<tr>
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<td>3</td>
<td>3.2</td>
<td>10.24</td>
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<tr>
<td>4</td>
<td>1.3</td>
<td>1.69</td>
</tr>
<tr>
<td>5</td>
<td>2.5</td>
<td>6.25</td>
</tr>
<tr>
<td>6</td>
<td>2.7</td>
<td>7.29</td>
</tr>
<tr>
<td>7</td>
<td>2.7</td>
<td>7.29</td>
</tr>
</tbody>
</table>

**Total** 8  

$$\frac{(d)^2}{N} = 53.561$$  

$$\frac{(d)^2}{N} = 428.49$$  

$$\sigma^2 = C. F. = 3.809$$  

$$N-1 = 7 \quad 3.809 : 7 = .5441$$  

$$= .5441 \quad \times .737631 = 1.744497315$$  

95% Level 2.365 x 1.744497315 = 4.105

Magnification = 5.5x 1.7444 - 5.5 = 0.317

Circle of Confusion = 0.317 mm.
FIGURE 5

A TRACING OF A LATERAL CEPhALOMETRIC
ROntGENOGRAM WITH HORIZONTAL
AND VERTICAL CO-ORDINATE LINES
teeth, it was desirable to adjust the headpositioner so that the central roentgen ray would pass through this area. A vertical coordinate was drawn down through the center of the ear rod perpendicular to the Frankfort Horizontal Plane to the level of the vertical center of the mandibular anchor teeth. A horizontal coordinate was then drawn perpendicular to the vertical coordinate connecting a point made in the center of this molar area. This line was, therefore, parallel to the Frankfort Horizontal Plane. The lengths of these two lines were measured in millimeters and recorded for each subject. These were the vertical and horizontal distances to which the headpositioner was then adjusted. The adjustments were initiated from the horizontal and vertical "zero" points which were arrived at in centering and super-posing the two ear rod indicators. The headpositioner was thus adjusted for each subject in order to allow the central ray to pass through the center of the area of the mandibular anchorage unit. In this manner the error of distortion was minimized.

The radiographic film used in taking the cephalometric lateral head roentgenograms 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 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 0-1, double coated dental film. The machine setting was the same as mentioned previously, but the exposure time was two and one-half seconds for each intra-oral roentgenogram.

D. Measurements

The subject was placed in the headpositioner after it had been adjusted to the previously determined measurements. Four intra-oral roentgenograms, two of the left and two of the right mandibular anchorage units, were taken prior to treatment. A new lateral cephalometric roentgenogram was taken during anchorage preparation and the headpositioner adjusted to the new measurements. The subject was again placed in the headpositioner and another set of four intra-oral roentgenograms taken. This same procedure was followed for those sets of intra-oral roentgenograms taken twice during space consolidation in the mandibular arch.

All four series of intra-oral roentgenograms were developed with time and temperature constant. The developing time was four minutes and thirty seconds, fixing time was ten minutes and wash time was twenty minutes. The temperature for these solutions was always kept at sixty-eight degrees
Fahrenheit. The concentration of fresh developer and fixer solutions was also kept as constant as possible.

The intra-oral roentgenograms taken on each subject consisted of four series. Two roentgenograms were taken of the mandibular anchor unit on the right side. The first film was marked 1A. A duplicate film, marked 1B, was taken (as stated previously) to provide a check of accuracy and to provide a larger number of readings to minimize error. A second series of two films was taken for the right side of the arch seventy-six days later, during anchorage preparation, and marked 2A, the original of the follow-up records and 2B, the duplicate of it. The third (174 days later) and fourth (324 days later) series were taken twice during space consolidation and marked 3A, 3B, 4A and 4B respectively. This same procedure was followed on the left side and marked 1C, 1D, 2C, 2D, and 3C etc. These sixteen intra-oral roentgenograms, four originals and four duplicates for both left and right sides, constituted the records for each subject.

The pre-treatment intra-oral roentgenograms (both right and left sides) for each subject were then transilluminated on a tracing table under a stationary three power magnifying lens and 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 mandibular molar tooth represented on the roentgenogram. They were labeled "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 6). These areas were selected on the pre-treatment intra-oral roentgenograms for each subject and marked at a place adjacent to each marginal and apical area where the periodontal space was clearly distinguishable. These pre-treatment roentgenograms, thus marked, were then superposed over each of the other roentgenograms individually in the four series. The perforation marks were then transferred by pressing the fine needle through the perforations and into the underlying roentgenogram. Thus it was possible to compare very nearly the same areas of the periodontal space on each of the intra-oral roentgenograms taken during the four treatment intervals. This was done on the 272 intra-oral roentgenograms taken in this study.

The intra-oral roentgenograms were then bound as slides and projected on a plain white poster board screen at a fixed distance (eight feet) 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
Figure 6

Areas at which change in width of periodontal space was evaluated prior to treatment.
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. R. Jarabak).

A technique was devised to compare the change in the width of the periodontal space on the mesial and distal root surfaces of these anchor molar teeth. A strip of plain white paper one inch wide and ten inches long was divided lengthwise into four sections (A, B, C, D), each corresponding to one of the four areas marked on the roentgenograms (previously described). In each section a vertical straight line was drawn and labeled as a reference line (Figure 7). The roentgenogram numbered 1A was then projected onto the screen and the white paper strip was interposed and placed against the screen. The reference line in section "A" was superposed 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 indicated for this area; and then a short vertical line representing this distance was drawn with a sharp red pencil on the white paper.
FIGURE 7

REFERENCE STRIP
strip parallel to the reference line. This procedure was followed for points "B", "C", and "D" on the same paper strip (Figure 8). (Figure 9 shows graphically the same areas - A, B, C, and D for the roentgenograms of the second series).

The next roentgenogram, numbered 2A, the record taken during 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 measured width of the periodontal space on this follow-up, during anchorage preparation roentgenogram (Figure 10). Thus, the difference between the red and blue pencil lines represented the change that had taken place in the width of the periodontal space of these records during the anchorage preparation period. If the blue line fell between the red line and the reference line, the space was evaluated as having decreased in width; but, if the blue line fell outside the red line, the space was evaluated as having increased in width. Thus, by weighing the proportionate amount of change and the direction of such change, it was possible to determine the direction and the relative type of movement of the mandibular molar teeth being investigated. This same measuring procedure (with different colored lines being drawn) was followed for those roentgenograms of the third and fourth series taken during the initial and final periods of space consolidation. This procedure was
FIGURE 8

EVALUATION OF AREAS

A, B, C, D, PRIOR TO TREATMENT
FIGURE 9
SAME RESPECTIVE AREAS AT WHICH CHANGE IN WIDTH OF PERIODONTAL SPACE WAS EVALUATED DURING PREPARATION OF ANCHORAGE
FIGURE 10

EVALUATION OF AREAS A, B, C, D,
DURING PREPARATION OF ANCHORAGE
used for each of the 272 roentgenograms. The descriptive evaluation of the direction and type of movement which the teeth underwent was then calculated.

In order to reduce error, the four roentgenograms for each treatment interval (the four series) were projected simultaneously on white poster board using the same enlargement factor of 20:1. This was done by using four identical Kodak projectors. The evaluations of the type and direction of tooth movement were affirmed by visual examination of these films. Additional information which was gained from the gross visual interpretation of the roentgenograms was amended to and correlated with the descriptions which had been previously calculated.

The roentgenograms for the four treatment intervals for each subject were again projected on the screen simultaneously, using four identical Kodak projectors, with the same enlargement factor of 20:1. The changes in the structure of the cribriform plate were carefully appraised subjectively and noted for the left and right mandibular molar anchor teeth for each subject.

E. Appliance Design

Each of the subjects was fully banded using angulated brackets on the bands. The brackets were angulated from the horizontal in order to give the teeth a distal angulation (tip-
ARTISTIC ALIGNMENT OF ANTERIOR TEETH

MESIO-DISTAL BRACKET ANGULATION

MAXILLA
5° OR 7°

OCCLUSAL PLANE

MANDIBLE
FIGURE 11

BRACKET ANGULATION FOR THE ANTERIOR AND POSTERIOR PARTS OF THE MOUTH
back) when a straight wire was fitted into the bracket boxes (Figure 11, Courtesy of Dr. J. R. Jarabak).

In this study only those subjects were used who were treated with light, highly resilient, round arch wires. The entire group of seventeen subjects was treated employing initial arch wires of .016 inch diameter Brigsiloy Semi-spring wire. Prior to their insertion, all arch wires were tempered to spring hardness after having been first fashioned individually for each subject.

Nine of the subjects were treated with differential forces appliances placed in both maxillary and mandibular arches. Most of these subjects required extraction of the four first premolar teeth due to insufficient arch length. This type of arch wire employed 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 extended distally through the buccal segments of the dental arch. These straight posterior segments were slightly curved in the horizontal plane of space to provide some arch form. (Figure 12 shows a typical helical loop arch). These subjects were also required to wear rubber elastics. These elastics were made of latex rubber 1/4 inch in diameter. They were of two types: (a) Light 1/4 inch elastics, which exerted an average pull of two ounces, and
FIGURE 12
A TYPICAL HELICAL TORSION LOOP ARCH
WIRE FOR DIFFERENTIAL FORCES APPLIANCE
(b) Heavy 1/4 inch elastics which exerted an average pull of three to four ounces. These averages were obtained when the elastics were stretched a distance of about one and one-quarter inches, this being the average distance from the buccal tube of the mandibular first molar band to the hook on the arch wire mesial to the mandibular canine tooth.

These subjects 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 mandibular molar tooth to the bent-in hook located mesially to the mandibular canine bracket (intra-maxillary elastic); (b) one 1/4 inch light elastic worn from a hook located on the lingual surface on the band on the mandibular first molar tooth to the bent-in hook located mesially to the maxillary canine bracket (oblique inter-maxillary elastic); (c) one 1/4 inch heavy elastic worn buccally from the mandibular to the maxillary arch as a triangle having its base on the maxillary arch and its apex on the mandibular arch. This elastic worn in a "triangular" fashion was attached from the end of the maxillary arch wire on the first molar to a ligature wire hook (pigtail) on the maxillary second premolar tooth and then down to a similar ligature wire hook on the mandibular second premolar tooth. (Figure 13 shows a subject with arch wires ligated into place and elastics in position).
FIGURE 13

ARCH WIRES IN PLACE AND ELASTICS IN POSITION
Five subjects, who did not require extraction of teeth, were treated with the use of extra-oral forces from cervical headgear applied to the mandibular arch. 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. There were two sections of .010 open coil spring placed on the wire to advance two sliding hooks (Figure 14). The distal end of the section of open coil spring was placed against the bracket of the mandibular first premolar and the hook was advanced by the coil to a position mesial to the mandibular canine. In these subjects the 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 hooks from the cervical headgear were attached bilaterally to the sliding hooks in the mouth. The cervical headgear hooks in turn were attached extra-oral to the material from which the headgear was constructed by means of "X" type Orthospec elastics. (Figure 15 shows an example of the cervical headgear, the manner in which it was worn, and the way in which the extra-oral hooks were attached from it to the mouth). In these subjects heavy 1/4 inch elastics were also worn in the same triangular manner as previously described.
FIGURE 14

ARCH WIRE WITH ATTACHMENTS FOR USE WITH
EXTRA ORAL FORCES FROM CERVICAL HEADGEAR
FIGURE 15

THE APPLICATION OF EXTRA ORAL FORCES FROM CERVICAL HEADGEAR TO THE MANDIBULAR ARCH
Finally, the remaining three subjects were treated using the same type of .016 inch diameter round Bigiloy wire as was used in all of the arch wires for the other subjects. However, these arch wires were used primarily to level the mandibular plane of occlusion only. 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. They carried no attachments or bent-in vertical helical loops or hooks (See Figure 16). These arch wires were used to affect minor tooth movements in an otherwise well shaped mandibular dental arch. In these cases 1/4 inch heavy elastics were applied in the previously described triangular fashion.

All of the arch wires used on these subjects were constructed from .016 inch diameter round Bigiloy wire. Bigiloy is a cobalt-base alloy compounded of eight materials. These are cobalt, 40%; chromium, 20%; nickel, 15%; molybdenum, 7%; manganese, 2%; beryllium, 0.04%; carbon, 0.15%; and iron, the balance.

A brief explanation is due concerning the three types of arch wires just described and their application in the treatment of the subjects. The differential forces appliances were used in nine subjects who, due to the discrepancy of arch length available to tooth size and/or the discrepancy in the
FIGURE 16

IDEAL ARCH WIRE WITH NO ATTACHMENTS

FOR LEVELING MANDIBULAR OCCLUSAL PLANE
relation of arch to arch, required the extraction of four first premolar teeth. This appliance was employed to accomplish several different types of tooth movement simultaneously. However, this study was concerned with the preparation and maintenance of the mandibular anchorage during space consolidation and the type of tooth movement seen in the mandibular anchor units during these periods of orthodontic treatment. Extra-oral force from cervical headgear was used in the preparation of the mandibular anchor units in those subjects which had malocclusions not sufficiently severe to require the extraction of permanent teeth. The extra-oral force (from 10 - 14 ounces) 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 (the immediately adjoining section of bone which underlies the apices of the teeth) was obtained. The ideal arch wires used in the treatment of the remaining subjects were employed to level the plane of occlusion and to prepare only the anchorage necessary for minor tooth movements and bracket alignment and, as in all of the subjects, to establish a more favorable vertical dimension. This was the purpose of these ideal arch wires in otherwise well situated mandibular dental arches.
The arch wires used for consolidation (closure) of spaces were identical in both the extraction and non-extraction subjects (See Figure 17). These wires had hooks bent into the arch wires just distal to the lateral incisors in order that latex elastics spanning from the anchor units could be attached. First order bends were also employed in these ideal arches.
FIGURE 17
ARCH WIRE FOR CONSOLIDATION OF SPACES
CHAPTER IV

EXPERIMENTAL RESULTS

A. Introduction

The seventeen subjects studied in this roentgenographic investigation were divided into those with malocclusions requiring extraction of maxillary and mandibular first premolar teeth, and those with malocclusions not requiring extraction of teeth. Many diagnostic factors, such as arch length discrepancy, facial profile, appraisal of lateral cephalometric roentgenograms, and age of subject, were taken into consideration to determine whether it was necessary to extract teeth in order that a satisfactory treatment could be attained.

Nine subjects with malocclusions which required extraction of the four first premolar teeth were treated with differential forces derived from vertical spring appliances. Five subjects with malocclusions not requiring extraction of teeth were treated with extra-oral forces from cervical headgear. There were, however, three exceptions to this general rule. These were the three subjects which were treated with leveling arch wires, primarily to level the occlusal plane and to affect minor tooth movements in an otherwise well shaped
mandibular dental arch. The various malocclusions of all three of these subgroups were treated utilizing the principles of the Loyola University Light Wire Technique.

The records in this study were appraised with regard to roentgenographic changes seen in the width of the periodontal space during orthodontic tooth movement for a 324 day treatment interval. There were four series of records taken; prior to treatment, (before tooth movements were started), during the preparation of anchorage (a clinical term meaning the resistance used to overcome an applied force which was done by uprighting the mandibular molar and premolar teeth), and twice during space consolidation (the closure of spaces). The results of the first two series were previously reported by Gantt.

The period of treatment termed space consolidation was used for both the extraction and non-extraction groups of subjects since the orthodontic mechanics involved were basically the same. Obviously there were more spaces to consolidate for those subjects in which teeth had been extracted. The canine teeth had been retracted into the space provided by extraction of the first premolar teeth at the same time anchorage was being prepared. Consolidation of spaces in the subjects which required extractions
consisted of tipping the four incisor teeth in a lingual direction over their apical base (the immediately adjoining section of bone which underlies the apices of the teeth). In a majority of the subjects not requiring extractions slight spaces were created between the mandibular canine and first premolar teeth (the points of application of the extra-oral distal force from the cervical or occipital headgear) during anchorage preparation. These spaces were then utilized to upright the mandibular canines and to realign the four incisor teeth, thus improving arch form. The consolidation arch wire and the mechanics to close the spaces were basically the same for both the extraction and non-extraction groups of subjects (Figure 17).

The findings were evaluated by projecting the roentgenograms individually on white poster board with an enlargement factor of 20:1 in order to reduce error. This was done to be in keeping with the method used by Gantt. The changes in width of the periodontal space of the mandibular first molar teeth were evaluated in four areas. 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 6). The manner in which the molar tooth moved during each of the stages in treatment was noted. All four areas were appraised as having increased or decreased in
width or as not having changed in width at all.

Since the appraisals in this study were subjective, the roentgenograms were again projected, with the same enlargement factor and visually reappraised by several other observers to eliminate bias and to reduce error. The direction of tooth movement which had been previously determined by the principle investigator was confirmed or modified by others.

B. Evaluation of the width changes of periodontal space

Two hundred and seventy-two records (intra-oral roentgenograms) were taken in this study, half (136) of which were originals and the other half duplicates. A significant similarity was obtained between the original and duplicate records. Each record had four areas of the periodontal space to be evaluated at four different treatment intervals (each of the four series). Therefore, there were 544 (136 x 4) evaluations for the original records and the same number for the duplicates. It was found that in thirty two instances the duplicate evaluations did not agree with those of the originals, so that 94.1% of the evaluations did coincide. It was also found that out of a possible 1,088 evaluations, only thirty-five (3.2%) could not be read with any reasonable degree of accuracy.

The types of tooth movements were placed into five main classifications; (1) bodily movements, (2) tipping movements, (3) elevation (actually a bodily movement also),
(4) a jiggling movement (tooth rocking mesially and distally), and (5) no apparent movement. The bodily movements were subdivided into mesial or distal directions. The tipping movements were subdivided according to (a) the location of the axis of the tipping movement, and (b) the direction of the tipping movement (mesial or distal). It should be understood that the elevation of the tooth could be combined with either tipping or bodily movements.

Table III shows (by numbers) the types of tooth movements and their subdivisions which were observed for (1) the subjects treated with differential forces appliances, (2) the subjects treated with extra-oral forces (anchorage from cervical or occipital headgear), (3) the subjects treated with leveling arch wires, and (4) the entire sample of subjects treated by the Loyola University Light Wire Technique. It can readily be seen from this table that certain types of movements were demonstrated more frequently than others.

1. Subjects which required extractions

Nine subjects (18 teeth) which require extraction of teeth were treated with differential forces appliances. Two of these teeth showed mesial bodily movements (Figure 22), fourteen showed distal tipping (Figure 18), and one showed a jiggling movement (Figure 23). All of these teeth also showed
### TABLE III

OBSERVATIONS OF TOOTH MOVEMENTS

<table>
<thead>
<tr>
<th>MOVEMENTS</th>
<th>TREATMENT OF SUBJECTS</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Differential Forces (18 teeth)</td>
<td>Extra-oral Forces (10 teeth)</td>
</tr>
<tr>
<td>Bodily</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesial</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Distal</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tipping</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesial</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Distal</td>
<td>14</td>
<td>10</td>
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<tr>
<td>Elevation</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>Jiggling</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>No Apparent</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Axis of Distal Tipping

<table>
<thead>
<tr>
<th>Axis of Distal Tipping</th>
<th>Differential Forces (18 teeth)</th>
<th>Extra-oral Forces (10 teeth)</th>
<th>Leveling (6 teeth)</th>
<th>(34 teeth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Third of Root</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Middle Third of Root</td>
<td>10</td>
<td>8</td>
<td>3</td>
<td>21</td>
</tr>
<tr>
<td>Lower Third of Root</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>
FIGURE 18

ROENTGENOGRAMS OF SUBJECT TREATED WITH
DIFFERENTIAL FORCES APPLIANCE SHOWING DISTAL TIPPING
elevation except one which showed no apparent movement.

The roentgenograms for the two teeth which moved bodily in a mesial direction showed an increase in the width of the periodontal space at the marginal (point "C") and apical (point "D") areas along the distal root surface. Most of this movement had already occurred before the second series of records was taken during anchorage preparation.

Elevation was evidenced by an increase in width of the periodontal space at the apices of the roots. This was readily seen at the mesial root apex of the distally tipped teeth.

The teeth which tipped distally showed a decrease in width of the periodontal space at the two pressure areas (point "B", apical area of mesial surface of mesial root and point "C", marginal area of distal surface of distal root). They also showed a corresponding increase in width of the periodontal space at the two tension areas (point "A", marginal area of mesial surface of mesial root and point "D", apical area of distal surface of distal root). Again, most of the elevation and distal tipping movements was seen during the anchorage preparation treatment interval (series two).

The jiggling movement was seen during the anchorage preparation interval (series two) as an increase in width of the periodontal space in all four areas evaluated (points A, B, C, and D). This generalized increase in width of the periodontal
FIRST ARCH WIRE PLACED
(SERIES 1)

DURING ANCHORAGE PREPARATION
(SERIES 2)

INITIAL SPACE
CONSOLIDATION PERIOD
(SERIES 3)

FINAL SPACE
CONSOLIDATION PERIOD
(SERIES 4)

FIGURE 19
ROENTGENOGRAMS OF SUBJECT TREATED
WITH EXTRA ORAL FORCES FROM HEADGEAR
SHOWING DISTAL TIPPING AND ELEVATION
space was seen to have decreased during the following two space consolidation intervals (third and fourth series).

The roentgenograms for the one tooth which showed no apparent movement did not present any noticeable variation in width of the periodontal space in any of the four series taken. This is not to say that the tooth did not actually move; but rather, the roentgenographic evidence certainly showed no indication of movement.

A comparison was made of the degree of movements noted in the second, third, and fourth series as seen in the changes in width of the periodontal space. It was found that the greatest variations in width occurred during anchorage preparation (second series, 76 days after treatment began). A greater variation in width was found during the initial period of consolidation (third series, 174 days after treatment began). In the two periods of space consolidation (third and fourth series) the periodontal space appeared to gradually decrease in width in those areas which had formerly been increased during anchorage preparation (second series); and to increase in width in those areas which had formerly been decreased during anchorage preparation. That is to say, the areas of the periodontal space which had increased or decreased in width during anchorage preparation were found to be returning to their former width (as seen in first series) during the two
periods of space consolidation. It was noted that during the final period of consolidation (fourth series) the periodontal space approached its normal width as seen prior to treatment in the first series (Figure 18).

2. Subjects which did not require extractions

Five subjects (10 teeth) which did not require extraction of teeth were treated with extra-oral forces from cervical headgear. All ten of these teeth showed distal tipping and elevation (Figure 19). These combined movements were most apparent during the anchorage preparation treatment interval (series two). The variations in width of the periodontal space were seen to reduce during the following two series of records taken during space consolidation. The width of the periodontal space was seen to be approaching its former (prior to treatment) width after anchorage preparation. This finding was similar to that of the extraction subjects.

3. Subjects treated with leveling arch wires

Three subjects (six teeth) were treated with leveling arch wires in the mandibular arch. One of these teeth showed a mesial bodily movement and five showed distal tipping movements. All six of these teeth, however, showed elevation. These movements were evidenced by the respective changes in width of the periodontal space as described previously. The variations in width of the periodontal space were greatest during the anchorage preparation treatment interval (series two). During
FIGURE 20

ROENTGENOGRAMS OF SUBJECT TREATED
WITH LEVELING ARCH WIRES SHOWING
CHANGES OF RESIDUAL CRIBRIFORM PLATE
the two periods of space consolidation the periodontal space approached its former width as seen in the other two subgroups.

4. The entire sample of subjects

The most common type of movement of the mandibular first molar for the entire sample of subjects was elevation. This was shown by thirty-four of the thirty-five teeth studied. Twenty-nine of these elevated teeth also showed distal tipping movements. This combined distal tipping - elevation movement was both intentional and desirable.

Very little difference in tooth movement was found when the subjects which required extraction of teeth were compared with the subjects which did not require extraction of teeth. The main difference was that the three teeth which showed a mesial bodily movement were all from subjects in which teeth were either congenitally missing or had been extracted. However, the mesial bodily movement of these teeth in each subject was found from the respective treatment records to have been intentional due to an excessive amount of arch length available. Therefore, with the deliberate mesial bodily movements being discounted, it can be stated that there was little significant difference in the roentgenographic findings between the extraction and non-extraction groups of subjects concerning the movements of the mandibular molar anchor teeth in this roentgenographic study.
FIRST ARCH WIRE PLACED  
(SERIES 1)  

INITIAL SPACE  
CONSOLIDATION PERIOD  
(SERIES 3)  

DURING ANCHORAGE PREPARATION  
(SERIES 2)  

FINAL SPACE  
CONSOLIDATION PERIOD  
(SERIES 4)  

FIGURE 21  
ROENTGENOGRAMS OF SUBJECT TREATED WITH  
EXTRA ORAL FORCES FROM HEADGEAR SHOWING  
AXIS OF DISTAL TIPPING IN MIDDLE THIRD OF ROOTS
FIGURE 22

ROENTGENOGRAMS OF SUBJECT TREATED WITH DIFFERENTIAL FORCES APPLIANCE SHOWING MESIAL BODILY MOVEMENT
C. Subjective appraisal of changes in cribriform plate

The changes seen in the structure of the cribriform plate during each of the four intervals of treatment (the four series) were evaluated by careful subjective appraisal. This was done for each subject by projecting the roentgenograms of all four series simultaneously on white poster board with the same enlargement factor of 20:1. The investigator obtained the assistance of two individuals (an orthodontic graduate student and a member of the faculty) to appraise the changes seen in the cribriform plate.

Twenty-two of the thirty-four mandibular first molar teeth studied showed definite changes in the relation of the cribriform plate to tooth root surface. The most outstanding change seen was an increase in the width of the interfacial area between the cribriform plate and the root surface of the elevated tooth at the fundus of the alveolus. While the mandibular molar was being distally tipped it also moved occlusally to such an extent that the distance between the root surface and the former or residual cribriform plate had increased considerably, particularly at the mesial root apex. A deposition of new bone was seen in the apical region of the fundus between the root surface and the remnant of the former cribriform plate. The former cribriform plate was shown to have disappeared (fourth series) in seven of these twenty-two records (Figure 19).
The remaining fifteen records also showed a decrease in radiopacity of the residual cribriform plate during the initial period of space consolidation (third series) but it still remained visible during the final period of space consolidation (fourth series), (Figure 20). This, therefore, showed that remodeling resorption of the residual cribriform was occurring in most of the cases. However, the former cribriform plate still remained partially visible in almost half of the cases even 324 days after treatment started and molar tooth movement had commenced.

Thirteen of the records showed a definite increase in the thickness of the cribriform plate at point "D" (apical area of distal surface of distal root). This increase in radiopacity was also seen to diminish during the two periods of space consolidation (third and fourth series; see Figure 21). In almost every case the cribriform plate in area "B" (apical area of mesial surface of mesial root) was seen to diminish in thickness corroborating the distal tipping movement. Exceptions to this were the three records which showed mesial bodily movement (Figure 22), and the record which showed a jiggling movement (Figure 23). In the records showing mesial bodily movement the cribriform plate decreased in thickness at both "A" and "B" points along the mesial surface of the mesial root. There was one tooth which showed a jiggling movement. This was identified
FIGURE 23
ROENTGENOGRAMS OF SUBJECT TREATED WITH DIFFERENTIAL FORCES SHOWING A JIGGLING MOVEMENT
by an increase in thickness of the cribriform plate in all four areas of the root surface. It was noted that during the final period of space consolidation (series four) the cribriform plate more nearly approximated its former thickness and structure as seen prior to treatment (series one). The changes seen in the cribriform plate appeared to confirm the movements indicated by the changes in width of the periodontal space in nearly every case.

These findings appeared to substantiate what might have been expected from the orthodontic mechanics used in the malocclusions treated for the subjects in this study. The mechanics used, such as triangularly placed elastics, oblique intermaxillary and mandibular intramaxillary elastics, and extra-oral forces from cervical headgear, will be discussed in the next chapter.
A. General Consideration

The subjects in this study were divided into those with malocclusions which required extraction of the four first premolar teeth and those with malocclusions which did not require extraction of teeth. The subjects which required extraction of teeth were treated with differential forces derived from vertical spring appliances. The subjects which did not require extraction of teeth were treated with extra-oral forces from cervical (occipital) headgear. There were, however, three exceptions to this and they were the subjects treated with leveling arch wires. The findings for these three subgroups were quite similar and will subsequently be discussed at length.

This roentgenographic experiment was designed to determine the type and direction of movement which occurred in the first mandibular molar teeth. The subjects were treated by utilizing the principles of the Loyola University Light Wire Technique (Jarabak) during three intervals of treatment. The sample was made up of subjects which had either neutroclusion or distocclusion before treatment started.

An interpretation of the roentgenographic changes which occurred in the periodontal space and the cribiform
plate adjacent to the mandibular first molar teeth during the three treatment intervals was appraised from intra-oral roentgenograms presenting the data from which an evaluation of tooth movement was made. The variations in width of the periodontal space and the corresponding changes of the cribriform plate were found to be highly indicative of the degree of tooth movement.

B. Interpretation of the changes in width of the periodontal space

The group of subjects treated with differential forces appliances had maxillary and mandibular first premolars extracted prior to treatment because of insufficient arch length. The canine teeth were then retracted into these extraction sites by use of arch wires with helical torsion springs (Figure 13) and latex elastics utilizing the principle of reciprocal forces. Anchorage (a clinical term meaning the resistance used to overcome an applied force) was being prepared by uprighting the mandibular molar and premolar teeth with angulated brackets and triangularly placed elastics. This internaxillary elastic was stretched from the distal end of the buccal tube of the maxillary first molar to a gingival hook on the maxillary second premolar. From there it was extended to a gingival hook on the mandibular second premolar forming a triangle. At the same time that anchorage was being prepared in the mandibular arch, the maxillary and mandibular canine teeth were being retracted into
the spaces provided by extraction of the four first premolar teeth. The maxillary canines were distally retracted with oblique intermaxillary elastics. These elastics were stretched from the hook on the mesio-lingual aspect of the band on the mandibular molar tooth to a hook bent into the maxillary arch wire just nasal to the bracket on the maxillary canine tooth. The mandibular canines were distally retracted by intra-axillary elastics which were worn from the distal end of the buccal tube on the mandibular molar tooth to a hook bent into the mandibular arch wire just nasal to the mandibular canine bracket. There were additional distal forces against the maxillary and mandibular canine teeth from helical torsion springs (Figure 13) between the lateral incisors and the canines. However, these forces had no effect on the mandibular molar anchor teeth.

After completion of maxillary and mandibular canine retraction the same three sets of elastics (oblique intermaxillary, mandibular intramaxillary and trianually placed elastics on each side) were worn during space consolidation (extraction site space closure). During this treatment interval, however, the oblique intermaxillary elastic was attached to a hook bent into the maxillary arch wire between the maxillary canine and lateral teeth. The mandibular intramaxillary elastic was likewise attached to a similar hook between the mandibular canine
and lateral incisor (consolidation arch wire, Figure 17).

Several of the subjects treated with differential forces appliances had distocclusions. In this type of malocclusion the mesiobuccal cusp of the maxillary permanent first molar occluded in the space between the mesiobuccal cusp of the mandibular permanent first molar and the distal aspect of the buccal cusp of the mandibular second premolar. After space consolidation was completed in the mandibular arch, oblique intermaxillary elastics were worn to correct the mesiodistal relationship of the maxillary molar. These subjects wore the intermaxillary elastics to sliding hooks on the maxillary arch wire between the canine and second premolar creating a distal force on the maxillary first molar.

After the maxillary molars had been moved distally into a neuetrocclusion the sliding hook was advanced along the maxillary arch wire and placed mesially to the canine in order to retract it distally by the oblique intermaxillary elastics. When this was completed and proper interdigitation of the incline planes of the teeth in the buccal segments was accomplished, space consolidation was carried out as described previously.

It was found in the group of subjects (18 teeth) treated with differential forces appliances that seventeen teeth had elevated while, at the same time, fourteen of them
were tipped distally. The distal tipping movement occurred in spite of the mesial forces from the oblique intermaxillary elastics, and intramaxillary elastics in the mandibular arch. The triangularly placed elastics used in conjunction with the angulated brackets were responsible for this elevation of the mesial molar roots and axial distal tipping (to be explained later). The axis of distal tipping was located in the middle third of the root in ten of the fourteen teeth studied. This naturally means that the apical third of the root moved anteriorly in a measure while the crown moved distally. A more desirable tipping movement was seen in three of the teeth in which the axis of tipping was actually located in the lower third of the root. Only one tooth in this group showed the axis of tipping to be in the upper third of the root.

Two teeth of the same subject showed a mesial bodily movement. This was evidenced by an increase in width of the periodontal space at the marginal (point "C") and apical (point "D") areas along the distal surface of the distal root. After consultation with the operator and reference to the treatment records it was apparent that this was the movement the operator desired in this subject. The subject had lost the two mandibular first molars several years before. The second molar had drifted mesially considerably and a slight space still existed between then and the second premolars. These spaces were closed
deliberately by pulling the second molars mesially. The force from the oblique intermaxillary and mandibular intramaxillary elastics in this case were increased and obviously exceeded the optimal range of 150 to 200 grams. Another factor was that prior to contact of the mandibular second molar with the second premolar the mesial forces from the elastics had been directed entirely upon the molar itself. In the other extraction subjects the molar anchor unit consisted of the mandibular first molar and second premolar both acting as one resistance unit. That is to say, the mesial forces pitted against the mandibular first molars in the other subjects were dissipated in part by the second premolars by way of the contact points. The combined molar and premolar anchor unit with more root surface area would have a greater tendency to resist the mesial forces from the elastics than just the molar alone.

The jiggling movement presented the picture as described by Wentz, Jarabak and Orban. There was an over-all increase in width of the periodontal space with a corresponding increase in density of the cribiform plate. The reason for the one jiggling movement was unknown. One explanation for such a movement could possible be cuspal interferences causing traumatic occlusion. This, however, was a temporary condition because during the two periods of space consolidation (third and fourth series) this tooth showed a periodontal space
approaching its normal width. The increased radiopacity of the
cribriform plate seen during anchorage preparation (series two)
was likewise diminishing during the two periods of space consoli-
dation.
2. Subjects which did not require extractions

The subjects which did not require extraction of teeth
were treated with extra-oral forces from cervical headgear to the
mandibular arch. The average distal force from the extra-oral
cervical headgear for each side of the mandibular arch was from
ten to fourteen ounces. This was found by placing the cervical
headgear in position on the subject and measuring its force
unilaterally with a Richmond spring gauge.

The extra-oral force from the cervical headgear which
was brought to bear against the mandibular first premolar tooth
was transmitted distally through the contacts to the other teeth
in the mandibular buccal segments. This, therefore, provided a
definite distal force on the first mandibular molar. Triangu-
larly placed elastics (described previously) were worn by all of
the subjects using extra-oral anchorage from a cervical headgear
in order to elevate the teeth, thus providing for a more desir-
able increase in vertical dimension. In some instances the
extra-oral anchorage (cervical headgear) was employed almost
continuously while in others it was used only eight to ten hours
a day. During space consolidation intramaxillary elastics in
the mandibular arch were worn to lingually retract or realign the anterior teeth into the space previously provided by uprighting and distally tipping the mandibular molar and premolar teeth.

After space consolidation in the mandibular arch had been completed, oblique intermaxillary elastics were worn to correct, if present, the distocclusion. This was done by placing the auxillary component of the oblique intermaxillary elastic to a sliding hook on the auxillary arch wire between the canine and first premolar teeth. After the maxillary molar had been moved distally into a neutroclusion the sliding hook was advanced along the auxillary arch wire just mesial to the canine tooth in order to retract it into the space previously provided distal to it. When this was completed the oblique intermaxillary elastic was attached to a hook bent into the arch wire between the maxillary lateral incisor and canine teeth (consolidation arch wire, see Figure 17) in order to pulstally tip the four maxillary incisor teeth. In many instances the extra-oral forces from cervical headgear were still applied to the mandibular arch to back up anchorage during correction of the distocclusion and the remaining time of treatment.

All of the teeth in these subjects treated with extra-oral forces from cervical headgear showed an elevated distal tipping movement. The axis of this distal tipping was located
in the middle third of the root in eight of the ten teeth while two showed it to be in the apical third.

3. Subjects treated with leveling arch wires

The subgroup treated with leveling arch wires consisted of three subject (six teeth). Cervical extra-oral forces were not used on the teeth in the mandibular arch in these subjects. One subject had congenitally missing maxillary and mandibular second premolars, another had only the maxillary first premolars extracted while the third had no extractions. Oblique and triangularly placed internaxillary elastics were worn in all of these subjects. All six of these teeth showed elevation while five showed a distal tipping movement also. The axis to tipping was located in the middle third of the root in three teeth and the upper third in two teeth. The subject with the congenitally missing teeth showed a mesial bodily movement of one molar which again was intentional. This movement was brought about by increasing the mesial force of the elastics. The mesial bodily movement was identified by an increase in width of the periodontal space and the cribriform plate at points "C" (marginal region) and "D" (apical region) along the distal surface of the distal root (Figure 23).

4. The entire sample of subjects

In considering all of the subjects treated by the Loyola University Light Wire Technique, the most common
movement seen was elevation of the mandibular molar. This occurred in thirty-three of the thirty-four teeth studied. The next most common movement was a distal tipping of the tooth as seen in twenty-nine records. It must be kept in mind, though, that these teeth were also being elevated at the same time they were being distally tipped. Most of the combined distal tipping—elevation movement had already occurred before the second series of records were taken (76 days after start of treatment). This was the interval of treatment in which anchorage was being prepared by uprighting the mandibular molar and premolar teeth to better resist mesial movement. These two movements were most common and conform with the findings of Gritt. Three teeth showed mesial bodily movement, but it was found that these teeth had been deliberately pulled mesially during treatment by increasing the mesial forces from the elastics above forces used in treatment of the rest of the subjects. This was done because there was an excessive amount of arch length available when treatment started.

The axis of the distal tipping movement was found to be located in the middle third of the root in a majority of the records studied. This axis of tipping has been affirmed histologically by Sandstedt, Johnson et al, and Schwarz. Their histological studies dealt with incisor and premolar teeth of animals rather than the molar teeth of human dentitions.
Schwarz employed the tritubercular premolars of dogs which were not in occlusion and, therefore, under very little masticatory stress. Also, the temporomandibular joint of a dog is a hinge and "screw" joint permitting only opening and closing mandibular movements with bodily lateral excursions. Johnson et al performed their experiments on incisor teeth of Macaque Rhesus monkeys and a comparison with the present study cannot be made due to the single rooted teeth and an entirely different occlusal function.

One of the most significant findings in this investigation was that a majority of the mandibular anchor molar teeth studied did tip distally while being elevated at the same time. The distal tipping was sought for because it increased vertical dimension and also prevented mesial slippage of the anchor units. This allowed the extraction spaces to be utilized to realign the incisor teeth by lingually tipping them over their apical base (the immediately adjoining section of bone which underlies the apices of the teeth). Although this finding has been mentioned previously, the reason for the distal tipping movement, from a mechanical standpoint, deserves to be elaborated upon at this time.

The primary reason for the distal tipping movement was that the brackets had been angulated to produce tip-backs when a straight resilient arch wire was placed in these brackets (Figure 12). A triangularly placed intermaxillary elastics was
spanned from the distal side of the maxillary molar buccal tube anteriorly to a gingival hook on the maxillary second premolar band. From there it was directed to a gingival hook on the mandibular second premolar band, thus forming a triangle (Figure 14). The force from the triangularly placed elastic was made up of a vertical component and a distal component, both acting on the arch wire in the vicinity of the mandibular second premolar. The resultant was an oblique force (known as a Class III force in clinical orthodontics) from the mesial of the mandibular second premolar to the maxillary arch wire between the maxillary first molar and second premolar. The distal component hastened the distal tipping action while the vertical component simultaneously elevated the molar. The result was a highly desired distal tipping - elevation movement which was maintained even during the consolidation of spaces, during which time the mandibular molar was subjected to the mesial forces from the intramaxillary and intermaxillary elastics.

Another significant finding was that in nearly every instance the variation in the width of the periodontal space had reduced somewhat during the initial period of space consolidation (third series) and more so during the final period of space consolidation (fourth series). At this time the width closely approximated the former normal width as seen prior to treatment (first series). Similar findings were seen in the roentgenographic changes of the cribiform plate. It, therefore, can be
stated that most of the movement of the mandibular molar anchor teeth observed in this study occurred in the first few months of treatment, during anchorage preparation while the mandibular molar and premolar teeth were being uprighted. Very little movement occurred in a mesial direction during the following two periods of space consolidation.

An explanation as to why little movement was seen in the molar anchor units after the first months of treatment can be conjectured. The elevation of the tooth due to the trianularly placed elastic was accomplished relatively easily. There is little resistance to extrusion of a tooth from its alveolus. The distal tipping movement was brought about by the angulated brackets (described previously). These forces caused resorption of bone by osteoclasts in the pressure areas (decreased width at points "B" and "C") and apposition of bone by osteoclasts in the tension areas (increased width at points "A" and "D") of the periodontal membrane. After the molar tooth had attained this distally tipped position (arch wire had become passive in the angulated bracket) the mesial forces from the intermaxillary and intramaxillary elastics were then distributed more evenly over a greater root surface area. Then the only way the tooth could have moved mesially would have been in a bodily (or axial) fashion. The fact that the periodontal space along the mesial root was returning to its
former width during the initial and final periods of space consolidation seemed to indicate that very little bone resorption was taking place during these periods of treatment. The amount of force then being dissipated over the entire root surface area did not exceed 200 grams (the mesial force from the two elastics during consolidation was approximately 170 grams). This then appeared to agree with Jarabak's statement that anchorage was not taxed during space consolidation if the total intermaxillary and intramaxillary forces did not exceed five ounces.

Orthodontic tooth movement can only occur when forces cause non-physiologic resorption of the supportive alveolar bone. This resorption is initiated by forces transmitted as pressure to the periodontal membrane. Changes in width of the periodontal membrane occur when the force exerted exceeds the capillary pressure (23 gms./cm.²). This causes an interference of blood supply and or venous drainage of the supportive alveolar bone. The fact that the periodontal space was seen to be returning to its former width during the space consolidation periods was indicative of the resumption of normal blood supply to the cribriform plate. The mesial forces (170 gms.) then obviously were not of sufficient strength when transmitted through the periodontal membrane to cause further bone resorption. To the contrary, an increase in thickness was seen in the apical region along the mesial surface of the mesial root in area "B". This apparent
bone apposition was also proof that blood circulation was no longer diminished and that the periodontal membrane had nearly returned to normal.

C. Changes of the cribriform plate

The fact that during tooth movement the cribriform plate became distinctly thicker and more radiopaque in tension areas and disappeared in pressure areas, and that the periodontal space became correspondingly wider and narrower in these same areas, seemed to confirm the previous roentgenological studies made by Storey, Massler, Hemley and Elfenbaum.

No explanation can be offered as to why a radiopaque outline of the former cribriform plate could still be seen in some cases and not in others even 324 days after treatment had been initiated (Figure 20). One can only conjecture on the precise length of time it would take for this bone to remodel. It has been estimated that the outline of the cribriform plate of a recent extraction site can still be seen roentgenographically four to eight months (or more) after tooth removal. This, of course, varies with the location in the mouth as well as the individual response. If it takes at times up to eight months for the cribriform plate to remodel in extraction sites where there is little need for this bone due to reduced stress and loss of function; then it is not surprising to still see at least a remnant of the former
(residual) cribiform plate of a tooth that has been elevated by orthodontic treatment ten months after tooth movement was started. The elevated tooth, although not functioning normally, due to the forces from the orthodontic appliance and elastics, certainly is bringing masticatory stress to bear on the surrounding alveolar bone. Therefore, one would not expect this bone to undergo rapid remodeling resorption. It is anticipated that this bone will be seen to remodel after completion of treatment, at which time the teeth will resume normal functional occlusion.

A more pertinent finding was the compensatory apposition of trabecular bone in the fundus as the tooth elevated and a new cribiform plate being formed adjacent to the root surface. This fact certainly seemed to indicate that the tooth was regaining stability during the periods of space consolidation.

An important consideration which may or may not have been evident from the experimental procedure, the data or the results, is the fact that the areas of the intra-oral roentgenograms under investigation in this study do not present the type of data which is of an exact measurable nature. It is impossible to measure the precise amount a tooth moved during a given period of time from intra-oral roentgenographic evidence, because new bone is constantly forming and old bone resorbing.
However, it was found that one could find evidence for type and direction of tooth movement as well as discover the significant roentgenographic changes seen in the investing tissues surrounding the tooth being moved.
Appended corrections as suggested by the Advisory Committee

It must be stated that there were individual variations in the previously described treatment procedures. The seventeen subjects were treated by five different clinicians. It was difficult, therefore, for the investigator to keep abreast with variations in the mechanics being employed at any particular period of treatment. In addition to this the malocclusions for the different subjects varied in severity. For example, anchorage preparation was not completed in exactly seventy-six days as might be interpreted from previous statements contained herein. Instead, some of the malocclusions required either longer or shorter periods of time for anchorage to be prepared. Likewise, the time that the space consolidation mechanics were employed also varied as did the time required to correct the distal molar relations. A few of the subjects were nearing completion of treatment when the last series of records were taken. These subjects no longer had the amount of mesial or distal force, as the case may be, applied to the mandibular anchor units as did the other subjects. In addition to all of the above mentioned variables, the mechanics employed were not exactly identical for any two subjects since there were operator technique variations.

The mechanics as previously described then cannot be strictly applied as an explanation of the tooth movements shown
by the intra-oral roentgenograms. These mechanics as outlined, however, were used in a majority of the subjects even though they were not initiated at identical periods in treatment or for the same durations of time. One cannot attribute tooth movements to forces which were changed both in magnitude and direction several times during the intervening period between exposure of successive roentgenograms. One can, however, attempt to explain the basic reasons for these movements, particularly if the results as seen in the bony environment were so similar as found in this study.

In conclusion, then, it can be said that the last series of roentgenograms showed one of two things; first, that forces at this time were subliminal (below threshold), or second, that bone repair was nearly complete.
CHAPTER VI
SUMMARY AND CONCLUSIONS

A. Summary

The purpose of this investigation was to determine the roentgenographic changes of the periodontal space and cribriform plate surrounding the mandibular molar anchor teeth in subjects undergoing orthodontic treatment. Seventeen subjects were treated utilizing the principles of the Loyola University Light Wire Technique. The subjects were divided into those with malocclusions which did or did not require extraction of teeth. The subjects which required extraction of the first four premolars were treated with differential forces appliances. The subjects which did not require extraction of teeth were treated with extra-oral forces from cervical headgear. A few subjects, however, were treated with leveling arch wires to affect minor tooth movements in otherwise well shaped mandibular dental arches.

The intra-oral roentgenograms used in this study were taken with a stationary roentgen ray source with the subjects placed in an adjustable headpositioner. Four series of intra-oral roentgenograms were taken during a 324 day treatment interval. The roentgenograms were taken prior to treatment;
seventy-six days later, during anchorage preparation; 174 days later, during the initial period of space consolidation; and 324 days later, during the final period of space consolidation.

The roentgenograms were studied by projection on white poster board with an enlargement factor of 20:1 to reduce error. Each roentgenogram was individually projected and the changes in width of the periodontal space were evaluated. To appraise and compare the changes in the periodontal space and cribriform plate, roentgenograms at each period of treatment were projected simultaneously and re-examined. The data for determining the types of tooth movement were obtained by evaluating the proportionate amounts of change in width which occurred in four areas of the periodontal space. The four areas evaluated were adjacent to marginal and apical areas of the mesial surface of the mesial root and the distal surface of the distal root of the mandibular first molar teeth.

B. Conclusions

The findings revealed the following conclusions:

1. The most common movement which occurred was an elevation of the tooth combined with a distal tipping of the crown of the tooth. The axis for the distal tipping movement was located most commonly in the middle third of the root.
2. The combined elevation and distal tipping movement was intentional and desirable. This movement was created by a highly resilient arch wire acting within the angulated brackets and augmented by the triangularly placed elastics.

3. The greatest variations in width of the periodontal space were found during the first few months when anchorage was being prepared. This indicated that the maximum movement of the anchor teeth occurred during this treatment interval.

4. During the two periods of space consolidation the periodontal space remodeled to nearly its former width as seen prior to treatment. This showed that the mandibular anchor units were resisting the mesial forces exerted during the closure of spaces, and, therefore, acting as excellent anchorage.

5. The radiopacity of the cribiform plate increased or decreased in direct proportion to the changes in width of the periodontal space. The changes in the structure of the cribiform plate seen during the preparation of anchorage became less distinguishable during the space consolidation periods, indicating that the tooth was again becoming stable.
6. There was little difference in the types of movement of the mandibular molar anchor teeth for the extraction and non-extraction subjects.

7. The importance of roentgenographic evidence for determining type and direction of orthodontic tooth movement was demonstrated. This study is being continued with the same subjects to completion of orthodontic treatment in order that the influence of the Loyola University Light Wire Technique on the tooth and its biologic medium can be fully appraised.
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APPROVAL SHEET

The thesis submitted by Dr. Kenneth L. Kemp 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.

5-19-61
DATE

Signature of Adviser