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AN ASSESSMENT OF RELATIONSHIPS AMONG DIETARY CONSISTENCY, BITE FORCE AND PALATAL MORPHOLOGY IN GROWING MONKEYS

by

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Submitted in partial fulfillment of the requirements

for the degree of Master of Science in Dentistry

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August 22, 1991

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Abstract

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The purpose of this study is to gain some understanding of palatal form and function. To obtain this understanding, an analysis of relationships between masticatory function and palatal morphology was undertaken. Parameters considered in this analysis include electrically induced in vivo bite force measurements, cephalometric and craniometrics The data was obtained from a population of growing African green monkeys during the time from mixed dentition to attainment of dental maturity. To test the hypothesis that the palatal growth is significantly affected by masticatory biomechanics, dietary consistency was manipulated in the hope of inducing differential growth by altering chewing function.

Correlations of bite force with the following measurements were studied: intercuspid width, intermolar width, palatal length, palatal vault depth, palatal volume, maxillary length, dental height, and palatal plane angle. Bite force at incisal, first molar, and second molar were also compared and correlated with the amount of palatal growth. The results showed statistically significant correlation between second molar bite force and palate related measurements. However, no statistically significant difference in palatal dimensions and manipulate bite force was found between monkeys fed contrastive diets.

Thus, it is concluded that changes in dietary consistency in this experiment did not significantly influence the palatal growth. This result mandates further investigations to include the effects of respiratory and tongue growth.

to

my wife CHIN-CHUN TSENG

and my son JESSE TSENG

ACKNOWLEDGMENT

The author

wishes to express

his sincere gratitude to

Drs. Ordean Oyen, Peter Tsay, Mark Hans,

and mostly

to my parents

for their continued support

of me and my educational endeavors

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INTRODUCTION

The intention of this study is to use cephalometric analysis and measurements of the palate combined with an evaluation of the masticatory system including in vivo bite force to enhance our understanding of palatal growth. This report is part of a longitudinal evaluation of the effects of masticatory biomechanics on the growth of craniofacial skeleton. The broader study started by Dr. Ordean Oyen in 1983 at Case Western Reserve University, includes an initial investigation of growth of the palate in the African green monkey undertaken by Cavalancia (1985). In the study by Cavalancia, post-natal development of occlusion and it's related effects on the palate, with respect to masticatory force, were examined in monkeys with mixed dentition; the current investigation is a modified continuation of the palatal studies using the same group of monkeys. However, in this instance the growth period examined extends from the mixed dentitional stage to dental maturity and additional analyses are carried out.

The primary objective of this study is to test this hypothesis that palatal growth is significantly affected by masticatory biomechanics. To test the hypothesis, the facial skeleton is regarded as a rigid frame structurally which adapts morphologically to repetitious, intermittent biomechanical effects that occur during biting and chewing, which are in some manner transmitted to the palate. In this model, the independent variables acting on the framework are forces produced during elevation of the mandible. If these forces are of sufficient intensity and duration, alternations in palatal morphology may take place.

To test this proposed hypothesis, the intensity and duration of mastication are experimentally manipulated in two groups of growing vervet monkeys: One group raised on a hard diet that required vigorous biting and chewing; the other group raised on a nutritionally

equivalent soft diet that required substantially less masticatory effort. It is presumed that this dietary consistency alternation will produce alternations in masticatory intensity and duration.

To gain insight into the relationships between masticaton and palatal growth, in this study several questions have been considered:

(1) To what extent does dietary consistency affect the ability to bite hard?

(2) How do different kinds of dietary environment affect palatal growth?

(3) What are the relationships between masticatory function and growth of palate-related structures?

In addition to its contribution to an understanding of the basic science of masticatory biomechanics and craniofacial structure and function, it is also hoped that this study will have some clinical relevance. In particular, it is hoped that the finding reported here will shed some light on the major arguments that center on whether skeletal adaptation result from intrinsic remodeling or from extrinsic mechanotherapy.

LITERATURE REVIEW

For decades many investigators in the field of craniofacial biology have focused on the dentofacial growth and development in human beings. Numerous investigations of skeletal changes during craniofacial development and growth have been done (Bolton Standard, Ricketts cephalometric analysis, Down's analysis, McNamara analysis, etc.). These craniofacial standardized head plates and different kinds of cephalometric analyses have contributed significantly to our knowledge in this area. However, no definitive conclusion exists concerning the structural and functional aspect of craniofacial growth.

It is broadly accepted that growth of the palate, as any other component of the facial skeleton is regulated by intrinsic, i.e., genetic and extrinsic, i.e., environmental, functional factors. It is also generally agree that the primary mechanisms that enable the palate to grow are sutural growth, and surface apposition and resorption (see Enlow [1990] for extensive discussion). Relatively little consensus seems to exist, however, about the external factors that influence actual growth of the palate, and much confusion seems to exist about this topic. For example, Scott (1954) has argued that growth of the cartilagenous nasal septum play a critical role in the mid-face, which includes the palate; according to the functional matrix theory of Moss (1960) the respiration airway is a regulator of growth in this area; Enlow (1968) has presented evidence that palatal growth reflects to a large extend the anatomy of the anterior craniofossa; and still another (Profit, 1961) argues that the soft tissue anatomy, especially the tongue and circum-orbital muscles influence palatal growth and form. To date, relatively little is actually known about the relationships between palatal morphology and masticatory function, other than observations include in studies of the effects of the dietary consistency on craniofacial morphology, e. g., Corrucini (1981).

Given the circumstances just described, what follows is a brief review of some of the findings and interpretations about palatal growth that bear on the specific questions about the relationships between biomechanics and palatal growth addressed in this study.

As Enlow (1974) described, the circumferential shape of the anterior cranial fossa is the blue print of the maxillary bone, and the maxillary bone decides the shape of palatine bone. The alveolar ridge of maxilla is decided by the shape of palatine bone. The maxillary teeth are mainly erupted and oriented by the maxillary alveolar ridge. Here we have the sequence of the dependents, which are:

(a) Anterior cranial base,
(b) Maxillary bone,
(c) Alveolar ridge,
(d) Maxillary teeth.

The only dependent to the masticatory force will be the teeth and their orientation of the roots. Bite force generated by masticatory function will directly affect on the crowns of these teeth. The major components to the upper dentition are the crowns of these maxillary teeth. With this thinking, the chewing magnitude of a growing individual is influenced by the masticatory force.

Enlow (1968) states that the external configuration of a bone is largely dependent upon a composite of its functions. Remodeling and relocation allows function to continue uninterrupted through the normal process of growth and development. The extent of this adaptability, however, is known to vary considerably according to the type and the location of the bone tissue involved.

Above the maxilla, it is also necessary to consider the growth of cranial base, which according to Enlow (1978) the cranial base acts as a blue-print for its inferior structures. Sutural growth along the boundaries of the sphenoid bone, a large component of cranial base, contributes significantly to endocranial expansion and displacement of the maxillary

segment of the face. An important consequence of the maxillary displacement that results from expansion of the middle and anterior cranial fossa is the changes that are simultaneously brought about on the mandible and jaw elevator muscle function. As Enlow (1978) points out, anterior displacement of the maxilla does several things, in addition to perhaps "carrying "the mandible forward with it. First, anterior displacement moves the entire dental arcade away from the fulcrum of the jaw joints, theoretically increasing the load arm length. Second, this movement carries the anterior-most points of attachment of the jaw elevator muscles away from the fulcrum, theoretically extending the lever arm. Third, forward displacement creates space in the posterior region of the dental arch, allowing for subsequent development of the maxillary tuberosity and the growth and eruption of any teeth therein. Simultaneous descent of the maxillae and accompanying mandible occurs in such a way that the lines of the jaw elevator muscles, especially the masseter and medial pterygoid, move further away from the fulcrum, thereby contributing to the theoretical increases in lever arm length.

When studying palatal growth, it is necessary to consider the role of maxilla. Maxillary displacement involves two different force-generating mechanisms reported by Latham (1976). In the embryonic and the greater part of the fetal periods, the nasal septum appears to apply a tractional stimulus by means of the septo-premaxillary ligament. A second maxillary displacing event commences in late fetal life and gradually supersedes that of the nasal septum. It is assumed that the second displacing mechanism is a function of cellular proliferation in the osteogenic layer of the posterior-superior maxillary periosteum and results in growth against the adjacent masses of fatty tissue and relationship in maxillary displacement. The maxillary sutures are initially a sliding joint, but later manifest increasing osteogenesis that could contribute to the displacing force at the free surfaces. The palate, follows the growth of the maxilla; mechanical influences on the maxilla may directly affect the growth of the palate.

The size of the airway, especially the transverse dimension is critical to the transverse dimension of the palate. Moreover, the nasal pharyngeal structure of the airway contributes to definition of the a posterior border of the palate.

The interrelationships of muscle function and bone growth has been established in many experimental studies, but the exact nature of this relationship is still under investigation. The studies of Sicher and Tandler (1928) offered that muscle stress is the key factor controlling bone development. However, such a conclusion is premature since many variables have not been considered. As Scott (1954) stated, the face, especially the muscles of mastication, have been shown to influence the morphologenesis of the craniofacial region. Moss (1962) has developed the functional matrix concept that places primary importance upon the adaptability of structure to functional patterns and extrinsic environmental conditions. In this concept the airway increases in size by adapting to the musculature function. Moss also forcefully argued that maintenance of adequate spaces critical to body functions is an important factor influencing working of the functional matrix. Yet, Enlow (1977) has shown that the patterns of muscle attachment do not necessarily coincide with patterns of resorption and deposition. In many instances, the vector of force of the musculature is opposite to the direction of bone growth. A single muscle may attach over areas of adjacent deposition and resorption. Enlow states that stress relationships do not follow the conventional tension-deposition and pressure-resorption presumption and that such explanations are an over simplification.

It is unclear that where is the bite force dissipated after it was generated by the masticatory muscles In a study done by Oyen and Tsay (1991), serious questions have been raised about the work of Benninghoff (1925), and the work of Sicher and Tandler (1928) who proposed a beam hypothesis, which suggested that the transmission of masticatory force occurs through several routes along the facial skeleton. In this model, force generated in the

molar area when the jaw closes is said to be transmitted through the key-ridge and along the zygomatic bone and lateral border of orbit until it is finally dissipated over the skull. Basically, all the masticatory forces are receipted by the palate and referred to the other apparati. Forces emanating from the molar region are also transmitted through the maxillary tuberosity along the posterior border of the maxilla and pterygoid buttress upward and dissipated over the base of skull. In the premaxillary area, bite force is said to be transmitted through the canine root eminence and along the lateral border of the piriform aperture and nasal bone to be dissipated over the skull. In the pilla-beam concept, forces generated in the molar area apparently are universally compressive in nature. In their analyses, Oyen and Tsay found those tensile forces predominant in the lateral orbital margin. Thus calling into question the validity of this model.

In Cowin's study (1984) it has been shown that tensile force may be more critical than compressive force in evoking non-tramatic remodeling changes in long bone. Moreover, the beam hypothesis is based on the premise that any impact generated by chewing is not drastically diminished when food is crushed between teeth. Since the architectural design of the skeleton also serves a very important function in providing stimulation to facial growth in growing persons and maintaining homeostasis of facial structure in the adult, the pillar-and-beam model can have a profound influence on attempts to apply the functional matrix concept (Moss, 1960) for the purpose of understanding the mechanisms that regulate and maintain facial harmony.

Because of the uncertain ties about dissipation of the bite force, it is necessary to understand the bite force from a different view angle. The three dimensional figures of the masticatory muscles are difficult to be considered as one unit. Before we can find a more accurate way to manipulate the masticatory muscles, it will be more convenient and logical to use the lever arm to substitute all the masticatory muscles. When considering the bite points

of a chewing pattern, load arm lengths will be a more accurate representation for our understanding of masticatory biomechanics. The masticatory force is directly transfer through dentition to palatal structure. To consider the masticatory biomechanics as a lever and load system seem to be an appropriate way to understand the biomechanics of masticatory function and the palatal development. Oyen (1983) points out that the human jaw functions as a third order lever during elevation, regardless of the degree of symmetry of the action involved. This is so because the lines of action of the jaw elevator muscles fall between the fulcrum and the point of force application, i.e., the bite point. Consequently, in this system the load arm length, i.e., the distance from the fulcrum to the bite point, exceeds the lever arm length, i.e., the distance from the fulcrum to the line of action of a given jaw elevator muscle, drawn perpendicular to the line of action of that muscle. The simple mechanical efficiency of the jaw system can thus be expressed in terms of load arm and lever arm lengths relative to each other; the longer the load arm relative to the lever arm the less efficient the system. Conversely, the longer the lever arm, the more efficient the system; any change in load arm length will directly affect the ability to generate bite force.

Oyen also points out that the amounts of the bite force a person can generate is the product of two basic factors, simple mechanical efficiency of the jaw system and size (cross sectional area) of the jaw elevator muscles. Thus, in a jaw system with relatively low mechanical efficiency, relatively larger musculature will be required to produce the level of force that could be generated by a more efficient system with relatively smaller muscles. If the size of the musculature is held constant and the mechanical efficiency is varied by altering the length of the load arm, the resultant bite force will fluctuate according to the changes in mechanical efficiency. This later instance accounts for how one can exert more force with the molar than with the incisors. Changes in mechanical efficiency or in cross-sectional area of the jaw elevator muscles directly affect the bite force. If changes in either of these parameters

are of sufficient magnitude, it may be necessary for compensatory alterations to take place elsewhere in the craniofacial musculoskeletal system for masticatory efficiency or structural-functional integrity to be maintained.

There are three sutures inside the palate that act as a sliding joint to accomplish the growth. The incisive suture, closes early in human beings but rather late in monkeys. With the late closing of this suture, monkeys have longer developing time than human being, also this late closure allows monkeys grow longer in anterior segment of the palate. The median palatine suture acts as a sliding joint for both the right and left palatine bones and allow the palate grow transversally. The transverse palatine suture, located posteriorly in palate, also act as a sliding joint to allow the palate grow anterior-posteriorly.

The role of the palatine sutures were not recognized until early this century. Two centuries ago Hunter (1788) wrote that the jaws lengthen only at their posterior aspects after the age of twelve months. The maxillary sutures were later included in this scheme of growth (Keith, 1902; Keith and Campion, 1922). This scheme of growth was later include the concept that the maxillary sutures were capable of expansive growth. Sutural growth was thus seen as the primary factor in maxillary displacement. However, this concept was strongly countered by Brash (1934), who stressed the greater importance of surface accretion on the anterior facial surfaces and on the alveolar processes. In his idea the facial growth is mainly contributed by the bony apposition on the outer surface of the facial skeleton. A third position was taken by Scott (1948), who recognized the contributions of both sutural growth and surface accretion, the former action takes place in the early years until about seven years of age, and the later dominating from then on.

It has become evident that different sutures have different periods of timing to act in the growth of facial skeletons. From the studies of Enlow (1976), we know that sutural growth acts as a secondary growth in the total facial development. Besides the secondary growth

function in the total facial growth, sutures also act as a sliding joint to accommodate the adjacent bony structures and let the whole face grow harmoniously. The appositional growth on facial skeleton does not necessary follow Scott's concept of apposition on the outside and resorption from the inside. The apposition and the resorption in the craniofacial structures can be very different depending on the position of the craniofacial structure (Enlow, 1976).

It is generally accepted that growth on the posterior and superior surfaces of the maxilla, resulting in a downward and forward displacement, is a major mode of facial growth in both prenatal and early postnatal periods. The bodily movement of the maxilla points to the existence of a maxilla-displacing force Enlow (1960). Despite considerable interest and research, the biological basis for this force has not yet been satisfactorily explained.

One of the unique situations in the African green monkey is that their maxillary arch is more tapered than human being's. In the monkey, since they have excessively long canines in both upper and lower arches, they have diastema on both right and left canine areas. The palatal suture in the monkey is fused considerably late in dental age compared to the human being. According to a review by Oyen (1984), Schultz (1948) showed that the size of the canine diastema was not entirely related to canine size. Sarnat (1958) demonstrated in macaques that unilateral surgical removal of the hard palate has no discernible effect on the development of the maxillary dentition. From Sarnat's study one can infer that the tooth's eruption is genetically controlled more than the influence of the environmental change. In a study done by Cavalancia (1985), he found that the consistency of the diet has influence in the width of dental arch. He described that early mixed dentition of monkeys fed with soft food, showed a statistically significant decrease in permanent intercuspid width versus palatal length.

Post-natal growth of palate begins with the growth of the palatine bone and the posterior portion of the soft palate will follow the growth of the palatine bone (Enlow 1974). In the mean time, sutures in the palate are functioning as a sliding joint to remold the whole facial growth. Teeth come as another factor later on. Tongue acts an important factor in the growth and development of the palate. The speaking and chewing functions of the tongue give palate a pushing force from inside. With this inside pushed force, the palate can expand and grow wider and longer in size. The size and the functional pattern of the tongue give palate a direct influence to its size and shape. We do not know how much influence is the eruption of the teeth to the development of the palate. We also do not know the relationship between the impacted tooth to the growth of the palate. However, from the studies of the tooth size and the crowding, we do know that the size of the tooth may affect the shape of the dental arch to some extent. The number of the erupted teeth is genetically controlled; however, the teeth connected to the palate have an indirect effect through the tongue to the growth of the palate.

Generally speaking, palate growth is directly depend on two factors:

(1) the apposition and resorption of palatal bone.

(2) the sliding joint function of sutures.

The indirect effects to the palate are numerous, they can be; the eruption of teeth, the size of teeth, the position of teeth, the number of teeth, the airway, the size of tongue, the function of tongue and the functional pattern of mastication, etc.

Freedman (1962 a, b) incorporated palate length into his biometric studies of monkeys. Reed (1965, 1967, 1973) included some information about the length of the palate in his descriptions of the growth in olive baboons. More recently, Beecher and Corruccini (1979) measured length and breadth of the palate of Rhesus macaques. In Oyen's study (1984), he described changes in palatal length and breadth in a cross-sectional collection of olive baboons. Even though many of these studies gave us important

information about the growth of palate, it is still not enough information to understand the growth and development of palate.

The effects of the physical consistency of diet on the growth and development of the masticatory apparatus have been of interest since Watt and Williams (1951). They demonstrated that weaning a rat fed on a soft diet developed a more narrow arch compared to weaning a rat fed on a hard diet. Because the rat is a poor analogy for the human masticatory system (Weijs, 1975), Beecher and Corruccini (1979) performed a similar experiment with seventeen Rhesus macaques. They also showed a decrease in maxillary arch width in the soft diet animals. Although these studies can lead us to a conclusion that soft-food diet can cause a decrease in maxillary width, they do not show us how the narrow maxillary arch in the experiment can be related to the growth of the palate, moreover to the whole craniofacial morphology.

In a study evaluating the growth of the palate in the African green monkeys, Cavalancia (1985) investigated palatal changes of the vervet monkeys between the experimental group and the control groups. He used the skull samples of animals at different ages as a control group, and the animals with deciduous teeth as the experimental group. In that study he measured changes between the post-natal monkeys and the monkeys in mixed dentitional stage. By comparing growth changes in the animals with measurements obtained from a cross-sectional collection of skulls that sewed as a control group, Cavalancia found, that in relative terms, the five monkeys raised on a soft food diet showed a statistically significant decreased in intercuspid width versus palatal length when compared with the ten monkeys on a hard food diet.

One of the most common reasons for the orthodontic patient to seek treatment is an unsatisfactory facial appearance. A frequent cause for this aesthetic state is an un-coordinated relationship between the arch length and the tooth size. While most of these

situations are due to the maxillary arch being too narrow to fit all the maxillary teeth, in some of the instances, the tooth material is far too large relative to the maxillary arch. If the maxillary arch is too narrow as a consequence of underdevelopment, the clinical indication would be to increase the breadth of the arch, which would also contribute to an increase of peripheral length of the arch. Expansion of the arch in this fashion makes it easier for the subsequent dentition to grow into a better position. Also, the space created through an increase of the maxillary arch, reduces the likelihood that teeth need to be extracted to accommodate succeeding permanent teeth. In some cases, after the expansion of the maxillary arch, non-extraction of the permanent teeth can be considered for the patient.

Expansion of the maxilla is one of the oldest forms of orthodontic treatment. Still, its use has consistently evoked professional controversy. Some have suggested to use rapid expansion (Haas, 1980), some recommended to use slow palatal expansion (Skieller, 1964), or no expansion at all(Tweed, 1943). Skieller (1964) inserted metal implants into thirteen girls and seven boys, using bioblock expansion appliance with the opening rate of 0.5 millimeter per week for 7 months and then maintained for 12 months. Skieller found that both the teeth and the palatal vault widened and the palatal vault continued to widen both during retention, and from then on. The teeth, however, commenced to relapse at the end of the expansion and continued to do so out of the retention, with the relapse amounting on average to about 25 percent of the total opening. He estimated that, at a rate of opening of 0.5 millimeters. per week, the widening was one-fifth the result of the growth at the palatal suture, and four-fifths from tooth movement. Although he did not mention it, Skieller's figures show that the dental relapse was less for the patients under 9 years old and noticeably higher for those over 12 years of age.

The aim of most fixed orthodontic appliance therapy is to correct the skeletal and dentoalveolar mal-relationships, with little or no attention paid to co-existing abnormal

functional patterns. Many clinicians assume that these abnormal functional patterns will spontaneously be corrected if structural balance is obtained. However, in cases in which only one part of the form-function relationship is considered, regression of the skeletal and dentoalveolar configuration toward their original mal-relationships usually occurs, as indicated by the troublesome amount of relapse observed in both growing and non-growing patients following appliance removal.

Although many kinds of maxillary arch expanders can create breadth for the maxillary arch, expansions may lead to disharmony between hard tissue (bones) and soft tissue (muscles, sutures). In other words, active expansion may give the already stable form-function relationship a new environment, that may cause an imbalance in the overall configuration. If it is clinically desirable to expand the palate, it seems that the most natural way to attain such a change in the maxillary arch should be to induce the maxillary growth itself, i.e., causes maxillary growth to occur in such a way that the palate expands as a consequence.

Orthodontic therapy undertaken throughout the world is aimed at correcting dentoalveolar and skeletal mal-relationships, and with current knowledge and techniques, can improve occlusion. However, in spite of our mechanical abilities, we often do not consider one important fact when designing our treatment regime: The craniofacial complex maintains a state of homeostasis regardless of whether structural balance or imbalance exists. Abnormal skeletal or dentoalveolar configurations are counterbalanced by abnormal or atypical patterns of masticatory and perioral muscle function and by passive pressure of the other associated soft tissues. Therefore, any given overall form-function relationship is relatively stable even though each of its individual components may have an abnormal configuration or pattern of activity. This stability is demonstrated by the relative consistency of the overall skeletal and dentoalveolar relationships during the growth period, and barring environmental insult or

therapeutic intervention, the individual in late adolescence generally resembles himself as he appeared many years earlier.

According to an experiment carried out on rabbits, Storey (1973), suggested that the ideal rate of opening the palate would be 1 millimeter per week. This opening rate, has also been recommended clinically by Mew(1977), Hicks and Cotton (1978). With the expansion technique being used for many years, some clinicians find that there are some cases where the amount of expansion is not enough after the removal of the appliance. Another idea introduced is "overe-xpansion". Clinicians who carried out the over-expansion of the maxillary arch do so to compensate for relapse of the arch. Haas (1980) has probably been the forerunner in this field.

Today it is understood that genetics, function, nutrition and numerous other environmental factors all have varying degrees of influence on form. To move beyond what is already known about craniofacial and palatal growth, we must obtain additional, more specific information about these phenomena.

MATERIALS AND METHODS

In this investigation, tracings and measurements were made from the cephalometric radiographs taken at two different times; one prior and one subsequent to adulthood. The cephalometric study was mainly focused on the changes between the early mixed dentitional stage and the permanent dentitional stage of their masticatory function in load arm and lever arm system. In the in vivo bite force generated by a lever arm, the load arm system is consider the derived bite force. Bite force and mechanical efficiencies of the masticatory system were compared with the growth changes of the palate, relative to aspects of the whole masticatory muscle force are also studied. Besides the comparison of the efficiency of the masticatory function, the positional changes of the palate as related to the whole dentofacial structure are also evaluated. Bite forces in the experimental animals were evaluated and compared between soft diet and hard diet groups. The data relative to the bite force are also correlated with the data found on various palatal measurements.

Study population

Fifteen growing, male, African green monkeys (Cercopithecus aethiops) were used in this study. These animals were wild-caught on the island of St. Kitts and have been part of a long term evaluation of the relationship between mastication and facial growth that began in 1983. These monkeys were chosen for study because their masticatory apparatus is comparable to that of other primates, including humans. In addition, there is considerable biologic information already available about another Cercopithecus monkey, the Rhesus macaque.

Since the animals were wild-caught and their chronological ages were unknown, individual ages were estimated on the basis of stages of dental eruption according to

procedures used in earlier studies (Oyen, 1984; Oyen et al. 1979; Oyen and Rice, 1980). The estimated ages when the data were gathered are presented in Table 1.

Table 1. The estimated chronological age of the monkeys according to dental status.

Stage	Number	Dental Age	Estimated Age (mos.)
I	12	M1 in occlusion	13
II	3	M2 in occlusion	28
III	15	Last molar (M2 or M3) in occlusion	65

Since the onset of the study, the monkeys were individually housed in cages specially designed for long-term maintenance of small primates. Feeding and care of the monkeys was monitored at least twice daily over the length of the entire study. These services had been provided by the Animal Resource Center of Case Western Reserve University. To increase variation in bite force capabilities, the monkeys were subdivided into *two* groups and maintained on constricting hard or soft diets of identical nutritional value.

The experimental animals were fed with either hard or soft food since 1984, which was one year after the animals were caught. The same kind of diet was continuously given to the same group for 36 to 40 months. In the beginning of the study, the experimental animals were at the mixed-dentition stage. By the time of the bite force study begun, all first molars are present.



Figure 1. African green or vervet monkey (Cercopithecus aethiops).

Experimental group I: Hard diet.

Ten monkeys maintained on a hard diet were # 2 Cornelius, # 3 Patrick, # 4 Billy, # 5 George, # 6 Tim, # 7 Steive, # 8 Phil, # 9 Mad Max, # 10 Tammie, and # 13 Eddie. According to the original research protocol (Oyen 1982), the hard diet consisted of nutritionally balanced, commercially prepared hard biscuits, augmented periodically with unpeeled apples. Although the biscuits were sufficiently enriched to meet the nutritional requirements of growing monkeys, apples were regularly provided because of their relative hardness and their resistance to softening during their retention in the oral cavity or buccal pouch before actual chewing (Isavaradee 1988). Moreover, Hylander (1979) has shown that mastication of apple skins involves the generation of significant levels of bite force and bone strain.

Experimental group II: Soft diet.

The animals maintained on a soft diet were: # 1 Michael, # 11 Dannie, # 12 Willie, # 15 Luciano, # 16 David. This diet had the consistency of soft fudge and required no mastication. It consisted of liquefied purina monkey chow, vitamin supplements, applesauce and fruit cocktail or preserved fruit segments, e.g., canned peach segments.

The teeth and gingiva of each monkey in both diet groups were routinely examined every six to eight weeks for the presence of dental caculi or tissue inflammation that might modify masticatory function. Nutritionally, the hard-food and soft-food diets were comparable. Additionally, water was readily available to the monkeys through a pressurized water valve.

Data acquisition

Cephalograms were taken two to three months before the experimental animals were sacrificed. Three different phenomena were measured and /or analyzed in this study, stone casts of impressions of the maxillary dentition, cephalometric radiographs, and in vivo bite force measurements. Efforts were made to ensure that data characterizing these phenomena were from the same two comparable growth stages, i.e., late mixed dentitional stage, and subsequent to obtain of dental maturity.

Model evaluation

Subsequent to their sacrifice following termination of the long-term study, each monkey was preserved intact by freezing. For the purposes of this study, maxillary dental impressions were obtained from each specimen follow thawing using customized trays. Each impression was taken separately and stone models prepared immediately afterward. Measurements taken from the stone casts are provided immediately below. The first group of stone casts were prepared from impressions taken by Cavalancia (1985) in the initial study in this series. The second group were prepared post mortem specifically for this study. The following measurements were collected directly from study models (see figures 2, 3).

1) Intercuspid width:

   The distance between right and left cuspids, which measured from the point intersecting between anterior groove of clinical crown of cuspid and cervical gingival margin, measured in millimeters (see figure 2).

2) Intermolar width:

   The distance between right and left molars, which measured from the most posterior point of the distal marginal ridge of clinical crown, measured in millimeters (see figure 2).

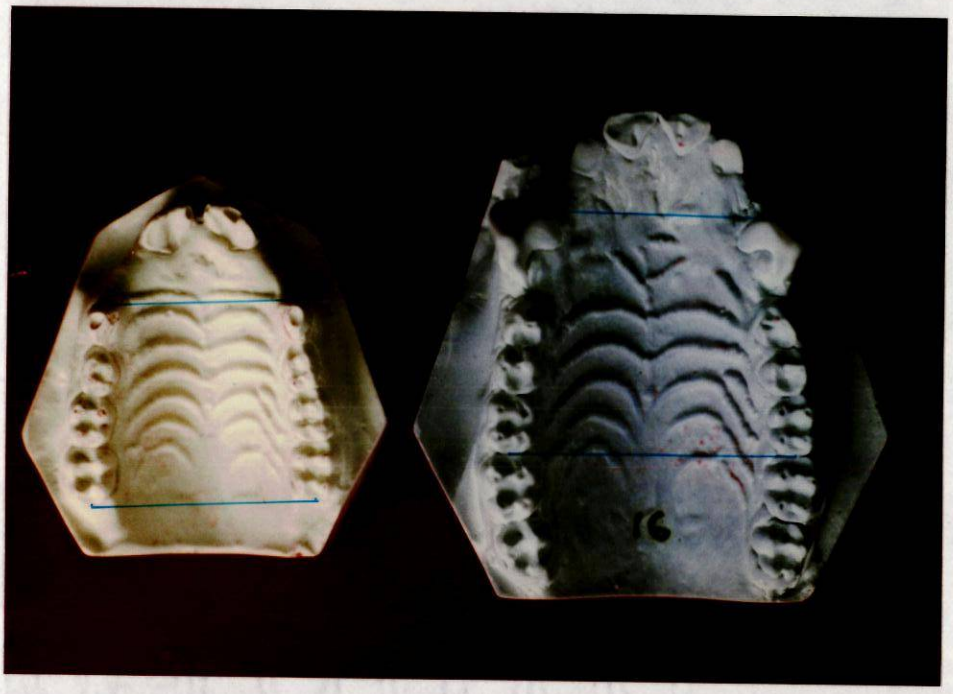


Figure 2. Initial and final maxillary models indicate intercuspid and intermolar widths.

3) Palatal depth in premolar area:

The greatest palatal depth at premolar area, measured from a line draw between right and left lingual cusp of first premolar, and through this line perpendicular to the deepest point of that area (see figure 3).

4) Palatal depth in molar area:

The greatest palatal depth at first molar area, measured from a line draw between right and left distal marginal ridge of first molar, and through this line perpendicular to the deepest point of that area (see figure 3).

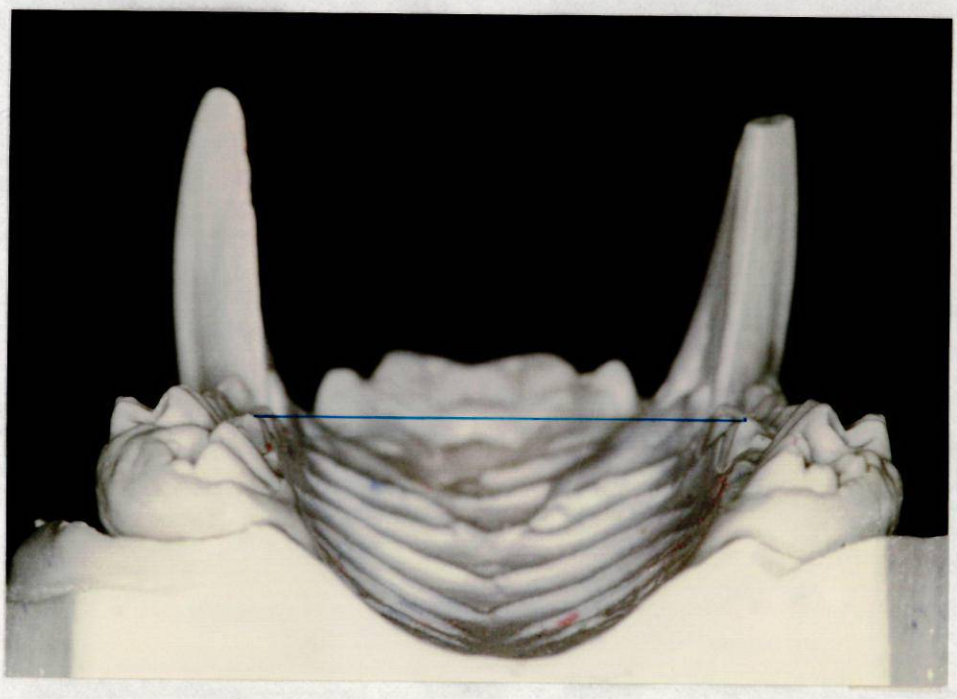


Figure 3. Palatal vault with landmarks used to determine vault heights.

5) Palatal Length:

The measurements of initial palatal length of the experimental animals were taken from a point bisecting a line tangent to the most posterior aspect of maxillary first molars to a point bisecting a line tangent to the lingual most aspect of the contact point between the maxillary central incisors. Since the maxillary tuberosity in final study models is more clearly identifiable than the initial study models, the final measurements in the palatal length were taken from a point bisecting a line tangent to the lingual most aspect of the contact point between the maxillary central incisors (see figure 4).

6) Palatal Volume:

The palatal volume was determined by filling the palate with clay. The palatal vault is defined as starting from the incisal area which even height to the cervical gingiva of upper incisors back to a line that line up by the posterior marginal ridge of the right and the left first molars. At the cuspid areas the clay is filled even to the cervical gingiva of the right and the left upper cuspids. At the premolar and molar areas, the clay is filled to a height that is even to the height of the lingual cusps of the right and the left molars and premolars (see figure 5).

After the clay was carefully trimmed to the boundary we define, it was then removed from the study model. The clay was put into a graduated 10 ml. cylinder filled with water at exactly level 7 ml, and the volume determined by displacement of the water.



Figure 4. Initial and final maxillary models, with palatal length measurements.



Figure 5. Study model filled with clay.

Cephalometric evaluation

Cephalograms were taken two to three months before the experimental animals were sacrificed. To assess change in parameters of the masticatory system, measurements were obtained according to procedures used by Oyen (1985). Details of how these radiographs were obtained is available elsewhere (e.g., Isaravadee, 1989).

Lever arm -- The distance between condylion to key-ridge, measured in millimeters, perpendicular to the functional occlusal plane.

Incisal load arm -- The distance between the condylion and the most anterior point of the incisor, measured in millimeters, perpendicular to the functional occlusal plane.

First molar load arm -- The distance between condylion and the mid-point of the first molar, measured in millimeters, perpendicular to the functional occlusal plane.

Second molar load arm -- The distance between condylion and the mid-point of the second molar, measured in millimeters, perpendicular to the occlusal plane. This measurement was only possible in the final stage of the experimental period, when the second molars were present (see figures 6,7).

Additional cephalometric measurements were taken for the purposes of understanding more about the growth of the palate and the surrounding structures (see figure 8).

Maxillary length -- measured from the sella point to the upper prosthion point in millimeters.

Mandibular length -- measured from the condylion to the lower prosthion point in millimeters.

Palatal plane angle -- the palatal plane is defined by drawing a line most tangent to the palatal arch. This angle was measured at an angle formed by sella-nasion line and palatal plane (see figure 9).

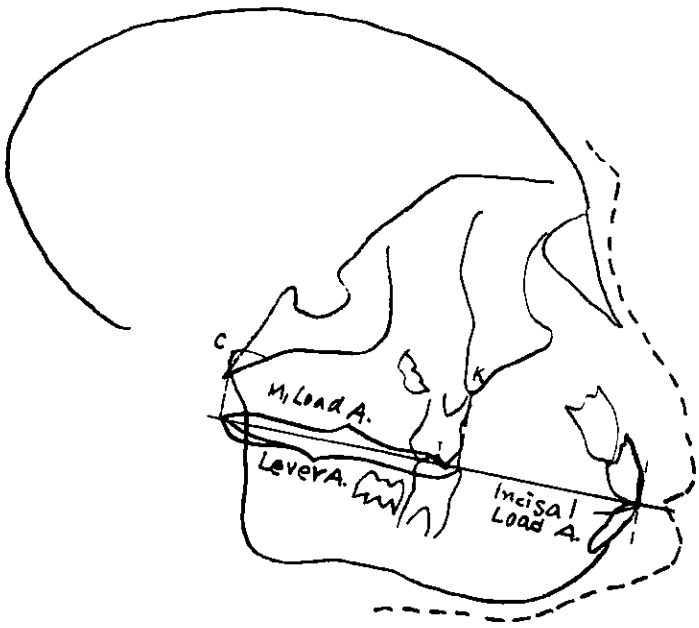


Figure 6. Initial load arm and lever arm measurements.

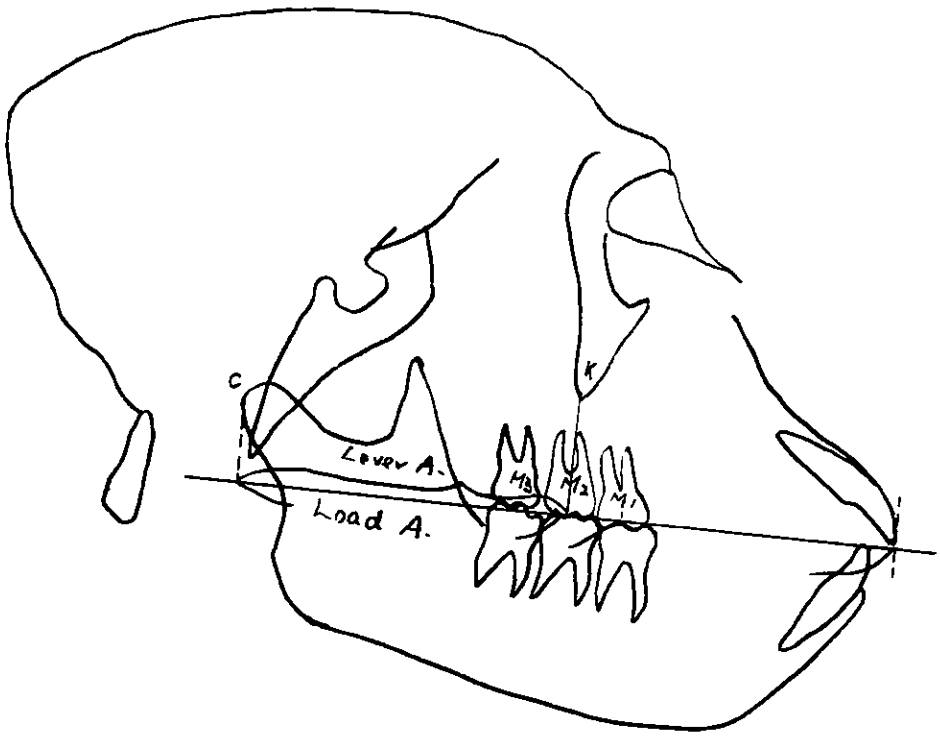


Figure 7. Final load arm and lever arm measurements.

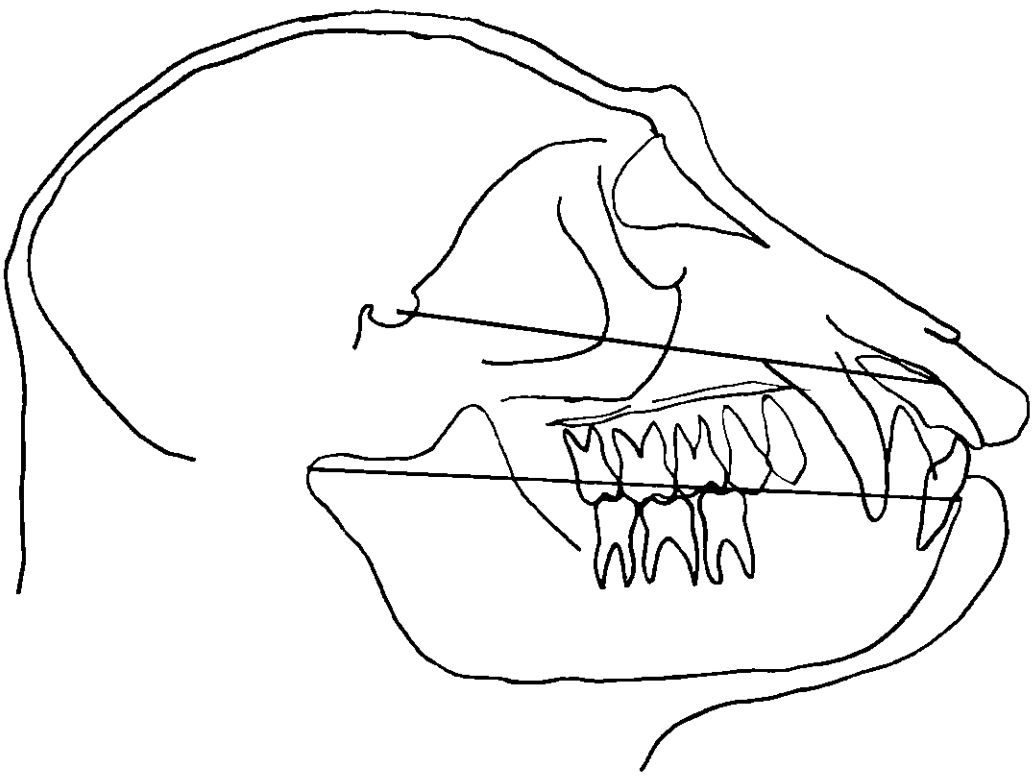


Figure 8. Maxillary and mandibular length measurements.

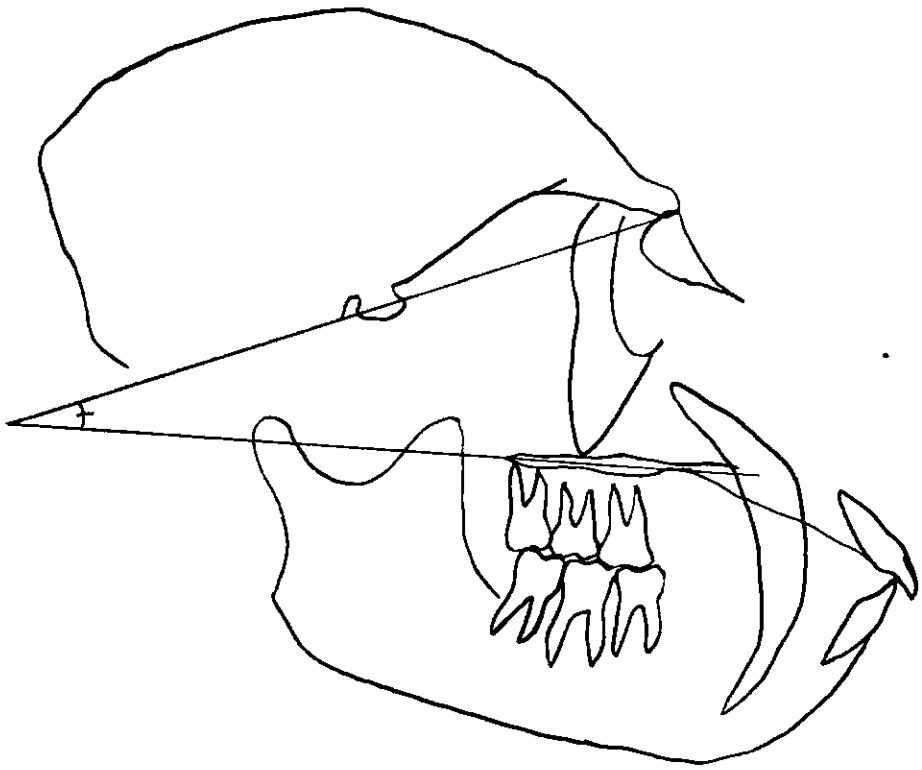


Figure 9. Palatal plane angle measurements.

Upper dental height --the linear measurement from nasion point to upper prosthion in millimeters.

Lower dental height -- the linear measurement from Nasion point to lower prosthion in millimeters.

Dental height ratio -- the percentage comparison between the upper dental height and the lower dental height.

Dental height ratio = upper dental height / lower dental height (see figure 10).



Figure 10. Upper and lower dental height measurements.

Bite Force Measurement

Masticatory electrically tetanic in vivo bite force values considered in this report were obtained earlier from the monkeys according to procedures that have been described extensively in Isavaradee (1985), and by Oyen and Tsay (1991).

Because of the mobility of the erupting permanent incisors in the initial phase of this study, only first molars bite forces were used; the results reported herein are the mean values of the forces measured in the right and left sides, combined.

Initial first molar bite forces were obtained by letting the monkeys bite on the bite force transducer at the first molar in mixed dentitional stage. Second molar bite forces were obtained in the same way, at the final stage of the experiment. The final first molar bite forces as well as the incisal bite forces were obtained in the same manner as previous statement at the final stage of the experiment (see figure 11).

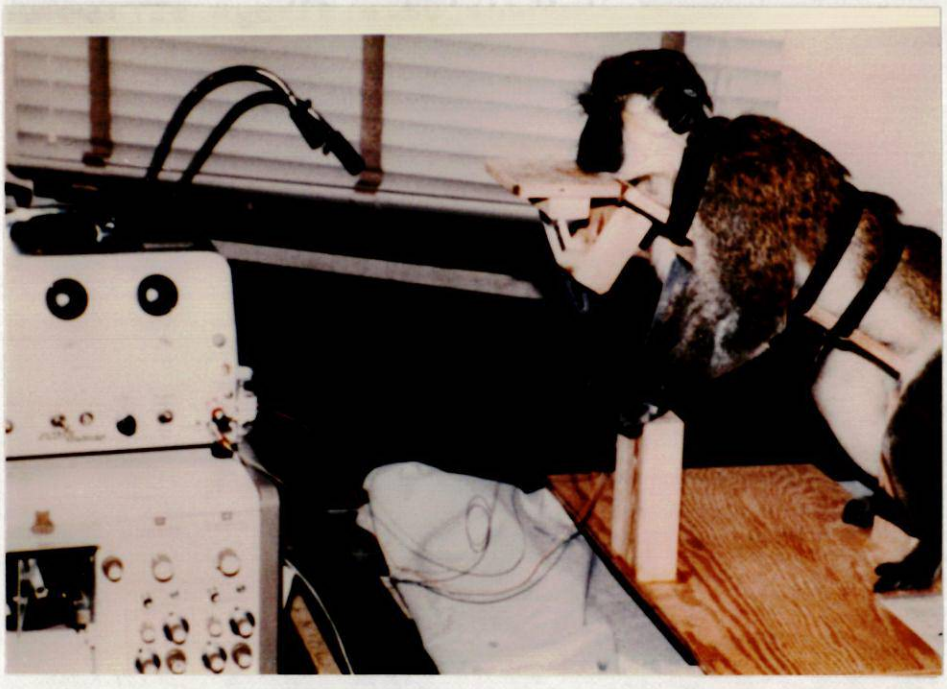


Figure 11. Bite force potentiometer placed between upper and lower jaw.

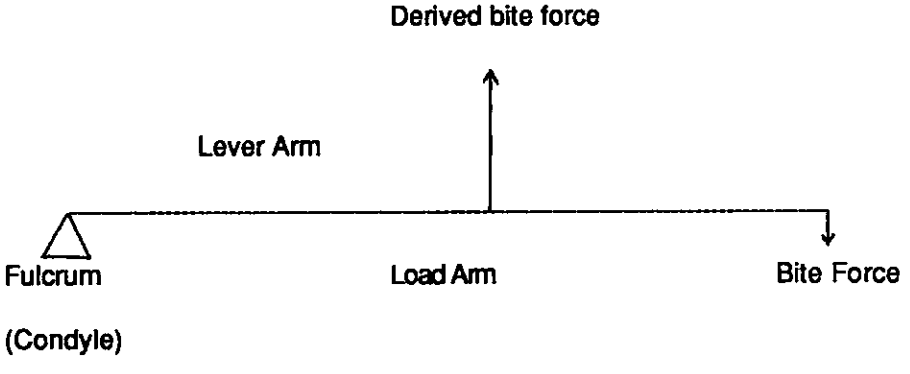
Derived bite force

Assessment of the palatal growth from the in vivo bite force data were derived through use of a lever system. Because the bite force data were obtained through different positions in the dental arch, these bite force data need to considered as obtained from different load positions. Through the lever system, it was possible to demonstrate to us how the bite force transferred in different loading positions.

According to the third principle of lever system (Oyen 1979), masticatory efficiencies at a certain bite point of the load arm and lever arm system can be defined by the ratio of the lever arm length divided by the load arm length.

$$\text{Efficiency} = \frac{\text{Load Arm}}{\text{Lever Arm}} \times \%$$

Because the mandibular condyles act as the hinge of a single fulcrum in masticatory system, the total masticatory muscle forces transmitted from a biting point at a certain area is related to the bit force and the efficiency of the lever arm and the load arm system. The derived bite force is then can be calculated as follow:



~~~ Derived bite Force = Efficiency (%) x Bite Force.
~~~

Statistical methods

In this study, several comparisons were done between measurements. Means were considered between soft and hard diet groups; as well as between initial and final stages (see table 2). Correlations bewteen bite force and animal body weights were calculated using the Pearson Product momentcorrelation method. The comparisons in this section include initial stage, final stage, and the body weight changes from the initial to the final stage (see tables 3,4,5). Bite force at different stages and at different bite points was compared, and correlations were determined (see tables 6, 7, and 8). The derived bite forces were obtained by calculating the biting efficiency, as determined by the lever system. Derived bite forces were then correlated with the palate-related measurements found in table 10 through 13. The changes observed for the soft diet and hard diet groups were compared in table 14 using the student t-test. Variables that show a significant correlation with body weight were compared using as analysis of covariance (ANOVA) as a co-variance (see table 15).

The student t-test was used in the comparison of two different diet groups to palate-related measurements. Correlation-coefficients were used to detect the relationships between palate-related measurements. Means and standard deviations were calculated from data collected from models, cephalometric radiographs and bite force measurements.

Because of the variation in body weights among the experimental monkeys, an initial Pearson correlation-coefficients tests were used to determine the correlation between body weight and palate-related measurements. Partial correlation-coefficient tests were then calculated using weight as the covariate.

Results

The results and analyses in this section containIn several parts. First part is table 2 , in which it summarized the individuals. The individual data of soft diet and hard diet monkeys were recorded in table 2-A to 2-J (see Appendex). The hard food diet animals' data were recorded in plain text, and the soft food diet animals were recorded in bold italics. In this part, the changes between the initial findings and final findings were compared with their raw data. In the second part of this section, the correlations between the palat related measurements to each other were checked . Since the body weight in different animals have different capabilities in chewing ability and growth potential, therefore animals' body weight were first considered in this analysis (see table 3, 4, 5). Both initial and final stages of the body weights were checked, the difference between these two stages were also examed. After the body weights were analized, the bite force at different stages and at various bite positions were compared. The correlations between bite force and palate-related apparatus were evaluated. Statistic method of Pearson correlation-coefficient were used in this study. Partial correlation-coefficient were also used in this section when body weights were a co-factor in this investigation.

The last parts of the statistical analyses contained the comparisons between the soft diet and hard diet groups (see tables 29-32). In this section, the changes from mixed dentitional stage to matured permanent dentitional stage were compared. The student t-test was used in this analysis.

and 42 %. In one instance, body weight, was the relative change of the soft diet groups separated by more than 5 %.

From the comparison of the palatal volume measurements, both soft and hard diet groups increased more than 55 %; ssimilar increases were found for palatal length measurements. However, increases in cuspid and molar width, as well as palatal vault depths in both groups, were only 16 % to 25 %.

Table 2. Means comparison between soft and hard diets as well as initial and final stages.

Variables			Initial		Final		Increases
	Diet	N	Mean	S.D.	Mean	S.D.	
Body weight/Kg.	H	10	2.98	0.86	5.73	0.90	2.75
	S	5	3.02	1.05	6.08	1.29	3.06
Molar width/mm.	H	9	26.16	1.78	30.30	1.40	4.20
	S	5	26.74	1.16	31.10	2.76	4.38
Cuspid width/mm.	H	9	21.39	2.18	26.30	1.83	4.94
	S	5	22.62	2.96	28.46	2.68	5.84
Palatal Length/mm.	H	9	32.37	4.38	48.97	2.98	16.6
	S	5	32.64	3.00	49.26	2.60	16.6
Volume/ml.	H	9	2.30	1.32	3.63	0.49	1.33
	S	5	2.40	0.48	3.76	0.34	1.36
1st Molar B.F./Kg.	H	10	29.20	3.56	40.81	8.43	11.61
	S	5	31.38	6.60	44.42	7.53	13.04
2nd Molar B.F./Kg.	H		N/A		49.54	8.83	20.34
	S		N/A		53.71	7.48	22.33
Lever Arm/mm.	H	10	31.07	2.61	41.45	2.31	10.38
	S	5	31.22	3.91	40.96	2.99	9.74
Maxillary L./mm.	H	10	52.97	2.96	70.29	3.42	17.32
	S	5	52.04	6.72	71.88	3.95	19.84
Vault depth at premolar/mm	H	9	6.64	0.62	8.44	1.02	1.80
	S	5	6.84	0.87	8.56	0.28	1.72
Vault depth at molar/mm.	H	9	8.87	0.77	10.76	0.99	1.98
	S	5	8.26	0.82	10.64	0.82	2.83

Because of the variations in the body weight of the experimental monkeys, an initial Pearson correlation-coefficient test was run to determine the correlation between body weight and palate-related measurements. Subsequently, partial correlation-coefficient tests were calculated. The results of the correlations between palatal measurements and body weight are lisyed in table 3, 4 and 5.

Table 18 shows the relationship between initial body weight and palate related measurements. Table 19 shows the relationship between final body weight and the palate related measurements. Table 20 shows the changes between the initial and final measurements with respect to changes in body weight.

After examining each variable's mean, standard deviation, and box plot, the following data points were considered outlier and deleted before beginning data analyses:

Variable	Case Number
Final palatal length	9
Initial maxillary length	9
Final maxillary length	9
Change in maxillary length	9*
Initial mandibular length	9, 12
Final mandibular length	9, 12
Change in mandibular length	9, 12**
Initial upper dental height	9
Initial lower dental height	9
Initial facial height ratio	9
Change in molar width	9

* Monkey #9's initial maxillary length and initial mandibular length are longer than other monkeys', while his final maxillary length and final mandibular length are shorter than others.

** Monkey #12's initial and final mandibular lengths are much longer than other monkeys'.

Initial body weight

The correlation between the initial experimental animals body weight and initial variable measurements were compared (see table 3). In that statistical calculation, the body weights of the initial experimental animals were significantly correlated with the following measurements:

(1) the initial maxillary length.
(2) the initial mandibular length
(3) the initial cuspid width.
(4) the initial molar width.
(5) the initial lever arm.
(6) the initial first molar load arm.
(7) the initial incisal load arm.

The following measurements for the same comparison were significantly correlated with body weight for the experimental animals:

(1) the initial palatal vault depth in premolar area.
(2) the initial palatal vault depth in molar area.
(3) the initial palatal volume.
(4) the initial upper and lower dental height ratio.

From the above statistical results, we may conclude that body weight at the initial stage is significantly correlated with most of the palate-related measurements. Since initial body weight was significantly correlated with these palate-related measurements, further evaluation was done using body weight as a co-variant.

Final body weight

In table 4, only final cuspid width correlated with the final body weight of the experimental animals. When considering the comparisons of the final cuspid width with others, final body weight was used as a covariant. There were very few measurements with significant correlation to final body weight.

Changes of the body weight

When considering the changes between the initial and the final stages, the changes in the animals' body weight were also considered(see Table 5). The following variables were found to be statistically correlated with body weight:

(1) the change in palatal length.
(2) the change in cuspid width.
(3) the change in the first molar load arm.
(4) the change in incisal load arm.

Body weight of the experiment animals were used as a co-variant for those measurements.

Table 3. Correlation of initial body weights with variables.

Variables	N	Mean	Standard deviation	Coefficient-Correlation
Initial premolar depth	14	6.71	0.6949	*0.4669
Initial molar depth	14	8.60	0.8038	*0.5339
Initial palatal length	14	32.40	3.8205	0.1457
Initial palatal volume	14	2.35	0.3368	*0.5847
Initial maxillary length	14	52.10	3.9811	**0.8607
Initial mandibular length	13	58.90	3.7856	**0.7845
Initial palatal plane angle	15	24.00	3.5349	-0.2771
Initial facial height	14	0.77	0.0197	*-0.4798
Initial intercuspid width	14	21.80	2.5236	**0.7624
Initial intermolar width	14	26.30	1.9061	**0.7322
Initial 1st molar bites F.	15	28.50	3.7774	0.4177
Initial lever arm	15	31.10	2.9586	**0.9398
Initial 1st molar load arm	15	31.90	5.0670	**0.9475
Initial incisal load arm	15	62.10	6.6800	**0.8957

* significant at $P < 0.05$
** significant at $P < 0.01$

Table 4. Final body weights correlated with variables.

Variables	N	Mean	Standard deviation	Coefficient-Correlation
Final premolar depth	14	8.480	0.8207	-0.331
Final molar depth	14	10.721	0.9048	-0.621
Final palatal length	13	49.523	2.2804	-0.167
Final palatal volume	14	3.678	0.4388	-0.073
Final maxillary length	14	71.393	2.8712	0.239
Final mandibular length	13	82.215	3.2380	-0.169
Final palatal plane angle	15	23.933	3.8446	-0.225
Final dental height ratio	15	0.795	0.0301	0.248
Final intercuspid width	14	27.093	2.3243	*0.492
Final intermolar width	14	30.629	1.5881	0.360
Final 1st molar bites F..	15	42.012	8.0639	0.236
Final lever arm	15	41.287	2.4593	0.108
Final 1st molar load arm	15	48.287	1.8138	0.026
Final incisal load arm	15	84.407	4.1365	0.237
2nd molar load arm	15	41.407	1.9308	0.113
2nd molar bites F.	15	50.928	8.3801	0.177
Incisal bites F.	15	23.244	4.4425	0.183

* significant at $P < 0.05$

Table 5. Changes in body weight correlated with variables.

Variables	N	Mean	Standard deviation	Coefficient-Correlation
Change in premolar depth.	14	1.77	0.6877	-0.4171
Change in molar depth.	14	2.12	1.0779	-0.1697
Change in palatal length.	14	13.51	12.9005	**0.6477
Change in palatal volume.	14	1.32	0.4003	-0.2604
Change in maxillary L.	13	19.25	2.8729	0.0019
Change in mandibular L.	13	23.27	2.5577	-0.2057
Change in palatal plane A.	15	-0.13	1.4075	-0.3702
Change in facial height.	14	0.01	0.0292	-0.0246
Change in intercuspid width.	14	5.26	2.2377	*0.5846
Change in intermolar width.	14	4.60	1.5882	-0.2489
Change in 1st molar B.F.	15	1.34	7.3171	0.2386
Change in lever arm.	15	10.16	2.4781	0.2143
Change in M1 load A.	15	16.37	4.8419	*0.5514
Change in incisal load A.	15	22.28	6.9413	**0.6269

* significant at $P < 0.05$
** significant at $P < 0.01$

Bite force correlated with palatal vault variables

When bite force acts as a factor in a growing animal, will there any influence occurs around the peripheral structures of palate? Is there any changes in these structures? To what extend does the bite force influence the palatal growth?

To answer these questions, we have to investigate into the initial stage and the final stage of these structures. Also, it is possible that the bite force at different load arms position may have different influences on the palatal structures.

After the previous tests (see tables 6, 7, 8), concerning the correlation between the body weights and the variables, the following bite force tests were be calculated in Pearson correlation-coefficient test. The variables which were statistically significant correlated with body weights will be calculated in partial correlation-coefficient method. Those variables were identified by following a "#" mark in behind.

Analysis of initial bite force at the first molar

In table 6, the correlation tests for initial first molar bite force with palate-related measurements are shown. Among these comparisons, a statistically significant correlation were found between first molar bite force and:

(1) initial palatal length.

(2) initial dental height.

(3) initial load arm at first molar.

(4) initial incisal load arm.

The initial bite force had no statistical correlation with palatal vault depths (premolar and molar areas) or palatal volume. There were no statistical correlations found between initial first molar bite force and palatal width. It was also found that the initial bite force at the first molar had no correlation with the animal's body weight.

In the measurements of the palatal angle, there was no correlation found with the first molar initial bite force was found among maxillary and mandibular lengths with initial first molar bite force. No statistical correlation.

Table 6. Initial bite force at the first molar correlated with variables.

Variables	Mean	Standard deviation	Coefficient-Correlation
Initial premolar depth.	6.714	0.6949	-0.148
Initial palatal length.	32.471	3.8205	*0.536
Initial palatal plane angle.	24.067	3.5349	-0.342
Initial dental height ratio.	0.774	0.0197	*-0.478
Initial body weight.	2.993	0.9184	0.417
Initial intermolar depth.#	8.475	0.7162	-0.246
Initial palatal volume.#	2.300	0.3191	-0.302
Initial maxillary length.#	51.583	3.0205	0.143
Initial mandibular length.#	59.258	3.7660	0.478
Initial intercuspid width.#	21.191	2.0861	0.058
Initial molar width.#	25.875	1.4692	0.233
Initial lever arm.#	30.391	1.7170	0.333
Initial 1st molar load arm.#	30.516	2.5236	*0.610
Initial incisal load arm.#	60.420	4.2261	*0.520

* significant at $P < 0.05$
\# calculated with partial correlation-coefficient.

Analysis of final bite force at first molar

Comparisons of final bite force at the first molar with other final parameters (see table 7), showed significant correlations with final palatal plane angle, final cuspid width, and final molar width. Less significant correlations were seen with final first molar load arm length and final incisal load arm.

Body weight comparisons in the initial stage were significantly correlated with first molar bite force in many palate-related measurements (see table 6). However, the final first molar bite forces were not highly correlated with those palate-related measurements. The comparisons between first molar bite force and palatal plane angle at the mixed dentition stage were not significantly correlated with first molar bite force (see table 6), however, they were significantly correlated at the permanent dentition stage(table 7). Palatal plane angles decreased during permanent dentition stage. This finding combined with other findings in dental height ratio changes, also show a decreases with increasing dental maturity of the animals. However, the decrease in palatal plane was only one degree, and therefore is probably not clinically significant.

In the initial stage, the cuspid width and molar width were not correlated with initial first molar bite force (see table 6). However,at the final stage, the cuspid width and the molar width were significantly correlated with final bite force at the first molar (see table 7).

Correlation tests between initial first molar bite force and palate-related measurements (see table 6) showed that the first molar load arm length and incisal load arm length were significantly correlated with the initial first molar bite force. However, there were no correlations found for the same comparisons at the final stage (table 7).

No statistically significant correlations were found among the final first molar bite force and the palatal vault depth, the palatal length, or the palatal volume. Also, there were no statistically significant correlations found for load arm and lever arm lengths.

Table 7. Final bite force at the first molar correlated with variables.

Variables	Mean	Standard deviation	Coefficient-Correlation
Final premolar depth.	8.4857	0.8207	0.2025
Final molar depth.	10.7214	0.9048	0.1868
Final palatal length.	49.5231	2.2804	-0.0819
Final palatal volume.	3.6786	0.4388	0.3326
Final maxillary length.	71.3929	2.8712	-0.0098
Final mandibular length.	82.2154	3.2380	0.0537
Final palatal plane angle.	23.9333	3.8446	*-0.5663
Final dental height ratio.	0.7957	0.0301	-0.2536
Final intercuspid width.#	27.0930	2.3243	*0.5465
Final intermolar width.	30.6286	1.5881	*0.5861
Final lever arm.	41.2867	2.4593	0.3403
Final 1st molar load arm.	48.2867	1.8138	0.3811
Final incisal load arm.	84.4067	4.1365	0.3956
2nd molar load arm.	41.4067	1.9308	0.3705
Final body weight.	5.8467	1.0433	0.2363

* significant at $P < 0.05$

\# calculated with partial correlation-coefficient

Analysis of final bite forces at the second molar

Significant statistical correlations were seen when final second molar bite force was compared to measurements of maxillary morphology (see table 8). Palatal plane angle, cuspid width, and molar width were also highly correlated. Significant, but lower correlations were observed with palatal volume, lever arm length, and second molar load arm length, palatal vault depth at premolar area, first molar load arm length, and incisal load arm length.

Previous tests of the first molar final bite force with intercuspid width and intermolar width (table 7), showed positive correlations . Similarily, intercuspid width and intermolar width were highly correlated with the final second molar bite force (see table 8).

The second molar load arm is significantly correlated with the second molar bite force. This finding is slightly different from the result found in table 7. In that table there is no significant correlation among the final first molar bite force and their load arm lengths.

The second molar bite force were found significantly correlated with the final palatal volume (table 8). However there were no statistical correlations found between the final first molar bite force and the palatal volume (table 7).

There were no significant findings among second molar bite force and palatal vaults depth, palatal length, and maxillary length.

These second molar bite force correlative relationships (table 8) were similar to correlations found for final first molar bite force to the other measurements (see table 7); However, they are higher and related to palate-related measurements.

Table 8. Final bite forces at the second molar correlated with variables.

Variables	Mean	Standard deviation	Coefficient-Correlation
Final premolar depth.	8.4857	0.8207	0.3877
Final molar depth.	10.7210	0.9048	0.3502
Final palatal length.	49.5231	2.2804	0.0944
Final palatal volume.	3.6786	0.4388	*0.5453
Final maxillary length.	71.3929	2.8712	0.1602
Final mandibular length.	82.2154	3.2380	0.2151
Final palatal plane angle.	23.9330	3.8450	**-0.6629
Final dental height ratio.	0.7957	0.0301	-0.1350
Final intercuspid width. #	27.0930	2.3243	**0.6589
Final intermolar width.	30.6290	1.5880	***0.6262
Final lever arm.	41.2870	2.4593	*0.4407
Final 1st molar load arm.	48.2867	1.8138	0.4089
Final incisal load arm.	84.4067	4.1365	0.3798
2nd molar load arm.	41.4067	1.9308	*0.4340
Final body weight.	5.8467	1.0433	0.1770

* significant at $P < 0.05$
** significant at $P < 0.01$
\# calculated with partial correlation-coefficient.

Incisal bite force

Because of problems associated with mobility of the erupting incisors, only a single set of final bite force measurements obtained in the end-phase of the study were considered. As shown in table 9, low correlations were seen between incisal bite force , palatal plane angle and final molar width. No other statistically significant were obtained.

With the statistical results summarized in table 9, one might think that the incisal bite force generated at the final stage ishow a low correlation with the other final measurements. This indicated that incisal bite force in the permanent dentitional stage is not totally correlated to the structures that are measured in this study. It may be there are some factors that have not been considered in this study could have influence on the development of incisal areas.

Table 9. Incisal bites force correlated with variables.

Variables	Mean	Standard deviation	Coefficient-Correlation
Final premolar depth.	8.4857	0.8207	0.918
Final molar depth.	10.7210	0.9048	0.135
Final palatal length.	49.5231	2.2804	-0.358
Final palatal volum.	3.6786	0.4388	0.105
Final maxillary length.	71.3929	2.8712	-0.346
Final mandibular length.	82.2154	3.2380	-0.219
Final palatal plane angle.	23.9330	3.8450	-0.367
Final dental height ratio.	0.7957	0.0301	-0.209
Final cuspid width. #	27.0930	2.3243	0.308
Final molar width.	30.6290	1.5880	0.392
Final lever arm.	41.2870	2.4593	0.146
Final 1st molar load arm.	48.2867	1.8138	0.139
Final incisal load arm.	84.4067	4.1365	0.048
2nd molar load arm.	41.4067	1.9308	0.113
Final body weight.	5.8467	1.0433	0.183

calculated with partial correlation-coefficient

Derived bite force

Forces that are generated through masticatory muscles are considered in this study as derived forces. In this study, the masticatory force can be identified at three positions:

(1) the second molar.

(2) the first molar.

(3) the incisor.

The reason the derived bite forces are considered separately from the raw bite force measurements was that the same bite force at the different load arm lengths generates different forces. In other words, in this section of tests, we consider the derived bite forces which depend on the lever arm and load arm system. Using this data one can justify bite force data gathered from electrical transducers. Further investigation of the influence of bite force on a growing palate was examined. The correlative relationships among the bite forces and palate-related measurements were re-evaluated using these tests (see tables 10-13).

Initial derived bite force

In table 10, a correlation between the initial first molar derived bite force and the palate-related measurements was made. The initial derived first molar bite force was significantly correlated with:

(1) the initial mandibular length.
(2) the Initial incisal load arm.
(3) the initial body weight.

There was no significant correlation between the palatal length, the palatal volume, and the palatal vault depth and bite force. Also, there was no significant correlation between the first molar derived bite force and the initial maxillary length. However, there was a low correlation between the first molar masticatory muscle force and the initial dental height.

When comparing the findings of initial first molar bite force (table 6) and the derived initial first molar bite force (table 10), there were some overlaps between them. The first molar load arm and the incisal load arm are significantly correlated with both kinds of bite forces. Because during the early mixed dentitional stage, the first molars were the most posterior teeth in a maxillary dental arch, and the incisors were the most anterior teeth in a maxillary dental arch, we may conclude that at the mixed dentitional stage, the development of the maxillary dental arch was significantly correlated with the first molar bite forces.

Table 10. Initial derived bite forces at the first molar correlated with variables.

Variables	N	Mean	Standard deviation	Coefficient-Correlation
Initial premolar depth.	14	6.714	0.6949	0.0690
Initial molar depth. #	14	8.600	0.8038	-0.1838
Initial palatal length.	14	32.471	3.8205	0.4087
Initial palatal volume. #	14	2.357	0.3368	0.0634
Initial maxillary length. #	14	52.143	3.9811	0.3057
Initial mandibular length. #	13	58.939	3.7856	*0.6274
Initial palatal plane angle.	15	24.067	3.5349	-0.3188
Initial dental height ratio.	14	0.774	0.0197	-0.4272
Initial cuspid width. #	14	21.829	2.5236	0.0603
Initial molar width. #	14	26.364	1.9061	0.2798
Initial incisal load arm. #	15	62.127	6.6807	*0.6874
Initial body weight.	15	2.993	0.9184	*0.6259

* significant at $P < 0.05$
\# calculated with partial correlation-coefficient.

Final derived bite force at the first molar

Final derived bite forces at the first molar (see table 11) were correlated with the following measurements:

(1) the final palatal plane angle.
(2) the final cuspid width.
(3) the final molar width.
(4) the second molar bite force.
(5) the incisal bite force.

Only the final intercuspid width was significantly correlated with the final first molar derived bite force. Correlations between final first molar bite force and maxillary dental arch dimension(table 8), were found for both intercuspid width and intermolar width. From these results we can infer that intercuspid width in the permanent dentition represents a higher correlation with both measurements of the bite force at the first molar.

The final first molar derived bite forces was also correlated with the second molar bite forces and the incisal bite forces. These relationships suggest that the bite forces generated at the incisor and at the second molar were closely correlated with the derived first molar bite forces in the permanent dentition.

Table 11. Final derived bite forces at the first molar correlated with variables.

Variables	N	Mean	Standard deviation	Coefficient-Correlation
Final premolar depth	14	8.485	0.8207	-0.1919
Final molar depth	14	10.721	0.9048	0.1180
Final palatal length	13	49.520	2.2804	-0.1527
Final palatal volume	14	3.678	0.4388	0.3008
Final maxillary length	14	71.393	2.8712	-0.0299
Final mandibular length	13	82.215	3.2380	0.0188
Final palatal plane angle#	15	23.933	3.8446	*-0.4681
Final dental height ratio	15	0.795	0.0301	*-0.2341
Final intercuspid width	14	27.093	2.3243	*0.5631
Final intermolar width	14	30.629	1.5881	0.5352
Incisal bites F.	15	23.244	4.4425	**0.8974
Final body weight	15	49.161	9.1677	0.2151
Final incisal load arm	15	84.407	4.1365	0.3955
2nd molar load arm	15	41.407	1.9308	0.3073
2nd molar bite F.	15	50.928	8.3801	**0.8691

* significant at $P < 0.05$
** significant at $P < 0.01$
\# calculated with partial correlation-coefficient.

Derived bite force at the second molar

Table 12 shows that the derived bite force at the second molar is correlated with the following measurements:

(1) the final palatal volume.

(2) the final palatal plane angle.

(3) the final intercuspid width.

(4) final intermolar width.

(5) the incisal bite force.

The above findings were very similar to the findings reported for the original final second molar bite force (table 8). From the table of significant statistical results and the positive correlation-coefficient value, one can infer that palatal volumes in the permanent dentition are increased in response to increases in second molar bite force. The final palatal plane angle was also significantly correlated with both kind of second molar bite force (tables 8, 12).

The final cuspid widths and the final molar widths also have significant correlations with the derived bite force generated at the second molar. They have a high correlation-coefficient value. It is also possible that the permanent maxillary dental arches are increased with the increases in the derived bite forces found in the second permanent molar. Besides the findings in this section (table 12), there were a significant correlations between the second molar derived bite force and the incisal bite force. Since they are highly correlated, we can conclude that the incisal bite forces at the final stage increasein response to increases in the derived bite force at the second molars.

Table 12. Final derived bite forces at the second molar correlated with variables.

Variables	N	Mean	Standard deviation	Coefficient-Correlation
Final premolar depth	14	8.4857	0.8207	0.3612
Final molar depth	14	10.721	0.9048	0.2746
Final palatal length	13	49.523	2.2804	0.0380
Final palatal volume	14	3.6786	0.4388	*0.5236
Final maxillary length	14	71.393	2.8712	0.1827
Final mandibular length	13	82.215	3.2380	0.2062
Final palatal plane angle#	15	23.933	3.8446	**-0.6087
Final dental height ratio	15	0.7957	0.0301	-0.1115
Final intercuspid width	14	27.093	2.3243	**0.6846
Final intermolar width	14	30.629	1.5881	*0.6126
Incisal bites F.	15	23.244	4.4425	**0.7582
Final 1st molar load arm	15	48.287	1.8138	0.4064
Final incisal load arm	15	84.407	4.1365	0.4332
Final body weight	15	49.161	9.1677	0.1787

* significant at $P < 0.05$
** significant at $P < 0.01$
# calculated with partial correlation-coefficient.

Incisal derived bite force

Two levels of statistically significant correlations were found when incisal derived bite forces were compared to other parameters (see table 13):

High correlations were seen with:

(1) final first molars bite force.

(2) and second molars bite force.

Significant but lower correlations were observed for:

(1) final intermolar width.

(2) final intercuspid width.

Because they have high correlations value with the incisal derived bite force, and the correlation-coefficient values are positive ; one may conclude that the incisal derived bite force follows the posterior measurements through the masticatory mechanics.

Less significant correlations were seen in intermolar and intercuspid widths at the permanent dentition. This may imply that increases in maxillary width may also follow the derived incisal bite force in the permanent dentition.

The findings in this section were similar to the findings; the raw incisal bite force (see table 9).

Table 13. Final derived bite forces at the incisor correlated with variables.

Variables	N	Mean	Standard deviation	Coefficient-Correlation
Final premolar depth.	14	8.485	0.8207	0.0930
Final molar depth.	14	10.721	0.9048	-0.0036
Final palatal length.	13	49.523	2.2804	-0.3330
Final palatal volume.	14	3.678	0.4388	0.1383
Final maxillary length.	14	71.393	2.8712	-0.2814
Final mandibular length.	13	82.215	3.238	-0.2087
Final palatal plane angle#	15	23.933	3.8446	-0.2577
Final dental height ratio.	15	0.795	0.0301	-0.1658
Final intercuspid width.	14	27.093	2.3243	0.4218
Final intermolar width.	14	30.629	1.5881	0.4486
Final 1st molar bite force	15	42.010	8.0639	**0.8891
Final 1st molar load arm.	15	48.287	1.8138	0.0719
2nd molar load arm.	15	41.407	1.9308	0.0355
2nd molar bite F.	15	50.928	8.3801	**0.7282
Final body weight.	15	49.161	9.1677	0.2115

** significant at p=0.01
# calculated with partial correlation-coefficient.

Changes between soft and hard diet groups

One of the purposes of this study was to investigate the changes in several palate-related structures. After the experimental animals werefed with either a soft or hard diet for three years, was there any difference in the growth of the palatal areas between these two groups? Tables 14 and 15 record the statistical results of these investigations.

In table 14, the changes in the palatal vault, the palatal volume, the maxillary length, the mandibular length, the palatal plane angle, the dental height ratio, the intermolar width and the lever arm were considered. Nodifference was found between the means of hard and soft diet groups.

Some of the palate-related measurements were significantly correlated with the body weight, therefore statistical comparison of those variables were consider the body weight as a co-variant (table 15). When body weight were usedas a co-variant, the comparison between soft and hard diet groups, still showed no statistical difference.

Table 14 and 15 demonstrate that, during a period of more than three years, with continuous feeding with soft or hard diets, these fifteen experimental vervet monkeys showed no statistical difference in their palatal development.

Table 14. Comparison of changes between soft and hard diet groups.

	number	mean	S.D.	T-value	P-value
Change of palatal vault depth at premolar area /m.m.					
Hard	9	1.8	0.747		
				0.2	*0.844*
Soft	5	1.72	0.646		
Change of palatal vault depth at molar area/ m.m.					
Hard	9	1.98	0.848		
				-0.65	*0.525*
Soft	5	2.38	1.486		
Change in palatal volume /ml.					
Hard	9	1.32	0.441		
				0.01	*0.993*
Soft	5	1.32	0.363		
Change in maxillary length /m.m.					
Hard	9	18.92	2.522		
				-0.56	*0.588*
Soft	5	19.84	3.664		
Change in mandibular length /m.m.					
Hard	9	22.59	2.286		
				-1.53	*0.153*
Soft	4	24.83	2.761		
Change in palatal plane angle /(0's)					
Hard	10	0	1.333		
				0.5	*0.622*
Soft	5	-0.4	1.673		
Change in dental height ratio /%					
Hard	9	0.0137	0.026		
				-0.86	*0.409*
Soft	5	0.0278	0.035		
Change in molar width /m.m.					
Hard	8	4.75	0.990		
				0.39	*0.701*
Soft	5	4.38	2.397		
Change in bite force of first molar /Kg.					
Hard	10	11.606	7.929		
				-1.44	*0.174*
Soft	5	17.164	4.492		
Change in lever arm /m.m.					
Hard	10	10.38	2.658		
				0.46	*0.654*
Soft	5	9.74	2.293		

Table 15. Comparison of changes between soft and hard diet groups, body weight as a covariance.

	number	mean	T-value	P-value
	Change in palatal length / m.m.			
Hard	9	11.79		
			0.091	*0.768*
Soft	5	16.62		
	Change in cuspid width / m.m.			
Hard	9	4.94		
			0.149	*0.706*
Soft	5	5.84		
	Change in load arm of first molar / m.m.			
Hard	10	15.88		
			0.104	*0.753*
Soft	5	17.36		
	Change in load arm of incisor / m.m.			
Hard	10	21.00		
			0.752	*0.403*
Soft	5	24.84		

Palatal measurements and body weights distribution rank according to decreased magnitude of second molar bite forces.

Do animals that bite harder have bigger palates? To be able to understand more about the relationships between bite force and palatal growth, the monkeys were rearranged by descending second molar bite forces generated by the experimental animals at the final stage (see table 16). In this table, the final stage cuspid width, molar width, and palatal volume were compared. Body weights of the experimental animals were also listed as a reference.

From table 16, the animals that bite harder have a bigger transverse dimension and larger palatal volumes when compared to the animals which did not bite as hard. However, there are some individual exceptions. For example, one of the experimental animals (#3 monkey) could bite harder than most of the monkeys, however, the intercuspid width and intermolar width were smaller than those monkeys which did not bite as hard.

Body weight varied the most in this investigation. Some of the monkeys who bite hard did not necessarily have a larger body size (see monkeys #5, #10 and #16). Monkeys which had a larger body did not always bite harder than monkeys which had a smaller body (see monkey # 8). This finding is very similar to the findings in table 4, which showed that the final body weights have very low correlations with most of the palate-related measurements.

Overall, except for the body weight, the monkeys that bite harder have a better chance of having bigger palatal dimensions than monkeys which did not bite as hard. From this we may conclude that the bite force has an influence on the development of the palate.

Table 16. Palatal measurements and body weights distribution rank according to decreased magnitude of second molar bite force. (@ means soft diet monkey)

Monkey's Name	**2nd molar BF/Kg.**	Final Cuspid Width/m.m.	Final Molar Width/m.m.	Final Palatal Volume	Final Body Weight
Willie@	63.18	29.8	32.3	3.6	7
Billy	60.66	28.7	32.1	3.8	6.9
Cornelius	60.30	27.4	31.4	3.4	6.3
George	57.42	27.5	32.3	4.4	4.8
Michael@	56.70	30.6	30.5	3.9	6.4
Dannie@	55.98	30.8	32.4	4.3	7.4
Patrick	54.00	25.3	29.6	3.8	5.4
Tammie	52.92	28.2	31.9	4.1	4.3
David@	48.78	25.5	30.6	3.5	4.2
Mad Max	48.42	24.9	27.8	3.9	5.4
Stevie	45.18	23.2	27.7	2.9	4.9
Luciano@	43.92	25.6	29.8	3.5	5.4
Phil	39.96	24.9	30.9	3	7.3
Eddie	39.06	26.9	29.5	3.4	5.9

Discussion

The present study is a continuation of the investigation of Cavalancia (1985).In his study, palatal growth of vervet monkeys from the deciduous stage to the early mixed dentitional stage was investigated. In the current study, the same group of fifteen experimental monkeys were used. Further investigations of changes which took place during the period from the mixed dentitional stage to the fully developed permanent dentitional stage were evaluated.

In this study we considered the bite force as a factor of mastication; by giving different diets which would alter the chewing duration and intensity to the experimental animals, we expect to see different measures of palatal growth between the two different diet groups. In this study, we also investigated several variables in the initial stage, the final stage and the changes between the beginning and the end of the experiment. With the results obtained using statistical analyses,, we will try to understand the force behind palatal growth and the structures which related to the palatal development.

The following significant results were obtained: The body weight in the mixed dentitional stage has a more significant correlation with palatal growth than in the permanent dentitional stage. The intercuspid width is correlated with first molar and second molar bite force. Palatal volume has a more significant correlation during the permanent dentitional stage than in the mixed dentitional stage. Bite forces at molar areas are significantly correlated with the load arm lengths at molar areas. The palatal plane angle has a slightly decreased tendency while the animals grew to permanent dentition. However, In this investigation there is no significant difference found in the palatal growth between soft and hard diet monkeys.

As indicated in table 3, the initial body weights were highly correlated with most of the palate-related measurements. The only two measurements which are not statistically significant as correlated with initial body weights were initial palatal length and initial palatal angle. The initial palatal lengths were measured from the initial study models. During the early mixed dentitional stage of these experimental animals, the incisors are not fully erupted, and the junction between soft tissue and incisors is difficult to define. Due to this reason it was difficult to identify the exact landmark of the most anterior point in measuring the initial palatal length. The palatal angles were obtained through the measurement of the angle formed between sella-nasion line and palatal plane. The palatal plane was defined by a line which most tangent to the palatal shape. Because of the sigmoid shape of the palatal arch, to define a perfect palatal line was difficult. Also, in the initial stage, the monkeys were in a mixed dentitional status; some of the teeth were erupting then. Since the adult dentition was not reached, it is understood that there is no significant correlation between body weight and palatal plane angle at the mixed dentitional stage.

At the final stage, the body weight becomes less correlated with most of the palate-related measurements; only cuspid width had a statistically significant correlation with body weight. From the evaluation of body weight changes with the palate-related measurements, there are some statistically significant correlations among them. The palatal length change is highly correlated with body weight change. This may imply that the palatal length increased with body weight increases. The changes in first molar load arms and incisal load arms are statistically significant and correlated with body weight changes. These statistical results may give us a clue that the anterior-posterior dimension increases as the body weight increases. The intercuspid widths are significantly correlated with changes of the body weight, this means that both increase proportionally.

At the onset of these analyses, the relationships between the body weights and the rest of the measurements were first checked statistically by using the Pearson correlation-coefficient method. The results tell us that some of the palate-related measurements have a statistically significant correlations with body weight. Subsequent statistical calculations will consider the body weight as a co-variance. Another reason for considering the body weight as a co-variance is that the nasal passage is directly above the palate. As the animal increases in body size or increases its amount of activity, there must be an increased need of oxygen. To take in more oxygen the air passages can increase in size. Therefore body weight is an important factor when considering the palatal growth.

There are no significant changes found in both soft and hard food diet animals concerning palatal vault depths (premolar area and molar area) and in palatal volume changes as well. However, there were correlations between the palatal volume with the second molar bit force. Because the second molars are the most posterior functional teeth considered in this study, it can be implied that the bite force at the posterior molar area had an influence on the palatal volume at the permanent dentitional stage. The palate is a three dimensional structure, it is not sufficient to describe the three dimensional palate morphologies by two dimensional measurements. The palatal morphology is enveloped by the airway and tongue, without knowing these two important structures and then trying to understand the development of the palate is inadequate. The limitation of our experiment is that, we tried to reduce three dimensional measurements to two dimensional measurements (intercuspid width, intermolar width, etc.) or even one dimensional measurement (palatal volume measurement by using water displacement method). The reason we did not find significant differences between soft and hard diet animals, is that the measurements we used did not necessarily reflect the change of the palate. The consistency of the diet may still have an influence on the growth of the palate. We think, by manipulating the consistency of the diet,

we will have different results of the palatal growth. The monkeys on a soft food diet required little chewing function, which brings the intensity of the chewing cycle to a minimum. Also, since the diet is soft, the chewing duration is minimized. However, we had no control concerning the duration of the chewing cycle in this study. Also the non-chewing behavior in those monkeys was not controllable in this study, i.e., the intensity of masticatory function.

In Cavalancia's study, he found that in the mixed dentitional stage of the monkey's palatal growth, hard food diet environment causes an increase in the intercuspid width versus palatal length. However, in this investigation at the permanent dentitional stage, there is no significant difference found between the hard food and the soft food diet groups. As Cavalancia mentioned in his findings, the data he obtained were the ratio of intercuspid width versus palatal length; this palatal length factor must be taken into consideration in the interpretation of his investigation. In the present investigation, regarding intercuspid width, we used the data from direct measurements of intercuspid width instead of using the ratio between intercuspid width versus palatal length. The body weights were considered as a co-variance in the comparison between soft and hard diet groups, since the sample size was small, body weight still might affect the statistical results. Regarding the intermolar width in this study, we also found that there is no significant difference between these two groups. In this study, only the normal daily food-related chewing patterns were considered. Beside the normal daily chewing patterns, there are non-food related factors existing in these experimental animals; for example: bruxism, non-masticatory oral behaviors, and cage biting behavior, etc. These non-food related chewing patterns could also have certain effects on the palatal growth. In Cavalancia's study, he estimated palatal growth in the deciduous stage and early mixed dentitional stage. At that stage when premaxillary growth took place, the maxillary bone and palatine bone were not fully developed. However, in this study we investigated at the later period of the palatal development, which included all the palatal

growth. This may be one of the reasons why, in this study, the results are different from what Cavalancia found.

There are statistically significant correlations between the second molar bite force and intermolar width as well as intercuspid width (see table 8). Also, there are correlations of the intermolar and intercuspid widths with first molar and second molar masticatory muscle forces. From these statistical results we can refer that the masticatory bite force might have an influence on the transverse growth of the palate.

Regarding maxillary and mandibular lengths in this study, we did not find a significant change between soft and hard diet groups. Also we did not found a statistical correlation of these two apparatuses to the other palate-related measurements. One of the reasons is that, in these two linear measurements it is difficult to identify the upper and lower prosthions on the cephalometric radiographs. The reason for this is that the monkeys' incisors are very flared, and the alveolar bone at those areas is too thin to identify. The other reason that we should consider in maxillary length measurement is that the airway is right above the palatal structure, and it has a direct influence on the morphology of the palate. The airway structure is directly influenced by oxygen requirement; on the other hand oxygen intake is affected by body size, and the activity of the animals. In this experiment we did not have control over the body size and the activity of these animals.

From the comparisons of the load arm at different positions, there are no statistically significant changes found between soft and hard food diet animals. There was a significant correlation found between the load arms with the first and second molar bit forces. However, in the statistical comparisons between incisal bite force and different load arms, there is no significance found in those tests. There is no significant finding on the change of the palatal plane or dental height between soft and hard food diet animals. However, from the correlation tests, we found that these two factors were significantly correlated with many

variables. In all the correlate tests we observed, there is a negative correlation-coefficient value. From these statistical findings, we may conclude that the anterior dental developments in these 15 monkeys show a decreased tendency in dental height. However, the significance in this finding is only within one degree; from a clinical view point this decrease shall be considered within a tracing error. To conclude the findings in dental height changes, we believed that the dental height was quite stable; further investigations concerning these are needed.

The data gathered in this investigation were electronic tetanic bite force, which was obtained by electronic stimulation on the masticatory muscles; this method is different from the voluntary biting method. From the methodological consideration, they are two different set of measurements. Physiological voluntary bite force would be more valuable in this investigation. The bite force comparisons between the hard and the soft groups has no significant difference in these tests. Also from table 16, ranking the animal according to the decreased second molar bite force, the hard food animals did not necessarily bite harder than the soft diet animals. The reason for this is uncertain. About the non-masticatory chewing behavior, further investigation is necessary to detect the dental attritional pattern on occlusal surface of these experimental monkeys to identify the non-chewing behavior which may be involved in masticatory function.

SUMMARY

In this experimental study, palatal growth with respect to masticatory forces was examined. Fifteen growing African green monkeys were used and their palate-related data were analyzed. These monkeys were divided into two groups, and maintained for three years on diets which differed in terms of physical consistency. This study extends works completed by Cavalancia (1985), which ended with the mixed dentitional stage.

In this study, significant relationships were found between second molar bite force and palate-related measurements. In contrast to earlier findings by Cavalancia hinting at significant differences between the soft and hard food populations, this analysis found no such differences. Several explanations are possible. First, the magnitude of difference in diet consistency may not be sufficient to induce palatal change. Second, measurements used in this study may not reflect true morphology of palate. Third, the oral-nasal function may compensate for, and thereby mask, alterations associated with dietary consistency. The results of this experiment underline the importance of identifying and taking into consideration all the factors that were actually involved.

Based on these findings, which centered on consideration of masticatory function, areas that deserve special consideration in the design of future analyses of the palate should include respiratory and lingual function.

APPENDIX

Table 17. Palatal vault depths and changes in premolar area.
(Soft diet animal with @ mark)

Monkey's Name	Initial Premolar Depth/m.m.	Final Premolar Depth/m. m.	Change
Eddie	7.0	8.7	1.7
Cornelius	6.2	8.2	2.0
Patrick	7.0	9.2	2.2
Billy	6.7	8.6	1.9
George	6.0	8.9	2.9
Stevie	6.0	7.5	1.5
Phil	6.2	6.3	0.1
Mad Max	7.9	9.8	1.9
Tammie	6.8	8.8	2.0
Dannie@	8.0	8.8	0.8
Willie@	6.8	8.7	1.9
Michael@	6.6	8.3	1.7
Luciano@	5.6	8.2	2.6
David@	7.2	8.8	1.6

Table 18. Palatal vault depths and changes in molar area.
(Soft diet animal with @ mark)

Monkey's Name	Initial Molar Depth/m.m.	Final Molar Depth/m.m.	Change
Eddie	8.6	10.3	1.7
Cornelius	8.7	11.1	2.4
Patrick	9.3	11.3	2.0
Billy	9.6	10.6	1.0
George	8.0	11.1	3.1
Stevie	8.5	9.2	0.7
Phil	8.4	9.8	1.4
Mad Max	10.2	12.7	2.5
Tammie	7.8	10.8	3.0
Dannie@	9.4	10.4	1.0
Willie@	8.5	10.3	1.8
Michael@	7.2	12.1	4.9
Luciano@	7.8	10.1	2.3
David@	8.4	10.3	1.9

Table 19. Palatal length measurements and changes . (Soft diet animal with @ mark)

Monkey's Name	Initial Palatal Length/m.m.	Final Palatal Length/m.m.	Change
Eddie	28.9	49.5	20.6
Cornelius	33.5	46.2	12.7
Patrick	31.2	49.9	18.7
Billy	30.5	48.1	17.6
George	32.7	53.2	20.5
Stevie	29.9	48.7	18.8
Phil	31.5	49.6	18.1
Mad Max	29.8	43.3	13.5
Tammie	43.4	52.3	8.90
Dannie@	35.4	51.2	15.8
Willie@	35.8	52.3	16.5
Michael@	32.8	45.7	12.9
Luciano@	29.6	48.2	18.6
David@	29.6	48.9	19.3

Table 20. Initial and final palatal volumes and changes.
(Soft diet animal with @ mark)

Monkey's Name	Initial Palatal Volume/c.c.	Final Palatal Volume/c.c.	Change
Eddie	2.1	3.4	1.3
Cornelius	2.7	3.4	0.7
Patrick	2.4	3.8	1.4
Billy	2.1	3.8	1.7
George	2.6	4.4	1.8
Stevie	2.0	2.9	0.9
Phil	2.2	3.0	0.8
Mad Max	2.5	3.9	1.4
Tammie	2.2	4.1	1.9
Dannie@	3.0	4.3	1.3
Willie@	2.9	3.6	0.7
Michael@	2.3	3.9	1.6
Luciano@	2.0	3.5	1.5
David@	2.0	3.5	1.5

Table 21. Maxillary lengths and changes.
(Soft diet animal with @ mark)

Monkey	Initial Maxillary Length/m.m.	Final Maxillary Length/m.m.	Change
Eddie	49.5	69.4	19.9
Cornelius	53.3	69.2	15.9
Patrick	54.1	73.2	19.1
Billy	52.1	66.9	14.8
George	52.3	72.2	19.9
Tim	49.2	71.9	22.7
Stevie	52.6	70.4	17.8
Phil	54.2	72.8	18.6
Mad Max	59.9	62.8	2.9
Tammie	52.5	74.1	21.6
Dannie@	56.2	76.8	20.6
Willie@	61.8	75.5	13.7
Michael@	46.5	69.8	23.3
Luciano@	48.9	68.8	19.9
David@	46.8	68.5	21.7

Table 22. Mandibular lengths and changes.
(Soft diet animal with @ mark)

Monkey	Initial Mandibular Length/m.m.	Final Mandibular Length/m.m.	Change
Eddie	55.3	78.9	23.6
Cornelius	56.8	78.8	22.0
Patrick	61.9	84.1	22.2
Billy	60.2	78.3	18.1
George	62.7	87.8	25.1
Tim	55.1	81.1	26.0
Stevie	58.7	80.7	22.0
Phil	62.9	84.2	21.3
Mad Max	69.5	73.3	3.8
Tammie	63.2	86.2	23.0
Dannie@	64.5	85.9	21.4
Willie@	76.2	90.3	14.1
Michael@	54.5	82.4	27.9
Luciano@	54.1	78.2	24.1
David@	56.3	82.2	25.9

Table 23. Palatal plane angles and changes.
(Soft diet animal with @ mark)

Monkey	Initial Palatal Plane Angle (degree)	Final Palatal Plane Angle (degree)	Change
Eddie	22	20	-2
Cornelius	21	22	1
Patrick	23	21	-2
Billy	22	21	-1
George	23	23	0
Tim	31	31	0
Stevie	29	30	1
Phil	26	27	1
Mad Max	26	26	0
Tammie	20	22	2
Dannie@	25	25	0
Willie@	18	18	0
Michael@	22	20	- 2
Luciano@	28	26	- 2
David@	25	27	2

Table 24. Initial dental heights and percentages.
(Soft diet animal with @ mark)

Monkey	Initial Upper Dental Height/m.m.	Initial Lower Dental Height/m.m.	Initial dental height %
Eddie	36.1	45.4	0.80
Cornelius	34.0	45.3	0.75
Patrick	35.2	44.8	0.79
Billy	33.5	45.1	0.74
George	35.1	47.1	0.75
Tim	34.6	42.5	0.81
Stevie	38.6	48.9	0.79
Phil	39.6	50.8	0.78
Mad Max	41.5	49.7	0.84
Tammie	36.9	47.6	0.78
Dannie@	37.8	48.5	0.78
Willie@	39.2	51.8	0.76
Michael@	32.9	42.3	0.78
Luciano@	34.8	44.8	0.78
David@	31.3	41.1	0.76

Table 25. Final facial heights and percentages.
(Soft diet animal with @ mark)

Monkey	Final Upper Dental Height/m.m.	Final Lower Dental Height/m.m.	Final Dental Height %
Eddie	43.1	55.6	0.78
Cornelius	45.6	56.1	0.81
Patrick	45.2	59.7	0.76
Billy	42.6	56.2	0.76
George	46.9	61.8	0.76
Tim	48.5	59.5	0.82
Stevie	50.6	62.1	0.81
Phil	49.3	60.8	0.81
Mad Max	42.5	50.8	0.84
Tammie	48.2	59.9	0.80
Dannie@	53.8	62.8	0.86
Willie@	48.1	60.2	0.80
Michael@	45.3	58.2	0.78
Luciano@	43.5	56.8	0.77
David@	45.5	57.5	0.79

Table 26. Cuspid widths and changes.
(Soft diet animal with @ mark)

Monkey's Name	Final Cuspid Width/m.m.	Initial Cuspid Width/m.m.	Change
Eddie	26.9	18.4	8.5
Cornelius	27.4	23.7	3.7
Patrick	25.3	19.2	6.1
Billy	28.7	20.9	7.8
George	27.5	22.9	4.6
Stevie	23.2	18.6	4.6
Phil	24.9	21.8	3.1
Mad Max	24.9	25.0	-0.1
Tammie	28.2	22.0	6.2
Dannie@	30.8	23.6	7.2
Willie@	29.8	26.3	3.5
Michael@	30.6	24.0	6.6
Luciano@	25.6	20.0	5.6
David@	25.5	19.2	6.3

Table 27. Molar widths and changes.
(Soft diet animal with @ mark)

Monkey's Name	Initial Molar Width/m.m.	Final Molar Width/m.m.	Change
Eddie	24.5	29.5	5.0
Cornelius	26.5	31.4	4.9
Patrick	25	29.6	4.6
Billy	26.8	32.1	5.3
George	27.3	32.3	5
Stevie	24.2	27.7	3.5
Phil	27.6	30.9	3.3
Mad Max	28.0	27.8	-0.2
Tammie	25.5	31.9	6.4
Dannie@	26.0	32.4	6.4
Willie@	30.6	32.3	1.7
Michael@	28.4	30.5	2.1
Luciano@	25	29.8	4.8
David@	23.7	30.6	6.9

Table 2-A. Initial and final body weights.
(Soft diet animal with @ mark)

Monkey	Initial Body Weight/Kg.	Final Body Weight/Kg.	Change
Eddie	2.3	5.9	3.6
Cornelius	2.8	6.3	3.5
Patrick	2.5	5.4	2.9
Billy	3.1	6.9	3.8
George	3.1	4.8	1.7
Tim	2.3	6.1	3.8
Stevie	2.2	4.9	2.7
Phil	3.4	7.3	3.9
Mad Max	5.3	5.4	0.1
Tammie	2.8	4.3	1.5
Dannie@	3.4	7.4	4.0
Willie@	4.7	7.0	2.3
Michael@	2.4	6.4	4.0
Luciano@	2.3	5.4	3.1
David@	2.3	4.2	1.9
Mean	**2.9**	**5.8**	**2.8**

Table 2-B. Initial first molar bite force.

Monkey	**Initial Bite Force at 1st Molar/Kg.**
Michael	**27.3**
Cornelius	**28.1**
Paricle	**27.9**
Billy	**32.2**
George	**33.1**
Tim	**27.0**
Stevie	**29.5**
Phil	**32.8**
Mad Max	**27.5**
Tammie	**32.8**
Dannie	**27.9**
Willie	**33.3**
Eddie	**21.1**
Luciano	**23.1**
David	**24.7**

Table 2-C. Final bite force at different bite points.
(Soft diet animal with @ mark)

Monkey's Name	**Bite Force at 2nd Molar**	**Final Bite Force at 1st Molar**	Final Bite Force at incisor
Cornelius	60.30	52.92	31.32
Paricle	54.00	45.00	22.68
Billy	60.66	52.74	32.04
George	57.42	49.14	25.20
Tim	37.44	35.28	19.80
Stevie	45.18	38.70	23.76
Phil	39.96	31.86	18.36
Mad Max	48.42	33.12	19.98
Tammie	52.92	37.26	19.44
Eddie	39.06	32.04	18.18
Mean ± SD	**49.5 ± 8.8**	**40.8 ± 8.4**	**23.1 ± 5.1**
Michael@	56.70	49.32	26.28
Dannie@	55.98	43.92	22.50
Willie@	63.18	53.10	25.56
Luciano@	43.92	33.30	18.36
David@	48.78	42.48	25.20
Mean ± SD	**53.7 ± 7.4**	**44.4 ± 7.5**	**23.6 ± 3.2**

Table 2-D. Comparison between monkeys bite hard and monkeys bite not so hard. Monkey's name in outline letter are soft diet group. (Soft diet monkey with @ mark)

Monkey's Name	2nd molar BF/Kg.	Final Cuspid Width/m.m.	Final Molar Width/m.m.	Final Palatal Volume	Final Body Weight
Willie@	63.18	29.8	32.3	3.6	7.0
Billy	60.66	28.7	32.1	3.8	6.9
Cornelius	60.30	27.4	31.4	3.4	6.3
George	57.42	27.5	32.3	4.4	4.8
Michael@	56.70	30.6	30.5	3.9	6.4
Dannie@	55.98	30.8	32.4	4.3	7.4
Patrick	54.00	25.3	29.6	3.8	5.4
Tammie	52.92	28.2	31.9	4.1	4.3
David@	48.78	25.5	30.6	3.5	4.2
Mad Max	48.42	24.9	27.8	3.9	5.4
Stevie	45.18	23.2	27.7	2.9	4.9
Luciano@	43.92	25.6	29.8	3.5	5.4
Phil	39.96	24.9	30.9	3.0	7.3
Eddie	39.06	26.9	29.5	3.4	5.9

Table 2-E. Initial and final lever arms and changes therein.
(Soft diet monkey with @ mark)

Monkey	Initial Lever Arm/m.m.	Final Lever Arm/m.m.	Change
Eddie	29.3	39.4	10.1
Cornelius	31.1	43.0	11.9
Patrick	29.6	41.1	11.5
Billy	31.7	39.1	7.4
George	30.7	44.9	14.2
Tim	27.8	38.3	10.5
Stevie	28.9	39.6	10.7
Phil	32.0	44.4	12.4
Mad Max	37.2	41.9	4.70
Tammie	32.4	42.8	10.4
Dannie@	32.5	38.9	6.4
Willie@	37.1	45.4	8.3
Michael@	31.1	42.7	11.6
Luciano@	27.6	38.6	11.0
David@	27.8	39.2	11.4

Table 2-F. Initial first molar and incisal load arms.
(Soft diet monkey with@ mark)

Monkey's Name	Initial 1st Molar Load Arm/m.m.	Initial Incisal Load Arm/m.m.
Eddie	28.2	56.3
Cornelius	30.7	60.7
Patrick	32.3	63.4
Billy	31.1	60.6
George	31.8	62.9
Tim	26.8	56.1
Stevie	30.4	60.5
Phil	34.6	64.5
Mad Max	43.4	73.4
Tammie	32.5	65.8
Dannie@	32.4	65.6
Willie@	42.3	77.3
Michael@	28.7	55.5
Luciano@	25.4	53.9
David@	28.1	55.4

Table 2-G Final load arm lengths.
(Soft diet monkey with @ mark)

Monkey's Name	2nd Molar Load Arm/m.m.	Final 1st molar Load Arm/m.m.	Final Incisal Load Arm/m.m.
Eddie	39.3	46.3	81.4
Cornelius	42.7	49.4	84.7
Patrick	42.6	49.5	86.7
Billy	38.4	45.1	79.1
George	42.9	50.1	88.2
Tim	38.8	45.8	83.8
Stevie	40.9	48.8	82.0
Phil	43.8	50.1	86.1
Mad Max	39.7	46.6	75.4
Tammie	42.7	48.9	86.8
Dannie@	41.0	47.9	90.2
Willie@	44.4	50.9	91.2
Michael@	43.4	50.2	85.1
Luciano@	39.9	46.8	82.1
David@	40.6	47.9	83.3

Table 2-H. Derived initial first molar bite force.
(Soft diet monkey with @ mark)

Monkey's Name	Initial Bite Force at 1st Molar/Kg.	Initial 1st Molar Load Arm/mm	Initial Level Arm mm.	Efficiency load/lever %	Derived B.F./Kg.
Cornelius	28.1	30.7	31.1	0.99	27.74
Paricle	27.9	32.3	29.6	1.09	30.44
Billy	32.2	31.1	31.7	0.98	31.59
George	33.1	31.8	30.7	1.04	34.29
Tim	27.0	26.8	27.8	0.96	26.03
Stevie	29.5	30.4	28.9	1.05	31.03
Phil	32.8	34.6	32.0	1.08	35.47
Mad Max	27.5	43.4	37.2	1.17	32.08
Tammie	32.8	32.5	32.4	1.00	32.90
Eddie	21.1	28.2	29.3	0.96	20.31
Michael@	27.3	28.7	31.1	0.92	25.19
Dannie@	27.9	32.4	32.5	1.00	27.81
Willie@	33.3	42.3	37.1	1.14	37.97
Luciano@	23.1	25.4	27.6	0.92	21.26
David@	24.7	28.1	27.8	1.01	24.97

Table 2-I. Derived final first molar bite force.
(Soft diet monkey with @ mark)

Monkey's Name	Final Bite Force at 1st Molar/Kg.	Percentage %	Derived B.F.
Cornelius	52.92	1.15	60.80
Paricle	45.00	1.20	54.20
Billy	52.74	1.15	60.83
George	49.14	1.12	54.83
Tim	35.28	1.20	42.19
Stevie	38.70	1.23	47.69
Phil	31.86	1.13	35.95
Mad Max	33.12	1.11	36.84
Tammie	37.26	1.14	42.57
Eddie	32.04	1.18	37.65
Michael@	49.32	1.18	57.98
Dannie@	43.92	1.23	54.08
Willie@	53.10	1.12	59.53
Luciano@	33.30	1.21	40.37
David@	42.48	1.22	51.91

Table 2-J. Derived second molar bite force.
(Soft diet with @ mark)

Monkey's Name	Bite Force at 2nd molar/Kg.	Percentage %	Derived B.F. Kg.
Cornelius	60.30	0.99	59.88
Paricle	54.00	1.04	55.97
Billy	60.66	0.98	59.57
George	57.42	0.96	54.86
Tim	37.44	1.01	37.93
Stevie	45.18	1.03	46.66
Phil	39.96	0.99	39.42
Mad Max	48.42	0.95	45.88
Tammie	52.92	1.00	52.80
Eddie	39.06	1.00	38.96
Michael@	56.70	1.02	57.63
Dannie@	55.98	1.05	59.00
Willie@	63.18	0.98	61.79
Luciano@	43.92	1.03	45.40
David@	48.78	1.04	50.52

REFERENCES

Barber, C. G., and Cox, G.J. (1963). Effects of the physical consistency of diet on the condylar growth of the rat mandible. J. Dent. Res. 42: 848-851.

Beecher, R.M., and Corruccini, R.S. (1981). Effects of Dietary Consistency on Maxillary Arch Breadth in Macaques, J. of Dent. Res., 1: 68.

Beecher, R.M. and Corruccini, R.S. (1981). Effect of dietary consistency on craniofacial and occlusal development in the rat. Angle Orthod. 51 : 61-69.

Bennighoff,A. (1925). Spaltlinien am Knochen. eine Methode zur Ermittlung der Architektur platter Knochen. Verh. Anat. Anz.; 60: 189-206.

Bouvier, M. and Hylander, W.L. (1981). Effect of bone strain on cortical bone structure in macaques (Macaca mulatta). J. Morhpol. 167: 1-12.

Cavalancia, J. A.(1985). The Relationship of Forceful Chewing and Palatal Form in the Vervet Monkey (Cercopithecus Aethiops). M.S. These, Case Western Reserve University.

Cotton, L. A. (1978). Slow maxillary expansion. Am. J. Orthod. 73 : 1-24.

Dickson, L. M.(1940). The develpoment of Nerve Endings in the Respiratory Muscles of the Sheep. J. Anat. 74 : 268-276.

Enlow, D.H. (1962). Functions of Harversian System. Am. J. Anat. 110: 269-306.

Enlow, D.H. (1968). The Human Face., New York, Hoeber Medical Division, Harper and Row.

Enlow, D.H. (1968). Wolff's law and the factor of architectonic circumstance. Am. J. Orthod.. 54: 803-822.

Freedman, L. (1962 a). Quantitative features of the deciduous dentition of Papio Ursinus. S. Afr. J. Sci., 58: 229-236.

Freedman, L. (1962 b). Growth of muzzle length relative to calvaria length in Papio Ursinus. Growth, 26: 117-228.

Hass, A. J. (1980). Long-term posttreatment evaluation of rapid palatal expansion, Angle Orthod. 50 : 189-217.

Hewer, E. E. (1927). The Development of Muscle in the Human Fetus. J. Anat. 62 : 72-78.

Hewer, E. E. (1935). The Develpoment of Nerve Endings in the Human Foetus. J. Anat. 69 : 369-378.

Hick, E. P. (1978). Slow maxillary expansion, Am. J. Orthod. 73 : 121-141.

Hunter, W.S. (1965). A study of the inheritance of craniofacial characteristics as seen in lateral cephalograms of 72 like-sexed twins. Trans. Europ. Orthod. Soc: 41:59-70.

Hylander, W.L. (1979). Mandibular function in Gagalgo crassicadatus and Macaca fascicularis : An in vivo approach to stress analysis of the mandible. J. Morphol: 253-296.

Hylander, W.L. (1987). A preliminary stress analysis of the the supraorbital region in Macaca fascicularis. Am. Phys. Anthropol; 72-214.

Mew,J. R. C. (1977). Semi-rapid maxillary expansion, Br. Dent. J. 143 : 301-306.

Moss, M.L, Young R.W. (1960). A functional approach to craniology. Am. J. Phys Anthropol. 57:904-8.

Moss, M.L (1962). The functional matrix. In: Vistas in Orthodontics, eds. B.S. Kraus and R.A. Riedel. Lea and Febiger, Philadelphia, Pa., pp 85-98.

Oyen ,O.J (1984). Palatal Growth in Baboons (Papio cynocephalus anubis) : Primates, 25 (3) : 337-351.

Oyen, O.J.; Tsay, P (1991). A biomechanical analysis of craniofacial form and bite force. Am. J. Orthod. Vol. 99. pp 298-309.

Reed, O.M. (1965). Studies of dentition and eruption oatterns: The baboon in Medical Resaerch, Vol. 1, H. Vatborg (ed), Austin University of Texas Press, pp. 167-180.

Reed, O.M. (1967). Cephalometric studies of the growth, development and eruption patterns.: The Baboon in Medical Research, Vol. 2, H. Vagtborg (ed), Austin University of Texas Oress, pp. 181-186.

Reed, O.M. (1973). Papio Cynocephalus age determination. Am. J. Phys. Anthro., 38: 309-314.

Scott, J.H. (1954). The growth and function of the muscles of mastication in relation to the development of the facial skeleton and of the dentition. Am.. J. Orthod. 40:429-449.

Sicher, H, Tandler W.L. (1928). J. Anatom. Fur Zahnarzte. Wien: Verlag von Springer: 298.

Skieller, V. (1964). Expansion of the midpalatal suture by removable plate analysed by the implante method. Trans. Eur. Orthod. Soc. pp. 143-158.

Storey, E. (1973). Tissue response to the movement of bones. Am. J. Orthod. 64 : 229-247.

Tower, S.S. (1973). Trophic control of non-nervous tissues by the nervous system. J. Comp. Neurol. 67: 241-261.

Udomsiri-Visetsiri, I. (1988). Magnetic Resonance Imaging and Functional Analyses of Masticatory Biomechanics. M.S. These ,Case Western Reserve University.

Ward, S.C, Beecher, R.M. and Corruccini, R.S. (1981). Effects of dietary consistency on craniofacial growth. Anat. Record: 267A. Abstract.

Warner, W.M. (1969). The relationship of the temporal muscle to the form and architecture of the skull of the rat. M.S. Thesis, The University of Michigan.

Washburn, S.L.(1974). The relation of the temporal muscal to the form of the skull. Anat. Res. 99: 239-248.

Watt, D.G., and Williams, C.H.M.(1951). The Effects of the Physical Consistency of Food on the Growth and Development of the Mandible and the Maxilla of the Rat. Am. J. of Orthodont. 37: 895-927.

Weijs, W.A. and DeJogh, H.J. (1977). Strain in mandibular alveolar alveolar bone during mastication in the rabbit. Archs. Oral Biol. 22: 667-775.

Windle, W. F. , and Fitzgerald, J. E (1973). Development of the Spinal Reflex Mechanism in Human Embryos. J. Comp. Neurol. 67 : 493-506.

AJO PUBLICATION

ABSTRACT

The purpose of this study is to gain some understanding of palatal form and function. To obtain this understanding, an analysis of relationships between masticatory function and palatal morphology was undertaken. Parameters considered in this analysis include electrically induced in vivo bite force measurements, cephalometrics and craniometrics The data was obtained from a population of growing African green monkeys during the time from mixed dentition to attainment of dental maturity. To test the hypothesis that the palatal growth is significantly affected by masticatory biomechanics, dietary consistency was manipulated in the hope of inducing differential growth by altering chewing function. Correlations of bite force with the following measurements were studied: intercuspid width, intermolar width, palatal length, palatal vault depth, palatal volume, maxillary length, dental height, and palatal plane angle. Bite force at incisor, first molar, and second molar were also compared and correlated with the amount of palatal growth. The results showed statistically significant correlation between second molar bite force and palate related measurements. However, no statistically significant difference in palatal dimensions and manipulate bite force was found between monkeys fed contractive diets. Thus, it is concluded that changes in dietary consistency in this experiment did not significantly influence the palatal growth. This result mandate further investigations to include the effects of respiratory and tongue growth.

INTRODUCTION

The intention of this study is to use cephalometric analysis and measurements of the palate combined with an evaluation of the masticatory system including in vivo bite force to enhance our understanding of palatal growth. This report is part of a longitudinal evaluation of the effects of masticatory biomechanics on the growth of craniofacial skeleton. In the study by Cavalancia, post-natal development of occlusion and it's related effects on the palate, with respect to masticatory force, were examined in monkeys with mixed dentition; the current investigation is a modified continuation of the palatal studies using the same group of monkeys. However, in this instance the growth period examined extends from the mixed dentitional stage to dental maturity and additional analyses are carried out.

The primary objective of this study is to test this hypothesis that palatal growth is significantly affected by masticatory biomechanics. To test the hypothesis, the facial skeleton is regarded as a rigid frame structurally which adapts morphologically to repetitious, intermittent biomechanical effects that occur during biting and chewing, which are in some manner transmitted to the palate. In this model, the independent variables acting on the framework are forces produced during elevation of the mandible. If these forces are of sufficient intensity and duration, alternations in palatal morphology may take place. In addition to its contribution to an understanding of the basic science of masticatory biomechanics and craniofacial structure and function, it is also hoped that this study will have some clinical relevance. In particular, it is hoped that the finding reported here will shed some light on the major arguments which center on whether skeletal adaptation result from intrinsic remodeling or from extrinsic mechanotherapy.

BACKGROUND

It is broadly accepted that growth of the palate, as any other component of the facial skeleton is regulated by intrinsic, i.e.,. genetic and extrinsic, i.e.,. environmental, functional factors. It is also generally agree that the primary mechanisms that enable the palate to grow are sutural growth, and surface apposition and resorption (see Enlow [1990] for extensive discussion). Relatively little consensus seems to exist, however, about the external factors which influence actual growth of the palate, and much confusion seems to exist about this topic. For example, Scot (1954) has argued that growth of the cartilaginous nasal septum play a critical role in the mid-face, which includes the palate; according to the functional matrix theory of Moss (1960) the respiration airway is a regulator of growth in this area; Enlow (1968) has presented evidence that palatal growth reflects to a large extend the anatomy of the anterior craniofossa; and still other To date, relatively little is actually known about the relationships between palatal morphology and masticatory function, other than observations include in studies of the effects of the dietary consistency on craniofacial morphology, for example, Corrucini (1981).

In a study evaluating the growth of the palate in the African green monkeys Cavalancia (1985) investigated palatal changes of the vervet monkeys between the experimental group and the control groups. He used the skull samples of animals at different ages as control group, and the animals with deciduous teeth as the experimental group. In that study he measured changes between the post-natal monkeys and the monkeys in mixed dentitional stage. By comparing growth changes in the animals with measurements obtained from a cross-sectional collection of skulls that sewed as a control group; Cavalancia found that in relative term the five monkeys raised on a soft food diet showed a statistically significant decreased in intercuspid width versus palatal length when compared with the ten monkeys on hard food diet.

MATERIALS AND METHODS

15 growing African vervet monkeys were used. These monkeys were then divided into two groups. One group fed with hard diet, the other group fed with soft diet. At the initial stage, the monkeys were at early mixed dentitional stage, by the time the experiment was ended, the monkeys were at permanent dentitional stage. Their in vivo bite forces were obtained through electrical tetanic stimulation. Initial and final record of study models, cephalometric radiographs were obtained. The total period of the experiment are 3 years in this study

model evaluation.

1) Intercuspid width

The distance between right and left cuspids, which measured from the point intersecting between anterior groove of clinical crown of cuspid and cervical gingival margin.

2) Intermolar width

The distance between right and left molars, which measured from the most posterior point of the distal marginal ridge of clinical crown.

3) Palatal depth in premolar area

The greatest palatal depth at premolar area, measured from a line draw between right and left lingual cusp of first premolar, and through this line perpendicular to the deepest point of that area.

4) Palatal depth in molar area

The greatest palatal depth at first molar area, measured from a line draw between right and left distal marginal ridge of first molar, and through this line perpendicular to the deepest point of that area.

5) Palatal Length

The measurements of initial palatal length of the experimental animals were taken from a point bisecting a line tangent to the most posterior aspect of maxillary first molars to a point bisecting a line tangent to the lingual most aspect of the contact point between the maxillary central incisors. Since the maxillary tuberosity in final study models is more clearly identifiable than the initial study models, the final measurements in the palatal length were taken from a point bisecting a line tangent to the lingual most aspect of the contact point between the maxillary central incisors.

6) Palatal Volume

The palatal volume was determined by filling the palate with clay. The palatal vault is defined as starting from the incisal area which even height to the cervical gingiva of upper incisors back to a line that line up by the posterior marginal ridge of the right and the left first molars. At the cuspid areas the clay is filled even to the cervical gingiva of the right and the left upper cuspids. At the premolar and molar areas, the clay is filled to a height that is even to the height of the lingual cusps of the right and the left molars' and premolars. After the clay was carefully trimmed to the boundary we define, it was then removed from the study model. The clay was put into a graduated 10 ml. cylinder filled with water at exactly level 7 ml, and the volume determined by displacement of the water.

Cephalometric evaluation

Cephalograms were taken two to three months before the experimental animals were sacrificed. To assess change in parameters of the masticatory system, measurements were obtained according to procedures used by Oyen (1985). Details of how these radiographs were obtained is available elsewhere (e.g., Isaravadee, 1989).

Lever Arm -----The distance between condylion to key-ridge, measured in millimeters, perpendicular to the functional occlusal plane.

Incisal Load Arm -----The distance between the condylion and the most anterior point of the incisor, measured in millimeters, perpendicular to the functional occlusal plane.

First molar load arm -----The distance between condylion and the mid-point of the first molar, measured in millimeters, perpendicular to the functional occlusal plane.

Second molar load arm ----- The distance between Condylion and the mid-point of the second molar, measured in millimeters, perpendicular to the occlusal plane. This measurement was only possible in the final stage of the experimental period, when the second molars were present.

Additional cephalometric measurements were taken for the purposes of understanding more about the growth of the palate and the surrounding structures.

Maxillary length, measured from the sella point to the upper prosthion point in millimeters.

Mandibular length, measured from the condylion to the lower prosthion point in millimeters.

Palatal plane angle, the palatal plane is defined by drawing a line most tangent to the palatal arch. This angle was measured at an angle formed by sella-nasion line and palatal plane.

Upper dental height ---- the linear measurement from nasion point to upper prosthion in millimeters.

Lower dental height ---- the linear measurement from nasion point to lower prosthion in millimeters. Dental height ratio, the percentage comparison between the upper dental height and the lower dental height. Dental height ratio = upper dental height / lower dental height.

Bite Force Measurement

Masticatory in vivo bite force values considered in this report were obtained earlier from the monkeys according to procedures that have been described extensively in Isavaradee (1985), and by Oyen and Tsay (1991).

Because of the mobility of the erupting permanent incisors in the initial phase of this study, only first molars bite forces were used; the results reported herein are the mean values of the forces measured in the right and left sides, combined.

Initial first molar bite forces were obtained in vivo by letting the monkeys bite on the bite force transducer at the first molar in mixed dentitional stage. Second molar bite forces were obtained in the same way, at the final stage of the experiment. The final first molar bite forces as well as the incisal bite forces were obtained in the same manner as previous statement at the final stage of the experiment.

Except testing the palatal growth with the vivo bite force data, here we re-justify the bite force through lever system. Because the bite force data were obtained through different positions in the dental arch, these bite force data should also be considered as obtained from different load positions. Through the lever system, it will demonstrate to us how the bite force transferred in different loading positions.

According to the third principle of lever system (Oyen 1979), masticatory efficiencies at a certain bite point of the load arm and lever arm system can be defined by the ratio of the lever arm length divided by the load arm length.

Load arm length / Lever arm length = Efficiency.

Because the mandibular condyles act as the hinge of a single fulcrum in masticatory system, the total masticatory muscle forces transmitted from a biting point at a certain area is related to the bit force and the efficiency of the lever arm and the load arm system. The derived bite force is then can be calculated as follow:

$$\sim\sim\sim \text{ Derived bite Force} = \frac{\text{Load Arm}}{\text{Lever Arm}} \times \text{Bite Force}$$

RESULTS

Table 1 summarizes individual measurements, which are provided in detail in the appendix. Over the period studied, the monkeys essentially doubled in size according to the body weights shown in table 2. In contrast, growth increments in parameter describing the palate range from approximately 16 % (molar width) to 58 % (volume). With regard to the masticatory system, relative increases in three measures fell between 31 % and 42 %. Only one instance, that is body weight, were the relative changes of the soft groups separated by more than 5 %.

From the comparison of the palatal volume measurements, both soft and hard diet groups increased more than 55 %; same amount of the increases found in palatal length measurements. However, the increases of the cuspid and molar width, as well as palatal vault depth in both groups are only 16 % to 25 %. From the above observation, we may infer hat the palate grew larger in volume than in transverse and vertical dimension. It is difficult by using one dimensional measurement (volume checked by the displacement of water) to describe the three dimensional palatal morphologies.

One of the purposes in this study is to investigate the changes in several palates related structures. After the experimental animals were fed with either soft or hard diet, will there be any difference in the growth of the palatal areas between these two groups? Table 2 and 3 are the statistical results in this investigation. Since some of the palate related measurements are significantly correlated with the body weight of the experimental animals, therefore some of the analysis considered the body weight as a co-variance. In table 3, all the variables has consider body weight as a co-factor in the statistic calculation.

In table 2, the changes in the palatal vault, the palatal volume, the maxillary length, the mandibular length, the palatal plane angle, the dental height ratio, the intermolar width and the lever arm are all considered. No statistical significance was found between the means of hard and soft diet groups. When considering the body weight

as a co-variance to the comparison between soft and hard diet groups in table 3, no statistical significant can be found.

The tests in table 2 and 3 show us that in a more than three years' period continuously feeding the different kind of diets to these fifteen experimental vervet monkeys, there is no statistical significant found in palatal development. These maybe due to the sample size is small. Also in this study the chewing pattern of the duration and intensity did not have effect on the palatal growth of these experimental animals.

To answer the question: Does animals bite harder have bigger palate? To able to understand more about the relationships between bite force and palatal growth, here we rearranged the monkeys by descending the second molar bite forces that generated by experimental animals at the final stage. In this table, the final stage of the cuspid width, the molar width, and the palatal volume were compared. Body weights of the experimental animals were also listed as a reference. In this study, except the body weight, the monkeys bite harder have a better chance to have bigger palatal dimension then monkeys bite not so hard. From this we may conclude that the bite force has influence on the development of the palate.

DISCUSSION

The following significant results were obtained: The body weight in the mixed dentitional stage has a more significant correlation with palatal growth than in the permanent dentitional stage. The intercuspid width is correlated with first molar and second molar bite force. Palatal volume has a more significant correlation during the permanent dentitional stage than in the mixed dentitional stage. Bite forces at molar areas are significantly correlated with the load arm lengths at molar areas. The palatal plane angle has a slightly decreased tendency while the animals grew to permanent dentition. However, in this investigation there is no significant difference found in the palatal growth between soft and hard diet monkeys.

At the onset of this analysis, the relationships between the body weight and the rest of the measurements were first checked statistically by using the Pearson correlation-coefficient method. The results tell us that some of the palate-related measurements have a statistically significant correlation with body weight. Subsequent statistical calculations will consider the body weight as a co-variance. Another reason for considering the body weight as a co-variance is that the nasal passage is directly above the palate. As the animal increases in body size or increases its amount of activity, there must be an increased need of oxygen. To take in more oxygen the air passages can

increase in size. Therefore body weights is an important factor when considering the palatal growth.

There are no significant changes found in both soft and hard food diet animals concerning palatal vault depth (premolar area and molar areas) and in palatal volume changes as well. However, there were correlations between the palatal volume with the second molar bit force. Because the second molars are the most posterior functional teeth considered in this study, it can be implied that the bite force at the posterior molar area had an influence on the palatal volume at the permanent dentitional stage. The palate is three dimensional structures, it is not sufficient to describe the three dimensional palate morphologies by two dimensional measurements. The palatal morphology is enveloped by the airway and tongue, without knowing these two important structures and then trying to understand the development of the palate is inadequate. The limitation of our experiment is that, we tried to reduce three dimensional measurements to two dimensional measurements (intercuspid width, intermolar width, etc.) or even one dimensional measurement (palatal volume measurement use water displacement). The reason we did not find significant differences between soft and hard diet animals, is that the measurements we used did not necessarily reflect the change of the palate. The consistency of the diet may still have an influence on the growth of the palate. We think, by manipulating the consistency of the diet, we will have different results of the palatal growth. The monkeys on a soft food diet required little chewing function, this bring the intensity of the chewing cycle to a minimum. Also, since the diet is soft, the chewing duration is minimized. However, we had no control concerning the duration of the chewing cycle in this study. Also the non-chewing behavior in those monkeys was not controllable in this study, i.e., the intensity of masticatory function.

In Cavalancia's study, he found that in the mixed dentitional stage of the monkey palatal growth, hard food diet environment cause an increase in the intercuspid width versus palatal length. However, in this investigation at the permanent dentitional stage, there is no significant difference found between the hard food and the soft food diet groups. As Cavalancia mentioned in his findings, the data he obtained were the ratio of intercuspid width versus palatal length; this palatal length factor must be taken into consideration in the interpretation of his investigation. In the present investigation, regarding intercuspid width, we used the data from direct measurement of intercuspid width instead of using the ratio between intercuspid width versus palatal length. When the body weights were considered as a co-variance in the comparison between soft and hard diet groups, since the sample size was small, body weight still might affect the statistical results. Regarding the intermolar width in this study, we also found that there is no

significant difference between these two groups. In this study, only the normal daily food-related chewing patterns were considered. Beside the normal daily chewing patterns, there are non-food related factors existing in these experimental animals; for example: bruxism, non-masticatory oral behaviors, and cage biting behavior, etc. This non-food related chewing patterns could also have certain effects on the palatal growth. In Cavalancia's study, he estimated palatal growth in the deciduous stage and early mixed dentitional stage. At that stage the premaxillary growth took place, the maxillary bone and palatine bone were not fully developed. However, in this study we investigated at the later period of the palatal development, which included all the palatal growth. This maybe one of the reasons why, in this study, the results are different from what Cavalancia found.

There are statistical significant correlations between the second molar bite force and intermolar width as well as intercuspid width. Also there are correlations of the intermolar and intercuspid widths with first molar and second molar masticatory muscle forces. From these statistical results we can refer that the masticatory bite force might have an influence on the transverse growth of the palate.

The data gather in this investigation were electronic tetanic bite force, which was obtained by electronic stimulation on the masticatory muscles, this method is different from the voluntary bite force method. From the methodological consideration, they are a different set of measurements. Physiological voluntary bite force would be more valuable in this investigation. The bite force comparison between the hard and the soft groups has no significant difference in this test. Also from table 4, ranking the animal according to the decreases second molar bite force, the hard food animals did not necessarily bite harder than the soft diet animals. The reason for this is uncertain. Further investigation is necessary to detect the dental attritional pattern on occlusal surface of these experimental monkeys to identify the non-chewing behavior that maybe involved in masticatory function.

CONCLUSIONS

In this experimental study, palatal growth with respect to masticatory forces was examined. Fifteen growing African green monkeys were used and theirs palate-related data were analyzed. These monkeys were divided into two groups, and maintained for three years on diets which differed in terms of physical consistency. This study extends works completed by Cavalancia (1985), which ended with the mixed dentitional stage.

In this study, significant relationships were found between second molar bite force and palate-related measurements. In contrast to earlier findings by Cavalancia

hinting at significant differences between the soft and hard food populations, this analysis found no such differences. Several explanations are possible. First, the magnitude of difference in diet consistency may not be sufficient to induce palatal change. Second, measurements used in this study may not reflect true morphology of palate. Third, the oral-nasal function may compensate for and thereby mask alterations associated with dietary consistency. The results of this experiment underline the importance of identifying taking into consideration all the factors that were actually involved.

Based on these findings, which centered on consideration of masticatory function, areas that deserve special consideration in the design of future analyses of the palate should include respiratory and lingual function.

REFERENCES

Beecher, R.M. and Corruccini, R.S. (1981) Effect of dietary consistency on craniofacial and occlusal development in the rat. Angle Orthod. 51: 61-69.

Cavalancia, J. A. (1985) The Relationship of Forceful Chewing and Palatal Form in the Vervet Monkey (Cercopithecus Aethiops). M.S. These, Case Western Reserve University.

Enlow, D. H. (1962) Functions of Harversian System. Am. J. Anat. 110: 269-306, 19

Enlow, D. H. (1968) Wolff's law and the factor of architectonic circumstance. Am. J. Orthod. 54: 803-822.

Moss, M.L.and Young R.W. (1960). A functional approach to craniology. Am. J. Phys Anthropol. 57:904-8.

Moss, M.L (1962) The functional matrix. In: Vistas in Orthodontics, eds. B.S. Kraus and R.A. Riedel. Lea and Febiger, Philadelphia, Pa., pp 85-98.

Oyen, O.J (1984), Palatal Growth in Baboons (Papio cynocephalus anubis). Primates, 25 (3): 337-351.

Oyen, O. J. and Tsay, P. (1991). A biomechanical analysis of craniofacial form and bite force. Am. J. Orthod. Vol. 99. pp 298-309.

Scott, J.H. (1954) The growth and function of the muscles of mastication in relation to the development of the facial skeleton and of the dentition. Am. J. Orthod. 40:429-449.

Udomsiri-Visetsiri, I. (1988). Magnetic Resonance Imaging and Functional Analyses of Masticatory Biomechanics. M.S. These, Case Western Reserve University.

Table 1. Means comparison between soft and hard diets as well as initial and final stages.

Variables			Initial		Final		Increases
	Diet	N	Mean	S.D.	Mean	S.D.	
Body weight	H	10	2.98 Kg.	0.86	5.73 Kg.	0.9	2.75 Kg.
	S	5	3.02 Kg.	1.05	6.08 Kg.	1.29	3.06 Kg.
Molar width	H	9	26.16 mm.	1.78	30.3 mm.	1.4	4.20 mm.
	S	5	26.74 mm.	1.16	31.1 mm.	2.76	4.38 mm.
Cuspid width	H	9	21.39 mm.	2.18	26.3 mm.	1.83	4.94 mm.
	S	5	22.62 mm.	2.96	28.46 mm.	2.68	5.84 mm.
Palatal Length	H	9	32.37 mm.	4.38	48.97 mm.	2.98	16.6 mm.
	S	5	32.64 mm.	3.0	49.26 mm.	2.6	16.6 mm.
Volume	H	9	2.30 ml.	1.32	3.63 ml.	0.49	1.33 ml.
	S	5	2.40 ml.	0.48	3.76 ml.	0.34	1.36 ml.
1st Molar B.F.	H	10	29.20 Kg.	3.56	40.81 Kg.	8.43	11.61 Kg.
	S	5	31.38 Kg.	6.6	44.42 Kg.	7.53	13.04 Kg.
2nd Molar B.F.	H		N/A		49.54 Kg.	8.83	20.34 Kg.
	S		N/A		53.71 Kg.	7.48	22.33 Kg.
Lever Arm	H	10	31.07 mm.	2.61	41.45 mm.	2.31	10.38 mm.
	S	5	31.22 mm.	3.91	40.96 mm.	2.99	9.74 mm.
Maxillary L.	H	10	52.97 mm.	2.96	70.29 mm.	3.42	17.32mm.
	S	5	52.04 mm.	6.72	71.88 mm.	3.95	19.84mm.
Vault depth at premolar	H	9	6.64 mm.	0.62	8.44 mm.	1.02	1.8 mm.
	S	5	6.84 mm.	0.87	8.56 mm.	0.28	1.72 mm.
Vault depth at molar	H	9	8.87 mm.	0.77	10.76 mm.	0.99	1.98 mm.
	S	5	8.26 mm.	0.82	10.64 mm.	0.82	2.83 mm.

Table 2. Comparison of changes between soft and hard diet groups.

	number	mean	S.D.	T-value	P-value
Change of palatal vault depth at premolar area /m.m.					
Hard	9	1.8	0.747		
				0.2	*0.844*
Soft	5	1.72	0.646		
Change of palatal vault depth at molar area/ m.m.					
Hard	9	1.98	0.848		
				-0.65	*0.525*
Soft	5	2.38	1.486		
Change in palatal volume /ml.					
Hard	9	1.32	0.441		
				0.01	*0.993*
Soft	5	1.32	0.363		
Change in maxillary length /m.m.					
Hard	9	18.92	2.522		
				-0.56	*0.588*
Soft	5	19.84	3.664		
Change in mandibular length /m.m.					
Hard	9	22.59	2.286		
				-1.53	*0.153*
Soft	4	24.83	2.761		
Change in palatal plane angle /(0's)					
Hard	10	0	1.333		
				0.5	*0.622*
Soft	5	-0.4	1.673		
Change in dental height ratio /%					
Hard	9	0.0137	0.026		
				-0.86	*0.409*
Soft	5	0.0278	0.035		
Change in molar width /m.m.					
Hard	8	4.75	0.990		
				0.39	*0.701*
Soft	5	4.38	2.397		
Change in bite force of first molar /Kg.					
Hard	10	11.606	7.929		
				-1.44	*0.174*
Soft	5	17.164	4.492		
Change in lever arm /m.m.					
Hard	10	10.38	2.658		
				0.46	*0.654*
Soft	5	9.74	2.293		

Table 3. Comparison of changes between soft and hard diet groups, body weight as a covariance.

	number	mean	T-value	P-value
Change in palatal length m.m.				
Hard	9	11.79		
			0.091	*0.768*
Soft	5	16.62		
Change in cuspid width m.m.				
Hard	9	4.94		
			0.149	*0.706*
Soft	5	5.84		
Change in load arm of first molar m.m.				
Hard	10	15.88		
			0.104	*0.753*
Soft	5	17.36		
Change in load arm of incisor m.m.				
Hard	10	21.00		
			0.752	*0.403*
Soft	5	24.84		

Table 4. Palatal measurements and body weights distribution rank according to decreased magnitude of second molar bite force. (@ means soft diet monkey)

Monkey's Name	**2nd molar BF/Kg.**	Final Cuspid Width/m.m.	Final Molar Width/m.m.	Final Palatal Volume	Final Body Weight
Willie@	63.18	29.8	32.3	3.6	7
Billy	60.66	28.7	32.1	3.8	6.9
Cornelius	60.30	27.4	31.4	3.4	6.3
George	57.42	27.5	32.3	4.4	4.8
Michael@	56.70	30.6	30.5	3.9	6.4
Dannie@	55.98	30.8	32.4	4.3	7.4
Patrick	54.00	25.3	29.6	3.8	5.4
Tammie	52.92	28.2	31.9	4.1	4.3
David@	48.78	25.5	30.6	3.5	4.2
Mad Max	48.42	24.9	27.8	3.9	5.4
Stevie	45.18	23.2	27.7	2.9	4.9
Luciano@	43.92	25.6	29.8	3.5	5.4
Phil	39.96	24.9	30.9	3	7.3
Eddie	39.06	26.9	29.5	3.4	5.9

AJO ABSTRACT

An Assessment of Dietary Consistency, Bite Force and Palatal Morphology in Growing Monkeys. C. TSENG
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The purpose of this study is to gain some understanding of palatal form and function. To obtain this understanding , an analysis of relationships between masticatory function and palatal morphology was undertaken.

Parameters considered in this analysis include electrically induced in vivo bite force measurements, cephalometric and craniometrics The data was obtained from a population of growing African green monkeys during the time period from mixed dentition to attainment of dental maturity. To test the hypothesis that the palatal growth is significantly affected by masticatory biomechanics, dietary consistency was manipulated in the hope of inducing differential growth by altering chewing function. Correlations of bite force with the following measurements were studied: intercuspid width, intermolar width, palatal length, palatal vault depth, palatal volume, maxillary length, dental height, and palatal plane angle. Bite force at incisal, first molar, and second molar were also compared and correlated with the amount of palatal growth. The results showed statistically significant correlation between second molar bite force and palate related measurements. However, no statistically significant difference in palatal dimensions and manipulate bite force was found between monkeys fed contractive diets. Thus, it is concluded that changes in dietary consistency in this experiment did not significantly influence the palatal growth. This result mandate further investigations includes the effects of respiratory and tongue growth.