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CRANIOFACIAL CHANGES INDUCED BY "ORTHOPEDIC FORCES" IN THE MACACA MULATTA RHESUS MONKEY

by

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ABSTRACT

The purpose of this study was to quantitatively assess the effects of various types of heavy "orthopedic" forces on the craniofacial complex of juvenile monkeys. The effects of laterally-directed heavy expansive forces and posteriorly-directed heavy extraoral forces applied alone and in combination to the maxilla were investigated. Seven female Macaca mulatta (rhesus) monkeys in the late mixed dentition stage were divided into a control group, an "orthopedic" headgear group, a rapid maxillary expansion group, and a combination rapid maxillary expansion followed by "orthopedic" headgear group.

Metallic implants were placed in several bones of the facioskeleton, cranial vault and cranial base. A method for precise reorientation of the animals in a cephalostat was developed and serial lateral cephalometric radiographs taken at specific time intervals in all groups.

In the "orthopedic" headgear group, 28 ounces (800 grams) per side of extraoral distal traction, slightly cervical to the occlusal plane, was applied continuously to the maxillary arch for periods up to 103 days. One animal underwent a 26 day post-headgear observation period.

In the rapid maxillary expansion group, palatal expansion using a split acrylic jackscrew-type appliance was carried out daily for a 12 day period.

In the combination rapid maxillary expansion followed by "orthopedic" headgear group, heavy extraoral traction comparable to that used in the "orthopedic" headgear group was applied on the 12th day of palatal expansion. The expansion appliance was activated for an additional 3 day period at twice the previous activation schedule and extraoral traction maintained for periods up to 72 days.

The longitudinal series of cephalometric radiographs of each animal were subjected to quantitative analysis.

Heavy extraoral traction to the monkey created severe mesiocclusal malocclusions with extreme anterior crossbites and caused dramatic changes in facial appearance. The spatial relationships of the facial bones were extensively altered. The maxillary and zygomatic bones rotated downwards and backwards, with respect to the implants in the basi-sphenoid bone, in a "clockwise" direction in the sagittal plane as viewed from the right side of the skull. The facial bones rotated differentially with respect to each other and the sphenoid bone. The anterior cranial base, consisting of the orbital processes of the frontal bone forming the floor of the anterior cranial fossa, also rotated "clockwise" with respect to the sphenoid bone. Accompanying the rotation of the upper facial structures, the mandible rotated downward and backward resulting in marked increase in vertical facial dimensions. The shape of the cranial vault was also altered by heavy extraoral traction with movement of the parietal bones with respect to the occipital and frontal bones.

The occlusal disproportion created by heavy extraoral traction was the result of posterior movement of the upper facial bones and maxillary teeth. The major part of the posterior movement of the maxillary dentition, relative to the cranial base implants, was due to posterior movement of the entire maxilla and contiguous bones rather than posterior movement of the maxillary teeth within the maxilla. The severe interarch occlusal disproportion was created independent of and irrespective of forward mandibular growth.

During a short 26 day post-headgear observation period, recovery of the affected bones toward their original position occurred to a certain

extent. The rate of movement of the individual bones during the short recovery period was much greater than that seen during normal growth over a similar time interval in the control animals.

Rapid maxillary expansion resulted in a slight downward movement of the palatal outline and palatal implants relative to the implants in the cranial base while either no movement or an upward movement of the implants in the body of the maxilla occurred. Little effect on the antero-posterior relationship of the maxilla was recorded. Indications of change in the position of the implants in the zygomatic bone and in the zygomatic process of the temporal bone relative to the cranial base implants suggested that adjustive movements in these bones had occurred during rapid maxillary expansion.

Rapid maxillary expansion did not enhance the susceptibility of the maxillary complex to posterior movement following application of heavy extraoral distal traction. The orthopedic response to heavy extraoral force was similar or lesser in animals subjected to rapid maxillary expansion compared with animals subjected to distal traction alone after comparable periods.

We choose our next world through what we learn in this one. Learn nothing, and the next world is the same as this one, all the same limitations and lead weights to overcome.

— Richard Bach —

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CHAPTER I

INTRODUCTION

For over a century, rapid maxillary expansion and extraoral distal traction have been used for the treatment of malocclusions. Although the clinical response of "orthopedic" extraoral distal forces to the maxilla has been reported, the precise effects of these heavy forces on the craniofacial complex are not well understood because of the limited opportunity for experimentation in man. The orthopedic effects of very heavy posteriorly-directed extraoral forces have not yet been studied in experimental animals, although the effects of lighter extraoral forces on the monkey have been reported. More is known, however, about the effects of laterally-directed heavy expansive forces applied during rapid maxillary expansion. Previous animal experimentation has shown specific orthopedic effects resulting from rapid maxillary expansion including opening of the midpalatal suture with forced separation and lateral arcing of the maxillary halves accompanied by concomitant reorientation of the facial bones occurring at the sutures. Recently, clinicians have speculated that rapid maxillary expansion may enhance the orthopedic effect of heavy posteriorly-directed extraoral forces applied to the maxilla. However, the effect of the simultaneous application of these two types of "orthopedic" forces upon the craniofacial complex has not undergone previous experimental study.

The purpose of this study was to investigate the dental and skeletal changes which occur throughout the craniofacial complex as a result of application to the maxilla of laterally-directed heavy expansive forces and posteriorly-directed heavy extraoral forces alone and in combination. The growing Macaca mulatta (rhesus) monkey was chosen as the most suitable experimental animal because of its close dental and skeletal similarity to man. The monkeys were divided into control and experimental groups. The following types of "orthopedic" force systems were applied in the experimental groups: (1) heavy extraoral distal traction to the maxilla, (2) rapid maxillary expansion, and (3) rapid maxillary expansion followed by heavy extraoral distal traction to the maxilla.

The study was carried out using a metallic implant-radiographic cephalometric method to accurately quantify the dental and osseous adaptations which accompanied application of the above types of "orthopedic" forces. Previous non-human primate investigations have demonstrated the difficulty of obtaining precise animal reorientation in the cephalostat essential for meaningful analysis of serial lateral cephalograms. This necessitated the development of a technique allowing for the precise reproduction of head orientation during the taking of longitudinal radiographic records.

The experiment was designed to accurately describe the specific effects of each type of "orthopedic" appliance and to determine whether the rapid maxillary expansion procedure enhances the effect of heavy posteriorly-directed forces on the skeletal structures. It was anticipated that this information not only would contribute to a better understanding of the effects of these heavy force systems on the craniofacial structures of the human but also would indicate the orthopedic potential of very large magnitudes of force to manipulate skeletal structures.

CHAPTER II

REVIEW OF THE LITERATURE

I. THE CONCEPT OF DENTOFACIAL ORTHOPEDICS

The effect of orthodontic forces on facial growth has been disputed for many years. The concept that external pressure can modify the direction of bone growth has been established for centuries. Primitive tribes of Columbian Indians bound the skulls of their infants between boards to create a characteristic cranial morphology which these early societies thought was desirable. Similarly, in the past, the Chinese considered small feet socially desirable for women and hence bound their feet during the early period of growth to restrict their length. These examples suggest that the shape and spatial position of bones can be altered (Graber, 1969; Sassouni, 1972).

Bunon, 1743, was among the first to mention the term "orthopedic" in connection with dentistry (Weinberger, 1926). In its present meaning, "dentofacial orthopedics" refers to the art of changing the relationship between the bones of the face by applying external forces. In 1895, prior to the inception of Orthodontics as an organized specialty, this term was favoured by Calvin S. Case who was concerned with the correction of facial deformities. In 1908, Case stated that:

> the term 'Orthodontia' is not sufficient in itself because its meaning is limited to irregularities of the teeth and their correction; whereas, a movement of other parts, quite as important in the reduction of certain facial deformities as the movement of the teeth, has long been recognized as within the possibilities of dental force application. ... 'Orthopedic Dentistry' or 'Dental Orthopedia' therefore would plainly specialize the art to the correction of all dental and facial deformities accomplished by orthopedic movements of the teeth and connecting bones.

Thus, it would appear that the orthodontic profession has long accepted the fact that therapeutic force application has the ability to alter the integrity of facial structures outside the local dento-alveolar area. However, this was not the case. Hellman in 1933 initiated a retrogressive attitude in the American continent when he reported:

> that development of the face is a natural process that takes place regardless of orthodontic treatment. ... The growth of the face is apparently not dependent on the effect of orthodontic treatment, but ... the success of orthodontic treatment may be dependent upon the effect of growth.

This kindled a doubt that orthodontic therapy in general may have an effect on cranio-facial growth. Brodie et al (1938), in a radiographic cephalometric study confirmed Hellman's contention that orthodontic treatment did little to alter facial growth. Brodie et al concluded that the morphogenetic pattern of the human skull was established at an early age and that once attained it did not change. Hence, bone changes accompanying the correction of a malocclusion were thought to be restricted to the alveolar processes. These studies had a strong influence on orthodontic thinking for many years by establishing dogmatic concepts of the pattern of facial growth and by creating a distinction between "basal" and "alveolar" bone tissue and their respective adaptive capabilities. These divisions, which were based essentially on radiographic landmarks, are biologically unsound. From a biological viewpoint, an external force system capable of moving teeth and altering the local dento-alveolar bone tissue adjacent to the teeth is just as likely to elicit adaptive changes in bone tissue at more remote sites if this same force is of large enough magnitude to be transmitted to the distant bone tissue. However, perhaps due to diminution of force transmission beyond the immediate alveolar area during most orthodontic procedures, these osseous changes in the basal structures may be more subtle and only demonstrable at the histological level, and hence escape detection by routine cephalometric methods.

Nonetheless, it was not until the late 1950's and 1960's that this attitude in the profession began to change as studies on the effects of various orthodontic procedures suggested that the cranio-facial complex was not an immutable structure but that during the growth period morphologic adaptation did occur. Hence, it has recently become fashionable to describe forces as "orthodontic" or "orthopedic" depending on whether their influence produces measurable changes in the basal structures. This distinction, however, is based on magnitude of skeletal change and is thus subject to the limitations of the cephalometric method. Therefore, heavy forces producing more obvious skeletal effects are often classified as "orthopedic" while lighter forces whose effects appear limited to tooth movements are classified as "orthodontic."

A modern example of the capability of external pressure to produce orthopedic change in the dento-facial structures is associated with the use of the Milwaukee brace for the treatment of scoliosis. During use of this brace, intermittent pressure from 0 to 10 pounds with a mean of 4 pounds has been recorded in the mandibular pad area (Glass, 1961). Clinical studies by Thors (1964), Lindskog (1967) and Eastham (1968) using implant-cephalometry and by Alexander (1964), Fairleigh (1965), Watson (1966), Barkley (1967) and Gee (1968) using routine cephalometric procedures reported indications of dental and skeletal changes which included depression of buccal teeth, resorption of the alveolar process corresponding to tooth depression, reduction in vertical face height, directional change in growth of the lower face, remodelling of the lower border of the mandible and possible inhibition of condylar growth. In addition, Alexander (1964) reported elevation of the palatal plane while Lindskog (1967) with the aid of metallic implants, reported superiorly directed bodily displacement of the maxilla itself. Barkley (1967) and Gee (1968) also studied the permanence of these dento-facial changes and reported approximately 33% recovery from lost anterior face height and 50% recovery from incisor protrusion. The morphologic changes in the mandible, however, did not tend to recover.

Cutler et al (1972) studied the effects of a modified Milwaukee brace on five growing Macaca monkeys for periods ranging from 54 to 252 days and found a directional change in dento-facial growth similar to that seen in scoliosis patients treated clinically. Using implant-cephalometry, analysis suggested a reversal of the normal downward and forward growth of the maxilla and mandible such that the entire dento-facial complex was displaced in a superior direction relative to the registration on the cranial base, with the mandibular change approximately twice as great as that in the maxilla. The orbital process of the frontal bone appeared to move upwards and forwards. In addition, morphologic alterations were seen in the posterior part of the cranium where the occipital bone had been subjected to pressure from the posterior pad of the brace. Two monkeys, who were still growing, underwent additional observation periods of 29 and 135 days respectively following brace removal. In general, there was a reversal of the changes noted during therapy with both dental and skeletal recovery evident. This was not well documented cephalometrically but histologically it appeared that the brace had retarded growth and after removal normal growth resumed. It was thought that possibly an initial compensatory spurt of growth had occurred during recovery; however, this was not substantiated.

For many years, European orthodontists have referred to the use of "functional jaw orthopedics" in connection with the use of the activator. However, widely differing opinions exist regarding the orthopedic effects of the activator. Korkhaus (1960, 1962), Freunthaller (1967), Gresham (1958) and Marschner and Harris (1962) contended that functional therapy increased mandibular condylar growth while Bjork (1951), Softley (1953), Jakobsson (1967), and Harvold and Vargevik (1971) disagreed. J. P. Moss (1962), Evald and Harvold (1966), Meach (1966), Jakobsson (1967), Hotz (1970), Harvold and Vargevik (1971) and Pfeifer and Groberty (1972) reported a restraining effect on the forward vector of maxillary growth. Bjork (1951) and Softley (1953) claimed that the effects of functional appliances were restricted to the dento-alveolar areas.

On the experimental level, Elgoyhen, Moyers and McNamara (1972) and McNamara (1972) used intra-oral splints to induce functional anterior positioning of the mandible in growing Macaca rhesus monkeys and created Class III malocclusions. Implant-cephalometric analysis demonstrated redirection of the vector of maxillary growth with inhibition of vertical growth apparently expressed as increased anterior displacement of the maxilla. Statistically significant increases in the rate and amount of condylar growth occurred primarily in infant and juvenile monkeys. Hiniker and Ramfjord (1966) and Ramfjord and Enlow (1971) carried out similar experiments on adult monkeys and found insignificant condylar change. Hence, it appears that maturational age predisposes the extent to which orthopedic changes in the monkey are possible using functional appliances.

In another experiment, Harvold, Chiericic and Vargevik (1972) fitted acrylic blocks in the palatal vault of normal rhesus monkeys which rotated the postural position of the mandible inferiorly and produced Class II malocclusions. It was concluded that the effect of the mandibular rotation and consequent increased downward and forward migration of the upper teeth into the additional interocclusal distance resulted in the altered molar relationship.

Other non-human primate experiments have studied the extent to which osseous morphogenesis could be affected by various other forms of mechanotherapy. Meikle (1970) studied the effect of Class II intermaxillary force in adult Macaca rhesus monkeys and reported a marked alteration in the dentofacial complex, including a downward and backward displacement of the maxillary complex, alteration of the occlusal relationships of the teeth and production of an "open bite." Condylar change was minimal in these adult monkeys, which led to the conclusion that fibrous joints such as the facial sutures are responsive to external mechanical forces in the adult whereas cartilaginous joints are more resistant. Indications of vector changes in maxillary growth have also been reported in other non-human primate experiments by Janzen and Bluher (1965), Adams (1969), and Joho (1971) even when the retractive forces were applied only to the mandible.

Among the most common and oldest forms of appliance therapy considered to have an orthopedic influence on the dentofacial complex are extraoral traction to the maxillary arch and rapid maxillary midpalatal expansion. The history of both these types of treatment will each be individually reviewed with special emphasis upon their orthopedic effects on the cranio-facial complex.

II. EXTRAORAL TRACTION TO THE MAXILLA

The application of extraoral force to the teeth is as old as Orthodontics itself. In fact, the first record of orthodontic treatment comes from the ancient Roman Celsus (B.C. 25-40 A.D.) who recommended the use of finger pressure to treat irregularities of the teeth (Weinberger, 1926). According to Weinberger, Gunnell claimed to be the first to use occipital anchorage in the form of a chincap as far back as 1822 but did not describe its use until 1841. In the meantime, Kniesel published the idea of occipital anchorage for the treatment of protrusion of the mandible in 1836. Weinberger credits Kingsley, 1855, with describing the first occipital traction appliance to the maxillary arch, which Kingsley used to retract protruding upper incisors (Figure I Type F). Farrar (1886), Angle (1889) and others modified Kingsley's design and during this period occipital anchorage was used to a great extent.

However, under the influence of Angle (1907) occipital anchorage fell into a long period of disfavour and was largely superceded by the use of intermaxillary elastics, the so-called Baker anchorage, which was introduced in 1893. Nonetheless, in 1913, Carl B. Case originated "cervical traction" which used the back of the neck as an adjunctive source of anchorage and throughout this period C. B. Case continued to stress the usefulness of extraoral anchorage as an orthodontic auxillary.

For approximately 30 to 40 years occipital anchorage was seldom used. In the mid-1930's, Oppenheim initiated its revival when he reported reduction of a Class II Division 1 malocclusion, using occipital anchorage applied only to the maxillary first molars, in an actress, who could not carry on her professional duties wearing a multi-banded

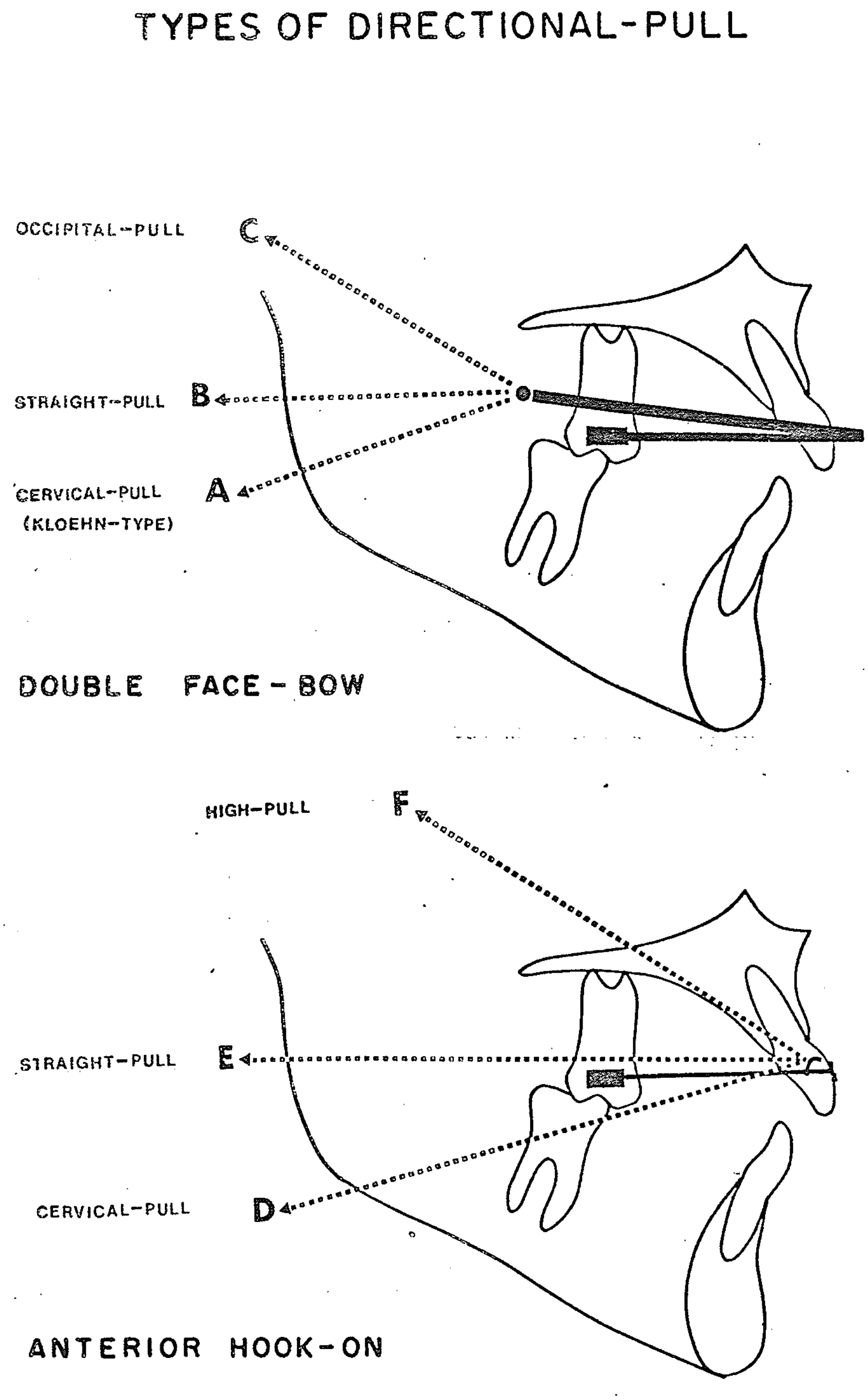

Figure 1. Types of extraoral headgear. The double face-bow appliance usually delivers the extraoral force to the maxillary first permanent molars while the conventional anterior hook-on appliance usually delivers the force to the archwire of a multi-banded orthodontic appliance. The earlier headgears attached in various other ingenious ways to the teeth. Variations and combinations of the types of directional-pull illustrated above can be used with each type of headgear appliance.

orthodontic appliance. Oppenheim (1944) stated that previously headcaps had been recommended only for reinforcing maxillary anchorage, whereas he suggested it be used for the mass distal movement of teeth. Oppenheim (1934, 1935-6, 1944) believed that the teeth moved distally due to transmission of the force from the molars through the transeptal fibers from tooth to tooth, and stressed that light, intermittent forces be used for the most effective results.

Following Oppenheim's re-introduction of occipital traction, Thompson (1940), Strang (1941), Kresnoff (1942), Waldron (1942), Johnson (1943), and Jerrold (1945) published descriptions of occipital appliances and emphasized their usefulness in Class II treatment.

However, it was Kloehn (1947) who popularized Oppenheim's double face-bow or "E arch" appliance which was attached to the maxillary first molars. Kloehn (1947, 1953) recommended its use with cervical neckstrap to enhance patient co-operation (Figure I Type A). Kloehn advocated early mixed dentition "guidance" treatment to guide the eruption of the maxillary teeth and alveolar growth while the mandible and the mandibular teeth were permitted their normal downward and forward growth. Kloehn (1947) believed that headgear treatment did not alter the growth pattern of the maxillary, mandibular, or any of the facial bones. Kloehn (1953) stated that the amount of force used was determined by patient tolerance and that it usually approximated 3/4 to 1 1/2 pounds (340 to 678 grams).

Epstein (1948) in a cephalometric study of twelve patients with Class II malocclusions that were corrected with extraoral anchorage as advocated by Oppenheim, concluded that the change in molar relationship was brought about, at least partially, by the posterior movement of the maxillary molars. In other cases correction appeared the result of "holding the maxillary molars stationary in the forward growing maxilla while the mandible grows forward." Hedges (1948) in a cephalometric study, concluded that in Class II treatment mandibular growth provided most of the change in molar relationship. Fischer (1947) and Nelson (1953) recommended the use of extraoral anchorage instead of intermaxillary elastics to correct Class II cases so as not to disturb the mandibular arch. Nelson stated that teeth can be held or moved distally using light, intermittent extraoral force.

In the 1950's investigators began to question whether clinically imperceptible skeletal changes in "basal" bone accompany dento-alveolar correction resulting from the extraoral force. Graber (1955), discussing extraoral force, stated that "there is no evidence that maxillary growth, per se, is affected. ... that maxillary alveolar growth can be influenced is another matter."

King (1957), in a cephalometric study of the effect of cervical traction on 50 Class II Division 1 malocclusions, supported the views held by Kloehn (1947), Epstein (1948) and Hedges (1948).

During the same period, however, Klein (1957), Newcomb (1958), Blueher (1959) and Ricketts (1960) studied cases treated with cervical traction and reported findings which included a marked downward tipping of the anterior part of the palatal plane, a reduction in facial convexity, and an inhibition of the normal forward movement of the anterior nasal spine.

Moore (May, 1959) discussed treatment factors in Class II malocclusions and stated that "there was no positive evidence to prove that orthodontic treatment influenced the normal forward growth of the maxilla." However, one month later, Moore (June, 1959) completely reversed his opinion when, after presenting several treated Class II cases, he concluded that:

> a distal or posterior force applied to the maxillary teeth may cause actual distal movement of the maxillary teeth. Also, such a force alters the horizontal growth pattern of the maxilla itself. Whether we call this 'inhibition of growth,' 'arrested growth,' or 'altered growth' at this time is a matter of semantics. However, it is plain that under such a force the profile length of the maxilla does not increase, or it increases a negligible amount.

The next year, following a comprehensive cephalometric study of the influence of orthodontic treatment on facial growth, Ricketts (1960) made the following statement:

> We no longer can accept the maxilla as an immutable structure. Vigorous retraction force on the teeth ... appears to prevent forward growth and even cause the maxilla to grow downward and backward.

Ricketts suggested that the pterygoid plates and deep bony structures in relation to the maxilla should be studied further as he felt that isolated cases possibly experienced alteration there.

Wieslander (1963) in a cephalometric study, investigated the effects of prolonged headgear treatment over a 3 1/2 year period in a sample of 30 mixed dentition Class II Division 1 cases. Wieslander superimposed serial cephalograms on the spheno-ethmoidal plane and registered on the midline point of the two great wings of the sphenoid bone as it intersects this plane (CBR point). Study of statistical data and superimposed tracings indicated an influence upon the direction of growth of the maxilla proper including posterior change in position of pterygo-maxillary fissure, smaller anterior movement of anterior nasal spine, and tipping of the palatal plane downward at the front. Further, a "clockwise" rotation (as viewed from the right side of the skull) of the sphenoid bone was indicated. This finding was partially based on superimposition of serial tracings on the line joining basion and CBR point and noting the rotation of the spheno-ethmoidal plane and partially on statistical correlations between increments of change of various anatomical landmarks. Hence, Wieslander, postulated that force application to the maxilla was transmitted to the pterygoid plates of the sphenoid bone resulting in a spatial alteration of the spheno-maxillary complex in the nature of a "clockwise" rotation. Wieslander concluded that headgear treatment can alter the direction of growth of the cranio-facial complex. However, Sassouni (1972) commented on Wieslander's paper concerning rotation of the sphenoid bone and stated that "since his was an isolated report and since it was further questionable in terms of methodology, this subject should be investigated further."

Seward (1964) discussed Class II treatment with cervical headgear. Finding no change in angle basion-sella-nasion, he superimposed on sella-nasion (S-N) with sella (S) registered, and observed changes in the maxilla not typical of normal growth including downward tipping of the anterior part of the maxilla, minimal increase in maxillary length but an increase in vertical height, and hypothesized a pivoting of the maxilla around its articulation with the lateral pterygoid plate. During the same period the mandible grew forward. After headgear was discontinued, normal growth resumed with increase in maxillary length and parallel descent of the palatal plane. Seward concluded that headcaps"can be used either to move teeth through the maxilla or to modify the growth of the maxilla depending on the forces employed."

Sandusky (1965) examined the effects of several combinations of treatment including application of Kloehn cervical traction to 20 Class II Division 1 cases using approximately 36 ounces of distal force.

Sandusky reported no significant change in the cranial base angle nasion-sella-basion (N-S-Ba) and only a tendency toward change in the angle formed by the line joining sella to nasion and the line tangent to the planum shenoidale (angle SpPl-SN). When he subdivided the headgear group, Sandusky found that in the younger age division (average age 10.12 years) consisting of 11 patients there was a mean net change of 1.39 degrees in the SpPl-SN angle which was significant at the 95% level of confidence and indicated that the sphenoid bone had rotated. Significant increases in maxillary length coincided with Wieslander's findings and indicated that maxillary growth was not retarded but rather spatially redirected as supported by the downward tipping of the palatal plane, reduction in angle ANB, and posterior movement of pterygomaxillary fissure in some cases. Unfortunately Sandusky used another treatment group, undergoing correction following Tweed mechanics, for statistical comparison and did not use an untreated control group. Both Wieslander and Sandusky suggested that the direction of growth and not magnitude of growth was altered by extraoral force.

Jakobsson (1967) compared treatment changes in Class II Division 1 cases between cervical headgear and monobloc groups and concluded that both extraoral and activator treatment had, in a posterior direction, a definite influence on the basal parts of the maxilla.

During the last decade, articles also began to appear which stressed the importance of the direction of force application. Poulton(1959, 1964 and 1967) discussed anterior hook-on high-pull headgear (Figure 1 Type F) and the merits of controlling the balance between vertical and horizontal movements of the upper teeth. Poulton reported inhibition of maxillary growth but felt that since extra-alveolar changes were so small, their clinical significance would be slight compared to the very obvious tooth movement that could be obtained using various types of directional extraoral forces. Poulton warned against indiscriminate use of cervical neckstrap because it harbours a considerable vertical force component. Schudy (1963, 1964, 1965, 1968) and Isaacson et al (1971) emphasized the importance of vertical growth and the vertical dimension when considering treatment mechanics and stressed that molar elongation must be avoided in cases exhibiting high mandibular plane angles as these patients usually also have a tendency toward anterior open bite since extrusion of posterior teeth tends to rotate the mandible dorsally, aggravating a retrognathic facial profile and accentuating an anterior open bite. Kuhn (1968) considered the control of posterior tooth eruption a major factor in attempts to modify or maintain lower face height.

Melson and Enemark (1969) used implant-cephalometry to study the effect of application of Kloehn headgear on 20 children in the late mixed dentition and to determine whether tilting the extraoral bow exerted any influence on the effect of the headgear. Melson and Enemark reported the following findings:

> In the group with upward tilt of the extraoral arch, only slight tooth movements occurred, but the entire maxillary complex shifted backwards and downwards in relation to the anterior cranial base during the period of treatment, resulting in an approach to normal molar relationships. In the group with downward tilt of the extraoral arch, greater intramaxillary tooth movements were measured; in particular, a distal tipping of the first molar occurred. In these patients no influence on the maxillary complex could be measured during the period of treatment.

Mays (1969) compared the effects of Kloehn cervical headgear and anterior hook-on headgear and reported greater skeletal changes with

Kloehn traction including clockwise rotation of the sphenoidal plane, opening of mandibular plane angle, and decrease in SNB. Vertical anterior lower face height increased twice as much with the Kloehn traction as with the anterior hook-on headgear, while SNB and mandibular plane did not change significantly in this latter group.

Greenspan (1970) discussed the biomechanical principles controlling the direction of movement of the maxillary molar in response to high-pull, horizontal-pull, and cervical-pull headcaps using the double face-bow as well as the effects of altering the length and angulation of the outer bow (Figure 1 Types A, B and C). Greenspan demonstrated that, theoretically, distal translation of the maxillary molar may be also accompanied by either intrusive or extrusive bodily movement of the molar with respect to the maxilla while the molar itself may simultaneously undergo either clockwise or counter-clockwise rotation around its own axis. Hence, Greenspan concluded that both direction of bodily movement and tipping of the molar could be controlled by applying directional forces according to biomechanical principles.

Merrifield and Cross (1970), discussing directional forces, strongly questioned the rationale of using cervical traction because of the concomitant extrusion of maxillary molars and consequent backward rotation of the mandible which may accompany its use. They recommended the use of anterior hook-on high-pull headgear (Figure 1 Type F) for a more desirable line of force to restrict downward and forward maxillary growth.

Within the last five years, emphasis has been placed on the magnitude and duration of force with some authors suggesting the use of very heavy extraoral forces in order to elicit more dramatic orthopedic changes in skeletal relationships. Graber, Chung and Aoba (1967) contended that very heavy "orthopedic" forces were "beyond the threshold of the tooth-moving range" and hence "the teeth merely serve as a handle to transmit the force to their base." Graber (1969) stated that Reitan (1969) showed that a force beyond one pound (400 grams), surpassed the tooth-moving threshold and hence variations in magnitude were less critical after that point. Graber (1969) recommended the use of very heavy interrupted forces to correct abnormal anteroposterior and vertical jaw relationships and stated:

> In dentofacial orthopedics, most tooth movement is secondary, or should be, with major emphasis on correcting the basal malrelationship. ... Teeth may be moved quickly and efficiently in conventional orthodontics whether there is a growth spurt or not. But, to establish a normal jaw relationship, growth is of more immediate concern, and seldom is the change as rapid. ... The challenge in Class II malocclusion is to correct the basal bone system abnormality and to eliminate abnormal neuromuscular activity. Then the changes that must be wrought within the tooth system are minimal and less often require extraction of teeth. The challenge is to withold horizontal maxillary growth increments while there is adjustive growth in the mandible during the accomplishment of the fullest potential of the morphogenetic pattern.

Thus, Graber was of the opinion that force on bone during a growth period influenced the direction of growth and possibly the amount of growth. Ideally, Graber felt, it would be better to apply pressure directly on the maxilla rather than through the teeth. With heavy increments of force, the direction of force application was thought less important. Whereas, theoretically, the ideal direction would be upward and backward, the cervical anchorage seemed relatively effective, as Graber believed it was the amount of force beyond the tooth moving range that was most important. Graber suggested using 1 to 2 pounds (450 to 900 grams) of force to the maxillary teeth since force levels greater than 2 pounds often produced soreness in the teeth and jaws, or in the cervical region. Graber advocated using interrupted forces 10 to 14 hours per day, followed by a rest period to prevent tissue damage and root resorption by allowing time for tissue recovery.

With respect to appliance design, Gräber (1969) recommended applying the extraoral force to as many teeth as possible to transmit the force to the basal bone and advocated the use of an anterior hook-on cervical headgear (Figure 1 Type D). Graber also reported that removable soft thermoplastic appliances which covered the teeth and anterior premaxillary alveolar process were used but resulted in greater tissue irritation and less patient comfort and suggested that until new materials and designs were forthcoming, application of force to conventional banded appliances was more practical.

In both papers, Graber presented treated cases but did not discuss what skeletal changes accompanied the marked facial improvements other than to suggest that maxillary growth could be altered.

In a comprehensive dissertation on dentofacial orthopedics. Haas (1970) reported dramatic improvements in facial appearance following treatment with various types and combinations of very heavy "orthopedic" forces to the maxilla and mandible. Haas advocated the application of 3 to 5 pounds (1300 to 2200 grams) per side of extraoral distal force to a rigid "palatal unit" which harnessed the maxilla and allowed the "heavy force to spill over into the hafting area sutures so that growth retardation and resorption at the sutures may occur." This "palatal unit" or "maxillary orthopedic crib" was used in the late mixed dentition stage prior to full banding procedures and consisted of banded buccal segments joined together by soldered anterior and posterior transpalatal bars, similar to the metallic framework of a split-acrylic palate-expansion appliance. In anteroposterior basal discrepancy cases presenting with good vertical dimension characteristics, the "orthopedic" force was delivered to the maxilla by cervical gear. In the deep-bite skeletal Class II type, the outer bows of the cervical gear were bent upwards to torque the maxilla down in the back, and with the concomitant distal thrust, provide a downward and backward vector of movement of the maxilla and maxillary dental arch. Thus, as molar height was increased, whether by tooth movement or by movement of the entire maxilla, the mandible rotated downward and backward. This resulted in the desired bite opening in conjunction with the anteroposterior correction. The open-bite Class II skeletal pattern was treated with heavy force applied through a high-pull headcap to prevent the maxilla from making its downward and forward descent.

Haas (1970) stated that many of his cases, especially those subjected to cervical orthopedic forces, showed more than an expected increment of vertical growth and that, perhaps, it was not possible to inhibit growth potential but rather the growth subtracted from the horizontal vector was added to the vertical vector. Haas speculated that inhibitive orthopedic force probably retards anteroposterior growth, may actually lessen the mass of the bone by resorption at the articulations it shares with contiguous bones, or perhaps may channel suppressed increments of horizontal growth into a greater vertical component of growth. However, Haas (1970) conceded that this was mostly speculation and that "more study of this phenomenon is indicated."

At the University of Washington, Masumoto (1970) and Damon (1970), as part of studies on "orthopedic" extraoral forces, examined the reliability of the implant-cephalometric method to assess dentofacial changes in human material. In both studies, tantulum implants were placed in the maxilla and the mandible of growing children, and it was determined that measurement and tracing errors were statistically insignificant compared to the much greater error of head orientation during repositioning the patient in the cephalostat, as determined by implant movement produced by this procedure. Because many of the linear measurement differences recorded in both these studies were within the potential accumulative range of errors of the cephalometric technique, their experimental groups did not undergo statistical analysis but instead were subjectively assessed. These investigators tried to reduce the head positioning errors in their experiment by attempting to duplicate the orientation of the original film of each patient by taking three post-treatment cephalograms with varied head positions in the cephalostat and selecting the film whose maxillary implants most closely superimposed on those of the original cephalogram. These studies definitely demonstrated the limitations placed on the interpretations of previous cephalometric studies which did not even consider the errors of head orientation when reporting their findings.

Masumoto studied the effects of Kloehn cervical traction in 31 children in which 27 patients had a force of 500 grams or more per side and four patients had 150 grams or less per side applied to the maxillary first molars daily for varying durations up to twenty hours. Masumoto observed that with respect to the cranial base, in the majority of cases the maxillary implants demonstrated a "clockwise," downward and backward rotation with extrusion of the first molars. In addition, the theories of optimal force and differential force were not substantiated in this study or by Damon (1970) as the amount of movement of the maxilla and the maxillary teeth did not appear to depend on the magnitude or duration per day of force application but rather on individual variation of tissue response between patients.

Damon studied 24 patients for 3 to 5 month periods to determine any dentofacial changes produced by heavy, upward and backward force applied to the maxilla for 14 hours per day. Damon used a "palatal crib," similar to the one described by Haas (1970), attached to the buccal segments, and a spring-loaded high-pull headgear assembly. Thirty-five percent of the patients tolerated a force of 4 pounds (1800 grams) per side; however, the remaining 65 percent experienced difficulty in maintaining this magnitude of pressure for more than four hour intervals and the force was reduced to 3 pounds (1350 grams). Several patients experienced headaches and scalp swelling, while two patients reported loss of hair and one patient a temporary loss of hair pigment. With respect to skeletal changes, Damon reported a marked individual variation in response to the high-pull headgear as some cases demonstrated extensive dental intrusion with little apparent change in the bony maxilla while other cases exhibited little, if any, dental intrusion with apparent changes in the bony maxilla. Damon concluded that rarely will two patients react in a similar manner to the same force, applied in the same direction, over identical periods of time.

Armstrong (1971) demonstrated that 2 to 4 1/2 pounds per side of extraoral face (4 to 9 pounds to the maxilla) applied in a controlled direction continuously (24 hours per day) for a period of 3 to 6 months in the late mixed dentition resulted in rapid Class II correction. He suggested that, except for vertical discrepancy cases, the optimum direction of force for the majority of cases was in a distal horizontal direction, parallel with the occlusal plane and approximately through the center of resistance of the first molar roots. However, because of the location of the ear, this type of force was difficult to attain, and, hence, Armstrong recommended the use of combination cervical-pull and occipital-pull headcaps to a double face-bow. These combination headgear assemblies not only permitted control over the resultant vector of extraoral force but also allowed for the application of greater magnitudes of forces as the patients did not experience discomfort due to the wider distribution of force at the base of anchorage. Armstrong contended that extremely heavy forces were not uncomfortable as long as there was no resultant extrusive component resulting in molar extrusion, traumatic occlusion, mobility and soreness.

The massive magnitude of force in the late mixed dentition, before the eruption of the maxillary second molars and canines, resulted in rapid distal movement of the first molars with concommitant distal migration of the unerupted premolars and canines, and distal translation of the unerupted second molars. In one mixed dentition case, Armstrong stated that, after 101 days of continuous extraoral force, serial cephalometric superimposition on S-N demonstrated that:

> the maxilla moved distally approximately 3 mm and downward 1 mm. ... Superimposition on the maxilla showed 4 to 5 mm of distal bodily molar movement, for a total distal molar movement of about 7 mm in relation to the lower teeth.

In addition, Armstrong reported that peri-apical radiographs showed no signs of root resorption or bone loss.

On the other hand, Armstrong stated that clinical response in the early permanent dentition to continuous extraoral forces did not prove rapid enough to justify full-time wear and, hence, the duration of time was reduced to 14 hours per day. It appeared that tissue response as indicated by visible tooth movement was most rapid in the mixed dentition. Therefore, Armstrong concluded that differences in treatment response were related more to differences in dental developmental age than to differences in the biologic response between patients. In his clinical presentation, Armstrong did not theorize to any extent as to specific skeletal changes accompanying his treatment.

A cephalometric study was undertaken by Sanders (1971) on the effect of heavy continuous distal traction to the maxillary first molars in 15 Class II mixed dentition cases in which the maxillary second molars were unerupted. Sanders used a combination high-pull and cervical-pull spring-loaded headgear attached to a face-bow, and applied a continuous force of 3 pounds (1350 grams) per side for 100 days. Statistical analysis of cephalometric records indicated disto-bodily movement of the maxillary first molars and posterior movement of the maxilla without significant tipping of the palatal plane. However, the posterior movement of the molars was much greater than that of the maxilla. The amount of change in anterior facial height was comparable to that accompanying normal growth and no significant changes in the anterior cranial base were found.

Watson (1972) studied the effect of "orthopedic high-pull face-bow" (Figure 1 Type C) on 14 mixed dentition Class II Division 1 patients, all of which presented tendencies toward open-bite and steep mandibular plane. Forces of from 600 to 1000 grams per side were recommended as it was suggested that no rapid movement may occur below 600 grams. Watson found marked intrusion and distal movement of the upper molars with respect to the maxilla before the eruption of the second molars. Watson advocated wearing the extraoral appliance 22 hours per day for a period of 6 to 9 months in order to achieve major maxillary correction and then only during sleeping hours to prevent maxillary rebound and allow for stabilization. Progress records taken shortly after complete discontinuation of intensive headgear wear indicated that rebound occurred in 1 to 3 months. It was speculated that this rebound was from periodontal space condensation, tipping, bone bending, and suture or fiber adaptation. Watson also reported that mandibular growth during early treatment may be helpful but not essential, since he found that one-half of his sample exhibited only 0 to 1 mm growth from articulare to pogonion. Hence, "orthopedic maxillary movement appeared to occur independent of growth - in a child with growth potential."

Differing opinions exist as to whether very heavy forces decrease or enhance the rate of tooth movement. Storey and Smith (1952a, 1952b) and Storey (1953) referred to a clinically definitive optimal magnitude of force for different teeth to produce a maximum rate of tooth movement. From this evolved the concept of differential forces which suggested that the rate of tooth movement between different teeth to reciprocal forces was related to the difference in root surface area. On the other hand, Utley (1968) reported that in the cat the rate of tooth movement resulting from an applied force was independent of the magnitude of that force. In similar studies on human material, Hixon et al (1969, 1970) found no data to support the clinical concepts of optimal and differential forces as in some cases heavier forces per unit root area increased the rate of tooth movement while in others the opposite occurred. Variation in metabolic response between patients was thought more important than magnitude of force as a major source of variation in clinical response.

This controversy complicates the distinction between "orthodontic" and "orthopedic" extraoral forces. On the one hand, Reitan (1957, 1969) and Graber (1969) were of the opinion that any interrupted force below one pound was in the tooth-moving range, while any force over one pound was in the "orthopedic" range, with no tooth movement taking place. Reitan (1969) reported that very heavy forces created extensive areas of hyalinization resulting in prolonged "lag" phases during which no tooth movement occurred. On the other hand, the clinical studies by Armstrong (1971), Sanders (1971) and Watson (1972) suggested the following: 1) heavier force, continuous or interrupted, moves teeth more rapidly than does a similar lighter force; 2) continuous force, light or heavy, moves teeth more rapidly than does a similar magnitude of interrupted 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. Finally, contrary to both of the above, Masumoto (1970) and Damon (1970) supported Utley (1968) and Hixon et al (1969, 1970) finding individual variability between patients a greater factor than force magnitude in determining the degree of "orthodontic" or "orthopedic" response.

Within the last four years, several investigators have applied extraoral distal traction to the maxilla of the monkey. Johnson (1968) applied 50,100, and 150 grams of continuous cervical traction to the maxillary first molars of 3 prepubertal Macaca mulatta monkeys for periods of 84, 94 and 94 days respectively. The experimental animals consisted of one female and two males while an additional female served as control. Direct measurement of amalgam implants across the facial sutures suggested slightly less growth activity of the zygomaticomaxillary sutures in the 3 experimental animals. However, no definitive difference in the downward and forward growth displacement of the maxillary bone implants between the experimentals and the control was observed in the cephalometric appraisal. Johnson reported slight distal tipping and slightly less forward movement of the maxillary first molars in the experimentals compared to the control.

Sproule (1968) applied 150 to 300 grams of continuous cervical traction to 3 growing Macaca mulatta monkeys, 2 females and 1 male, for periods of 76, 81 and 103 days respectively, using a double face-bow attached to a maxillary splint wired interproximally to all the maxillary teeth but only firmly cemented to the first molars. Control material for lateral cephalometric and histologic comparison were obtained from theses by Erickson (1958), Turpin (1966) and Henderson (1967). Since inherent errors of head orientation precluded accurate quantitative analysis, cephalometric records were subjectively assessed. For overall implant-cephalometric assessment, serial films were superimposed on the anterior outline of sella as an area of registration with superimposition along the outlines of the anterior cranial fossa, the posterior superior orbital roof and cribiform plate, when distinct, as no implants were placed in the cranial base.

Although superimposition on the maxillary implants demonstrated considerable downward and backward movement of the teeth due to cervical traction, the overall superimposition indicated more tooth movement which suggested that some of the occlusal alteration was due to changes outside the local dentoalveolar area in the bones of the face. Nonetheless, a major portion of change was dental rather than skeletal due to harnessing the appliance mainly to the maxillary first molars. The entire maxilla and zygomatic bone complex appeared displaced posteriorly and rotated downward and backward with exaggerated downward tipping of the anterior aspects of the palatal outline and occlusal plane resulting in mandibular rotation in the same direction and bite opening. In the sagittal plane, there appeared to be independent "clockwise" rotations (as viewed from the right side of the skull) of the zygomatic bone and the maxilla, such that in relation to each other the facial bones were moving as independent units, each around a different axis. Direct implant measurements and histologic examination indicated that the frontomaxillary and frontozygomatic sutures were induced to grow more rapidly than normal while the zygomaticotemoral suture was caused to resorb when normally it was depository. For two experimental monkeys, the overall superimpositioned tracings showed abnormal changes in the outline of the cranial vault. Since no abnormal histologic changes could be observed in the vault, it was concluded that the relationships of the bones used for superimposition were affected and this assumption was used to support the concept of Wieslander (1963) and Sandusky (1965) that the spatial relationship of the sphenoid bone may be affected by vigorous headgear treatment. However, no substantial evidence was presented to support this assumption of rotation of the sphenoid bone.

In a follow-up study using the same control material as used by Sproule, Fredrick (1969) applied 300 grams per side of high-pull traction using a double face-bow (Figure 1 Type C) to two growing Macaca mulatta monkeys for 105 and 100 day periods respectively. The intraoral appliances were similar to those used by Sproule. Subjective analysis of implant-cephalometric records revealed a clockwise rotation of the facial complex but to a lesser degree than reported by Sproule using cervical traction. The maxilla and zygomatic bone appeared to move upward and backward together in contrast to Sproule's finding of independent clockwise rotation of these bones. The palatal outline was displaced distally in both studies but tipped downward anteriorly only slightly with the high-pull force. Fredrick reported less distal retraction of the entire maxillary dentition, intrusion rather than extrusion of the molars, and less tipping of the occlusal plane than seen with cervical-pull by Sproule. Depression of posterior teeth and elongation of anterior teeth resulted in occlusal interferences, "bite-opening" and downward and backward rotation of the mandible. Both studies reported resorptive remodelling on the facial surface of the maxilla. Also, in both studies, histologic study of the cranial base including the basi-occipital and anterior sphenoidal synchondroses appeared normal, as did the nasoethmoidal junction. With high-pull traction, Fredrick found no difference from normal at articulations of the vomer, the palatine and sphenoid bones. However, Sproule, using cervical traction observed resorptive activity at these sites. Sproule reported relative resistance to resorptive remodelling of the tuberosity compared to the pterygoid plates resulting in posterior cortical drift of the pterygoid plates. This suggested that the force was transmitted from the maxilla to the sphenoid bone.

Meldrum (1971) applied 300 grams per side of continuous high-pull traction using a double face-bow to 3 prepubertal Macaca mulatta monkeys for 81, 87 and 89 days respectively. Clinically, Meldrum reported a small opening of the bite in the incisor region (1.0 to 2.0 mm) and a slight distal displacement (0.5 to 1.0 mm) of the maxillary teeth in relation to the mandibular teeth. Observation of the overall cephalometric superimposition indicated that almost all amalgam facial implants were slightly displaced upward and backward with the maxillary implants showing the most movement. The frontal bone implant at the frontomaxillary suture did not show significant movement in any treated animal. All experimental monkeys exhibited a definite compression of the occipital region of the cranial vault where the acrylic helmet had gained its anchorage; however, other aspects of the cranial contour increased in size normally. Meldrum's cephalometric technique was questionable and possibly the experimental error exceeded the experimental changes reported.

III. RAPID MAXILLARY MID-PALATAL EXPANSION

Although the clinical efficacy of the rapid palatal expansion procedure has been heavily documented since its introduction by Angell in 1860, detailed descriptions of its mechanism of action and effects on the facial skeleton have been more limited. Immediately after its inception, controversy arose concerning whether the mid-palatal suture was actually opened by the expansion screw appliance. Supporters of this concept included Angell (1860), Goddard (1893), G. V. Black (1893), Brown (1903, 1913, 1914), Ottolengui (1904), Brady (1904), Pfaff (1905), N. M. Black (1909), Landsberger (1910), Willis (1911), Hawley (1912), Barnes (1913), Northcroft (1914), and Dewey (1914, 1924). On the other hand, investigators who were antagonistic toward the procedure and questioned whether the mid-palatal suture actually separated included McQuillen (1860), Farrar (1888), Ketcham (1912), Cryer (1913), Kemple and Stanton (1914), Dewey (1913), Federspiel (1913), and Ottolengui (1914). It is interesting to note that several clinicians such as Dewey and Ottolengui reversed their opinions during this controversial period.

During this early period, rhinologists also became interested in the procedure as a possible method of treatment in their profession. According to Pfaff (1905), Eysell in 1886, was the first rhinologist to suggest midpalatal expansion as a possible treatment for nasal insufficiency. Brown (1903) was the first to mention a possible connection between deviated nasal septum and the constricted maxillary dental arch. Brown also reported other benefits including increased nasal air flow with relief of nasal stenosis and respiratory embarrassment, better sinus drainage, improved speech and even hearing in some cases. Monson (1898), Brady

(1904), Pfaff (1905), Bogue (1907, 1911), Dean (1909, 1911), N. M. Black (1909), Wright (1911), Brown and Hartzell (1911), Pullen (1912), Haskin (1912), Schroeder-Bensler (1915), Lohman (1916) and Dewey (1917, 1924) all reported on various rhinological improvements associated with palatal expansion.

However, due to the indifference of Dewey, Case, and especially Angle (1910), who preferred more conventional methods of widening the dental arch, a marked decline in the use of rapid palatal expansion occurred in North America after the turn of the century. Hence, rapid expansion went into disfavour at approximately the same time as extra-oral traction, as mentioned in the previous section.

Nonetheless, Europeans continued to use the rapid expansion procedure. Huet (1926) and Mesnard (1929) discussed its use in nasal insufficiency while in later years Korkhaus (1953), Derischsweiler (1953), Gerlach (1956), Thorne (1956, 1960) and Krebs (1958, 1959) reported opening of the midpalatal suture, lowering of the palatal vault and nasal floor, increase in nasal cavity width with straightening of the septa, improved nasal breathing, increased maxillary arch width and length, diastema between centrals which closed spontaneously, and slight increase in mandibular arch width. Most of these findings were reported earlier by previously mentioned investigators.

Derischsweiler (1957) studied rapid expansion in rhesus monkeys and reported transverse displacement of the maxillae, enlargement of the midpalatal suture with loss of regular sutural morphology, and gross reactions at the fronto-nasal and pterygomaxillary sutures.

Krebs (1958, 1959) using anteroposterior and lateral implant-radiography reported that the increase width of the dental arch was about twice that of the buccal maxillary segments and noted that maxillary segments rotated in both the frontal and transverse planes.

The revival of rapid maxillary expansion in North America, according to Haas (1965), was initiated by Korkhaus while on a visit to the University of Illinois. A renewed interest stimulated considerable research into its effects on the facial skeleton.

Since its revival, substantial experimental evidence that the expansion procedure opens the mid-palatal suture has been presented by Debbane (1958) histologically in cats; Haas (1959, 1961) radiographically and by dissection in pigs; Montgomery (1963) histologically in pigs; Cleall et al (1965) and later Murray (1971) histologically and radiographically in monkeys; and Walters (1967) by implant-radiography in monkeys.

During this period, a series of studies at the University of Minnesota investigated the facio-skeletal effects of rapid expansion. Youngquist (1962) maintained 3 monkeys under general anaesthesia for up to 24 hours while maxillary expansion was conducted on a greatly accelerated schedule. A load cell transducer incorporated into the appliance recorded the magnitude of load present during treatment while a strain gauge attached across the zygomaticotemporal suture recorded any forced positional changes occurring relative to this suture. An increase of load at the strain gauge at the zygomaticotemporal suture slowly occurred following activation and was interpreted as showing that the appliance load was decayed due to movement of the bones of the face at the facial sutures.

In a second study, Loudon (1963), placed spring forces on the zygomaticomaxillary suture in pigs to produce both expansive and contractive forces and demonstrated that sutures were capable of being stimulated for both growth and resorption by mechanical forces.

A third study by Isaacson and Murphy (1964) used implant-radiography to investigate rapid maxillary expansion in cleft palate patients. The absence of skeletal resistance in the midpalatal region of these patients permitted the effects of the procedure on the adjacent facial skeleton to be more clearly assessed. Anteroposterior radiography indicated that in growing patients maxillary basal bone was expanded up to 40% of the lateral expansion of the dental structures. However, the amount of movement and rotation of the two halves of the maxilla was not symmetrical. In addition, lateral implant-cephalometric assessment demonstrated some maxillary movement in an anterior or superior direction, but the variability indicated that the repositioning of the maxillary segments through varying adjustments of adjacent sutural articulations was unpredictable. An adult cleft palate patient demonstrated no lateral skeletal movement of the implants which suggested that an age dependent increase in the rigidity of the articulations of the facial skeleton may be more important than the question of ossification of the midpalatal suture during rapid expansion.

A fourth study by Isaacson, Wood, and Ingram (1964) investigated how much resistance the midpalatal suture offered to separation compared to the other facial articulations. A force-measuring dynamometer incorporated into the expansion appliance indicated that in the patients studied a single activation of the expansion screw produced 3 to 10 pounds of load. No significant changes in the load value present during the time the midpalatal suture separated were apparent and this suture did not appear to offer significant resistance to maxillary expansion. It was concluded that the major resistance occurred at the remainder of the maxillary articulations. Therefore, it was thought that retention of rapid maxillary expansion did not necessarily depend on the presence of bone in the opened midpalatal suture but rather more probably relied on the creation of a stable relationship at the articulations of the maxilla and the other bones of the facial skeleton. New bone deposition in the midpalatal suture was felt not to ensure stability as it could be readily resorbed if forces at the adjacent maxillary articulations produced relapse loads. Hence, adjustment at these unions was assumed necessary to assure stability of the maxillary expansion procedure.

In a fifth study at Minnesota, Zimring and Isaacson (1965) improved the dynanometer and investigated the duration of time the load was stored in the appliance following the cessation of active treatment. It was found that if the rate of activation was not decreased progressively greater residual loads accumulated and forces over 30 pounds were recorded. Immediate appliance removal was accompanied by dizziness, pressure in the nasal bridge and throughout the face, and partial dental relapse. However, appliance recementation with re-establishment of heavy loads relieved all symptoms. Following active treatment in all patients, the total load decayed progressively within 6 weeks. Appliance removal revealed no immediate relapse in interarch width and minimal relapse 30 days later. Hence, load decay appeared to occur through movement of the skeletal structures and rigid retention was recommended until the articulations reached equilibrium as indicated by decay of the loads stored in the appliance.

A sixth study by Jentoft (1966) measured the loads created during maxillary expansion in cleft palate patients and found similar loads and decay rates as seen in normal patients which supported the hypothesis that the midpalatal suture was relatively unimportant compared to the maxillary articulations with adjacent bones as a source of resistance to orthopedic expansion.

On the experimental level, several non-human primate studies have recently investigated the facioskeletal effects of rapid palatal expansion. Cleall et al (1965) reported that rapid maxillary expansion in the Macaca rhesus monkey resulted in breakdown of the midpalatal suture while a follow-up study of Starnbach et al (1966), studying the facioskeletal changes which occurred in these monkeys, reported a re-orientation of the facial bones at the sutures, as well as increased cellular activity and increased vascularity at the sutures. The fronto-nasal suture showed the greatest histological reaction to the expansion procedure, followed by the zygomaticomaxillary and zygomaticotemporal areas respectively. Their findings strongly reinforced the contention that changes in the orientation of bones in one region may well involve sutural adjustments in remote regions of the face. Cleall et al (1965), Starnbach et al (1966) and Murray and Cleall (1972) have shown that the initial separation of the palatal and facial sutures were rapidly followed by reparative processes and restoration of normal sutural morphology.

Brossman (1970) using Macaca cynomologous administered tetracycline daily throughout the palatal expansion procedure, and reported that examination of coronal sections of the skull photographed under ultra-violet light to induce fluorescence indicated that all changes associated with rapid palatal expansion were limited to the facial skeleton. Contrary to these findings, Gardner and Kronman (1971) in a gross anatomical investigation on the Macaca reported distant effects of rapid palatal expansion including opening of the spheno-occipital synchondrosis and disruption of the midsaggital, frontal-parietal and lambdoid cranial sutures.

On the clinical level, cephalometric studies on human material, using either lateral or anteroposterior radiographs, have been reported by Krebs (1958, 1959), Haas (1961, 1965, 1970), Isaacson and Murphy (1964), Wertz (1968, 1970), Davis and Kronman (1969), Halpern (1969) and Byrum (1970). Whereas Haas (1970), using lateral cephalometry, reported that when the midpalatal suture opened, the maxilla always moved forward and downward, Wertz (1970) found more variability stating that the maxilla was routinely displaced downward 1 to 2 mm while its anterior displacement was variable even with occasional distal displacement of the maxilla. In addition, Wertz reported that vertical displacement of the maxilla varied as the palatal plane descended parallel, opened or else closed relative to S-N, although opening of the palatal plane predominated. On the contrary, Haas (1970) reported tipping of the palatal plane down at the back and consequent bite opening. Byrum (1970) found the maxilla was carried inferiorly and slightly anteriorly with the palatal plane showing little change as the maxilla descended uniformly while Davis and Kronman (1969) found that "A" point moved forward, that the palatal plane opened in 50% of the cases with a lowering of "A" point but that the roof of the vault did not lower. Contrary to this latter finding, Haas (1970) reported that the alveolar processes moved laterally with the maxillae so that the horizontal palatal processes swung inferiorly at their lower free margin, lowering the palatal vault and resulting in dental expansion and increase in intranasal capacity. These findings were previously reported by Starnbach et al (1965) in the monkey.

Almost all investigators reported that change in maxillary posture and associated dental units resulted in a downward and backward rotation of the mandible, increase in the mandibular plane angle, opening of the bite, and increase in anterior facial height. Wertz (1970) attributed the change in mandibular posture to occusal interferences.

With respect to lateral increases in the skeletal base, measured on P-A radiographs, Haas (1970) stated that in 100 patients under 17 years, all of whom showed dental expansion of 10 to 11.5 mm, nasal cavity width increased significantly with a range from 3 to 5.5 mm. On the other hand, Wertz (1968) found changes in nasal airflow insufficient to justify opening of the midpalatal suture for the sole purpose of increasing nasal permeability. Wertz (1970) found that gain in nasal cavity width on P-A radiographs averaged only 1.9 mm with the fulcrum of maxillary rotation approximately at the frontomaxillary suture. In addition to arcing of the maxillary halves, Wertz (1970) reported that apparent alveolar bending and extrusion of teeth accounted for wider lateral movement of the erupted dental units as compared to the movement of the maxillary halves. Similar findings were previously reported by Krebs (1958, 1959). However, Isaacson and Murphy (1964) stressed the unpredictability of lateral movement of the maxilla, the limited increase in nasal cavity width and the possible age dependency of this skeletal increase. On the other hand, Davis and Kronman (1969) found no statistically significant changes on the P-A radiographs subsequent to treatment in the bizygomatic, birotundal, biorbital, and bicondylar widths; however, they questioned the reproducibility of these parameters on P-A cephalograms.

Radiographic cephalometry has also been used to study palatal expansion in the Macaca rhesus monkey. Sugiyama (1968) investigated the effects of midpalatal expansion on 6 Macaca monkeys. Appliance activation was completed in a 3 week period but the appliances were left in place for stabilization periods of 2, 4 and 6 months, prior to the post-experimental records and sacrifice. Hence, the findings included a combination of orthopedic treatment changes and growth changes over these extended periods. Lateral implant-cephalometric analysis indicated that in both the experimental and control animals, there was a decrease in the mandibular plane angle, but a greater amount of decrease in the treated groups. Sugiyama stated that in clinically treated cases the mandibular plane angle tends to increase due to the correction of a lingual crossbite relationship to a normal occlusal relationship. However, in the Macaca a normal occlusion was changed by expansion such that the maxillary buccal teeth underwent change in position in an upward direction which would have the same effect as intruding these teeth resulting in a decrease in mandibular plane angle. Sugiyama also reported a decrease in the palatal plane angle and an increase in the occlusal plane angle in the treated animals. The premaxillary region, represented by prosthion, demonstrated no movement of any significant degree antero-posteriorly or in a predictable direction when comparing treated to control animals. The differences between the control and experimental groups reported by Sugiyama were small and since no error of method was calculated, it is not known whether the experimental error exceeded the experimental treatment changes observed.

In summary, rapid palatal expansion has been demonstrated at both the experimental and clinical level to separate the two halves of the maxilla with subsequent reformation of a normal suture and permanent expansion of the maxillary arch. It appears that extremely heavy forces up to 30 pounds (13,600 grams) are transmitted from the appliance throughout the skeletal architecture resulting in forced disruption and partial separation of the remote articulations of the nasomaxillary complex, thus allowing forced physical movement of the facial bones to occur, essentially in a lateral rotary direction. Therefore, the type of structural alterations noted appear to be mainly in the spatial relationships of the midfacial skeletal structures such as the facial sutures which exhibit marked cellular hyperactivity and increased vascularity. Furthermore, distant cranial structures are possibly also affected.

The above description suggests the possibility that the rapid expansion procedure might render the maxillary complex more labile and more susceptible to further spatial repositioning by reducing the physical integrity of the facial sutures and possibly enhancing their reactivity to additional external force application in an antero-posterior direction. This orthopedic concept will be reviewed in the following section.

IV. COMBINATION OF RAPID MAXILLARY MID-PALATAL EXPANSION FOLLOWED BY EXTRAORAL TRACTION TO THE MAXILLA

Very little has been written on the effect of applying heavy forces in the anteroposterior direction to the maxilla immediately following palatal expansion. However, recently, Haas (1970) stated that "the entire maxilla appears to be made more mobile by the palate expansion procedure. At least this could be hypothesized from the reaction of the bone to subsequent manipulation." Following expansion, Haas applied mesially directed forces in an attempt to protract the maxilla in some cases and distally directed forces in attempt to enhance distilization of the maxilla in other cases. Although no objective study was carried out, Haas presented several clinically treated cases using these mechanics.

With respect to the protractive forces, Haas recommended that in deep bite Class III cases, if the anterior crossbite was not corrected by anterior displacement of the maxilla due to rapid palatal expansion, vigorous Class III elastics should be applied directly to the stabilized palatal appliance. Haas stated that the maxilla would respond by moving forward and tipping down at the back with concomitant extrusion of the molars. These events would contribute to increased posterior vertical dimension and consequent downward and backward mandibular rotation. Haas suggested that this synergistic negative mandibular rotation and positive forward maxillary movement would orthopedically correct the anterior dental crossbite and improve the anteroposterior dental base relationship.

In the openbite Class III skeletal pattern cases, Haas stated that the above mechanics would be disastrous resulting in additional skeletal or dental bite opening. Hence, Haas recommended using a vertical-pull chincap to counter the bite opening during palate expansion and use of elastics from protraction spines on the chincap to the distal of the stabilized palatal appliance so that the direction of the protractive force was horizontal. Haas reported that these mechanics would orthopedically influence the mandible in a forward and upward rotation while pulling the entire maxilla forward.

In contrast to Haas' contentions, DiPaolo (1970) discussed the possibility of forward repositioning of the maxilla following palate splitting. DiPaolo stated that in 6 cases in which palate splitting was carried out in conjunction with a chincap and elastics to reposition the maxilla anteriorly, 5 cases showed no measurable forward change at point A while the other case showed an increase of only 1 degree in angle SNA.

With respect to application of heavy distal extraoral forces to the maxilla immediately following rapid palatal expansion, Haas (1970) stated that it was not considered "expedient to wait for the maxilla to make a spontaneous recovery following degeneration of the Class II pattern following palatal expansion." Haas was of the opinion that the maxilla was always displaced downward and forward during palatal expansion which made the Class II Division 1 skeleton pattern decidely worse. Haas felt that the deepbite Class II skeletal patterns were not too adversely affected whereas the openbite case was always adversely affected by maxillary expansion. However, Haas stated that these adverse effects in Class II cases tend to recover as the maxilla and mandible tend to return to their former posture. Thus, Haas recommended that heavy interrupted extraoral force, 3 to 5 pounds per side, be applied with a Kloehn cervical gear directly to the maxilla, through the palatal appliance, immediately after stabilization. Haas reported cases which demonstrated striking improvement of the distocclusion with apparent posterior movement of the maxilla after 9 months or more of heavy orthopedic distal traction. However, Haas reported only isolated cases and did not undertake an objective study with control material. Hence, Haas does not give any evidence to support the thesis that the rapid palatal expansion procedure actually expediated the orthopedic effect of the cervical traction. As pointed out previously, Armstrong (1970), Sanders (1970) and Watson (1970) reported dramatic orthodontic and presumably orthopedic correction using very heavy extraoral forces alone in periods of 3 to 9 months.

Davis and Kronman (1969) evaluated the effects of palatal expansion using lateral and anteroposterior radiography. Four out of the 26 cases studied were subjected to headgear immediately after rapid palatal expansion during the stabilization period. In all cases of pure palatal expansion, "A" point was repositioned forward in relation to the posterior border of PTM, whereas in the cases subjected to distal headgear traction during stabilization, "A" point was not only prevented from coming forward, but actually was positioned posteriorly. However, due to lack of comparative material undergoing headgear therapy alone for similar periods, no evidence was offered to support the contention that the rapid palatal expansion enhanced the response of the maxilla to distal force application.

In his clinical presentation on heavy continuous extraoral forces to the maxilla during the mixed dentition, Armstrong (1971) reported one case in which rapid palatal expansion was followed by 2 pounds per side of continuous extraoral traction. No measurable movement of the maxilla occurred, however, Armstrong stated that he had some doubts concerning patient co-operation in this case.

Search of the literature to date has not revealed any previous animal research investigating the combination of rapid palatal expansion and orthopedic extraoral traction to the maxilla.

V. NORMAL CRANIOFACIAL GROWTH OF THE MACACA MULATTA MONKEY

The Macaca mulatta rhesus monkey has been widely used in many experimental studies of craniofacial growth and development. Normal craniofacial growth of the Macaca has been assessed using different histological methods including various vital bone-marking agents by several investigators including Schour and Massler (1944), Moore (1949), Baume (1953), Craven (1956), Enlow (1966, 1968),Henderson (1967), Bahreman and Gilda (1967), and Duterloo and Enlow (1970). In addition, normal growth has also been studied in the monkey using radiographic cephalometry by Baume and Becks (1950). The more recent use of metallic implants has added much validity to the radiographic cephalometric technique and has been used by several investigators including Gans and Sarnat (1951), Erickson (1958), Thatcher (1968), Pihl (1959), Nickelsen (1969), Elgoyhen et al (1972), and McNamara (1972).

According to Duterloo and Enlow (1970), the effective growth of the middle face of the monkey, as in man, is the result of a passive displacement of the whole nasomaxillary complex associated with sutural growth as well as differential deposition and resorption on bony surfaces and the vertical and horizontal drift of the dentition. However, the complexity of the maturational growth pattern of the facial complex precludes an extensive and intricate description of the growth phenomenon by cephalometric analysis of changes in the external configuration alone even with the aid of stable metallic landmarks. Nonetheless, descriptions of the general translatory and transformative pattern of facial growth have been reported using the implant-cephalometric method.

Gans and Sarnat (1951) studied sutural growth in the upper face of four infant and four juvenile rhesus monkeys using implant-cephalometry and reported that the horizontal component of growth was predominant in the infant monkeys while the vertical component was most active in the juvenile and young adolescents.

Erickson (1958), Pihl (1958), Thatcher (1968) and Nickelsen (1969) all used implant-cephalometry and reported a general downward and forward facial growth pattern. Nickelsen (1969) found that the Macaca displayed a regularity of total facial proportions during growth, yet individual areas showed quite a range of proportional changes throughout the growth period which suggested that areas of growth tended to compensate for each other.

Elgoyhen et al (1972) studied normal craniofacial growth of 13 juvenile Macaca monkeys in the mixed dentition using implant-cephalometry over a five month period. Tantulum implants were placed on either side of the zygomaticomaxillary and midpalatal sutures and also in the mandible. Superimposition on the cranial base demonstrated that the horizontal growth component of the facio-skeleton was greater than the vertical component. Superimposition on the maxillary implants demonstrated that the growth pattern of the maxilla included apposition on the tuberosity, the muzzle, and the floor of the orbit. Apposition of bone in the palatal region was relatively low during the period studied. The eruption and vertical growth of the maxillary dentition contributed significantly to the vertical development of the face, and there was a noticeable forward migration of the entire maxillary dental arch. The forward migration of the maxillary incisors may have been due to migration of teeth within the bone or growth at the maxillary-premaxillary suture.

The relative role of each could not be detected from the radiographs.

Contrary to these findings, superimposition of tracings on the mandibular implants indicated that the mandibular occlusion demonstrated little variability, and was characterized primarily by vertical development with minimal mesial migration of the buccal segments.

Variability was noted in maxillo-mandibular basal relationships during growth, for in all animals the mandible demonstrated a rotational displacement and at the same time a greater forward displacement than the maxilla; however, the relative amount of this displacement varied from animal to animal. These changing maxillo-mandibular basal relationships were balanced, to varying degrees, by a higher rate of deposition on the muzzle than on the chin and by forward migration of the upper dental arch with a rather stable anteroposterior location of the lower dental arch. Nonetheless, for the period studied, the variability in direction and amount of growth was found to be quite low when compared to human material as reported by Bjork (1960, 1963, 1964). All animals maintained a full Class I molar relationship throughout the study. In addition, direct observation of 30 dry skulls and over 100 live monkeys of all ages revealed a Class I molar relationship and suggested that there was much less variability in occlusal relationships in the Macaca rhesus monkey than in the human.

In a follow-up study to Elgoyhen et al (1972) and as part of a more intensive investigation, McNamara (1972) quantitatively assessed normal growth on additional Macaca monkeys which were divided into infant, juvenile, adolescent and adult groups. A total of 28 animals were studied for a 3 month period while 16 of these monkeys continued on for a 6 month period. Metallic implants were placed in various bones of the cranio-facial complex including the cranial base on either side of the spheno-occipital synchondrosis.

For overall superimposition, the implants in the basi-sphenoid bone and the outline of the inferior portion of the endocranial surface of the orbital roof were registered. Contrary to the findings of Gans and Sarnat (1951), McNamara found the horizontal growth component more prominent than the vertical component in all age groups. Vertical growth was dominant in only a few random animals throughout the whole sample and, hence, McNamara concluded that the conflict of findings may be based on sample size or on cranial base superimposition used in the two studies. The use of implants revealed remodeling activity in the superior portion of the orbital roof, an area used for superimposition by Sproule (1968) and Fredrick (1969) who studied extraoral force to the monkey.

The effective overall movement of the dentition relative to the cranial base was directed forward and downward, although the horizontal growth component was dominant by a ratio of 4:1 compared to the vertical component of maxillary dental movement. The extent of the forward movement was slightly higher in the anterior teeth.

Displacement of the maxillary implants relative to the implants in the anterior cranial base indicated a counterclockwise rotation of the maxillary complex, as evidenced by forward and downward movement of the tuberosity implant while the premaxillary implant moved horizontally with minimal but variable vertical translation. Superimposition of serial tracings on the maxillary implants indicated that the effect of maxillary displacement was compensated for by the differential pattern of dentitional drift as vertical tooth drift was greater anteriorly than posteriorly, hence, offsetting the rotation of the maxillary base and sustaining a relatively constant occlusal plane. Nonetheless, with respect to the maxillary superimposition, the horizontal drift component of the teeth was usually greater than the vertical even in the incisor region where the ratio was about 2:1 for the juvenile group. The forward translation of the middle face accounted for the greater portion of the overall increase in size of the nasomaxillary complex as about 80% of the overall horizontal movement of the first permanent molars was due to maxillary translation in the juvenile group.

The mandible was carried anteriorly and inferiorly relative to the cranial base with a greater vertical growth component in the posterior region resulting in a corresponding counterclockwise rotation of the mandible. Superimposition on the mandibular implants indicated that in the juvenile monkeys relatively greater bone apposition along the anterior part of the lower border of the mandible offset the effect of rotation of the mandibular corpus. Vertical migration with only limited mesial migration of mandibular molars occurred which compensated for the mandibular rotation and maintained the orientation of the occlusal plane.

CHAPTER III

MATERIALS AND METHODS

I. SAMPLE

Seven female Macaca mulatta (rhesus) monkeys were used in this study, and an additional monkey (Monkey A) was used for the development of the cephalometric technique.

The monkey was selected for this investigation because of its close evolutionary skeletal and dental proximity to man and because its morphologic growth pattern, both dental and cranio-facial, reveals a uniformity and consistency not found in man (Baume and Becks, 1950; Gans and Sarnat, 1951; Elgoyhen et al 1972). In contrast to the usually observed growth pattern, variant growth pattern changes which occurred during the application of orthopedic forces to this animal can be attributed more assuredly to such forces. Similar observations in man would not be as conclusive because of the greater variability in his facial growth pattern (Sproule 1968).

Although the Macaca mulatta presents a close anatomical similarity to the human, the following relevant differences exist:

1. The monkey presents a separate premaxilla separated from the palatal processes of the maxilla (secondary palate) by the premaxillary-maxillary suture. The premaxillary midline suture in the monkey ossifies at a much earlier age than in humans.

2. The monkey presents slight morphological differences in the teeth and the persistence of "primate spaces" into the permanent dentition. The animals used in this study all presented Class I molar relationships and normal occlusions. This observation is confirmed by Elgoyhen et al (1972) by direct cross-sectional observation of 120 live Macaca monkeys of all ages and 30 dry skulls.

These anatomical differences merit consideration relative to maxillary expansion procedures and application to clinical practice. During palatal expansion in this study a normal occlusal relationship was moved into an abnormal buccal crossbite. Similarly in the headgear groups a normal dental relationship and skeletal pattern was altered by heavy orthopedic distal force creating a malocclusion and a skeletal dysplasia.

All monkeys were caught in India in the wild and imported via a domestic supplier* All animals were required to have a specific dental pattern consisting of the presence of the following teeth:

1. Maxillary permanent central incisors.
2. Maxillary permanent lateral incisors.
3. Maxillary deciduous cuspids.
4. Maxillary deciduous first molars.
5. Maxillary deciduous second molars.
6. Maxillary first permanent molars.

The maxillary and mandibular second and third permanent molars were present and in various stages of development. The age of the monkeys, as determined by their dental formula, was approximately 35 to 40 months (Hurme, 1960). However, with respect to clinical comparison, all monkeys corresponded in age approximately to a 7 to 9 year old human child. These animals, on arrival, all weighed between 8 and 9 pounds; that is, about 4 kilograms.

*Primate Imports Corporation, Port Washington, Long Island, New York

II. EXPERIMENTAL DESIGN

The monkeys were randomly divided into the following groups:

Control Group:

Monkey No. 1
Monkey No. 5

Orthopedic Headgear Group:

Monkey No. 3
Monkey No. 4

Rapid Palatal Expansion Group:

Monkey No. 2
Monkey No. 6
Monkey No. 7

Combination Group: (Palatal Expansion Followed by Headgear)

Monkey No. 6
Monkey No. 7

The experimental groups underwent different experimental phases. These included a pre-experimental normal growth period and various active treatment periods depending on the group. In addition, one monkey of the headgear group underwent a post-treatment "relapse" period.

The control animal group was used to gather comparative growth data for direct comparison to the experimental groups. The control animals underwent a normal growth period during which records were taken to directly correspond to the various experimental intervals for all the phases of the experimental groups. The following summarizes the treatment phases for the respective animals in each experimental group:

<u>Orthopedic Headgear Group</u>:

Monkey No. 3

Normal Growth Period ... Continuous Headgear (103 days) ... Relapse Period (26 days)

Monkey No. 4

Normal Growth Period ... Continuous Headgear (72 days)

<u>Palatal Expansion Group</u>:

Monkey No. 2

Normal Growth Period ... Rapid Palatal Expansion (activated daily for 14 days)

Monkey No. 6

Normal Growth Period ... Rapid Palatal Expansion (activated daily for 12 days)

Monkey No. 7

Normal Growth Period ... Rapid Palatal Expansion (activated daily for 12 days)

<u>Combination Group</u>:

Monkey No. 6

Normal Growth Period ... Palatal Expansion (12 days) ... Headgear + Palatal Expansion (3 days) ... Headgear (72 days)

Monkey No. 7

Normal Growth Period ... Palatal Expansion (12 days) ... Headgear + Palatal Expansion (3 days) ... Headgear (12 days)

III. METHODS

Anaesthesia

In preparation for experimental procedures, all animals were premedicated with intramuscular injections of phencyclidine HCl (Sernylan)*. Deeper anaesthesia, if necessary, was completed by intraperitoneal injection of pentobarbital sodium (Nembutal)†. Atropine sulfate[ϕ] was administered intramuscularly for intra-oral procedures to inhibit salivary secretion, a side effect of phencyclidine HCl (Kuroda and McNamara, 1972). Concentrations and dosages of the various drugs used are listed below:

DRUG	CONCENTRATION	ADMINISTRATION	DOSAGE
PHENYCYCLIDINE HCl	20 mg/cc	I.M.	0.1 cc/kgm
PENTOBARBITAL Na	50 mg/cc	I.P.	0.5 cc/kgm
ATROPINE SULFATE	0.4 mg/cc	I.M.	0.1 cc/kgm

Comparative Serial Implant-Cephalometry

Metallic Implant Placement

Metallic implants were fabricated by cutting 0.020 inch round elgiloy wire into 1.5 mm lengths which were then ground to a fine point on one end and flattened on the other. The implants were then heat-treated. The metallic elgiloy implants were placed in all of the

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*Bio-Ceutic Laboratories, St. Joseph, Missouri

†Abbott Laboratories Limited, Montreal, Quebec

ϕGlaxo-Allenburys (Canada) Limited, Toronto, Ontario animals using the implanter* described by Bjork (1955) in the following anatomical sites:

Maxilla

8 implants - left side

Body of Maxilla:	4
Palatal Process:	2
Zygomatic Process:	2

Premaxilla

2 implants

Body:	1
Palate:	1

Mandible

5 implants - left side

Zygomatic Bone

2 implants - left side

Zygomatic Process of Temporal Bone

2 implants - left side

Zygomatic Process of Frontal Bone

2 implants - left side†

Cranial Base

6 implants - mid-line

Basi-Sphenoid Bone:	3
Basi-Occipital Bone:	3

Cranium

7 implants

Mid-line cranium

Anterior (frontal bone):	1†
Vertex:	1
Posterior:	1

Bilateral "Superimpositioning" Implants

Lateral Frontal:	2†
Lateral Parietal:	2

†A minimum of 5 implants were placed in the frontal bone

In the maxillary region approximately 10 implants were placed on the left side since the left side was closer to the film. The implanting was accomplished by an intraoral approach, without any incisions, by firmly pressing the tip of the implanter through the periosteum and malleting the implants into the cortical bone. The implants were placed in the body of the maxilla above the apices of the teeth in the canine,

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*Ole Bich Instrument Makers, Hvidovre, Denmark premolar, molar and tuberosity areas and above the central incisor in the premaxilla. Palatal implants were placed midway between the alveolar process and the mid-palatal suture, in the areas of the premaxilla, deciduous molars, and permanent second molars. In addition, 2 implants were placed in the zygomatic process of the maxilla by an extraoral approach through a small skin incision.

Five implants were placed by an intraoral approach in the body of the mandible on the left side. The implants were placed apical to the roots of the teeth in the central incisor, canine, premolar and molar areas and in the gonial angle area of the ramus.

Two implants were placed in the zygomatic bone and in the zygomatic processes of the temporal and frontal bones. These implants were placed on the left side of the skull by an extraoral approach through small skin incisions.

Approximately 6 implants were placed in the mid-sagittal area of the cranial base on either side of the spheno-occipital synchondrosis by an intraoral approach using the method developed by McNamara (1972). The mouth of the monkey was propped open and the implanter placed against the posterior pharyngeal wall with the long axis of the implanter approximately parallel to the maxillary occlusal plane. Hence, the tip of the implanter approximated the basi-occipital bone. The implants were then lightly tapped through the mucosal lining of the posterior pharyngeal wall into the basi-occipital bone. No incisions were necessary. To place the basi-sphenoid implants, a small incision was made through the soft palate approximately 1 cm lateral to the midline of the soft palate. The implanter was gently placed through the incision and pressed upward so that its tip approximated the basi-sphenoid bone. The implants were then lightly tapped through the mucosal lining of the posterior pharyngeal wall into the basi-sphenoid bone. No sutures were placed. The incision in the soft palate completely healed in 24 hours.

Three implants were placed along the mid-sagittal line of the cranium: anteriorly, at the vertex, and posteriorly. In addition, 4 "superimpositioning implants" were placed (see next section), 2 in the frontal bone and 1 in each of the parietal bones. All implants in the cranial vault were placed through small skin incisions.

Thus, a minimum of 34 metallic implants were placed in each animal. Exceptions to this included Monkey No. 2 and Monkey No. 4 in which implants were not placed in the zygomatic bone and zygomatic process of the frontal bone. Several monkeys had additional implants placed, especially in the cranial base where up to 10 or 12 implants were placed.

Animal Orientation

In order to accurately quantitate growth increments and growth direction, a cephalometric technique was developed and refined to ensure reliable and standardized cephalograms with a minimal error due to reproducibility of animal orientation. The external auditory canals of the monkey are formed of flexible cartilage and connective tissue which makes it difficult for ear rods to adequately stabilize the monkey's head in a reliably reproducible position. Previous monkey studies assessing growth (Gans and Sarnat, 1951; Erickson, 1958; Nickelsen, 1969; Thatcher, 1968; Elgoyhen et al, 1972b) and particularly those assessing the effects of orthopedic forces (Sproule, 1968; Sugiyama, 1968; Fredrick, 1969; Meldrum, 1971) have utilized monkey cephalostats which primarily used small ear rods for animal orientation. However, considerable error is inevitable with this technique alone (Hansel, 1970) and the magnitude of this error due to repositioning the monkey in the cephalostat may approach or exceed any difference between growth increments of the control and experimental groups. Other techniques have been recently used (Delinger, 1967; Hansel, 1970; Joho, 1971) but with limited success. Hence, the following technique for animal orientation was developed.

Animal Preparation

The head of the monkey was closely shaved. The animal was then placed in a stereotaxic instrument* in the Frankfort Horizontal position (Figure 2). The head was scrubbed using a solution of aqueous zephren chloride. Two metallic implants were then placed through small skin incisions by means of a Bjork implanter on both the right and left external lateral surfaces of the frontal bone so that these two implants were exactly opposite each other and such that the line joining these two implants was perpendicular to the mid-sagittal plane and parallel to the Frankfort Horizontal (Figure 3). The metopic suture of the monkey closes early so that the frontal portion of the cranial vault is one bone. An additional pair of metallic implants was placed one on either side of the external lateral surface of the parietal bones in the same manner.

Headholding Device

A monkey cephalostat was designed to be attached to the head-holder of a Picker radiographic fluoroscopic unit† which was standardized for cephalometric radiography (Figure 4). This attachment consisted of

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*David Kopf Instruments, Tujunga, California

†Picker X-ray Engineering Limited, Winnipeg, Manitoba

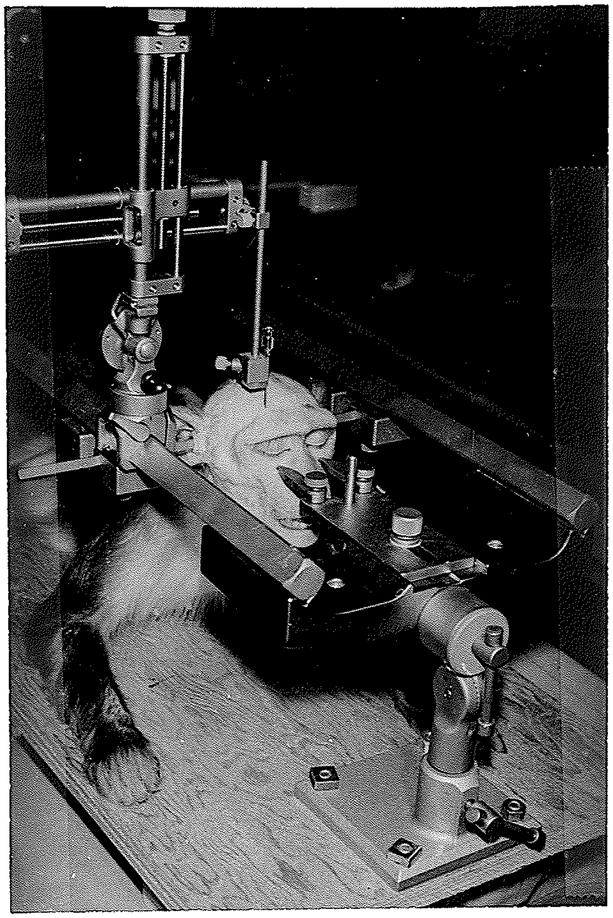

Figure 2. Monkey placed in stereotaxic instrument in the Frankfort Horizontal position. The adjustable electrode carrier (upper left) moves in the horizontal and vertical directions and was used for selection of sites for placement of "superimpositioning implants."

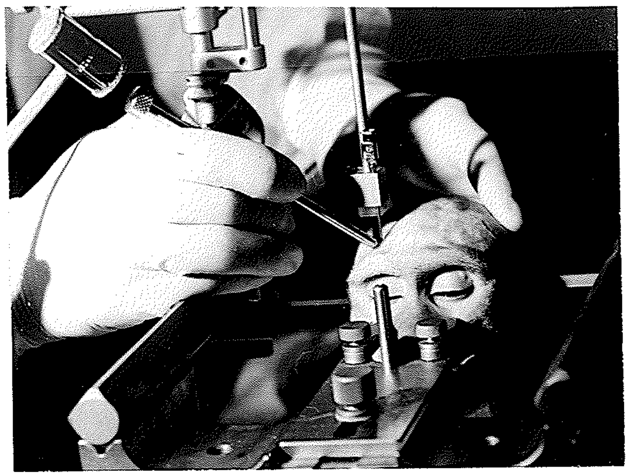

Figure 3. Placement of metallic implant, using a Bjork implanter, on the right side of the skull in the frontal bone at the site designated by the electrode carrier. Another implant was placed on the left side of the skull in the frontal bone so that the line joining the two implants was perpendicular to the mid-sagittal plane and parallel to the Frankfort Horizontal Plane.

plastic plates which supported small, adjustable ear rods (Figure 5). Further, a metal bar was attached horizontally in the mid-saggital plane and was used to support a moveable tattooing device and also to support an adjustable calibrated chin rest (Figure 6).

A specially designed monkey chair was used to support the animal. The monkey was then placed in the cephalostat and the ear rods were carefully and tightly positioned. The radiographic fluoroscopic unit included a twelve inch television monitor which permitted fluoroscopic viewing of the monkey prior to taking the cephalometric exposure. The television monitor was observed and the position of the metallic implants in the frontal bone was noted. The ear rods were then adjusted to very slightly rotate the monkey's head so that the central beam of the X-ray passed through the paired implants in the frontal bone so that their images were exactly superimposed. The ear rods were then firmly fixed in this position. Once in this position, the monkey was tattooed along the mid-sagittal line of its scalp and forehead using India ink and the specially designed mid-sagittal tattooing needles which only moved in the mid-sagittal and vertical planes (Delinger, 1967). The monkey's head was thus tattooed with fine dots, which during subsequent repositioning of the monkey, were lined up by inspection with the points of the needles by looking down the mid-sagittal line. This then was used as a secondary check.

Additional animals were similarly prepared, but as only slight variation existed in the anatomical size of the heads of the various monkeys, no correction of the ear rods was necessary and the same corrected ear rod position was utilized for all animals.

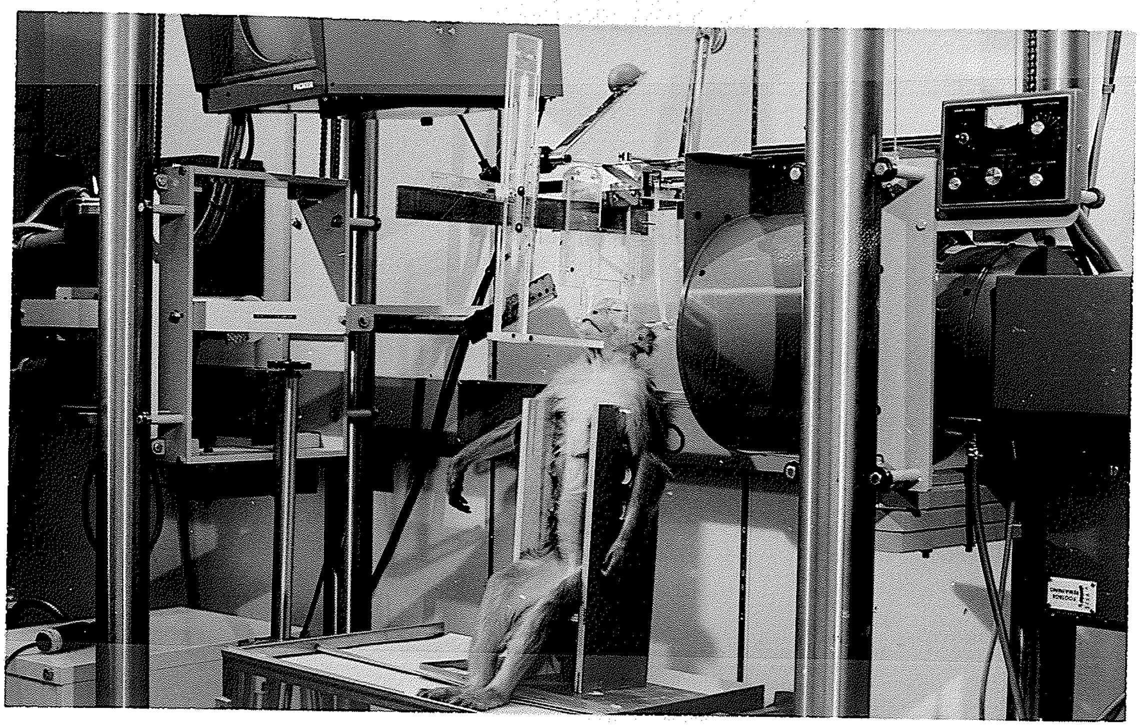

Figure 4. Monkey cephalostat attached to the headholder of Picker radiographic fluoroscopic unit. A metal bar attached horizontally in the mid-sagittal plane supports a moveable tattooing device and an adjustable chin rest. The monkey is supported in a wooden chair. By inspection of the television monitor, the images of the bilateral "superimpositioning implants" placed in the frontal bone were superimposed on each other by adjustment of the head of the monkey in the cephalostat so that the central beam of the x-ray passed through both implants.

Figure 5. Monkey cephalostat consisting of plastic plates supporting small adjustable ear rods. The metal screw shown in the area of the external auditory meatus attaches the ear rod to the plastic plate. The moveable tattooing device only moves in mid-sagittal and vertical planes.

Figure 6. Monkey cephalostat consisting of plastic plates which support adjustable ear rods (inserted in monkey's ear) is attached by plastic dowels and smaller plastic plates to the headholder of the radiographic unit. The metal bar (top) supports the mid-sagittal tattooing device and adjustable chin rest. Black dots are tattooed on the mid-sagittal line of the monkey's scalp, forehead and nose.

Repositioning Procedure

Each animal was repositioned in the ear rods and by using the tattooing line as a guide the head was closely approximated to its correct position. Inspection of the "superimpositioning implants" on the television monitor then indicated whether a very slight rotation was necessary to compensate for variation in soft tissue compression at the external auditory meati. A lateral cephalometric exposure was then made and developed while the monkey, under deep anaesthesia, remained stationary in the ear rods. The additional clarity of the cephalometric negative was necesssry to verify the correct position due to the lack of definition on the television monitor. If the images of the implants in the frontal bone were not exactly superimposed, a slight alteration in head position was made, checked on the television monitor and another cephalometric exposure made to verify the attainment of the correct position.

In control Monkey No. 1, due to inaccurate placement of bilateral implants using the stereotaxic instrument, an additional pair of amalgam implants were placed to be used for superimpositioning. In this animal, the images of the amalgam implants were superimposed during head orientation procedures, while the images of the originally placed bilateral elgiloy implants in the frontal bone were used for additional confirmation of correct orientation by maintaining their distance apart and relationship to each other constant for each repositioning of the animal.

Focal-film distance (48 inches) and mid-sagittal plane-film distance (10 inches) were standardized as were voltage (80KV) and amperage (50 mA). A grid was placed between the film and the monkey for better definition and Kodak Blue Brand BB-14 film* with intensifying screens used. Exposure time was varied to include exposures of 3/10, 2/5 and 1/2 seconds at each sitting to obtain optimum contrast for both anatomical and metallic landmarks. However, the 3/10 second exposure was preferred for analytical purposes.

Appliance Construction

Extraoral Appliance

An alginate impression was taken of the head and face of Monkey A and poured in plaster to give a working model for the design and fabrication of a headgear appliance. The headgear incorporated calibrated coil springs[†] which delivered up to a maximum of 2 pounds per side of extraoral traction (Figure 7). In addition, a calibrated Ohaus strain gauge[ϕ] was used to measure the force of the headgear at regular intervals during the experimental phase. The headgear was adjusted when placed on the monkey to accurately deliver 28 ounces per side (approximately 800 grams per side) of continuous distal extraoral force approximately parallel, but slightly cervical to the occlusal plane (Figure 8).

The size of the monkey's head is perhaps 1/3 to 1/4 that of the human head. Hence, 28 ounces per side of distal traction delivers more pressure in human equivalents to the cranio-facial bones of the monkey. Thus, the magnitude of force used in this study probably

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*Kodak Canada Limited, Winnipeg, Manitoba

[†]Northwest Orthodontics Incorporated, Seattle, Washington

[ϕ]Ohaus Scale Corporation, Florham Park, New Jersey

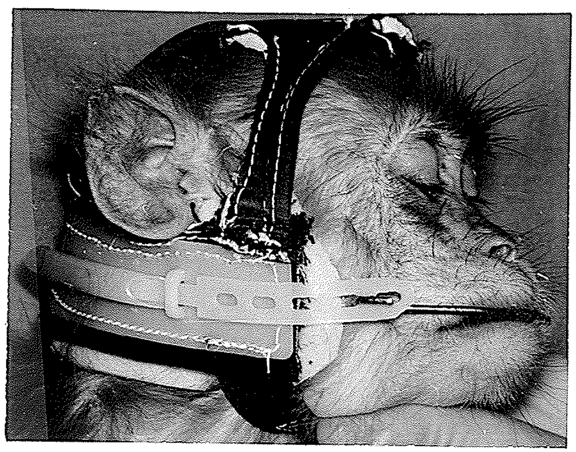

Figure 7. Extraoral headgear appliance incorporating calibrated coil springs. Monkey No. 3 of the headgear group is shown at the beginning of the experiment with 12 ounces per side of force applied. Four days later the force was increased to 28 ounces (800 grams) per side.

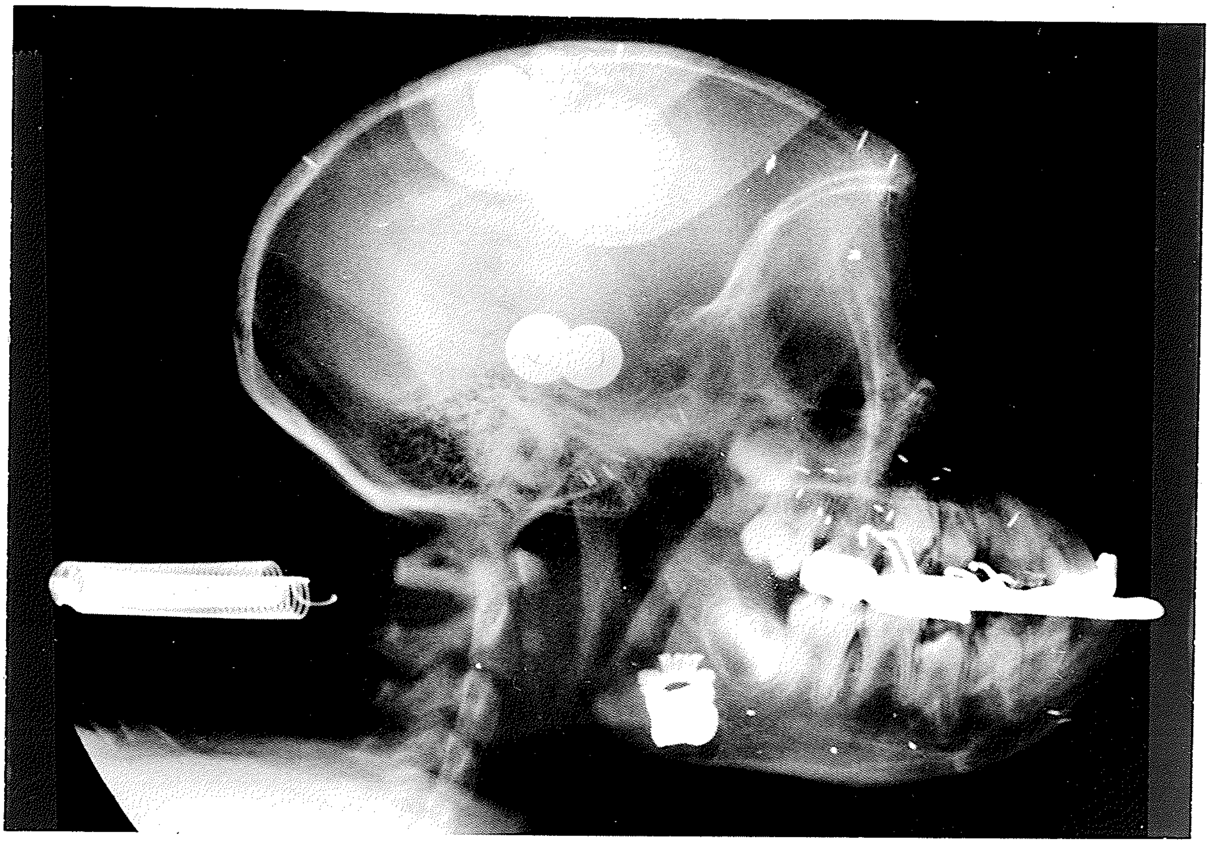

Figure 8. Cephalometric radiograph of Monkey No. 3 of the headgear group after 38 days of continuous extraoral traction showing the direction of the extraoral force slightly cervical to the occlusal plane. This radiograph was chosen to show the images of both bilateral "superimpositioning implants" in the frontal bone (above and to left of roof of orbits) when they are not exactly superimposed.

exceeds in human equivalents the 4 to 5 pounds per side of distal traction advocated by Armstrong (1971) and Haas (1970).

Intraoral Appliances

Two types of intraoral appliances were used in this experiment:

1. Orthopedic Headgear Appliance
2. Combination Headgear - Palatal Expansion Appliance

The type of appliance used in each group was as follows:

Headgear Group:

The appliance design in this group was aimed at harnessing the maxillary bone so that the maximum amount of force could be transmitted to the bone rather than the small anchor teeth. The appliance was designed to take advantage of as much retention as possible, so that the heavy forces used would not dislodge the appliance from the mouth. It was, thus, decided to harness the premaxillary area especially in the mucogingival area. In addition, since in both Monkeys No. 3 and No. 4 the maxillary second permanent molars were erupted and the maxillary third molars were unerupted but in an advanced stage of development, it was decided not to band the second molars but to band the first molars. This allowed the investigation of possible distal movement of the maxillary denture against the unbanded maxillary second and unerupted third molars.

Under general anaesthesia, bands were fitted on the maxillary central incisors and maxillary first permanent molars of Monkeys No. 3 and No. 4. Compound impressions were taken with the bands seated on the teeth, and working stone models were poured with the bands reseated into the impression. A 0.030 wire framework was then fabricated consisting of buccal and lingual wires soldered from the central incisor band to the first molar band on either side of the arch. Wire extensions into the palatal area were soldered to the lingual wires. Thus, each appliance consisted of two separate frameworks (Figure 9). On the buccal wires of the two frameworks 0.045 tubing, to accept the face-bow of the headgear, was soldered so that the long axis of each tubing was parallel to the occlusal plane and to each other. Wire extensions were soldered to the labial surfaces of the central incisor bands and extended gingivally into the vestibular fold area (Figure 10). One framework was removed from the working model and the other left on the model. Quick cure acrylic resin was then applied on the palatal area of the model, being retained by the palatal extensions of the framework. Grooves were then cut into the polished palatal acrylic to allow for the seating of the wire extensions of the framework from the other half of the appliance. Thus, this appliance was fabricated and designed to be inserted into the mouth in two units in order to attain additional retention beyond that of a cement bond by making use of two separate non-parallel paths of insertion and the consequent undercut, thus, created.

Under general anaesthesia, superficial grooves were cut into the labial and lingual surfaces of the maxillary incisors and first permanent molars. A completely dry field was achieved by intra-muscular injection of atropine sulfate. The appliance was then cemented with Caulk Grip Cement* in two phases. Once cemented in the mouth, acrylic was quick cured over the grooves in the palatal acrylic in which rested

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*L. D. Caulk Company, Toronto, Ontario

the palatal extensions from the second part of the appliance. In addition, acrylic was quick cured in the mouth in the muco-labial fold area over the extensions from the central incisors, thus, uniting the two sections of the appliance in the anterior area, engaging an undercut area for enhanced retention and providing a large surface area for transmission of force directly from the appliance to the maxillary basal bone (Figure 10).

Two days after cementation pre-experimental records were taken. The following day orthopedic headgear was adapted. A conventional facebow, available commercially*, was modified and used in conjunction with the extraoral headcap (Figures 11 and 12). The inner bow was of 0.045 inch round wire and carried a soldered stop to allow the inner arch of the facebow to be tied into the buccal tubes of the intraoral appliance using 0.012 ligatures (Figure 11).

On the first day, only 12 ounces of extraoral force were applied to allow the animal to adjust to the headgear. Four days later the force was increased to 28 ounces per side of continuous traction. The force was maintained in place and padding was added to relieve areas of pressure on the back of the neck. During the experiment the length of the inner bow from the buccal tube had to be lengthened due to distal movement of the maxillary dentition and the maxilla resulting in the lower incisors impinging on the inner bow on closure of the mandible. The inner bow was lengthened by sliding pieces of 0.045 (2 mm long) tubing on the inner bow. In addition, new facebows had to be fitted throughout the experiment to accommodate this requirement for an increased length of the inner arch.

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*Ormco Corporation, Glendora, California

Figure 9. Intraoral Orthopedic Headgear Appliance. Inserted as two separate units, each consisting of a molar and an incisor band joined by a wire framework. The palatal wire extensions of one unit (left side of photograph) are shown resting in grooves in the palatal acrylic which is attached to the other unit (right side). After cementation of each unit, the two units were united in the mouth by covering the palatal extensions with quick-cure acrylic.

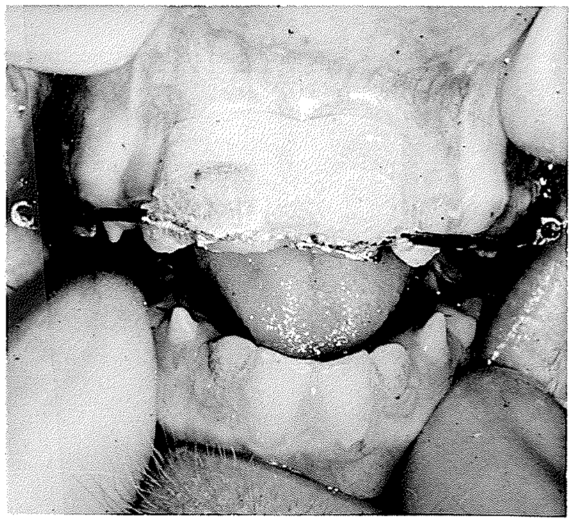

Figure 10. Intraoral Orthopedic Headgear Appliance. Labial wire extensions from the incisor bands are covered with quick-cure acrylic and hence are barely visible. The acrylic was applied in the mouth in order to unite the two halves of the appliance in the front and to harness the premaxillary alveolar bone.

Records were taken on the 38th day and 72nd day at which time Monkey No. 4 was sacrificed. Monkey No. 3 continued to wear the headgear for an additional period and records were taken on the 103rd day. Subsequently, all appliances were removed from Monkey No. 3 for a "relapse" observation period of 26 days during and after which records were taken.

Control Group

Monkey No. 1 did not have an intraoral appliance inserted. A recent article by Harvold et al (1972), reported that experimental monkeys, each fitted with an acrylic block in their palatal vault, exhibited changes in dentofacial growth and developed Class II Division 1 malocclusions due to the presence of the passive palatal appliance. Thus, it was felt that control animals with and without intraoral appliances was indicated to investigate whether or not the presence of the appliance alone affected growth during the experimental period. Harvold's experimental period, which was 6 months, was longer than the active experimental periods used in this study.

Monkey No. 5 underwent the same procedures for preparation and insertion of an intraoral appliance as the animals in the headgear experimental group. This appliance was comparable to the headgear group appliance.

Monkeys No. 1 and No. 5 underwent growth periods of 253 days and 208 days respectively. However, records were taken to coincide with the intervals of the experimental groups.

Palatal Expansion Group and Combination Group

The appliance design in all monkeys who underwent palatal expansion was directly comparable to and corresponded to the appliance design as used by Murray (1971). Under general anaesthesia, teeth in the posterior segments were banded in the animals as follows:

Monkey No. 2: Banded 64/46

Monkey No. 6: Banded 76e/e67

Monkey No. 7: Banded 76d/d67

Compound impressions were taken with the bands seated on the teeth and working stone models were poured with the bands seated in the impression. Buccal and lingual 0.030 inch wires were soldered to the bands to provide added rigidity and split acrylic appliances were fabricated, each with an expansion screw in the midline of the appliance (Figure 12). It was found that each appliance opened approximately 1 mm after 4 one-quarter turns of the screw. Buccal tubing of 0.045 inch diameter was soldered onto the buccal wires of the framework so that their long axes were parallel to the occlusal plane and to each other (Figure 12).

Under general anaesthesia the buccal and lingual surfaces of the involved teeth were superficially grooved. The appliances were cemented in one piece using Caulk Grip cement.

This appliance design did not incorporate the pre-maxillary area and thus allowed for the separation of the mid-palatal suture of the maxilla without involving the ossified pre-maxillary mid-palatal suture. However, this appliance did not harness the maxillary basal bone as effectively as the headgear group appliance, and, for the sake of retention, in the Combination Group necessitated the banding of the maxillary second molars.

Records were taken before and after appliance insertion. The palatal appliances were activated according to the schedule used by Murray (1971), in a previous study in this laboratory, to allow for application of his findings to the present experiment. The initial activation consisted of 3 one-quarter turns of the screw, that is, 0.75 mm. The screw was then given 1 one-quarter turn, that is, 0.25 mm of activation, every 24 hours thereafter for 14 days in the case of Monkey No. 2 and 12 days in the case of Monkeys No. 6 and No. 7. At this time post-palatal expansion records were taken.

On the 13th day of activation of the palatal appliance in Monkeys No. 6 and No. 7 the orthopedic headgear was adapted and immediately adjusted to deliver 28 ounces per side of extraoral distal traction. At this time the palatal appliance was given 2 one-quarter turns, that is, 0.50 mm activation. Twenty-fours hours later the animals were lightly sedated and the palatal appliance activated an additional 2 one-quarter turns while the headgear was maintained in place. The same procedure was carried out the following day so that for a period of 3 days, following the initial 12 day expansion period, a combination of rapid palatal expansion and heavy continuous distal force of 28 ounces per side was simultaneously applied to Monkeys No. 6 and No. 7. During these 3 days Monkeys No. 6 and No. 7 were tranquilized with daily intramuscular injections of Valium* as it was anticipated that the immediate application of this combination of very heavy forces might initially increase their activity to such an extent that they might disturb their appliances. Monkey No. 6 continued to wear the extraoral appliance and records were taken on the 38th and 72nd days of continuous extraoral traction. Monkey No. 7 continued to wear the orthopedic headgear for 12 continuous days after palate-splitting, at which time, due to a severe infection, the

*Hoffmann-LaRoche Limited, Montreal, Quebec

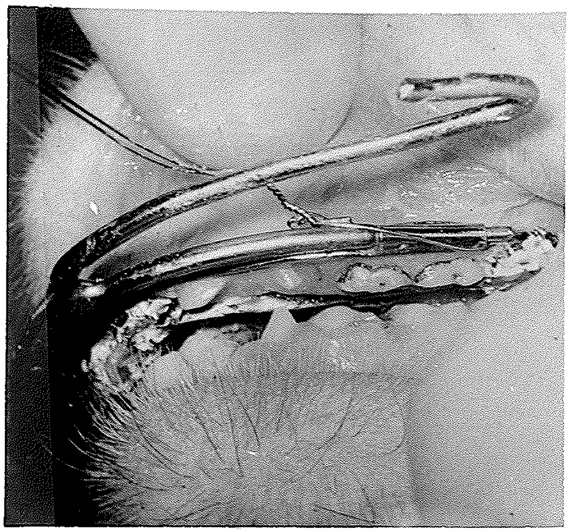

Figure 11. Double Face-bow inserted into buccal tubes of the Intraoral Orthopedic Headgear Appliance and secured with 0.012 ligature tie to a stop soldered on the inner arch of the Double Face-bow.

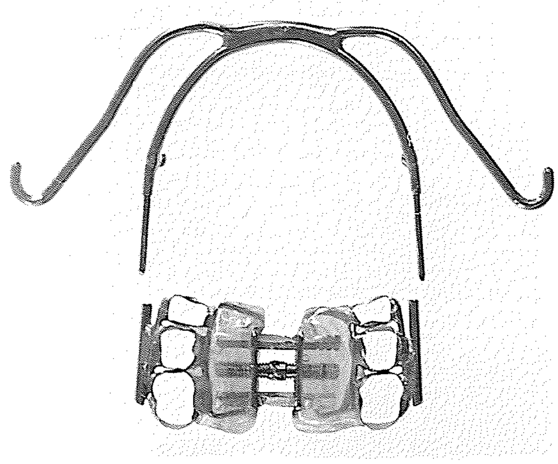

Figure 12. Double Face-bow (top) and Intraoral Combination Headgear-Palatal Expansion Appliance (bottom).

animal went into a coma. Records were taken and the animal sacrificed.

Development of "Space-Helmet" Restrainer Feeder

A restraining device was designed and constructed to prevent the monkeys from disturbing their orthopedic appliances (Figure 13). At the same time, the restraining device served as a feeder for the animals. The monkeys were placed in the restrainers one week pre-experimentally to allow them to adapt to the appliance and their new feeding method.

The restrainer-feeder basically consisted of two component parts which fitted on the animal and were then joined together (Figure 14). The lower part was a cone-shaped collar which fitted over the monkey's head and rested loosely around its neck and extended downwards over the shoulders to encircle the monkey's body. The upper part was essentially a deep "globe" open at the top, similar to a "space-helmet" and was fitted over the monkey's head and was attached to and supported by the lower part of the restrainer-feeder.

Construction

Both the upper and lower parts of the restrainer-feeder were fabricated from light plastic bowls (Figure 14).

Lower Part of Restrainer-Feeder

The lower part consisted of one cone-shaped plastic bowl (A), approximately 8 inches in diameter at its rim and 4 1/2 inches deep. Most of the base of the bowl was removed producing a large circular hole which could be fitted over the monkey's head. A horizontal extension (B), consisting of the basal portion of a second, but larger bowl with a matching hole was attached to the lower cone such that the two holes superimposed. This extension facilitated the attachment of the upper part of the restrainer-feeder to the lower.

Upper Part of the Restrainer-Feeder

The upper part was fabricated from portions of three separate bowls, each approximately 12 inches in diameter and 5 inches deep. The major bowl(C), of the upper part had a "keyhole" shaped opening cut from its base to allow the bowl to fit over the monkey's head through the wide portion of the "keyhole," and then allow the bowl to be adjusted so that the narrow port of the "keyhole" fit around the monkey's neck. A sliding panel (D), designed to cover the wide portion of the "keyhole" of the major bowl was removed from the matching curvature of a second bowl. This sliding panel, when placed under the monkey's chin and secured to the major bowl, formed a small circular hole around the monkey's neck.

The narrow portion of the keyhole of the major bowl and the matching portion of the sliding panel were lined with Plastozote, a synthetic foam, and then covered with soft protective leather which was sprayed with a water-proofing agent. This soft lining was placed to prevent irritation to the monkey's neck. In order to increase the depth of the major bowl of the "space-helmet," a rim of a third bowl (E) of the same size was removed and this 3 inch rim was attached to the rim of the major bowl.

Placement of Restrainer-Feeder

The lower part of the restrainer-feeder was placed over the monkey's head first. Extraoral orthopedic appliances were then placed or adjusted. The upper part of the restrainer-feeder was then placed

Figure 13. "Space-Helmet" Restrainer-Feeder worn by the monkeys to prevent them from damaging the extraoral appliance. Soft food was placed inside the major bowl and the monkeys adapted to a new feeding technique. Soft padding is shown under the headgear appliance.

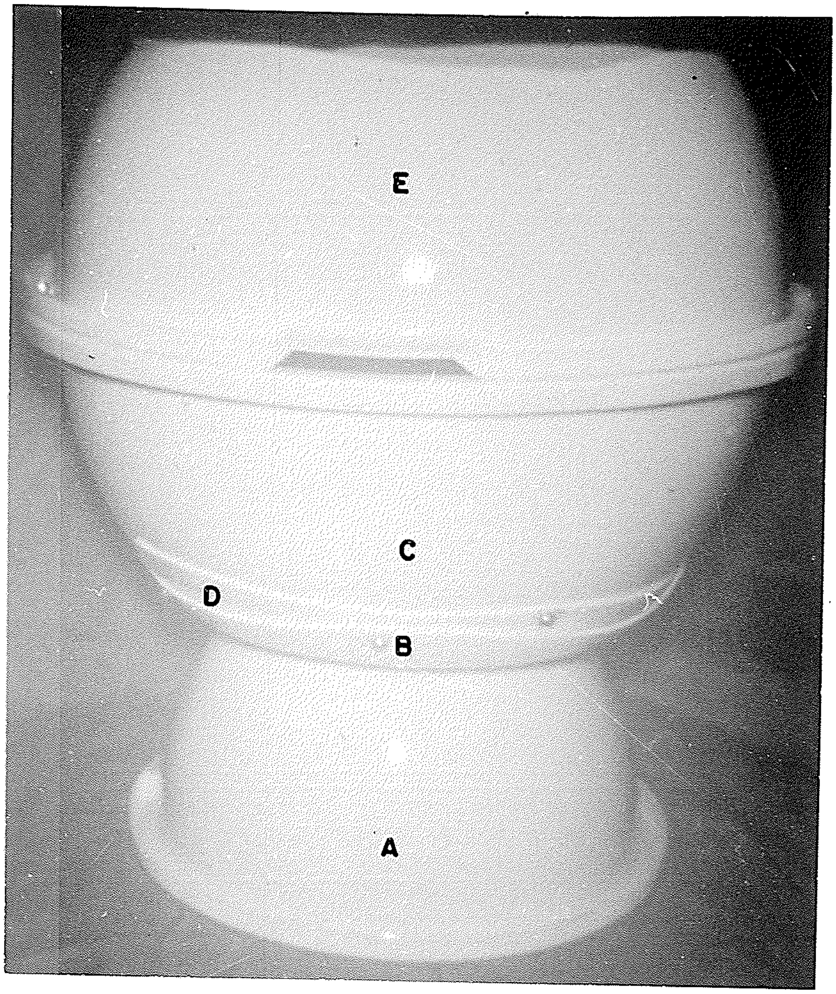

Figure 14. "Space-Helmet" Restrainer-Feeder. This appliance was constructed from the following parts: (A) Cone-shaped plastic bowl of lower part (B) Horizontal extension of lower part for attachment to upper part (C) Major bowl of the upper part (D) Sliding panel and (E) Rim to increase depth of major bowl.

over the monkey's head and the sliding panel positioned under the monkey's chin, and was then bolted to the major bowl. The upper part was then bolted to the horizontal extension of the lower part.

Functions of the Restrainer-Feeder

The upper bowl was designed to serve two functions:

1. To prevent the head and face of the monkey from contacting anything in the cage. The major bowl was shaped such that the animal's face and the facebow could not touch the inner sides of the bowl.

2. To serve as a feeding dish. Small pieces of commercial monkey chow*, soft fruits such as bananas, plums, raisins, grapes and oranges were dropped into the "space-helmet" through its open top. The monkey adapted to a new method of eating and by manipulation of the bowl by holding the lower part of the restrainer-feeder with its hands the monkey was able to roll the food towards its mouth and scoop it up with its tongue without the outer or inner bow of the headgear appliance contacting anything but the soft food.

The lower bowl was designed to serve three functions:

1. To distribute the total weight (350 grams) of the restrainer-feeder over the monkey's shoulders and to stabilize the entire apparatus.

2. To prevent the monkey from putting its fingers through the loose neck hole. Movement of the monkey's hands and shoulders would tend to tilt the restrainer-feeder and, hence, prevent the monkey from getting its fingers through the neckhole into the upper bowl.

3. To allow the animal freedom of movement within the cage.

Animal Maintainance

An experiment of this nature extending over a prolonged period of time involves many physical problems in the care and handling of the

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*Ralston Purina Company, St. Louis, Missouri animals. The monkey proved to be a very difficult animal to handle as it displayed a hostility toward man when approached and as a result required sedation prior to handling. Hence, supervision of the appliances during the experiment necessitated the development of devices to facilitate handling the animals. In order to sedate the animals, a net was inserted into the cage through a slot at the top and a movable panel inside and at the rear of the cage was pulled forward forcing the animal into the net. The door of the cage was then opened and sedation given through the net by intramuscular injection. Light sedation was necessary during routine checks of the appliances, regular cleaning of the restrainer-feeder, and prior to experimental procedures.

The difficulties involved in handling the Macaca mulatta were further complicated as this species may carry various pathogens which may infect the human. Therefore, at all times during the handling of the animals, disposable gloves and mask were worn by the researcher to prevent contraction of possible diseases carried by the monkey, especially Herpesvirus B which is fatal to man.

It should be pointed out to those interested in undertaking similar projects that the many physical problems involved with handling and maintaining the animals proved to be the most difficult and time-consuming part of this experiment. Therefore, a color movie was made in order to more explicitly document the methods used during this study and is stored at the Department of Orthodontics, Faculty of Dentistry, University of Manitoba. It is hoped that this visual aid will prove useful to those interested in pursuing similar non-human primate experiments.

During the experiment, all animals were injected at specific time intervals with a sequence of vital bone-marking agents consisting of 50 mg/kgm of tetracycline hydrochloride (Frost, 1962, 1968, 1969; Cleall et al 1964), 10 cc/kgm of 2% aqueous solution of alizarin red S dye (Cleall et al 1964), and a combination of 50 mg/kgm tetracycline hydrochloride followed by 5 cc/kgm of 2% alizarin red S solution (Cleall et al 1964). The results of this work are not included in this dissertation, but the bone marking agents will be used to assess the amount of bone reaction in a future study.

Method of Sacrifice

The animals were sacrificed by means of perfusion fixation via the left ventricle. The cardiovascular system was first flushed with 500 cc of normal saline and then perfused with 2,000 cc of neutral buffered formalin for approximately 30 minutes. The animals were then decapitated and the heads stored in 10% neutral buffered formalin.

Sequence of Cephalometric Records

Standardized lateral cephalograms were taken immediately after implant placement, prior to commencement of the experimental periods, and at specific intervals throughout the various experimental periods in all animals. In the first animal to undergo each type of force application, cephalometric records were arbitrarily taken after occlusal changes were evident clinically. Records were then taken on subsequent experimental animals and in the control animals to coincide with the intervals in the first animal. Figure 15 summarizes the longitudinal sequence of cephalometric records.

Random P-A, A-P, basilar and oblique radiographs were also taken but were not used for quantitative analysis.

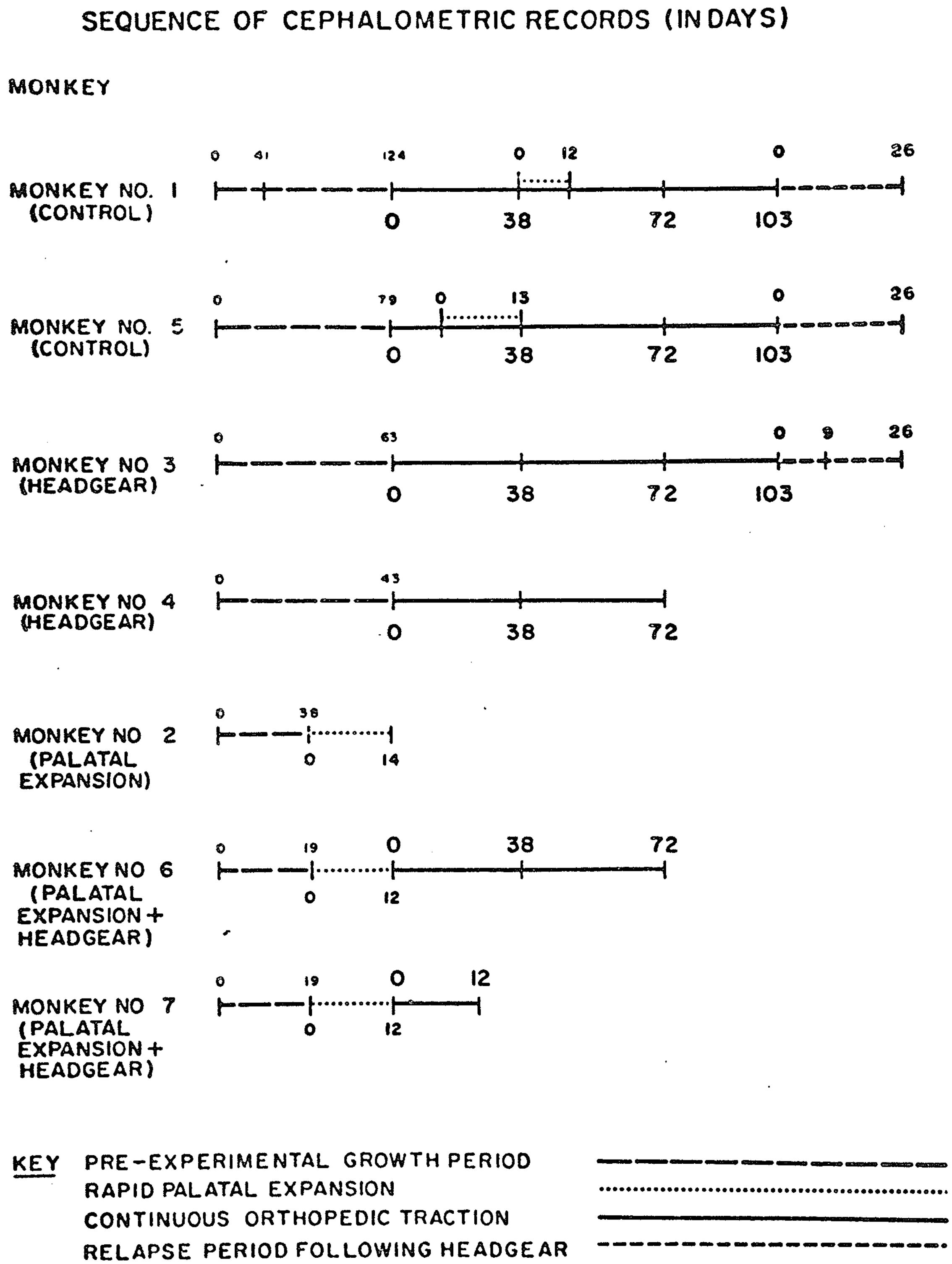

Figure 15. Longitudinal series of radiographic cephalometric records taken at each stage during the various experimental periods of each animal.

IV. CEPHALOMETRIC ANALYSIS

A quantitative analysis was performed on the cephalograms of each animal using the data processing system described by Cleall and Chebib (1971). In order to reduce tracing and measurement errors, the coordinates of selected cephalometric landmarks were recorded directly from the film onto IBM computer cards using a strip-chart digitizer* and an IBM 26 Printing Card Punch†. All measurements and statistical calculations were then carried out using the University of Manitoba IBM 360/65 computer system$^{\phi}$.

Error of Cephalometric Method

Three animals were used for this analysis. Each monkey was oriented in the cephalostat, a lateral cephalogram taken, the animal repositioned again and another exposure taken. This reorientation procedure was repeated 10 times for Monkey No. 4, 13 times for Monkey No. 5, and 15 times for Monkey No. 6, resulting in 38 cephalograms. Seven representative implants (Figure 16), were selected and the coordinates plotted in sequence for each cephalogram of each animal. At a separate sitting the plotting procedure was repeated a second time on the same 38 films so that data representing a total of 78 radiographs underwent analysis.

Several linear, horizontal, vertical and angular (short, medium and long arms) measurements (Figure 16) were calculated for each

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*Ruscom Logistic Limited, Rexdale, Ontario

†IBM, Don Mills, Ontario

$^{\phi}$University of Manitoba Health Sciences Computer Department, Winnipeg, Manitoba

MEASUREMENTS FOR ERROR OF CEPHALOMETRIC METHOD

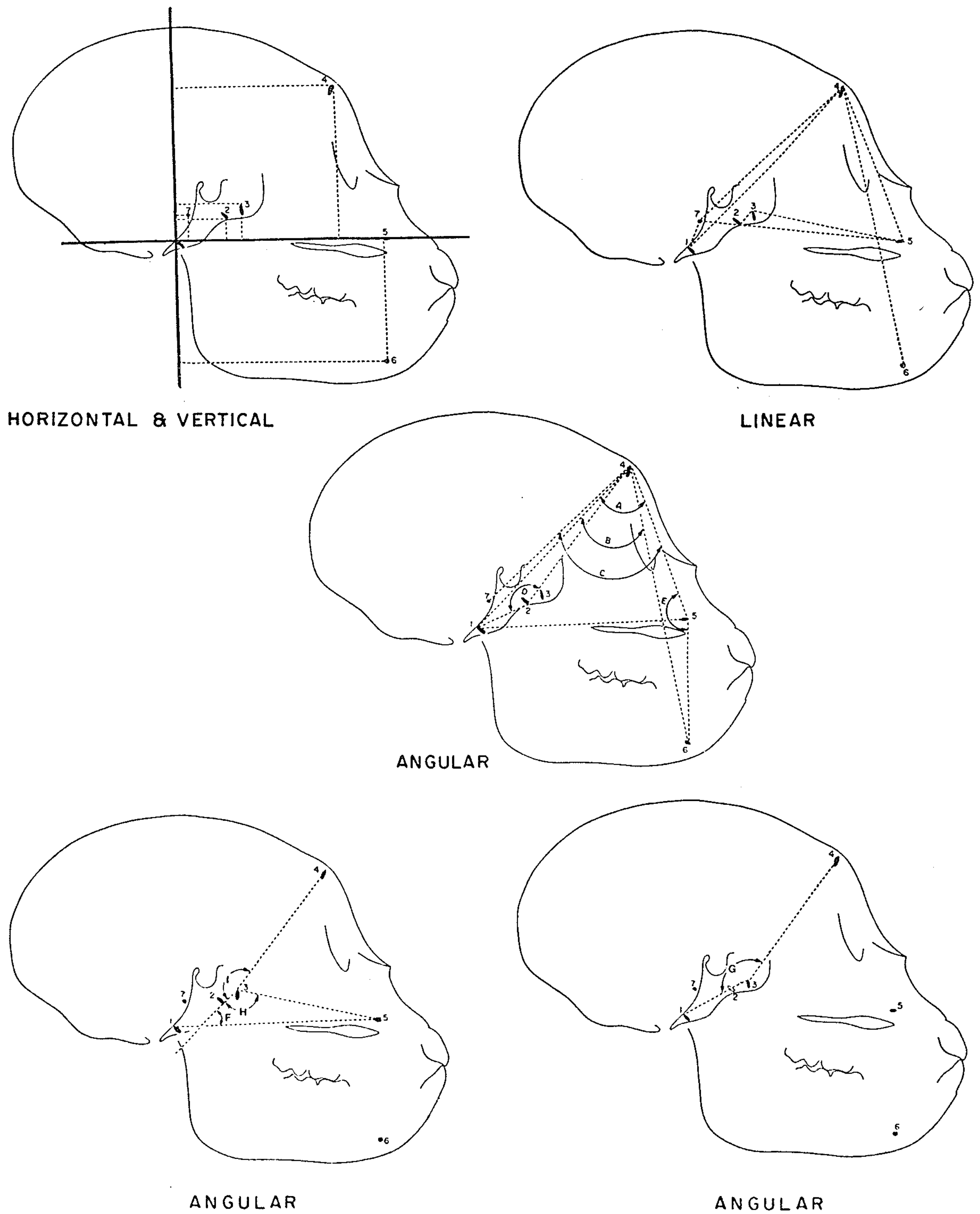


Figure 16. Linear, horizontal, vertical and angular measurements used for determination of error of cephalometric method.

cephalogram and the repeated measurements statistically analyzed to determine the errors involved using the pooled standard deviation method described by Chebib and Burdick (1973). The results of this analysis are reported in the findings.

Quantitative Analyses

Landmarks

For each cephalogram, a maximum of 184 points which represented anatomical landmarks and all possible implant sites were recorded (Figures 17 and 18). Definitions of these landmarks may be found in the Glossary. Since the sequence represented the maximum number of implants in each bone, several sites were missing in each animal, while some were redundant for analytical purposes. Hence, several implant sites in the sequence were discarded and do not appear in Figure 18. In addition, several anatomical sites which proved repetitive were excluded from analysis.

Intra-Bone Implant Stability (Error Test)

This analysis consisted of measuring all possible combinations of linear distances between all the implants in each bone for the cephalometric sequences of each animal. Since the implants in any one bone, if stable, maintain the same spatial relationship with respect to all other implants in that same bone throughout the experimental period, the amount of inter-implant linear variation within each bone constitutes an assessment of all the inherent errors in the cephalometric technique, including stability of implant placement, head orientation errors, and plotting errors.

ANATOMICAL LANDMARKS

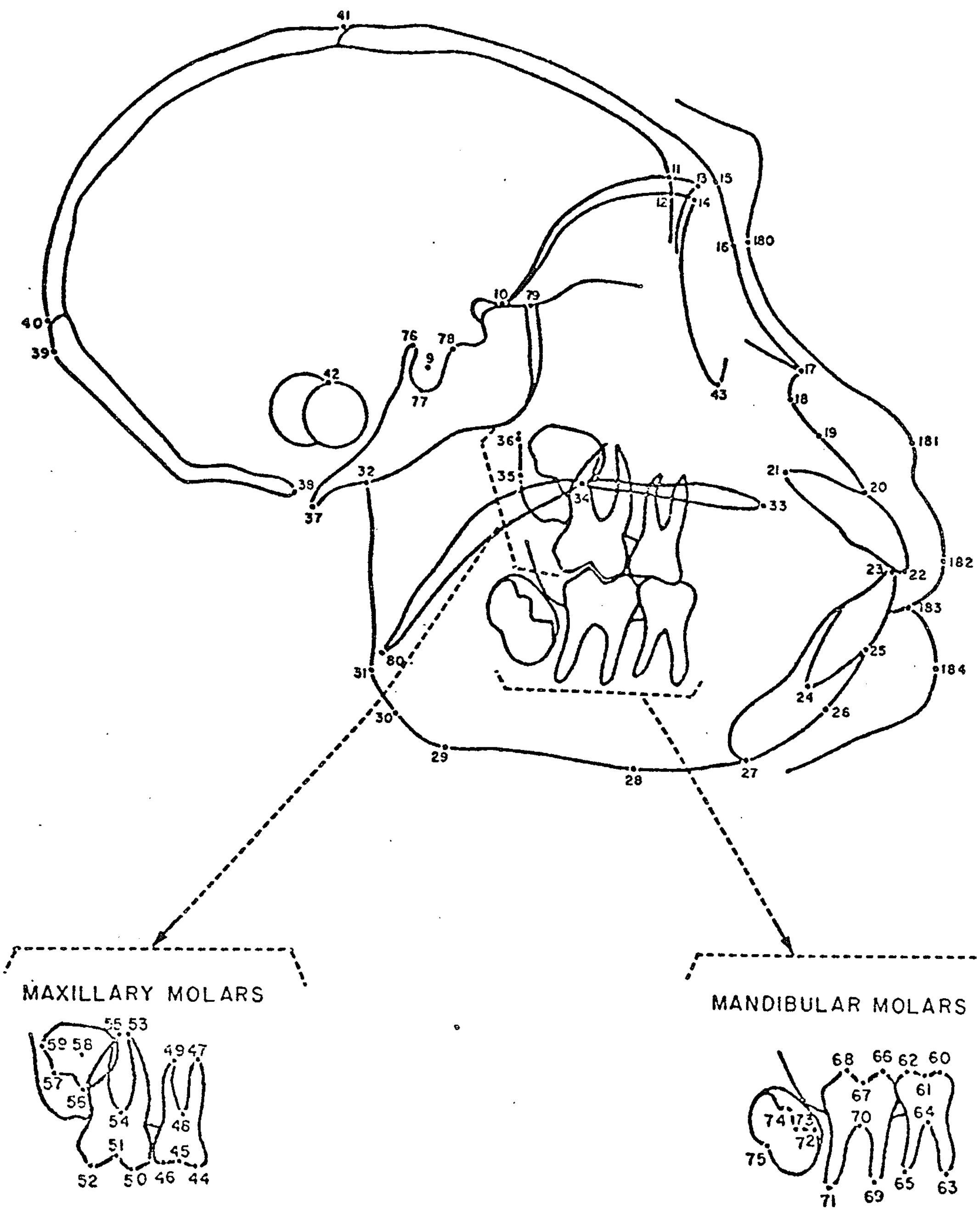


Figure 17. Sequence of anatomical landmarks on lateral cephalometric radiograph.

METALLIC IMPLANTS

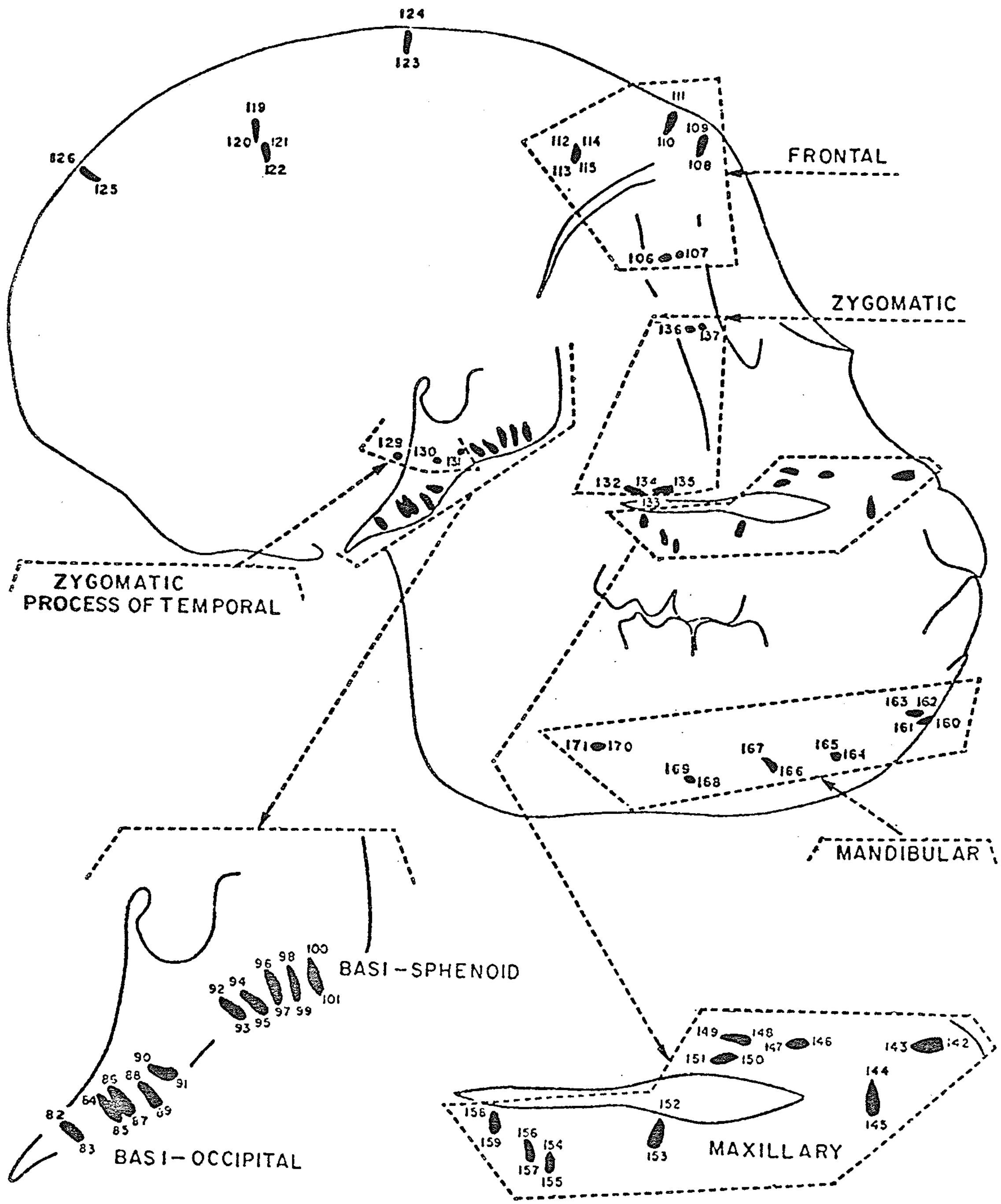


Figure 18. Sequence of metallic implant sites on lateral cephalometric radiograph. Sites 112 to 115 represent the bilateral "superimpositioning implants" in the frontal bone and sites 119 to 122 represent the bilateral implants in the parietal bone. These implants were used for head orientation in the cephalostat.

Individual Analyses

Coordinate Analyses

Overall Superimposition on Basi-Sphenoid Bone

In order to quantify increments of growth of the various cranio-facial bones with respect to the cranial base (basi-sphenoid bone), a "template-transfer system" was used to superimpose serial cephalograms. This "template-transfer system" was used to transfer a reference line from the initial cephalogram to subsequent films so as to superimpose this original reference line, as it relates to the basi-sphenoid bone in the initial film, on all subsequent films of that animal. Thus, in effect all measurements for this reference line referred to the cranial structures of the original headfilm. In order to allow for inter-animal comparison, the reference line on the initial film of each animal was selected so as to coincide with the Frankfort Horizontal Plane.

Template Construction.- Two distant points, Point 1 and Point 2, on a line coinciding with the Frankfort Horizontal Plane were marked with a fine pin point on the initial cephalogram of the series for each animal. The outline of the basi-sphenoid bone and the implants in the basi-sphenoid bone were then traced on acetate tracing paper with a 6H pencil. In addition, Point 1 and Point 2 were marked on the tracing paper with fine pin points.

Transfer Method.- The template-tracing was superimposed on the next film of the series so that the basi-sphenoid implants and outline of the basi-sphenoid bone registered. Point 1 and Point 2 were then marked on the second cephalogram with a fine pin. This transfer procedure was repeated for each additional film of the series.

The coordinates of Point 1 and Point 2 on each cephalogram were plotted and used as the origin and direction of the horizontal axis for the coordinate analysis (Chebib and Cleall, 1971). The vertical axis was constructed at the point of origin, Point 1 (Figure 19). The distances of specific landmarks were calculated in the horizontal and vertical directions relative to these axes for all films in each series (Figure 19). The increments of change between stages for each landmark in the horizontal and vertical direction were then calculated by subtraction. These increments were used to describe the direction, magnitude and rate of growth changes in the various groups at these sites.

Error of "Template-Transfer System."- Theoretically, the relationship between the implants in the basi-sphenoid bone and the line 1-2 should remain constant from stage to stage in each animal. Hence, the horizontal and vertical distances of the basi-sphenoid implants were assessed relative to the axes through Points 1 and 2 and their linear deviations used as an estimate of the error of superimpositioning.

Maxillary Superimposition

The template transfer method was also used to quantify both dental movement relative to the maxilla and transformative changes of the maxilla itself. A reference line, joining Points 3 and 4, distant points on a line coinciding with the palatal plane on the initial film, was transferred from the initial film of each series to successive films by registering the template on the implants in the body of the maxilla.

A coordinate analysis was carried out using Point 3 as origin and Point 4 as direction for the horizontal axis with the vertical axis constructed perpendicular at Point 3 (Figures 20 and 21). Horizontal and vertical distances for the selected maxillary landmarks shown in Figures 20 and 21 were calculated and the increments of change between stages determined by subtraction for each animal. The deviation of maxillary implants was used as an estimate of the error of superimpositioning.

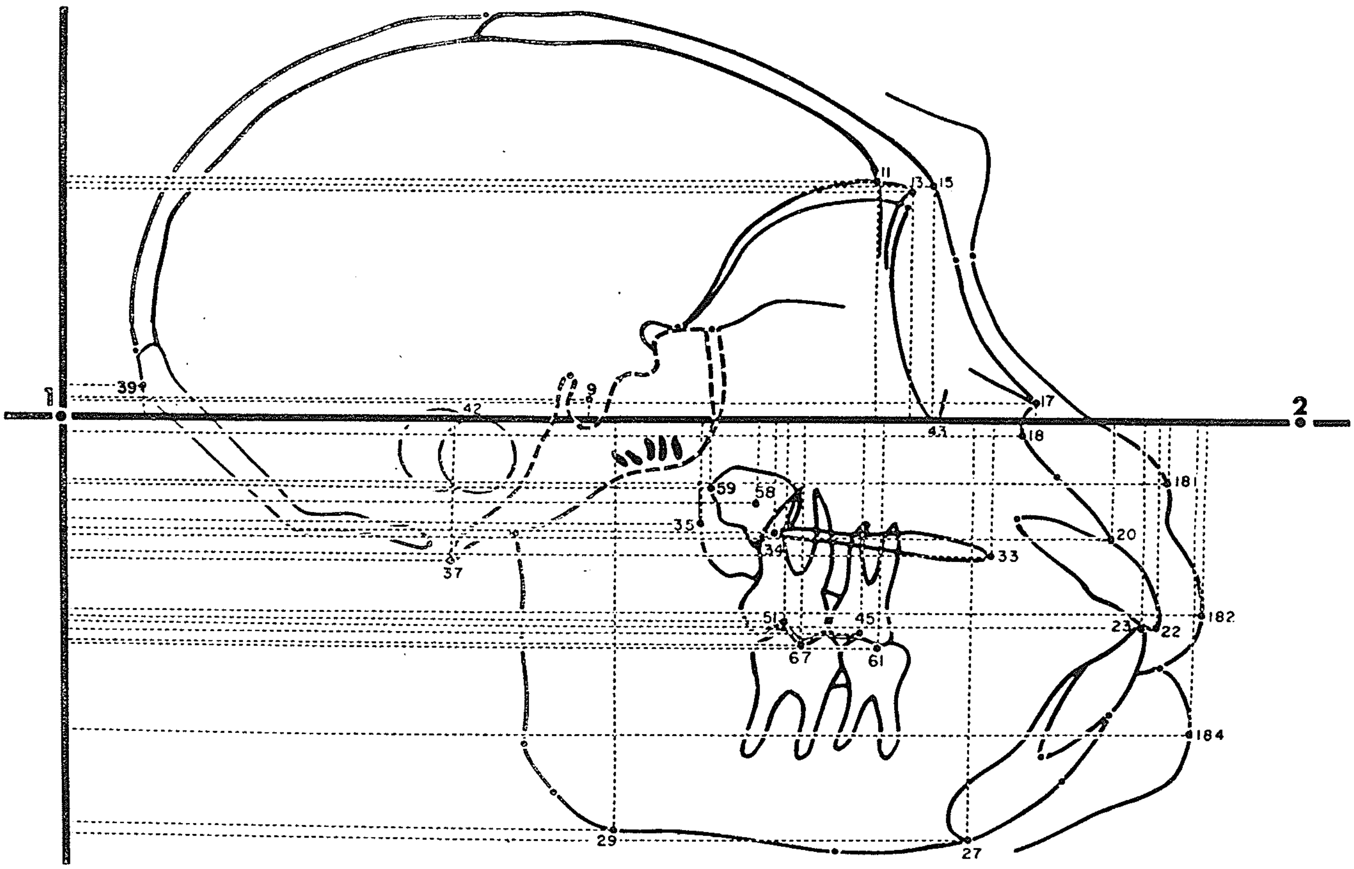


Figure 19. Horizontal and vertical distances measured in the coordinate analysis of the overall superimposition on the basi-sphenoid bone. Point 1 and Point 2 were transferred from the initial cephalogram to each cephalogram of the series using a "template-tracing" registered on the implants in the basi-sphenoid bone and the outline of the basi-sphenoid bone. In addition to the distances illustrated above, horizontal and vertical distances of representative implants in each bone were measured relative to the axes through Point 1 and Point 2. The increments of change in each distance between stages were calculated by subtraction.

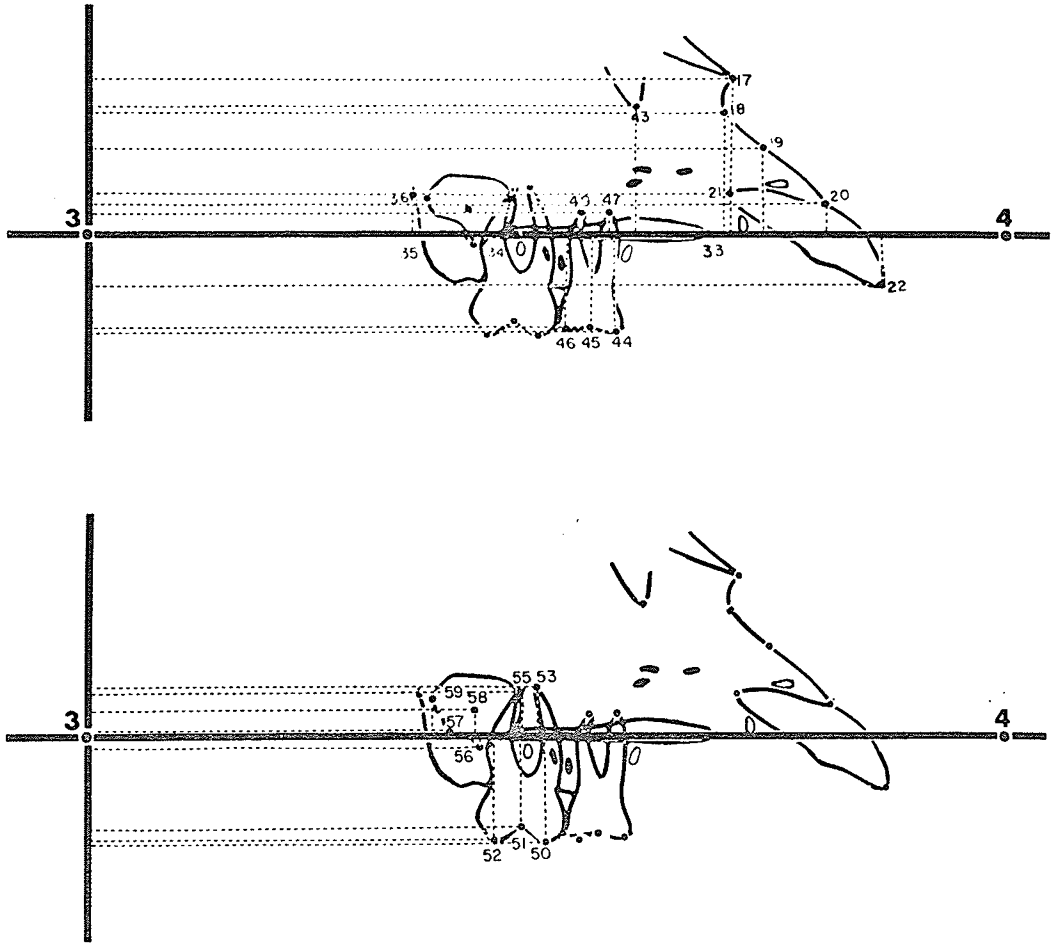


Figure 20 (top) and 21 (bottom). Horizontal and vertical distances measured in the coordinate analysis of the maxillary superimposition on the implants in the body of the maxilla. Point 3 and Point 4 were transferred from the initial cephalogram to each cephalogram of the series using a "template-tracing" registered on the implants in the body of the maxilla. The increments of change in each distance between stages were calculated by subtraction.

Mandibular Superimposition

The "template-transfer system" was also used to assess changes in mandibular morphology and dental movement. Mandibular implants were registered and line 5-6, coinciding with the tangent to the lower border of the mandible on the initial cephalogram, was transferred to successive films of each series and a coordinate axis system established. Horizontal and vertical distances for selected mandibular landmarks (Figure 22) were calculated for each animal and the increments of change between stages determined by subtraction. Once again deviation of the mandibular implants relative to the axes was used as an estimate of the error of the superimpositioning procedure.

Linear Analysis

For each animal, the linear distances illustrated in Figures 23, 24 and 25 were calculated. These absolute distances included several assessments of vertical facial dimensions and anteroposterior maxillary length. In addition, linear distances of the maxilla, mandible, and maxillary molars respectively to the cranial base were determined using several alternative landmarks. In each animal, the increments of change between stages for these linear distances were calculated by subtraction and used to assess changes in the vertical dimensions of the face, length of the maxilla and position of the maxilla, mandible and maxillary teeth relative to the cranial base.

Angular Analysis

In order to assess rotation of the various bones with respect to each other, the changes between stages in angles made by several planes were assessed.

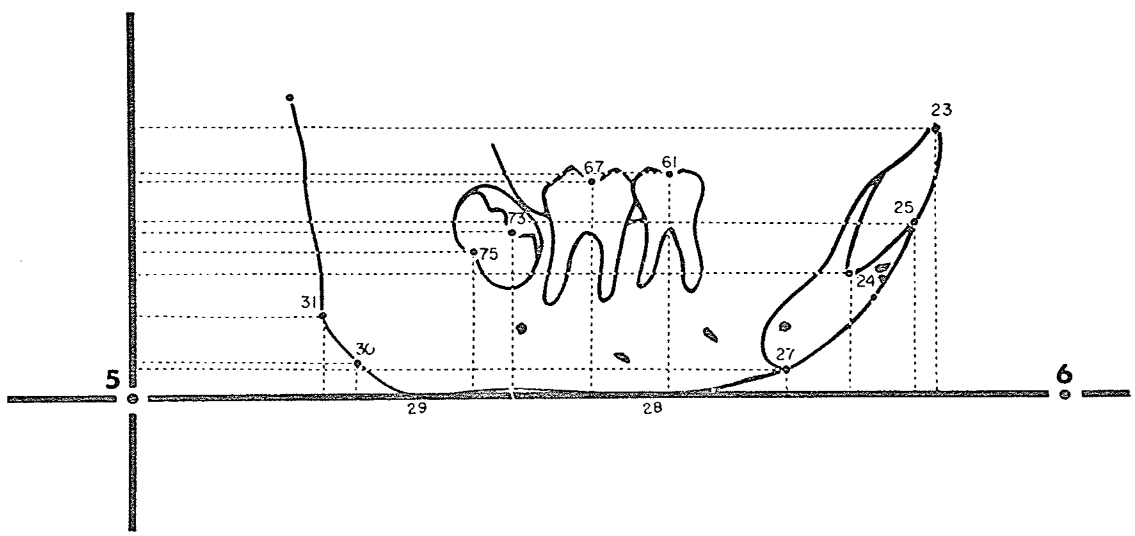
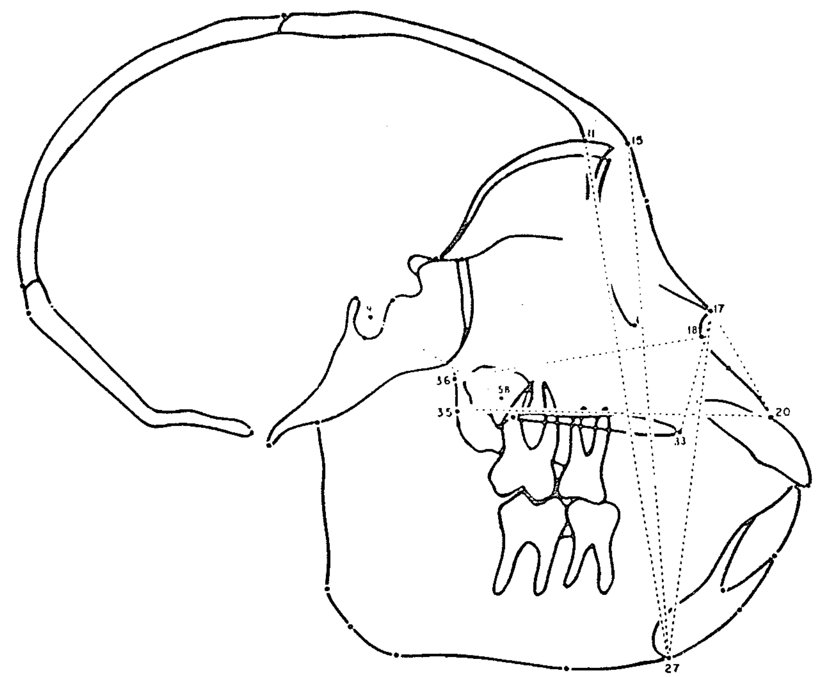
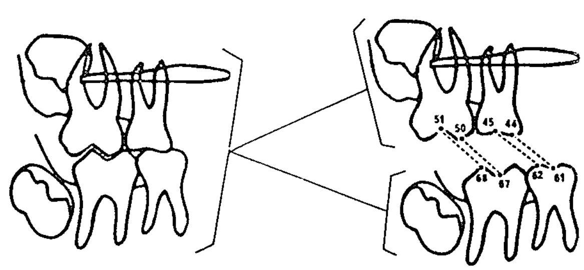


Figure 22. Horizontal and vertical distances measured in the coordinate analysis of the mandibular superimposition on the mandibular implants. Point 5 and Point 6 were transferred from the initial cephalogram to each cephalogram of the series using a "template-tracing" registered on the implants in the mandible. The increments of change in each distance between stages were calculated by subtraction.





Figures 23 (top) and 24 (bottom). Linear distances measured on each cephalogram. The increments of change in each distance between stages were calculated by subtraction.

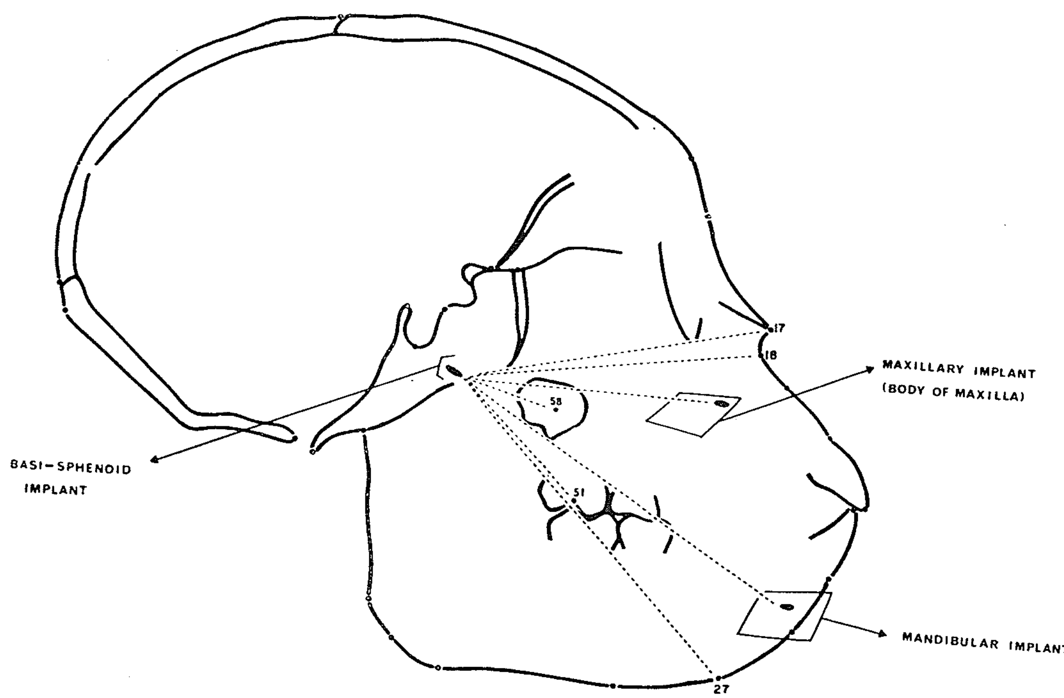


Figure 25. Linear distances measured on each cephalogram. The increments of change in each distance between stages were calculated by subtraction.

Rotation of the maxilla and mandible relative to each other and to the basi-sphenoid bone was assessed by measuring the change in the angles formed by the "template-transfer lines" (Figure 26, angles a, b and c). Since each "transfer-line" is in essence a physical extension of the implants in each respective bone, rotation of the "transfer-line" indicates rotation of the implants in that bone and the bone as a whole.

In order to assess rotation of the maxilla without using the "template-transfer-lines," an alternative method was used. As demonstrated in Figure 27 a line joining any two implants in a bone may be used to describe the rotation of that bone. Hence, the change in the angle between the line joining any two distant implants in the body of the maxilla and any two implants in the basi-sphenoid bone was assessed (Figure 28, angle d). However, the closer the implants in each bone, the greater the error of the measured angle. Hence, in addition the change in the angle joining one implant in the basi-occipital bone to one in the basi-sphenoid bone and the line joining two maxillary implants (Figure 28, angle e) was also measured. Therefore, changes in angles a, d and e were all used to assess rotation of the maxillary bone with respect to the cranial base.

Similarly, to assess alteration in the nature of rotation of the anterior cranial base with respect to the posterior cranial base, the changes in several angles formed by either the roof of the orbit (frontal bone) or the frontal bone implant (anterior mid-line) and posterior cranial base landmarks were assessed (Figure 29, angles f, g, h and i).

Rotation of the zygomatic bone relative to the cranial base was calculated by measuring changes in the angle formed by the line joining two implants in the zygomatic bone and the basi-sphenoid "transfer-line"

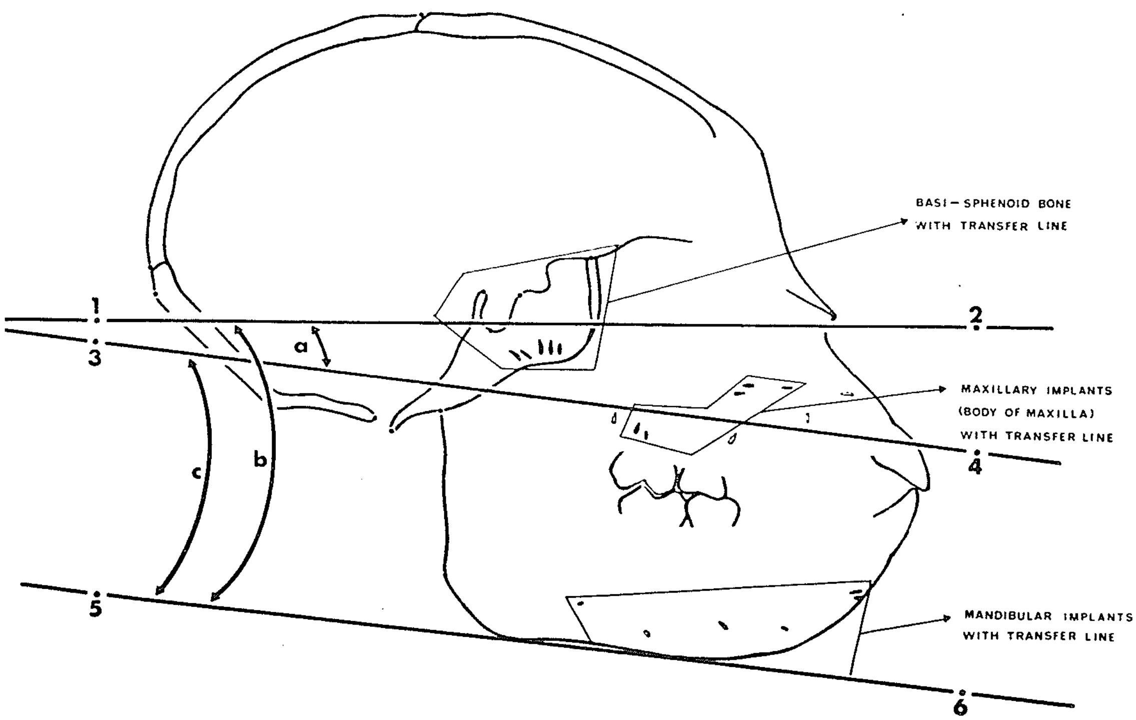


Figure 26. Angular measurements used to assess the relationship of the maxilla to the sphenoid bone (angle a), the mandible to the sphenoid bone (angle b) and the maxilla to the mandible (angle c). The increments of change in each angle between stages were calculated by subtraction.

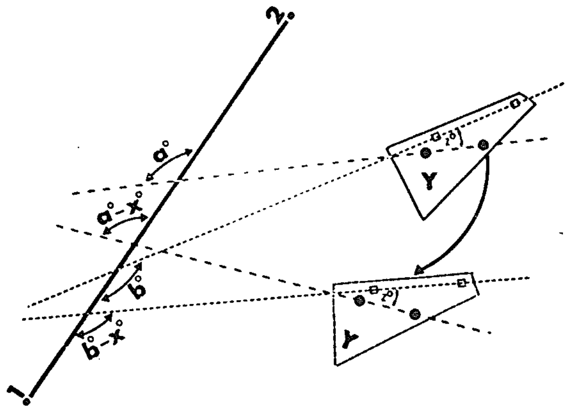


Figure 27. Diagramatic illustration demonstrating that the line joining any two implants in one bone may be chosen to describe the angular relationship of that bone. The increment of change in the angular relationship of the line joining any two implants in that bone, with respect to a reference line, describes the rotation of that bone relative to the reference line. In the above diagram, the body "Y" translated downwards and backwards while rotating "clockwise" x° with respect to line 1-2.

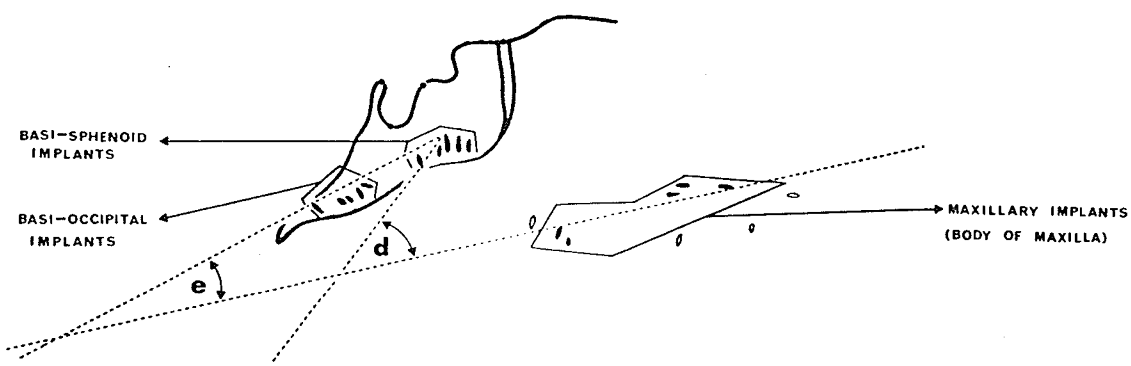


Figure 28. Angular measurements used to assess the relationship of the maxilla to the sphenoid bone (angle d) and to the posterior cranial base (angle e). The increments of change in each angle between stages were calculated by subtraction.

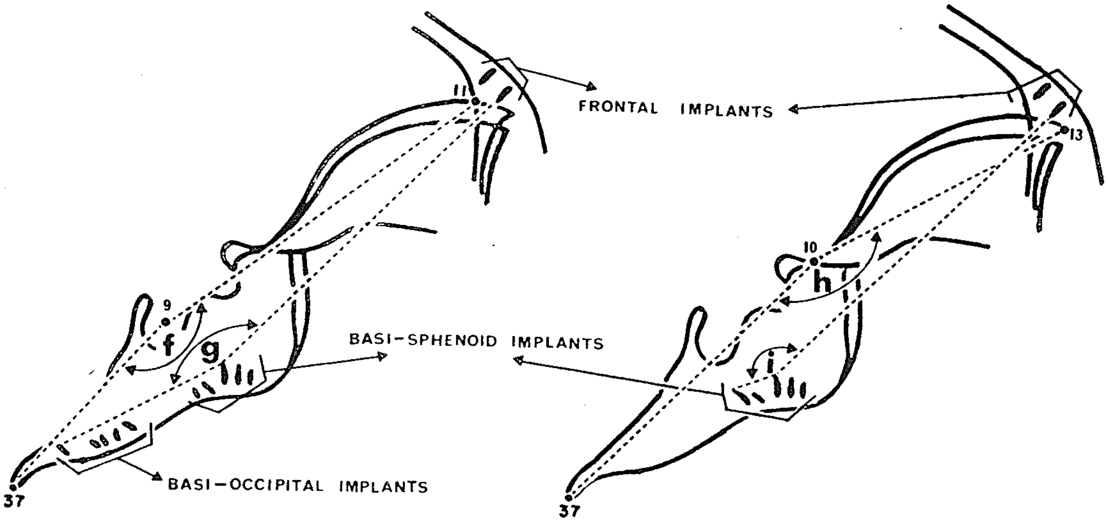


Figure 29. Angular measurements used to assess the spatial relationship of frontal bone to the posterior cranial base. The increments of change in each angle between stages were calculated by subtraction.

1-2 (Figure 30, angle j). Differential rotation between the zygomatic and maxillary facial bones was similarly calculated by measuring the change in the angle formed by the line joining two implants in the zygomatic bone and the "maxillary transfer-line" 3-4 (Figure 31, angle k).

Tipping and rotation of the maxillary teeth with respect to the body of the maxilla was assessed by measuring changes in the angles between the long axes of the teeth and the "maxillary transfer-line" 3-4 (Figure 32, angles l, m, n, o and p). Similarly, rotation of the maxillary incisor relative to the basi-sphenoid bone was assessed by changes in the angle formed by the long axis of the incisor and the "transfer-line" 1-2 (Figure 33, angle q).

Statistical Methods

Due to the availability of only two or three animals within each of the study groups, data for each animal was analyzed and reported separately. The small sample size per group precluded the use of statistical means and application of statistical tests and hence did not allow for the interpretation of the changes in each group as representative of the response of all monkeys in general to the force system used in each group. The analytical phase of this study was aimed at accurately quantitating the specific skeletal changes which accompanied the experimental procedures. It was felt that accurate documentation of the skeletal changes in the individual animals would increase the limited information available concerning the extent to which the craniofacial structures are amenable to physical manipulation. If the changes in the experimental animals differed markedly from the types of changes in the control animals, these changes were considered associated with the experimental

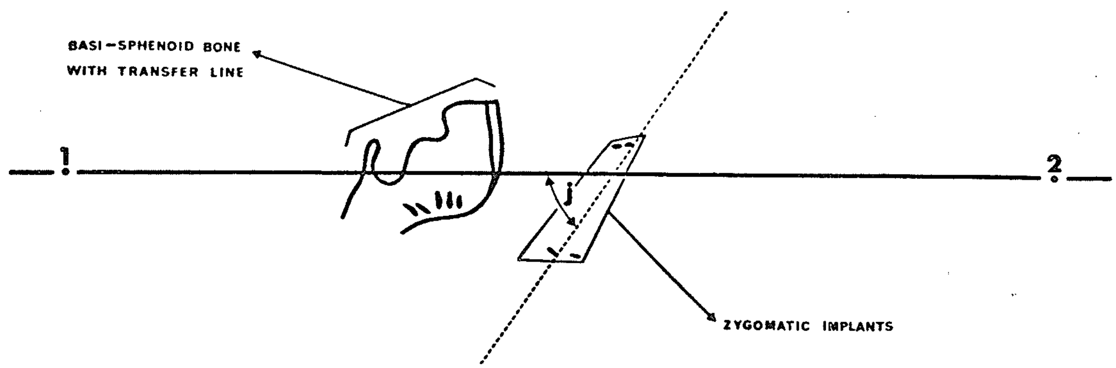


Figure 30. Angular measurement (angle j) used to assess the relationship of the zygomatic bone to the sphenoid bone. The increments of change in this angle between stages were calculated by subtraction.

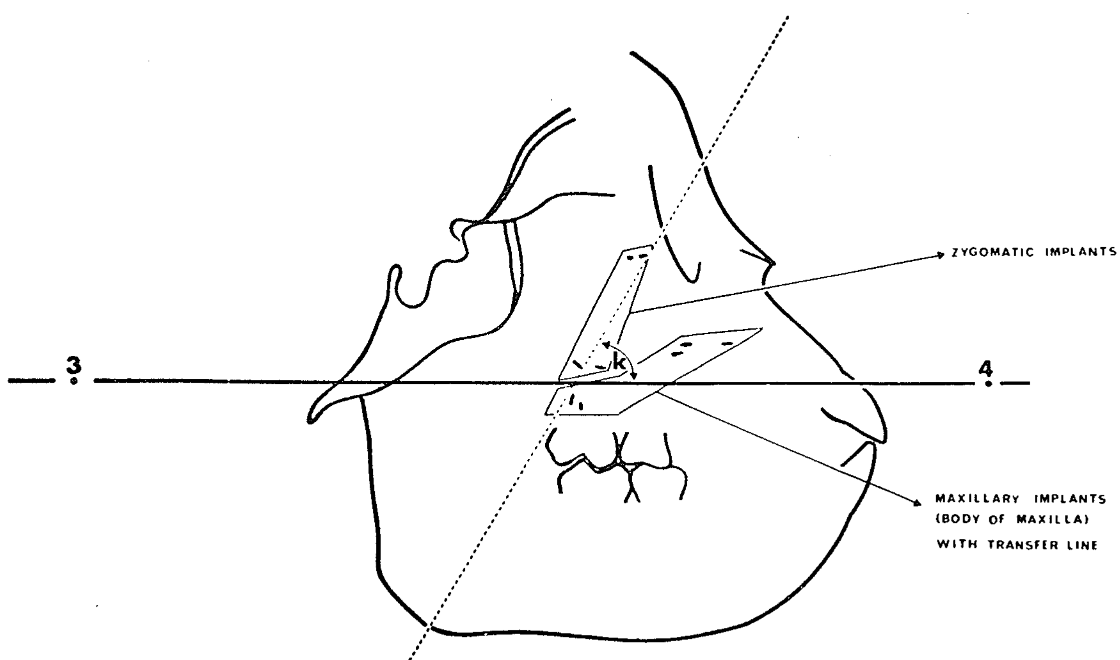


Figure 31. Angular measurement (angle k) used to assess the relationship of the zygomatic bone to the maxilla. The increments of change in this angle between stages were calculated by subtraction.

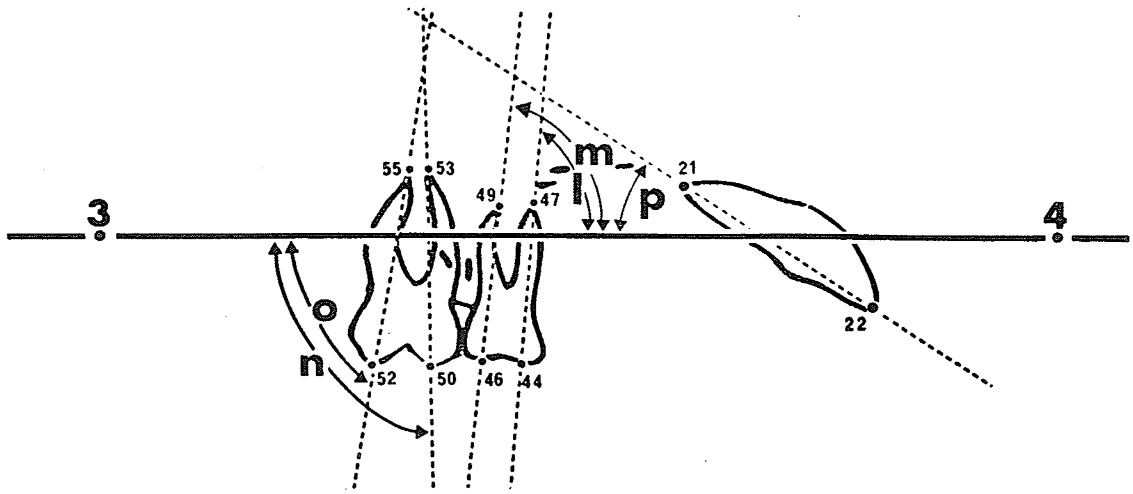


Figure 32. Angular measurements used to assess the angular relationships of the maxillary teeth to the body of the maxilla (maxillary implants). Angle l and angle m refer to the maxillary first permanent molar, angle n and angle o refer to the maxillary second permanent molar, and angle p refers to the maxillary central incisor. The increments of change of each angle between stages were calculated by subtraction.

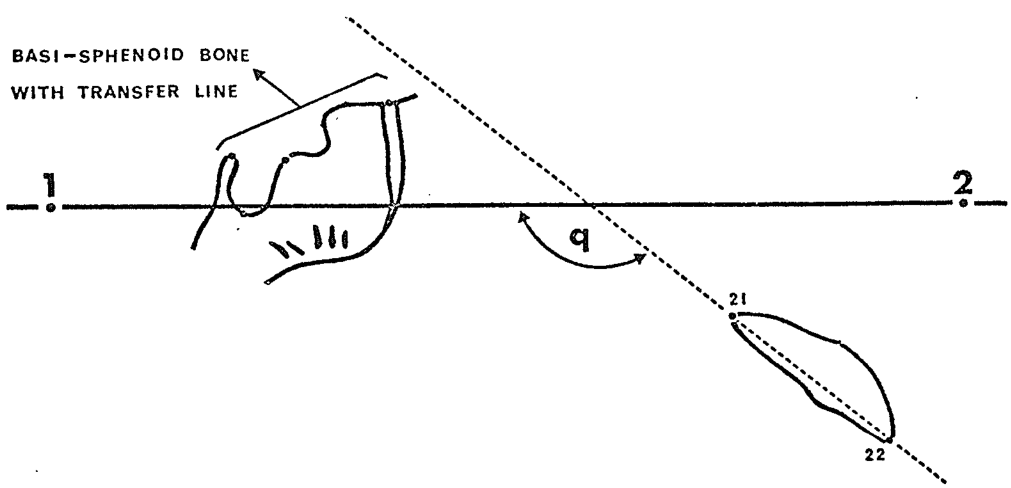


Figure 33. Angular measurement (angle q) used to assess the angular relationship of the maxillary central incisor to the sphenoid bone. The increments of change in this angle between stages was calculated by subtraction.

procedures rather than with variation of normal growth as previous studies have reported that the variability in direction and amount of normal growth in the Macaca monkey is quite low (Elgoyhen _et al_, 1972b; McNamara, 1972).

Duplicates of Figures 19, 20, 21, 22, 23, 24, 25, 26, 28, 29, 30, 31, 32 and 33.

This set of illustrations may be removed to assist interpretation during the reading of the Results.

COORDINATE ANALYSES

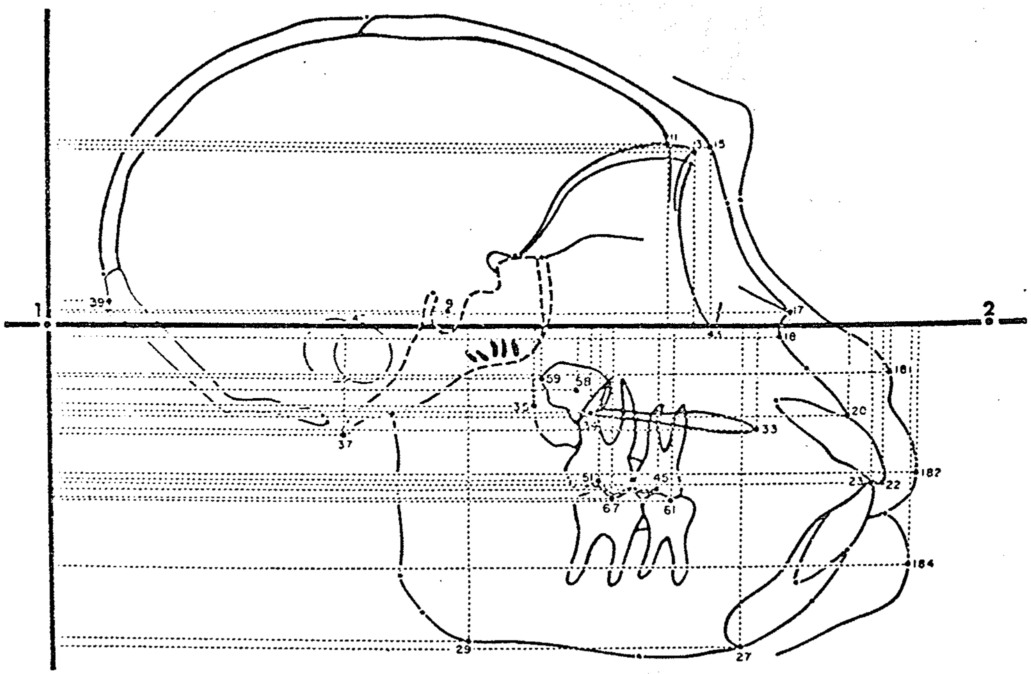
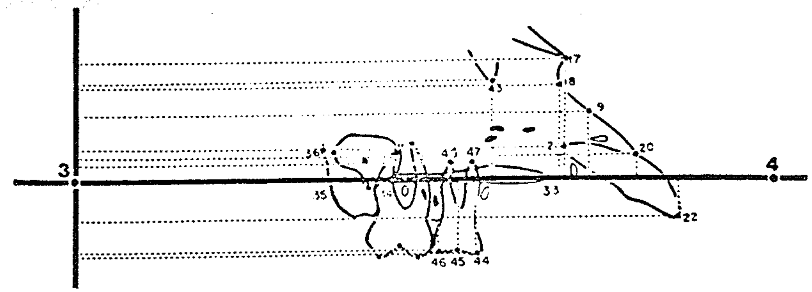


Figure 19. Horizontal and vertical distances measured in the coordinate analysis of the overall superimposition on the basi-sphenoid bone. Point 1 and Point 2 were transferred from the initial cephalogram to each cephalogram of the series using a "template-tracing" registered on the implants in the basi-sphenoid bone and the outline of the basi-sphenoid bone. In addition to the distances illustrated above, horizontal and vertical distances of representative implants in each bone were measured relative to the axes through Point 1 and Point 2. The increments of change in each distance between stages were calculated by subtraction.



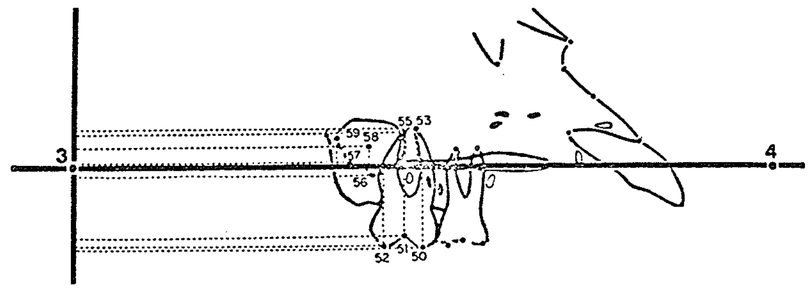


Figure 20 (top) and 21 (bottom). Horizontal and vertical distances measured in the coordinate analysis of the maxillary superimposition on the implants in the body of the maxilla. Point 3 and Point 4 were transferred from the initial cephalogram to each cephalogram of the series using a "template-tracing" registered on the implants in the body of the maxilla. The increments of change in each distance between stages were calculated by subtraction.

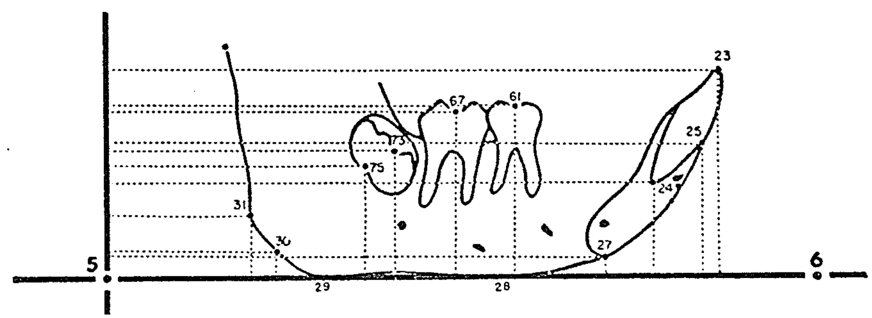


Figure 22. Horizontal and vertical distances measured in the coordinate analysis of the mandibular superimposition on the mandibular implants. Point 5 and Point 6 were transferred from the initial cephalogram to each cephalogram of the series using a "template-tracing" registered on the implants in the mandible. The increments of change in each distance between stages were calculated by subtraction.

LINEAR ANALYSIS

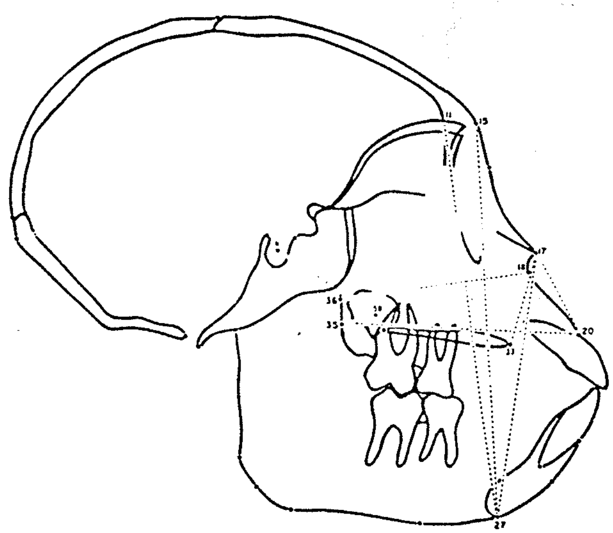


Figure 23

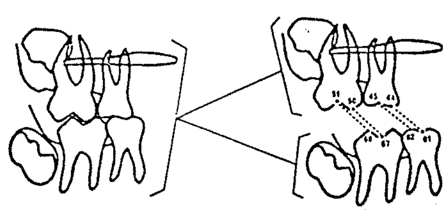


Figure 24

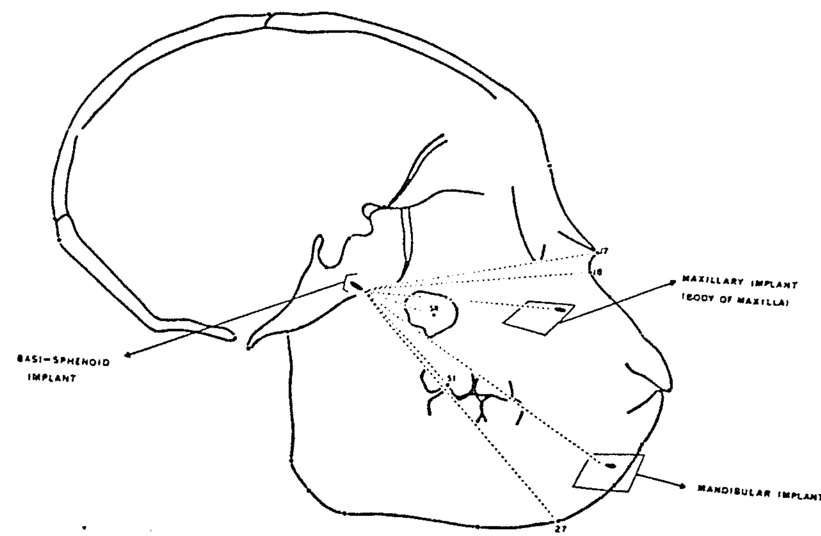


Figure 25.

ANGULAR ANALYSIS

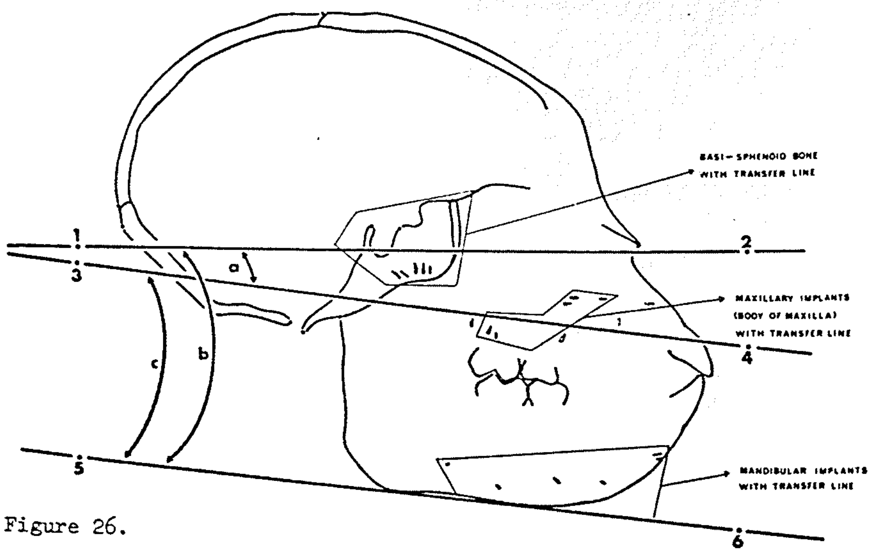


Figure 26.

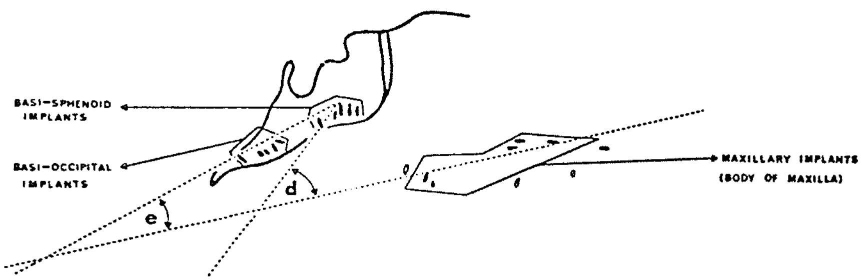


Figure 28.

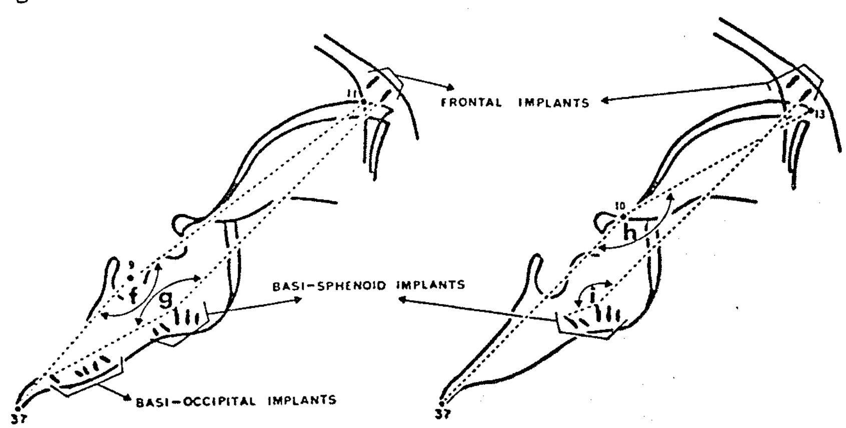


Figure 29.

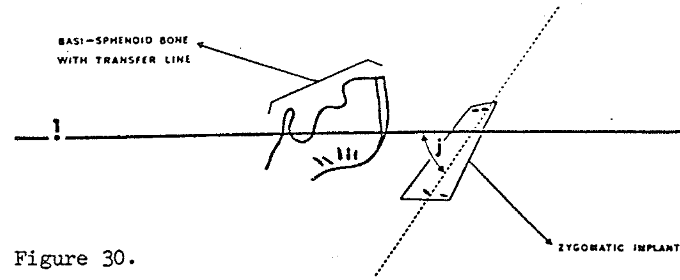


Figure 30.

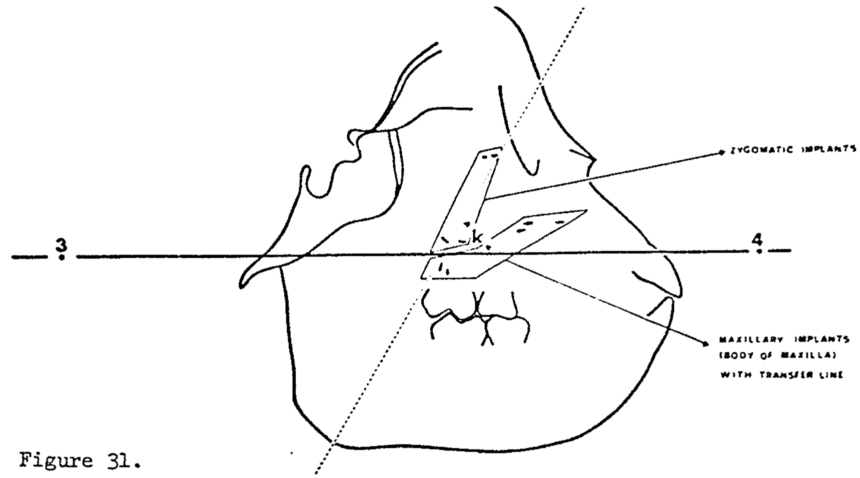


Figure 31.

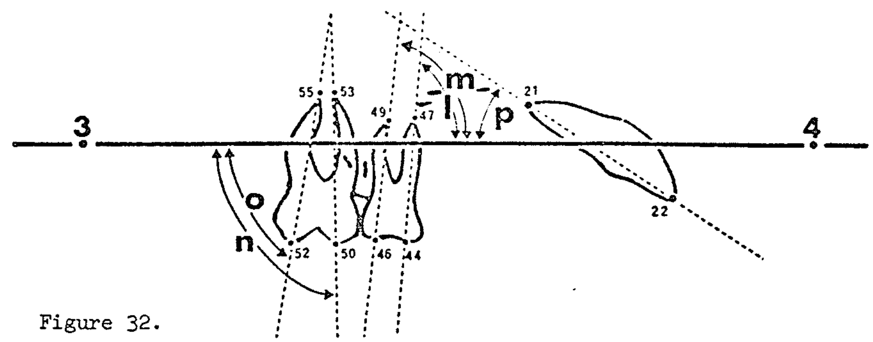


Figure 32.

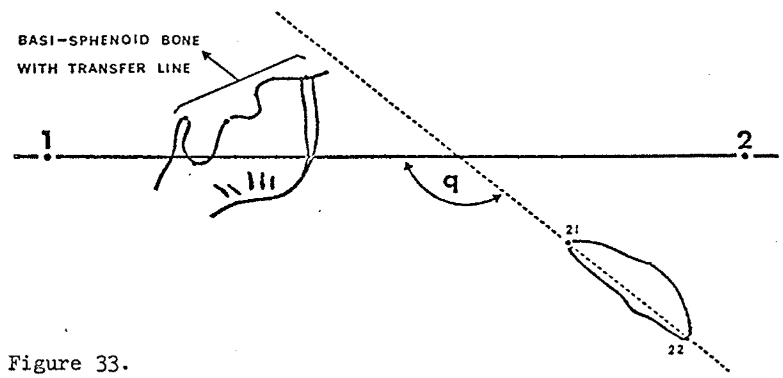


Figure 33.

CHAPTER IV

RESULTS

I. GENERAL OBSERVATIONS

The majority of the animals tolerated the experimental procedures satisfactorily. The restrainer-feeder appliance allowed for the application of very heavy extraoral forces while giving the monkeys freedom of movement and yet affording complete protection to the orthopedic appliances. The monkeys adapted remarkably well to their new environment and quickly learned the new feeding technique. The changes in weight of each animal during the experimental periods are illustrated in Figure 34.

Throughout the course of the experiment all animals undergoing headgear application occasionally developed ulcers on the back of their neck from the headgear appliance. These ulcers usually occurred at the edge of the neckstrap where movement of the neck rubbed the skin against the neckstrap material. In all instances, the headgear was removed, the lesion cleansed, antiseptic applied, the lesion dressed and soft padding relief placed over the area of the lesion and the headgear immediately replaced. Intramuscular injections of the antibiotic Fortimycin* were administered daily until the lesion healed. These lesions routinely healed in a few days even though the extraoral traction was maintained in place over the padding. Each animal developed one or two lesions but these did not pose a serious problem with the exception of Monkey No. 7, the last to receive extraoral traction.

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*Ayerst Laboratories, Montreal, Quebec

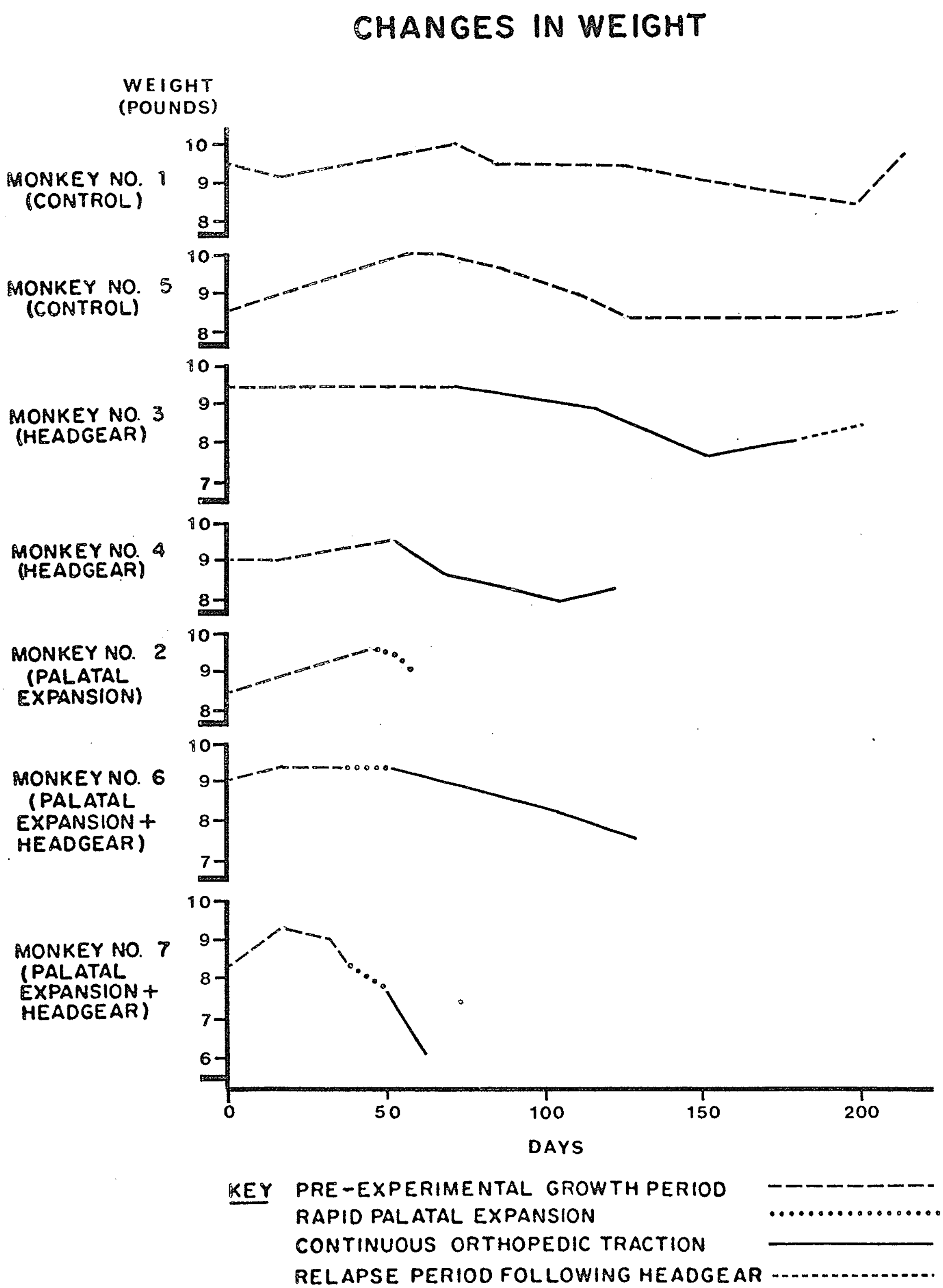


Figure 34. Changes in weight of the control and experimental animals during the various phases of the study.

Monkey No. 7 of the combination group developed an ulcer on the back of her neck on the 6th day of extraoral traction following palatal expansion. The lesion was medicated, routine soft padding relief placed, antibiotics administered, and the headgear maintained in place. The animal lost her appetite and became dehydrated. On the 12th day of headgear the animal was lightly sedated for dressing of the lesion and antibiotic administration, but did not recover from the sedation and went into a coma. It was felt, however, that headgear administration had been placed long enough in this animal to determine whether or not any immediate posterior movement of the maxilla had occurred.

The only other fatality was Monkey No. 2 who was originally chosen to be a member of the combination group. After palatal expansion, however, the headgear appliance was adapted but the animal failed to recover from anaesthesia. Hence, Monkey No. 2 was used for the palatal expansion group only.

Only two intraoral appliances fell off during the experiment. The first occurrence was on the 72nd day of distal traction in Monkey No. 4 of the headgear group who was the first animal to undergo distal force application. At this time, such dramatic clinical changes had been attained that it was elected to take final records and sacrifice the animal. The second appliance to fall out was in Monkey No. 3 of the headgear group on the 62nd day of traction and was recemented the same day. On the 72nd day in this animal records were taken and it was elected to continue the extraoral traction. By the 103rd day, the appliance was quite loose and therefore headgear application was discontinued in Monkey No. 3. The only other incident of an appliance becoming loose occurred in Monkey No. 6 of the combination group due to exfoliation of deciduous anchor teeth. The appliance was removed on the 72nd day and the experiment terminated.

Clinical Observations

Control Group

During the growth period the two control animals passed through the late mixed dentition stage and at the time of sacrifice presented full permanent dentitions. Throughout the study, both animals exhibited normal occlusal relations (Figure 35).

Subjective clinical appraisal of the facial appearance suggested a slight increase in the prominence of the muzzle in both control animals. Profile and frontal photographs of Monkey No. 1 are shown in Figures 36 and 37 and illustrate the general appearance characteristic of all Macaca Mulatta monkeys.

Headgear Group

Monkey No. 4 was the first animal to receive orthopedic distal traction. After 38 days of continuous traction, it was observed clinically that the maxillary molars occluded one full cusp distally with respect to the mandibular molars and hence a full Class III molar relationship was created. This was accompanied by an anterior crossbite. This change was progressive in that by the 72nd day in this animal the maxillary first molar occluded with the mandibular second molar and considerable anterior crossbite was present. Noticeable changes in the facial profile were evident.

Monkey No. 3 was the second animal to receive orthopedic distal

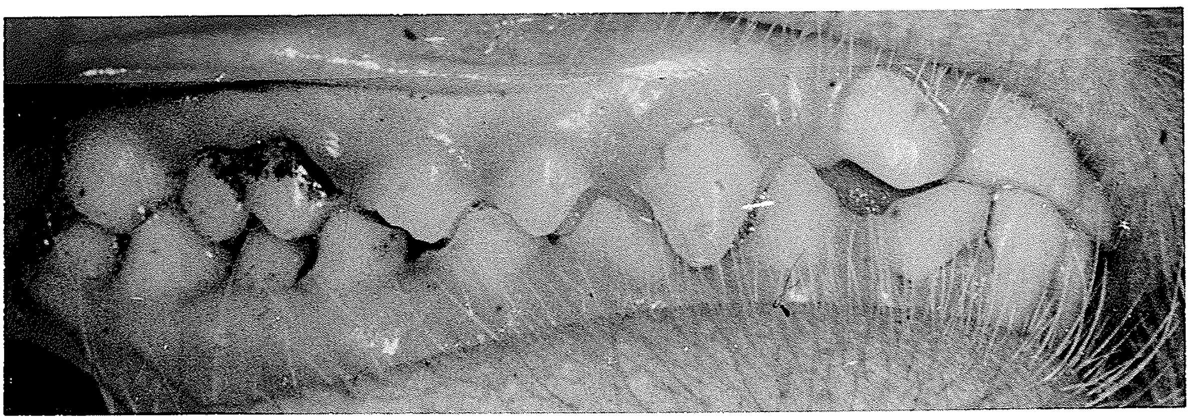


Figure 35. Intraoral photograph of control Monkey No. 1 at the termination of the study period demonstrating normal occlusal relations in the permanent dentition. All monkeys used in this study presented normal occlusions in the late mixed dentition stage at the beginning of the various study periods.

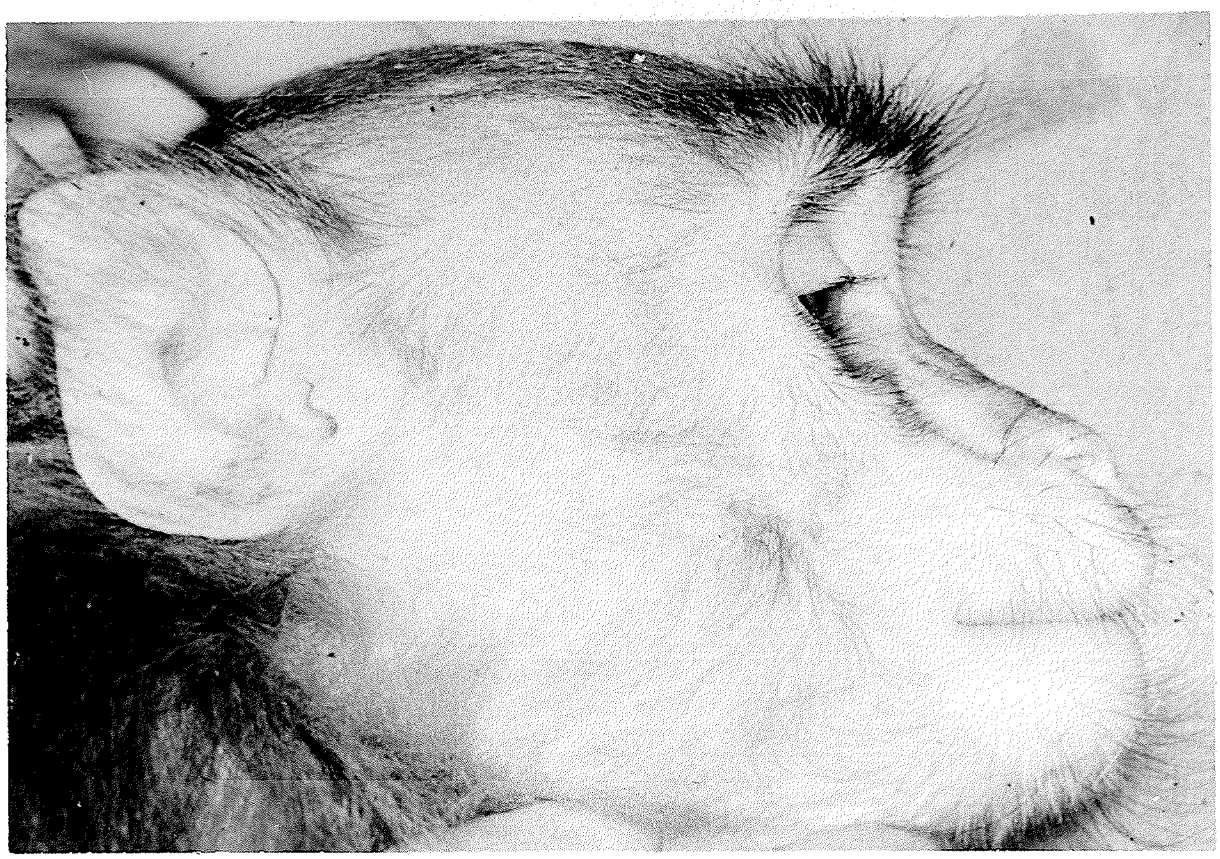


Figure 36. Profile photograph of control Monkey No. 1 demonstrating the facial appearance characteristic of the Macaca mulatta rhesus monkey used in this study.

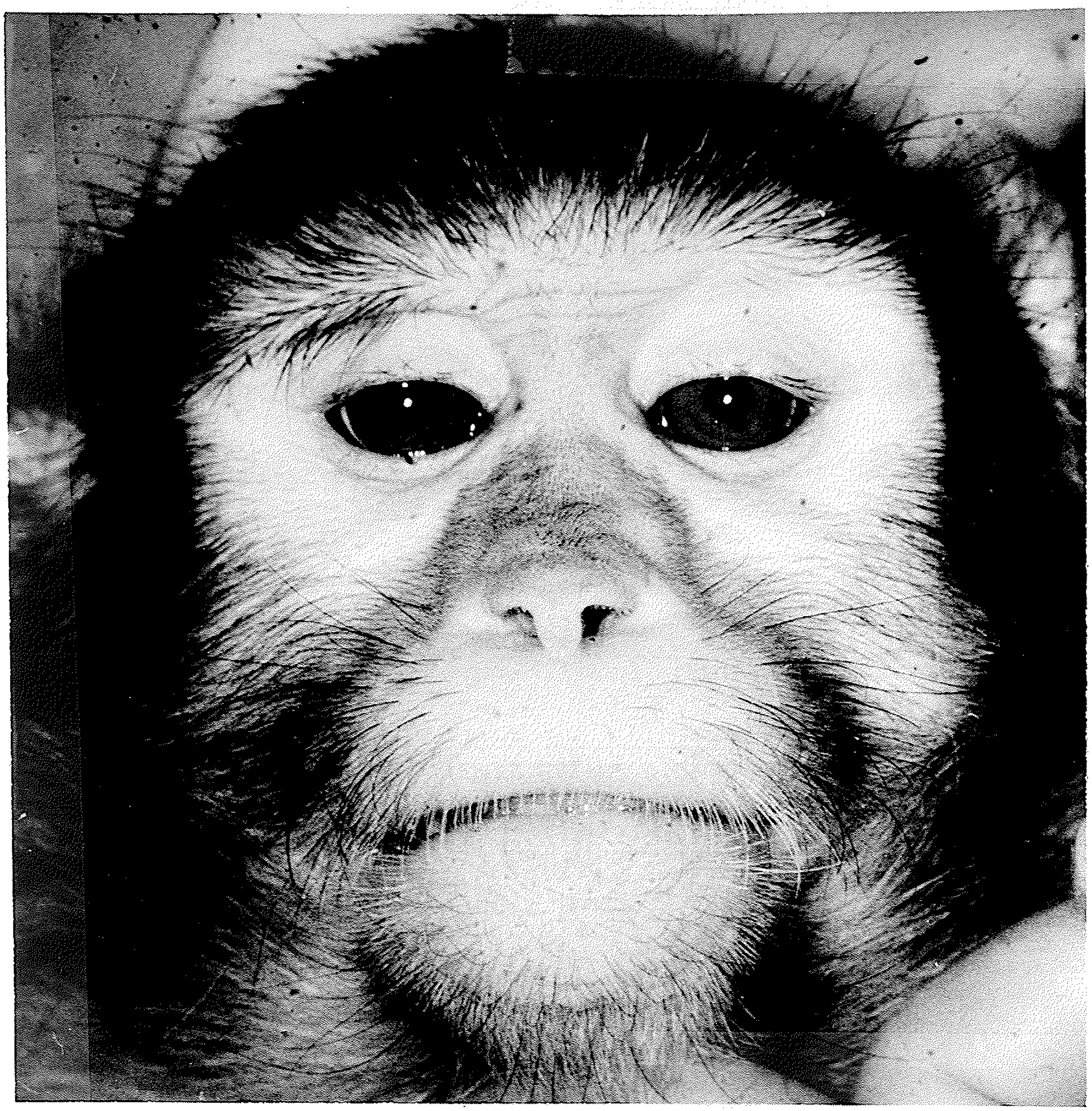


Figure 37. Frontal photograph of control Monkey No. 1 demonstrating the facial appearance characteristic of the Macaca mulatta rhesus monkey used in this study.

traction. The normal occlusal relations of Monkey No. 3 at the beginning of the experiment are shown in Figure 38. By the 38th day, Monkey No. 3 presented a Class III molar relationship and an anterior crossbite. This change was progressive in that by the 72nd day the maxillary first molar occluded distally to the mandibular second molar and noticeable profile changes were evident. By the 103rd day, an extreme anterior crossbite was present (Figure 39). At this time, the intraoral appliance created occlusal interferences and hence exact occlusal relations were difficult to assess clinically. Nonetheless, the mesio-buccal cusp of the maxillary second deciduous molar occluded distal to the buccal groove of mandibular second permanent molar (Class III molar relationship by almost five cusps). The maxillary second permanent molars which were in occlusion pre-experimentally in Monkey No. 3 were completely impacted in the soft tissue while the maxillary first permanent molars, which harnessed the appliance, were partially impacted in the soft tissue. Figures 40 and 41 show the occlusion of Monkey No. 3 nine days after the termination of distal traction at which time the intraoral appliance was removed. As seen in Figure 41 the mesio-buccal cusp of the maxillary first deciduous molar occluded slightly distal to the buccal groove of the mandibular first permanent molar while the mesio-buccal cusp of the maxillary second deciduous molar occluded slightly distal to the buccal groove of the mandibular second permanent molar.

The facial appearance of Monkey No. 3 was dramatically changed with marked flattening of the facial profile (Figures 42 and 43). Figures 44 and 45 demonstrate the comparative flattening of the muzzle and reduction of the facial prominence which is normally presented by the Macaca monkey. The frontal view of Monkey No. 3 after the termination of distal traction is shown in Figure 46.

Figure 38. Intraoral photograph of the occlusion of Monkey No. 3 of the headgear group in the late mixed dentition stage prior to the application of heavy extraoral traction. A normal Class I molar relationship and normal overbite and overjet were present. The maxillary permanent cuspids were in the process of erupting into a normal relationship while the second permanent molars (partially seen at far left) were fully erupted and in normal occlusion.

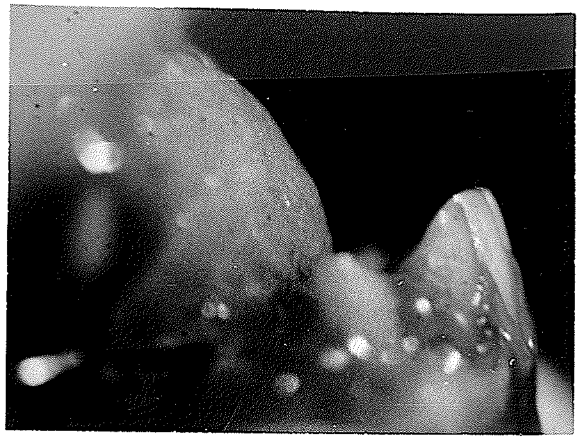


Figure 39. Intraoral photograph of the severe anterior crossbite created in Monkey No. 3 of the headgear group after 103 days of heavy extraoral traction. The acrylic of the intraoral appliance covering the maxillary incisors and premaxillary alveolar bone is shown.

Figure 40. Intraoral photograph of Monkey No. 3 of the headgear group at the time of intraoral appliance removal 9 days after the termination of heavy extraoral traction. A severe anterior crossbite and a deep overbite were present.

Figure 41. Intraoral photograph of Monkey No. 3 of the headgear group at the time of intraoral appliance removal 9 days after the termination of heavy extraoral traction. A marked mesiocclusal malocclusion was created. The mesio-buccal cusp of the maxillary first deciduous molar is seen occluding slightly distal to the buccal groove of the mandibular first permanent molar. The mesiobuccal cusp of the maxillary second deciduous molar (partially visible at far left) is seen occluding slightly distal to the buccal groove of the mandibular second permanent molar. The maxillary permanent cuspid was partially erupted and is seen occluding distal to the mandibular premolars which were beginning to erupt. Compare the interarch molar and cuspid relationships with those in Figure 38.

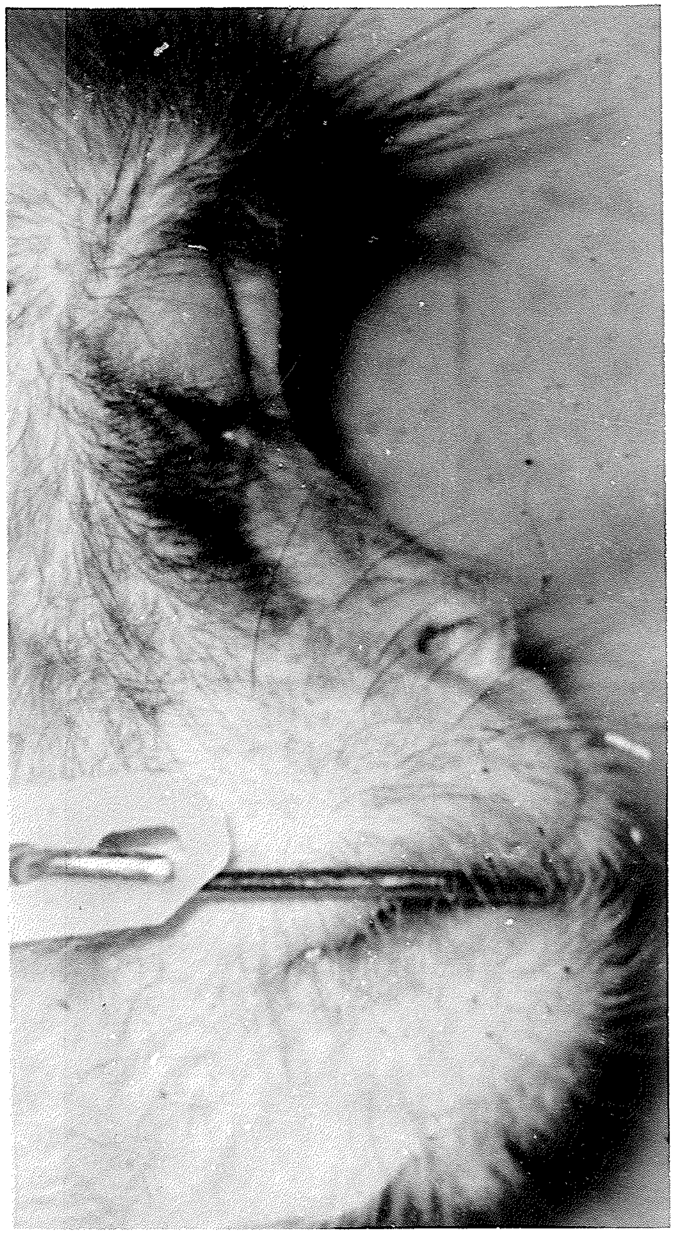


Figure 42. Profile photograph of Monkey No. 3 of the headgear group demonstrating facial appearance shortly after application of heavy extraoral traction at the beginning of the experimental period.

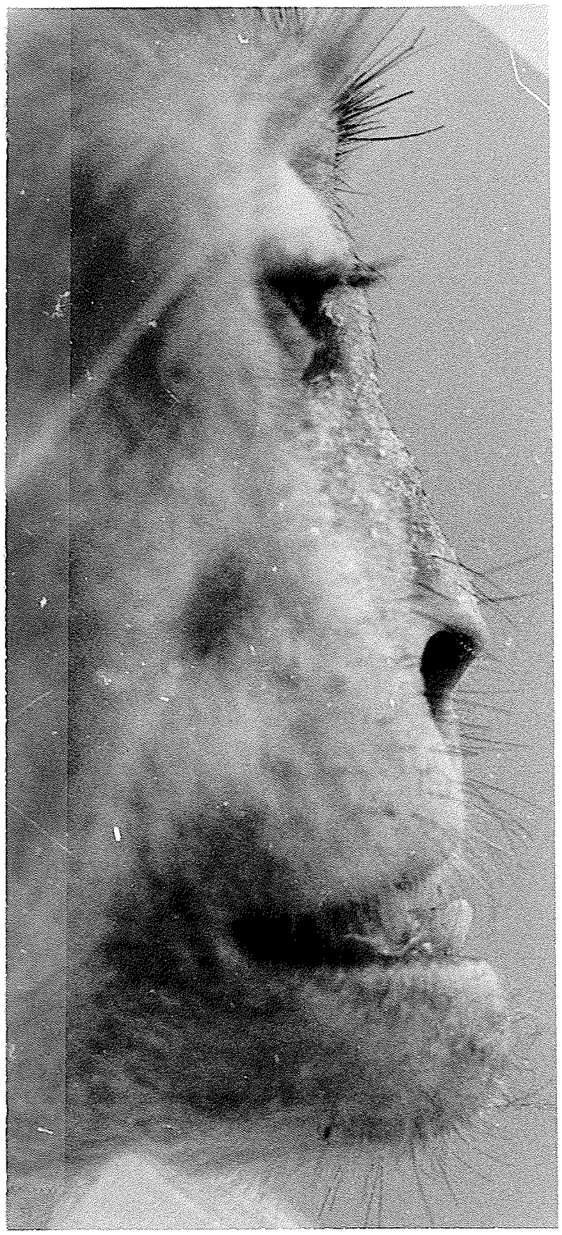


Figure 43. Profile photograph of Monkey No. 3 of the headgear group after 103 days of heavy extraoral traction and after the removal of all appliances. A marked change in facial appearance is evident compared with that in Figure 42.

Figure 44. Photograph of control Monkey No. 1 as viewed looking down on the face from above. The prominence of the muzzle characteristic of the Macaca monkey is evident.

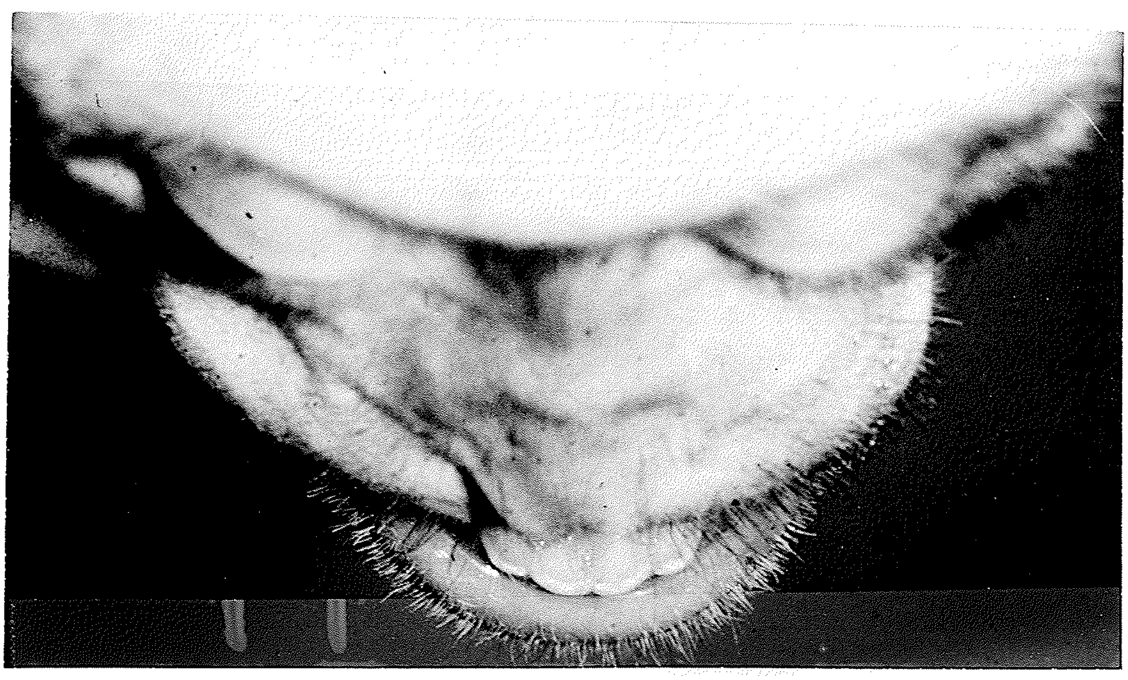


Figure 45. Photograph of Monkey No. 3 of the headgear group as viewed looking down on the face from above after 103 days of heavy extra-oral traction. A marked flattening and reduction of the prominence of the upper face is evident.

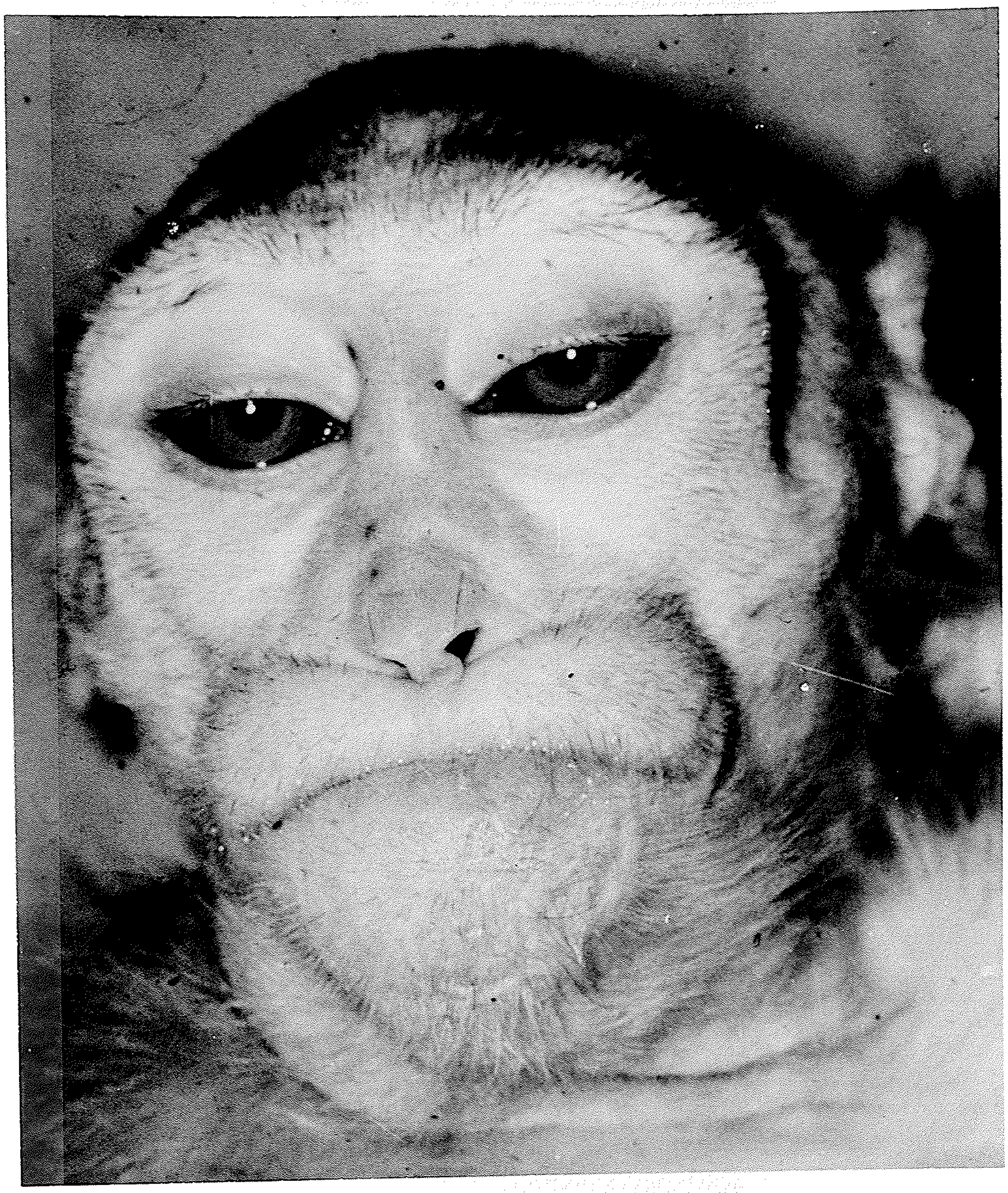


Figure 46. Frontal photograph of Monkey No. 3 of the headgear group demonstrating facial appearance after 103 days of extraoral traction.

Following the termination of extraoral traction, Monkey No. 3 appeared to demonstrate normal neuromuscular reflexes and did not appear to demonstrate evidence of neurologic damage.

Palatal Expansion Group

In the palatal expansion group, activation of the appliance was continued daily until the maxillary molars were in buccal crossbite with the mandibular molars. Figure No. 47 shows the occlusion of Monkey No. 6 on the 10th day of palatal expansion. No noticeable changes in the facial appearance were evident clinically in any of the monkeys following palatal expansion.

Combination Group

Following 12 days of palatal expansion, 28 ounces per side of extraoral traction were applied to the palatal appliances in Monkeys No. 6 and No. 7 and the palatal appliances were continued to be activated 2 turns per day for an additional 3 days. The animals were tranquilized during these 3 days and did not demonstrate overactivity due to the sudden application of these heavy forces, but rather appeared to tolerate the initial heavy force application quite well.

On the 12th day of headgear, Monkey No. 7 died. No change in occlusal pattern antero-posteriorly was evident clinically between the post-expansion and post-expansion-post-headgear periods. Hence clinically there appeared to be no evidence to support the thesis that palatal expansion enhanced the susceptibility of the maxilla to an immediate forced distal displacement.

In Monkey No. 6 on the 38th day of continuous headgear the incisors which originally presented 1.5 mm of overbite and overjet were

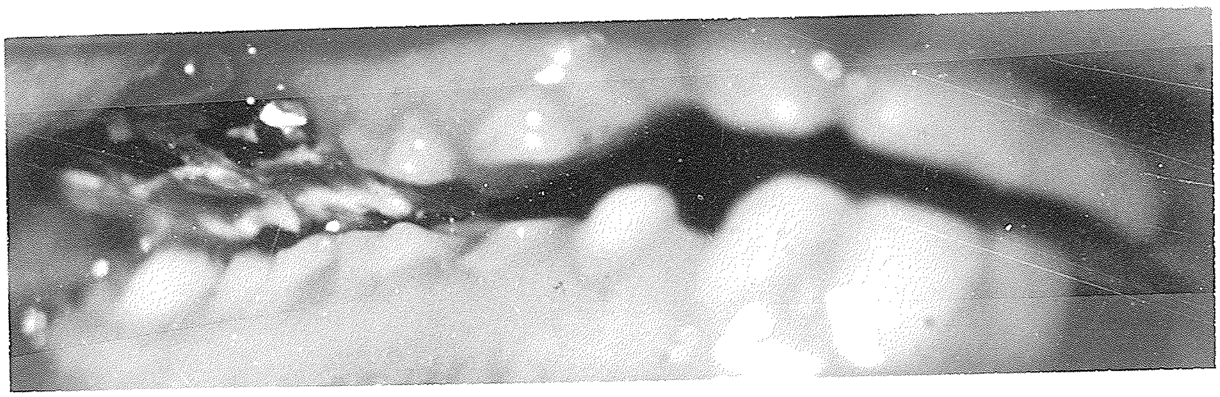


Figure 47. Intraoral photograph of the occlusion of Monkey No. 6 following 10 days of rapid maxillary expansion. The maxillary buccal segments have been expanded toward buccal crossbite with the mandibular buccal segments.

end-to-end whereas the maxillary first molar occluded with the mandibular second molar (Class III molar relationship). By the 72nd day the combination appliance had tipped considerably downwards at the front and upwards at the back and was deeply embedded in the soft palate with consequent severe laceration of the soft tissues. The maxillary second deciduous molar which served as an anchor tooth had exfoliated and the appliance was quite loose. The maxillary first permanent molar occluded distal to the mandibular second molar while the maxillary second molar which harnessed the appliance was completely impacted in the soft tissue. The incisors were in anterior crossbite (Figure 48), indicating that skeletal changes had occurred as the incisors were not banded in this animal. However, the anterior crossbite was not nearly as severe as those which were created in the animals in the headgear group after comparable periods of extraoral traction. The arch length between the maxillary first molar and the incisor was increased in Monkey No. 6 (Figure 48).

The facial appearance of Monkey No. 6 was only slightly altered. It appeared clinically that much less facial change had occurred in this animal compared to the animals in the headgear group after similar periods of traction.

Figure 48. Intraoral photograph of the occlusion of Monkey No. 6 of the combination group following 72 days of continuous heavy extraoral traction. A mesiocclusal malocclusion and anterior crossbite were created. The maxillary first permanent molar (partially visible at far left) is shown occluding distal to the mandibular second permanent molar.

II. CEPHALOMETRIC ANALYSIS

Error of Cephalometric Method

The error of the cephalometric method for each of the linear, horizontal, vertical and angular variables illustrated in Figure 16 was calculated using a total of 78 repeated cephalograms of 3 animals. As these radiographs were all taken at one session for each animal, negligible growth occurred between successive exposures, and hence the variability between repeated measurements for each variable within each animal constituted an assessment of all the inherent errors associated with that variable. These inherent errors included errors which may have resulted from the following: 1) animal re-orientation in the cephalostat; 2) machine adjustments; 3) processing of film and 4) locating and plotting (digitization) of landmarks.

To assess this overall error represented by the variability associated with each variable, the standard deviations for each variable were pooled over the 3 animals and the maximum error associated with 99% of the measurements was calculated according to the method described by Chebib and Burdick (1973). These are listed in Table I in the appendix.

It is recognized that the error associated with each variable is unique; however, for the sake of simplicity in this dissertation, representative errors for the various types of measurements used in the actual study were calculated by further pooling the standard deviations of comparable variables. The maximum errors associated with 99% of each type of measurement were found to be as follows:

	Maximum Error Associated With 99% of Measurements
Linear Distances	0.419 mm
Horizontal Distances	0.500 mm
Vertical Distances	0.599 mm
Angles (long arms)	0.817°
Angles (medium arms)	1.711°
Angles (short arms)	3.799°

It should be realized that these are the extreme errors, indicating the amount of error that may be associated with the worst of 99% of single measurements. The average errors committed, however, were much less than the errors listed above and were calculated using the following formula described by Chebib and Burdick (1973):

$$\bar{e} = \pm \sqrt{2/\pi}\ \dot{s}$$

$$= 0.7979\ s$$

where $\bar{e}$ is the mean error and s is the pooled standard deviation of the variable.

The mean errors were found to be as follows:

	Mean Error
Linear Distances	0.129 mm
Horizontal Distances	0.153 mm
Vertical Distances	0.184 mm
Angles (long arms)	0.251°
Angles (medium arms)	0.522°
Angles (short arms)	1.166°

From the above findings, it may be concluded that the method of head reorientation in the cephalostat allowed for the accurate reproduction of the above variables on the radiographs. Hence, these findings support the reliability of the cephalometric method used in this study.

The above findings also suggested that the accuracy of the angular measurements was to a great extent a function of the length of the arms forming each angle. The closer the points forming an angle, the greater was the measurement error. For example, such angles as those formed by one arm joining two implants in the basi-sphenoid bone, which were only 3 to 5 mm apart, inherently incorporated a large error even though the coordinates of these implant sites were recorded to the same accuracy as other implant sites. However, other angles formed by landmarks whose distance apart was considerably greater demonstrated less error.

The various types of angular errors estimated from this study of repeated measurements may be applied to the angles chosen for the actual study depending on the length of the arms of these latter angles. The applicable errors are therefore as follows:

Angle	Type	Maximum Error Associated with 99% of Measurements (in degrees)	Mean Errors (in degrees)
a,b,c,	long arm	0.817	0.251
e,g,	medium arm	1.711	0.522
d,i,j,k	short arm	3.799	1.166

Due to the greater human error involved in locating and plotting the dental landmarks defining the long axes of the teeth compared to the more clearly demarcated implant sites, the errors associated with the angles describing rotation of the teeth are possibly greater than those categorized above. However, as these angular measurements of the teeth are not considered critical and their importance is of a low priority in this study, a generous error comparable to the short arm angle error was applied to these variables during the interpretation of the results.

Quantitative Analyses

Intra-Bone Implant Stability (Error Test)

This additional method for error determination was used to assess both implant stability and errors in linear measurements. This determination was based on the premise that all implants in one bone maintained the same spatial relationship to each other throughout the experiment since no interstitial growth occurs in bone. Hence, the variability of the inter-implant linear distances within each bone between stages was used as a measure of the error of the cephalometric method. Since the serial cephalograms of each animal measured in the actual study were used for this error determination, this assessment included all errors associated with linear measurements for each animal. However, due to the large number of inter-implant distances measured for each stage of each animal, only the range of error will be reported. The standard deviation of the linear distances between implants was used as an estimate of the variability of measurement. A standard deviation between 0.05 to 0.15 mm and hence a maximum error of 0.13 to 0.39 mm was associated with 99% of the measurements for the majority of the variables. Any inter-site distance with a standard deviation greater than 0.25 mm was interpreted as indicative of implant instability and the implant or implants in question were rejected from further use in this study. Few implants presented evidence of this type instability.

Control Group

Coordinate Analyses

Overall Superimposition on Basi-Sphenoid Bone

Both control animals demonstrated very similar patterns of facial growth. The overall superimposition on the basi-sphenoid implants demonstrated that the facial bones in both animals translated forward horizontally with minimal vertical displacement. Increments of growth in the horizontal and vertical directions, relative to the initial Frankfort Horizontal, between stages for the various anatomical landmarks and implants are tabulated in Table II in the Appendix. The data and tracings (Figures 49 and 53) of the overall superimposition for the 103 day interval for the respective control animals showed that the horizontal forward translation of the mandible (mandibular implants) was approximately twice as great as the forward displacement of the maxilla (maxillary implants). However, the forward movement of the maxillary teeth relative to the cranial base was approximately equal to the amount of forward translation of the mandibular teeth and, hence, the Class I molar relationships and normal occlusal relations were maintained.

Forward and downward displacement of the implants in the posterior region of the mandible, relative to the implants in the basi-sphenoid bone, in conjunction with forward but minimal vertical displacement of the implants in the anterior region of the mandible resulted in a rotation of the reference line 5-6 and indicated a slight "counter-clockwise" (as viewed from the right side of the skull) rotation of the body of the mandible. Although small, this rotation was slightly greater in Monkey No. 1 than Monkey No. 5. Nonetheless, the orientation of the lower border of the mandible was maintained in both animals.

Similarly, slightly greater vertical movement of the posterior compared with the anterior maxillary implants resulted in a consequent slight rotation of the reference line 3-4 and hence indicated that the body of the maxilla rotated slightly in a "counterclockwise" direction. However, the level of the occlusal plane was approximately maintained.

Slight upward movement of the roof of the orbits and increase in the size of the cranium occurred in both animals.

The increments of change during the 103 day interval were small for most landmarks in both animals and thus the rate of growth was relatively slow. In both control animals no detectable change occurred in the 12 day interval used for comparison with the palatal expansion period (Table VII in the Appendix; Figures 52 and 56).

Maxillary Superimposition

The maxillary superimposition for the control animals demonstrated that the maxillary dentition migrated forward horizontally a slight amount relative to the maxillary implants (body of the maxilla) while undergoing minimal vertical eruption. Increments of change of the maxillary dentition and maxillary landmarks are tabulated in Table III in the Appendix and demonstrate the horizontal and vertical changes in relation to the initial palatal plane which occurred due to both dental alveolar growth and maxillary transformation relative to the maxillary implants. As seen in Figures 50 and 54 of the control animals, respectively, the amount of forward tooth migration within the maxilla accounted for only approximately 25% of the forward displacement of the maxillary teeth in the overall superimpositions. Appositional growth was observed on the facial surface of the premaxilla and on the posterior and inferior surface of the tuberosity. The palatal outline maintained its same relationship to the implants in the body of the maxilla throughout the growth period. In Monkey No. 5, slightly greater vertical migration of the maxillary incisor compared with the first molar offset the slight "counterclockwise" rotation of the maxilla seen in the overall superimposition and maintained the level of the occlusal plane.

Mandibular Superimposition

The increments of change of the teeth and mandibular landmarks relative to the mandibular implants are tabulated in Table IV in the Appendix and the tracings for the 103 day intervals for Monkeys No. 1 and No. 5 are shown in Figures 51 and 55, respectively. The mandibular superimposition of the control animals demonstrated minimal forward migration of the mandibular dentition and predominantly vertical movement of the mandibular teeth relative to the mandibular implants. Slight appositional growth was observed along the anterior part of the lower border of the mandible of Monkey No. 1. This localized bone remodelling masked the slight "counterclockwise" rotation of the mandibular corpus and maintained the orientation of the lower border of the mandible in the overall superimposition. Monkey No. 5 demonstrated minimal rotation of the body of the mandible in the overall superimposition and no change of the lower border on the mandibular superimposition.

The disproportionately greater forward growth of the mandible with respect to the maxilla observed in the overall superimposition was compensated for by greater forward migration of the maxillary dentition within the maxilla accompanied by primarily vertical migration of the mandibular dentition within the mandible and thereby the normal occlusal relationships were maintained.

Linear Analysis

The increments of change of the linear measurements made between specific implant and anatomical sites during normal growth are tabulated in Table V in the Appendix. Minimal change in the vertical dimension of the face occurred in the control animals during the growth period. Absolute linear measurements from a basi-sphenoid implant to maxillary landmarks, a maxillary implant, and the maxillary teeth all indicated that the maxilla moved forward away from the cranial base a slight amount during growth. These measurements supported the findings using the superimpositioning method.

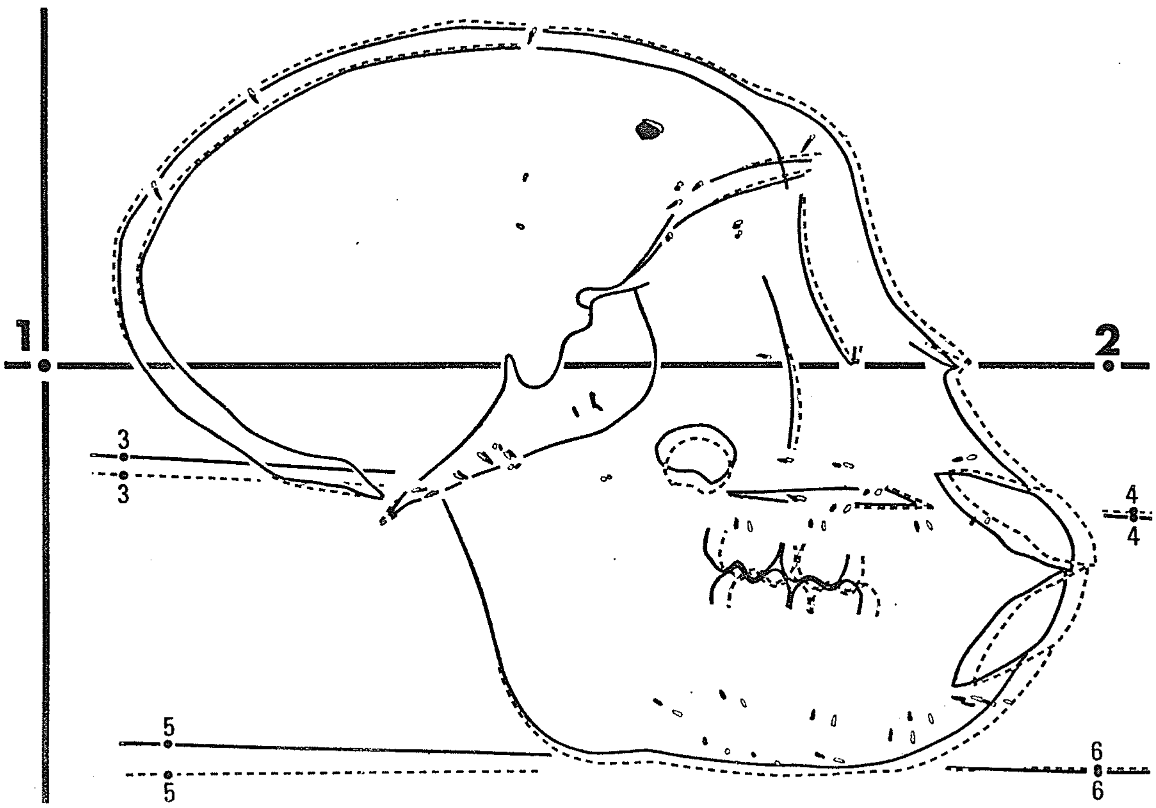
The interarch measurements from the maxillary to the mandibular first molars indicated that the molar relationships were maintained in both animals.

Angular Analysis

The increments of change of the angular measurements used in this analysis of the control animals, are tabulated in Table VI in the Appendix. As indicated by the changes in angles a and b, the maxilla and mandible demonstrated a very slight tendency toward "counterclockwise" rotation relative to the cranial base. Angles d and e, which were associated with a higher error of measurement, indicated minimal change in the angular relationship of the maxilla to the cranial base. Slight "counterclockwise" change in the angles formed by the frontal bone and posterior cranial base was evident and apparently due to upward and forward growth of the frontal bone. However, the changes in the angles f, g, h and i were all approximately within the range of the measurement error. The zygomatic bone showed insignificant rotation relative to the cranial base (angle j) and to the maxilla (angle k) during the normal growth period.

The maxillary molars demonstrated approximately 3° alteration in angulation relative to the maxilla but this fluctuation was assumed within the range of measurement error for these variables. The maxillary second molar of Monkey No. 5 demonstrated change in angular relations during its eruptive path into occlusion. The maxillary incisor similarly showed a slight range of rotation (2°) with respect to both the maxilla and the cranial base, but this was also interpreted as within the range of measurement error and hence indicative of a relative constancy of incisor angulation.

MONKEY No.1 (Control Group)



OVERALL SUPERIMPOSITION

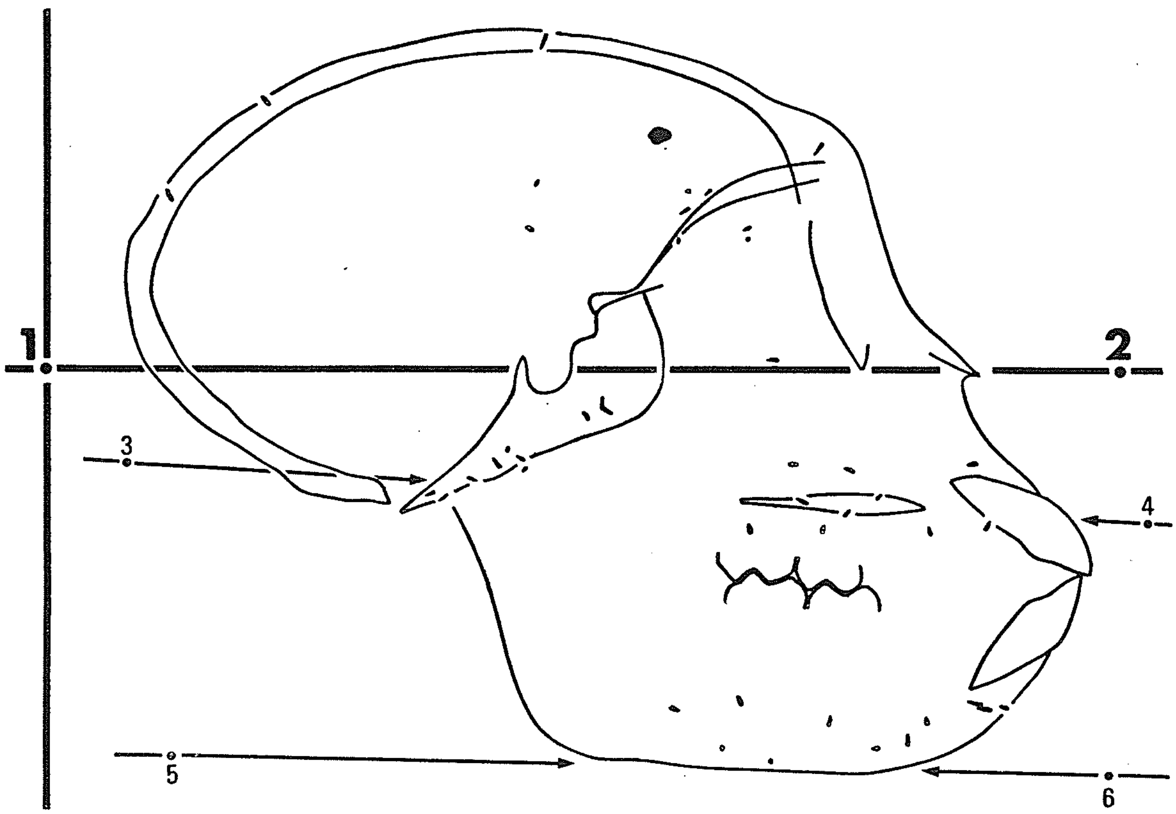
Figure 49.

Day 0 ————————

Day 103 ·····················

Figure 52. Overall superimposition on basi-sphenoid bone of Day 0 and Day 12 cephalograms of Monkey No. 1 of the control group. The tracings are superimposed on the outline of the basi-sphenoid bone with the implants in the basi-sphenoid bone registered. Note that in this short growth period, no changes were evident and all implants exactly superimposed.

MONKEY No. I (Control Group)

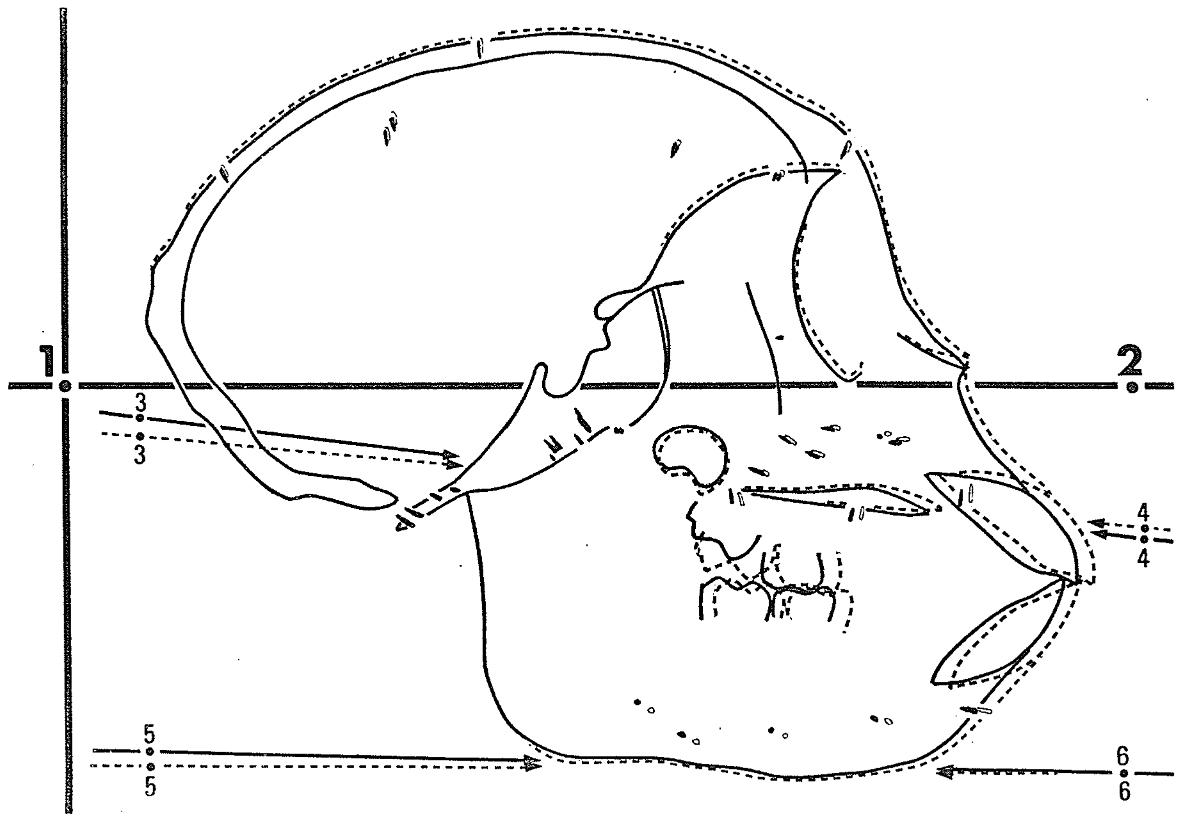


OVERALL SUPERIMPOSITION

Figure 52.

Day 0 ————————
Day 12 ....

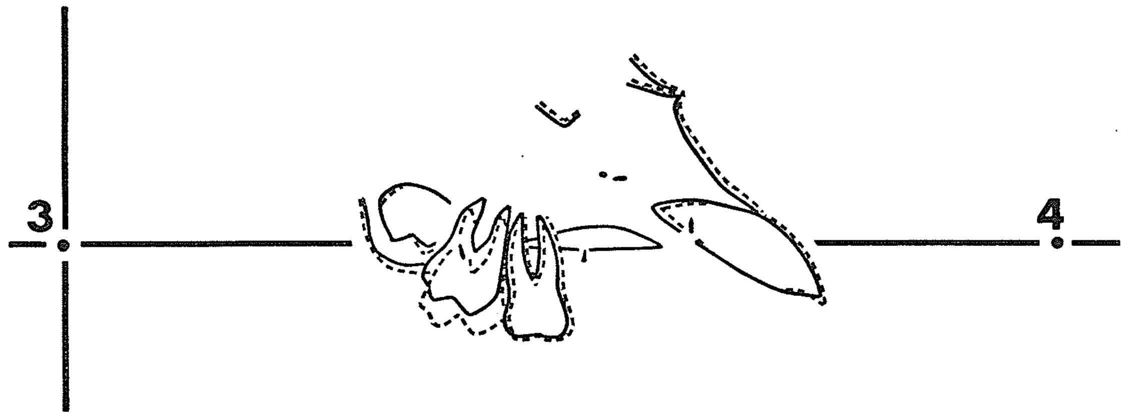
MONKEY No. 5 (Control Group)



OVERALL SUPERIMPOSITION

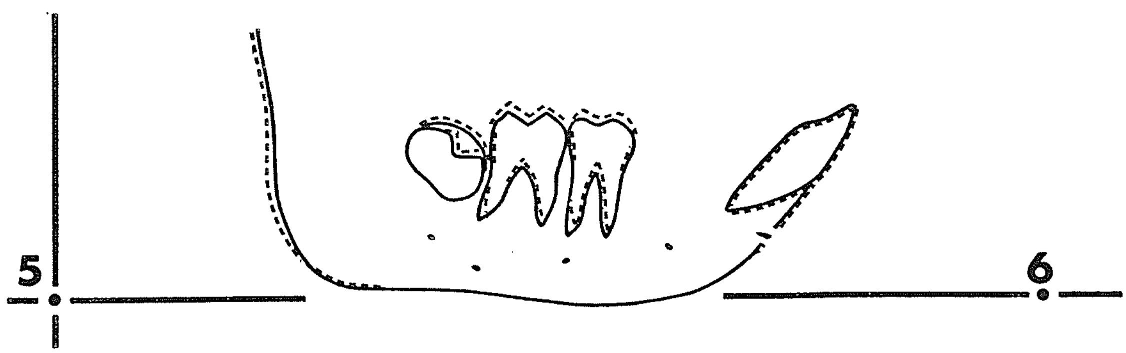
Figure 53.

MONKEY No. 5 (Control Group)



MAXILLARY SUPERIMPOSITION

Figure 54.



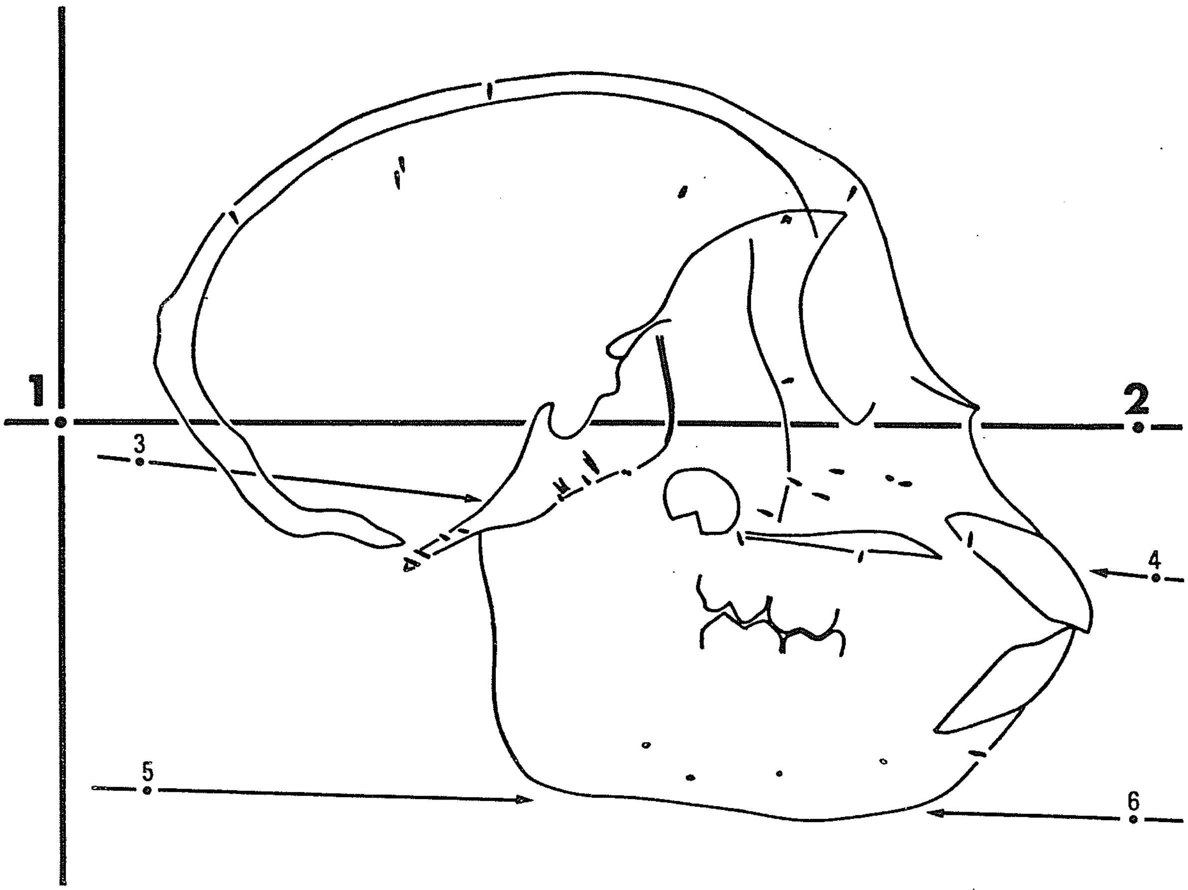
MANDIBULAR SUPERIMPOSITION

Figure 55.

Day 0 ————————

Day 103 ----------------

MONKEY No. 5 (Control Group)



OVERALL SUPERIMPOSITION

Figure 56.

Day 0 ————————
Day 13 ....

Headgear Group

Coordinate Analyses

Overall Superimposition on Basi-Sphenoid Bone

Quantitative assessment of the movement of the various landmarks in relation to the basi-sphenoid bone in the overall superimposition in both the horizontal and vertical directions relative to the original Frankfort Horizontal of each animal are presented in Table II in the Appendix. Photographs of the cephalograms before and after the experimental period are shown for Monkey No. 3 in Figures 57, 58, 59, 60 and 61 and for Monkey No. 4 in Figures 71 and 72. The overall superimposition for the headgear group (Figures 62, 65 and 73) demonstrated that dramatic changes in the morphologic pattern of the craniofacial complex had occurred in both experimental animals compared to the pattern demonstrated by the controls. In general terms, both Monkeys No. 3 and No. 4 demonstrated a posterior displacement of the upper facial bones with a concomitant marked increase in the vertical facial dimensions. While the entire craniofacial complex was affected, the most dramatic effects, however, occurred in the facial bones closest to the site of force application.

The maxillary complex rotated downwards and backwards in a "clockwise" direction when viewed from the right side of the skull. The anterior cranial base, represented by the orbital processes of the frontal bone forming the floor of the anterior cranial fossa, also rotated "clockwise" with respect to the body of the sphenoid bone.

The bones comprising the cranial vault were also affected. Monkey No. 3 showed the most severe alterations in the shape of the cranial vault as shown in Figure 62 after 103 days of continuous traction. The radiograph of Monkey No. 3 (Figures 58, 59 and 60) demonstrated that disruption and separation of the cranial vault sutures adjacent to the parietal bone appeared to have occurred and resulted in bodily translation of the parietal bone with respect to the frontal and occipital vault bones. This phenomenon appeared to resemble the changes which have been reported to occur by Moloy (1942) during birth molding.

Very large increments of bone movement occurred in the headgear animals for most facial landmarks compared to the control animals. Hence, the rate of movement of these landmarks was accelerated compared with the rate of movement of these landmarks in the opposite direction which occurred during displacement by the normal growth processes in the control animals.

With respect to the maxilla, the anterior maxillary implants moved downwards much more than the posterior maxillary implants in Monkey No. 4 which accounted for the "clockwise" rotation of the maxilla. The "clockwise" rotation was even more exaggerated in Monkey No. 3 where the anterior maxillary implants moved downwards while the posterior maxillary implants moved upwards.

The frontal, zygomatic, and maxillary bones moved independently of each other, as indicated by the differences of the increments of movement among these bones.

The dental landmarks describing the position of the teeth refer to the left maxillary molars which were closer to the film. The images of the right molars were not digitized. Examination of the post-headgear cephalograms (Figures 58 and 61) and the overall superimposition for Monkey No. 3 (Figure 62) after 103 days demonstrate that the right molar teeth moved downwards with respect to the left molar teeth. Hence, while the maxilla was rotated backwards in the A-P dimension, it simultaneously underwent transverse tipping as viewed from the frontal aspect. This was probably associated with unequal transmission of force from the base of anchorage at the back of the neck to the right and left sides of the maxilla, as this monkey had a habit of constantly tilting and rotating her head to one side, which probably tended to proportionately change the amount and direction of force applied to the respective sides of the maxillary arch.

Maxillary Superimposition

The maxillary superimposition on the implants in the body of the maxilla for the headgear group demonstrated the amount of tooth movement and cortical transformation of the maxilla which occurred between the various experimental stages. These changes are tabulated in Table III in the Appendix and illustrated in Figures 63 and 66 for Monkey No. 3 and Figure 74 for Monkey No. 4.

The amount of tooth movement that occurred relative to the body of the maxilla was small compared to the marked tooth movement that occurred relative to the cranial base. Thus, the major part of the distal movement of the maxillary dentition was due to posterior movement of the entire maxilla and contiguous bones rather than posterior movement of the teeth themselves within the maxilla. A detailed description of the movement of the various maxillary teeth relative to the cranial base in comparison to their movement relative to the maxilla is given by comparing the amount of movement of the dental variables in the overall superimposition with the amount in the maxillary superimposition. An example is seen by studying landmark 45 (buccal groove of maxillary first molar) of Monkey No. 3 in the overall and maxillary superimpositions. It is seen that relative to the basi-sphenoid bone, the first molar moved posteriorly 15.75 mm and upward 3.42 mm after 103 days of extraoral traction. However, relative to the body of the maxilla, the first molar moved posteriorly only 4.22 mm and downward 1.80 mm. Hence, the change in occlusal relation was due to approximately 25% tooth movement and 75% maxillary movement in Monkey No. 3. A similar finding was seen to occur in Monkey No. 4.

The unerupted third molar in the overall superimposition moved upward and backward in both animals (Figures 62 and 73). However, in the maxillary superimposition the unerupted third molar moved slightly forward with respect to the maxillary implants. Therefore, the upward and backward displacement of the unerupted third molar in the overall superimposition of each animal was completely the result of movement of the maxilla proper in that direction.

The magnitude of translation of each maxillary tooth in the overall superimposition was associated with its relative position in the maxilla since the anterior part of the maxilla underwent more movement than the posterior part. Thus, as the maxilla rotated "clockwise" the maxillary incisor in Monkey No. 3 after 103 days was carried backward 25.44 mm and downward 20.11 mm relative to the cranial base in the overall superimposition while relative to the maxillary implants in the maxillary superimposition the incisor was moved backward only 4.06 mm and downward 12.05 mm. On the other hand, the maxillary second molar was displaced backward 10.44 mm and upward 8.54 mm in the overall superimposition while the unerupted third molar was displaced only slightly backward but considerably upward as the maxilla rotated "clockwise".

The palatal outline of Monkey No. 3 after 103 days of headgear moved downward relative to the implants in the body of the left side of the maxilla. This observation was due to an unequal transverse movement of the entire maxilla as the right side was translated in the vertical dimension more than the left side. As previously mentioned, this was thought due to unequal force transmission to the respective sides of the maxilla.

Mandibular Superimposition

The horizontal and vertical movements of the mandibular teeth and landmarks with respect to the mandibular implants are presented in Table IV in the Appendix and are shown for Monkey No. 3 in Figures 64 and 67 and for Monkey No. 4 in Figure 75. It is seen that the mandibular molars essentially moved vertically upward while the mandibular incisors tipped lingually. Minimal changes in the outline of the body of the mandible were found in either animal.

Linear Analysis

Table V in the Appendix lists the changes in the absolute linear distances. It is seen that a dramatic increase in the vertical height of the face occurred in Monkey No. 3 while a considerable increase occurred in Monkey No. 4. In Monkey No. 3, the presence of the intra-oral appliance on the 103rd day created occlusal interferences which rotated the mandible inferiorly and increased the vertical dimension. Removal of the appliance 9 days later indicated the actual increase in facial height due to dentoskeletal change.

The length of the maxilla was reduced in Monkey No. 3 by 3.47 mm after 103 days and only 1.66 mm after 72 days in Monkey No. 4. Hence, distal movement of the maxilla was partially due to decrease in the A-P length of the mass of the maxillary bone. However, the posterior landmarks of the maxilla, Tuberosity Point (Inferior) and Tuberosity Point (Superior), were difficult to locate and therefore a large error must be associated with assessment of the length of the maxilla. As seen by the measurement of the anterior maxillary implant to the cranial base implant, the distance between the maxilla and cranial base decreased but to approximately the same amount as the maxillary length decreased.

The maxillary third molar moved only slightly closer to the cranial base implant while the maxillary second molar moved much closer (12.49 mm in Monkey No. 3). The magnitude of translation of each molar, as shown by the coordinate analyses, was associated with its relative position in the maxilla as the maxilla rotated "clockwise."

The measurements between the maxillary and mandibular teeth demonstrated the marked occlusal disproportions which were created. In Monkey No. 3 after 103 days a 16.4 mm occlusal disproportion was created between the maxillary and mandibular first molars. However, as seen by the linear distance between the maxillary molar and the cranial base implant and by the measurements in the overall superimposition (Table II in Appendix), this occlusal disproportion was caused predominantly by distal movement of the maxilla and maxillary teeth and not by restraint of forward maxillary growth while forward mandibular growth created the disproportion.

Angular Analysis

The changes which occurred in the various angles describing the relationship of the various bones to each other are tabulated in Table VI in the Appendix. The maxilla underwent a very marked "clockwise" rotation with respect to the basi-sphenoid bone in Monkey No. 3 after 103 days and a considerable rotation in Monkey No. 4 after 72 days of force application. Angles a, d and e, all of which used different landmarks to describe the rotation of the maxilla, indicated that the maxilla rotated between 27.47° to 30.33° in Monkey No. 3 after 103 days and between 11.75° and 6.22° in Monkey No. 4 after 72 days. In Monkey No. 4 the rotation of the maxilla was probably between 6.22° and 8.49° as the error associated with angle d (11.74°) was higher than the former two assessments.

The mandible similarly demonstrated a marked "clockwise" rotation consistent with the rotation of the maxilla.

The zygomatic bone demonstrated a differential rotation in comparison to the amount of rotation experienced by the maxilla. Hence, the facial bones underwent similar types of rotation but to varying degrees and each bone rotated individually as a separate body.

The anterior cranial base as measured by angles f, g, h and i rotated "clockwise" especially in Monkey No. 3 which demonstrated 5.4° change in angle f, 5.99° change in angle g, 5.55° change in angle h and 8.16° change in angle i after 103 days of headgear. These marked changes in angular measurements exceeded the experimental error of measurement and were in marked contrast to the slight tendency toward "counterclockwise" rotation in the control animals. However, these angular measurements in the control animals were within the experimental error of measurement. Monkey No. 4 of the headgear group also demonstrated a tendency toward "clockwise" rotation of the anterior cranial base; however, the error of measurement of the various angles in this animal almost approximated the observed rotation.

With respect to rotation and tipping of the maxillary molars in relation to the body of the maxilla, both Monkeys No. 3 and No. 4 demonstrated considerable distal tipping of the maxillary first and second molars. Although the experimental error of measurement of these angles may be assumed to be slightly higher than other angular measurements, the molar tipping was in the range of 20° to 30° in both animals and far exceeded the 3° or 4° error of measurement. These findings are further supported by the maxillary superimposition data (Table III in Appendix) which indicates slight mesial movement of the apices of the roots of the maxillary molars in combination with marked distal movement of the crowns of these teeth.

The maxillary incisor rotated "clockwise" 44° with respect to the cranial base and "clockwise" 16.59° with respect to the maxilla in Monkey No. 3 after 103 days of headgear while it rotated "clockwise" 22.8° with respect to the cranial base and "clockwise" 16.6° with respect to the maxilla in Monkey No. 4 after 72 days. The additional rotation of the incisor relative to the cranial base was due to the "clockwise" rotation of the maxilla previously described.

Post-Headgear Observation Period

Monkey No. 3 underwent an observation period for 26 days following the removal of extraoral forces. The data in Tables II, III, V and VI in the Appendix indicate that an initial recovery in most of the dental and skeletal variables occurred to a certain extent in this short period. Figures 68, 69 and 70 demonstrate this recovery.

The increments of change during recovery were much greater than the increments which accompanied normal growth in the control animals during a similar interval of time or even a much longer period of time. The initial recovery was in the nature of a reversal of the experimentally induced skeletal changes with translation of the individual craniofacial bones toward their original position. The facial bones rotated "counterclockwise" with the maxilla and zygomatic bone moving upward and forward. The changes in the frontal bone complex and cranial vault also appeared to recover to a certain extent.

Recovery of the skeletal structures was accompanied by a concomitant reduction of the occlusal disproportion. Comparison of the overall superimposition (Figure 68) with the maxillary superimposition (Figure 69) demonstrates that some recovery from molar tipping occurred relative to the maxilla but that most of the change in interarch molar relationship was due to forward movement of the maxilla itself. The maxillary incisor, however, demonstrated marked labial tipping relative to the maxilla during this period.

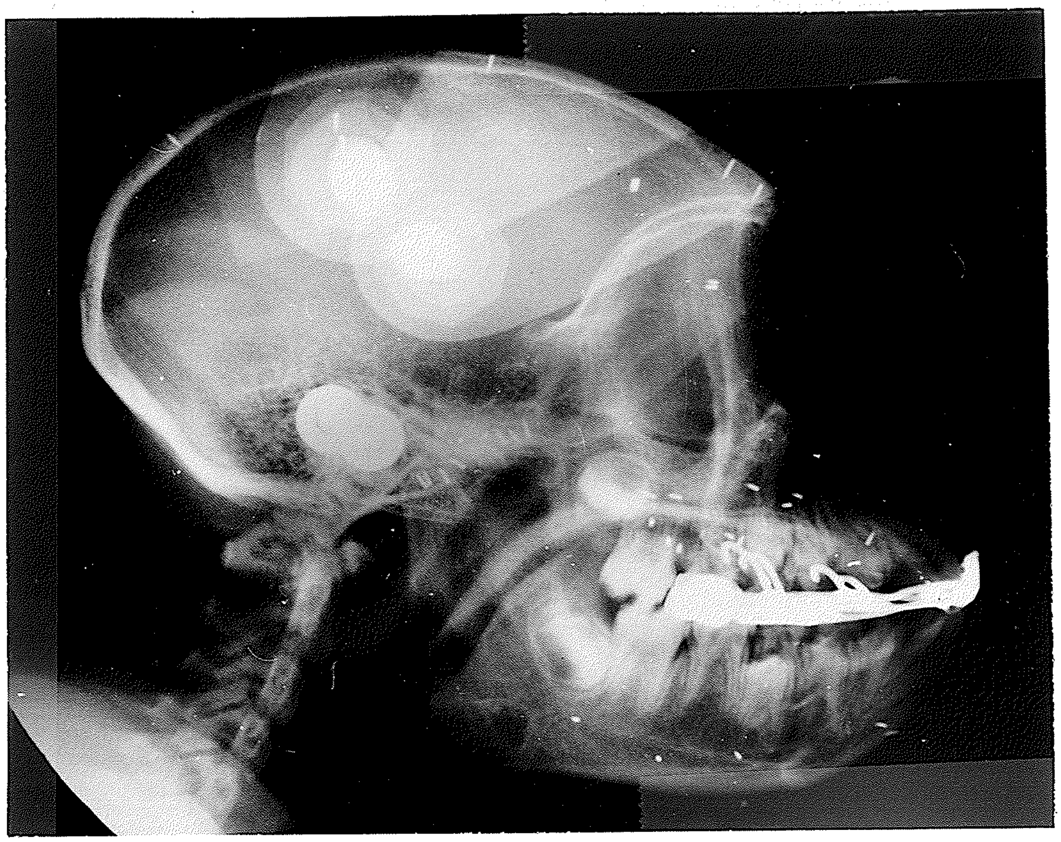


Figure 57. Pre-headgear cephalometric radiograph of Monkey No. 3 of the headgear group. Note that the images of the bilateral "superimpositioning implants" in the frontal bone (above and to left of outline of roof of orbits) used for orientation of the monkey in the cephalostat are superimposed. (Approximately 1:1 photographic reproduction.)

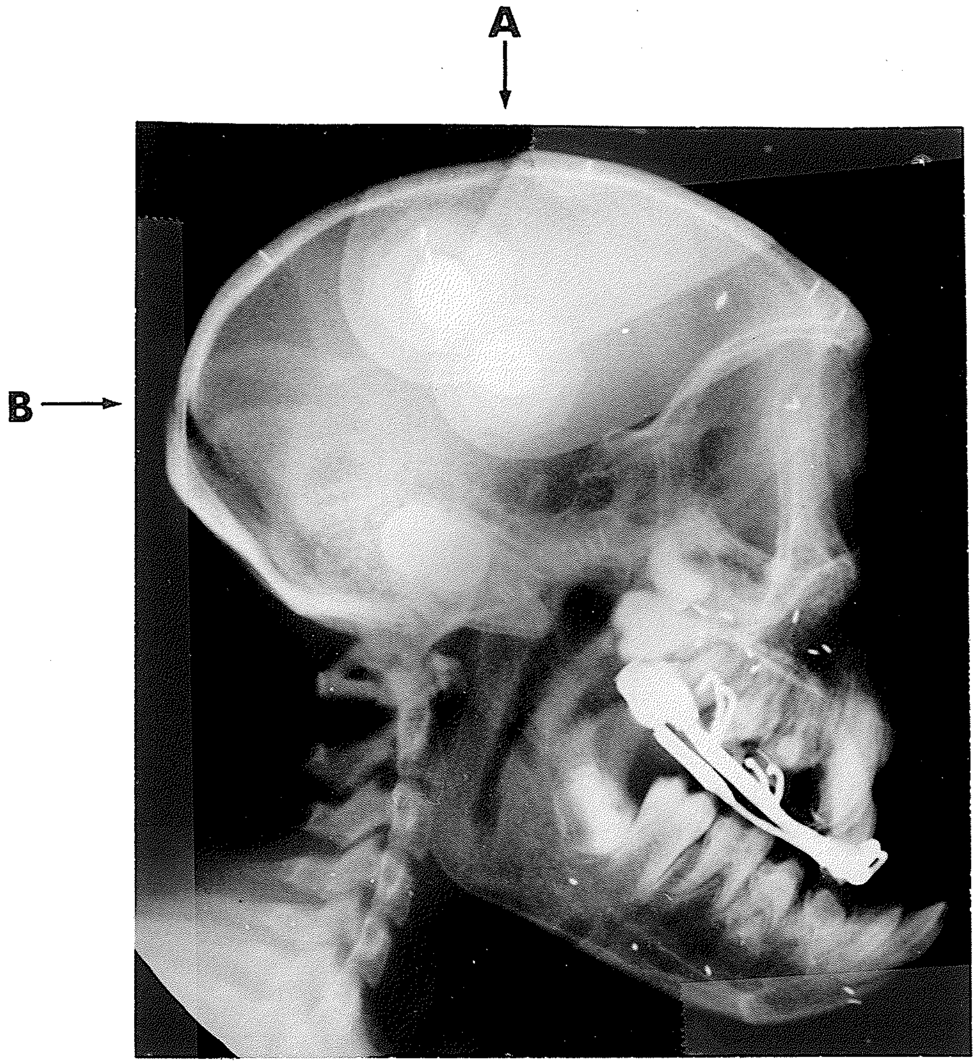


Figure 58. Post-headgear cephalometric radiograph of Monkey No. 3 of the headgear group on the 103rd day of heavy extraoral traction. Marked occlusal changes are evident. The intraoral appliance caused occlusal interferences and accentuated the backward rotation of the mandible. Deformity of the cranial vault is evident at areas A and B. Enlargements of these areas are shown in Figures 59 and 60 respectively. The head orientation in the cephalostat was very slightly off (compare relationship of images of bilateral "superimpositioning implants" in frontal bone and relationship of bilateral implants in parietal bones with those in Figure 57). The radiograph was re-taken 9 days later (Figure 61) and exact head orientation achieved at that time. (Approximately 1:1 photographic reproduction.)

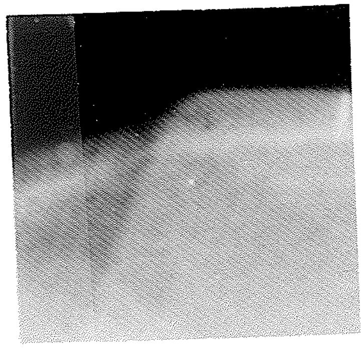


Figure 59. Photographic enlargement of area A of Figure 58. The cranial vault in the area of the fronto-parietal suture is shown. The sutural outline is evident and shape of vault appears deformed compared with this area in the pre-headgear cephalogram (Figure 57).

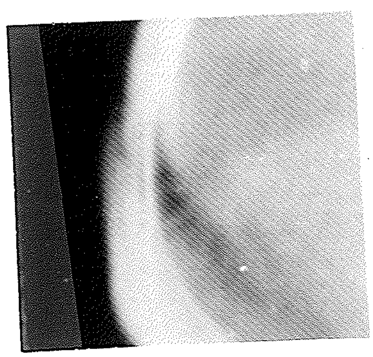


Figure 60. Photographic enlargement of area B of Figure 58. The cranial vault in the area of the occipito-parietal suture is shown. The sutural outline indicates that physical disruption of the suture and movement of the adjacent cranial bones relative to each other had occurred.

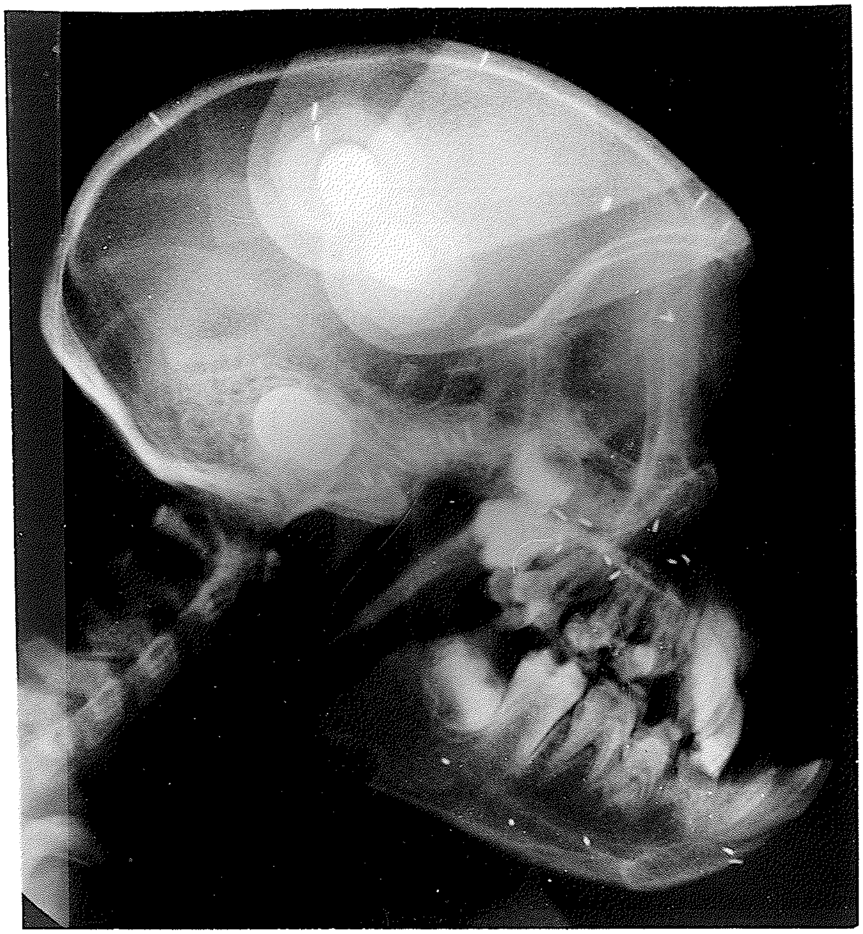
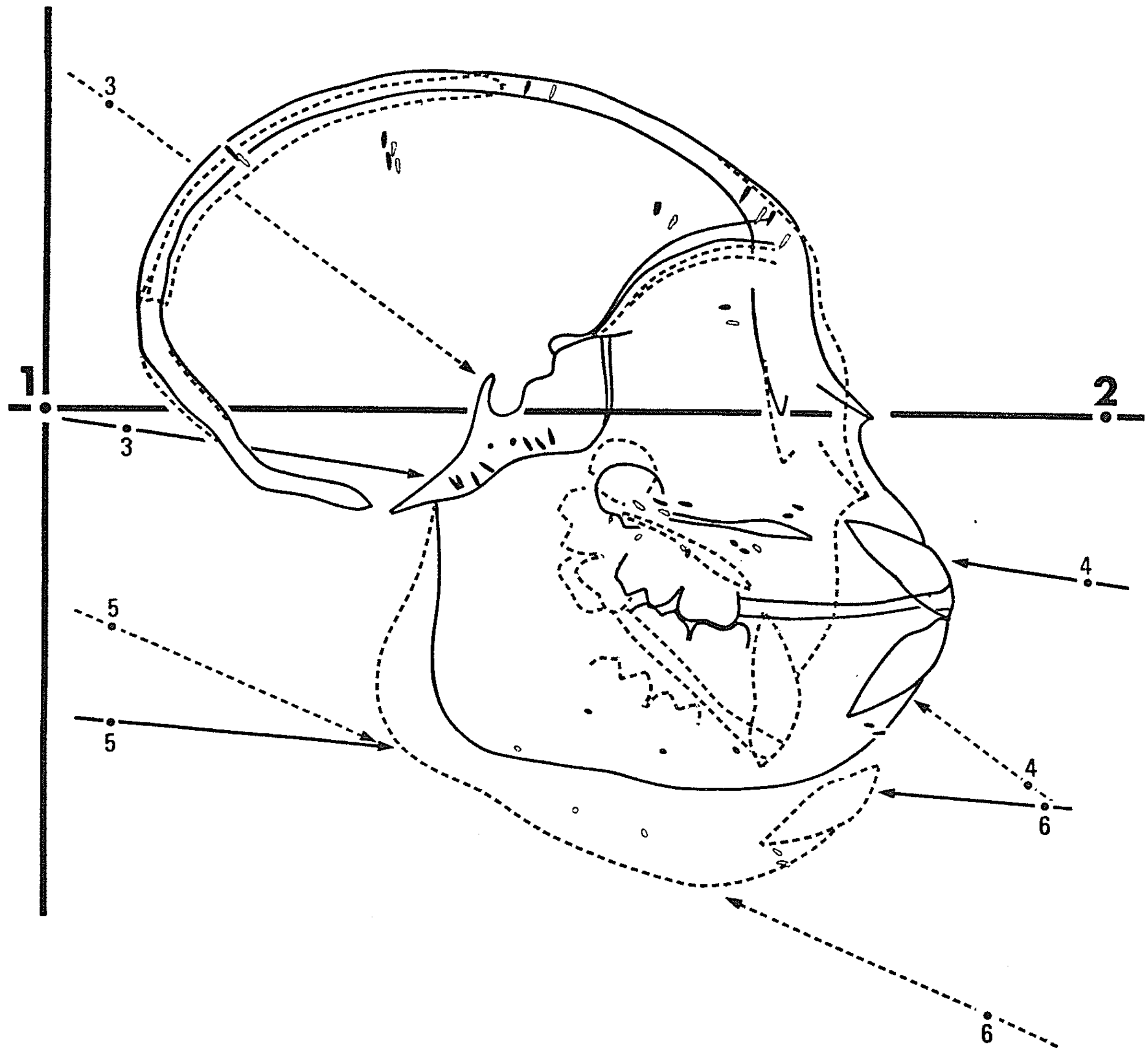


Figure 61. Post-headgear cephalometric radiograph of Monkey No. 3 of the headgear group after 103 days of heavy extraoral traction at the time of removal of the intraoral appliance 9 days after the termination of traction. The head orientation was the same as that in the pre-headgear cephalogram (Figure 57) as indicated by position of bilateral implants in frontal and parietal bones used for orientation. (Approximately 1:1 photographic reproduction.)

Figure 62. Overall superimposition on basi-sphenoid bone of pre-headgear and immediate post-headgear (103 days) cephalograms of Monkey No. 3 of the headgear group. The tracings are superimposed on the outline of the basi-sphenoid bone with the implants in the basi-sphenoid bone registered. Horizontal and vertical changes in the landmarks are shown relative to the axes through Point 1 and Point 2. Implants of the pre-headgear cephalogram are shown as solid and those of the immediate post-headgear cephalogram as open.

MONKEY No. 3 (Headgear Group)



OVERALL SUPERIMPOSITION

Figure 62.

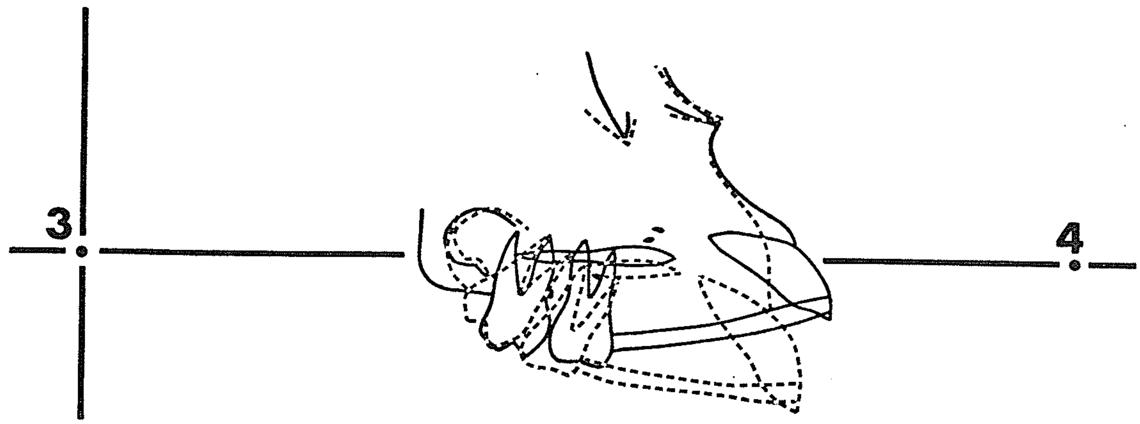
Pre-headgear

Immediate post-headgear (103 days)

Figure 63. Maxillary superimposition of pre-headgear and immediate post-headgear (103 days) cephalograms of Monkey No. 3 of the headgear group. The tracings are superimposed on the implants in the body of the maxilla. Horizontal and vertical changes are shown relative to the axes through Point 3 and Point 4.

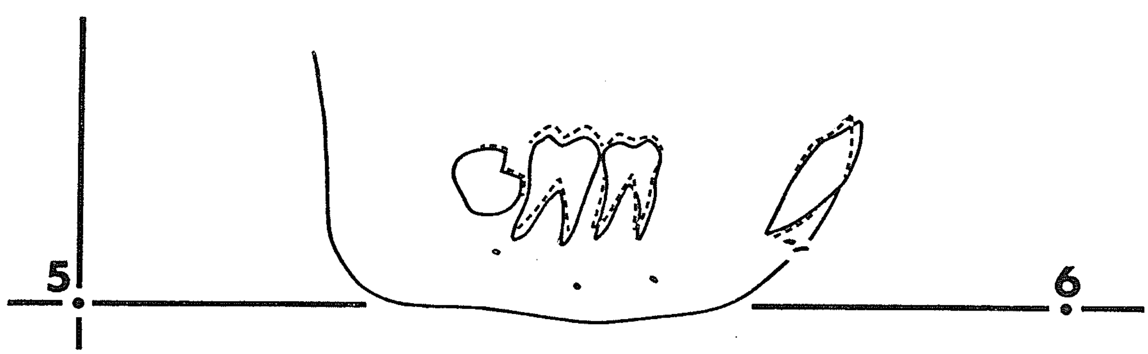
Figure 64. Mandibular superimposition of pre-headgear and immediate post-headgear (103 days) cephalograms of Monkey No. 3 of the headgear group. The tracings are superimposed on the mandibular implants. Horizontal and vertical changes are shown relative to the axes through Point 5 and Point 6.

MONKEY No. 3 (Headgear Group)



MAXILLARY SUPERIMPOSITION

Figure 63.



MANDIBULAR SUPERIMPOSITION

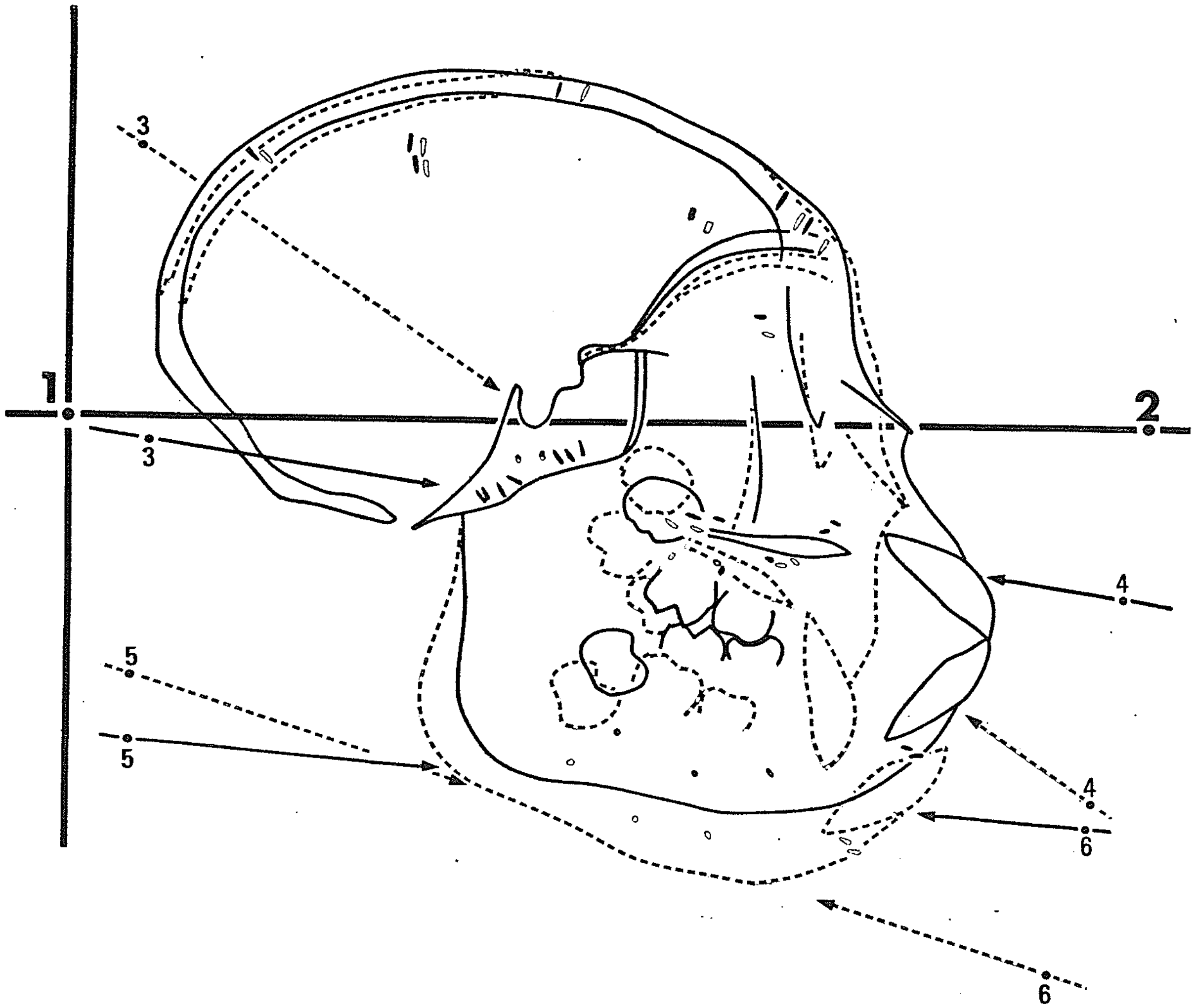
Figure 64.

Pre-headgear ————————

Immediate post-headgear ····················
(103 days)

Figure 65. Overall superimposition on basi-sphenoid bone of pre-headgear and post-headgear (at time of intraoral appliance removal 9 days after termination of extraoral traction) cephalograms of Monkey No. 3 of the headgear group. The tracings are superimposed on the outline of the basi-sphenoid bone with the implants in the basi-sphenoid bone registered. Horizontal and vertical changes in the landmarks are shown relative to the axes through Point 1 and Point 2. Implants of the pre-headgear cephalogram are shown as solid and those of the post-headgear cephalogram are shown as open. Similar changes as described in Figure 62 are noted. Removal of intraoral appliance allowed mandible to assume actual occlusal position. Slightly less skeletal and dental change is seen compared with Figure 62 indicating that slight recovery occurred in the 9 day interval following termination of extraoral traction.

MONKEY No. 3 (Headgear Group)



OVERALL SUPERIMPOSITION

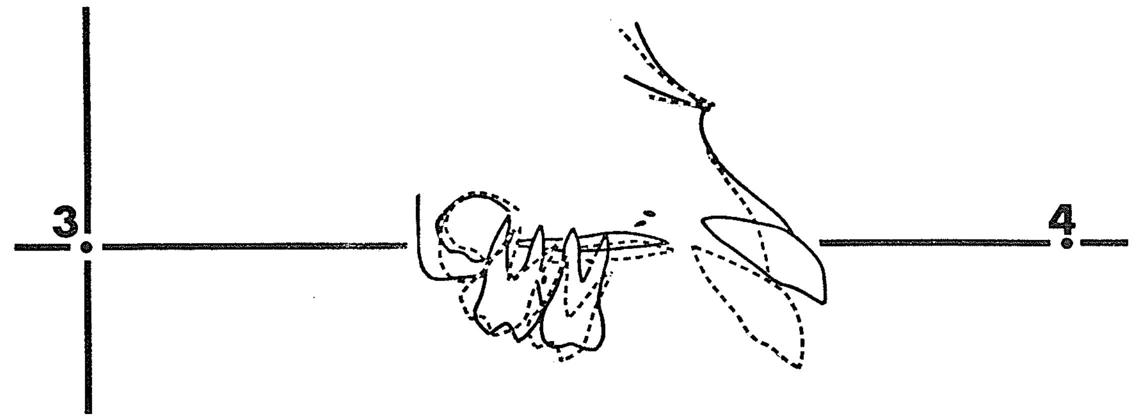
Figure 65.

Pre - headgear	————————
Post - headgear (103 days) Day 9 Relapse period Intraoral appliance removal	----------------

Figure 66. Maxillary superimposition of pre-headgear and post-headgear (at time of intraoral appliance removal 9 days after termination of extraoral traction) cephalograms of Monkey No. 3 of the headgear group. The tracings are superimposed on the implants in the body of the maxilla. Horizontal and vertical changes are shown relative to the axes through Point 3 and Point 4. Similar changes as demonstrated in Figure 63 are noted; however, less marked changes in the molar and central incisor indicate that dental recovery occurred in the 9 day period following termination of extraoral traction.

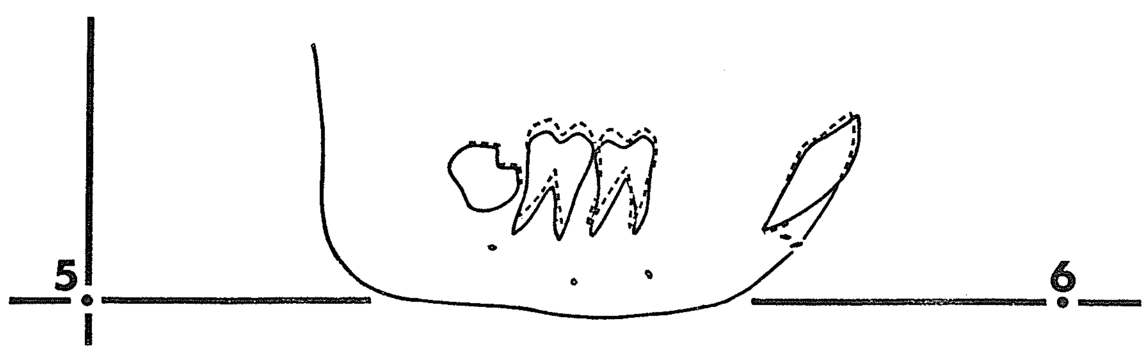
Figure 67. Mandibular superimposition of pre-headgear and post-headgear (at time of intraoral appliance removal 9 days after termination of extraoral traction) cephalograms of Monkey No. 3 of the headgear group. The tracings are superimposed on the mandibular implants. Horizontal and vertical changes are shown relative to the axes through Point 5 and Point 6. Similar changes occurred as those shown in Figure 64 indicating that minimal change occurred within the mandible in the 9 day period following termination of extraoral traction.

MONKEY No. 3 (Headgear Group)



MAXILLARY SUPERIMPOSITION

Figure 66.



MANDIBULAR SUPERIMPOSITION

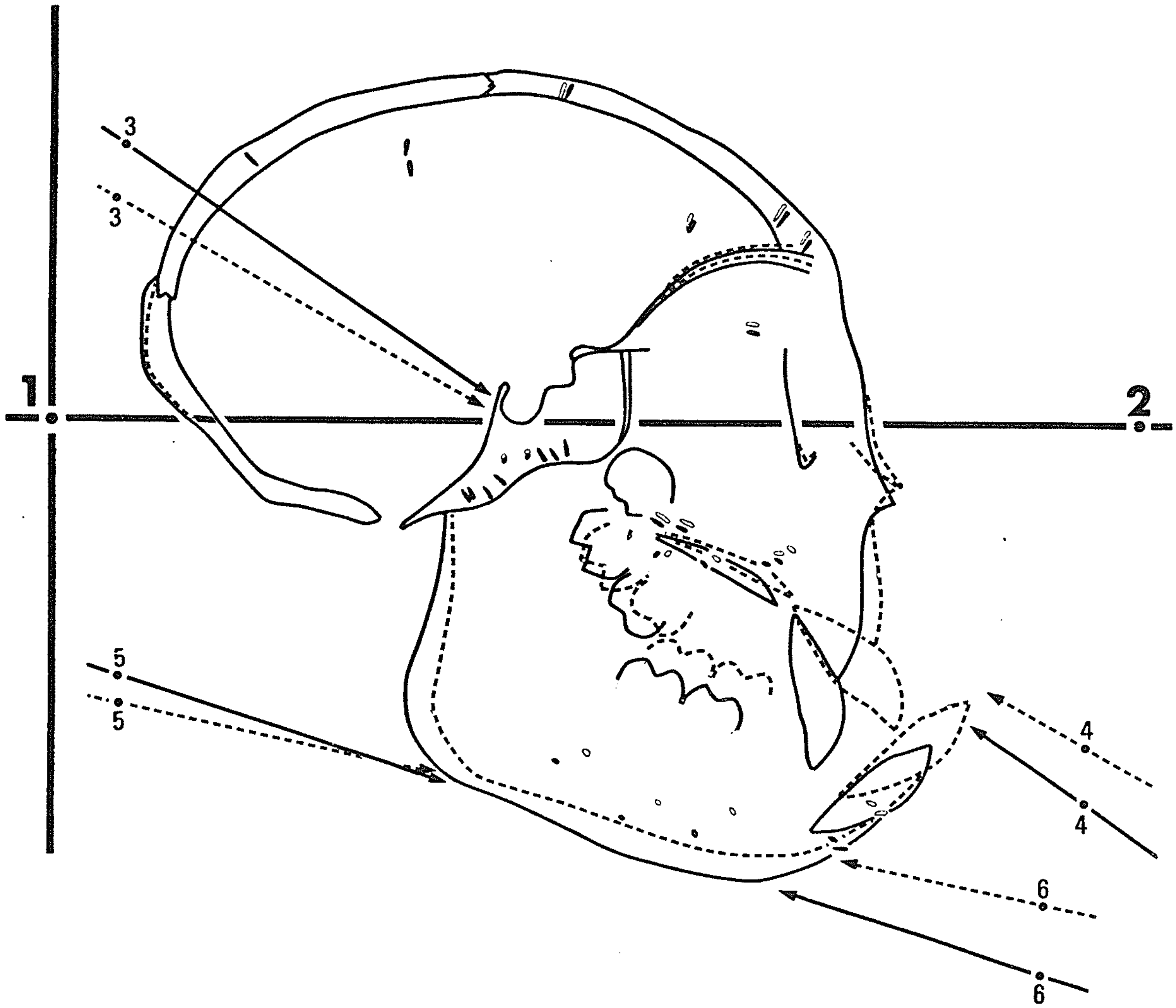
Figure 67.

Pre-headgear ————————

Post-headgear (103 days)
Day 9 Relapse period
Intraoral appliance removal ----------------

Figure 68. Overall superimposition on basi-sphenoid bone for post-headgear observation period of Monkey No. 3 of the headgear group. The tracings of the post-headgear cephalogram (taken at time of intraoral appliance removal 9 days after termination of extraoral traction) and the post-observation period cephalogram (taken 26 days after the termination of extraoral traction) are superimposed on the outline of the basi-sphenoid bone with the implants in the basi-sphenoid bone registered. Horizontal and vertical changes in the landmarks are shown relative to the axes through Point 1 and Point 2. Implants of the post-headgear cephalogram are shown as solid and those of the post-observation period cephalogram are shown as open. Note that movement of both dental and skeletal landmarks occurred in the reverse direction as the changes which occurred during the experimental interval (Figures 62 and 65).

MONKEY No. 3 (Headgear Group)



OVERALL SUPERIMPOSITION

Figure 68.

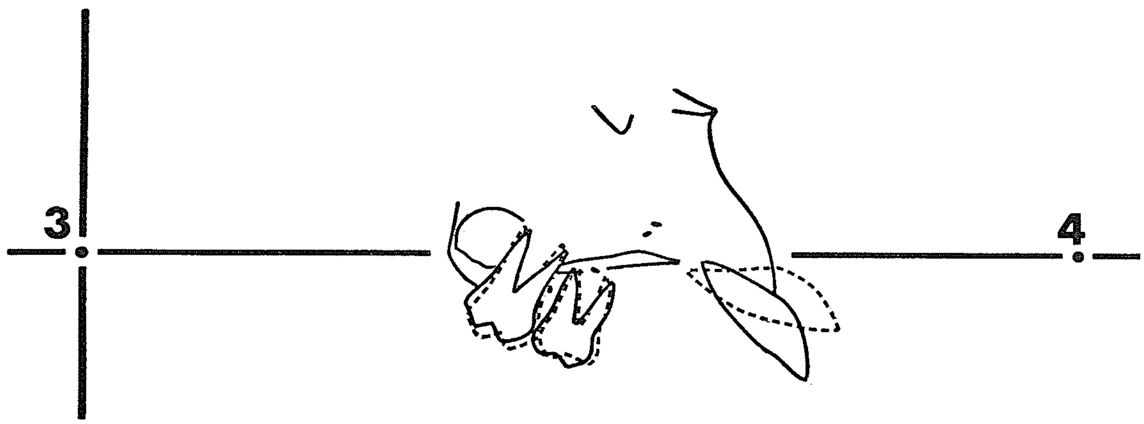
Day 9 Relapse period
Intraoral appliance removal ————

Day 26 Relapse period ------------

Figure 69. Maxillary superimposition for post-headgear observation period of Monkey No. 3 of the headgear group. The tracings of the post-headgear cephalogram (taken at time of intraoral appliance removal 9 days after termination of extraoral traction) and the post-observation period cephalogram (taken 26 days after the termination of extraoral traction) are superimposed on the implants in the body of the maxilla. Horizontal and vertical changes are shown relative to the axes through Point 3 and Point 4.

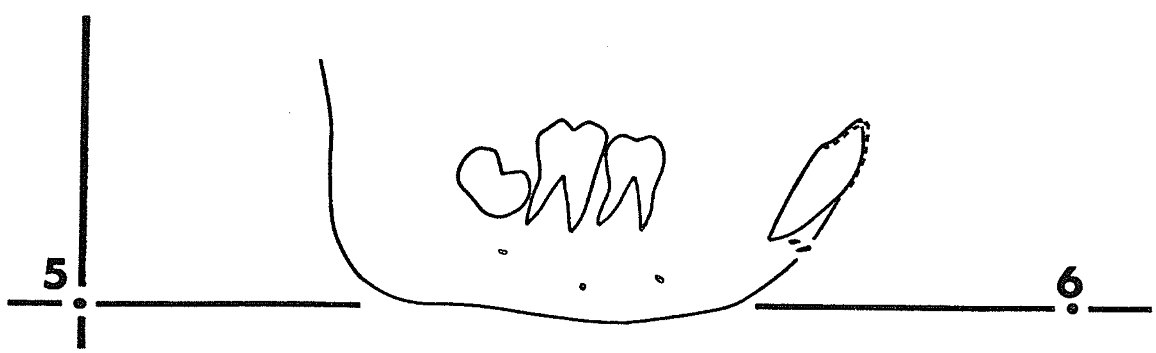
Figure 70. Mandibular superimposition for the post-headgear observation period of Monkey No. 3 of the headgear group. The tracings of the post-headgear cephalogram (taken at the time of intraoral appliance removal 9 days after termination of extraoral traction) and the post-observation period cephalogram (taken 26 days after the termination of extraoral traction) are superimposed on the mandibular implants. Horizontal and vertical changes are shown relative to the axes through Point 5 and Point 6.

MONKEY No. 3 (Headgear Group)



MAXILLARY SUPERIMPOSITION

Figure 69.



MANDIBULAR SUPERIMPOSITION

Figure 70.

Day 9 Relapse period Intraoral appliance removal	————
Day 26 Relapse period	------------

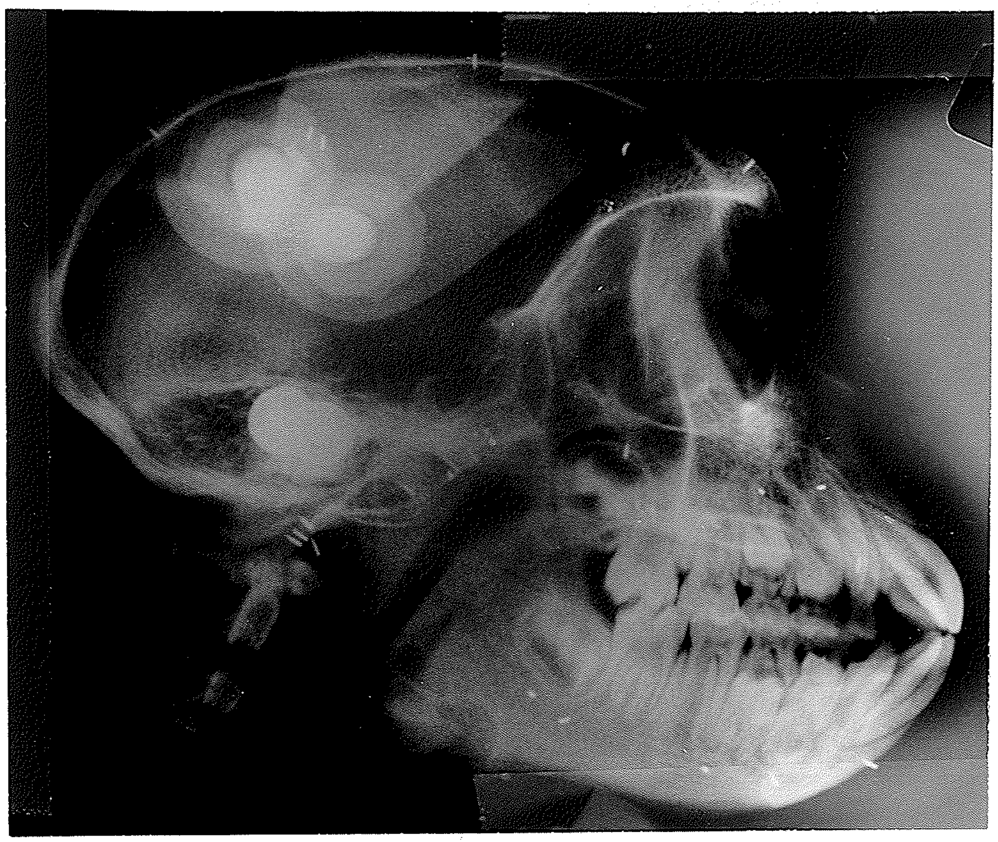


Figure 71. Pre-headgear cephalometric radiograph of Monkey No. 4 of the headgear group prior to insertion of intraoral appliance.

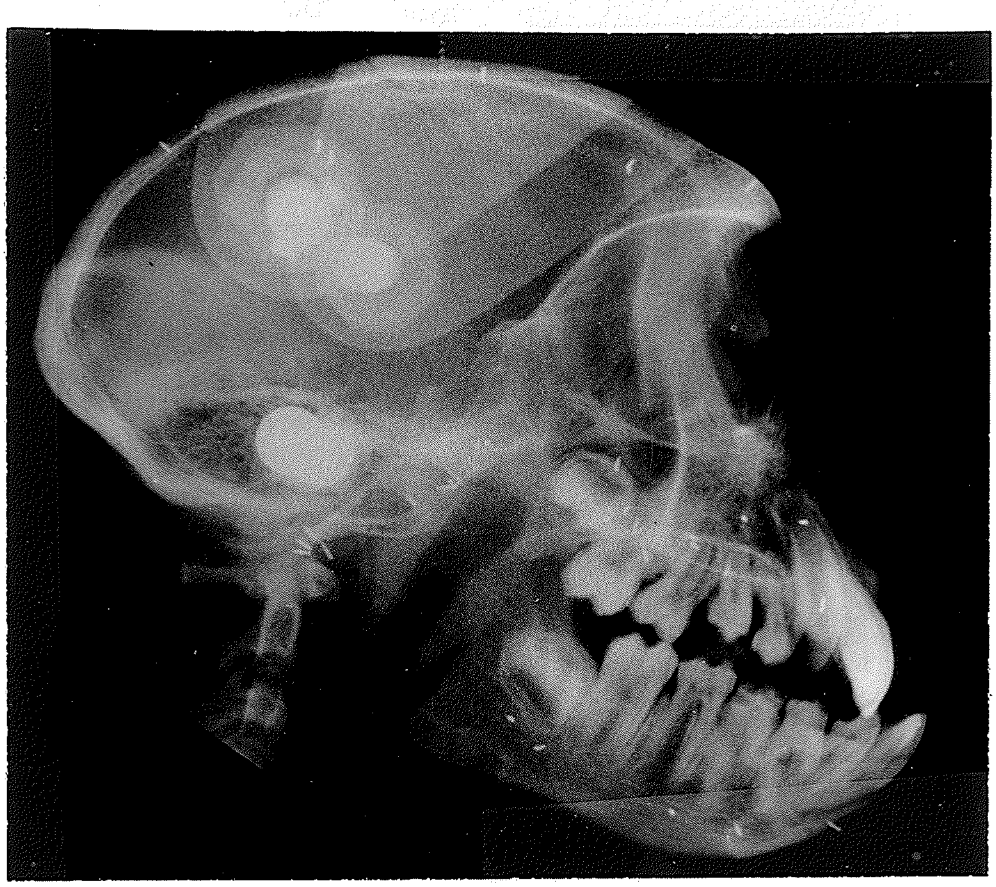
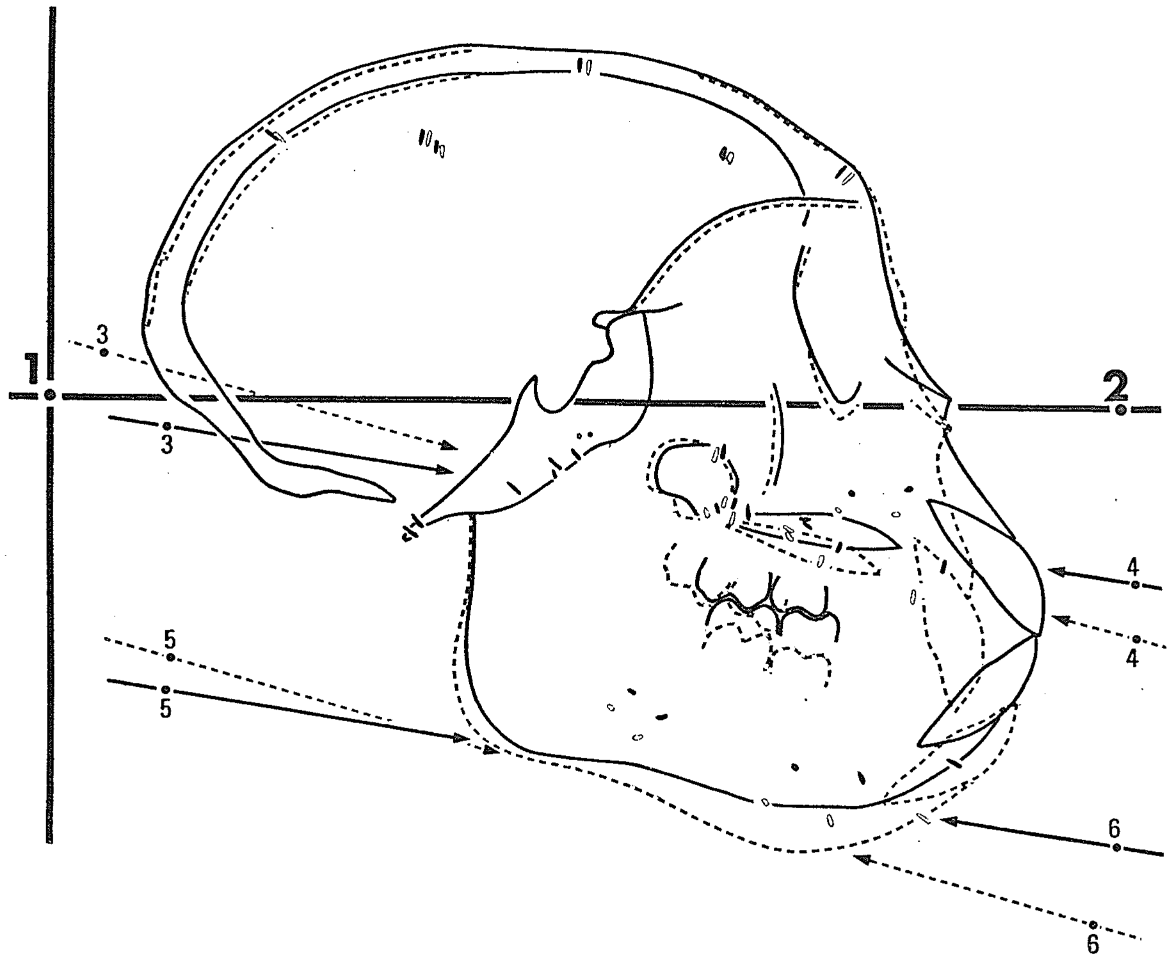


Figure 72. Post-headgear cephalometric radiograph of Monkey No. 4 of the headgear group on 72nd day of extraoral traction. A marked occlusal disproportion was created. The head orientation was the same as in the pre-headgear cephalogram (Figure 71) as seen by relationship of bilateral frontal and parietal implants in the respective films. (Approximate 1:1 photographic reproduction.)

Figure 73. Overall superimposition on basi-sphenoid bone of pre-headgear and post-headgear (72 days) cephalograms of Monkey No. 4 of the headgear group. The tracings are superimposed on the outline of the basi-sphenoid bone with the implants in the basi-sphenoid bone registered. Horizontal and vertical changes in the landmarks are shown relative to the axes through Point 1 and Point 2. Implants of the pre-headgear cephalogram are shown as solid and those of the post-headgear cephalogram as open.

MONKEY No.4 (Headgear Group)



OVERALL SUPERIMPOSITION

Figure 73.

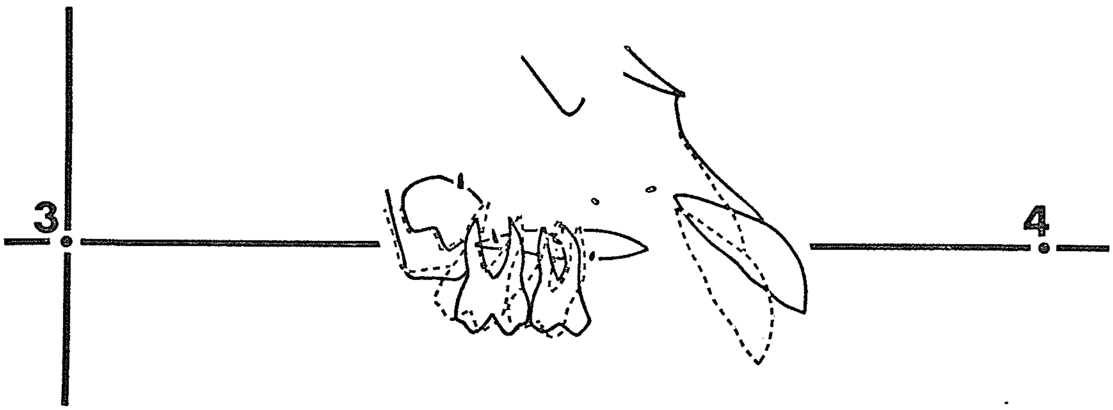
Pre-headgear ————————

Post-headgear (72 days) ----------------

Figure 74. Maxillary superimposition of pre-headgear and post-headgear cephalograms (72 days) of Monkey No. 4 of the headgear group. The tracings are superimposed on the implants in the body of the maxilla. Horizontal and vertical changes are shown relative to the axes through Point 3 and Point 4.

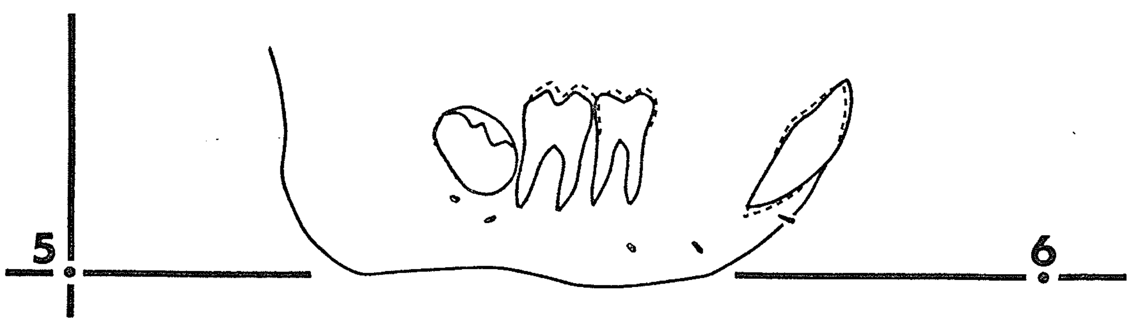
Figure 75. Mandibular superimposition of pre-headgear and post-headgear cephalograms (72 days) of Monkey No. 4 of the headgear group. Tracings are superimposed on the mandibular implants. Horizontal and vertical changes are shown relative to the axes through Point 5 and Point 6.

MONKEY No.4 (Headgear Group)



MAXILLARY SUPERIMPOSITION

Figure 74.



MANDIBULAR SUPERIMPOSITION

Figure 75.

Pre - headgear ————————

Post - headgear ----------------------
(72 days)

Palatal Expansion Group

Coordinate Analyses

Overall Superimposition

The changes which occurred following rapid palatal expansion are presented in Table VII in the Appendix. The overall superimposition indicated that minimal change occurred as viewed by the lateral cephalogram. The error of measurement exceeded the magnitude of change of most of the landmarks. All three animals demonstrated a slight downward decline of the roof of the palate (Figures 76, 79 and 87). Monkey No. 7 demonstrated a slight upward movement of the implants in the body of the maxilla with a concomitant downward movement of the palatal implants while Monkeys No. 6 and No. 7 demonstrated only downward movement of the palate. Monkeys No. 6 and No. 7 demonstrated an apparent lowering of the top of the palatal appliance (banding material and framework) although the maxillary molars did not demonstrate any downward movement. This was probably due to lateral rotation of the maxillary halves buccally, consequent buccal rotation of the maxillary molars and appliance and hence change in the radiographic image of the appliance. Cuspal interferences created in the occlusion resulted in a slight backward rotation of the mandible.

Slight movement of the implants in the zygomatic bone and the zygomatic processes of the temporal bone was indicated by the superimposed tracings of Monkeys No. 6 and No. 7; however, the error of measurement exceeded the change recorded.

Maxillary Superimposition

Superimposition on the implants in the body of the maxilla revealed a downward movement of the roof of the palatal vault and the palatal implants. These changes are illustrated in Figures 77, 80 and 88 for the respective animals but as indicated in Table VIII in the Appendix were within the possible error of measurement. The maxillary molars did not demonstrate change in relation to the implants in the body of the maxilla. The implants used for superimposition, being situated in the buccal surface of the left side of the maxilla above the apices of the molars, probably were translated outward and upward with the teeth as the maxillary halves rotated laterally. Hence, superimposition on these implants resulted in the relative changes in the roof of the palate.

Mandibular Superimposition

The data tabulated in Table IX in the Appendix and Figures 78, 83 and 89 indicate that no measurable changes occurred in the mandible during the palatal expansion period.

Linear Analysis

Minimal change of importance was observed in this analysis (Table X in Appendix).

Angular Analysis

Minimal change was observed in the various angular measurements (Table XI in Appendix).

Combination Group

Coordinate Analyses

Overall Superimposition

Photographs of the cephalograms of Monkey No. 6 before and after extraoral traction are shown in Figures 82 and 83. The data for the overall superimposition is tabulated in Table II in the Appendix for Monkeys No. 6 and No. 7 and the tracings are reproduced in Figures 84 and 90 respectively.

Monkey No. 6 demonstrated marked skeletal changes after 72 days of extraoral traction which appeared to be similar to the changes documented in Monkeys No. 3 and No. 4 of the headgear group after comparable periods of time. The nasomaxillary complex rotated "clockwise" downwards and backwards. The amount of posterior movement of the maxilla was similar to that which occurred in Monkey No. 4 but less than that in Monkey No. 3 after 72 days. Posterior movement of the maxillary molars was greater than that which occurred in Monkey No. 4 but comparable to that in Monkey No. 3 after 72 days.

The mandible concomitantly followed the "clockwise" rotation of the maxilla and rotated downward and backward. In addition, "clockwise" rotation of the anterior cranial base and slight changes in the shape of the cranial vault appeared to occur in Monkey No. 6.

Contrary to the above findings in Monkey No. 6 after 72 days of extraoral force, minimal skeletal changes occurred in Monkey No. 7 after 12 days of continuous traction.

Therefore, the data for Monkeys No. 6 and No. 7 demonstrated that the palatal expansion procedure did not enhance the susceptibility of the maxillary complex to more rapid posterior movement.

Maxillary Superimposition

The data for the maxillary superimposition on the implants in the body of the maxilla is tabulated in Table III in the Appendix. As seen in Figure 85 for Monkey No. 6 the maxillary molars tipped distally with the crowns moving posteriorly and the root apices remaining relatively stable with respect to the maxillary implants. The unerupted third molar moved forward slightly relative to the maxillary implants. Thus, the upward and backward movement of the unerupted third molar in the overall superimposition (Figure 84) was due to movement of the maxilla itself in that direction.

The maxillary incisor tipped forward relative to the maxillary implants. The incisor was not banded in the combination group and hence this forward incisor movement was caused by either growth occurring at the premaxillary-maxillary suture or else the incisor tipping forward on its base. The premaxillary implants, however, superimposed along with the implants in the body of the maxilla. Hence, the changes in the maxillary incisor were due to forward tipping of the tooth itself within the premaxilla and was probably associated with occlusal forces acting on the incisor as the maxilla was moved bodily posteriorly. As a result, maxillary arch length was increased.

Appositional growth and cortical remodelling of the facial surface of the maxilla and orbital floor was evident in Monkey No. 6.

Monkey No. 7 demonstrated minimal change which could be attributed to the 12 days of headgear wear and all increments were within the range of measurement error. Nonetheless, the maxillary tracing (Figure 91) suggested a slight increase in the changes reported in the previous palatal expansion period of this animal. The palatal roof appeared to drop slightly and this was attributed to the continuation of the palatal expansion procedure during the initial stages of headgear wear (two activations of appliance for three days following the pure palatal expansion period). No posterior movement of the dentition with respect to the maxillary implants was measured.

Mandibular Superimposition

Mandibular changes with respect to the mandibular implants were minimal (Table IV in Appendix). Monkey No. 7 demonstrated minimal change after 12 days of headgear (Figure 92) while Monkey No. 6 exhibited a very slight labial tipping of the mandibular incisor (Figure 86).

Linear Analysis

The linear analysis (Table V in the Appendix) for Monkey No. 6 demonstrated considerable increases in the facial height measurements. The magnitude of these changes after 72 days of traction was greater than those for Monkey No. 4 of the headgear group but less than those for Monkey No. 3 after comparable periods. Maxillary A-P length demonstrated only slight change in Monkey No. 6. The unerupted third molar showed little change in its linear distance from the cranial base implant while the maxillary second molar showed 7.76 mm decrease in this distance. This difference was associated with the relative positions of these teeth in the maxilla as it rotated "clockwise." The distance between the body of the maxilla proper and the cranial base implant slightly decreased. A marked occlusal disproportion of 8.16 mm was created between the maxillary and mandibular first molars. However, all linear analyses as well as the overall coordinate analysis demonstrated that this interarch occlusal disproportion was the result of posterior movement of the maxillary molars and the maxilla proper and not due to forward mandibular growth in the period studied.

Monkey No. 7 demonstrated minimal change after 12 days of extraoral traction in all the linear variables measured which supported the findings using the overall superimposition method of assessment.

Angular Analysis

The angular changes for the combination group are presented in Table VI in the Appendix. In Monkey No. 6 the maxilla demonstrated a marked "clockwise" rotation with respect to the cranial base after 72 days. The three angles used to assess this rotation demonstrated the following changes: angle a changed 17.26°, angle d changed 17.69°, and angle e changed 19.58°. The discrepancy is related to the measurement error associated with each angle. Thus, the maxilla rotated "clockwise" in Monkey No. 6 more than in Monkey No. 4 and slightly more than in Monkey No. 3 of the headgear group after comparable periods. The mandible in Monkey No. 6 also rotated "clockwise" with respect to the basisphenoid bone as assessed by the 7.55° change in angle b.

The angular measurements of the anterior cranial base suggested a tendency toward "clockwise" rotation but the error of measurement approached the change in most of the angles used in this assessment.

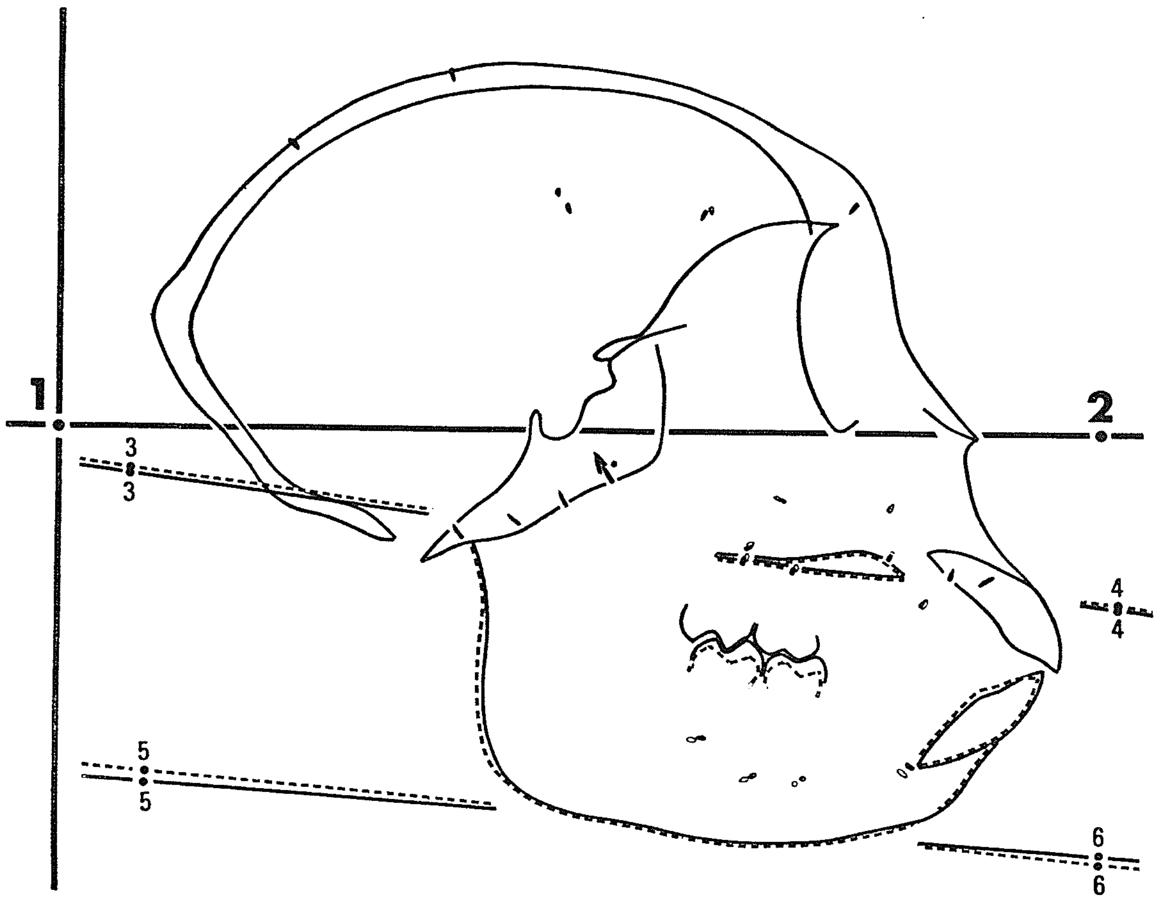
The zygomatic bone demonstrated a "clockwise" rotary movement with respect to the cranial base. Differential rotation of the facial bones was demonstrated by the angular change between the zygomatic bone and the maxilla in Monkey No. 6.

The maxillary molars tipped distally with respect to the maxilla in Monkey No. 6. The maxillary incisor tipped "counterclockwise" with respect to the maxilla 7.83° while tipping "clockwise" 9.44° with respect to the cranial base. This difference resulted from "clockwise" rotation of the maxilla itself relative to the cranial base as previously mentioned.

In Monkey No. 7 the angular assessments were all within the range of measurement error for each angle and supported the coordinate and linear analyses which also demonstrated minimal change following 12 days of heavy extraoral traction in this animal.

Figure 76. Overall superimposition on basi-sphenoid bone of pre-palatal expansion and immediate post-palatal expansion cephalograms of Monkey No. 2 of the palatal expansion group. The tracings are superimposed on the outline of the basi-sphenoid bone with the implants in the basi-sphenoid bone registered. Horizontal and vertical changes in the landmarks are shown relative to the axes through Point 1 and Point 2. Implants of the pre-expansion cephalogram are shown as solid and those of the post-expansion cephalogram as open.

MONKEY No. 2
(Palatal Expansion Group)



OVERALL SUPERIMPOSITION

Figure 76.

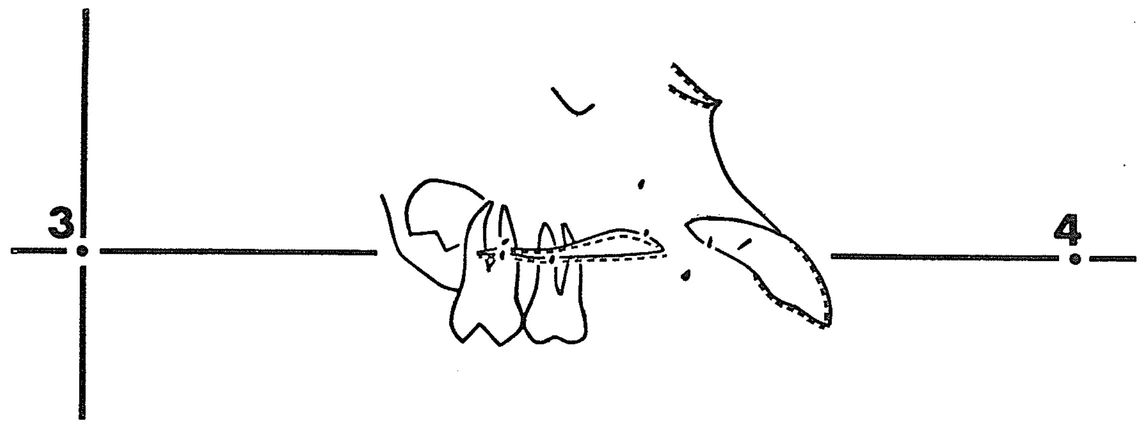
Pre-palatal expansion ————

Immediate post-expansion ------------
(14 days)

Figure 77. Maxillary superimposition of pre-palatal expansion and immediate post-palatal expansion cephalograms of Monkey No. 2 of the palatal expansion group. The tracings are superimposed on the implants in the body of the maxilla. Horizontal and vertical changes are shown relative to the axes through Point 3 and Point 4.

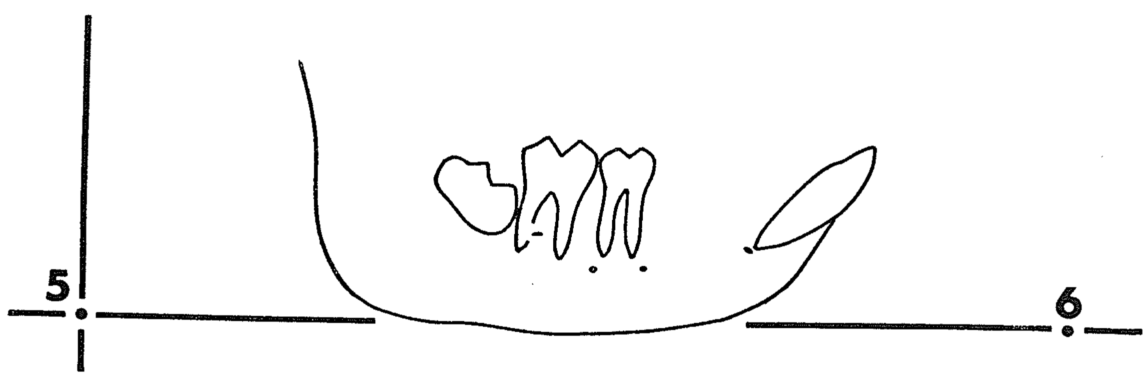
Figure 78. Mandibular superimposition of pre-palatal expansion and immediate post-palatal cephalograms of Monkey No. 2 of the palatal expansion group. The tracings are superimposed on the mandibular implants. Note that in this short period, no changes were evident.

MONKEY No. 2
(Palatal Expansion Group)



MAXILLARY SUPERIMPOSITION

Figure 77.



MANDIBULAR SUPERIMPOSITION

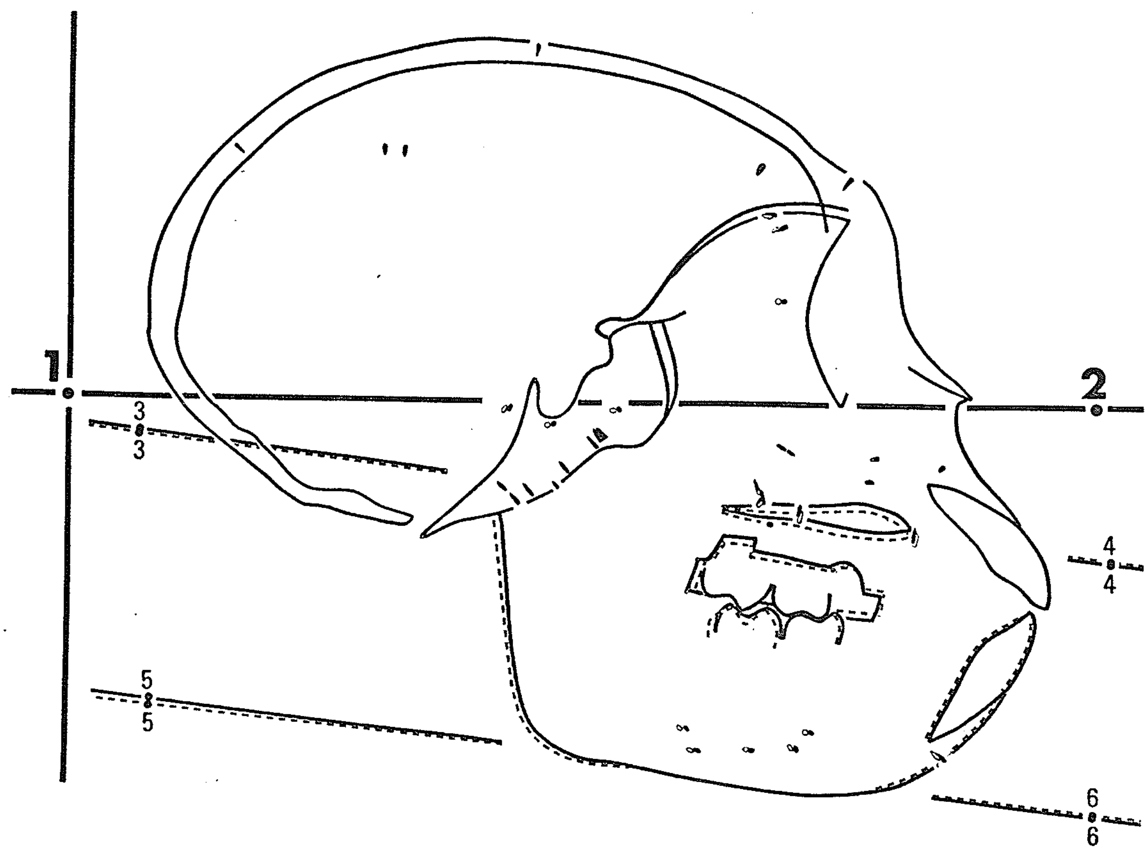
Figure 78.

Pre-palatal expansion ————

Immediate post-expansion ------------
(14 days)

Figure 79. Overall superimposition on basi-sphenoid bone of pre-palatal expansion and immediate post-palatal cephalograms of Monkey No. 6 of the palatal expansion group. The tracings are superimposed on the outline of the basi-sphenoid bone with the implants in the basi-sphenoid bone registered. Horizontal and vertical changes in the landmarks are shown relative to the axes through Point 1 and Point 2.

MONKEY No. 6
(Palatal Expansion Group)



OVERALL SUPERIMPOSITION

Figure 79.

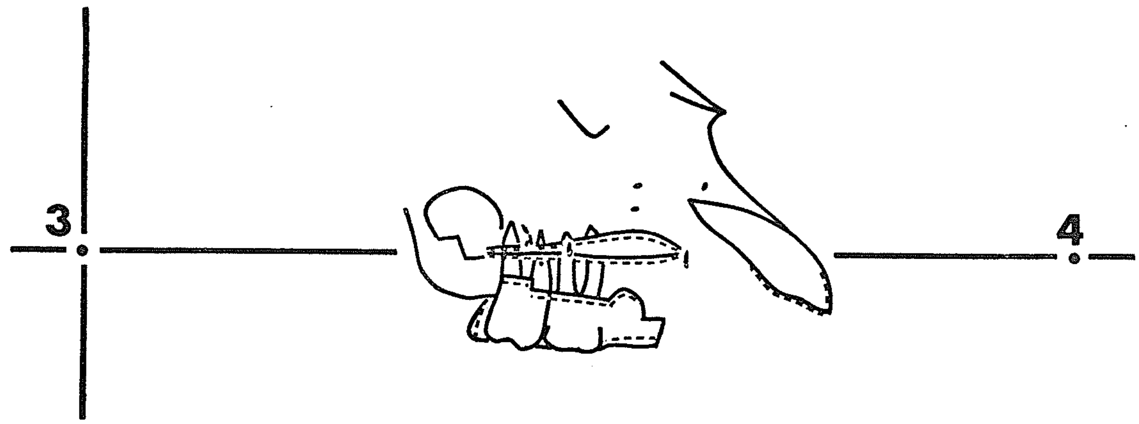
Pre-palatal expansion ————

Immediate post-expansion (12 days) ------------

Figure 80. Maxillary superimposition of pre-palatal expansion and immediate post-palatal expansion cephalograms of Monkey No. 6 of the palatal expansion group. The tracings are superimposed on the implants in the body of the maxilla. Horizontal and vertical changes are shown relative to the axes through Point 3 and Point 4.

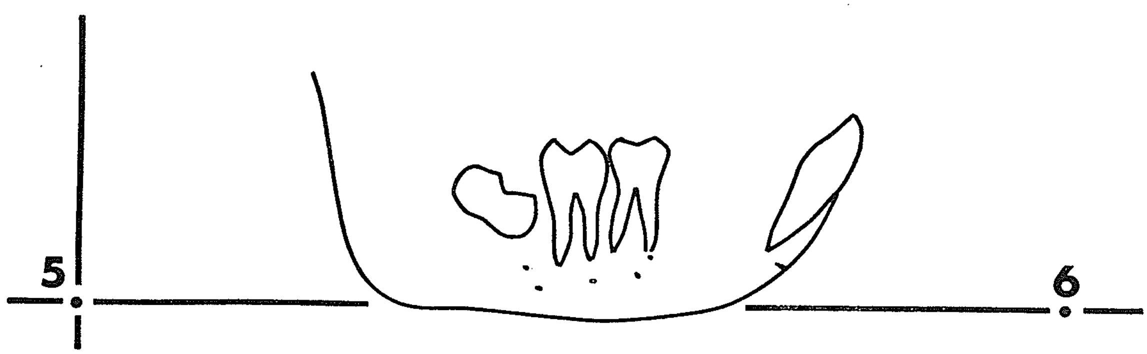
Figure 81. Mandibular superimposition of pre-palatal expansion and immediate post-palatal expansion cephalograms of Monkey No. 6 of the palatal expansion group. The tracings are superimposed on the mandibular implants. Note that in this short period, no changes were evident.

MONKEY No. 6
(Palatal Expansion Group)



MAXILLARY SUPERIMPOSITION

Figure 80.



MANDIBULAR SUPERIMPOSITION

Figure 81.

Pre - palatal expansion ————

Immediate post - expansion ------------
(12 days)

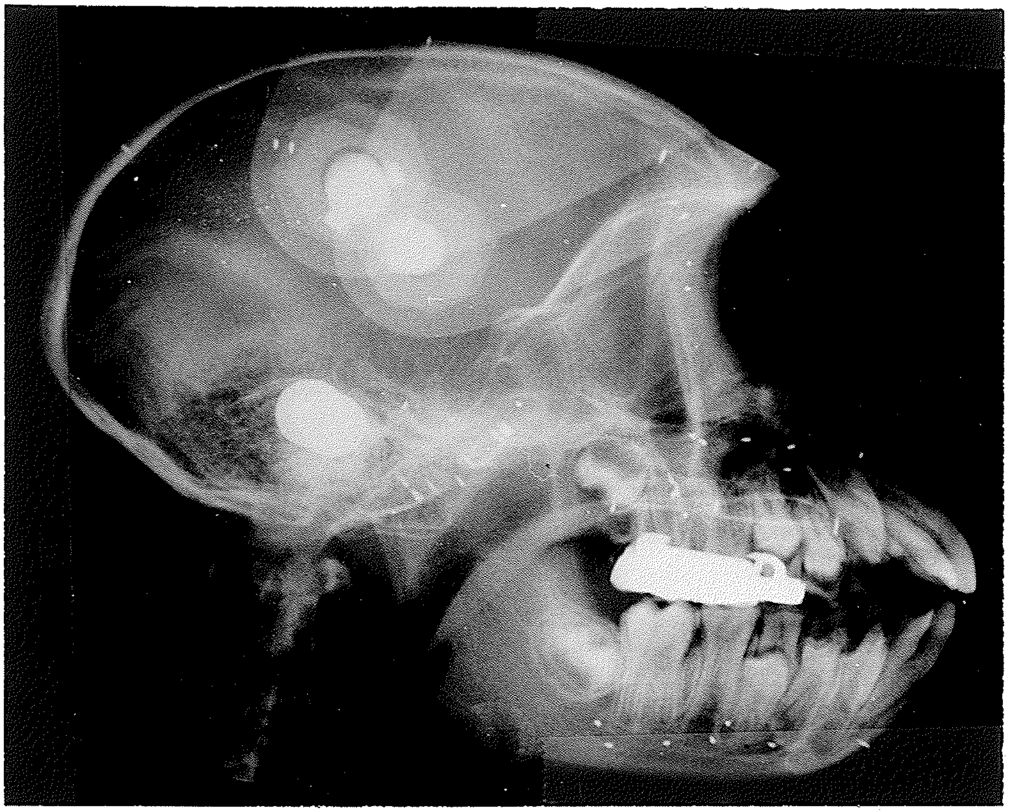


Figure 82. Pre-headgear cephalometric radiograph of Monkey No. 6 of the combination group immediately following rapid maxillary expansion. (Approximate 1:1 photographic reproduction.)

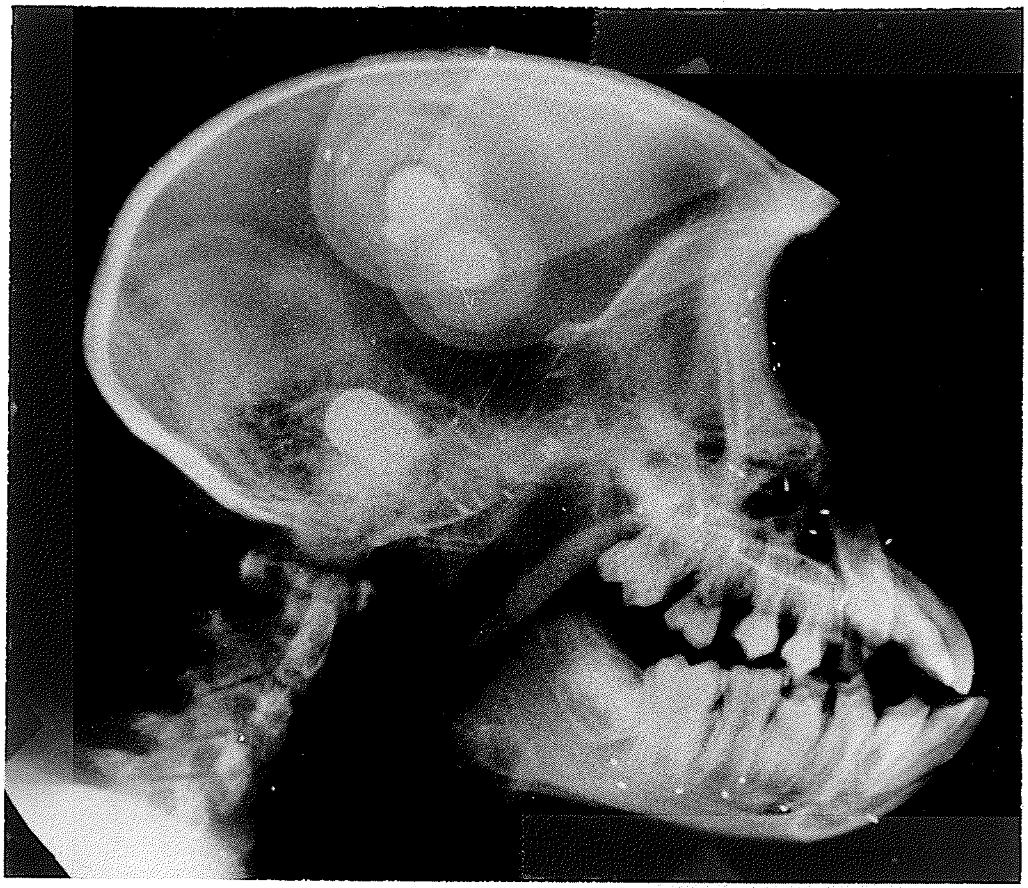
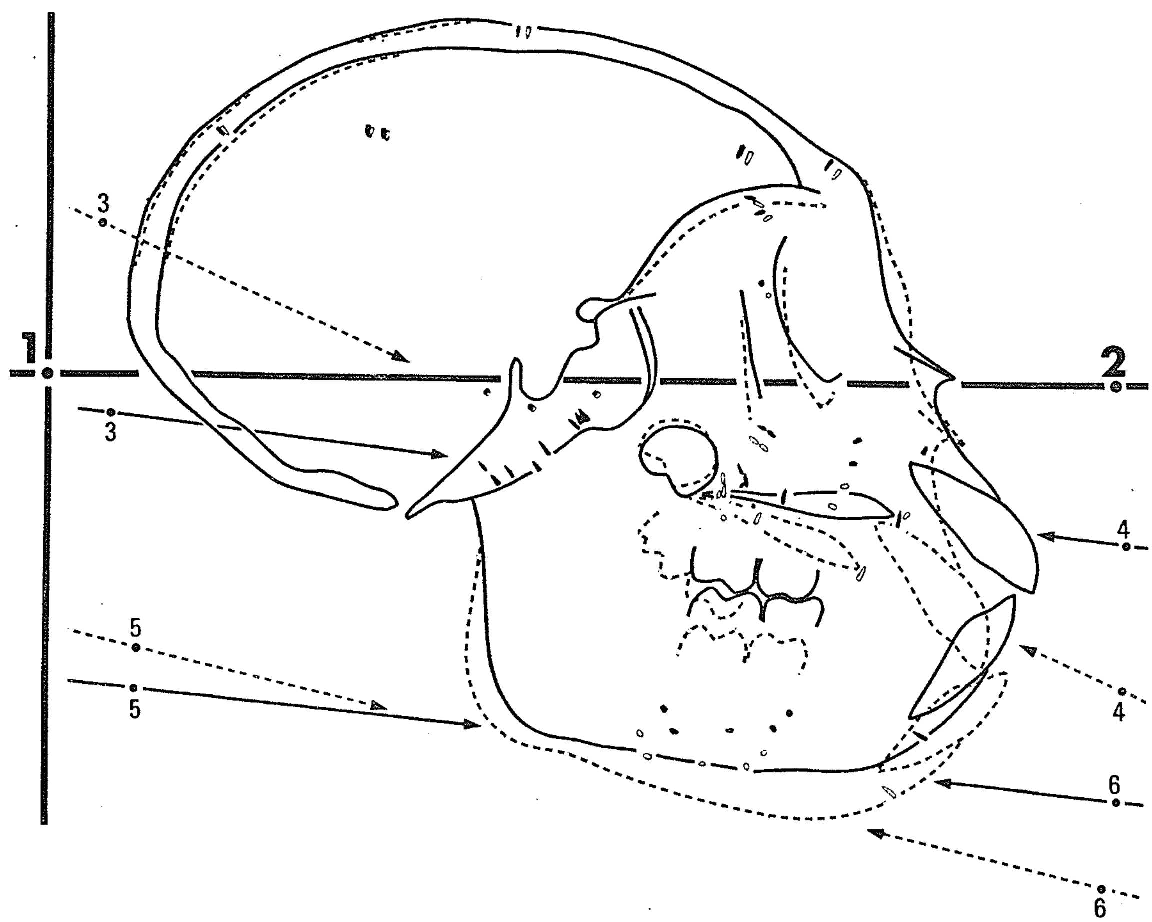


Figure 83. Post-headgear cephalometric radiograph of Monkey No. 6 of the combination group on the 72nd day of extraoral traction. A marked occlusal disproportion was created. Note that the images of the bilateral implants in the frontal bone were exactly superimposed as they were in the pre-headgear cephalogram (Figure 82). (Approximate 1:1 photographic reproduction.)

Figure 84. Overall superimposition on basi-sphenoid bone of pre-headgear and post-headgear (72 days) cephalograms of Monkey No. 6 of the combination group. The tracings are superimposed on the outline of the basi-sphenoid bone with the implants in the basi-sphenoid bone registered. Horizontal and vertical changes in the landmarks are shown relative to the axes through Point 1 and Point 2. Implants of the pre-headgear cephalogram are shown as solid and those of the post-headgear cephalogram as open.

MONKEY No. 6
(Combination Palatal Expansion) Plus Headgear Group)



OVERALL SUPERIMPOSITION

Figure 84.

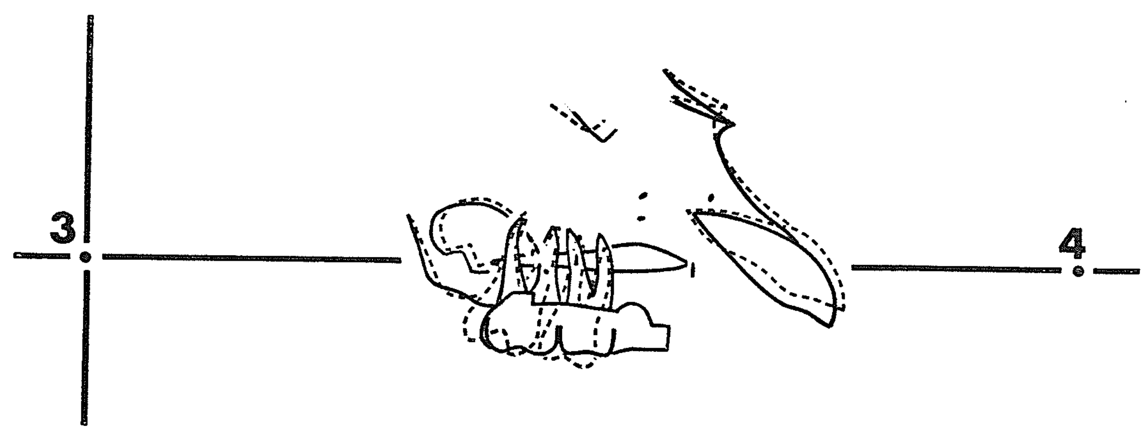
Post- palatal expansion
Pre - headgear ————————

Post- palatal expansion
Post- headgear (72 days) ----------------

Figure 85. Maxillary superimposition of pre-headgear and post-headgear cephalograms of Monkey No. 6 of the combination group. The tracings are superimposed on the implants in the body of the maxilla. Horizontal and vertical changes are shown relative to the axes through Point 3 and Point 4.

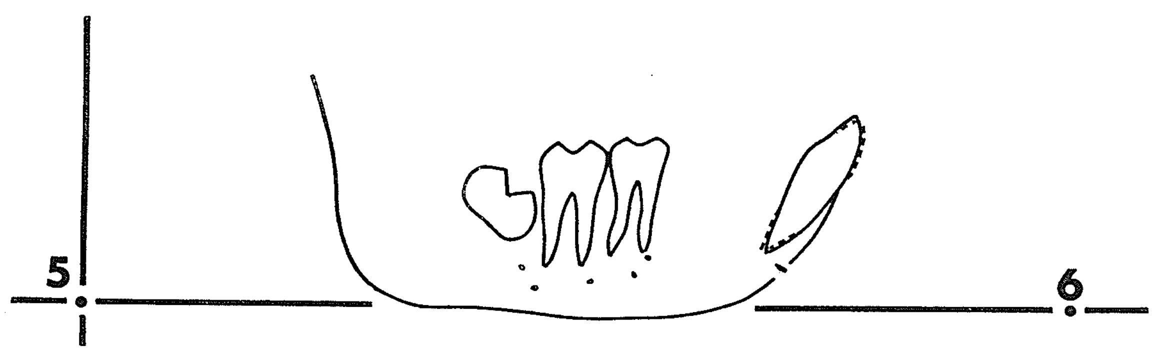
Figure 86. Mandibular superimposition of pre-headgear and post-headgear cephalograms of Monkey No. 6 of the combination group. The tracings are superimposed on the mandibular implants. Horizontal and vertical changes are shown relative to the axes through Point 5 and Point 6.

MONKEY No. 6
(Combination Palatal Expansion) Plus Headgear Group)



MAXILLARY SUPERIMPOSITION

Figure 85.



MANDIBULAR SUPERIMPOSITION

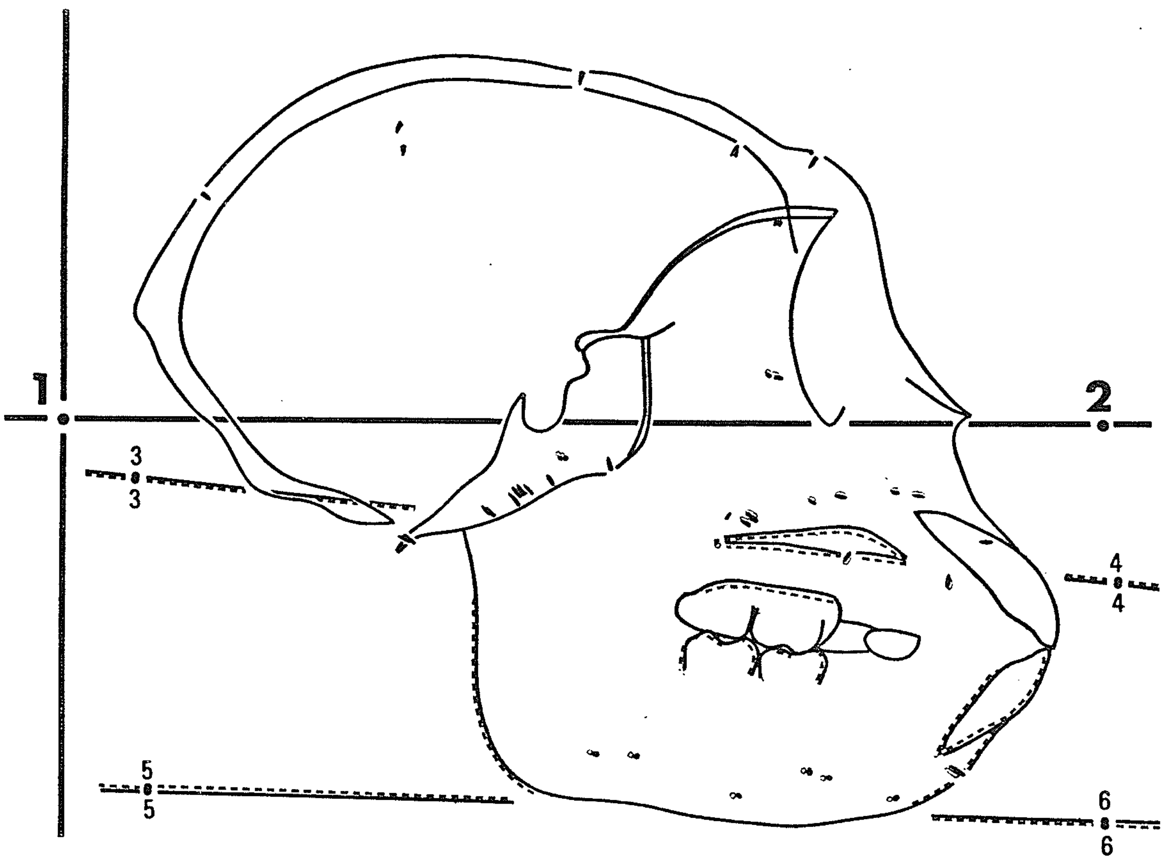
Figure 86.

Post- palatal expansion
Pre - headgear ————————

Post- palatal expansion
Post- headgear (72 days) ....

Figure 87. Overall superimposition on basi-sphenoid bone of pre-palatal expansion and immediate post-palatal expansion cephalograms of Monkey No. 7 of the palatal expansion group. The tracings are superimposed on the outline of the basi-sphenoid bone with the implants in the basi-sphenoid bone registered. Horizontal and vertical changes in the landmarks are shown relative to the axes through Point 1 and Point 2. Implants of the pre-expansion cephalogram are shown as solid and those of the post-expansion cephalogram as open.

MONKEY No. 7
(Palatal Expansion Group)



OVERALL SUPERIMPOSITION

Figure 87.

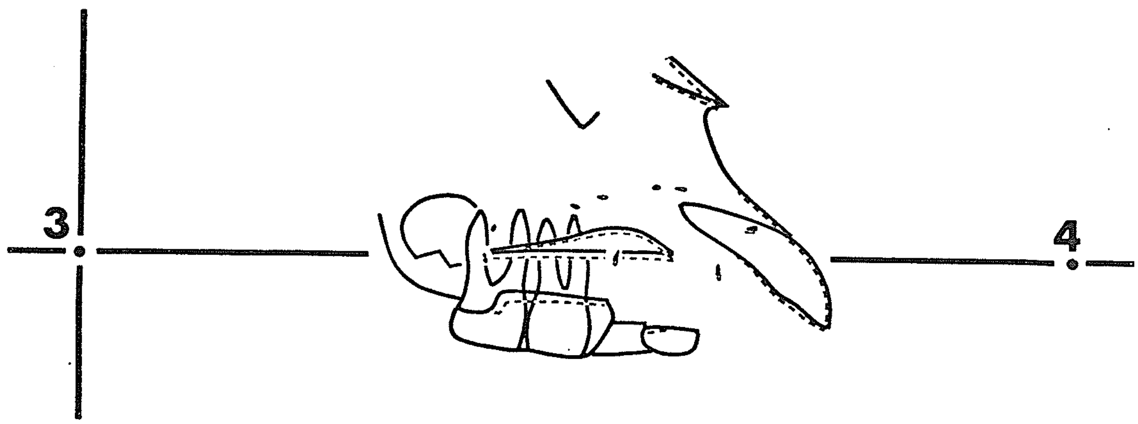
Pre-palatal expansion ———

Immediate post-expansion ....
(12 days)

Figure 88. Maxillary superimposition of pre-palatal expansion and immediate post-palatal expansion cephalograms of Monkey No. 7 of the palatal expansion group. The tracings are superimposed on the implants in the body of the maxilla. Horizontal and vertical changes are shown relative to the axes through Point 3 and Point 4.

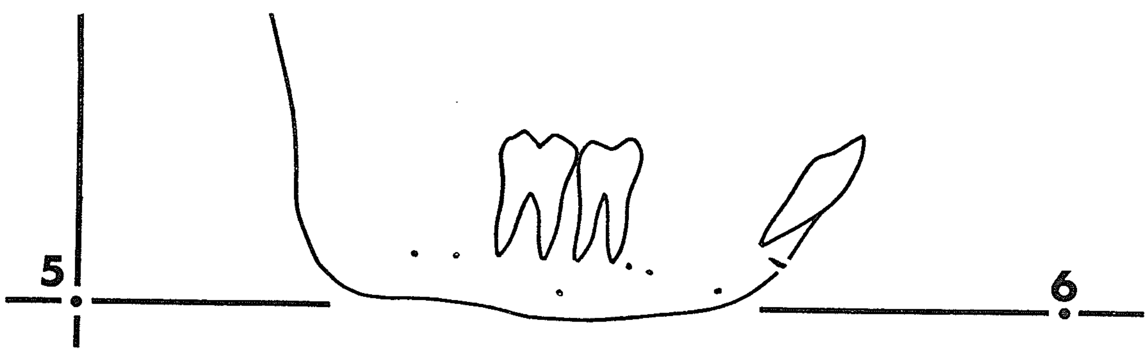
Figure 89. Mandibular superimposition of pre-palatal expansion and immediate post-palatal expansion cephalograms of Monkey No. 7 of the palatal expansion group. The tracings are superimposed on the mandibular implants. Note that in this short period, no changes were evident.

MONKEY No. 7
(Palatal Expansion Group)



MAXILLARY SUPERIMPOSITION

Figure 88.



MANDIBULAR SUPERIMPOSITION

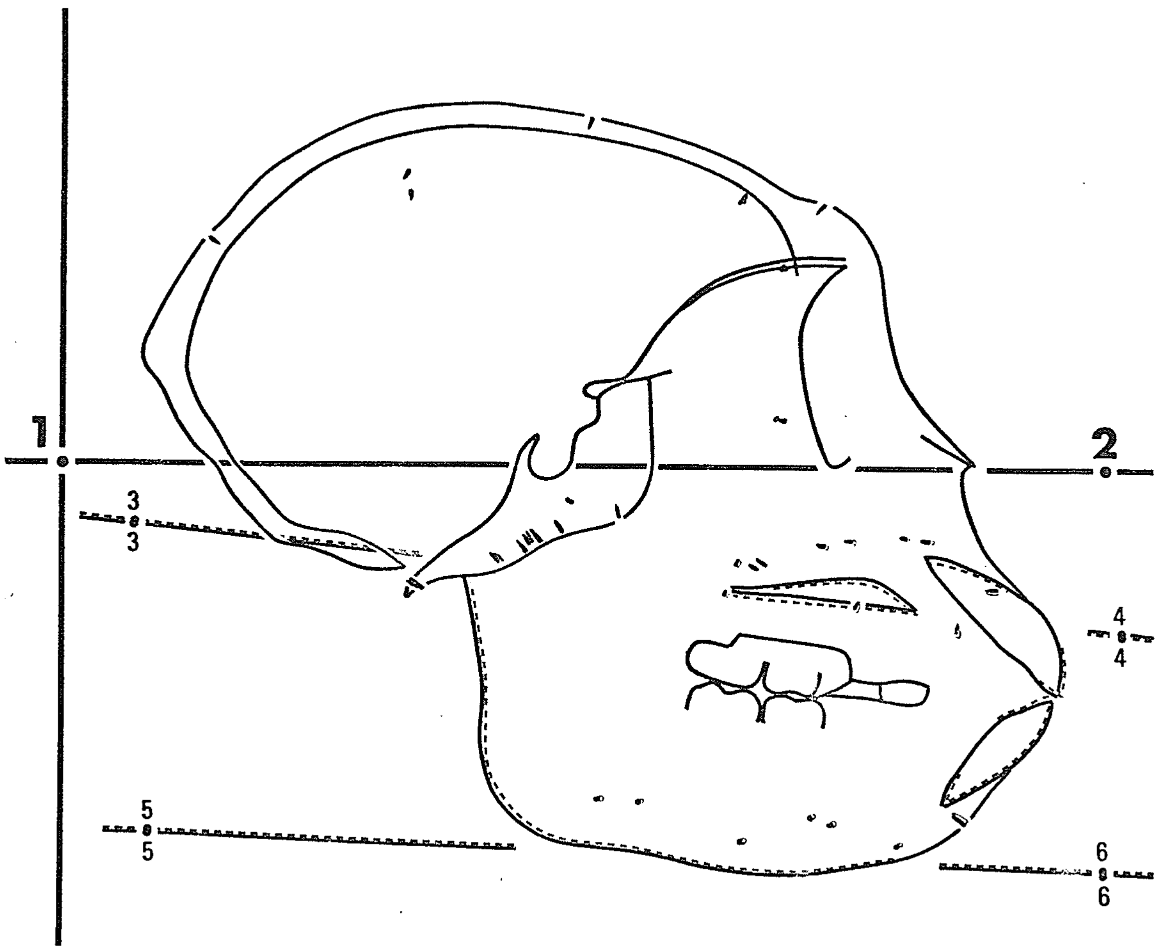
Figure 89.

Pre-palatal expansion ————

Immediate post-expansion ------------
(12 days)

Figure 90. Overall superimposition on basi-sphenoid bone of pre-headgear and post-headgear (12 days) cephalograms of Monkey No. 7 of the combination group. The tracings are superimposed on the outline of the basi-sphenoid bone with the implants in the basi-sphenoid bone registered. Horizontal and vertical changes in the landmarks are shown relative to the axes through Point 1 and Point 2. Implants of the pre-headgear cephalogram are shown as solid and those of the post-headgear cephalogram as open.

MONKEY No. 7
(Combination Palatal Expansion) Plus Headgear Group)



OVERALL SUPERIMPOSITION

Figure 90.

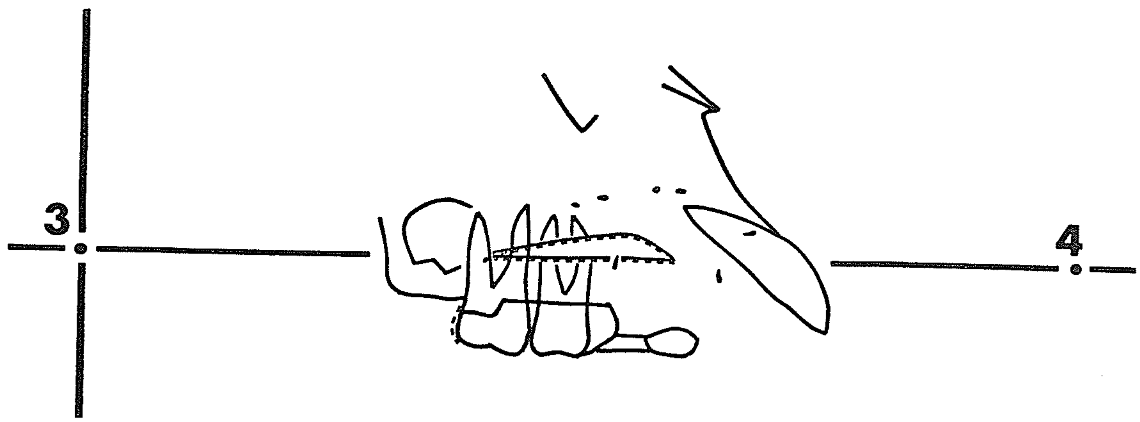
Post- palatal expansion
Pre - headgear ______

Post- palatal expansion
Post- headgear (12 days) ....

Figure 91. Maxillary superimposition of pre-headgear and post-headgear cephalograms of Monkey No. 7 of the combination group. The tracings are superimposed on the implants in the body of the maxilla. Horizontal and vertical changes are shown relative to the axes through Point 3 and Point 4.

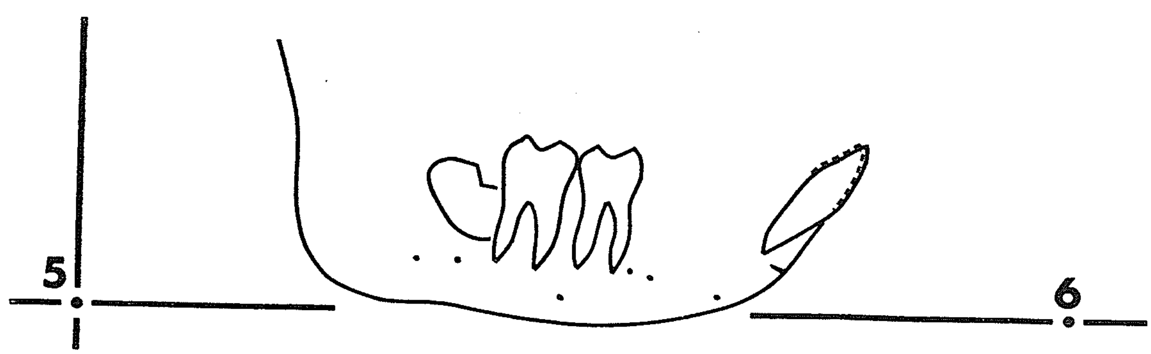
Figure 92. Mandibular superimposition of pre-headgear and post-headgear cephalograms of Monkey No. 7 of the combination group. The tracings are superimposed on the mandibular implants. Minimal changes were evident.

MONKEY No. 7
(Combination Palatal Expansion) Plus Headgear Group)



MAXILLARY SUPERIMPOSITION

Figure 91.



MANDIBULAR SUPERIMPOSITION

Figure 92.

Post- palatal expansion Pre - headgear	――――――――
Post- palatal expansion Post- headgear (12 days)	---------------

CHAPTER V

DISCUSSION

In the present study, simulated "orthopedic" appliance systems were experimentally applied to the maxilla of growing rhesus monkeys. Heavy posteriorly-directed extraoral forces (800 grams per side) alone and in combination with rapid maxillary expansion created marked occlusal disproportions and induced widespread skeletal changes to occur throughout the craniofacial complex of the experimental animals.

Comparison with Previous Animal Studies

Normal Growth of Control Group

During normal growth in the two control animals, the maxilla and mandible translated forward horizontally, with minimal vertical growth, away from the cranial base with approximately twice as much forward movement of the mandibular implants as the maxillary implants. The disproportionate amount of forward translation of the mandible with respect to the maxilla was compensated for by differential migration of the maxillary and mandibular teeth within their respective bones which maintained the normal occlusal interarch relations throughout the growth period. This differential dental migration was in the nature of vertical movement of the mandibular teeth with respect to the mandible in combination with predominantly forward migration of the maxillary teeth with respect to the maxilla.

The changes which occurred during normal growth in the control animals in this study closely followed the description of normal growth of the Macaca monkey presented by Elgoyhen *et al* (1972) and McNamara

(1972). These studies used a much larger sample of Macaca mulatta (rhesus) monkeys and, hence, their findings reinforce the results of the small control sample used in this study.

Harvold, Chiericic and Vargevik (1972) fitted acrylic blocks in the palatal vault of normal rhesus monkeys which rotated the postural position of the mandible inferiorly, resulted in increased downward and forward migration of the maxillary teeth and created Class II malocclusions after a six month interval. Contrary to these findings, in the present study, the control animal fitted with an acrylic appliance in the palatal vault maintained normal occlusal relations throughout the study period and demonstrated minimal difference in craniofacial growth pattern in comparison with the control animal without an appliance. Perhaps the longer observation period and size of the acrylic block used in the respective studies accounted for the different results.

The changes in the experimental animals in the present study, in general, differed so markedly from the changes accompanying normal growth of the control animals that the experimental changes can be attributed to application of the various force systems.

Headgear Group

In the headgear group, there was no doubt that the effects of extraoral forces applied to the maxillary teeth extended beyond the dentoalveolar area. The effects of these external forces extended throughout the craniofacial skeleton and altered the relative positions of the facial and cranial bones to each other.

The heavy extraoral distal forces resulted in a posterior displacement of the facial bones with a concomitant marked increase in vertical facial dimensions. The maxillary complex rotated downwards and backwards in a "clockwise" direction with respect to the posterior cranial base when viewed from the right side of the skull. The downward rotational movement of the upper facial complex caused a similar backward rotation to occur in the mandible. Similar observations but of lesser degree were reported by Sproule (1968) in the facioskeleton after application of 150 to 300 grams of cervical traction to three Macaca monkeys. Johnson (1968) applied 50, 100 and 150 grams of cervical traction to three Macaca monkeys and found minimal change in the facial growth pattern. Hence, it appears that the magnitude of the applied force is a major factor with respect to the magnitude of skeletal change resulting from extraoral traction to the monkey.

High-pull extraoral traction has also been applied to the maxilla of the Macaca monkey. Fredrick (1969) applied 300 grams per side of high-pull traction to two growing Macaca monkeys and reported a "clockwise" rotation of the facial complex but to a lesser degree than that reported by Sproule (1968) using cervical traction. Meldrum (1971) also applied 300 grams per side of high-pull traction to three growing Macaca monkeys and reported slight upward and backward displacement of the facial implants. Comparison of the results of the present experiment with the findings of these studies suggest that the direction of extraoral force application has an effect on the nature of the skeletal response in the monkey.

In the present study, the facial bones rotated differentially with respect to each other and to the cranial base. Sproule, similarly, reported that the zygomatic and maxillary bones rotated independently of each other in a "clockwise" direction following cervical traction.

However, following high-pull traction, Fredrick reported that the maxillary and zygomatic bones moved upward and backward together while Meldrum reported that the maxillary implants showed the most movement.

Although these previous studies did not undertake quantitative analysis of the skeletal changes with estimation of the errors of the cephalometric technique; nonetheless, these studies support the findings of the present study and indicate that the facial bones of the monkey can be altered by extraoral forces.

In addition to affecting the facial bones, heavy extraoral force application in this experiment resulted in a "clockwise" rotation of the frontal bone complex enclosing the orbits and forming both the roof of the orbits and floor of the anterior cranial fossa. This movement was demonstrated to occur in Monkey No. 3 of the headgear group and was thought to have occurred in Monkey No. 4 of the headgear group and Monkey No. 6 of the combination group. In these latter two animals the errors of the various methods of analysis approached the observed degree of rotation. This "clockwise" rotation of the roof of the orbits occurred in relation to the basi-sphenoid bone and posterior cranial base. The previous headgear studies on the monkey by Johnson (1968), Sproule (1968), Fredrick (1969) and Meldrum (1971) did not demonstrate any effect of the extraoral forces on the frontal bone complex forming the anterior cranial fossa. The studies by Sproule (1968) and Fredrick (1969) superimposed serial films on the anterior outline of sella as an area of registration with superimposition along the outlines of the anterior cranial fossa and hence, any changes which may have occurred between the anterior and posterior cranial base were masked in their studies.

Cutler (1972) reported on the effects of a modified Milwaukee brace on five growing Macaca monkeys and found that the entire dentofacial complex was displaced in a superior direction relative to the registration of the cranial base. The orbital processes appeared to move upwards and forwards. Hence, an extraoral force system different from that used in the present study has been reported to cause changes in the anterior cranial base. Although these changes reported by Cutler were in the opposite direction to those reported in this study, they support the contention that the frontal bone complex is susceptible to changes resulting from forces applied at distant sites.

The bones comprising the cranial vault were altered in the animals receiving extraoral traction. In Monkey No. 3 the most dramatic cranial deformation was evident. In this animal the cranial bones were affected to such a degree that the radiographs clearly demonstrated physical separation at the sutures and bodily translation of the parietal bone with respect to the frontal and occipital bones in a manner similar to, but to a lesser degree than, that reported by Moloy (1942) during birth molding. Localized remodeling at the sutural articulations were assumed to have occurred and allowed for this movement.

Of the previous headgear studies in the monkey, both Sproule (1968) and Meldrum (1971) discussed possible changes in the cranial vault. Sproule (1968) studying cervical traction on the Macaca reported that in the overall superimposition two experimental monkeys showed abnormal changes in the outline of the cranial vault. Sproule assumed that the sphenoid bone used for registration in the overall superimposition was affected rather than the cranial vault. Sproule accepted Wieslander's concept (1963) that the spatial relationship of the sphenoid bone in human material may possibly be affected by extraoral traction. Sproule found no abnormal histologic changes in the bones of the cranial vault.

On the other hand, Meldrum (1971) studying occipital traction in Macaca monkeys reported a compression of the occipital region of the cranial vault where the acrylic helmet had gained its anchorage. Other aspects of the cranial contour increased in size normally.

Cutler (1972) reported morphologic alterations in the posterior part of the cranium in Macaca monkeys during a study of the effects of a modified Milwaukee brace. The cranial alteration occurred in the area where the occipital bone had been subjected to pressure from the posterior pad of the brace and resulted in a ventral relocation of the posterior cranial fossa. Endocranial bone deposition plus a moderate degree of sutural readjustment at the articulations of the occipital and parietal bones was considered responsible for the magnitude of the observed changes.

The fact that the cranial bones can be affected is not a surprising finding. Since the applied extraoral force is reciprocal in nature, it is just as likely to have orthopedic effects at its site of application at the back of the head as it is at the front of the head.

In the present study marked occlusal disproportions were created predominantly as a result of posterior movement of the maxilla and adjacent bones rather than posterior movement of the teeth within the maxilla. Using less force (150 to 300 grams per side) Sproule reported a greater proportion of tooth movement to skeletal movement but less dramatic occlusal change as in the present study after a similar 103 day period. The intraoral appliance used by Sproule was wired to all the maxillary teeth but only cemented to the first permanent molars. Johnson using much less extraoral force (50 to 150 grams) reported essentially dental changes with minimal skeletal change. Johnson banded only the maxillary first molars and reported slight distal tipping and slightly less forward movement of the maxillary first molars in the experimental animals compared to the controls. Thus, it appears that as the magnitude of the extraoral force increases and as the number of anchor teeth increases, the ratio of "bone movement" to "tooth movement" increases in the Macaca monkey. Further, it appears that the greater the magnitude of applied force to the monkey, the greater the change in occlusal relations seen clinically.

Palatal Expansion Group

Although the radiographic changes which occurred during rapid maxillary expansion were minimal and most were within the possible range of measurement error, nonetheless, the changes in this study tended to support many findings previously reported. Analysis of the lateral cephalograms demonstrated that the palatal outline and palatal implants moved downwards in the overall superimposition on the cranial base while the maxillary buccal segments and implants in the buccal plate of the body of the maxilla above these teeth either remained constant or else moved upwards. This observation may be interpreted as consistent with the findings of Starnbach et al (1965) who found by metric analysis of soft tissue radiographs of coronal sections of the maxilla of the monkey that the halves of the maxilla arced laterally during palatal expansion with the free margins of the palatal processes dropping inferiorly. This interpretation was further supported in the present study by superimposition of serial tracings on the implants in the cortical plate of the body of the maxilla above the apices of the molar teeth. This demonstrated that the roof of the palate and palatal implants dropped inferiorly with respect to these implants in the body of the maxilla.

In the present study, no measurable forward translation of the implants in the body of the maxilla relative to the cranial base was recorded. Similarly, a previous radiographic-cephalometric study by Sugiyama (1968) on the effects of palatal expansion on the Macaca monkey reported no significant antero-posterior movement of the maxilla as indicated by the movement of prosthion. Thus it would appear that in the Macaca monkey the orthopedic effect of rapid palatal expansion is expressed predominantly in the lateral dimension with minimal concomitant antero-posterior movement of the maxilla resulting from adjustments at the sutural articulations during the lateral rotation of the maxillary halves.

Following palatal expansion in the present study, the mandible rotated slightly backward apparently due to occlusal interferences. The post-expansion records were taken after the maxillary buccal segments had been expanded from a normal to an almost complete crossbite relationship with the lower arch, although cusp tip contact was still present. Contrary to this finding, Sugiyama (1968) reported a decrease in the mandibular plane angle. Sugiyama suggested that the maxillary buccal segments had moved in an upward direction as they moved from a normal to a buccal crossbite relationship in the experimental monkeys which had the effect of intruding the buccal segments resulting in a decrease in the mandibular plane.

Slight movement of the implants in the zygomatic bone and zygomatic process of the temporal bone with respect to the cranial base accompanied the palatal expansion procedure in the present study. However, the movement was within the possible range of measurement error committed during analysis. This finding is consistent with the previous studies by Starnbach et al (1965), Youngquist (1962) and Gardner and Kronman (1971) who reported evidence of reorientation of the facial bones at the suture accompanying palatal expansion in monkeys.

Gardner and Kronman (1971) in a gross anatomical investigation on the Macaca monkey reported distant effects of rapid palatal expansion including opening of the spheno-occipital synchondrosis and disruption of the mid-sagittal, fronto-parietal and lambdoid cranial sutures. Contrary to these findings, no measurable changes were found in the skeletal structures beyond the facioskeleton in the present study or in the study by Brossman (1970). The conflict in findings is probably associated with the sequence of activation and amount of palatal expansion carried out as well as the limitations of the experimental methods used to study the skeletal changes in the respective studies.

Combination Group

The study of the combination group did not support the contention that rapid midpalatal expansion enhances the susceptibility of the maxilla to further orthopedic manipulation by application of heavy posteriorly-directed extraoral forces to the monkey. Murray (1971) in a previous study in this laboratory, used a similar appliance and the same activation sequence as used in the combination group in this study on Macaca monkeys of comparable age and reported that the midpalatal suture opened between the 4th and 7th day of expansion. Hence, it is probable that the midpalatal suture had opened in Monkeys No. 6 and No. 7 in this study after 12 days of expansion. Starnbach et al (1965) also used a similar appliance on Macaca monkeys and reported a reorientation of the facial bones at the sutures as well as increased cellular activity and increased vascularity at the sutures. Therefore, it is also probable that after 12 days of expansion in Monkeys No. 6 and No. 7 a similar stated existed in these sutures at the time of application of the extra-oral forces. To ensure that the integrity of the facial articulations was affected and that heavy expansive forces were transmitted throughout the structural framework of the facioskeleton, after the application of 28 ounces (800 grams) per side of distal traction to each monkey, the palatal expansion appliances were simultaneously activated at twice the previous rate for three additional days.

No immediate change occurred in either monkey following headgear application. Further, after 72 days of continuous traction in Monkey No. 6 similar or slightly lesser skeletal changes were measured compared to the two headgear group animals, respectively. Much less change in facial appearance occurred in Monkey No. 6 than in the animals of the headgear group. This difference in change of the soft tissue profile was associated with the forward movement of the unbanded maxillary incisors in Monkey No. 6 compared to the marked posterior movement of the banded maxillary incisors in the animals in the headgear group with consequent increased change of the oro-facial soft tissues in these animals.

Therefore, it must be concluded that rapid palatal expansion does not enhance the response of the facial skeleton of the monkey to further orthopedic manipulation in a posterior direction.

Consideration of the "Orthopedic" Response

This study has shown that in a small sample of monkeys very heavy extraoral forces caused the facial bones and even the cranial bones to move spatially with respect to each other in the antero-posterior dimension. Although no conclusions can be made as to the precise changes which occurred at the cellular level and which accompanied the radiographic changes, speculation as to the mechanism by which the skeletal changes occurred may be made.

Previous studies on the effects of application of laterally-directed "orthopedic" forces to the monkey during rapid maxillary expansion have shown the sutures to be sites of adjustment (Youngquist, 1962; Starnbach et al 1965; Gardner and Kronman 1961). Youngquist, (1962) measured the physical movement of the facial bones during rapid maxillary expansion in the monkey by placing strain gauges across the zygomatico-temporal suture. A load cell transducer measured the accumulated forces in the palatal appliance. Physical movement of the zygomatic and temporal bones at the facial sutures was assumed responsible for the dissipation of the forces applied to the maxilla as measured in the palatal appliance. From the nature of the radiographic changes in the present study, it appears that similar physical adjustments occurred at the facial sutures following application of posteriorly-directed extraoral forces in the monkey. Thus it is probable that the sutures in areas of abutement of adjacent bones are the sites of major orthopedic adjustment. However, the precise manner by which the transmitted forces induced the changes to occur is uncertain.

Following the termination of active extraoral force application in Monkey No. 3, considerable dental and skeletal recovery occurred during a short 26 day observation period. The maxillary, zygomatic, frontal and cranial vault bones all clearly demonstrated recovery to a certain extent with bodily movement of these bones toward their original positions. During a similar interval of time in the control animals, minimal skeletal change occurred.

The factors responsible for this initial recovery are a matter of speculation. The relapse of the skeletal structures may be explained as resulting from recovery from either bone deformation or sutural connective tissue compression accompanying the relief of the internal stresses created in the skeleton by the extraoral "orthopedic" appliance. Although the animal was sacrificed after a 26 day observation period, and hence, long-term cephalometric documentation was not available, it is reasonable to assume that the recovery observed was the initial recovery from bone deformation or soft tissue compression at the sutures and that additional relapse was unlikely. This reasoning parallels the rationale presented by Isaacson and Zimring (1965) on human material who found an initial rapid phase of relapse to occur following rapid palatal expansion when the internal accumulated stresses were not completely dissipated. Isaacson and Zimring suggested that load decay occurred through movement of the skeletal structures and recommended rigid retention following rapid palatal expansion until the articulations reached equilibrium as indicated by decay of the loads stored in the palatal appliance.

Cutler (1972) studying the effects of a modified Milwaukee brace on growing Macaca monkeys allowed two animals to undergo post-treatment observation periods of 29 and 135 days respectively. In general, Cutler reported a reversal of the changes noted during the experiment with both dental and skeletal recovery evident. Cutler thought that possibly an initial compensatory spurt of growth had occurred during recovery; however, this was not substantiated. The present study using a different force system, did show a marked initial compensatory spurt of skeletal recovery following removal of "orthopedic" forces.

It may be speculated that the susceptibility of the nasomaxillary complex to orthopedic movement using extraoral forces is related to maturational factors governing the resistance of the facial and cranial articulations to these external forces. Isaacson and Murphy (1964) have suggested that with respect to palatal expansion in humans, the effectiveness of the orthopedic procedure in expanding the maxillary halves laterally is dependent upon the age at which the facial sutures involved, begin to offer more resistance to the expansion procedure. This maturational factor appears to be associated with the fusion of the midpalatal and circum-maxillary sutures. Hence, it may be that the important criteria with respect to orthopedic response using either rapid palatal expansion or heavy extraoral force application is the responsiveness of the facial sutures. Once the facial sutures start to ossify, their response to either laterally-directed expansive forces or distally-directed extraoral forces is probably greatly reduced. This reasoning is consistent with the clinical findings which indicate a marked decrease in response to orthopedic forces in older patients with minimal growth potential.

On the other hand, Meikle (1970) created occlusal disproportions in adult Macaca monkeys using Class II intermaxillary forces and reported that the maxillary complex was displaced downward and backward which indicated that the facial sutures do have adjustive capabilities in the adult. McNamara (1972) reported that following experimental functional anterior repositioning of the mandible using intraoral occlusal splints in the Macaca monkey osseous adaptations occurred throughout the dentofacial complex. However, the extent of the specific skeletal adaptations depended upon the level of maturation of the animal. It would seem logical that adjustments do occur at the sutures and that their responsiveness to extraoral forces is probably reduced with increased skeletal maturation.

Applications to Clinical Practice

Comparison of the response which occurred in the Macaca monkey with other primate species, particularly man, should be made with caution as morphological and physiological differences between these species exist. Nonetheless, the close evolutionary dental and skeletal proximity of the Macaca monkey to man does permit comparison of the experimental findings with the human clinical situation.

Occlusal disproportions and skeletal disharmonies were created in the experimental animals. The monkeys presented "normal" skeletal and dental relations and were made "abnormal." In the clinical situation the reverse situation exists. With these limitations in mind, consideration will be given to the results of this study with respect to findings of clinical investigations.

Clinical studies by Klein (1957), Newcomb (1958), Blueher (1959) and Ricketts (1960) on the effects of extraoral cervical traction reported findings which included a marked downward tipping of the anterior part of the palatal plane, a reduction in facial convexity, and an inhibition of the normal forward movement of the anterior nasal spine. Similar effects were also seen to occur in the monkey following headgear application but to a much greater extent.

Wieslander (1963) and later Sandusky (1965) inferred that headgear therapy in growing children appeared to result in a "clockwise" rotation of the sphenoid bone. Wieslander noted that the spheno-ethmoidal plane rotated in relation to the line joining Basion to CBR point. Sandusky reported that the line tangent to the planum sphenoidale rotated with respect to the line joining sella to nasion. Thus, the sphenoid bone demonstrated angular change relative to the anterior cranial base. These investigators suggested that the force was transmitted from the maxilla to the pterygoid buttress resulting in rotation of the sphenomaxillary complex relative to the rest of the cranium.

In the present study, the anterior cranial base of the monkey, as represented by the frontal bone forming the roof of the orbits, was rotated "clockwise" in relation to the sphenoid bone by heavy extraoral forces. Therefore, the frontal bone rotated in the same direction as the maxilla relative to the sphenoid bone. It appears that similar anatomical changes occurred in the monkey as in the human; however, the changes were interpreted in the present study to indicate rotation of the frontomaxillary complex relative to the sphenoid bone rather than rotation of the sphenomaxillary complex relative to the rest of the cranium.

Poulton (1959, 1964, 1967), Kuhn (1968), and Merrifield and Cross (1970) reported that cervical traction had the potential to elongate posterior molar height resulting in backward rotation of the mandible with consequent increase in vertical facial dimension. Haas (1970) stated that cervical gear could increase molar height, by either tooth movement or by movement of the entire maxilla downward at the back, and consequently rotate the mandible downward and backward. In open bite cases, Schudy

(1963, 1964, 1965 and 1968) and Isaacson et al (1971) stated that such treatment would accentuate the open bite tendency.

In the present study, extraoral traction slightly cervical to the occlusal plane of the monkey resulted in marked increase in vertical facial dimensions. However, the increase in vertical facial height was due to "clockwise" rotation of the upper facial complex with downward movement of the anterior part of the maxilla and consequent inferior rotation of the mandible. Although the mandible rotated downward and backward, nonetheless, the vertical overbite of the incisors, which were in anterior crossbite following headgear, was increased. This increased overbite was associated with the downward tipping of the anterior part of the maxilla. The maxillary first molars moved downward relative to the cranial base in Monkey No. 4 of the headgear group and Monkey No. 6 of the combination group. However, the major cause of increased vertical dimension in all monkeys subjected to extraoral traction was downward rotation of the anterior part of the maxilla.

In the clinical situation, Graber (1969) stated that extremely heavy forces corrected dental and skeletal malrelationships in the antero-posterior dimension by restraining forward maxillary growth while continued forward mandibular growth corrected the discrepancy. On the other hand, Watson (1972), reported that mandibular growth during early "orthopedic" headgear treatment may be helpful but not essential, since he found that one-half of his sample exhibited 0 to 1 mm growth from articulare to pogonion. Watson stated that "orthopedic maxillary movement appeared to occur independent of growth - in a child with growth potential."

The findings of the present study demonstrated that the occlusal disproportion experimentally induced by heavy extraoral force application occurred independent of forward mandibular growth. The malocclusions and anterior crossbites were not created by continued forward growth of the mandible while forward maxillary growth was restrained. On the contrary, the occlusal discrepancies were created in growing Macaca monkeys by posterior movement of the upper facial bones and teeth irrespective of forward mandibular growth. That is, forward mandibular growth did not contribute to the creation of the malocclusion. Application of this finding in the monkey to the human clinical situation would suggest that heavy extraoral forces may bring about antero-posterior occlusal corrections in growing children in a similar manner, independent of forward mandibular growth, by orthopedically moving the upper facial structures in a posterior direction.

Graber, Chung, Aoba (1967), Graber (1969), Haas (1970), Armstrong (1971), Sanders (1971) and Watson (1972) have advocated the use of very heavy extraoral forces to the maxilla to effect "orthopedic" change and elicit more dramatic occlusal correction. These clinicians used up to 5 pounds per side (10 pounds to the maxilla) of extraoral force and suggested that the greater the force, the greater the clinical response. The force level of the extraoral force used on the monkey in this study was 28 ounces per side (3 1/2 pounds to the maxilla) and resulted in very dramatic and widespread craniofacial changes and marked changes in occlusal relations. As the size of the head of the monkey was proportionately much smaller than the head of the human child of comparable maturational age, the force levels applied in this experiment were probably much greater than any used by the above clinicians on patients. The marked changes in this experiment demonstrated the potential of very heavy extraoral forces to elicit orthopedic changes in a biological system anatomically similar to the human. However, the widespread cranial changes which occurred in the monkey should serve not only to indicate the orthopedic potential of very heavy extraoral forces but also to caution against their injudicious use clinically.

Damon (1970) using high-pull headcaps reported that 65% of his sample had difficulty in maintaining a force level of 4 pounds per side and the force was reduced to 3 pounds in these patients. Several patients of his reported headaches, scalp swelling and even loss of hair. Graber (1969) using cervical-pull traction reported that force levels greater than 2 pounds produced soreness in the teeth and jaws or in the cervical region. Armstrong (1971), however, using combination-pull headgear assemblies with forces up to 4 1/2 pounds per side, contended that distribution of the force at the base of anchorage and avoidance of extrusive forces eliminated many untoward effects of heavy force application. On the experimental level, the monkeys in this study occasionally developed ulcers at the edge of the neckstrap where movement of the neck rubbed the skin against the neckstrap material. Previous animal studies using much lighter extraoral forces (Fredrick, 1969) and other types of forces (Cutler, 1970) have reported the occurrence of ulcers and indicate the problem of applying force systems to experimental animals.

Clinical studies by Krebs (1958, 1959), Haas (1961, 1965, 1970), Isaacson and Murphy (1964), Wertz (1968, 1970), Davis and Kronman (1969), Halpern (1969) and Byrum (1970) have used radiographic-cephalometry to investigate the effects of palatal expansion and have offered varying opinions concerning the movement of the maxilla relative to the cranial base following expansion in the human. The general consensus appears to be that although the response may be variable, the maxilla is often translated downwards and forwards. With respect to the palatal plane, Wertz (1970) found that it routinely descended but with variable tipping while Byrum (1970) found that the palatal plane showed little angular change as the maxilla descended uniformly. Davis and Kronman (1969) found opening of the palatal plane in 50% of their cases but that the roof of the vault did not lower. Contrary to this finding, Haas (1970) reported consistent tipping of the palatal plane down at the back and suggested that as the alveolar processes moved laterally with the maxillary halves, the horizontal palatal processes swung inferiorly lowering the cephalometric image of the palatal vault. In the monkey, little effect on the antero-posterior relationship of the maxilla occurred. No movement or else slight upward movement of the implants in the body of the maxilla occurred relative to the implants in the cranial base. However, the outline of the palate dropped downward during rapid palatal expansion and was interpreted to indicate downward movement of the free margins of the palatal processes as the maxillary halves arced laterally. Superimposition on the implants in the body of the maxilla also indicated downward movement of the palatal outline and supported this interpretation. Morphologic differences including fusion of the inter-premaxillary suture and existence of the premaxillary-maxillary suture in the monkey may be related to the varying responses in the two species.

Haas (1970) stated that "the entire maxilla appears to be made more mobile by the palate expansion procedure. At least this could be hypothesized from the reaction of the bone to subsequent manipulation." Haas applied either mesially-directed or distally-directed forces to the maxilla following rapid palatal expansion and suggested that the orthopedic response in many of his patients was increased. The basis of his hypothesis was subjective clinical evaluation of patient response to these forms of combination therapy. In the present experiment, rapid palatal expansion in the monkey did not enhance the susceptibility of the maxilla to posterior orthopedic movement following application of very heavy extraoral distal forces. Quantitative analysis indicated that the response to heavy extraoral force was similar or lesser in animals subjected to the rapid maxillary expansion compared with animals subjected to distal traction alone. A similar response to this combination of forces may occur in the human child.

In summary, it was shown in this experiment that very heavy extraoral forces can induce widespread skeletal changes to occur throughout the craniofacial complex of the Macaca monkey. These heavy forces altered the spatial relationships of the facial and cranial bones and created skeletal and dental disproportions. Although comparison of the response in the monkey with the human clinical situation has definite limitations, nonetheless, the marked skeletal changes in the experimental animals would suggest that in the human child, the skeletal structures are amenable to orthopedic manipulation. Further, the extent of the changes in this experiment indicates the orthopedic potential of very heavy extraoral forces for use in the correction of abnormal skeletal relationships.

CHAPTER VI

SUMMARY AND CONCLUSIONS

This study was undertaken to investigate the effects of various types of heavy "orthopedic" forces on the craniofacial morphology of a small sample of growing monkeys. Seven female Macaca mulatta (rhesus) monkeys in the late mixed dentition stage were divided into a control group, an "orthopedic" headgear group, a rapid maxillary expansion group, and a combination rapid maxillary expansion followed by "orthopedic" headgear group.

Metallic implants were placed in several of the craniofacial bones. A method for precise reorientation of the animals in a cephalostat was developed and serial lateral cephalometric radiographs taken at specific time intervals in all groups.

In the "orthopedic" headgear group, 28 ounces (800 grams) per side of extraoral distal traction, slightly cervical to the occlusal plane, was applied continuously to the maxillary arch for 72 and 103 days respectively in two animals. In addition, one animal underwent a 26 day post-headgear observation period.

In the rapid maxillary expansion group, palatal expansion using a split acrylic jackscrew-type appliance was carried out daily for a 12 day period.

In the combination rapid maxillary expansion followed by "orthopedic" headgear group, 28 ounces (800 grams) per side of distal force, comparable to that used in the "orthopedic" headgear group, was applied on the 12th day of palatal expansion. The expansion appliance was activated for an additional three day period at twice the previous activation schedule. The extraoral traction was continuously applied for 12 days in one animal and 72 days in another.

In the control animals, cephalometric records were taken to coincide with all the time intervals of the various experimental groups.

The serial cephalometric radiographs of each animal were subjected to quantitative analysis. The findings of this experiment allow the following conclusions to be drawn:

1. Heavy extraoral traction to the monkey created severe mesiocclusal malocclusions with extreme anterior crossbites as well as dramatic changes in facial appearance. The spatial relationships of the facial bones were extensively altered and distant effects occurred in the bones comprising the anterior cranial fossa and the cranial vault.

2. Rapid maxillary expansion did not enhance the susceptibility of the maxillary complex to posterior movement following application of heavy extraoral distal traction.

3. Heavy extraoral traction caused the maxillary and zygomatic bones to rotate downwards and backwards, with respect to the sphenoid bone, in a "clockwise" direction in the sagittal plane as viewed from the right side of the skull. The facial bones rotated differentially with respect to each other and to the sphenoid bone.

4. The anterior cranial base, consisting of the orbital processes of the frontal bone forming the floor of the anterior cranial fossa, also rotated "clockwise" with respect to the sphenoid bone following application of heavy extraoral traction.

5. Accompanying the rotation of the upper facial structures following headgear application, the mandible rotated "clockwise" in a downward and backward direction resulting in marked increase in vertical facial dimensions.

6. The occlusal disproportion created by heavy extraoral traction was the result of posterior movement of the upper facial bones and the maxillary teeth. The major part of the posterior movement of the maxillary dentition, relative to the cranial base implants, was due to posterior movement of the entire maxilla and contiguous bones rather than posterior movement of the maxillary teeth within the maxilla.

7. The severe interarch occlusal disproportion created by heavy extraoral traction occurred independent of forward mandibular growth. Forward movement of the mandible did not contribute to the creation of the malocclusion.

8. The shape of the cranial vault was altered by heavy extraoral traction with movement of the parietal bones with respect to the frontal and occipital vault bones.

9. During a short 26 day post-headgear observation period, recovery of the affected bones toward their original position occurred to a certain extent. The rate of movement of the individual bones during the short recovery period was much greater than that seen during normal growth over a similar time interval.

10. Rapid maxillary expansion resulted in a downward movement of the palatal outline and palatal implants relative to the implants in the cranial base while either no movement or an upward movement of the implants in the body of the maxilla occurred. Little effect on the antero-posterior relationship of the maxilla was recorded. Indications of changes in the position of the implants in the zygomatic bone and in the zygomatic process of the temporal bone relative to the cranial base suggested that adjustive movements in these bones had occurred during rapid maxillary expansion.

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APPENDIX

TABLE I

ERROR OF CEPHALOMETRIC METHOD

VARIABLE	POOLED STANDARD DEVIATION*	DEGREES OF FREEDOM	MAXIMUM ERROR ASSOCIATED WITH 99% OF MEASUREMENTS
LINEAR (mm)			
4-5	0.379	73	0.988†
4-7	0.105	73	0.278
4-6	0.110	73	0.290
4-1	0.126	73	0.335
5-7	0.084	73	0.222
5-3	0.118	73	0.313
5-2	0.122	73	0.324
2-3	0.126	73	0.335
1-7	0.138	73	0.365
ALL	0.161	657	0.419
HORIZONTAL (mm)			
1-2	0.141	73	0.375
1-3	0.155	73	0.410
1-4	0.265	73	0.701
1-5	0.134	73	0.355
1-6	0.268	73	0.711
1-7	0.164	73	0.435
ALL	0.192	438	0.500
VERTICAL (mm)			
5-2	0.126	73	0.335
5-3	0.155	73	0.410
5-4	0.352	73	0.933†
5-6	0.313	73	0.829†
5-7	0.100	73	0.265
ALL	0.230	365	0.599
LONG ARM ANGLE (degrees)			
A	0.287	73	0.760
B	0.154	73	0.409
C	0.287	73	0.760
E	0.454	73	1.204
ALL	0.314	292	0.817
MEDIUM ARM ANGLE (degrees)			
D	0.643	73	1.703
G	0.665	73	1.761
ALL	0.654	146	1.711
SHORT ARM ANGLE (degrees)			
I	1.512	73	4.006
H	1.474	73	3.907
F	1.395	73	3.697
ALL	1.461	219	3.799

*Pooled among repeated measures within 3 animals
†Includes human error which was committed in digitization of one landmark on one of the 78 films.

TABLE II

OVERALL SUPERIMPOSITION ON BASI-SPHENOID BONE

HORIZONTAL† AND VERTICAL†† INCREMENTS OF CHANGE (IN MM) OF LANDMARKS FOLLOWING 12, 38, 72 AND 103 DAYS OF HEADGEAR AND 9 AND 26 DAYS OF POST-HEADGEAR OBSERVATION

		CONTROL GROUP				HEADGEAR GROUP				COMBINATION GROUP			
		MONKEY NO. 1		MONKEY NO. 5		MONKEY NO. 3		MONKEY NO. 4		MONKEY NO. 6		MONKEY NO. 7	
LANDMARK	TIME (DAYS)	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver
9	12											-0.12	-0.13
Sella	38	0.06	-0.29	0.07	0.20	0.01	0.01	-0.18	0.17	0.07	-0.29		
Turcica	72	0.42	0.18	-0.01	-0.27	0.48	0.24	-0.23	0.25	0.04	-0.09		
	103	0.68	-0.05	-0.13	0.29	-0.13	0.07						
	103+9					0.48	0.15						
	103+26	0.79	0.20	-0.53	-0.21	-0.07	0.50						
11	12											-0.05	-0.13
Supra-	38	0.07	0.34	-1.13	0.16	-0.11	-0.32	-0.67	0.15	0.15	-0.26		
Orbitale	72	-0.07	0.83	-0.51	0.62	0.99	-1.69	-0.05	-0.16	0.60	-0.95		
(Upper)	103	0.38	0.53	-0.66	0.70	1.05	-2.67						
	103+9					1.05	-2.46						
	103+26	0.38	1.10	-0.50	0.57	0.70	-1.54						
13	12											0.08	-0.03
Superior	38	0.28	0.41	0.25	0.01	0.89	-0.36	0.76	-0.32	0.64	-0.21		
Orbital	72	0.37	0.81	-0.12	0.56	1.88	-2.29	1.64	-0.79	1.44	-1.01		
Point	103	1.00	0.68	-0.27	0.18	1.99	-2.87						
(Upper)	103+9					2.74	-2.84						
	103+26	1.28	1.26	0.69	0.66	2.36	-1.81						
15	12											-0.37	1.55
Frontale	38	-0.02	0.77	-0.33	0.27	1.07	-1.15	0.28	-0.47	0.85	-0.60		
	72	0.40	0.45	0.34	0.40	1.56	-2.63	0.59	-0.39	1.60	-1.66		
	103	0.92	0.78	0.48	0.01	2.01	-4.45						
	103+9					2.38	-4.42						
	103+26	0.94	1.45	0.48	-0.34	1.45	-1.88						
17													
Nasal Tip	12											0.16	-0.33
	38	0.82	0.03	-0.48	0.45	0.20	-2.48	-0.14	-1.08	0.90	-3.78		
	72	1.44	0.22	-0.15	1.09	0.56	-7.46	0.12	-3.93	0.74	-8.12		
	103	1.64	0.48	0.41	1.17	-0.86	-10.85						
	103+9					-0.46	-10.04						
	103+26	2.12	0.57	0.55	0.90	0.08	-7.74						
18	12											0.43	-0.77
A Point	38	0.41	0.39	0.01	0.40	0.20	-2.34	-0.52	-1.43	0.47	-3.48		
(Subspinale)	72	1.09	-0.39	0.60	0.49	-1.63	-5.27	-0.94	-4.06	-0.37	-8.25		
	103	2.10	-0.23	1.01	1.09	-4.07	-9.05						
	103+9					-3.19	-10.06						
	103+26	2.37	0.41	0.94	0.81	-2.55	-7.60						
20	12											-0.12	0.00
Prosthion	38	-0.04	0.61	1.07	-0.04	-2.48	-5.37	-1.17	-2.64	-2.37	-3.51		
	72	1.36	0.64	0.11	1.22	-9.72	-13.57	-4.12	-7.70	-4.79	-9.41		
	103	2.65	0.00	2.01	0.46	-17.15	-18.25						
	103+9					-14.31	-16.45						
	103+26	2.98	0.48	1.39	1.02	-10.43	-11.62						

† Positive indicates Forward Movement while Negative indicates Backward Movement

†† Positive indicates Upward Movement while Negative indicates Downward Movement

TABLE II (Continued)

LANDMARK	TIME (DAYS)	CONTROL GROUP: MONKEY NO. 1 Hor	Ver	MONKEY NO. 5 Hor	Ver	HEADGEAR GROUP: MONKEY NO. 3 Hor	Ver	MONKEY NO. 4 Hor	Ver	COMBINATION GROUP: MONKEY NO. 6 Hor	Ver	MONKEY NO. 7 Hor	Ver
22	12											0.50	0.04
Incisal Edge	38	1.21	0.56	0.18	-0.07	-6.49	-6.36	-2.74	-3.57	-1.30	-3.71		
Maxillary	72	2.01	0.38	0.79	0.48	-14.47	-15.16	-9.20	-8.96	-6.19	-10.33		
Incisor	103	3.06	0.58	1.67	0.11	-25.44	-20.11						
	103+9					-20.75	-17.83						
	103+26	3.23	0.54	1.61	0.18	-10.40	-11.76						
23	12											-0.17	0.54
Incisal Edge	38	0.92	0.25	0.15	-0.06	-1.08	-5.57	-0.16	-1.24	0.68	-3.75		
Mandibular	72	1.70	0.44	0.56	0.12	-4.65	-15.48	-2.57	-6.67	-0.46	-10.31		
Incisor	103	3.13	0.29	1.67	0.40	-9.52	-19.93						
	103+9					-5.60	-14.37						
	103+26	3.18	0.46	1.88	0.47	-1.21	-8.60						
27	12											0.11	0.21
Menton	38	1.50	-0.10	0.05	-0.08	-3.12	-3.97	-0.63	-1.00	0.24	-2.43		
	72	1.89	-0.49	1.07	-0.20	-9.27	-10.21	-3.42	-4.39	-3.42	-6.72		
	103	3.24	-0.66	2.22	-0.21	-14.50	-13.53						
	103+9					-9.07	-10.16						
	103+26	3.06	-0.97	2.55	0.02	-4.11	-6.80						
29	12											-0.13	0.42
Posterior	38	2.08	-0.81	-0.21	-0.06	-3.11	0.05	-0.02	-0.60	-0.26	-0.93		
Point Mandi-	72	2.85	-1.09	0.38	0.16	-7.96	-0.84	-0.80	-0.86	-5.35	-1.20		
bular Tangent	103	4.16	-1.54	-0.69	-0.19	-11.87	-0.85						
	103+9					-8.16	-0.63						
	103+26	0.80	-1.39	1.26	-0.62	-4.27	-0.22						
33	12											0.48	-0.36
Anterior	38	-0.05	0.27	0.37	0.20	-1.37	-2.27	-0.93	-1.21	-1.39	-3.61		
Palatal	72	0.83	0.12	0.87	0.65	-5.14	-4.60	-2.97	-3.30	-4.16	-7.25		
Point	103	1.88	0.06	1.14	1.24	-8.56	-6.56						
	103+9					-7.39	-6.71						
	103+26	2.05	0.14	1.72	0.88	-5.79	-5.36						
34	12											0.49	0.28
Posterior	38	1.02	-0.46	-0.09	-0.11	-0.93	0.22	-0.84	0.19	-1.56	-0.35		
Nasal	72	1.25	-0.16	0.49	0.46	-1.94	-1.13	-2.36	-0.58	-2.66	-0.64		
Spine	103	2.32	-0.61	0.88	1.08	0.99	-2.88						
	103+9					-1.01	-1.80						
	103+26	2.72	-0.44	1.27	0.54	-1.94	-0.90						
35	12											-0.10	0.09
Tuberosity	38	0.10	-0.24	-0.10	-1.42	-0.43	0.29	-1.35	-0.58	0.03	0.78		
Point	72	0.48	-0.29	0.56	-0.98	-0.02	3.04	-2.63	4.11	-0.89	0.97		
(Inferior)	103	0.72	-1.31	1.28	-0.81	-1.10	3.34						
	103+9					-0.25	3.57						
	103+26	0.91	-0.15	0.62	-0.94	-0.25	1.85						
37	12											-0.60	-0.45
Basion	38	-0.36	1.09	-0.45	0.39	-0.54	-0.72	0.58	1.50	-0.17	-0.62		
	72	-2.12	-0.42	0.18	0.70	-0.53	-0.77	0.37	0.29	0.26	-0.36		
	103	-1.08	-0.28	-0.39	0.66	0.12	-0.39						
	103+9					0.19	-0.28						
	103+26	-1.32	-0.29	-0.76	0.19	-1.51	-0.83						
39	12											-0.07	0.15
Occipital	38	-0.31	-0.20	-0.50	0.89	-0.15	-0.62	-0.37	-0.09	0.12	0.42		
Point	72	-0.75	0.34	0.03	1.24	-0.09	-1.19	0.12	0.36	0.32	-0.09		
	103	-0.54	1.01	-0.13	1.42	-0.68	-2.56						
	103+9					-0.09	-2.20						
	103+26	-0.83	1.29	-0.40	1.65	-0.57	-1.47						
43	12											0.72	-0.23
Orbitale	38	0.10	-0.04	-0.47	0.19	-0.53	-0.95	-0.29	-0.50	0.19	-1.34		
	72	0.32	0.28	0.22	0.63	-0.06	-4.15	0.11	-1.69	-0.57	-3.37		
	103	0.83	0.33	0.30	0.86	-0.23	-6.21						
	103+9					0.07	-5.79						
	103+26	0.97	0.82	0.15	0.76	0.13	-4.67						

TABLE II (Continued)

LANDMARK	TIME (DAYS)	CONTROL GROUP MONKEY NO. 1 Hor	Ver	MONKEY NO. 5 Hor	Ver	HEADGEAR GROUP MONKEY NO. 3 Hor	Ver	MONKEY NO. 4 Hor	Ver	COMBINATION GROUP MONKEY NO. 6 Hor	Ver	MONKEY NO. 7 Hor	Ver
45	12											-0.75	-0.38
/6 Buccal	38	0.59	-0.14	0.25	-0.17	-3.91	0.45	-2.02	0.35	-6.17	-0.98		
Groove	72	1.03	-0.36	1.45	-0.04	-9.61	0.57	-4.97	1.18	-10.51	-1.35		
	103	2.42	-0.93	1.81	0.52	-15.75	3.42						
	103+9					-12.51	3.02						
	103+26	2.61	-0.42	0.96	1.26	-9.81	2.46						
51	12											-0.23	0.67
/7 Buccal	38	1.04	-0.48	0.06	-1.77	-3.30	1.72	-1.94	0.71	-4.55	0.86		
Groove	72	1.52	-0.31	1.08	-3.05	-7.85	4.40	-5.68	0.66	-7.33	3.05		
	103	2.81	-0.94	2.05	-2.92	-10.44	8.54						
	103+9					-9.48	7.21						
	103+26	3.02	-1.10	2.00	-3.91	-7.87	5.26						
58	12											-0.08	-0.50
/8 Geometric	38	0.13	-1.90	0.06	-0.67	-1.10	1.29	-0.67	0.49	-0.39	-0.09		
Center	72	0.22	-1.53	1.02	-0.99	-1.54	2.76	-1.91	0.62	-0.41	0.57		
	103	1.09	-2.28	1.57	-1.33	-0.81	3.79						
	103+9					-0.62	3.45						
	103+26	0.53	-3.19	1.78	-1.12	-1.41	4.06						
59	12											0.01	0.30
/8 Posterior	38	-0.27	-0.87	-0.62	-1.54	0.91	3.99	0.16	0.77	-0.35	0.63		
Point	72	0.67	-0.76	-0.01	-1.82	-0.21	4.84	-1.02	0.62	0.43	1.09		
	103	1.90	-0.52	0.27	-2.84	1.98	7.01						
	103+9					1.15	6.75						
	103+26	0.64	-2.79	0.83	-1.29	0.16	5.86						
61	12											-0.09	0.97
/6 Buccal	38	1.04	0.01	-0.09	-0.46	-0.79	-3.06	-0.16	-1.20	-0.79	-2.27		
Groove	72	1.49	-0.16	1.06	-0.24	-4.26	-8.76	-0.68	-3.95	-1.72	-5.76		
	103	2.35	-0.28	1.60	-0.12	-6.62	-11.64						
	103+9					-3.43	-7.79						
	103+26	2.67	-0.33	1.36	0.07	-0.63	-4.46						
67	12											-0.40	0.30
/7 Buccal	38	0.96	-0.47	-0.10	0.66	-0.89	-1.90	-0.65	-1.23	0.87	-1.58		
Groove	72	1.22	-0.83	1.13	0.08	-3.53	-5.93	-1.12	-2.88	-0.92	-5.02		
	103	2.40	-0.89	1.66	0.00	-6.00	-7.96						
	103+9					-2.89	-5.19						
	103+26	2.90	-0.69	1.66	0.09	-0.01	-2.86						
181	12											-0.93	-0.92
Soft Tissue	38	0.56	1.36	0.10	-0.75	-2.47	-1.70	-1.45	-2.31	-0.38	-3.75		
Tip of Nose	72	0.91	1.49	0.49	1.09	-5.05	-9.34	-3.00	-5.06	-3.86	-8.71		
	103	1.62	1.20	1.15	1.44	-9.80	-15.31						
	103+9					-8.54	-13.42						
	103+26	2.03	1.39	0.77	1.74	-6.04	-10.22						
182	12											0.34	-0.03
Labrale	38	-0.17	1.33	-0.12	0.95	-3.29	-6.14	-2.05	-3.32	-1.03	-4.46		
Superius	72	0.84	2.93	0.89	0.80	-8.87	-12.62	-8.65	-7.10	-5.14	-10.96		
	103	1.61	1.36	1.60	-0.13	-16.48	-15.96						
	103+9					-15.61	-12.52						
	103+26	2.12	0.61	0.83	0.34	-9.08	-8.40						
184	12											0.25	1.88
Labrale	38	1.70	1.20	-0.04	0.29	-2.21	-6.73	-0.57	-3.15	0.96	-3.16		
Inferius	72	2.24	0.73	0.84	0.60	-6.38	-15.38	-3.02	-8.45	-3.59	-7.72		
	103	3.54	0.34	1.85	-0.38	-11.53	-20.35						
	103+9					-7.36	-15.10						
	103+26	3.69	0.60	1.54	-0.18	-2.32	-9.83						
82	12											-0.26	-0.29
Basi-	38	-0.40	-0.25	-0.30	-0.04	0.14	0.16	0.10	-0.12	-0.04	0.11		
Occipital	72	-1.01	-0.50	0.05	0.16	-0.04	-0.03	0.23	-0.15	0.02	-0.40		
Implant	103	-0.67	-0.27	-0.13	0.19	-0.35	0.21						
	103+9					-0.25	0.17						
	103+26	-0.93	-0.05	-0.98	-0.25	-0.36	0.19						

TABLE II (Continued)

		CONTROL GROUP				HEADGEAR GROUP				COMBINATION GROUP			
		MONKEY NO. 1		MONKEY NO. 5		MONKEY NO. 3		MONKEY NO. 4		MONKEY NO. 6		MONKEY NO. 7	
LANDMARK	TIME (DAYS)	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver
89	12											-0.37	0.04
Basi-	38	-0.33	-0.33	-0.23	-0.17	0.22	0.22						
Occipital	72	-0.81	-0.14	0.07	-0.13	0.33	-0.23						
Implant	103	-0.67	-0.29	0.21	-0.05	-0.32	-0.12						
	103+9					-0.19	-0.23						
	103+26	-0.85	-0.35	-0.67	-0.25	-0.33	0.08						
92*	12											-0.50	0.20
Basi-	38					0.09	0.64		0.06	-0.13	-0.29		
Sphenoid	72					-0.07	-0.08		0.10	-0.12	-0.08		
Implant	103					-0.57	0.21						
	103+9					-0.07	-0.06						
	103+26					-0.37	0.46						
93*	12											-0.40	-0.11
Basi-	38					0.07	0.07			0.30	0.12		
Sphenoid	72					0.10	-0.32			0.15	0.04		
Implant	103					-0.26	-0.08						
	103+9					0.04	-0.36						
	103+26					-0.10	-0.02						
94*	12											-0.54	0.11
Basi-	38	-0.22	-0.23	-0.39	-0.18	-0.21	0.22	0.13	-0.24	0.32	-0.16		
Sphenoid	72	-0.35	-0.52	0.19	0.15	-0.01	-0.32	-0.05	-0.20	0.07	-0.09		
Implant	103	0.29	-0.55	0.31	0.05	-0.44	0.01						
	103+9					-0.08	-0.22						
	103+26	-0.13	0.02	-0.51	-0.14	-0.25	0.42						
95*	12											-0.38	0.01
Basi-	38	-0.22	-0.07	-0.43	0.07	-0.06	0.22			0.18	-0.02		
Sphenoid	72	-0.33	-0.30	0.07	0.14	0.17	-0.28			0.04	-0.12		
Implant	103	0.06	-0.17	0.27	0.14	-0.41	-0.13						
	103+9					-0.10	-0.36						
	103+26	-0.10	-0.11	-0.56	-0.11	-0.32	-0.15						
96*	12											-0.31	-0.25
Basi-	38	-0.16		-0.14	0.22	0.02	0.56	-0.02	0.17	-0.08	-0.02		
Sphenoid	72	-0.49	0.03	0.55	0.00	0.24	-0.16	0.15	0.11	-0.17	0.00		
Implant	103	0.15	-0.11	0.25	0.02	-0.36	0.52						
	103+9					0.08	0.04						
	103+26	-0.11	0.25	-0.13	-0.15	-0.31	0.53						
97*	12											-0.37	0.15
Basi-	38	-0.15	0.14	-0.36	-0.25	-0.21	0.22	0.16	-0.23	0.33	-0.05		
Sphenoid	72	-0.34	-0.29	0.33	0.20	-0.04	-0.37	0.30	-0.03	0.08	-0.18		
Implant	103	0.32	-0.07	0.29	-0.13	-0.44	0.08						
	103+9					-0.17	-0.30						
	103+26	-0.04	0.20	-0.44	-0.34	-0.43	0.02						
98*	12											-0.46	
Basi-	38	-0.39	-0.05	-0.12	-0.08			-0.09	-0.09	-0.14	0.47		
Sphenoid	72	-0.56	-0.28	0.27	0.32			0.09	0.33	-0.15	0.14		
Implant	103	0.10	-0.04	0.17	0.33								
	103+9												
	103+26	-0.14	0.02	-0.17	-0.09								
99*	12											-0.29	-0.10
Basi-	38			-0.50	-0.01			0.07	-0.19	0.19	-0.04		
Sphenoid	72			0.25	0.26			0.12	0.01	-0.04	-0.03		
Implant	103			0.30	0.11								
	103+9												
	103+26			-0.45	-0.07								
100*	12											-0.35	-0.01
Basi-	38			-0.06	-0.32					0.14	0.31		
Sphenoid	72			0.50	-0.17					-0.07	0.19		
Implant	103			0.65	-0.26								
	103+9												
	103+26			-0.39	-0.37								

*Constitutes overall error of method including "Template-Transfer" of reference line 1-2 as relationship of Basi-Sphenoid implants to axis 1-2 is constant.

TABLE II (Continued)

LANDMARK	TIME (DAYS)	CONTROL GROUP				HEADGEAR GROUP				COMBINATION GROUP			
		MONKEY NO. 1		MONKEY NO. 5		MONKEY NO. 3		MONKEY NO. 4		MONKEY NO. 6		MONKEY NO. 7	
		Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver
101*	12											-0.27	0.11
Basi-	38			-0.35	0.03					0.06	0.10		
Sphenoid	72			0.18	0.22					0.03	-0.11		
Implant	103			0.31	0.07								
	103+9												
	103+26			-0.48	0.10								
106	12											-0.09	-0.09
Zygomatic	38	-0.29	0.32	0.11	0.06	-0.11	-0.03			0.33	-0.44		
Process of	72	-0.43	0.00	0.40	0.44	0.18	-2.14			1.19	-0.81		
Frontal Bone	103	0.44	0.38	0.57	0.16	0.68	-1.69						
Implant	103+9					0.90	-2.35						
	103+26	-0.05	0.42	-0.24	0.30	0.25	-0.83						
107	12											-0.03	0.12
Zygomatic	38	-0.23	0.27	-0.09	-0.01	0.09	-0.12			0.54	-0.67		
Process of	72	-0.29	0.04	0.37	0.60	0.60	-2.20			1.13	-0.90		
Frontal Bone	103	0.47	0.48	0.68	0.00	0.96	-1.61						
Implant	103+9					1.30	-2.68						
	103+26	0.08	0.47	-0.35	0.18	0.60	-0.93						
108	12											-0.19	-0.07
Frontal Bone	38	0.05	0.40	-0.30	0.15	0.53	-0.14	0.56	-0.70	0.43	-0.56		
Implant (Mid-	72	-0.34	0.19	0.34	0.71	1.59	-2.26	1.09	-0.94	0.97	-1.36		
Line Cranial)	103	0.48	0.16	0.40	0.53	1.28	-2.78						
	103+9					1.73	-3.08						
	103+26	0.01	0.28	-0.36	0.39	1.21	-1.61						
109	12											-0.48	-0.33
Frontal Bone	38	-0.36	0.17	-0.11		0.54	-0.13	0.45	-0.49	0.65	-0.36		
Implant (Mid-	72	-0.53	0.07	0.19	0.56	1.84	-2.36	1.31	-0.85	1.00	-1.08		
Line Cranial)	103	0.45	0.18	0.43	0.37	1.44	-2.72						
	103+9					2.03	-3.09						
	103+26	0.16	0.53	-0.36	0.35	1.28	-1.60						
123													
Mid-Line	12											-0.56	-0.25
Cranial	38	-0.35	0.30	-0.22	0.07	0.85	0.18	0.50	-0.26	0.53	-0.07		
Implant	72	-0.58	0.16	0.26	0.52	2.86	-0.12	1.34	0.31	1.39	-0.21		
(Vertex)	103	0.12	0.21	0.45	0.31	2.84	-0.26						
	103+9					3.23	-0.61						
	103+26	0.13	0.52	-0.35	0.35	2.33	0.16						
125	12											-0.09	-0.01
Mid-Line	38	-0.41	0.15		0.01	0.43	0.55	-0.11	-0.22	0.74	-0.15		
Cranial	72	-0.62	0.04	0.48	0.17	1.54	0.02	0.52	0.15	0.97	-0.29		
Implant	103	0.02	0.50	0.42	0.38	0.91	-0.53						
(Posterior)	103+9					1.46	-0.65						
	103+26	-0.22	0.80	-0.25	0.16	0.71	-0.25						
129	12											0.00	-0.04
Zygomatic	38	-0.63	0.13	-0.14	-0.28	0.06	0.36	0.15	0.24	0.13	-0.46		
Process of	72	-0.86	-0.23	0.15	0.29	0.27	-0.69	0.25	-0.03	0.29	-0.14		
Temporal Bone	103	-0.48	-0.30	-0.21	-0.45	0.22	-0.01						
Implant	103+9					0.04	-0.67						
	103+26	-0.93	-0.30	-0.68	-0.05	0.49	0.25						
130	12											-0.02	0.22
Zygomatic	38	-0.82	0.18	-0.17	-0.11	0.33	0.80	0.10	0.25	0.18	-0.71		
Process of	72	-0.79	-0.50	0.31	0.18	0.26	-0.61	0.00	-0.31	0.47	-0.44		
Temporal	103	-0.58	-0.08	-0.01	-0.32	0.37	0.30						
Implant	103+9					0.11	-0.41						
	103+26	-1.11	-0.20	-0.67	-0.01	0.45	0.67						
132	12											-0.09	0.24
Zygomatic	38	-0.42	0.25	0.01	-0.23	1.29	0.02	-0.31	0.20	0.49	-1.10		
Bone Implant	72	-0.39	-0.36	0.51	0.33	2.32	-1.07	-1.23	-0.53	1.28	-1.90		
	103	0.23	-0.06	0.30	-0.47	3.20	-0.14						
	103+9					2.51	-1.02						
	103+26	-0.30	-0.15	-0.24	0.06	2.46	-0.12						

*Constitutes overall error of method including "Template-Transfer" of reference line 1-2 as relationship of Basi-Sphenoid implants to axis 1-2 is constant.

TABLE II (Continued)

LANDMARK	TIME (DAYS)	CONTROL GROUP: MONKEY NO. 1 Hor	Ver	MONKEY NO. 5 Hor	Ver	HEADGEAR GROUP: MONKEY NO. 3 Hor	Ver	MONKEY NO. 4 Hor	Ver	COMBINATION GROUP: MONKEY NO. 6 Hor	Ver	MONKEY NO. 7 Hor	Ver
135	12											-0.19	0.15
Zygomatic	38	-0.27	0.32	-0.19	-0.20	-1.08	-0.06	0.00	0.00	-0.69	-1.14		
Bone	72	-0.15	-0.15	0.56	0.44	-2.51	-1.74			-1.31	-1.96		
Implant	103	0.50	-0.18	-1.39	-0.09	-3.35	-1.21						
	103+9					-2.91	-1.96						
	103+26	0.00	-0.21	0.18	0.43	-2.73	-0.84						
142	12											-0.34	0.16
Maxillary	38	0.35	0.08	-0.15	-0.13	-1.62	-1.41	-0.39	-0.95	-0.35	-3.80		
Implant	72	0.72	-0.05	0.82	0.39	-3.94	-4.79	-1.42	-3.06	-2.04	-8.73		
	103	1.80	0.12	1.21	0.09	-6.02	-5.65						
	103+9					-5.41	-5.87						
	103+26	2.08	0.34	0.68	0.54	-4.46	-4.04						
143	12											-0.33	-0.07
Maxillary	38	0.38	0.27	0.10	-0.04	-1.55	-1.20	-0.45	-0.98	-0.64	-3.64		
Implant	72	0.99	0.02	0.96	0.39	-3.49	-4.22	-1.37	-2.88	-2.60	-8.14		
	103	2.00	0.23	1.33	-0.17	-5.77	-4.88						
	103+9					-4.96	-5.17						
	103+26	2.13	0.43	0.64	0.32	-4.15	-3.50						
144	12											-0.11	0.07
Maxillary	38	0.45	0.24	-0.02	-0.01	-1.41	-1.21	-0.31	-0.45	-0.52	-2.55		
Implant	72	0.92	0.08	0.87	0.44	-3.86	-4.13	-1.64	-2.09	-1.70	-5.87		
	103	2.21	0.30	1.25	0.09	-6.21	-4.68						
	103+9					-5.46	-5.08						
	103+26	2.36	0.63	0.72	0.69	-4.28	-3.57						
145	12											-0.13	0.10
Maxillary	38	0.48	0.23	0.01	-0.22	-1.76	-1.26	-0.48	-0.43	-0.67	-2.54		
Implant	72	0.88	0.22	0.84	0.20	-4.07	-4.02	-1.43	-1.79	-1.78	-5.92		
	103	2.26	0.16	1.27	-0.09	-6.42	-4.53						
	103+9					-5.65	-4.71						
	103+26	2.25	0.46	0.47	0.41	-4.57	-3.09						
150												-0.26	0.22
Maxillary	38	0.08	0.09	-0.26	-0.58	-2.13	0.47	-0.62	-0.23	-1.08	-1.06		
Implant	72	0.51	-0.40	0.94	-0.08	-4.94	0.09	-1.91	-1.37	-2.96	-2.98		
	103	1.54	-0.12	1.35	-0.65	-6.99	2.04						
	103+9					-6.35	1.58						
	103+26	1.46	-0.07	0.90	-0.62	-5.48	1.96						
151	12											-0.38	-0.07
Maxillary	38	0.20	0.09	0.25	-0.19	-2.27	0.34	-0.63	-0.02	-1.38	-1.19		
Implant	72	0.53	-0.18	1.20	-0.11	-5.24	0.12	-1.70	-0.96	-3.75	-2.73		
	103	1.67	-0.11	1.44	-0.65	-7.57	2.37						
	103+9					-6.84	1.82						
	103+26	1.63	-0.17	1.18	-0.43	-5.90	2.14						
161	12											-0.16	0.49
Mandibular	38	0.70	0.14	-0.04	-0.35	-2.92	-4.78	-0.22	-1.22	0.40	-2.62		
Implant	72	1.38	-0.18	1.04	-0.12	-8.08	-12.99	-3.04	-5.36	-3.73	-7.32		
(Symphysis)	103	2.79	0.03	1.77	-0.48	-13.35	-17.30						
	103+9					-8.27	-12.56						
	103+26	2.77	-0.35	1.80	0.20	-3.56	-7.80						
165	12											0.26	0.50
Mandibular	38	0.60	0.12	0.08	-0.36	-2.49	-2.58	-0.33	-0.75	0.35	-2.02		
Implant	72	1.45	-0.22	1.12	-0.27	-8.02	-8.24	-3.04	-3.54	-3.34	-5.09		
(Mid-Body)	103	2.67	-0.18	1.73	-0.89	-12.42	-10.81						
	103+9					-7.60	-8.13						
	103+26	2.54	-0.32	1.91	-0.48	-3.30	-4.95						
169	12												
Mandibular	38	0.67	0.12	0.25	-0.28	-2.43	-1.27	-0.40	-0.19	0.15	-1.74		
Implant	72	1.67	-0.47	1.31	-0.35	-6.52	-4.31	-2.00	-1.50	-3.37	-3.41		
(Ramus)	103	3.01	-0.42	2.04	-1.23	-9.94	-5.00						
	103+9					-6.20	-4.27						
	103+26	3.03	-0.83	1.95	-1.08	-2.82	-2.95						

TABLE III

MAXILLARY SUPERIMPOSITION

HORIZONTAL[†] AND VERTICAL[††] INCREMENTS OF CHANGE (IN MM) OF LANDMARKS FOLLOWING 12, 38, 72 AND 103 DAYS OF HEADGEAR AND 9 AND 26 DAYS OF POST-HEADGEAR OBSERVATION

		CONTROL GROUP				HEADGEAR GROUP				COMBINATION GROUP			
		MONKEY NO. 1		MONKEY NO. 5		MONKEY NO. 3		MONKEY NO. 4		MONKEY NO. 6		MONKEY NO. 7	
LANDMARK	TIME (DAYS)	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver
17	12											-0.27	-0.30
Nasal Tip	38	0.32	0.04	-0.60	0.24	0.51	-0.17	0.32	0.00	0.34	0.68		
	72	0.66	0.09	-0.91	0.31	1.38	0.61	0.73	-0.23	-0.17	2.05		
	103	0.33	0.27	-0.40	0.43	0.17	0.41						
	103+9					-0.05	0.43						
	103+26	0.64	0.38	-0.40	-0.07	0.69	0.10						
18	12											0.06	-0.71
A Point	38	-0.13	0.38	-0.15	0.25	1.06	-0.02	0.22	-0.40	0.23	0.62		
(Subspinale)	72	0.27	-0.52	-0.15	-0.20	0.09	1.82	0.28	-0.58	-0.27	1.01		
	103	0.73	-0.40	0.07	0.42	-0.86	0.50						
	103+9					0.15	-0.68						
	103+26	0.81	0.25	-0.18	-0.11	0.33	-0.78						
19	12											0.01	-0.69
Anterior	38	-0.37	0.26	-0.34	0.58	1.90	-1.54	0.84	-0.72	0.11	0.64		
Maxillary	72	0.40	0.06	0.10	0.03	5.23	-6.18	0.93	-1.34	-0.36	1.52		
Point	103	0.34	0.03	0.40	0.16	3.77	-7.98						
	103+9					3.48	-6.82						
	103+26	0.69	0.21	1.06	-0.54	3.57	-5.69						
20	12											-0.49	0.05
Prosthion	38	-0.66	0.51	0.82	-0.18	0.22	-2.57	0.30	-1.32	-0.79	1.46		
	72	0.27	0.31	-0.87	0.35	-1.24	-5.96	-0.57	-3.83	-0.50	1.83		
	103	0.98	-0.42	0.76	-0.46	-2.48	-9.05						
	103+9					-2.14	-7.07						
	103+26	1.12	0.07	-0.24	-0.31	-1.70	-4.11						
21	12											-0.05	-0.70
Root Apex	38	0.27	0.01	-0.16	-0.50	-0.69	-1.22	-0.19	-0.96	-0.40	-0.83		
Maxillary	72	0.52	0.51	-0.19	-0.74	-0.72	-2.68	1.05	-1.32	-0.56	-0.03		
Incisor	103	0.52	0.10	-0.32	-0.38	-2.03	-5.82						
	103+9					-1.42	-4.23						
	103+26	0.90	0.54	0.05	-0.71	-3.07	-5.95						
22	12											0.19	0.19
Incisal	38	0.53	0.50	-0.16	-0.39	-2.42	-3.99	-0.57	-2.31	1.76	2.34		
Edge	72	0.75	-0.03	-0.23	-0.41	-2.24	-7.60	-3.83	-5.71	1.58	2.35		
Maxillary	103	1.13	0.05	0.11	-1.07	-4.06	-12.05						
Incisor	103+9					-2.93	-8.76						
	103+26	1.12	0.01	-0.40	-1.43	1.53	-1.85						
33	12											0.16	-0.33
Anterior	38	-0.67	0.25	0.06	0.12	0.80	-0.83	0.38	-0.36	0.77	-0.31		
Palatal	72	-0.28	0.03	-0.10	0.02	0.30	-0.04	-0.21	-0.61	0.78	0.06		
Point	103	0.15	-0.04	-0.31	0.65	0.22	-1.14						
	103+9					0.49	-2.29						
	103+26	0.15	0.04	-0.06	0.11	0.97	-1.45						

[†] Positive indicates Forward Movement while Negative indicates Backward Movement

[††] Positive indicates Upward Movement while Negative indicates Downward Movement

TABLE III (Continued)

LANDMARK	TIME (DAYS)	CONTROL GROUP MONKEY NO. 1 Hor	Ver	MONKEY NO. 5 Hor	Ver	HEADGEAR GROUP MONKEY NO. 3 Hor	Ver	MONKEY NO. 4 Hor	Ver	COMBINATION GROUP MONKEY NO. 6 Hor	Ver	MONKEY NO. 7 Hor	Ver
34 Posterior Nasal Spine	12											0.10	0.16
	38	0.45	-0.27	-0.36	0.05	0.71	-0.38	0.22	0.15	0.04	-0.76		
	72	0.16	0.25	-0.46	0.13	2.54	-1.26	-0.17	-0.21	0.64	-0.76		
	103	0.63	-0.09	-0.56	1.35	8.01	-1.79						
	103+9					4.95	-2.26						
	103+26	0.85	0.10	-0.48	0.91	3.43	-2.72						
36 Tuberosity Point (Superior)	12											-0.41	0.43
	38	-0.43	-0.47	-0.11	-1.26	1.99	-1.22	0.82	-0.21	0.74	-1.13		
	72	-0.51	-0.82	-0.42	-1.07	3.53	-1.31	1.82	0.16	1.13	-1.73		
	103	-0.52	-1.67	-0.61	0.40	3.40	-3.13						
	103+9					3.21	-2.48						
	103+26	-0.75	-0.78	-1.06	-0.68	2.49	-4.87						
43 Orbitale	12											0.29	-0.24
	38	-0.39	0.00	-0.61	0.14	-0.34	-0.10	0.11	0.44	-0.46	0.56		
	72	-0.45	0.35	-0.55	0.08	0.39	0.01	0.59	0.44	-1.83	1.07		
	103	-0.47	0.41	-0.60	0.59	0.06	-0.77						
	103+9					-0.12	-0.70						
	103+26	-0.52	0.91	-0.95	0.40	0.58	-1.26						
44 /6 Mesio-Buccal Cusp	12											-0.95	0.33
	38	0.05	0.17	-0.47	-0.02	-1.09	0.54	-1.44	-0.39	-2.38	-1.45		
	72	0.18	0.00	0.77	-0.36	-1.90	0.08	-2.65	0.58	-3.32	-1.68		
	103	0.54	-0.18	-0.01	0.00	-4.27	-1.35						
	103+9					-3.76	-2.02						
	103+26	0.68	-0.23	-1.63	0.36	-1.79	-0.94						
45 /6 Buccal Groove	12											-1.00	-0.56
	38	-0.06	-0.04	-0.15	-0.10	-0.97	-0.09	-0.51	0.47	-2.76	-0.64		
	72	-0.24	-0.19	-.41	-0.40	-1.83	-0.38	-1.95	1.89	-3.41	-0.30		
	103	0.51	-0.70	0.05	0.52	-4.22	-1.80						
	103+9					-2.57	-0.35						
	103+26	0.50	-0.17	-1.33	1.13	-1.12	-0.26						
46 /6 Disto-Buccal Cusp	12											-1.23	-0.11
	38	0.72	-0.33	-0.52	0.07	-1.15	-0.22	-0.12	-0.09	-2.88	-0.46		
	72	0.22	-0.06	0.15	-0.27	-2.32	-0.47	-1.80	0.83	-3.32	-0.84		
	103	0.84	0.63	0.26	0.05	-5.01	-1.57						
	103+9					-2.77	-1.50						
	103+26	1.07	-0.22	-1.00	0.79	-1.11	-1.31						
47 /6 Mesio-Buccal Root Apex	12											-0.46	0.28
	38	-0.26	0.33	0.31	0.39	-0.03	-2.01	1.98	-1.60	0.76	-1.57		
	72	-0.27	0.16	0.54	-0.72	0.43	-2.43	2.44	-1.82	0.85	-2.32		
	103	0.22	-0.48	0.20	0.07	-0.42	-5.10						
	103+9					0.32	-5.27						
	103+26	-0.04	0.05	-0.20	0.00	-1.06	-4.33						
48 /6 Trifurcation	12											-0.66	0.03
	38	0.02	-0.43	0.10	-0.44	-0.99	-3.33	-0.22	-0.84	-0.83	-0.96		
	72	0.21	0.07	0.11	-0.70	-1.34	-2.28	-0.92	-1.66	-1.59	-1.54		
	103	0.31	0.12	0.34	-0.56	-1.91	-4.99						
	103+9					-1.84	-5.20						
	103+26	0.84	-0.41	-0.12	-0.72	-1.09	-4.43						
49 /6 Disto-Buccal Root Apex	12											-0.38	-0.22
	38	0.58	-0.46	0.16	-0.45	0.45	-1.43	2.03	-0.49	0.76	-0.40		
	72	0.31	-0.64	-0.36	-0.70	1.35	-1.87	2.54	0.04	1.46	-1.40		
	103	1.31	-0.54	-0.14	-0.34	1.23	-4.29						
	103+9					-0.28	-4.02						
	103+26	0.91	-0.47	0.18	-0.60	0.43	-3.41						
50 /7 Mesio-Buccal Cusp	12											-0.61	0.65
	38	-0.18	0.05	-0.12	-1.43	-1.36	0.91	-0.86	0.64	-1.85	-0.30		
	72	0.32	-0.24	0.58	-2.00	-2.92	1.59	-3.10	0.43	-3.20	0.36		
	103	0.76	-0.51	1.48	-2.11	4.13	1.17						
	103+9					-3.23	0.62						
	103+26	0.78	-0.24	0.32	-2.14	-1.84	0.13						

TABLE III (Continued)

LANDMARK	TIME (DAYS)	CONTROL GROUP MONKEY NO. 1 Hor	 Ver	 MONKEY NO. 5 Hor	 Ver	HEADGEAR GROUP MONKEY NO. 3 Hor	 Ver	 MONKEY NO. 4 Hor	 Ver	COMBINATION GROUP MONKEY NO. 6 Hor	 Ver	 MONKEY NO. 7 Hor	 Ver
51	12											-0.59	0.48
/7 Buccal	38	0.41	-0.29	-0.10	-1.60	-0.92	0.38	-0.60	0.50	-1.67	0.27		
Groove	72	0.28	0.08	0.45	-3.30	-2.27	1.23	-2.75	0.32	-2.09	2.28		
	103	0.93	-0.44	0.79	-2.55	-3.20	1.15						
	103+9					-2.70	0.82						
	103+26	0.96	-0.58	0.37	-3.48	-1.17	-0.09						
52	12											-0.45	-0.22
/7 Disto-	38	0.17	-0.41	-0.25	-2.19	-1.75	0.64	-1.17	-0.33	-1.08	0.37		
Buccal Cusp	72	0.50	-0.25	0.50	-3.22	-2.47	2.20	-3.11	1.39	-1.62	1.67		
	103	0.72	-0.76	0.68	-3.40	-3.26	3.48						
	103+9					-2.90	1.48						
	103+26	1.18	-0.44	0.05	-3.60	-1.69	0.17						
53	12											-0.20	0.25
/7 Mesio-	38	-0.18	-0.15	-1.08	-2.28	0.00	-1.95	0.55	-0.49	0.06	0.49		
Buccal Root	72	-1.49	-0.27	-0.89	-2.13	0.77	-2.59	0.93	-0.70	1.00	-0.08		
Apex	103	-0.52	-0.87	-0.93	-0.15	2.61	-1.89						
	103+9					1.63	-2.85						
	103+26	-0.45	-0.15	-1.50	0.19	1.66	-0.50						
54	12											-0.14	0.73
/7 Trifurcation	38	-0.59	-0.14	-1.97	-4.45	-0.45	-0.88	-0.37	0.71	-0.73	0.52		
	72	-0.49	-0.52	-1.82	-3.66	-0.57	-0.29	-1.19	0.89	-1.53	2.26		
	103	0.19	-0.94	-1.56	-3.89	-0.33	0.04						
	103+9					-0.97	-0.24						
	103+26	0.25	-0.56	-2.35	-3.32	-0.22	-0.47						
55	12											0.24	-0.34
/7 Disto-	38	0.37	-0.91	-2.98	-3.02	0.53	-0.27	-.62	0.04	1.37	-0.03		
Buccal Root	72	-0.80	-0.80	-2.56	-2.26	1.44	0.03	1.54	0.77	0.95	1.05		
Apex	103	0.41	-0.75	-1.52	-1.66	5.01	-0.33						
	103+9					1.93	-1.23						
	103+26	-0.27	-0.51	-2.63	-0.92	1.88	-0.53						
56	12											-0.23	-0.65
/8 Mesio-	38	-1.85	-1.74	-0.46	-2.10	0.12	-0.39	-0.42	-0.41	0.81	-0.01		
Buccal Cusp	72	-1.79	-1.72	-0.15	-1.63	0.26	0.93	-0.29	-0.11	1.43	0.34		
	103	-1.45	-2.35	-1.26	-1.25	0.74	-0.15						
	103+9					0.73	-0.44						
	103+26	-1.41	-3.03	-0.83	-0.93	2.41	-0.33						
57	12											-0.32	-0.73
/8 Disto-	38	-0.65	-0.49	-0.40	-0.94	-0.26	0.79	0.34	-0.28	0.51	-0.12		
Buccal Cusp	72	-0.93	-0.51	-0.26	-0.79	1.28	0.65	-0.25	0.71	0.46	0.57		
	103	-1.04	-0.93	0.02	-0.14	1.88	-0.07						
	103+9					1.93	-0.32						
	103+26	-1.94	-2.50	-0.45	-0.03	2.25	-0.75						
58	12											-0.40	-0.69
/8 Geometric	38	-0.33	-1.75	-0.09	-0.46	0.08	0.08	0.18	0.28	0.49	-0.61		
Center	72	-0.71	-1.11	0.29	-1.20	0.84	0.92	-0.46	0.52	0.95	0.31		
	103	-0.40	-1.74	0.52	-0.85	2.19	0.00						
	103+9					1.89	-0.02						
	103+26	-1.10	-2.66	0.39	-0.53	1.04	0.00						
59	12											-0.40	0.08
/8 Most	38	-0.78	-0.70	-0.67	-1.34	1.33	2.60	0.86	0.47	0.09	-0.62		
Posterior	72	-0.28	-0.21	-0.63	-2.09	1.28	1.72	0.19	0.08	1.11	-0.44		
Point	103	0.36	0.20	-0.60	-2.32	3.02	1.53						
	103+9					1.90	1.18						
	103+26	-0.99	-2.10	-0.49	-0.57	1.76	0.29						

TABLE III (Continued)

LANDMARK	TIME (DAYS)	CONTROL GROUP				HEADGEAR GROUP				COMBINATION GROUP			
		MONKEY NO. 1		MONKEY NO. 5		MONKEY NO. 3		MONKEY NO. 4		MONKEY NO. 6		MONKEY NO. 7	
		Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver
142	12											-0.76*	0.1*
Maxillary	38	-0.21Φ	0.05Φ	-0.33*	-0.21*	-0.05*	-0.25*			0.45Φ	0.09Φ		
Implant	72	-0.26Φ	-0.24Φ	-0.01*	-0.18*	0.41*	-0.31*			0.38Φ	0.04Φ		
	103	0.23Φ	-0.11Φ	0.15*	-0.33*	0.10*	-0.10*						
	103+9					0.13*	-0.58*						
	103+26	0.33Φ	0.11Φ	-0.68*	-0.09*	0.21*	-0.46*						
143	12											-0.73*	-0.12*
Maxillary	38	-0.21Φ	0.25Φ	-0.09*	-0.09*	-0.03*	-0.19*	0.51*	-0.10*	0.36Φ	0.17Φ		
Implant	72	-0.01Φ	-0.13Φ	0.13*	-0.14*	0.64*	-0.07*	0.45*	0.04*	0.08Φ	0.40Φ		
	103	0.40Φ	0.03Φ	0.29*	-0.52*	0.02*	-0.05*						
	103+9					0.26*	-0.42*						
	103+26	0.36Φ	0.24Φ	-0.72*	-0.23*	0.33*	-0.40*						
144	12											-0.52*	0.02*
Maxillary	38	-0.17Φ	0.21Φ	-0.21*	-0.06*	0.23*	-0.13*	0.43*	0.16*	0.10*	0.11*		
Implant	72	-0.21Φ	-0.14Φ	0.05*	-0.10*	0.60*	-0.03*	0.21*	0.07*	-0.01*	0.38*		
	103	0.45Φ	0.04Φ	0.20*	-0.26*	0.07*	0.06*						
	103+9					0.28*	-0.42*						
	103+26	0.40Φ	0.36Φ	-0.64*	0.16*	0.65*	-0.38*						
145	12											-0.53*	0.02*
Maxillary	38	-0.15Φ	0.20Φ	-0.15*	-0.26*	-0.06*	-0.40*	0.43*	0.17*	0.02*	-0.10*		
Implant	72	-0.28Φ	0.00Φ	0.04*	-0.33*	0.50*	-0.37*	0.28*	0.34*	0.10*	-0.07*		
	103	0.48Φ	-0.09Φ	0.25*	-0.40*	0.10*	-0.49*						
	103+9					0.16*	-0.73*						
	103+26	0.28Φ	0.20Φ	-0.86*	-0.10*	0.35*	-0.52*						
146	12												
Maxillary	38	-0.16¶	0.11¶	-0.12Φ	-0.09Φ	0.20¶	-0.22¶	0.44¶	-0.06¶	0.08*	0.14*		
Implant	72	-0.45¶	0.00¶	0.09Φ	-0.42Φ	1.02¶	-0.16¶	0.44¶	0.15¶	-0.04*	0.28*		
	103	0.13¶	-0.04¶	0.35Φ	-0.39Φ	0.55¶	-0.74¶						
	103+9					0.76¶	-0.83¶						
	103+26	-0.21¶	0.32¶	-0.73Φ	-0.43Φ	0.95¶	-0.70¶						
147	12											-0.44*	0.26*
Maxillary	38	-0.09¶	0.21¶	-0.26Φ	-0.18Φ	0.23¶	-0.31¶	0.53¶	-0.33¶	0.15*	0.06*		
Implant	72	-0.26¶	-0.02¶	0.19Φ	-0.25Φ	0.10¶	-0.41¶	0.09¶	0.33¶	-0.13*	0.11*		
	103	0.19¶	0.13¶	0.19Φ	-0.29Φ	0.66¶	-0.85¶						
	103+9					0.71¶	-0.87¶						
	103+26	-0.03¶	0.52¶	-0.57Φ	-0.47Φ	0.86¶	-0.83¶						
148	12											-0.51*	-0.14*
Maxillary	38	-0.47*	-0.05*	-0.26¶	0.05¶	0.03*	-0.16*			0.38¶	-0.19¶		
Implant	72	-0.49*	-0.30*	-0.02¶	-0.06¶	0.42*	-0.08*			0.27¶	0.42¶		
	103	0.08*	-0.14*	0.07¶	-0.17¶	-0.10*	-0.02*						
	103+9					0.05*	-0.24*						
	103+26	-0.17*	-0.06*	-0.73¶	0.03¶	0.26*	0.02*						
149	12											-0.28*	-0.04*
Maxillary	38	0.03*	0.26*	-0.06¶	0.00¶	-0.22*	-0.02*	0.39*	-0.16*	0.50¶	-0.24¶		
Implant	72	-0.10*	0.08*	0.31¶	-0.11¶	-0.02*	-0.11*	0.23*	0.14*	0.28¶	0.11¶		
	103	0.43*	0.14*	0.34¶	-0.31¶	-0.26*	-0.08*						
	103+9					-0.21*	-0.36*						
	103+26	-0.06*	0.25*	-0.58¶	-0.02¶	0.06*	-0.30*						
150	12												
Maxillary	38	-0.50*	0.13*			-0.12*	-0.02*	0.44*	0.16*	0.35¶	0.15¶		
Implant	72	-0.48*	-0.32*			0.29*	-0.14*	0.22*	0.16*	0.36¶	0.04¶		
	103	-0.06*	0.00*			0.06*	-0.26*						
	103+9					-0.03*	-0.37*						
	103+26	-0.31*	0.05*			0.09*	-0.31*						
151	12											-0.75Φ	-0.07Φ
Maxillary	38	-0.38*	0.16*	-0.03¶	-0.02¶	-0.10*	-0.20*	0.40*	0.29*	0.38¶	-0.02¶		
Implant	72	-0.47*	-0.07*	0.30¶	-0.38¶	0.36*	-0.25*	0.35*	0.43*	0.13¶	0.07¶		
	103	0.07*	0.06*	0.12¶	-0.37¶	-0.01*	0.30*						
	103+9					-0.02*	-0.42*						
	103+26	-0.14*	0.00*	-0.54¶	-0.13¶	0.08*	-0.35*						

*Implant in Body of Maxilla registered during superimposition. Constitutes error of method including "Template-Transfer" of reference line 3-4.

ΦImplant in Premaxilla

¶Implant in Palatal Process of Maxilla

TABLE IV

MANDIBULAR SUPERIMPOSITION

HORIZONTAL† AND VERTICAL†† INCREMENTS OF CHANGE (IN MM) OF LANDMARKS FOLLOWING 12, 38, 72 AND 103 DAYS OF HEADGEAR AND 9 AND 26 DAYS OF POST-HEADGEAR OBSERVATION

		CONTROL GROUP				HEADGEAR GROUP				COMBINATION GROUP			
		MONKEY NO. 1		MONKEY NO. 5		MONKEY NO. 3		MONKEY NO. 4		MONKEY NO. 6		MONKEY NO. 7	
LANDMARK	TIME (DAYS)	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver
23	12											-0.57	0.32
Incisal Edge	38	0.03	0.05	0.03	0.08	0.11	0.22	0.01	0.03	0.09	-0.71		
Mandibular	72	0.34	-0.02	-0.20	0.19	0.48	0.16	-0.78	-0.17	1.08	-0.59		
Incisor	103	0.94	-0.09	0.41	0.15	-1.49	1.19						
	103+9					-0.86	0.52						
	103+26	1.03	0.27	0.02	-0.17	0.23	0.49						
24	12											-0.30	0.24
Root Apex	38	0.09	0.22	1.13	-0.16	0.73	-0.03	0.18	-0.78	-0.36	-0.52		
Mandibular	72	0.41	0.43	0.70	0.32	0.59	-0.74	-0.35	-0.85	-0.60	0.26		
Incisor	103	0.62	0.70	1.00	-0.14	-0.67	-0.87						
	103+9					-0.54	-1.10						
	103+26	0.52	0.46	0.85	0.26	1.22	-1.15						
25	12											-0.06	0.31
B Point	38	0.53	0.45	0.16	0.04	-0.01	-0.23	0.37	-0.56	-0.64	-0.87		
(Supra-	72	0.62	0.45	-0.06	-0.25	-0.05	-0.88	-0.59	-0.93	-0.29	-0.77		
Mentale)	103	0.70	0.10	0.69	0.22	-0.32	-0.45						
	103+9					0.38	-0.02						
	103+26	1.14	0.45	0.29	0.06	-0.42	-0.75						
27	12											-0.28	0.00
Menton	38	0.26	0.01	-0.05	0.04	-0.07	-0.16	0.04	-0.23	0.26	-0.01		
	72	-0.20	-0.34	0.28	-0.09	0.36	-0.15	0.23	0.10	0.80	0.04		
	103	0.04	-0.10	0.50	-0.02	0.20	-0.17						
	103+9					0.34	-0.36						
	103+26	-0.21	-0.21	0.04	0.00	0.19	-0.70						
28	12											-2.78	0.17
Anterior	38	1.46	-0.12	-1.19	-0.30	-0.88	-0.14	-0.50	-0.33	-0.07	-0.13		
Point	72	-1.28	-0.44	-1.71	0.01	-0.84	0.21	0.44	0.27	-0.64	-0.01		
Mandibular	103	-1.10	-0.60	-0.73	-0.09	1.35	0.14						
Tangent	103+9					0.23	-0.04						
	103+26	-0.72	-0.08	-1.19	0.14	1.36	0.59						
29	12											-0.53	0.19
Posterior	38	0.83	-0.11	-0.32	0.02	-0.60	0.58	0.55	-0.63	-0.42	0.21		
Point	72	0.76	0.25	-0.43	0.32	-0.28	0.59	1.97	0.09	-2.02	-0.07		
Mandibular	103	0.96	0.56	-2.40	0.72	-0.44	0.16						
Tangent	103+9					-0.72	0.56						
	103+26	-2.46	1.22	-1.23	0.41	-1.04	0.90						
30	12											0.57	-0.57
Gonion	38	-0.15	-1.08	0.57	-1.02	0.14	0.47	0.60	-0.97	-2.01	1.15		
	72	-0.40	-0.98	0.19	-0.25	0.23	0.49	1.67	-1.80	-1.07	0.39		
	103	-0.69	-0.73	-0.66	-0.15	-0.15	0.15						
	103+9					0.11	0.21						
	103+26	-2.05	0.87	-0.12	-0.79	0.08	0.47						

† Positive indicates Forward Movement while Negative indicates Backward Movement
†† Positive indicates Upward Movement while Negative indicates Downward Movement

TABLE IV (Continued)

LANDMARK	TIME (DAYS)	CONTROL GROUP				HEADGEAR GROUP				COMBINATION GROUP			
		MONKEY NO. 1		MONKEY NO. 5		MONKEY NO. 3		MONKEY NO. 4		MONKEY NO. 6		MONKEY NO. 7	
		Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver
31	12											0.26	-0.94
Inferior	38	-0.61	-0.64	0.21	-1.08	0.14	1.12	0.86	-0.86	-1.62	2.54		
Point	72	-1.66	-1.06	-0.72	0.48	0.23	0.87	1.03	-0.23	-1.12	0.93		
Posterior	103	-2.78	0.73	-1.26	-0.38	-0.15	0.71						
Tangent	103+9					0.11	0.18						
	103+26	-3.14	1.10	-1.78	-0.25	0.08	-0.79						
61/6 Buccal	12											-0.51	0.76
Groove	38	0.10	0.24	-0.20	-0.34	0.39	0.23	0.06	-0.54	0.13	-0.09		
	72	0.04	0.27	0.30	-0.09	0.34	0.04	0.68	0.24	-0.46	-0.07		
	103	0.03	0.57	0.30	0.27	0.57	0.45						
	103+9					0.73	0.93						
	103+26	0.38	0.84	-0.54	0.34	0.61	0.92						
67/7 Buccal	12											-0.79	0.07
Groove	38	0.04	-0.10	-0.23	0.75	0.12	0.61	-0.40	-0.83	0.17	0.32		
	72	-0.22	-0.13	0.36	0.22	0.39	0.98	0.03	0.41	0.40	-0.35		
	103	0.10	0.34	0.36	0.55	0.13	1.23						
	103+9					0.67	1.63						
	103+26	0.64	0.90	-0.23	0.59	0.95	1.50						
73/8 Buccal	12											-0.63	-0.76
Groove	38	-0.57	-0.02	-0.08	0.00	-0.06	0.42	-0.27	0.81	-0.12	0.21		
	72	-0.51	-0.10	0.46	0.18	0.34	0.87	0.24	1.01	0.02	-0.19		
	103	0.19	0.03	0.56	0.42	-0.11	0.36						
	103+9					0.04	0.19						
	103+26	0.20	0.82	0.22	0.84	0.01	0.18						
75/8 Mid-Point	12											-0.48	-0.33
Inferior	38	0.30	0.07	0.12	-0.07	-0.02	0.15	0.09	-0.61	0.02	-0.43		
Outline	72	0.22	-0.58	0.30	-0.20	0.87	-0.59	0.38	-0.28	0.38	-1.29		
	103	0.41	-0.51	0.55	0.05	0.17	-0.47						
	103+9					0.22	-0.14						
	103+26	0.59	-0.04	-0.18	-0.02	0.02	-0.58						
160*	12											-0.59	0.21
Mandibular	38	-0.48	0.21	0.22	-0.04	0.19	0.15	0.30	-0.18	0.28	0.25		
Implant	72	-0.46	-0.30	0.22	0.15	1.15	-0.17	0.42	0.02	0.02	0.14		
	103	-0.15	0.14	0.43	-0.46	0.20	-0.18						
	103+9					0.48	-0.52						
	103+26	-0.24	0.12	-0.45	-0.11	0.51	-0.25						
161*	12											-0.56	0.26
Mandibular	38	-0.45	0.07	-0.15	-0.22	-0.40	0.03	0.32	-0.15	0.27	0.06		
Implant	72	-0.50	-0.35	0.25	-0.02	0.39	-0.02	0.09	0.19	-0.14	0.34		
	103	-0.11	0.05	0.20	-0.47	-0.23	0.18						
	103+9					-0.08	-0.04						
	103+26	-0.16	-0.08	-0.50	-0.07	-0.08	-0.16						
162*	12											-0.30	-0.01
Mandibular	38	-0.35	0.24	-0.17	-0.20	-0.03	0.31	0.17	-0.51	0.25	-0.28		
Implant	72	-0.33	-0.21	0.14	-0.19	0.66	0.03	0.05	-0.18	-0.17	-0.14		
	103	-0.20	0.34	0.10	-0.69	-0.04	0.33						
	103+9					0.45	0.08						
	103+26	0.02	0.29	-0.54	-0.21	0.40	0.00						
163*	12											-0.38	0.37
Mandibular	38	-0.40	0.15	0.08	0.04	-0.63	0.42	0.30	-0.09	0.64	0.02		
Implant	72	-0.50	-0.27	0.49	0.16	0.10	0.02	0.32	0.26	0.37	0.18		
	103	-0.07	-0.01	0.36	-0.28	-0.53	0.46						
	103+9					-0.19	0.12						
	103+26	-0.13	-0.09	-0.33	-0.04	-0.19	0.16						
164*	12											-0.12	0.10
Mandibular	38	-0.27	0.19	-0.01	-0.15	-0.38	0.52	-0.13	-0.08	-0.14	0.09		
Implant	72	-0.33	-0.39	0.32	-0.12	0.34	0.08	-0.13	-0.08	-0.11	0.23		
	103	-0.16	0.02	0.42	-0.28	0.00	0.54						
	103+9					0.27	0.18						
	103+26	0.04	0.13	-0.37	-0.04	0.05	0.11						

*Constitutes error of method including "Template-Transfer" of reference line 5-6 as relationship of Mandibular Implants to Axis 5-6 is constant.

TABLE IV (Continued)

LANDMARK	TIME (DAYS)	CONTROL GROUP				HEADGEAR GROUP				COMBINATION GROUP			
		MONKEY NO. 1		MONKEY NO. 5		MONKEY NO. 3		MONKEY NO. 4		MONKEY NO. 6		MONKEY NO. 7	
		Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver
165*	12											-0.14	0.30
Mandibular	38	-0.53	0.11	-0.02	-0.25	0.02	0.71	0.20	-0.11	0.18	0.06		
Implant	72	-0.40	-0.29	0.33	-0.12	0.27	0.41	0.03	0.14	-0.01	0.20		
	103	-0.19	-0.01	0.10	-0.42	0.16	0.64						
	103+9					0.46	0.35						
	103+26	-0.35	0.12	-0.48	-0.08	0.17	0.35						
166*	12											-0.32	0.01
Mandibular	38	-0.48	0.18	-0.01	-0.21	-0.15	0.33	0.17	0.01	-0.14	0.11		
Implant	72	-0.37	-0.41	0.64	0.00	-0.41	0.04	0.25	0.06	-0.02	0.25		
	103	-0.27	0.28	0.21	-0.45	0.10	0.38						
	103+9					0.31	0.20						
	103+26	-0.27	0.05	-0.25	-0.22	0.08	0.04						
167*	12											-0.23	0.09
Mandibular	38	-0.47	0.18			-0.08	0.59	0.33	-0.06	0.08	-0.09		
Implant	72	-0.37	-0.33			0.48	0.18	0.21	0.03	-0.04	0.09		
	103	-0.08	-0.10			0.12	0.51						
	103+9					0.46	0.06						
	103+26	-0.27	-0.01			0.00	0.28						
168*	12											0.00	0.00
Mandibular	38	-0.40	-0.11	0.11	-0.34	0.16	0.32	0.33	-0.09	0.03	-0.20		
Implant	72	-0.40	-0.48	0.28	-0.35	0.74	0.01	0.01	-0.06	0.02	0.12		
	103	-0.01	-0.07	0.28	-0.52	0.50	0.49						
	103+9					0.78	0.00						
	103+26	-0.26	-0.02	-0.49	-0.19	0.31	0.08						
169*	12											0.00	0.00
Mandibular	38	-0.55	0.21	0.15	-0.19	-0.36	0.26	-0.11	-0.06	0.02	-0.09		
Implant	72	-0.36	-0.31	0.53	-0.17	0.25	-0.11	0.11	0.22	0.01	0.11		
	103	-0.10	0.06	0.48	-0.42	0.11	0.12						
	103+9					0.38	-0.18						
	103+26	-0.13	-0.05	-0.34	-0.21	-0.05	-0.21						

*Constitutes error of method including "Template-Transfer" of reference line 5-6 as relationship of Mandibular Implants to axis 5-6 is constant.

TABLE V

LINEAR ANALYSIS

INCREMENTS OF CHANGE (IN MM) IN LINEAR MEASUREMENTS FOLLOWING 12, 38, 72 AND 103 DAYS OF HEADGEAR AND 9 AND 26 DAYS OF POST-HEADGEAR OBSERVATION

		CONTROL GROUP		HEADGEAR GROUP		COMBINATION GROUP	
VARIABLE	TIME (DAYS)	MONKEY NO.1	MONKEY NO.5	MONKEY NO.3	MONKEY NO.4	MONKEY NO.6	MONKEY NO.7
15-27	12						1.35
Frontale to	38	1.00	0.37	3.03	0.56	1.84	
Menton	72	1.08	0.64	8.54	4.17	5.21	
	103	1.66	0.30	11.06			
	103+9			6.82			
	103+26	2.61	-0.25	5.25			
11-27	12						-0.31
Supra-Orbitale(U)	38	0.72	0.41	3.52	1.15	2.17	
to Menton	72	1.69	1.06	8.55	3.98	5.52	
	103	1.76	1.35	11.37			
	103+9			7.72			
	103+26	2.58	1.04	5.11			
17-33	12						-0.09
Nasal Tip to	38	0.03	0.07	0.55	0.35	0.85	
Ant Palatal Pt	72	0.27	0.23	0.95	0.52	1.69	
	103	0.34	-0.22	1.48			
	103+9			1.51			
	103+26	0.43	-0.21	1.41			
17-27	12						-0.52
Nasal Tip to	38	0.02	0.42	2.29	0.03	-1.14	
Menton	72	0.63	1.05	5.63	1.32	-0.15	
	103	0.90	1.02	7.11			
	103+9			2.73			
	103+26	1.38	0.51	0.22			
17-20	12						-0.41
Nasal Tip to	38	-0.93	1.16	1.96	1.16	-1.22	
Prosthion	72	-0.41	0.00	4.95	2.69	0.03	
	103	0.93	1.38	7.73			
	103+9			6.01			
	103+26	0.52	0.29	2.79			
18-36	12						0.20
A Point to	38	0.46	0.32	-0.74	-0.63	0.01	
Tuberosity Pt(Sup)	72	0.83	0.46	-2.80	-1.66	-0.52	
	103	1.48	0.65	-3.47			
	103+9			-2.72			
	103+26	1.74	0.97	-1.32			
20-35	12						-0.01
Prosthion to	38	-0.14	1.13	-0.72	0.43	-2.04	
Tuberosity Pt(Inf)	72	0.87	-0.49	-3.07	1.21	-2.32	
	103	1.93	0.70	-4.96			
	103+9			-4.52			
	103+26	2.07	0.74	-5.11			
58-9	12						0.26
/8 Center to	38	0.78	0.39	-1.65	-0.58	-0.50	
Sella Turcica	72	0.59	1.24	-3.09	-1.63	-0.69	
	103	1.37	2.24	-2.58			
	103+9			-2.73			
	103+26	1.37	2.46	-3.07			

TABLE V (Continued)

VARIABLE	TIME (DAYS)	CONTROL GROUP MONKEY NO.1	CONTROL GROUP MONKEY NO.5	HEADGEAR GROUP MONKEY NO.3	HEADGEAR GROUP MONKEY NO.4	COMBINATION GROUP MONKEY NO.6	COMBINATION GROUP MONKEY NO.7
58-Basi-Sph /8 Center to Basi-Sphenoid Implant	12						0.50
	38	1.21	0.24	-1.36	0.03	-0.26	
	72	1.38	0.56	-2.49	-1.26	-0.26	
	103	1.90	1.45	-1.55			
	103+9			-1.82			
	103+26	2.37	1.99	-2.31			
51-Basi-Sph /7 Buccal Groove to Basi-Sphenoid Implant	12						-0.01
	38	1.13	0.97	-2.91	-2.24	-4.33	
	72	1.58	2.07	-8.11	-5.42	-7.76	
	103	2.37	3.07	-12.49			
	103+9			-11.34			
	103+26	3.07	3.80	-8.25			
17-Basi-Sph Nasal Tip to Basi-Sphenoid Implant	12						
	38	0.98	-0.21	0.01	-0.63	0.41	
	72	1.94	-0.49	0.71	-0.91	-0.20	
	103	1.53	0.36	0.28			
	103+9			0.02			
	103+26	2.25	0.87	0.62			
18-Basi-Sph A Point to Basi-Sphenoid Implant	12						0.82
	38	0.56	0.21	0.36	-0.92	0.14	
	72	1.59	0.10	-0.97	-1.61	-1.01	
	103	1.94	0.86	-1.99			
	103+9			-1.42			
	103+26	2.48	1.16	-1.00			
Maxillary Implant to Basi-Sphenoid Implant	12						0.14
	38	0.49	-0.01	-1.09	-0.62	-0.50	
	72	1.21	0.27	-2.21	-1.60	-1.60	
	103	1.58	0.96	-3.20			
	103+9			-3.11			
	103+26	2.15	0.82	-2.50			
27-Basi-Sph Menton to Basi-Sphenoid Implant	12						0.45
	38	1.14	0.05	1.95	0.17	1.76	
	72	1.93	0.53	3.94	0.93	2.60	
	103	2.41	1.60	5.48			
	103+9			3.99			
	103+26	2.97	1.85	3.94			
Mandibular Implant to Basi-Sphenoid Implant	12						0.13
	38	0.58		1.48	0.36	1.80	
	72	1.59		3.93	0.72	1.72	
	103	1.98		5.08			
	103+9			3.49			
	103+26	2.63		3.43			
44-61 /6 M-B Cusp to /6 Buccal Groove	12						-0.71
	38	-0.06	-0.12	4.65	2.93	5.02	
	72	0.00	0.64	10.31	6.55	8.16	
	103	0.07	0.04	17.09			
	103+9			14.75			
	103+26	0.07	-0.88	12.08			
45-62 /6 Buccal Groove to /6 D-B Cusp	12						-1.06
	38	0.05	0.14	4.49	2.21	5.30	
	72	-0.13	0.04	9.97	6.83	8.44	
	103	-0.19	-0.10	16.40			
	103+9			13.91			
	103+26	0.01	-1.29	11.71			
50-67 /7 M-B Cusp to /7 Buccal Groove	12						0.49
	38	0.47	-2.12	5.14	2.62	3.55	
	72	0.33	-1.80	12.13	6.18	8.66	
	103	0.03	-2.72	18.12			
	103+9			15.03			
	103+26	0.00	-2.61	12.70			
51-68 /7 Buccal Groove to /7 D-B Cusp	12						0.37
	38	0.03	-2.00	4.03	1.70	4.60	
	72	0.31	-2.85	10.68	5.69	9.44	
	103	-0.11	-2.41	16.06			
	103+9			13.95			
	103+26	-0.49	-4.19	10.50			

TABLE VI

ANGULAR ANALYSIS

INCREMENTS OF CHANGE (IN DEGREES) IN ANGULAR MEASUREMENTS FOLLOWING 12, 38, 72 AND 103 DAYS OF HEADGEAR AND 9 AND 26 DAYS OF POST-HEADGEAR OBSERVATION

		CONTROL GROUP		HEADGEAR GROUP		COMBINATION GROUP	
VARIABLE	TIME (DAYS)	MONKEY NO.1	MONKEY NO.5	MONKEY NO.3	MONKEY NO.4	MONKEY NO.6	MONKEY NO.7
Angle a^T	12						0.326
	38	-0.336	-0.591	5.948	2.286	8.098	
	72	-1.074	-0.695	16.574	6.215	17.264	
	103	-1.363	-1.816	27.466			
	103+9			25.401			
	103+26	-1.395	-2.392	20.525			
Angle b^T	12						-0.004
	38	-0.818	0.045	4.827	1.195	1.790	
	72	-1.666	-0.094	12.956	5.344	7.549	
	103	-2.290	-1.073	18.819			
	103+9			12.728			
	103+26	-2.543	-1.536	7.216			
Angle c^T	12						-0.329
	38	-0.483	0.636	-1.121	-1.091	-6.308	
	72	-0.592	0.601	-3.619	-0.871	-9.715	
	103	-0.927	0.743	-8.647			
	103+9			-12.673			
	103+26	-1.148	0.856	-13.309			
Angle d^λ	12						0.000
	38	0.758	0.531	5.435	10.043	10.122	
	72	1.024	0.887	14.137	11.745	17.687	
	103	0.936	-4.461	30.329			
	103+9			26.755			
	103+26	1.303	-0.143	21.757			
Angle e^δ	12						1.293
	38	0.265	-0.904	7.736	4.358	7.472	
	72	-0.012	-1.998	15.925	8.486	19.577	
	103	-1.316	-3.243	28.156			
	103+9			25.058			
	103+26	-1.901	-3.012	22.118			
Angle f^ξ	12						0.164
	38	3.405	2.088	-0.567	1.247	-0.128	
	72	3.910	2.579	-2.583	-1.435	-2.159	
	103	3.147	1.839	-5.412			
	103+9			-3.773			
	103+26	3.683	1.768	-2.664			
Angle g^δ	12						0.091
	38	-0.147	-0.444	2.734	1.690	0.456	
	72	0.360	-1.021	2.769	2.301	3.803	
	103	-0.520	-1.823	5.987			
	103+9			3.972			
	103+26	-0.277	-0.672	4.642			

^{T} Long arm error applicable. Maximum error associated with worst of 99% of measurements is 0.817°
$^\delta$ Medium arm error applicable. Maximum error associated with worst of 99% of measurements is 1.711°
$^\lambda$ Short arm error applicable. Maximum error associated with worst of 99% of measurements is 3.799°
$^\xi$ Angle composed of anatomical sites rather than implant sites. No error available.

TABLE VI (Continued)

VARIABLE	TIME (DAYS)	CONTROL GROUP MONKEY NO.1	MONKEY NO.5	HEADGEAR GROUP MONKEY NO.3	MONKEY NO.4	COMBINATION GROUP MONKEY NO.6	MONKEY NO.7
Angle h[ξ]	12						-0.255
	38	2.124	-1.107	-1.725	-1.821	-1.012	
	72	1.488	0.661	-5.528	-3.593	-2.311	
	103	1.241	-0.049	-5.538			
	103+9			-5.062			
	103+26	1.728	0.195	-4.035			
Angle i[λ]	12						
	38	-0.817	0.991	0.432	7.375	1.956	
	72	-1.651	1.864	0.981	5.561	2.635	
	103	3.673	-3.041	8.160			
	103+9	-0.788		5.669			
	103+26	2.099	2.197	4.281			
Angle j[λ]	12						0.296
	38	0.987	0.603	0.461		3.014	
	72	2.148	-0.354	7.096		6.591	
	103	1.847	5.129	10.832			
	103+9			10.610			
	103+26	2.295	-2.215	7.963			
Angle k[λ]	12						0.029
	38	0.651	-1.193	5.487		5.084	
	72	1.074	-0.340	9.478		10.673	
	103	0.484	-6.944	16.634			
	103+9			14.791			
	103+26	0.899	-0.176	12.561			
Angle l[ξ]	12						1.531
	38	-1.138	2.886	6.464	12.703	11.411	
	72	-1.675	-1.040	11.895	20.069	15.453	
	103	-1.331	0.737	20.461			
	103+9			20.300			
	103+26	-2.635	4.907	5.920			
Angle m[ξ]	12						2.670
	38	-0.524	2.448	7.460	8.647	12.436	
	72	0.320	-1.775	15.893	17.292	16.711	
	103	1.679	-1.367	27.631			
	103+9			12.998			
	103+26	-0.630	4.495	8.301			
Angle n[ξ]	12						1.360
	38	0.046	-2.697	8.738	5.603	5.768	
	72	-5.372	-5.790	20.775	15.104	14.013	
	103	-3.790	-11.262	27.906			
	103+9			23.147			
	103+26	-3.665	-9.352	13.008			
Angle o[ξ]	12						2.301
	38	0.891	-10.055	9.560	6.338	8.126	
	72	-3.976	-13.207	17.542	17.313	8.724	
	103	-1.000	-10.575	35.092			
	103+9			21.862			
	103+26	-4.591	-13.092	13.839			
Angle p[ξ]	12						1.965
	38	1.487	0.229	-9.654	-3.068	9.534	
	72	-0.881	0.656	-13.332	-16.646	7.826	
	103	0.748	-0.914	-16.591			
	103+9			-12.613			
	103+26	-0.865	-2.046	16.552			
Angle q[ξ]	12						1.639
	38	1.823	0.819	-15.602	-5.354	1.437	
	72	0.193	1.351	-29.906	-22.861	-9.437	
	103	2.112	0.902	-44.057			
	103+9			-38.014			
	103+26	0.530	0.346	-3.973			

[λ] Short arm error applicable. Maximum error associated with worst of 99% of measurements is 3.799°

[ξ] Angle composed of anatomical sites rather than implant sites. No error available

TABLE VII

OVERALL SUPERIMPOSITION

HORIZONTAL† AND VERTICAL†† INCREMENTS OF CHANGE (IN MM) OF EACH LANDMARK DURING THE RAPID PALATAL EXPANSION INTERVAL

	CONTROL GROUP				RAPID PALATAL EXPANSION GROUP					
	MONKEY NO. 1		MONKEY NO. 5		MONKEY NO. 2		MONKEY NO. 6		MONKEY NO. 7	
LANDMARK	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver
9 Sella Turcica	0.37	0.42	0.35	-0.21	0.46	-0.22	0.37	0.08	0.18	0.21
11 Supra-Orbitale(U)	-0.01	0.27	-0.68	0.17	-0.47	-0.08	0.13	-0.16	-0.01	-0.07
13 Sup Orbital Pt	0.78	-0.04	0.79	-0.01	-0.22	0.04	-1.08	-0.09	0.23	-0.04
15 Frontale	0.49	-0.46	-0.35	0.17	0.21	-0.48	-0.34	0.29	-0.16	-0.02
17 Nasal Tip	0.25	0.48	-0.59	0.45	-0.79	0.36	0.02	-0.10	-0.14	0.08
18 A Point	0.76	-0.91	-0.43	0.77	-0.23	0.00	0.11	1.54	0.21	0.68
20 Prosthion	0.96	-0.24	0.39	-0.03	-0.54	0.51	0.47	-0.16	0.23	-0.08
22 1 Incisal Edge	0.20	-0.09	-0.32	0.13	0.83	-0.27	0.18	-0.25	-0.19	-0.03
23 1 Incisal Edge	0.49	0.19	0.02	-0.38	-0.81	-0.67	0.18	0.18	-0.65	-0.15
27 Menton	0.15	0.07	-0.25	0.30	-1.72	-0.72	-0.98	0.35	-0.69	0.06
29 Post Pt Mand Tan	-1.13	0.00	-0.61	0.33	-0.80	0.34	-0.11	0.48	-0.69	0.30
33 Ant Palatal Pt	0.90	0.00	-0.04	0.34	0.54	-0.28	0.11	-0.12	0.13	-0.28
34 Post Nasal Spine	-0.12	0.02	-0.05	0.19	-0.18	0.22	0.20	-0.15	-0.05	-0.49
35 Tuberosity Pt (I)	0.05	0.06	-0.24	0.65	-0.60	0.43	0.28	0.27	-0.12	-1.17
37 Basion	-0.69	-1.07	-0.28	0.64	-0.09	0.04	0.09	0.35	0.31	0.57
39 Occipital Pt	0.13	-0.01	-0.34	0.29	-0.02	0.50	0.34	-0.16	0.14	-0.02
43 Orbitale	0.35	0.50	-0.54	0.33	0.05	0.57	0.61	0.72	-0.40	0.70
45 /6 Buccal Groove	0.09	0.45	-0.39	-0.17	0.95	0.16	0.61	0.40	0.24	0.51
51 /7 Buccal Groove	0.29	0.63	-0.71	0.96	-0.09	0.31	1.24	-0.33	1.04	-0.39
58 /8 Center	0.07	-0.14	-0.38	0.17	-0.52	-0.92	0.14	-0.77	0.12	-0.40
59 /8 Post Pt	0.67	0.70	-1.05	-0.86	-0.56	-0.31	1.96	1.00	0.48	0.10
61 /6 Buccal Groove	0.14	0.06	-0.14	-0.13	-0.89	-1.53	0.16	-0.17	-0.31	-0.46
67 /7 Buccal Groove	0.10	-0.06	-0.12	0.79	-0.31	-0.45	-0.26	0.19	-0.15	-0.22
181 S Tis Tip Nose	0.95	-0.37	-0.27	-1.45	-0.38	-0.06	0.40	-1.70	-0.44	0.25
182 Labrale Superius	0.78	-0.86	-0.48	1.06	-0.77	-1.82	0.18	-0.44	0.05	0.47
184 Labrale Inferius	0.34	-0.50	-0.66	-0.12	-2.20	-2.71	-1.26	-0.95	-1.31	-2.14
82 Basi-Occ Imp	0.26	0.06	-0.03	0.02	0.11	0.03	0.43	0.13	0.04	0.42
89 Basi-Occ Imp	0.30	0.15	-0.08	0.13	0.00	0.00	0.00	0.00	0.22	0.07
92 Basi-Sph Imp*	0.41	-0.22	-0.21	-0.23	-0.05	0.20	0.22	0.02	0.23	0.10
93 Basi-Sph Imp*	-0.20	0.24	-0.11	-0.12	-0.26	-0.19	0.07	0.01	0.20	0.30
94 Basi-Sph Imp*	0.16	0.16	-0.36	-0.13	-0.25	0.23	-0.03	0.30	0.54	0.06
95 Basi-Sph Imp*	0.20	0.18	-0.20	0.22	-0.16	-0.14	0.22	0.00	0.15	0.06
96 Basi-Sph Imp*	0.24	0.05	-0.20	-0.12	0.33	-0.30	0.33	-0.09	0.22	0.37
97 Basi-Sph Imp*	0.21	0.10	-0.22	-0.04	-0.06	0.06	0.18	0.04	0.20	-0.13
98 Basi-Sph Imp*	0.35	-0.06	-0.29	-0.14	0.06	-0.23	0.34	-0.24	0.25	0.14
99 Basi-Sph Imp*			-0.48	0.05	-0.13	-0.11	0.40	-0.18	0.19	0.07
100 Basi-Sph Imp*			-0.01	-0.04	0.00	0.00	0.19	-0.38	0.08	-0.03
101 Basi-Sph Imp*			-0.26	0.18	0.00	0.00	0.46	0.03	0.35	-0.26
106 Zyg Pro Fron Imp	0.29	-0.24	-0.17	0.22	0.00	0.00	-0.25	-0.32	0.02	0.34
107 Zyg Pro Fron Imp	0.22	-0.11	-0.43	0.07	0.00	0.00	-0.24	-0.05	0.10	0.43
108 Fron Imp (Mid-L)	0.18	-0.11	-0.57	0.21	-0.29	0.23	0.16	0.24	-0.03	0.09
109 Fron Imp (Mid-L)	0.48	-0.05	-0.25	0.09	-0.39	0.15	0.38	-0.27	0.29	0.17
123 Mid-L Cran Imp(V)	0.61	-0.02	-0.28	0.46	-0.09	0.36	0.28	0.39	0.30	0.34
125 Mid-L Cran Imp(P)	0.40	0.18	-0.23	0.41	-0.29	0.58	0.12	0.60	-0.09	0.12
129 Zyg Pro Temp Imp	0.25	-0.42	-0.23	0.00	-0.34	0.74	-0.35	-0.14	-0.13	0.55

*Constitutes overall error of method including "Template-Transfer" of reference line 1-2 as relationship of Basi-Sphenoid implants to Axis 1-2 is constant.

†Positive indicates Forward Movement while Negative indicates Backward Movement

††Positive indicates Upward Movement while Negative indicates Downward Movement

TABLE VII (Continued)

LANDMARK	CONTROL GROUP				RAPID PALATAL EXPANSION GROUP					
	MONKEY NO. 1		MONKEY NO. 5		MONKEY NO. 2		MONKEY NO. 6		MONKEY NO. 7	
	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver
130 Zyg Pro Temp Imp	0.36	-0.49	-0.31	0.10	0.00	0.00	-0.44	-0.11	-0.03	0.24
132 Zyg Imp	0.57	-0.44	-0.25	-0.01	-0.12	0.66	-0.28	0.09	-0.15	0.76
135 Zyg Imp	0.54	-0.48	-0.40	0.06	0.00	0.00	-0.02	0.22	0.19	0.74
142 Max Imp	0.55	-0.18	-0.63	0.13	0.16	0.39	0.17	-0.15	0.53	0.40
143 Max Imp	0.73	-0.31	-0.38	0.20	0.26	0.18	0.58	-0.44	0.52	0.43
144 Max Imp	0.66	-0.08	-0.34	0.12	0.08	0.37	0.45	-0.23	0.35	0.44
145 Max Imp	0.64	-0.19	-0.36	-0.18	-0.18	0.05	0.60	-0.09	0.38	0.37
150 Max Imp	0.63	-0.29	-0.54	-0.19	0.00	0.20	0.33	-0.66	0.30	0.31
151 Max Imp	0.53	-0.50	-0.43	0.13	0.20	-0.08	0.59	-0.81	-0.01	-0.03
161 Mand Imp	0.86	-0.04	0.01	-0.07	-1.54	-0.85	-0.38	0.15	-0.41	-0.14
165 Mand Imp	0.67	-0.05	0.06	-0.14	-1.98	0.22	-0.52	0.14	-0.64	0.07
169 Mand Imp	0.79	-0.12	-0.13	0.23	0.00	0.00	-0.54	-0.04	0.00	0.00

TABLE VIII

MAXILLARY SUPERIMPOSITION

HORIZONTAL† AND VERTICAL†† INCREMENTS OF CHANGE (IN MM) OF EACH LANDMARK DURING THE RAPID PALATAL EXPANSION INTERVAL

	CONTROL GROUP				RAPID PALATAL EXPANSION GROUP					
	MONKEY NO. 1		MONKEY NO. 5		MONKEY NO. 2		MONKEY NO. 6		MONKEY NO. 7	
LANDMARK	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver
17 Nasal Tip	0.24	0.45	-0.64	0.39	-1.20	-0.08	-0.35	-0.15	-0.27	-0.18
18 A Point	0.81	-0.90	-0.51	0.72	-0.59	-0.36	-0.48	1.49	0.00	0.46
19 Ant Max Pt	0.45	-0.23	0.18	-0.14	-0.58	-0.03	-0.40	0.84	-0.07	0.76
20 Prosthion	0.93	-0.26	0.37	0.01	-0.90	0.13	0.05	-0.17	0.07	-0.32
21 1 Root Apex	0.13	-0.06	-0.18	0.06	0.79	0.95	-0.76	-0.13	0.30	0.16
22 1 Incisal Edge	0.13	-0.18	-0.36	0.08	-1.05	-0.65	-0.27	-0.32	-0.40	-0.34
33 Ant Palatal Pt	0.85	0.02	-0.09	0.34	0.28	-0.57	-0.33	-0.14	-0.01	-0.49
34 Post Nasal Spine	-0.18	0.07	-0.09	0.22	-0.51	-0.26	-0.24	-0.09	-0.17	-0.65
36 Tuberosity Pt S	0.63	-0.56	0.01	-0.76	-0.61	-0.76	-0.29	-0.27	0.25	-1.09
43 Orbitale	0.34	0.53	-0.58	0.30	-0.40	0.16	0.11	0.79	-0.60	0.45
44 /6 M-B Cusp	1.02	0.06	-0.44	0.23	0.42	0.21	-0.04	0.79	0.10	0.30
45 /6 Buccal Groove	-0.02	0.47	-0.41	-0.19	0.68	-0.13	0.07	0.47	-0.02	0.34
46 /6 D-B Cusp	0.08	0.30	-0.67	0.12	0.31	0.56	-0.21	0.46	-0.09	0.33
47 /6 M-B Root Apex	0.23	0.00	-0.46	0.81	0.29	-0.21	0.33	0.90	0.44	0.09
48 /6 Trifurcation	0.21	0.22	-0.04	0.48	-0.53	1.29	0.40	1.41	-0.23	-0.13
49 /6 D-B Root Apex	0.39	0.31	-0.32	0.46	0.28	-0.17	0.03	0.41	1.14	0.52
50 /7 M-B Cusp	0.88	0.01	-1.28	-0.13	-0.94	-0.04	0.81	0.19	0.72	-0.21
51 /7 Buccal Groove	0.18	0.70	-0.85	0.91	-0.38	-0.17	0.79	-0.15	0.87	-0.43
52 /7 D-B Cusp	0.54	0.39	-0.92	0.81	-0.92	0.06	0.11	0.30	0.67	0.03
53 /7 M-B Root Apex	-0.54	-1.82	-1.05	-2.14	-0.16	-0.85	0.57	-0.01	0.29	-0.22
54 /7 Trifurcation	0.72	-0.92	-0.93	-1.00	-0.36	-1.37	0.05	-0.68	0.00	-0.62
55 /7 D-B Root Apex	-1.39	-0.93	-3.09	-1.49	0.14	-0.42	-0.21	0.94	-0.34	-0.26
56 /8 M-B Cusp	-0.02	-0.65	-0.19	-0.95	-0.67	-0.63	0.33	-0.14	-0.31	-0.82
57 /8 D-B Cusp	-0.99	-0.08	-0.26	-0.25	-0.61	-0.38	0.11	-0.55	-0.11	-0.37
58 /8 Center	0.03	-0.06	-0.41	0.16	-0.71	-1.46	-0.19	-0.70	0.00	-0.54
59 /8 Most Post Pt	0.60	0.84	-0.96	-0.92	-0.84	-0.88	1.40	1.29	0.30	0.02
142 Max Imp	0.52φ	-0.19φ	-0.65*	0.07*	-0.20φ	0.11φ	-0.23φ	-0.17φ	0.33*	0.22*
143 Max Imp	0.72φ	-0.32φ	-0.40*	0.17*	-0.06φ	-0.11φ	0.20φ	-0.41φ	0.32*	0.25*
144 Max Imp	0.60φ	-0.10φ	-0.36*	0.10*	-0.27¶	0.04¶	0.06*	-0.20*	0.14*	0.26*
145 Max Imp	0.60φ	-0.21φ	-0.36*	-0.21*	-0.49¶	-0.30¶	0.18*	-0.03*	0.18*	0.19*
146 Max Imp	0.45¶	0.02¶	-0.20φ	0.21φ			-0.03*	-0.27*	0.24*	0.18*
147 Max Imp	0.35¶	-0.01¶	-0.43φ	0.08φ			0.24*	-0.09*	0.15*	0.19*
148 Max Imp	0.63*	-0.03*	-0.45¶	0.26¶	-0.34*	0.07*	0.06¶	-0.33¶	0.38*	0.42*
149 Max Imp	0.30*	-0.10*	-0.28¶	0.11¶	-0.44*	0.26*	0.33¶	-0.44¶	-0.12*	0.35*
150 Max Imp	0.62*	-0.24*			-0.31¶	-0.15¶	-0.04¶	-0.60¶	0.12*	0.15*
151 Max Imp	0.53*	-0.46*	-0.46¶	0.11¶	-0.07¶	-0.41¶	0.24¶	-0.72¶	-0.17φ	-0.28φ

*Implant in Body of Maxilla registered during superimposition. Constitutes error of method including "Template-Transfer" of reference line 3-4.
φImplant in Premaxilla
¶Implant in Palatal Process of Maxilla

†Positive indicates Forward Movement while Negative indicates Backward Movement
††Positive indicates Upward Movement while Negative indicates Downward Movement

TABLE IX

MANDIBULAR SUPERIMPOSITION

HORIZONTAL† AND VERTICAL†† INCREMENTS OF CHANGE (IN MM) OF EACH LANDMARK DURING THE RAPID PALATAL EXPANSION INTERVAL

	CONTROL GROUP				RAPID PALATAL EXPANSION GROUP					
	MONKEY NO. 1		MONKEY NO. 5		MONKEY NO. 2		MONKEY NO. 6		MONKEY NO. 7	
LANDMARK	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver	Hor	Ver
23 Ī Incisal Edge	0.13	-0.03	0.12	-0.31	0.02	0.36	1.10	-0.32	-0.01	0.14
24 Ī Root Apex	-0.12	-0.35	1.44	0.48	-0.14	0.81	0.54	-0.17	0.35	-0.23
25 B Point	-0.01	0.09	0.84	0.95	-0.25	0.50	0.98	0.08	-0.12	-0.04
27 Menton	-0.35	-0.05	-0.14	0.34	-0.36	-0.21	-0.28	-0.13	0.15	0.16
28 Ant Pt Mand Tan			-0.57	0.09	-2.23	0.04	2.59	0.25	0.68	0.26
29 Post Pt Mand Tan	-1.61	0.10	-0.51	0.33	0.46	0.06	0.57	0.42	0.15	0.01
30 Gonion	-0.38	1.38	-0.74	0.47	0.23	0.35	1.21	-0.62	-0.68	0.77
31 Imf Pt Post Tan	-0.75	0.49	-0.53	0.58	-0.45	-0.14	0.41	-1.51	0.03	0.52
61 /6 Buccal Groove	-0.22	0.00	-0.04	-0.09	0.07	-1.16	1.09	-0.44	0.36	-0.46
67 /7 Buccal Groove	-0.27	-0.07	-0.05	0.82	0.56	-0.26	0.62	-0.05	0.51	-0.30
73 /8 Buccal Groove	0.87	-0.04	-0.59	0.03	-0.08	-0.66	0.99	-0.31	0.48	0.14
75 /8 Mid-Pt Inf Out	0.44	-0.19	-0.15	0.27	-0.37	-0.93	1.02	-0.32	0.17	0.39
160* Mand Imp	0.33	-0.34	0.00	0.13	-0.39	0.08	0.43	-0.29	0.25	-0.02
161* Mand Imp	0.42	-0.19	0.11	-0.01	-0.39	-0.22	0.39	-0.34	0.39	0.06
162* Mand Imp	0.21	-0.20	-0.07	0.08	-0.20	-0.06	0.64	-0.15	0.44	0.06
163* Mand Imp	0.42	-0.25	0.03	-0.08	-0.13	0.05	0.42	-0.08	0.34	-0.18
164* Mand Imp	0.24	-0.14	-0.18	0.00	-0.66	0.21	0.42	-0.35	0.25	-0.08
165* Mand Imp	0.23	-0.19	0.17	-0.11	-0.73	0.24	0.24	-0.19	0.19	-0.01
166* Mand Imp	0.32	-0.22	-0.28	0.08	-0.20	0.10	0.30	-0.41	0.38	-0.05
167* Mand Imp	0.44	-0.25	-0.14	0.02	-0.38	0.09	0.29	-0.18	0.35	0.01
168* Mand Imp	0.41	-0.17	0.10	-0.13	0.00	0.00	0.21	-0.14	0.00	0.00
169* Mand Imp	0.32	-0.21	-0.03	0.23	0.00	0.00	0.22	-0.27	0.00	0.00

*Constitutes error of method including "Template-Transfer" of reference line 5-6 as relationship of Mandibular Implants to Axis 5-6 is constant.

† Positive indicates Forward movement while Negative indicates Backward movement
†† Positive indicates Upward movement while Negative indicates Downward movement

TABLE X

LINEAR ANALYSIS

INCREMENT OF CHANGE (IN MM) IN EACH LINEAR DISTANCE DURING THE RAPID PALATAL EXPANSION INTERVAL

	CONTROL GROUP		RAPID PALATAL EXPANSION GROUP		
VARIABLE	MONKEY NO.1	MONKEY NO.5	MONKEY NO.2	MONKEY NO.6	MONKEY NO.7
15-27 Frontale to Menton	-0.56	-0.12	0.27	-0.07	-0.10
11-27 Supra-Orbitale(U) to Menton	0.22	-0.06	0.53	-0.63	-0.24
17-33 Nasal Tip to Ant Palatal Pt	0.25	0.01	0.04	-0.02	0.22
17-27 Nasal Tip to Menton	0.42	0.09	1.28	-0.21	0.13
17-20 Nasal Tip to Prosthion	0.96	0.90	-0.05	0.21	0.27
18-36 A Point to Tuberosity Pt (Sup)	0.11	-0.15	0.12	0.25	0.11
20-35 Prosthion to Tuberosity Pt (Inf)	0.91	0.63	0.05	0.21	0.32
58- 9 /8 Center to Sella Turcica	0.00	-0.82	-0.47	0.15	0.29
58-BS /8 Center to Basi-Sphenoid Implant	-0.05	-0.15	-0.28	-0.13	-0.05
51-BS /7 Buccal Groove to Basi-Sphenoid Implant	-0.40	-0.96	-0.11	1.05	0.94
17-BS Nasal Tip to Basi-Sphenoid Implant	0.05	-0.22	-0.71	-0.21	-0.36
18-BS A Point to Basi-Sphenoid Implant	0.54	-0.08	-0.18	0.13	0.05
Maxillary Implant to Basi-Sphenoid Implant	0.35	-0.39	0.17	-0.21	0.30
27-BS Menton to Basi-Sphenoid Implant	-0.08	-0.37	-0.42	-1.11	-0.67
44-61 /6 M-B Cusp to /6 Buccal Groove	0.61	-0.35	2.61	0.65	0.96
45-62 /6 Buccal Groove to /6 D-B Cusp	0.09	0.02	1.90	0.25	0.69
50-67 /7 M-B Cusp to /7 Buccal Groove	-0.04	-0.48	0.99	0.24	0.63
51-68 /7 Buccal Groove to /7 D-B Cusp	0.56	0.58	0.77	-0.38	-0.03

TABLE XI

ANGULAR ANALYSIS

INCREMENT OF CHANGE (IN DEGREES) IN EACH ANGULAR MEASUREMENT DURING THE RAPID PALATAL EXPANSION INTERVAL

	CONTROL GROUP		RAPID PALATAL EXPANSION GROUP		
VARIABLE	MONKEY NO.1	MONKEY NO.5	MONKEY NO.2	MONKEY NO.6	MONKEY NO.7
Angle a[T]	-0.201	-0.060	0.249	-0.165	-0.150
Angle b[T]	-0.311	0.058	1.255	-0.487	0.539
Angle c[T]	-0.108	0.118	1.006	-0.321	0.688
Angle d[λ]	0.702	-0.355	-3.815	-1.764	
Angle e[δ]	-1.079	-0.218	-2.700	-2.856	3.167
Angle f[ξ]	-0.523	3.473	2.298	0.806	0.259
Angle g[δ]	0.325	-0.280	-0.740	-0.523	-0.189
Angle h[ξ]	-1.554	-0.986	0.746	1.719	-0.192
Angle i[λ]	-1.915	-0.417	-1.855	-1.024	
Angle j[λ]	1.321	0.331		-0.671	-1.016
Angle k[λ]	-1.522	-0.390		0.506	0.867
Angle l[ξ]	-3.026	0.164	-0.578	1.351	1.022
Angle m[ξ]	1.121	1.209	-0.106	0.838	3.840
Angle n[ξ]	-4.090	3.307	2.650	-0.708	-1.252
Angle o[ξ]	-5.943	-5.788	3.648	-1.433	-3.217
Angle p[ξ]	-0.280	-0.180	-6.147	0.409	-1.907
Angle q[ξ]	-0.079	-0.121	-6.394	0.573	-1.756

[T] Long arm error applicable. Maximum error associated with worst of 99% of measurements is 0.817°

[δ] Medium arm error applicable. Maximum error associated with worst of 99% of measurements is 1.711°

[λ] Short arm error applicable. Maximum error associated with worst of 99% of measurements is 3.799°

[ξ] Angle composed of anatomical sites rather than implant sites. No error available.

G L O S S A R Y

GLOSSARY

ANATOMICAL LANDMARKS

Site 9 Sella Turcica (S): The geometric centre of the pituitary fossa determined by inspection.

Site 10 Point of intersection of Planum Sphenoidale and Anterior Clinoid Process.

Site 11 Supra-orbitale (Upper): Point of intersection of outline of left roof of orbit (upper image) with lateral contour of orbital ridges.

Site 12 Supra-orbitale (Lower): Point of intersection of outline of right roof of orbit (lower image) with lateral contour of orbital ridges.

Site 13 Superior Orbital Point (Upper): Anterior limit of outline of left roof of orbit (upper image).

Site 14 Superior Orbital Point (Lower): Anterior limit of outline of right roof of orbit (lower image).

Site 15 Frontale (F): The most anterior point on the frontal bone.

Site 16 Nasion (Na): The midpoint of the frontonasal suture at its most anterior margin.

Site 17 Nasal Tip (Nt): The most anterior inferior point on the nasal bones.

Site 18 A Point (Subspinale): The deepest midline point on the anterior maxillary outline.

Site 19 Anterior Maxillary Point (AMP): The point on the anterior outline of the maxilla at the level of the apex of maxillary incisor.

Site 20 Prosthion (Pros): Point of intersection between the labial surface of maxillary central incisor and the premaxillary alveolar process.

Site 21 Maxillary incisor root apex.

Site 22 Maxillary incisor incisal edge.

Site 23 Mandibular incisor incisal edge.

Site 24 Mandibular incisor root apex

Site 25 Infradentale (Inf): Point of intersection between the labial surface of mandibular central incisor and the mandibular alveolar process.

Site 26 B Point (Supra-Mentale): The point on the anterior convex curvature of the mandible level with the apex of the mandibular incisor.

Site 27 Menton (Me): The most inferior point on the mandibular symphisis.

Site 28 Anterior point on tangent to lower border of mandible at intersection of the tangent and the mandible.

Site 29 Posterior point on tangent to lower border of mandible at intersection of the tangent and the mandible.

Site 30 Gonion (Go): The midpoint in the curve of the mandible between the posterior border of the ramus and the lower border of the corpus.

Site 31 The inferior point on tangent to posterior border of mandibular ramus at intersection of the tangent to the mandible.

Site 32 Articulare (Ar): The point of intersection of the images of the posterior border of the mandible and of the inferior surface of the basilar process of the occipital bone.

Site 33 Anterior Palatine Point (APP): The most anterior point on the outline of the palate.

Site 34 Posterior Nasal Spine (PNS): Tip of the posterior spine of the hard palate.

Site 35 Tuberosity Point (Inf): The most posterior point on the maxillary tuberosity at the level of the palatal plane.

Site 36 Tuberosity Point (Sup): The most posterior superior point on the outline of the maxillary tuberosity.

Site 37 Basion (Ba): The midline point at the inferior margin of the anterior border of foramen magnum.

Site 38 Opisthion: The midline point at the inferior margin of the posterior border of foramen magnum

Site 39 Occipital Point (Occ): The most posterior prominent point of the contour of the occipital bone with respect to the Frankfort Horizontal.

Site 40 Occipito-Parietal Suture Point: The point on the parietal side of the occipito-parietal suture demarcating the margin of the suture.

Site 41 Parieto-Frontal Suture Point: The point on the parietal side of the parieto-frontal suture demarcating the margin of the suture.

Site 42 Porion (P): A machine point of the cephalometer demarcated by the junction of the superior outlines of the right and left earposts.

Site 43 Orbitale (Or): The most inferior point of the outline of the bony orbit. Orbitale is a maxillary landmark.

Site 44 /6 M-B Cusp: Mesio-buccal cusp tip of maxillary left first molar.

Site 45 /6 Buccal Groove: Buccal groove of maxillary left first molar.

Site 46 /6 D-B Cusp: Disto-buccal cusp tip of maxillary left first molar.

Site 47 /6 M-B Root Apex: Root apex of mesio-buccal root of maxillary left first molar.

Site 48 /6 Trifurcation: Trifurcation of root of maxillary left first molar.

Site 49 /6 D-B Root Apex: Root apex of disto-buccal root of maxillary left first molar.

Site 50 /7 M-B Cusp: Mesio-buccal cusp tip of maxillary left second molar.

Site 51 /7 Buccal Groove: Buccal groove of maxillary left second molar.

Site 52 /7 D-B Cusp: Disto-buccal cusp tip of maxillary left second molar.

Site 53 /7 M-B Root Apex: Root apex of mesio-buccal root of maxillary left second molar.

Site 54 /7 Trifurcation: Trifurcation of root of maxillary left second molar.

Site 55 /7 D-B Root Apex: Root apex of disto-buccal root of maxillary left second molar.

Site 56 /8 M-B Cusp: Mesio-buccal cusp tip of maxillary left third molar (unerupted).

Site 57 /8 D-B Cusp: Disto-buccal cusp tip of maxillary left third molar (unerupted).

Site 58 /8 Center: Geometrical center of maxillary left third molar (unerupted).

Site 59 /8 Most Post Pt: Most posterior point on outline of maxillary left third molar (unerupted)

Site 60 /6 M-B Cusp: Mesio-buccal cusp tip of mandibular left first molar.

Site 61 /6 Buccal Groove: Buccal groove of mandibular left first molar.

Site 62 /6 D-B Cusp: Disto-buccal cusp tip of mandibular left first molar.

Site 63 /6 M Root Apex: Root apex of mesial root of mandibular left first molar.

Site 64 /6 Bifurcation: Bifurcation of root of mandibular left first molar.

Site 65 /6 D Root Apex: Root apex of distal root of mandibular left first molar.

Site 66 /7 M-B Cusp: Mesio-buccal cusp tip of mandibular left second molar.

Site 67 /7 Buccal Groove: Buccal groove of mandibular left second molar.

Site 68 /7 D-B Cusp: Disto-buccal cusp tip of mandibular left second molar.

Site 69 /7 M Root Apex: Root apex of mesial root of mandibular left second molar.

Site 70 /7 Bifurcation: Bifurcation of root of mandibular left second molar.

Site 71 /7 D Root Apex: Root apex of distal root of mandibular left second molar.

Site 72 /8 M-B Cusp: Mesio-buccal cusp tip of mandibular left third molar (unerupted).

Site 73 /8 Buccal Groove: Buccal groove of mandibular left third molar (unerupted).

Site 74 /8 D-B Cusp: Disto-buccal cusp tip of mandibular left third molar (unerupted).

Site 75 /8 Mid-Pt Inf Out: Mid-point of inferior outline of mandibular left third (unerupted).

Site 76 Posterior Clinoid Process.

Site 77 Most inferior point on outline of sella turcica.

Site 78 Most anterior superior point on outline of sella turcica.

Site 79 Junction of Planum Shenoidale with midpoint of greater wings of sphenoid bone (CBR Pt).

Site 80 Tip of free end of soft palate.

Site 180 Soft tissue Nasion: The most posterior point on the contour of the soft tissue between the forehead and the nose.

Site 181 Soft Tissue Tip of Nose (S Tis Tip Nose): The most anterior inferior point on the contour of soft tissue of the nose.

Site 182 Labrale Superius (Ls): The most prominent point on the outline of the upper lip.

Site 183 Mid-point of vertical distance between upper and lower lips chosen by inspection.

Site 184 Labrale Inferius (Li): The most prominent point on the outline of the lower lip.

METALLIC IMPLANT SITES

Sites 82 to 91: Implants in basi-occipital bone.

Sites 92 to 101: Implants in basi-sphenoid bone.

Sites 106 to 107: Implants in zygomatic process of frontal bone.

Sites 108 to 111: Implants in frontal bone in the midline of the forehead.

Sites 112 to 115: Implants placed bilaterally in the frontal bone with stereotaxic instrument for use in "head orientation."

Sites 119 to 122: Implants placed bilaterally in parietal bones with stereotaxic instrument for use in "head orientation."

Sites 123 to 124: Implant in mid-line of cranium at vertex of skull.

Sites 125 to 126: Implant in mid-line of cranium at posterior of skull.

Sites 129 to 131: Implants in zygomatic process of temporal bone.

Sites 132 to 137: Implants in zygomatic bone.

Sites 142 to 159: Implants in maxilla.

Sites 160 to 171: Implants in mandible.