1971

Dentofacial Changes of the Pre-Adolescent Child Produced by Heavy, Continuous Posterior Traction to the Maxillary Molars, Parallel to the Occlusal Plane: A Serial Cephalometric Investigation

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Recommended Citation
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DENTOFACIAL CHANGES OF THE PRE-ADOLESCENT CHILD PRODUCED BY HEAVY, CONTINUOUS POSTERIOR TRACTION TO THE MAXILLARY MOLARS, PARALLEL TO THE OCCLUSAL PLANE: A SERIAL CEPHALOMETRIC INVESTIGATION

A Thesis
Submitted in Partial Fulfillment of the Requirements for the Degree Master of Science by
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May, 1971
ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to the many people who have helped make this study possible. Special gratitude is extended to Dr. Maclay Armstrong for his assistance in designing the project, and to Dr. Douglas Bowman and Dr. Ravindra Nanda for their unselfish and valuable guidance in writing this paper. I am deeply indebted to Mr. Dennis Shafer and Mrs. Mary Suranek for their generous and competent technical assistance.

Thanks to Dr. Donald Hilgers and the clinical staff for providing an outstanding orthodontic education, and to Dr. Gustav Rapp for making my graduate study possible.

My warmest appreciation is extended to my parents and to Renee and Julie, whose love, understanding, and refreshing spirits have made these past two years enjoyable when they might otherwise have seemed intolerable.
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Roentgenographic cephalometry has been accepted as an established, accurate means of measuring dimensional changes in the head and face since its introduction by Broadbent in 1931. As a result of the utilization of this tool, an increasing knowledge of the nature of normal growth and development of the craniofacial complex has since evolved. Changes in the dentofacial complex brought about by orthodontic treatment have been studied using this same method. A sensitive appreciation of the direction and scope of normal growth is imperative before a discriminate evaluation of changes produced by orthodontic treatment can be made.

Growth is considered to be a product of three factors: direction, rate, and time. It is generally agreed by most investigators that normal growth of the maxilla is strongly influenced by growth of the cranial base. Growth impetus in the anteroposterior direction is considered to be provided mainly by growth at the sphenoid-occipital and sphenoid-ethmoidal synchondroses (Pritchard, Scott, Girgis; 1956). Sutural growth at the frontomaxillary, zygomaticomaxillary, zygomaticotemporal, and pterygopalatine sutures is thought to
contribute to anteroposterior as well as vertical growth (Sicher; 1965, Enlow; 1966, Bjork; 1964). The remaining vertical growth of the maxilla is generally attributed to endochondral bone growth of the maxilla, surface apposition of alveolar bone, and growth of the nasal septum (Moss; 1964, Scott; 1954, Enlow; 1965).

The rate and time factors of growth must also be considered in order to gain a true understanding of normal growth changes. Longitudinal growth studies have indicated that the mean annual growth increments of maxillary depth and height in children between the ages of nine and eleven years are approximately one millimeter in depth and two millimeters in height (Coben; 1955, Savara; 1968, Burstone).

Extraoral traction to the maxillary dentition has been used since the beginning of the nineteenth century for the purpose of attempting to correct anteroposterior discrepancies of the dentofacial complex. The types of extraoral anchorage, or headgear, most commonly used can be divided into two categories: occipital (highpull) and cervical. The highpull headgear delivers a force to the maxilla in a superior-posterior direction, while the cervical headgear delivers an inferior-posterior force.

Many investigators have reported that cervical traction may inhibit forward growth of the maxilla or redirect this
forward growth so that it is manifested in a downward and backward rotation (Klein; 1957, Weislander; 1963, Poulton; 1964, Sproule; 1968).

There are relatively few studies concerning the effects of highpull headgear on the dentofacial complex (Poulton; 1959, 1964, Fredrick; 1969, Damon; 1970). These studies, however, indicated that the maxillary molars could be retracted and depressed. The effects on the maxilla were admittedly inconclusive in some cases, while a clockwise (viewed from the right) rotation of the maxilla was observed in others. This was the same type of rotation observed with the use of cervical traction.

No purposely relevant study has been made concerning the use of a heavy, continuous retractive force on the human maxilla in the posterior direction, with little or no vertical component. Armstrong (1971) clinically demonstrated considerable maxillary molar movement with the use of such a force system, but no organized study was undertaken as to its effects either on the maxillary molars or on the facial skeleton.

The purpose of this serial cephalometric investigation is to assess any changes in the dentofacial complex produced by a "heavy" continuous posterior traction on the human maxillary first molars directly, and indirectly on the maxilla.
The force is intended to be approximately parallel to the occlusal plane, with a superior-posterior moment. The results will be compared to similar measurements of untreated samples of the same age (Coben; 1955, Krogman; 1958, Muller; 1963, Pike; 1964, Savara; 1968, and Burstone; 1971).
CHAPTER II
REVIEW OF THE LITERATURE

Growth Studies

Studies concerning changes of the craniofacial bone complex during the growth period have employed several methods. Investigations using dry skull material, vital staining techniques, histologic examination, radioactive isotopes, cephalometry, and metallic implants have brought about the present understanding of the basic nature, location, and relative activity of the growth sites of the head and face. These studies have also led to an increasing knowledge of the amount of growth that normally takes place in these areas in a given unit of time.

The literature discussed in this section of the review, in order to be pertinent to this study, is limited to investigations of growth of the maxilla and cranial base of humans. Special emphasis is placed on incremental growth studies of the maxillae of Caucasian children between the ages of nine and eleven years. Some of the related incremental findings are considered in the discussion of this paper.
Broadbent and Hofrath introduced a technique of roentgenographic cephalometry in 1931. This provided a means by which a growing individual could be morphologically studied at chosen stages of his development.

Broadbent (1937) reported on the normal development of the face, utilizing his cephalometric technique in a cross-sectional study of large groups of children.

A longitudinal investigation was reported by Brodie (1941) in which the growth of twenty-one male children was studied from the third month to the eighth year of life. Brodie found that the conformation of the skull is unchanged after the third month of life. He further showed that the direction of growth of most of the points studied followed a straight line, the facial growth path conformed to the direction of the sellagnathion plane, and the maxillary first molars always lay in this plane, regardless of age. In his study, Brodie observed a complete lack of growth spurts, and he concluded that growth occurs as a regular process.

Bjork (1947) studied facial prognathism of 322 twelve-year-old Swedish boys and compared them to 281 young men ranging in age from twenty to twenty-two years. Bjork studied the degree of prognathism of the maxilla and mandible in relation to each other and of each jaw relative
to the anterior cranial base. He showed an increase in vertical height of the face with age, as well as an increase in prognathism. He attributed the prognathism to altering of the relation of cranial base to jaw length. Bjork's findings indicated the existence of differential changes in the craniofacial complex during growth. These findings supported the previous evidence of individual variation and differential growth rates as reported by Hellman (1932) (1935), and Goldstein (1936).

In a comparison of the relation of the maxilla to the cranial base in individuals with normal occlusion as opposed to those with malocclusions, Riedel (1948) concluded that both groups had the same maxilla to cranial base relationship.

Scott (1948) stated that the cartilage of the nasal septum contributes to much of the growth of the upper part of the face. At the mesethmoid center of ossification, the posterior part of the septal cartilage is replaced by bone to form the perpendicular plate of the ethmoid. The perpendicular plate of the ethmoid later unites with the vomer and lateral masses of the ethmoid by ossification of the cribiform plate. A bony craniofacial union is thus established, and growth at the sutures between these
cranial and facial bones ceases. Scott reported that this usually occurs at the same time, or precedes, the eruption of the first permanent molars. He postulated that if growth stops at the posterior part of the maxilla at the same time as the eruption of the first permanent molars, space is made for the remaining permanent molars by a forward migration of the teeth through alveolar bone, and the alveolar process must be enlarged by growth at the front of the face. Scott attributed this anterior facial growth to the thrust of the nasal septal cartilage.

In 1951 Bjork cited several longitudinal observations in which he noted that within an individual, maxillary prognathism may increase, decrease, or remain unchanged. Bjork stressed the considerable variation of the growth pattern within any facial type.

Lande (1951) performed a longitudinal investigation of thirty-four males between the ages of seven and seventeen years. He concluded that the mandible becomes more prognathic than the maxilla in relation to the cranial base. Lande further stated that the original facial type at seven years of age had no correlation with growth changes later in life.

Baum (1951) studied sixty-two boys and girls from the eleventh to the thirteenth year of life, and concluded that
it is important to compare a child to a normal range for his own age group.

In the second part of his serial growth study, Brodie (1953) was now concerned with facial changes taking place between the eighth to seventeenth year of life. Brodie reported the pterygo-maxillary fissure to be the most stable point in the face. The anterior nasal spine and pogonion moved downward and forward. Brodie modified his previous theory of the constancy of facial growth with variation between individuals, maintaining, however, a nearly constant pattern within the individual himself.

Allan Brodie, Jr. (1953) investigated the behavior of the cranial base during growth with the use of serial cephalometric radiograms. He observed that growth curves of the entire cranial base resembled those of the brain case, and once the growth pattern was established, it did not change significantly.

In 1954, Bjork reported that individual deviations from the general growth pattern may be considerable. Bjork (1955) studied growing children using metallic implants in conjunction with roentgenographic cephalometry. In this study, Bjork reported considerable individual variability. Bjork's findings suggested little, if any, predictability of a growth tendency.

A longitudinal cephalometric growth study of the human
face was done by Coben in 1955. Coben's subjects included forty-seven males and females ranging in age from eight to sixteen years. He concluded that the average growth tendencies for any given age level would not allow the prediction of the ultimate potential for any given individual's total facial complex. Coben reported no significant differences between males and females at the prepubertal stage. Coben observed that many faces show extreme variations, but harmony or disharmony of the face is determined by an integration of these variations to the total facial morphology.

In 1955, Nanda longitudinally studied ten boys and five girls using cephalometric roentgenograms. Nanda reported that the growth of all the skeletal facial dimensions studied followed either a neural or skeletal pattern except the sella-nasion plane, which displayed a combination of the neural and skeletal patterns of growth. Nanda noted that the circum-pubertal facial growth spurt takes place at a later age than does the circumpubertal body height maximum. His findings indicated that the rate of facial growth of females was less than that of males during adolescence, and that differential growth of the seven dimensions studied produced changes in facial form.

In their study of cranial sutural structure and de-
velopment, Pritchard, Scott, and Girgis (1956) concluded that the suture consists of five distinct layers. They further reported that the histology of the suture suggests two main functions: that of active bone growth and that of a firm bond or union between the two adjacent bones.

Scott (1956), in his paper concerning growth at facial sutures, stressed that bone separation at the sutures is not due solely to sutural growth, but also to a variety of other causes (growth of the chondrocranial and chondrofacial skeleton, brain, eyeball, and tongue), necessitating compensatory growth in these areas. Scott reported that the craniofacial suture system permits growth of the maxilla in a downward and forward direction, with sutural growth stopping at three to five years of age. The maxilla is held between the zygomatic and palatine bones and grows downward and forward between them due to growth of the cartilage of the nasal septum. He also maintained that nasion ascends on the frontal bone from child to adult, and for this reason nasion cannot be used as direct evidence of sutural growth in the analysis of growth changes in the maxilla.

Ford (1958) made direct measurements of juvenile and adult skulls to study growth of the cranial base. Ford
observed that growth of the cranial base as a whole has an intermediate pattern, but the individual components of the cranial base display either a skeletal or neural growth pattern. The spheno-ethmoidal synchondrosis growth stops at seven years of age, while the spheno-occipital synchondrosis grows until about twenty-five years of age. The thickness of the frontal bone is responsible for an increase in the measurement between sella and nasion during the growth period. Ford stated that, while nasion moves upward, sella also rises slightly, making the sella-nasion line an acceptable base line. Care must be taken, however, not to attribute this rise in the sella-nasion line to excessive vertical facial growth. Ford also confirmed DeCoster's observation that the cribriform plane growth is complete by the time of eruption of the first permanent molars, and this line, therefore, is an ideal base line.

In his study of growth of the head and face in Philadelphia children from six to fourteen years of age, Krogman (1958) reported that facial growth is differential, with face height following the generalized sigmoid curve of growth. The upper face height increased more than the lower face height. The greatest increases in upper face height were associated with concomitant increases in nasal height.
Marshall (1958) reported that the antero-posterior growth of the face took place in three spurts, the first spur at six months, the second from four to seven years, and the third from fifteen to nineteen years.

In an attempt to study the influence of heredity on facial growth, Kraus, Wise, and Frei (1959) made a longitudinal investigation of six sets of triplets of the same sex. Their observations were that the growth of the craniofacial complex is a product of so many interactions of discrete forces that the role of heredity cannot be estimated.

Moore (1959) studied the individual facial patterns of growing children and concluded that variation of the facial growth pattern is the rule and not the exception.

In his discussions on child development, Tanner (1960) (1962) described growth as any change, in time, which is measureable, such as length, volume, concentration, pressure, etcetera.

Moss (1955) (1957) (1960) (1964) described bone growth as primarily a functional response to extrinsic factors (the functional matrices), and that growth may be a negative as well as a positive change in size.

A longitudinal cephalometric growth study of children at the ages of eight and fifteen years was made by Merrow
in 1962. Merrow used a coordinate system of measurement orienting Frankfort plane as his X axis and registering on Broadbent's R point on the Y axis. The findings from this study were that point A and the maxillary central incisor moved proportionally, and the upper face exhibited more vertical than horizontal growth, while the lower face grew more horizontally than in the vertical direction.

Muller (1963) made a serial roentgenographic examination of 541 German children over a four year period from approximately age seven to age eleven. Muller measured both horizontal and vertical growth changes in the upper face and found that upper face height increased about four millimeters, while the anteroposterior change was approximately a three millimeter increase over the four year period.

Bjork (1964) studied forty-five Danish boys from early juvenile ages to adulthood. Bjork's investigation was a serial cephalometric study using the metallic implant method. He reported that growth of the maxilla in length was sutural, with accompanying periosteal apposition at the maxillary tuberosity. Bjork found no evidence of periosteal apposition on the anterior surface of the maxilla except for
the alveolar process. Growth of the maxilla in height took place at the sutural articulations of the frontal and zygomatic processes, and by periosteal apposition on the lower border of the alveolar process. The annual forward growth of the upper face was about one millimeter in the juvenile period, about one-fourth millimeter for the pre-pubertal minimum, and one and one-half millimeters for the pubertal maximum. The pre-pubertal minimum occurred at eleven and one-half years, and the maximum was at fourteen years for both sutural and condylar growth. The sutural growth ceased at seventeen years. Puberty and completion of growth occur at about one and one-half years earlier in Danish girls than boys, according to Bjork.

In a comparison of facial growth to skeletal and chronological age, Moreschi (1964) used a sample of twenty white females from the age of eleven to eighteen years. Moreschi's findings suggested that upper face height and depth (as well as ramus height and body length) are ruled by biologic age, whereas the position of the mandible in relation to the cranial base, face height, and face depth was unaffected by biologic age.

A study of the facial and statural growth of twenty-five children was made by Pike in 1964. The mean age at the onset was about seven years. This was a four year study,
with four lateral headfilms taken annually. The measurements studied were mandibular length, maxillary length, total anterior face height, and ramus height. Pike found that all individuals showed constant growth rates of the statural and facial dimensions studied. No significant sex difference was observed in any of the measurements, but a relatively high degree of individual variation existed in the sample. A positive correlation was found between the rate of statural growth and the growth rates of facial skeletal dimensions. Pike concluded that a method could be obtained of predicting statural and facial skeletal dimensions based on information concerning variation from a constant rate of growth.

Enlow (1965) serially sectioned and studied the maxillary bones of twelve human skulls. The findings of this study indicated that as the maxilla increases in size, its various parts occupy new positions in the bone through structural adjustment. Growth of the maxilla in the posterior direction results in a downward and forward movement of the growing bone as a whole. This repositioning of the maxilla is accompanied by bony apposition along the posterior surface of the maxillary tuberosity. This, according to Enlow, functions to lengthen the dental arch and to enlarge the anterior-posterior dimensions of the entire
maxillary body. There is a concomitant movement of the entire zygomatic process in a corresponding posterior direction to maintain the position of the zygomatic process relative to the remainder of the maxilla. Enlow reported that the palatine process moves downward as a result of resorption on the nasal side and apposition on the oral side.

In 1966 Bergersen reported his longitudinal study of thirty white males and thirty white females, using lateral cephalometric radiographs from the Bolton Study at Western Reserve University. The mean age of his sample ranged from 5.3 to 18.3 years. Bergersen found that the anterior facial landmarks studied migrated on fairly straight lines. Anterior nasal spine and nasion had the least variable direction of growth.

Enlow and Hunter (1966) made a longitudinal cephalometric study of ten children (five boys and five girls), beginning at six years of age and ending at fifteen years. Their findings showed that facial height increased at a greater rate than did facial depth (length).

In 1966, Hunter reported a study of radiographs of twenty-five males and thirty-four females from the Child Research Council, Denver, Colorado. These radiographs were taken at six-month intervals from seven years of age
through adolescence. Hunter observed that the maximum rate of facial growth was coincident with maximum growth in body height in the majority of his subjects. Orthodontic treatment had no effect on the time of maximum facial growth, regardless of the age of the patient when he was treated, the length of treatment, or the type of appliance. Of all facial dimensions used in this study, the antero-posterior length of the mandible showed the highest correlation with growth in height. Hunter also concluded that females entered the pubertal growth period 2.4 years earlier than males, and that the mean duration of the pubertal growth period was the same for both males and females.

Koski (1968) examined the question of which alleged postnatal growth centers of the craniofacial skeleton could actually be considered growth centers as opposed to growth sites. Koski defined a growth center as "a site of endochondral ossification with tissue-separating force, contributing to the increase of skeletal mass." A considerable amount of growth occurs in sutural areas, and for that reason, stated Koski, sutural growth is an important aspect of craniofacial growth. The question was not whether growth takes place in sutural areas, but whether sutural growth is an active or passive mechanism; that is, are sutures primary growth agents, or is growth in these areas a result
of growth of cartilage or of the functional matrix? Koski concluded that, from all available information, sutures lack independent growth-promoting potential and are not, therefore, comparable to growth centers. Koski then examined the possible role of cranial base synchondroses as growth centers. He reasoned that although synchondroses structurally resemble epiphyseal growth plates and that endochondral ossification takes place adjacent to the synchondroses, there was at that time no published evidence of the existence of a tissue-separating force in the synchondroses. In the sense of the definition, therefore, synchondroses could not be considered to be growth centers. In studying current information on the cartilaginous nasal septum, Koski concluded that the septoethmoidal junction possibly acts as a growth center, and that more information was necessary before a judgement could be made.

A mixed longitudinal study of maxillary growth in fifty-two boys from three to sixteen years of age was reported by Savara in 1968. Each boy was observed for at least six years. Seven dimensions of the maxilla were measured from lateral and posterior-anterior cephalograms: four for maxillary height, one for maxillary length, and two for maxillary width. Savara observed that a fairly constant rate of growth in maxillary length took place
except for an adolescent increase from thirteen to fourteen years of age. The adolescent increase in maxillary height occurred at fourteen to fifteen years for boys, and eleven to twelve years for girls. Growth changes in the maxilla were most marked in height, less so in length, and least in width. Savara reported that the adolescent spurt in boys occurred from one to three years later than in girls.

Moss (1969) described growth of the face in terms of orofacial functional matrices. He stated that all functional cranial components of the facial skull are located within an orofacial capsule. Facial skull growth, according to this theory, is primarily a result of the volumetric growth of the oronasopharyngeal functioning spaces within the orofacial capsule.

Scott (1969) held that the functional matrix theory is of considerable value in analysis of the development, growth and function of the oral cavity "providing it [the theory] is not given too rigid a definition, as in insisting on the necessity of a skeletal component".

In his study of headfilms from the Child Research Council, Denver, Colorado, Burstone (1971) measured annual increments of growth of the cranial base, maxilla, mandible, facial height, facial profile, and dental development. Burstone's measurements began at age four and ran through
Rothstein (1971) examined 608 lateral headfilms, 273 presenting normal occlusions and 335 presenting Class II, Division 1 malocclusions. Rothstein compared the craniofacial and dentofacial skeletal characteristics of these two groups, subdividing each group into six samples, three male and three female, showing skeletal ages of ten, twelve, and fourteen years. The findings indicated that Class II, Division 1 malocclusions were consistent with a forward position of the maxillary dentition, a larger anterior-posterior cranial length, an increased frontal bone thickness, a longer anterior cranial base, a large maxilla, and an inclined palate (inferiorly positioned at the posterior border or superiorly positioned at the anterior aspect or both). The size, form, and position of the mandible were within the normal range. Rothstein also observed that his findings indicated that Class II, Division 1 children of both sexes have a circumpubertal growth spurt which is attended by a change in maxillary and mandibular growth direction from vertical to horizontal. This occurred between the ages of ten and fourteen years in females, and between the ages of twelve and fourteen years in males.
Extraoral Anchorage: Its Development and its Effects on the Human Dentofacial Complex

For the sake of relevance to this paper, references to headgear or extraoral anchorage generally pertain to appliances utilizing the double face-bow. Special emphasis is placed on studies dealing with the effects of different types of headgear on the human dentofacial complex.

Weinberger (1926) stated in his history of orthodontics that Cellier (1802) was the first to use any form of occipital anchorage. Fox (1803) used a similar appliance to Cellier's. Both appliances were used for the purpose of mandibular repositioning in cases of luxation. Weinberger credits Gunnel (1822) with the first use of a removable occipital anchorage appliance for treatment of Class II malocclusions.

Kingsley (1875) used a skullcap with elastics attached to a labial bow to retract and depress maxillary incisors.

In a modification of Kingsley's appliance, Farrar (1886) used a non-elastic force from the skullcap to correct protrusion of maxillary incisors. Farrar's appliance provided an intermittent force while Kingsley's utilized a continuous traction.

Angle (1887) also used a modification of Kingsley's appliance, consisting of a round intraoral arch inserted
into the tubes soldered to the upper molar bands. A traction bar connected the labial bar to the silk net headcap.

Kingsley (1892) developed modifications of his own original appliance. The headcap he described consisted of two main straps, one passing above the ear and one below, enabling Kingsley to change both the direction and the amount of force.

The development of extraoral anchorage suffered a long setback when Angle (1907) stated that as intermaxillary elastics gained in popularity, the necessity for the use of occipital anchorage would decline. Angle's attitude about this seemed to predominate, for interest in the use of extraoral anchorage in the next twenty years was minimal.

Case (1921), however, did emphasize the use of extraoral traction as an important auxiliary with the use of intermaxillary traction.

Considering extraoral anchorage to be the most ideal method for the application of light intermittent forces, Oppenheim (1936) recommended the use of the headcap and traction bar. According to Oppenheim's basic concept of biologic tooth movement, no orthodontic appliance could optimally fulfill the requirements, but the headcap was the best appliance at that time.
Hellman (1933) and Brodie (1938) felt that the development of the face was a natural process and that it was not influenced by orthodontic therapy. Brodie felt that the successful treatment of Class II malocclusions was predominantly dependent upon growth of the mandible.

Thompson (1940), Strang (1941), Kresnoff (1942), Waldron (1943), Johnson (1943), Oppenheim (1944) and Jerrold (1945) advocated the use of occipital anchorage to support maxillary anchorage in the treatment of Class II malocclusions.

In 1941 a modification of extraoral anchorage was made which largely influenced headgear therapy in the years to follow. Kloehn (1941) changed from an occipital headcap to a cervical strap for patient accommodation. Kloehn advocated beginning his cervical gear therapy for Class II malocclusion correction when the upper first molars erupt, during the period of rapid facial growth.

Kloehn (1947) stated that "cephalometric findings have proven that orthodontic correction of a malocclusion does not alter the growth pattern of the maxilla, mandible, or any of the [other] facial bones". Kloehn did feel that the forward growth of the maxillary teeth and alveolar process could be retarded to allow the normal forward growth of the mandible to advance into a normal relationship.
On the basis of independent cephalometric studies, Hedges (1948) and Epstein (1948) concluded that the success of headgear therapy depended on forward growth of the mandible to correct the Class II malocclusion.

In his article on extraoral anchorage, Closson (1950) reported that it was possible with the headcap to move maxillary molars distally. Closson did admit, however, that there was no proof of this claim other than gnathostatic casts and photographs.

Kloehn (1953) stated that growth was the orthodontist's greatest ally in successful treatment of the Class II malocclusion, and that during growth orthodontists should attempt to guide the developing occlusion toward the normal relationship.

Silverstein (1954) analyzed seventy-four Class II, Division 1 cases treated with cervical headgear using twenty-eight untreated cases as a control. Silverstein concluded that the headgear treatment did not alter the maxilla in any way.

A study was made by Graber (1955) of 152 cases of Class II, Division 1 malocclusions treated with cervical headgear. Graber concluded that it was possible to change maxillo-mandibular apical base relationships with cervical gear therapy. He observed that growth, despite its un-
predictability, was an important factor in successful treatment and that the presence or absence of growth were of extreme importance. Graber claimed that there was no evidence that growth of the maxilla was affected by his treatment.

Moran (1955) investigated the effects of occipital anchorage therapy on forty-six patients initially ranging in age from seven to twelve years eight months. Moran concluded, among other things, that all but five of the cases studied exhibited a downward or backward movement of the maxillary denture. The change in molar relation was accomplished through forward growth of the mandible, while the maxillary first permanent molars were tipped back and prevented from following their expected downward and forward movement. Moran also reported a definite correlation between the distal movement of the maxillary first permanent molar and the posterior migration of maxillary premolars.

In his cephalometric study of the effects of headgear treatment, Ketterhagen (1957) concluded that a distal eruption pattern of maxillary molars and premolars was apparent, as well as a retardation in the forward development of the maxilla.

King (1957), in an investigation of fifty patients in the late mixed and early permanent dentition stages
treated with cervical anchorage, found that point A moved posteriorly in relation to Nasion, with the amount of change correlating to the length of treatment. King noted small changes in the occlusal and mandibular planes.

A study of a sample of twenty-four patients treated with cervical traction was made by Klein in 1957. He claimed that distal bodily movement of the maxillary first molars occurred in the majority of cases. Klein also reported that the palatal plane tipped downward in the anterior region.

Moore (1959) reported that the maxillary denture may be inhibited by elastic traction or occipital anchorage. He stated, however, that there was no definite proof that orthodontic therapy influenced the growth of the maxilla.

Poulton (1959) used cranial base landmarks for superimposition in his study of the effects of cervical headgear. In the twenty-nine cases studied, Poulton observed that the molar relationships were corrected, but a tipping downward of the anterior aspect of the palate was observed.

In 1960, Ricketts studied the effects of cervical headgear, Class II elastics, and the combination of the two on fifty cases in each group. He concluded that the maxilla could "no longer be accepted as an immutable structure". Ricketts reported that cervical headgear pro-
duced a downward and backward rotation of the maxilla and the sphenoid bone.

Weislander (1960) observed that headgear treatment affected not only the dento-alveolar area, but that during the growth period, it may influence the growth pattern of the entire cranio-facial complex.

A serial cephalometric study of fourteen females who had exhibited Class II, Division 1 malocclusions and were treated with the use of cervical headgear was made by Nyegaard in 1962. Nyegaard's findings indicated that highly variable directional changes occurred, some of the changes being favorable while others were unfavorable.

In 1963 Weislander conducted a study of thirty mixed dentition cases treated with cervical headgear compared with an equal number of untreated patients with normal occlusions. Weislander concluded that cervical headgear produced an inferior-posterior movement of the pterygo-maxillary fissure and the anterior nasal spine, and a downward tipping of the anterior aspect of the palatal plane. These results indicated that the growth changes produced by cervical headgear affected not only the maxilla, but also the bones in contact with the maxilla, particularly the sphenoid bone.

Poulton (1964) reported a three-year study of high-
pull headgear therapy using twenty-two patients with an average age of ten years, four months at the beginning of treatment. Poulton compared his findings to those changes noted in Weislander's cervical headgear study. Poulton discussed only the changes in tooth position and noted that the forward movement of the maxillary molar crown was retarded similar to the findings of Weislander. Poulton's findings did indicate a decrease in the angulation of the occlusal plane in his treatment group.

In his M. S. Thesis, Manning (1965) reported that cervical headgear and Class II elastics resulted in a holding back of the maxillary first permanent molars as well as a distal displacement and/or a prevention of the anterior growth of the palate.

Sandusky (1965) described the changes produced by cervical headgear therapy. He noted a downward tipping of the anterior portion of the palatal plane, posterior movement of the pterygomaxillary fissure, a clockwise rotation of the sphenoid plane, an increase in the mandibular plane inclination, and an increased anterior vertical face height.

Schudy (1965) compared the effects of highpull headgear as opposed to cervical traction on the vertical dimension of patients undergoing Class II correction. High-
pull headgear, according to Schudy, was useful in inhibiting the downward growth of the maxillary alveolar process and possibly the entire maxilla. He explained that cervical traction, on the other hand, could increase the vertical growth of the face.

In a study of the effects of cervical headgear therapy as opposed to activator therapy, Meach (1966) observed that when compared to a control group, cervical traction produced a downward and backward molar movement, an increase in the mandibular plane inclination, a backward movement of point A, and in twenty-eight percent of the cases, a backward movement of pogonion.

Poulton (1967) reported on the effects of cervical and highpull headgears. He explained that cervical traction often extrudes maxillary molars and increases the inclination of the mandibular plane. Poulton stated that this is generally undesirable and may be permanent unless condylar growth compensates for it. He showed retraction of maxillary molars using highpull headgear without this opening of the bite.

In his research on the Macaca mulatta monkey, Sproule (1968) made a histologic and serial cephalometric study of the effects of continuous cervical traction on the maxilla of the monkey. Sproule observed adaptive resorptive re-
modeling at some suture sites, while the maxilla rotated in a clockwise direction. The growth of the middle face took place in a downward and backward direction as opposed to a downward and forward direction in control animals.

Fredrick (1969) studied the effects on the dentofacial complex of *M. mulatta* monkeys produced by continuous occipital (highpull) traction. In comparing his findings to those of Sproule (1968), Fredrick observed that the occipital traction retracted the maxillary dentition to a lesser degree and the molars were intruded slightly rather than extruded. The occlusal plane tipped downward at the anterior aspect to a lesser degree than was observed to occur with the cervical headgear.

A report of the effects of a highpull traction on the human maxilla was made by Damon in 1970. Damon's sample consisted of twenty-four patients with a mean age at the beginning of treatment of thirteen years. Damon utilized a heavy force of three pounds per side or more, instructing the patients to wear the appliance a minimum of fourteen hours per day. The dentofacial changes that took place were analyzed by means of superimposing cephalometric radiographs taken at the beginning of treatment and at the completion, three to five months later. His results indi-
icated that maxillary molars can be intruded. Because of the number of variables beyond his control and the number of errors in technique, the effects on the maxilla were admittedly inconclusive on a statistical basis.

Masumoto (1970) investigated the changes of the dento-facial complex of thirty-one children as a result of cervical headgear therapy. The mean age of the sample at the beginning of treatment was twelve years, nine months. This study was done with the use of cephalometric radiographs and metallic implants. Masumoto noted a clockwise rotation of the maxilla in the experimental group as compared to the control group. He indicated that the amount of maxillary and maxillary tooth movement apparently did not depend on the duration of force application nor the magnitude of force used; however, this was only his clinical impression.

Merrifield and Cross (1970) reported their theoretical and clinical impressions of different types of headgears and the effect of each type on the dentofacial complex of the patient. They pointed out the detrimental effects produced by the "cervical face-bow" (cervical traction on a Kloehn-type face bow). These effects included extrusion of the maxillary denture, mandibular rotation, and distal
movement of upper molars (the latter not considered to be detrimental by many observers; in fact, considered desirable by many). The position of three maxillary sutures was given, and the effects on these sutures produced by cervical headgear was explained. The pterygopalatine suture, according to Merrifield, is compressed, while the zygomatico-maxillary suture is sheared and the frontomaxillary suture is placed under tension. The average directional force of the "cervical face-bow" was determined to be approximately thirty degrees below the occlusal plane, with a range of twenty to thirty-seven degrees. The resultant effect of this direction of force was reasoned to be one of a downward and backward rotation. Merrifield then deduced that since the cervical face-bow stimulated downward growth of the maxilla, the face-bow itself has no value.

A brief description of different types of headgear attached to the arch wire was given, with the highpull headgear delivering the most ideal force.

Nisson (1970) compared the results of patients treated with highpull traction as opposed to those treated with cervical traction. The important differences which Nisson attributed to the direction of pull were less tipping of the occlusal plane, better reduction of facial convexity,
and less upper facial height in the highpull group as opposed to the cervical group.

In 1970, Sanders, Wollney, and Jawor presented a modular demonstration of the directions of force delivered to the maxillary molars as a result of different types of headgears and face-bows. This presentation was based on the theory of the center of resistance of a tooth (or any other body) to movement, as proposed by Burstone (1962) and Haack (1963). It was demonstrated that the line of force in relation to the center of resistance of the upper molar determined if the force would include a tipping moment to the molar. If the line of force from the headgear passed apical to the center of resistance a superior-posterior moment was introduced. If the line of force passed occlusal, or inferior, to the center of resistance of the tooth, an inferior-posterior moment resulted, causing a tipping distally of the molar crown. It was further shown that if the line of force was divergent inferior-posteriorly from the occlusal plane, as in cervical headgear, an extrusive distal force was delivered to the molar. If the line of force was at an angle to the occlusal plane in the superior-posterior direction, as in highpull headgear, an intrusive, distal force was delivered to the molar. Finally, it was observed that if the line of force
passed through the center of resistance of the molars, parallel to the occlusal plane, the resultant force delivered to the molars would be in the distal direction, with no intrusion, extrusion, or tipping.

Armstrong (1971) reported the results of applying a combination of cervical and highpull headgears with the outer bow of the face-bow elevated. Armstrong designed this type of appliance to attempt to apply a distal force parallel to the occlusal plane, and through the center of resistance of the upper molars. He also designed his own calibrated, spring-loaded headcap and neckstrap so that he could measure the amount of force being delivered by each unit, and know that the force would not diminish appreciably due to fatigue or "creep" of the material. Armstrong fixed the face-bow to the upper molar bands and used a heavy continuous force to the upper molars. He thereby attempted to control the three mechanical variables stressed in his paper: magnitude, direction, and duration of force. The results showed marked distal movement of the upper molars after a short period of wear. (approximately 100 days) with little or no distal crown tipping or extrusion. The cases shown in Armstrong's paper were in the late mixed dentition stage, with Class II malocclusions.
His objective was to establish normal occlusion and muscle balance to allow the upper and lower jaws to grow downward and forward together.
CHAPTER III

METHODS AND MATERIALS

Selection of Sample

The requirements for patient selection in this study were: 1) age, nine to eleven years; 2) race, Caucasian; 3) molar relationship, Class II malocclusion; 4) stage of tooth eruption, mixed dentition with maxillary second permanent molars unerupted; and 5) attitude, willing to undergo the proposed headgear treatment for the prescribed length of time (combination occipital and cervical anchorage, 100 days continuous wear).

Fifteen patients meeting these criteria were selected from the Department of Orthodontics at Loyola University. All were treated by the same operator. The age distribution of the patients at the start of treatment as well as the length of the treatment period appear in Table I.

Appliance Construction

Bands were placed on the maxillary first permanent molars, with a .051 inch inner diameter tube welded to the buccal surface of each band. A double face-bow (Oscar) was used, constructed of a .062 inch diameter, short
TABLE I

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Sex</th>
<th>Initial Age:</th>
<th>Length of Treatment*</th>
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<tr>
<td></td>
<td></td>
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<td>Months</td>
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<tr>
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<td>10</td>
<td>7</td>
</tr>
<tr>
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<td>F</td>
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</tr>
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<td>M</td>
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</tr>
<tr>
<td>15</td>
<td>M</td>
<td>10</td>
<td>9</td>
</tr>
</tbody>
</table>

M = 6, F = 9
Mean: 10, 4
Range: 8, 10
to
94 - 104

*Length of time of actual appliance wear
outer bow and a .050 inch inner bow. (See Figure 1). An orthodontic eyelet was welded to each side of the inner bow. The face-bow was inserted into the buccal tubes of the maxillary molars and secured with .012 steel ligature wire tied from the eyelet to the buccal tube on each side. The outer bow of the face-bow was elevated so that the distal end was about fifteen millimeters above the level of the inner bow and buccal tube.

A calibrated, spring-loaded highpull headcap and cervical neckstrap (Northwest) were used in combination, as shown in Figure 2. The springs in this type of headgear were tested by this and other observers (Armstrong, 1971) at the Loyola Orthodontic Department and found to fatigue only about one to six percent after a continuous twenty-four-ounce load for 100 days. The highpull and cervical headgears were adjustable for varying amounts of force. Both units were adjusted in length to deliver twenty-four ounces each, to produce a combined force of three pounds on each side of the head. They were then attached to the outer bow of the face-bow. (See Figure 3.)

The patients had been informed that the face-bow would be secured in the mouth and not removeable. They were instructed to wear the headcap and neckstrap at all times except when swimming, bathing, or brushing their hair.
FIGURE 1

DOUBLE FACE BOW, SHORT OUTER BOW

Top: Side View
Bottom: Front View
FIGURE 2

APPLIANCE IN PLACE

Left: Front View
Right: Side View
FIGURE 3

APPLIANCE IN PLACE

Lateral Cephalogram
Each patient was seen one week after the appliance application to make any necessary adjustments and to reinforce the patient's confidence and positive attitude toward his appliance. After this second visit, successive observations were made at one-month intervals until the completion of the 100-day period. Time of wear lost due to broken appliances or loose bands was added to the 100-day period of treatment.

Cephalometric Records

Roentgenographic cephalograms were taken in a standard manner, with the anode-to-target distance of five feet and the mid-saggital plane-to-film distance of fifteen inches. Lateral centric and P-A centric headfilms were taken at the beginning of treatment and at approximately thirty-three-day intervals, the fourth series of radiographs being taken at the end of treatment (at 100 days). Only the lateral centric headfilms were used in this study.

Method of Tracing

The initial film representing the beginning of treatment and the final film were traced according to standard procedures. Mid-saggital landmarks were traced and the mid-lines of bilateral structures were used in recording
their locations. The reliability of all landmarks in the beginning and final films was determined by the intra-judge method as described by Manning (1965). The sources of error in the selection of landmarks were then determined by re-examination, and the resultant assessment of each location was made.

Selection of Reference Points and Lines

The reference points and lines used in tracing the cephalograms are defined in Table II and illustrated in Figure 4.

Method of Measurement

The measurements selected for use in this study are defined in Table III and illustrated in Figure 5. Only linear measurements were used, and these were made using the coordinate system. A line parallel to Frankfort horizontal plane and passing through Nasion served as the X-axis. A line perpendicular to this and passing through Basion was selected as the Y-axis (Cohen, 1955). Measurements were made in reference to the Frankfort plane in the first tracing only. The second tracing was superimposed over the first using Basion and deCoste's line as stable landmarks on which to superimpose. The Frankfort plane
TABLE II
GLOSSARY OF REFERENCE POINTS AND PLANES USED IN THIS STUDY

POINTS

Anterior Nasal Spine (ANS): The median, sharp bony process of the maxilla at the lower margin of the anterior nasal opening.

Basion (Ba): The lowermost point on the anterior margin of the foramen magnum in the midsagittal plane.

Maxillary Molar Crown (6c): The most distal point on the maxillary first permanent molar crown.

Maxillary Molar Apex (6a): The mesiodistal midline of the maxillary first permanent molar at the level of the apex.

Menton (Mc): The lowermost point on the symphysis.

Nasion (N): The most anterior point on the frontonasal suture.

Nasion Primed (N'): Nasion of the final cephalogram.

Orbitale (Or): The lowest point on the margin of the orbit.

Porion (Po): The midpoint on the upper edge of the external auditory meatus.

Posterior Nasal Spine (PNS): The tip of the posterior spine of the palatine bone in the hard palate.

Pterygomaxillary Fissure (Ftm): The point where the pterygoid process of the maxilla and the pterygoid process of the sphenoid bone begin to form the pterygomaxillary fissure.

Sella Turcica (S): The geometric center of the pituitary fossa of the sphenoid bone.

Subspinale (Point A): The deepest midline point on the anterior contour of the maxillary alveolar process.
(TABLE II, Con't.)

PLANES

DeCoste's Line (DL): The plano-ethmoidal line from the anterior contour of sella turcica to the roof of the cribriform plate and the internal plate of the frontal bone.

Frankfort Horizontal (FH): The plane through orbitale and porion.

Projected Frankfort Horizontal (PFH): The Frankfort horizontal plane of the first cephalogram projected or transferred to tracings of succeeding cephalograms.
FIGURE 4

DIAGRAM OF LANDMARKS USED
### Table III

**GLOSSARY OF MEASUREMENTS USED**

**I. ANTEROPOSTERIOR MEASUREMENTS**

**A. CRANIAL BASE**

1. **Ba - N:** Basion and nasion are projected perpendicular to the Frankfort horizontal plane (FH) and measured parallel to FH.

2. **Ba - S:** Basion and sella are projected perpendicular to FH and measured parallel to FH.

**B. MAXILLA**

1. **Ba - A:** Basion and subspinale are projected perpendicular to FH and measured parallel to FH.

2. **Ba - Ptm:** Basion and pterygomaxillary fissure are projected perpendicular to FH and measured parallel to FH.

**C. MAXILLARY MOLARS**

1. **Ba - 6c:** Basion and the distal of maxillary first molar crown are projected perpendicular to FH and measured parallel to FH.

2. **Ba - 6a:** Basion and the apex of maxillary first molar root are projected perpendicular to FH and measured parallel to FH.

**II. VERTICAL MEASUREMENTS**

**A. CRANIAL BASE**

1. **N - N':** Nasion and nasion primed are projected parallel to FH and measured perpendicular to FH.

2. **N - PNS:** Nasion and posterior nasal spine are projected parallel to FH and measured perpendicular to FH.

**C. ANTERIOR FACE**

1. **N - Me:** Nasion and menton are projected parallel to FH and measured perpendicular to FH.
FIGURE 5

DIAGRAM OF MEASUREMENTS USED

Anteroposterior Measurements Parallel to FH.
Measurements Perpendicular to FH.
Superior-Inferior
and Nasion from the first tracing were then transferred to the second. This was done to avoid any measurement errors due to a possible change in the position of the Frankfort plane or Nasion during the treatment period. The X-axis of the second tracing passed through Nasion (projected from the first tracing), and was parallel to the Frankfort plane (also projected from the first tracing). The Y-axis of the second tracing passed through Basion and was perpendicular to the projected Frankfort plane. The only landmarks presupposed to be fixed, or stable, through the treatment period were Basion and DeCoster's line.

Measurements of anteroposterior changes within the dentofacial complex were made along the X-axis in reference to Basion, while measurements of vertical changes were made along the Y-axis relative to the initial Nasion. (See Figure 5.) In keeping with the coordinate system of plotting and measuring landmarks, no measurements of angles or absolute distances between two landmarks were used in this study.

Measurements were made on a grid corrected for seven percent magnification, and were recorded to the nearest one-half millimeter. Where two images appeared in the bilateral structures, the mid-point between them was accepted for registration.
Data Analysis

The findings of this study were subjected to statistical analysis. In each patient, the determination was made of the difference of each measurement from the beginning to the end of treatment. The means and standard deviations of the differences in each measurement were determined. The evaluation of the statistical significance of these differences was determined through the use of the Paired Student "t" test.

Comparisons were made to similar measurements in incremental studies of untreated children in the same age group.
CHAPTER IV
FINDINGS

The findings of this study were divided into two major groups. The first group consisted of changes in the anteroposterior measurements, while the second group consisted of the vertical changes that took place. The results are shown in Tables IV and V.

The horizontal measurements (Table IV) were made in reference to the landmark Basion. These were divided into values of the anterior cranial base (Basion-Nasion, Basion-Sella); the maxilla (Basion-Point A, Basion-Pterygomaxillary fissure); and the maxillary molars (Basion-molar crown, Basion-molar apex).

The anterior cranial base showed no anteroposterior changes. The mean alteration of Ba-N was +0.07 mm., while Ba-S had a mean increment of 0.00 mm. Neither was found to be statistically significant.

Both of the anteroposterior maxillary measurements decreased. Ba-A showed a mean change of -0.50 mm., and the mean change of Ba-Ptm was -0.33 mm. Both differences were found to be statistically significant (P<0.05).
### TABLE IV
**SUMMARY OF ANTEROPOSTERIOR FINDINGS**

<table>
<thead>
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<th>Measurement</th>
<th>Mean Change</th>
<th>Standard Deviation</th>
<th>Probability</th>
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<tbody>
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<tr>
<td>Ba - N</td>
<td>+0.07</td>
<td>0.17</td>
<td>0.05</td>
</tr>
<tr>
<td>Ba - S</td>
<td>0.00</td>
<td>0.63</td>
<td>0.05</td>
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<td><strong>MAXILLA</strong></td>
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<tr>
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<td>0.76</td>
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<td>0.56</td>
<td>0.05&gt;P&gt;0.01</td>
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<td><strong>MAXILLARY MOLARS</strong></td>
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<tr>
<td>Ba - 6a</td>
<td>-2.00</td>
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</tr>
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</table>

Measurements in millimeters.
**TABLE V**

**SUMMARY OF VERTICAL FINDINGS**

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<th>Measurement</th>
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<th>Standard Deviation</th>
<th>Probability</th>
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Measurements in millimeters.
The maxillary molar measurements exhibited a dramatic alteration. \( \text{Ba-6c (molar crown)} \) decreased a mean of 3.4 mm., while \( \text{Ba-6a (molar root)} \) decreased a mean of 2.0 mm. Both of these findings were found to be statistically significant \((P<0.01)\).

Vertical measurements (Table V) were made in relation to projected Nasion. These were divided into values of the anterior cranial base \((N-N', N-S)\); the maxilla \((N-ANS, N-PNS)\); and the anterior facial skeleton \((N-Me)\).

The anterior cranial base did not demonstrate any appreciable change. \(N-N'\) displayed a mean difference of +0.03 mm., and \(N-S\) decreased a mean of 0.13 mm. Neither proved to be statistically significant.

The maxillary vertical measurements (palatal plane) did not change a significant amount. \(N-ANS\) increased a mean of 0.33 mm., while \(N-PNS\) had a mean variation of -0.03 mm. Neither value was found to be statistically significant.

The anterior facial skeleton \((N-Me)\) increased vertically a mean value of 0.60 mm., which was statistically significant \((P<0.05)\).
Patient Education and Cooperation-Control of Appliance Wear

The patients had initially been advised of the proposed treatment, including a demonstration of the appliance and the requirements of the patient in wearing it. Each patient was allowed to determine whether or not he would be a part of this investigation. As a result, there were no objections to: 1) having the face-bow fixed in the mouth, 2) wearing the appliance twenty-four hours per day, or 3) undergoing treatment for 100 days.

Since the patients had been educated in their treatment, and because the appliance had been comfortable to wear, cooperation and control of the time-per-day variable was maximum.

Patient Discomfort

In cases where skin sensitivity developed, Desitin ointment or Dr. Scholl's "mole skin" lining for the neckstrap was prescribed, one or the other usually being effective. The only tooth discomfort occurred when the
outer bow had not been adjusted high enough. This resulted in tipping, extrusion of the mesial cusps, mobility, and increased sensitivity of the upper first molars. After the outer bows were properly adjusted, these effects were corrected and the sensitivity was alleviated.

No discomfort was observed in this study as a direct result of the magnitude of force employed (three pounds per side).

Loose or Broken Appliances

In some cases, a loose band or broken face-bow caused an interruption in appliance wear until it was replaced. In four cases this occurred during a holiday period, and the intermission in treatment ranged from one to three weeks. In all of the patients with broken appliances, the amount of time that had lapsed was added to the 100-day period so that the total time of actual wear still equalled 100 days. The overall dentofacial result in these patients, however, was probably impaired because of the relapse that took place during the interruption.

Retention

The maxillary molars, once they reached a Class I relationship, were retained with headgear (usually highpull)
at night only for a period of about three months, depending upon the individual case.

**Direction of Forces**

**Dental Considerations**

The design of the force used in this study was intended to: 1) be directed posteriorly, parallel to the occlusal plane; 2) pass through the center of resistance of the maxillary first permanent molars; and 3) as a result, include a counter-clockwise (viewed from the right) moment to the upper molars and maxilla (Figure 6).

The force was designed to be in the posterior direction and parallel to the occlusal plane so that the maxillary molars (and maxilla) could be moved distally without any intrusive or extrusive effects. Nearly every objective article written about cervical headgear has pointed out the undesirable effects of the vertical component of force inherent in this appliance. Merrifield (1970) determined the line of force with cervical headgear to be approximately thirty degrees below the occlusal plane. He also reported that the line of force produced by highpull headgear (to the arch wire) was approximately thirty-five degrees above the occlusal plane.
FIGURE 6

DIAGRAM OF DIRECTION OF FORCES USED

Combination of Cervical and Highpull Headgear with a 1:1 Force Ratio

Point of Attachment of Outer Bow Ten Millimeters Above Level of Inner Bow

Resultant Force: Posterior, Parallel to Occlusal Plane, Through Center of Resistance of Maxillary Molars
Armstrong (1971) observed that, with a short outer bow, the angle between the attachment of the neckstrap and headcap "in the great majority of cases" was fifty-five degrees.

The direction of the line of force with either the highpull or cervical headgear is dependent upon the length of the outer bow as well as the vertical adjustment of the outer bow. In addition, the direction of force from the cervical headgear relative to the occlusal plane deviates, not only from one patient to another, but within the same individual, depending upon his head posture at the time of measurement.

The outer bow in this study was short and bent upward so that the attachment for the highpull and cervical headgear was approximately ten millimeters above the level of the inner bow. It was assumed that the direction of force from the neckstrap was approximately the same angulation below the occlusal plane as the force from the headcap was above the occlusal plane.

Burstone (1962); Haack (1963); Weinstein (audio-visual); Sanders, Jawor, and Wollney (1970); and Armstrong (1971) have described tooth movement relative to the center of resistance of a tooth. The center of resistance is described as that point on a tooth which, if a force were directly applied to it, would result in uniform bodily movement of
the tooth. The center of resistance of the maxillary molar is generally considered to be in the middle one-third of the root structure, or in the approximate position of the trifurcation. Because a force cannot be applied directly to this point, the line of force must effectively pass "through" this point. With this idea in mind, the outer bow was elevated approximately ten millimeters, as described above (Figure 6).

Skeletal Considerations

Only the maxillary first molars had been banded in this study, and during treatment these teeth underwent several times more movement than did the maxilla. This inequality of movement may have been due in part to the fact that only two teeth received the extraoral force. Had this force been delivered to all of the maxillary teeth, probably more skeletal movement would have resulted. In other words, with a greater number of teeth receiving the extraoral force, the orthopedic effect probably would have been greater and the orthodontic effect not as great.

If skeletal, or "orthopedic" changes are considered in designing a force system to the maxillary dentition, the sutural anatomy of the craniofacial complex must be understood. Whether orthopedic changes are desired or not, the position and direction of the maxillary sutures are of great
importance, because the improper direction of a force intended for tooth movement can and often does produce unwanted skeletal changes.

Figure 7 illustrates a composite lateral view of the relative positions of the frontomaxillary, zygomaticomaxillary, zygomaticotemporal, and pterygopalatine sutures, as well as the spheno-occipital and spheno-ethmoidal synchondroses. These areas are all considered to be sites of growth until at least twelve to fourteen years of age. If orthopedic effects are considered, the center of resistance of the maxilla should be contemplated.

It would seem that the center of resistance of the maxilla probably lies somewhere in the vicinity of the geographic center of the maxillary sutures. This would be approximately at the level of orbitale in the vertical dimension, and at the level of the maxillary first molar in the anteroposterior dimension.

This theoretical position of the center of resistance of the maxilla would explain why the force delivered from a cervical headgear has been observed to open the frontonasal and frontomaxillary sutures, tip the palate down and back at the anterior aspect, and rotate the maxilla (and possibly the sphenoid bone).

The direction of force used in this study, while it did not pass through the theoretical center of resistance
FIGURE 7

DIAGRAM OF CRANIOFACIAL SUTURES

Frontomaxillary Suture
Zygomaticoaxillary Suture
Zygomaticotemporal Suture
Pterygopalatine Suture

Spheno-ethmoidal Synchondrosis
Spheno-occipital Synchondrosis
of the maxilla, did approach this point, and no apparent rotation of the maxilla (N-ANS compared with N-PNS) was observed.

It was noted that the frontonasal suture appeared more radiolucent in the final headfilms as compared with the initial ones, but whether the radiolucency was an indication of an opening of this suture or a slipping of the suture is a matter for speculation at this point. Perhaps histologic examination using this direction of force on laboratory animals would resolve the question.

Continuous vs. Intermittent Force; Light vs. Heavy Force

The question of the proper combination of duration and magnitude of extraoral force is a matter of debate. Research on the teeth of monkeys, dogs, guinea pigs, and rats have produced conflicting, confusing, and questionable information. Teitan (1957) and Graber (1971) in their reports were of the opinion that any intermittent force below one pound was in the tooth-moving (orthodontic) realm, while any intermittent force over one pound was in the orthopedic range, with no tooth movement taking place. Graber held that if such a heavy intermittent force is used, the direction of force is immaterial. For example, a cervical headgear using heavy (in excess of one pound)
intermittent (fourteen hours per day) force would, according to Graber, retard the forward growth of the maxilla without extruding the maxillary dentition, tipping the palatal plane, or elongating the face.

The author's observations of extraoral force would generally indicate the following: 1) continuous force, light or heavy, moves teeth more rapidly than does a similar magnitude of intermittent force; 2) heavier force, continuous or intermittent, moves teeth more rapidly than does a similar lighter force; 3) increased orthopedic effects are produced by delivering the force to a larger number of teeth; and 4) the direction of force has a dynamic effect on the type and direction of orthodontic or orthopedic response elicited. The latter observation is particularly evident with the direction of force delivered by cervical headgear. The downward and backward tipping of the dentofacial complex as reported by Klein (1957), Poulton (1959), Weislander (1960), Sandusky (1965) and others is increased in direct correlation with the amount of force, continuity of force, and duration of cervical headgear application.
Root Resorption

Periapical and panographic roentgenograms taken after treatment revealed no detectable root resorption of the maxillary first molars. DeShields (1969) observed that the greatest cause of root resorption was due to prolonged treatment, while Armstrong (1971) felt that long-term, intermittent tooth movement was the most frequent cause of root resorption. If some resorption of the roots did take place in this study, it was not great enough to be detected through normal roentgenographic investigation.

Status of Maxillary Second and Third Molars

When observing changes in the position of the unerupted maxillary second permanent molars in both lateral and P-A headfilms, it was observed that these teeth moved distally almost to the same extent as the first molars, and in most cases some buccal displacement occurred.

A logical question that comes to mind involves the probability of impacting the upper second or third molars as a result of distal movement of the first molars. If the first molars are moved distobodily, and not tipped back, the second molars are not likely to become entrapped under the first molar crowns. Many observers feel that the
first molars were not "intended by Nature" to occupy a more distal position in the arch. If the first molars are moved distally, these people reason, sufficient room for the erupting second and third molars would not be available.

Radiographs of cases treated in this study (in which the first molars had been moved distally about three and one-half millimeters) were submitted to the Oral Surgery Department at Loyola University for consultation. The probability of impaction of the second or third molars, in the oral surgeons' judgement, was doubtful. They were of the opinion that impaction of the second molars particularly was highly improbable. In the event that the third molars should become impacted, the oral surgeons foresaw no unusual complications in their extraction.

Comparison of Treated Group with Untreated Groups

The dentofacial effects observed in this investigation were compared with changes that normally occur in untreated children. The incremental growth studies selected for comparison were those which used at least one measurement similar to the measurements used in this study. In order to provide a better comparison, the findings from the growth studies were reduced to 100-day increments. A linear growth pattern was, out of necessity, assumed. The figures are,
however, believed to be descriptive of normal growth changes that occur in a 100-day period in the age group of the sample studied.

The comparisons are shown in Table VI.

Coben's study (1955) yielded mean increments in craniofacial depth and height of forty-seven children studied from the age of eight to sixteen years. The means of measurement in this study were patterned after Coben's, and the following common determinations were used in both studies: 1) Ba-N, 2) Ba-S, 3) Ba-A, 4) Ba-Ptm, 5) N-S, 6) N-ANS, and 7) N-Me.

Krogman (1953) studied the craniofacial growth increments of Philadelphia children from the age of six to fourteen years. The common measurement in Krogman's study was N-Me.

Muller (1963) performed a serial roentgenographic examination of 541 German children from the Bonn Clinic. The children were studied over a four-year period with the mean initial age of seven and one-half years. The measurements selected from Muller's study were: 1) N-ANS, and 2) S-PNS. The latter would have increments similar to those of N-PNS (perpendicular to Frankfort plane), and the two were compared.

Pike (1964) observed twenty-five children for four
### TABLE VI
**COMPARISON WITH NORMAL GROWTH FINDINGS**

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<tr>
<th>Measurement</th>
<th>This Study</th>
<th>Coben</th>
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Measurements in millimeters

* 0.05 > P > 0.01
years, the mean initial age being seven and one-half years. The increment selected from Pike's study was N-Me.

Savara (1968) studied the dentofacial growth of fifty-two Northwest European boys from the age of three to sixteen years. The measurement selected from Savara's investigation was N-ANS.

Burstone studied craniofacial growth increments in males and females from four to twenty-two years. The measurements for the nine to eleven year age group selected for comparison were: 1) Ba-N, and 2) N-Me. As with the others, the increments from this study were reduced to a 100-day period for the purpose of comparison with the changes seen in this investigation.

It is seen in Table VI that the difference in N-Me (which was statistically significant) in this study was the same as the alteration that normally takes place in N-Me during a 100-day period in untreated children. This indicates that the treatment in this investigation had little or no effect on the measurement N-Me. N-Me is a determination of anterior face height, and abnormal increases in this measurement are reflective of extrusion of the molars and/or abnormal vertical growth of the anterior facial skeleton. It can be reasoned, then, that since the treatment in this study had no discernable effect on N-Me,
the upper molars were not extruded to any significant degree.

The anteroposterior assessment of the maxilla (Ba-A and Ba-Ptm) indicated that the maxilla moved posteriorly in relation to basion. Findings from the growth studies, however, indicate that the maxilla normally moves anteriorly. The posterior movement of points A and Ptm (which was statistically significant) was 0.50 mm. and 0.33 mm., respectively, while these points normally move anteriorly about 0.32 mm. and 0.15 mm. in 100 days.

Comparison of the remaining skeletal measurements indicated that the other changes observed in this study closely resemble the increments seen in normal growth studies. The difference between the changes in N-ANS and N-PNS indicated that the palatal plane was not significantly tipped during treatment.

Case Report

One representative case was selected for illustration. It was neither the most dramatic case in the study nor the least. At the beginning of treatment, the age of the patient, a female, was eleven years, five months, and the molars were in full Class II relationship. The dentition was mixed, the second permanent molars were unerupted, and the bite was moderately closed (Figures 8-11). Insufficient room was available for the maxillary left second bicuspid to erupt into proper alignment.
Figures 12 and 13 show the case at the end of thirty-four and sixty-four days, respectively, with the molars being progressively moved distally.

The case at the completion of the study (at 101 days) is shown in Figures 8-10 and 14. The molar relationship was corrected to Class I with the bite still moderately closed. The maxillary left second bicuspid was in proper alignment in the arch, and the first bicuspid had moved distally enough to allow the upper left canine to erupt in an uncrowded state.

The measurement changes (Table VII) indicate that the maxilla remained in a stable position. The maxillary first molar crowns moved distally four millimeters, while the roots moved distally five millimeters. Anterior facial height increased one millimeter (normal increase = 0.6 mm.).

Figure 15 shows the patient after three months of retention (headgear at night only), ready to begin full orthodontic therapy. The difficulty of this case has diminished: treatment can be completed in a relatively short period of time, possibly without the necessity of extracting teeth. The overall effect on the malocclusion was: 1) correction of the molar relationship, 2) interception of the lingual eruption of second bicuspsids, and 3) prevention of further crowding of the anterior teeth with the eruption of the canines.
CASE NO. 3 MODELS
LEFT SIDE OCCLUSION

Top: Beginning
Bottom: Final (100 Days)
FIGURE 9

CASE NO. 8 MODELS
MAXILLARY OCCLUSAL VIEW

Top: Beginning
Bottom: Final (100 Days)
FIGURE 10

CASE NO. 8

LEFT SIDE OCCLUSION

Top: Beginning
Bottom: Final (100 Days)
FIGURE 11

CASE NO. 3
LATERAL CEPHALOGRAM

Beginning
FIGURE 12

CASE NO. 8
LATERAL CEPHALOGRAM

Thirty-four Days
FIGURE 13

CASE NO. 8
LATERAL CEPHALOGRAM

Sixty-four Days
FIGURE 14

CASE NO. 8
LATERAL CENTER CEPIALOGRAM

Final (100 Days)
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Measurements in millimeters.
FIGURE 15

CASE NO. 8

Three Months Retention
CHAPTER VI
SUMMARY AND CONCLUSIONS

The purpose of this study was to assess any changes in the dentofacial complex produced by a heavy continuous distal traction on the human maxillary molars directly, and on the maxilla indirectly.

The sample consisted of nine females and six males ranging in age from eight years, ten months to eleven years, five months. The mean age was ten years, four months. The cases were all Caucasian, with Class II molar relationships, and mixed dentitions. The maxillary second permanent molars were unerupted.

The appliance used to deliver the extraoral traction was the combination of a highpull and cervical spring-loaded headgear (Northwest) attached to a face bow with the short outer bow elevated (Oscar). Only the upper first molars were banded, and the face bow was inserted into buccal tubes on these teeth and fixed in this position. A continuous force of three pounds per side was used over a period of 100 days (range: 94-104 days).

Lateral centric and P-A centric roentgenograms were taken at the onset and at approximately 33-day intervals.
until completion 100 days later. The lateral centric roentgenograms were traced in a normal manner. The initial and final tracings were superimposed on Basion and De Coster's line, and coordinate measurements were made parallel and perpendicular to the Frankfort plane.

The mean initial and final values were recorded for each measurement, and the difference between the means was statistically analyzed using the paired "t" test.

Some of the findings were compared with normal growth changes that occur over the same length of time.

From the findings of this study, the following conclusions were made:

1) The combination of cervical and highpull headgear, delivering a heavy, continuous traction to the maxillary first molars for 100 days, produced marked distobodily movement of these teeth.

2) This same force produced a posterior movement of the maxilla without significantly tipping the palatal plane.

3) The amount of posterior movement of the maxillary molars was much greater than that of the maxilla.

4) The amount of change in anterior facial height was similar to that which is commonly attributed to normal growth.
5) The force used in this study produced no statistically significant changes in the anterior cranial base in either the anteroposterior or vertical dimension.
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Graber, T. M. Personal Communication.


Moffett, B. C. Personal Communication.


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Measurements in millimeters.
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Measurements in millimeters.
The thesis submitted by Norman L. Sanders, B.A., D.D.S., has been read and approved by members of the Department of Oral Biology.

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.

May 18, 1971

DATE

[Signature]

SIGNED OF ADVISOR