CASE WESTERN RESERVE UNIVERSITY

GRADUATE STUDIES

We hereby approve the thesis of

LUKA POPOVIC

candidate for the MASTER OF SCIENCE IN DENTISTRY degree.

Signed: Robert Carlsgaard
(Chairman)

Donald H. Enlow

Rolf G. Behrents

Date May 1, 1981

TRANSVERSE GROWTH CHANGES IN THE RABBIT MAXILLA UTILIZING VESTIBULAR SHIELDS

by

LUKA POPOVIC

Submitted in partial fulfillment of the requirements

for the Degree of Master of Science in Dentistry

Department of Orthodontics

School of Dentistry

CASE WESTERN RESERVE UNIVERSITY

May 1981

TRANSVERSE GROWTH CHANGES IN THE RABBIT MAXILLA UTILIZING VESTIBULAR SHIELDS

Abstract

by

LUKA POPOVIC

The vestibular shield has been used extensively as an integral component of functional appliances. Data accumulated from this clinical use suggests a direct cause-effect relationship resulting in alterations of the maxillary dental arch transverse dimension. Previous investigators have postulated that transverse growth changes obtained through the application of vestibular shields may be due to periosteal deposition on the apical walls of the buccal alveolar plates. Sutural growth changes have also been cited as a possible mechanism underlying maxillary growth alterations.

The purpose of the present study was to assess the morphogenic and histogenic effects of vestibular shields on the transverse growth of the maxilla utilizing a laboratory model. Buccal shields were inserted in the oral cavity of five actively growing New Zealand white rabbits and were maintained in position by means of bilateral circumzygomatic ligature fixation. The treatment group was evaluated after a period of 35 days and compared to a sham control group of three age-similar animals.

Several categories of data were collected. Dental casts, obtained at the beginning and at the end of the experimental period, were used to compare differences in transverse dental arch dimensions. Results suggest a maintenance of normal dental arch increases in those specific areas in which undesired flexion of the vestibular shields, caused by a compressive effect of the buccal soft tissues, was not possible. Regions distal to the maxillary second premolar, however, exhibited actual reduction in transverse dental arch dimension, and it is postulated that undesired impingement caused by buccal soft tissue pressure on the appliance produced a constrictive effect on lateral dental growth movements. Histologic evaluation did not provide evidence of any remodeling differences in regional alveolar and palatal remodeling between the control and experimental groups.

An analysis of general body growth using tibial length standards, supported by body weight comparisons, revealed gross differences in overall body and skeletal development between the groups related to feeding interferences caused by the appliances. However, cephalometric analyses suggest that retarded body growth affects maxillary and basicranial maturation to a somewhat lesser degree than post-cranial regions. Anatomic and radiographic variables used as indicators for differences in transverse cranial base and maxillary growth suggest that growth boundaries such as those prescribed by the cranial base cannot be signifi-

cantly exceeded, but growth under compromised nutritional conditions may fall short of the growth field boundaries. In the present study, the counterpart relationship between the anterior cranial fossa and the nasomaxillary complex was not altered significantly under conditions of experimental functional modification of the perioral soft tissue. Results obtained in this study, therefore, suggest that normal skeletal relationships between the maxilla and its counterpart, the anterior cranial fossa, cannot be altered beyond prescribed growth boundaries through the application of vestibular shields as utilized in the present investigation.

Results obtained clinically demonstrate increased maxillary transverse dimensions. Perhaps the design of the appliance and the animal model used in this study failed to simulate the actual mechanisms of action produced by vestibular shields. In addition, future studies should attempt to design an experimental model which does not produce severe growth retardation between treatment and control groups.

ACKNOWLEDGEMENTS

The author wishes to extend his sincere appreciation to the following individuals and groups:

Dr. Robert Cederquist, Assistant Professor of Orthodontics, School of Dentistry, Case Western Reserve University, who, as my advisor, provided the impetus for this study. His many hours of close attention, willingness to confront various problems, technical skills and most of all sincere interest made its successful completion possible.

Dr. Donald H. Enlow, Director of Graduate Studies and Chairman of the Orthodontic Department, School of Dentistry, Case Western Reserve University, who provided an excellent background in growth and development and assisted in the preparation of this thesis. His genuine interest in the project and skillful handling of difficult situations were greatly appreciated.

Dr. Rolf G. Behrents, Director of the Orthodontic Clinic, School of Dentistry, Case Western Reserve University, who assisted in the preparation of this thesis. His editorial skills and constructive criticisms were sincerely appreciated.

Dr. Apostolos Tsolakis, for his willingness to help during the very difficult times of preparing the experimental protocol. His personal friendship and true sincerity in many matters will be remembered always.

this study.

DR Rosalba Rangel, for her friendship, support and invaluable Technical assistance and advice offered in the preparation and evaluation of decalcified section

Mr. Adolf Vozka, for his precision and adeptness in Construction of the

invaluable support and advise in writting this Thesis ~~throughout~~

Dr Karen Katz for her generous support and freindship during the past three years.

Cephalometrat and ~~Model~~ casting

ground section:

Mrs Sandy Parrish, for her help

in histological preparation.

~~Dr~~ Associate professor in Depart of O.B

Dr Dean oyen for his Constructive

Criticism and expert advice Throughout

this study

Assistant professore in The D.O.B

study, To gether with his technical skills which have been of utmost importance to me.

Dr DAVID Johnson, Chairmen of the pediatric Dentistry for his Constructive criticism and his support Throughout

Miss Joan Zolkoski, who helped me gather much of the literature used during the course of the project.

Ms. Linda Nicholl, for her excellent skills in typing this thesis.

The members of the Clinical Faculty, Department of Orthodontics, School of Dentistry, Case Western Reserve University. I sincerely appreciate their efforts, skills and personal interest during the course of my graduate studies in orthodontics. Thank you for providing a most outstanding education for me and my classmates.

The staff, for their help in providing an environment that facilitated learning.

Mr. Adolf Vozka, for his precision and adeptness in the construction of the cephalostat and appliances.

Mrs. Sandy Parrish, for her skillful preparation of histological sections.

And, finally, to my classmates, who made the past two years a very interesting experience.

DEDICATED

TO

My wife, Kay, whose love, support and encouragement helped me achieve my education.

Megan, our daughter, whose birth brought true joy and happiness.

My parents, whose love, guidance and generosity have helped always.
Mama i Tata, Hfala

TABLE OF CONTENTS

	Page
ABSTRACT	ii
ACKNOWLEDGEMENTS	v
DEDICATION	vii
LIST OF TABLES	ix
LIST OF PLATES	x
LIST OF FIGURES	xi
INTRODUCTION	1
LITERATURE REVIEW	3
STATEMENT OF THESIS	15
METHODS AND MATERIALS	16
RESULTS	47
DISCUSSION	69
SUMMARY AND CONCLUSIONS	76
LITERATURE CITED	79

LIST OF TABLES

Table		Page
I.	Treatment Assignment and Age	17
II.	Vital Dye Dosage and Route of Administration	30
III.	Cephalometric Analysis	44
IV.	Initial and Final Weight Data	48
V.	Average Weight Gain per Day	49
VI.	Changes in Maxillary Dental Arch Transverse Dimension for the Maxillary First and Second Premolars	51
VII.	Changes in Maxillary Dental Arch Transverse Dimension for the Maxillary Third Premolar and the Maxillary First and Second Molars	52
VIII.	Statistical Analysis: Transverse Dental Changes	53
IX.	Tibial Growth	55
X.	Mean Changes: Radiographic and Cephalometric Variables	56
XI.	Statistical Analysis: Tibial and Cephalometric Measurements	57

LIST OF PLATES

Plate		Page
I.	Cephalostat	19
II.	Appliance Design and Intraoral Placement	24

LIST OF ILLUSTRATIONS

Figure		Page
1.	Implant Location	28
2.	Rabbit: Dorso-ventral View	36
3.	Cephalometric Landmarks	38
4.	Cephalometric Analysis: Implant Lines	41
5.	Cephalometric Analysis: Anatomical Measures	43
6.	Local Growth Processes in the Maxilla in the Region of the Maxillary First and Second Premolars	63
7.	Local Growth Processes in the Maxillary and Palatine Bones in the Region of the Maxillary Third Premolar	65
8.	Local Growth Processes in the Maxillary and Palatine Bones in the Region of the Maxillary First Molar.	67

INTRODUCTION

In recent years understanding of the importance of soft tissues in the control of maxillary growth and correction of malocclusion has focused on methods utilizing "functional orthopedics." The theoretical basis of the system of functional treatment suggests that new patterns of function dictated by the appliance lead to correspondingly new morphological patterns. Adherents of this philosophy of treatment believe the tongue, lips and facial and masticatory muscles provide stimuli for osseous remodeling. Further, the extent of such growth adjustment is not believed to be limited to the dentition and alveolar processes, but also to altered form in the templates housing these elements.

The system of functional appliance treatment advocated by Frankel (1966) is designed to optimize the developmental potential of the orofacial complex. In the region of the oral vestibule the appliance is considered a local extrinsic factor which performs two specific functions: (1) eliminates direct forces by the buccinator mechanism and (2) produces tensile stress in the mucobuccal fold.

The present study involved an experimental alteration of function of the orofacial musculature. The appliance used was

intended to cause an expansion of the orofacial soft tissue capsule, and in addition, to exert tension in the region of the mucobuccal fold opposite the buccal dentition and thus serve to simulate part of the action of the Frankel appliance. The New Zealand white rabbit (Oryctolagus cuniculus) served as the experimental model.

Quantitative data was obtained from serial dorsoventral headfilms and dental casts. Metallic implants were placed in the maxilla to provide for orientation and documentation of growth adjustments. In addition, vital dyes were administered to provide markers for documentation of the extent of any remodeling changes in the transverse dimension. Finally, histologic examination was carried out to determine the nature of possible microscopic bone, muscle and connective tissue alterations.

As will be evident in the "Literature Review" no general consensus of opinion exists regarding the anatomic definitions of that part of the maxilla immediately superior to the root apices. In the present study the term "basal bone" is used to denote that part of the maxilla which forms the foundation for the root apices, and the term "apical base" is that maxillary bone most adjacent to the root apices.

LITERATURE REVIEW

Considerable debate regarding the definition of the terms (1) apical base, and (2) basal bone prevails in the literature. Lundstrom (1925) introduced the term "apical base" and defined it as the region superior to and limited by the alveolar apical zones. The latter structures are band-like zones of alveolar bone extending both buccally and lingually to the tooth roots. A developmental basis has been used to provide a definition for the maxillary apical base (Howes, 1947). The apical base is that part of the maxilla which initially houses the tooth germs and also provides a template for the growth and development of the alveolar process. Other investigators (Brodie, 1966; Frankel, 1971) have defined the apical base as that part of the maxilla associated with the root apices. Enlow (1975) has pointed out the histologic similarity between the maxillary corpus and the alveolus, noting that one area grades into the other without any histological boundary. He defined the basal bone as that part of the corpus which is not involved in alveolar movements of the teeth.

Classical teachings (Brady, 1905; Angle, 1907) stressed the significant influence of the dentoalveolar apparatus on the apical base. Lundstrom (1925) broke with these traditions when

he emphasized that factors responsible for the size, shape and position of the apical base are independent of the factors responsible for tooth position. With regard to etiologic factors of malocclusion, local causes were clearly differentiated from those more developmental in nature. Lundstrom (1925) strongly concluded that a dental arch may develop in harmony or disharmony with the apical base.

Genetic predetermination has been accorded the utmost importance on the pattern, rate and timing of bone growth by Brodie (1948). The role of function was viewed to be insignificant when compared to inherent tendencies, and apical base bone growth was viewed inherently unalterable. The existing muscular balance was held to be immutable (Strang, 1949). The viewpoint of Angle (1907) stressed growth induction through orthodontic management while Brodie and co-workers (1938) described the extent of orthodontic treatment to be limited to the alveolar processes.

Studies dealing specifically with transverse changes in maxillary apical base width as a result of treatment methodologies are limited in the literature, although there is much documentation that changes in maxillary dental arch width do occur. An early statement regarding this topic was presented by Hunter (1771):

> The jaw still increases in all parts till twelve months after birth, when the bodies of all six teeth are pretty well formed; but it never increases in length between the

> symphysis and the sixth tooth; and from this time, too, the alveolar process which makes the anterior part of the arches of both jaws, never becomes a section of a larger circle, whence the lower part of a child's face is flatter or not so projecting forwards as in the adult.

Similarly, Strang (1949) held that both lateral and posteroanterior growth of the jaws anterior to the first permanent molars was completed by seven years of age. Howes (1947) stated that the apical base in the region of the deciduous molars matured before the eruption of the premolars. Prior to this, it had been shown (Lundstrom, 1925) that the apical base of the deciduous dentition is more like the arc of the primary teeth than the base of the permanent dentition is to its dental arc.

A study directed at the apical base (Richardson and Brodie, 1964), incorporating dental casts and radiographic data, concluded that the growth of the apical base appears to occur during the mixed dentition period, but the timing between dental eruption and apical base growth was not found to be predictable. It was concluded that the apical base follows its own growth schedule. Frankel (1971) concluded that definitive formation of the apical base occurs during eruption. Radiographic data showing movement of tooth apices in an occlusal direction supported this view. The distance between the root apices of premolars and the mandibular border was found to increase up to one centimeter during the period of eruption.

Considerable focus by many investigators has been directed on discerning the relative contribution of sutural growth versus remodeling growth in the transverse developmental dynamics of the maxilla. The sutural theory of facial growth viewed the median palatal suture as an active growth center in the growth in width of the hard palate (Keith and Campion, 1922). Scott (1956) proposed a temporal limit for the significance of the sagittal suture system. He suggested that because the metopic suture and the mandibular symphysis usually fuse by the end of the first year, active contribution to transverse increase by the sagittal suture system is doubtful thereafter. Scott (1958), however, did view surface accretion growth as proposed by Brash (1934) to be a significant factor in the transverse growth of the maxilla.

Histological examination of the midpalatal suture (Latham, 1971) has produced results indicating midpalatal sutural growth completion by the ages of one and two years. This was evidenced by a change in bone growth on the sutural margins. Specimens indicating active midpalatal sutural growth exhibited resorptive remodeling of adjacent medullary surfaces, whereas those which were considered to be lacking in sutural growth activity showed depository remodeling growth of the adjacent medullary surfaces. Melsen (1975) has demonstrated signs of cellular activity in the palatal suture up to the age of 16 in fe-

males and 18 in males. Another histological study suggested that sutural activity continues beyond the ages of 13 and 14 years at which time a cessation of the increase in width of the dental arches has been observed (Moorrees, 1969).

Intraosseous bone markers have been used to evaluate the nature of palatal sutural growth (Krebs, 1964; Skieller, 1964). The growth effect of the midpalatal suture was determined by the increase in width of the maxillary base, measured on antero-posterior radiographs, between implants inserted bilaterally into the upper jaw. Results suggested active sutural activity after puberty. The concept of sutural growth rate periodicity (Björk, 1972) which directly relates sutural growth to an individual's skeletal growth velocity curve is supported by the data gathered by Krebs (1964) and Skieller (1964).

Based on a quantitative evaluation of palatal suture activity employing the implant method, Björk and Skieller (1974) concluded that growth in the median suture is the most important factor in the growth in width of the maxilla. The increase in maxillary dental arch width, measured between the first molars, was only one-fourth of the sutural growth in width of the maxilla in this area. Sutural activity was determined to be greater posteriorly. The measured change between the bizygomatic implants was found to be three times greater than between implants placed on either side of the midpalatal suture apical to the maxil-

lary central incisors. This disproportionate growth activity in the horizontal plane produces mutual transverse rotation of the two maxillae resulting in dental arch length reduction if measured in the mid-sagittal plane (Björk and Skieller, 1976).

Enlow's principles of growth (1962, 1966, 1975) focused attention on the significance of remodeling processes in the growth of the maxilla, including widening of the hard palate and the upper dental arch. Enlow and Bang (1965) described the contribution of remodeling to lateral palatal movement. The "V" principle of remodeling growth as introduced by Enlow (1962) serves to explain increases in width of the maxilla. If posterior and vertical components of maxillary growth are active, apposition on inner surfaces and resorption from outer surfaces produces increases in width.

Enlow (1975) views remodeling as the basis for area relocation. The latter allows for maintenance of relative positions of anatomical structures during growth. Posterior relocation of structures such as the zygomatic arch, zygomatic process of the maxilla and the premaxilla allows for maintenance of proportion. Concurrently, the deposition in the region of the maxillary tuberosity, in conjunction with "V" principle remodeling of the hard palate, produces a longer maxilla with a broader transverse dimension in the posterior regions.

Accretion of bone at the free margins of the alveolus in conjunction with alveolar periosteal and endosteal remodeling processes produces dental arch adjustments (Enlow, 1975). Histological examination in the region of the premaxilla (Enlow and Bang, 1965) exhibited lingual periosteal deposition. The buccal walls were thin and were composed of a single plate of endosteal lamellar bone. Scattered, very thin patches of overlying periosteal bone were observed on the buccal surfaces and were attributed to cortical adjustments resulting from tooth movements during eruption and drift (Enlow and Bang, 1965).

The growth of the maxilla is also influenced by surrounding soft tissues, but a direct cause-effect relationship is presently debatable. The functional matrix concept (Moss and Young, 1960), which is based on the work of van der Klaauw (1948), directs attention to the relationship of form and function where the latter is accorded dominance. Moss (1969) contends that genetic factors are considered to be important in the initiation of bone formation but further growth, development and maintenance of the skeletal tissues are primarily dependent on soft tissue development and the functional state of the soft tissue and bone relationship.

Moss (1967) believes that the individual bones of the cranium do not grow as whole parts but rather are composed of skeletal units which in turn grow independently of other skeletal

units. The microskeletal units are affiliated with periosteal matrices, and the macroskeletal units are associated with capsular matrices. Moss (1969) equates translative growth with capsular matrices and transformative growth with periosteal matrices. The components of a functional matrix include soft tissues, organs and functioning spaces. An implication of the functional matrix hypothesis is that if one wishes to alter the size, shape and position of a particular skeletal unit, it is possible to do so by altering a specific functional matrix. Theoretically, the theory subdivides a bone such as the maxilla into several relatively independent, functional skeletal units, each associated with a particular functional matrix (Moss, 1967).

The infraorbital neurovascular triad is designated as part of the functional matrix for the maxillary bone (Moss, 1967). The latter is defined as a skeletal unit, but Moss does not clearly account for the nature of the developmental interrelationship between the two members of this functional cranial component. Similarly, Moss (1967) accords to the teeth the role of a functional matrix for the alveolar skeletal unit. It is suggested that tooth movements produce secondary alveolar compensations which, through alterations in size and shape, subsequently continue to provide a supportive and biomechanical role.

The theory of "Functional Adaptation" advanced by Roux (1895) stressed that by altering the soft tissue environment the

osseous tissue would change its form permanently. Congruently, Moss (1967) has contended that treatment of a specific functional matrix will produce growth alterations of the related skeletal unit. Hoyte and Enlow (1966) have concluded that various regions possess regional growth behavior patterns but the underlying control mechanisms of remodeling and translative growth are presently not fully accounted for.

Bassett (1962, 1965) suggested that stress-induced bioelectric potentials are the command signals in the operation of Wolff's Law of Transformation. This principle maintains that the form and structure of a bone develops in a manner that best adapts to biomechanical forces. Bassett believes that bioelectric potentials serve to control cell activity and the orientation of the extracellular material but suggests that other modifying factors exist. Similarly, Enlow (1968) concludes that stress forces, bioelectric factors, cell induction, genetic predisposition and response to stimuli are factors which should be regarded as contributory to the control of local growth processes.

Frankel's Functional Orthodontic Treatment

The theoretical basis of this system of functional treatment suggests that a new pattern of function dictated by a "functional" appliance leads to the development of a correspondingly new morphological pattern, not only of tooth arrangement,

but also of regional skeletal size and regional proportions (Frankel, 1966). Conceptual support for this thesis was derived from the previous studies of Wolff (1892), Roux (1895) and Moss (1960).

Frankel (1980) recognizes a viewpoint which attributes developmental dominance to the soft tissues and functioning spaces (Moss, 1969), but he stresses more strongly the viewpoint of van der Klaauw (1948) which does not deny the dominant influence of hereditary factors. Frankel (1966) believes that the size or extent of a membrane bone should correspond to that part of the soft tissue complex which it is designed to protect. In addition, he differentiates between growth sites of intramembranous ossification and sites involving cartilaginous growth structures. The former sites can be influenced by the contiguous tissues whereas the latter regions are presumably under autonomous control mediated by growth hormone. He concludes:

> The differentiation of the pluripotent cells in the intramembranous growth sites is governed by biomechanical factors which activate the ossification processes and determine the course of events.

Frankel's therapeutic concept (1966) for the use of vestibular shields is to intercept aberrant forces from the perioral musculature and to induce remodeling changes in the outer alveolar wall through the application of traction in the region of the mucobuccal fold. The growth fields in these regions are

purported to be altered through the conversion of the subperiosteal fibrous connective tissue into an osteogenic scaffolding. Frankel (1969, 1974) has documented increases in maxillary dental arch width ranging from 4.5 mm. to 7.5 mm. in treated cases. Although no data was presented, Frankel strongly believes that the treatment extends to the basal bone.

Adams (1969) disagrees with the contention that treatment with the Functional Regulator appliance extends beyond the dentition. His conclusions are derived from cephalometric and dental cast evaluation of patients treated with this appliance. Other investigators (Eirew, 1969; Pac, 1970) firmly believe that the treatment effect does extend beyond the alveolar process. Logan (1971) concluded that maxillary dental expansion is self-limiting. He did not extrapolate the results obtained from measurements of dental casts to possible treatment effect beyond the dentition.

Organ (1979) used the monkey (Macaca fasicularis) as the subject of an experimental model to study the effects of the Function Regulator. Histologic examination of the bone in the region of the maxillary mucobuccal fold and vital dye marker examination produced no discernible differences between experimental and control animals. Similarly, dental cast measurements failed to demonstrate dental adjustments leading to increased transverse arch adjustments. An interpretation of the data gathered in this study must take into account the appliance design.

The appliance did possess vestibular shields but the maxillary buccal dentition was used to support the appliance in place and thus perhaps limited potential osseous and dental arch changes.

STATEMENT OF THESIS

The purpose of the present investigation was to study the effect of functional orofacial alterations on the transverse growth of the maxilla. Significant alteration would substantiate a portion of the biologic basis for therapeutic principles proposed by Frankel; if there was no effect on the maxilla, then a re-evaluation of parts of the biologic explanations for observed expansion utilizing functional vestibular shields would be warranted.

The design of the experiment to address this question involved vestibular shields which were placed bilaterally in young, growing rabbits to attempt to alter the orofacial volume and to induce tension in the region of the mucobuccal fold. The appliance design used in this experiment represented the equivalent of an integral component of the Frankel Function Regulator. Previously it has been assumed that the vestibular shield will increase the transverse dental and maxillary dimension. To prove or disprove this assumption it will be determined whether or not the following experimental effects are observed:

1. Enlargement of the orofacial volume to produce a corresponding change in the maxilla.
2. Altered eruptive paths of the teeth with concurrent change in the alveolar bone morphology.

METHODS AND MATERIALS

Sample

The present investigation utilized eight New Zealand white rabbits (Oryctolagus cuniculus) obtained from two litters. The animals were either 35 or 45 days of age at the start of the experiment. The two older animals were assigned to different treatment groups. This species was selected for the following reasons:

1. Forced, early weaning allows normal maturation without compromising the growth and development of the animal.
2. The docility of the laboratory rabbit facilitates animal management and appliance tolerance.
3. The rabbit matures rapidly, and the relatively large size of the animal reduces potential error in the analysis of the data.
4. The experimental period allows for the major skeletal growth spurt which is between 30 and 50 days (Harel et al., 1972). By three months the animal obtains adult proportions skeletally (Engdahl, 1972).

Five animals were used as experimental subjects to test the effect of maxillary functional alteration. Three animals served as sham controls. The animals were randomly assigned to their respective treatment groups. Table I outlines the treatment assignments, animal identification number and age at the start of the experiment.

TABLE I

TREATMENT ASSIGNMENT AND AGE

Experimental Animal	Age (days)	Control Animal	Age (days)
8	35	11	35
9	35	13	35
10	35	3	45
12	35		
4	45		

Experimental Design and Procedures

Vestibular acrylic shield appliances were constructed to attempt to alter the orofacial muscular environment of the experimental group by witholding the cheek musculature from the posterior dentition. Pilot studies were first undertaken to devise:

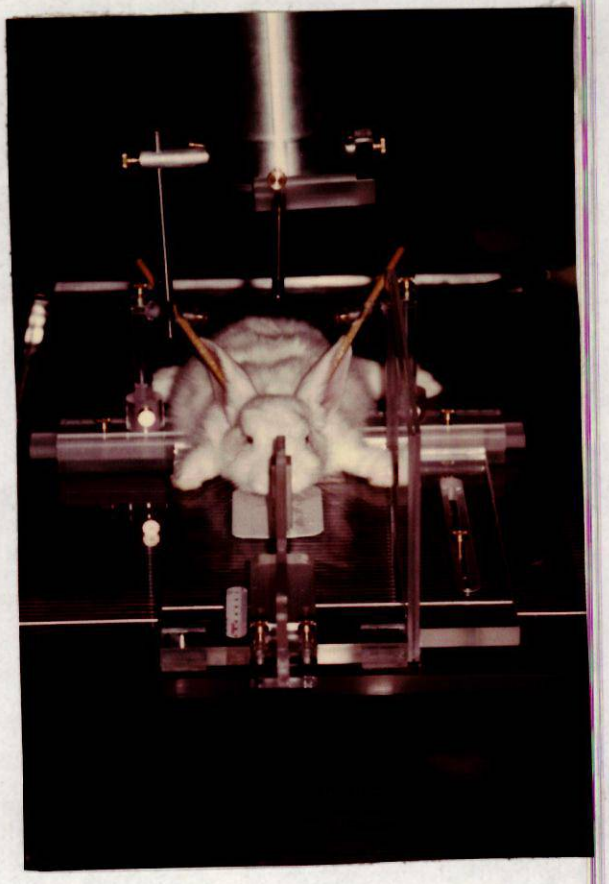
1. a technique for the taking of serial dorsoventral roentgenograms of the rabbit on a specially constructed cephalometer;
2. an impression technique which would produce detailed casts of the maxillary and mandibular dentitions;
3. an appliance which would produce buccal muscular alterations but which would not impede normal masticatory function;
4. a tantalum implant regimen which would allow for the evaluation of the transverse growth of the maxilla; and
5. a methodology and schedule of vital dye administration.

Radiographic Method

A special cephalometer (Plate I) was designed consisting of a plexiglass base with plastic uprights upon which were mounted an earpost and a support for centering and holding the upper anterior teeth of the rabbit. A metal collar was machined to be attached to the x-ray cone. The collar was constructed to allow for reproducible target-object placement. This was obtained by withdrawing the distance pin a fixed distance at each recording.

PLATE I

Cephalometer



The x-ray cone was centered in the midsagittal plane and was positioned anteroposteriorly at the level of the interorbital axis. The x-ray film was placed on a table below the plexiglass base. Thus, a fixed film placement and fixed target distance were obtained.

Exposure times were determined by a series of trials using a rabbit dry skull fixed on the apparatus. Radiographs were taken on 5" x 8" ready pack film (Kodak No-Screen Film, NS-2T, Eastman Kodak Company, Rochester, New York) at 0.6 seconds, 15 milliamperes and 70 kilovolts. The source-to-film distance was held constant at 0.5 meters. To insure maximum clarity, all the films were manually processed with a developing time of 4.5 minutes and a fix time of 12.5 minutes.

Anesthesia Regimen

All data collection was taken with the animals under general anesthesia. Because narcosis of approximately one hour in duration was required, combination therapy was used (Sachs, 1980). A dose of 5 mg/kg of body weight of Xylazine (Rompun, Bayvet Corporation, Shawnee, Kansas) preceded the administration of Acepromazine Maleate (Ayerst Laboratories, Inc., New York, N.Y.) and Ketamine Hydrochloride (Ketaset, Bristol Laboratories, Syracuse, New York) which were combined in a volumetric ratio of 1:10. This second administration was given five to ten

minutes subsequent to the Xylazine at dosages of 35 mg/kg of Ketamine Hydrochloride and 0.318 mg/kg of Acepromazine Maleate. Both injections were intramuscular. If additional anesthesia time was required, Ketamine Hydrochloride was administered at subsequent 10 minute intervals using a dosage of 10 mg/kg (Weisbroth, 1972).

Impression Technique

Under general anesthesia, the animals were positioned in supine posture with all four extremities extended and fixed on the surgical table. Prior to the taking of impressions, rabbit skulls at corresponding ages were used to fabricate custom trays. Suture retractors were placed in the lower lip and the tongue together with stabilization of the maxillary incisors to allow for maximal oral opening of the rabbit and vision by the operator. Excess accelerator was added to the silicone impression material to facilitate setting time of the impression for later preparation of maxillary and mandibular casts.

Appliance Design

The appliances were constructed using specifications determined from several trial prototypes. In order to ensure rigidity and stability, 0.50" stainless steel wire was used. A framework bent in the shape of an "U" was first prepared. A set screw was incorporated into a horizontal, palatal bar placed on

the frame. This design allowed for lateral adjustment of the appliance during the course of the experiment.

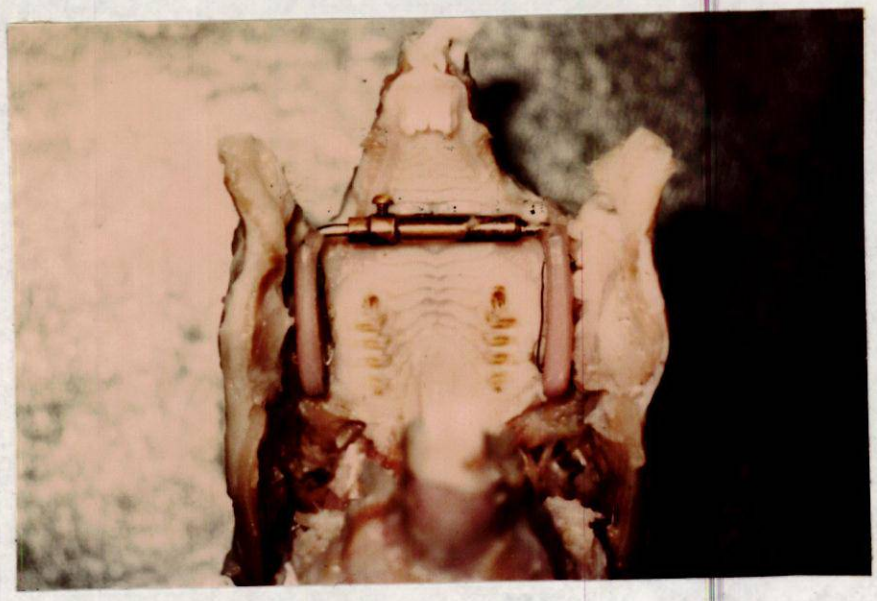
The right and left anteroposterior sections were used as a framework onto which acrylic shields were fabricated. The vestibular shields were designed to extend the entire length of the buccal dentition and had a vertical dimension which would screen both the maxillary and mandibular buccal teeth from the cheek mucosa and musculature. Attachment holes were placed anteriorly and posteriorly to allow passage of 0.010" dead soft ligature wire. The ligature wire allowed the appliance to be suspended intraorally using circumzygomatic fixation.

Appliance Placement

At time of appliance placement, the animals were anesthetized and stabilized, and the mandible and tongue were sutured. To allow for circumzygomatic fixation two incisions were made, one along each zygomatic crest. A cannula was inserted medial to the zygomatic bone and positioned in the region of the humular notch intraorally. This procedure was performed bilaterally. The ligatures were subsequently passed through the attachment holes of the vestibular screens. Fixation was completed with the passing of the ligatures lateral to the zygoma from the anterior attachment hole. The free ends were twisted, cut and positioned to allow closure of the circumzygomatic incision (Plate II).

PLATE II

Appliance design and placement



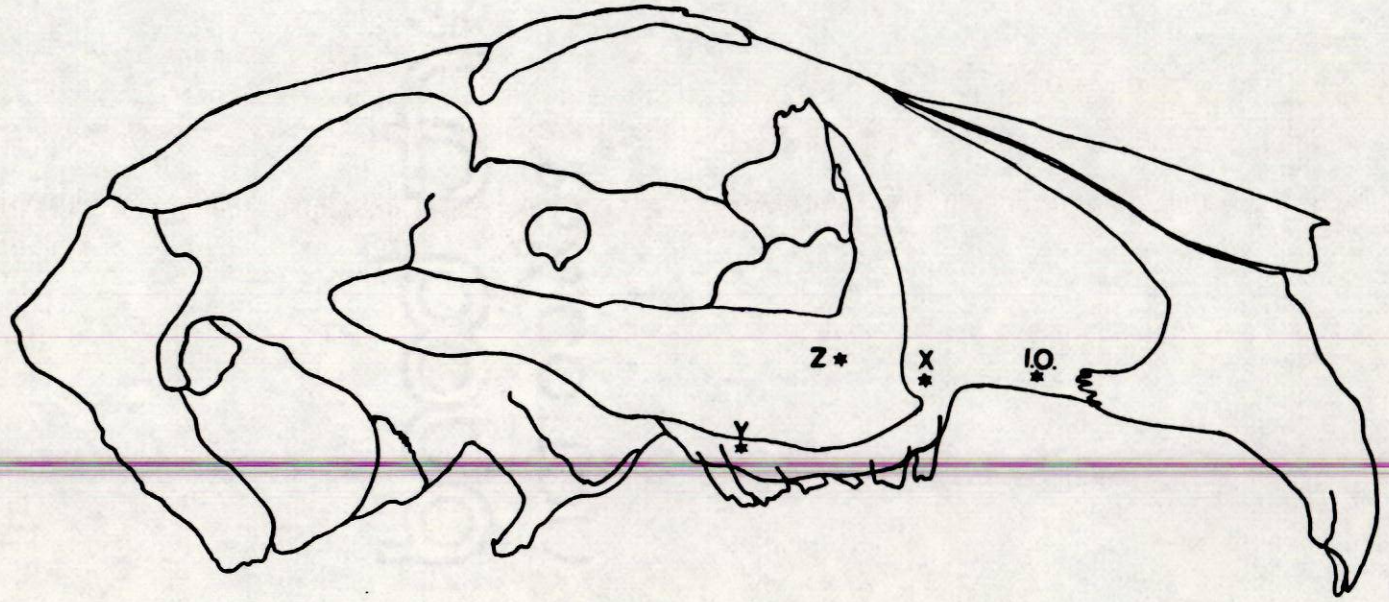
The transverse dimension of the appliance was determined at the time of placement. Initial impressions were taken concurrently, and the distance from right to left mucobuccal folds in each animal determined the extent of transverse adjustment needed. The appliances were adjusted laterally to a position 3-5 millimeters away from the buccal surfaces of the posterior dentition.

Anesthesia and identical surgical manipulation were performed on the control animals. In addition, ligatures were positioned circumzygomatically to simulate insertion of the fixation apparatus. Only the appliance itself was deleted from the control animal procedure.

Implants

The use of intraosseous metallic markers makes possible accurate radiologic measurements of increases in width in those areas of the maxilla where no well defined natural reference points exist. In the present study a total of eight tantalum implants, 1.5 mm. long and 0.5 mm. in diameter were placed in the maxilla (Figure 1). The anterior-most implants were inserted using an intraoral approach, and the zygomatic and alveolar implants were placed by an extraoral approach. An incision along the zygomatic crest was made to allow the tip of the implant instrument to directly contact the periosteum, thus enhancing stable insertion of each pin.

Figure 1. Implant Location


Z
X
10.
Y

Placement of the lateral maxillary corpus implants was performed to compare the extent of midpalatal sutural growth with the extent of periosteal alveolar remodeling (Björk, 1966) in the region of the maxilla directly associated with the appliance.

Vital Dyes

In vivo administration of vital dyes was utilized to permit identification of specific areas involving sutural bone growth and remodeling activity, and to provide histologic markers so that regional extents of bone deposition could be measured. Three vital dyes were administered to each animal:

1. tetracycline (Terramycin, Pfizer, Inc., New York, N.Y.);
2. alizarin (Alizarin Complexon, Eastman Kodak Company, Rochester, New York);
3. amino-methyl fluorescein (DCAF, ICN Pharmaceuticals, Cleveland, Ohio).

The vital dyes used, dosage and routes of administration are outlined in Table II.

Growth Retardation Resulting from Appliance Insertion

Pilot study trials revealed a definite trend regarding the degree of general body growth and development of the rabbits subsequent to appliance insertion. These animals did not eat as aggressively as pilot controls, and growth retardation resulted. Because of this circumstance long bone correlative growth deter-

TABLE II

VITAL DYE DOSAGE AND ROUTE OF ADMINISTRATION

Vital Dye	Dosage mg/kg	Route of Administration
Terramycin	50	Intramuscular
Alizarin Complexon	30	Intraperitoneal
DCAF	15	Intraperitoneal

minations were made in order to quantify the extent of disproportionate skeletal growth. Previous studies of rabbit long bones (Lowrance, 1953; Heikl, 1959) provided a reference which allowed comparative analysis of the body growth status of experimental and control animals.

Radiographs of the right tibia in each animal were made using the same target-film distance utilized for the serial dorsoventral skull series. Tibia length was measured as the maximum distance from the proximal to the distal epiphyseal edges. Measurements were recorded to the nearest 0.5 millimeter.

Post-Operative Course

The diet consisted of a commercial feed (Purina Rabbit Chow) and water ad libitum. Both the experimental and control groups were fed the same diet. The animals were housed two or three per cage in a room having thermostatically controlled temperature at 69°±1° F.

The experimental group did not eat as vigorously as the control group, and this can be attributed to intraoral interference produced by the appliance. Other than feeding, no adverse complications involving tissue trauma or orofacial functions arose due to appliance placement. Visual inspection confirmed an altered positioning of the orofacial muscular drape for the experimental group due to the appliance.

Experimental Timetable

The animals were received one week prior to the start of experimentation. Three days before the start, the implants were placed and the placement stability was verified by dorsoventral headfilms 48 hours later.

Appliance construction was completed prior to commencing the experiment. The animals were all started on the same day, and the procedures performed were coordinated to minimize the duration of narcosis. Following anesthesia, the animals were initially weighed, positioned on the surgical table, the maxillary and mandibular impressions obtained, and the appliances then adjusted to individualize the transverse dimensions of the buccal shields using each maxillary impression as a respective template.

Appliance insertion immediately followed the impression procedure. Vital dye administration was then performed. Terramycin was the first dye to be administered. The animal was then transferred to the cephalostat. Definitive headfilm exposures preceded the tibial recordings.

Each animal was weighed at three day intervals without anesthesia. At 16 days intermediate records were obtained. Roentgenograms, both skull and tibiae, were taken and the second vital dye administered using the current weight for dosage determination. The final dye was administered at 31 days, four days before the termination of the experiment.

Final Data Collection

The animals were killed at 35 days by anesthesia followed by Nembutal. Cardiac perfusion was then performed, with thoracic entrance gained by cutting the ribs bilaterally and raising the excised parts. Incision of the pericardium exposed the heart, and the left ventricle was cannulated through to the aorta. Concurrent rupture of the right atrium was performed to allow blood removal as the 10% buffered formalin solution filled the systemic vessels. The pressure was maintained at 120 mm. Hg using a sphygmomanometer until perfusion was completed.

The animal was then decapitated and the skin removed from the head. Specimens were submerged in 10% buffered formalin. The right tibiae were dissected and placed in the same fixative. Final radiographs were subsequently obtained. The mandibles were dissected free to facilitate the impression procedure.

Gross Observations

The initial effects of appliance insertion were noted during the experimental period. A gross comparison between control and experimental animal facial form and outline was made and evaluated. Similarily, the initial and final dental casts were examined to determine alterations in arch form, arch height, palatal vault depth and symmetry. Gross observation of each animal head was made and recorded at time of animal sacrifice.

Cephalograms

The radiographs obtained for each animal were enlarged 3X to reduce tracing error. Tracings were done on 0.003" acetate using an England Eagle Turquoise 10 pencil with 1 H drawing leads.

Cephalometric Landmarks

The enlarged radiographs were traced (Figure 2) and the following landmarks were identified to aid in the analysis (Figure 3):

1. the most posterior aspect of the skull at the external occipital protuberance in the midline (0);
2. the most posterior aspect of foramen magnum in the midline (FMP);
3. the most anterior aspect of foramen magnum in the midline (FMA);
4. the most anterior aspect of the right and left tympanic bullae (TB and TB');
5. the intersection of the shadows of the zygomatic process of the squamosal bone and the zygomatic bone bilaterally (TZ and TZ');
6. the most medial aspect of the hamular notch lateral to the origin of the pterygoid plates (HN and HN');
7. the most anterior aspect of the zygomatic process of the maxilla in the temporal fossa (TF and TF');
8. the posterior maxillary corpus implants (x' and x");
9. the anterior maxillary corpus implants (y' and y"):
10. the implants inserted into the zygomatic process of the maxilla (z' and z");

Figure 2. Rabbit: Dorso-ventral view

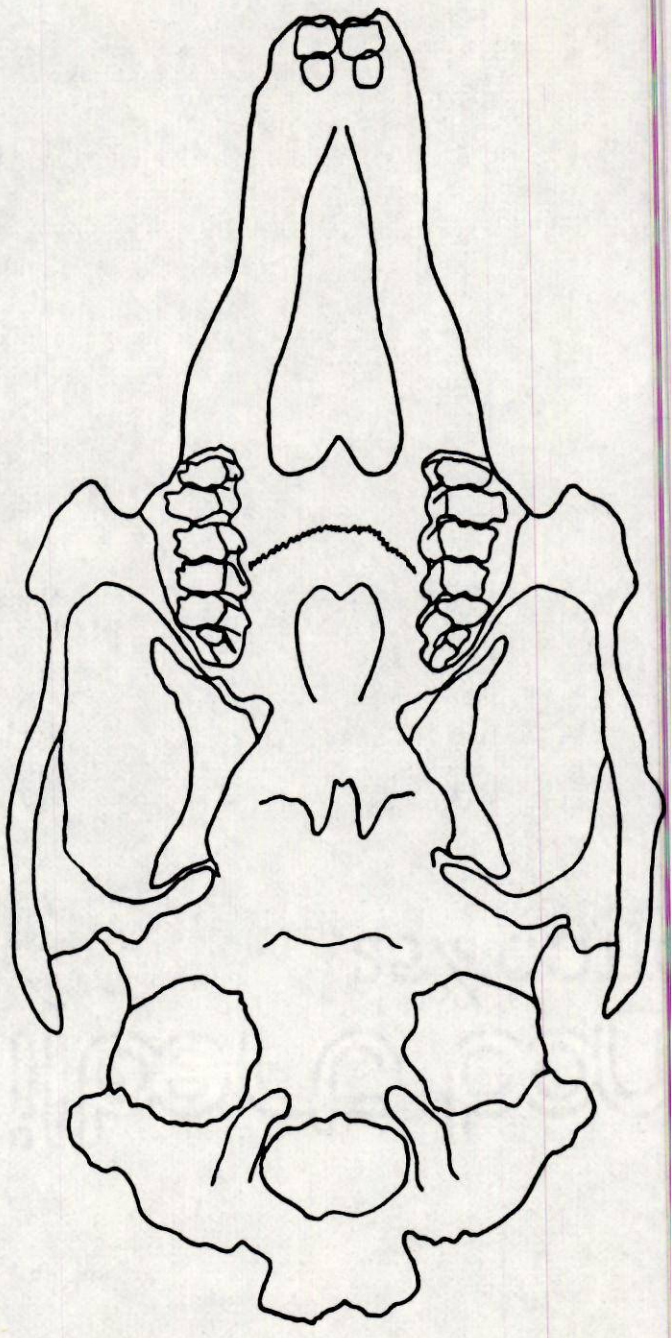
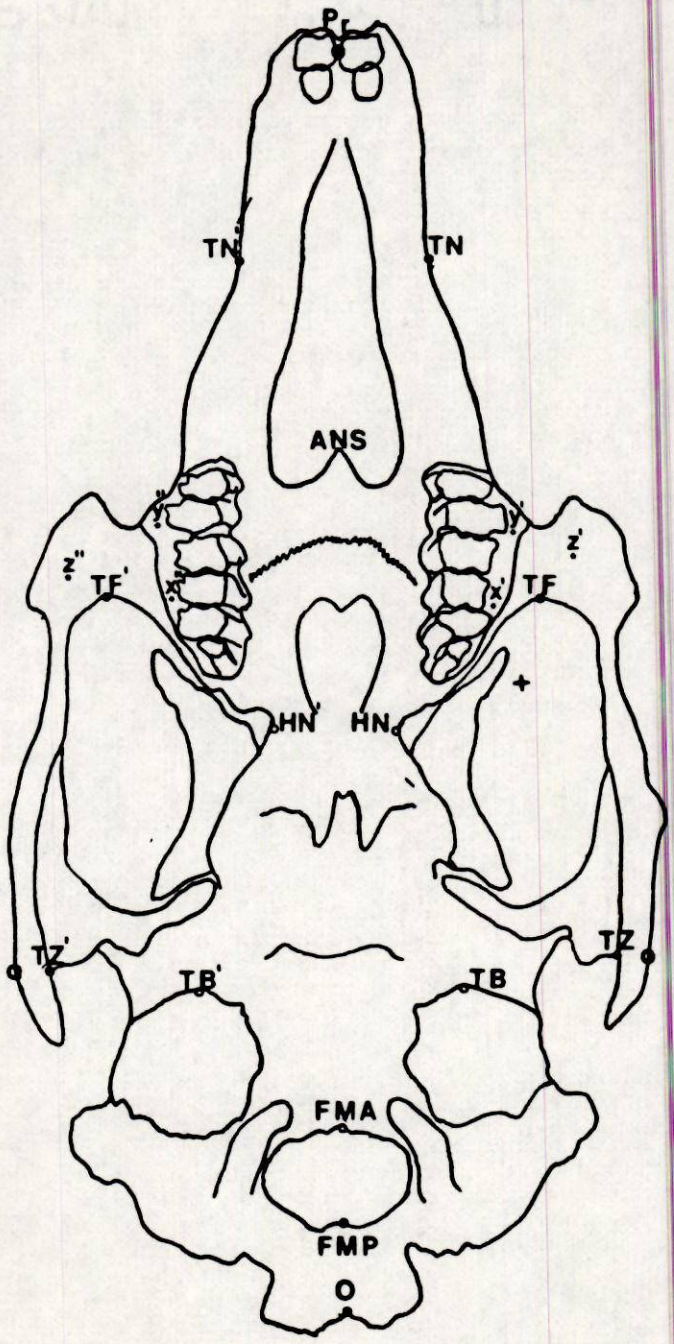


Figure 3. Cephalometric Landmarks


Pr
TN'
TN
ANS
z''
TF'
z'
TF
HN'
HN
TZ'
TZ
TB'
TB
FMA
FMP
O

11. the most anterior point of the palatal processes of the maxillae (ANS);

12. the lateral aspects of the maxilla one-half the distance between the point ANS and the point Pr (TN and TN');

13. the contact point between the right and left central incisors (Pr).

Cephalometric Analysis

To facilitate direct measurement unilaterally and bilaterally and to serve as a reference a midpalatal line from point Pr through points FMP and FMA to point O was first constructed. Subsequent measurements were made to line Pr-O and perpendicular to it.

A total of 11 measurements were recorded to characterize the size and position of the cranium and facial complex. The implant measurements were unilateral, and they were only recorded for those implants that remained stable throughout the experimental period (Figure 4). The construction lines for the other points were bilateral (Figure 5). The various measures are listed in Table III.

Measurements were taken to the nearest 0.05 millimeter with dial vernier calipers (Helios Calipers, DCA Corporation, Washington, D.C.). Calculations were performed on an electronic calculator (Model T1-50, Texas Instruments, Inc., Dallas, Texas).

Figure 4. Cephalometric Analysis: Implant Lines

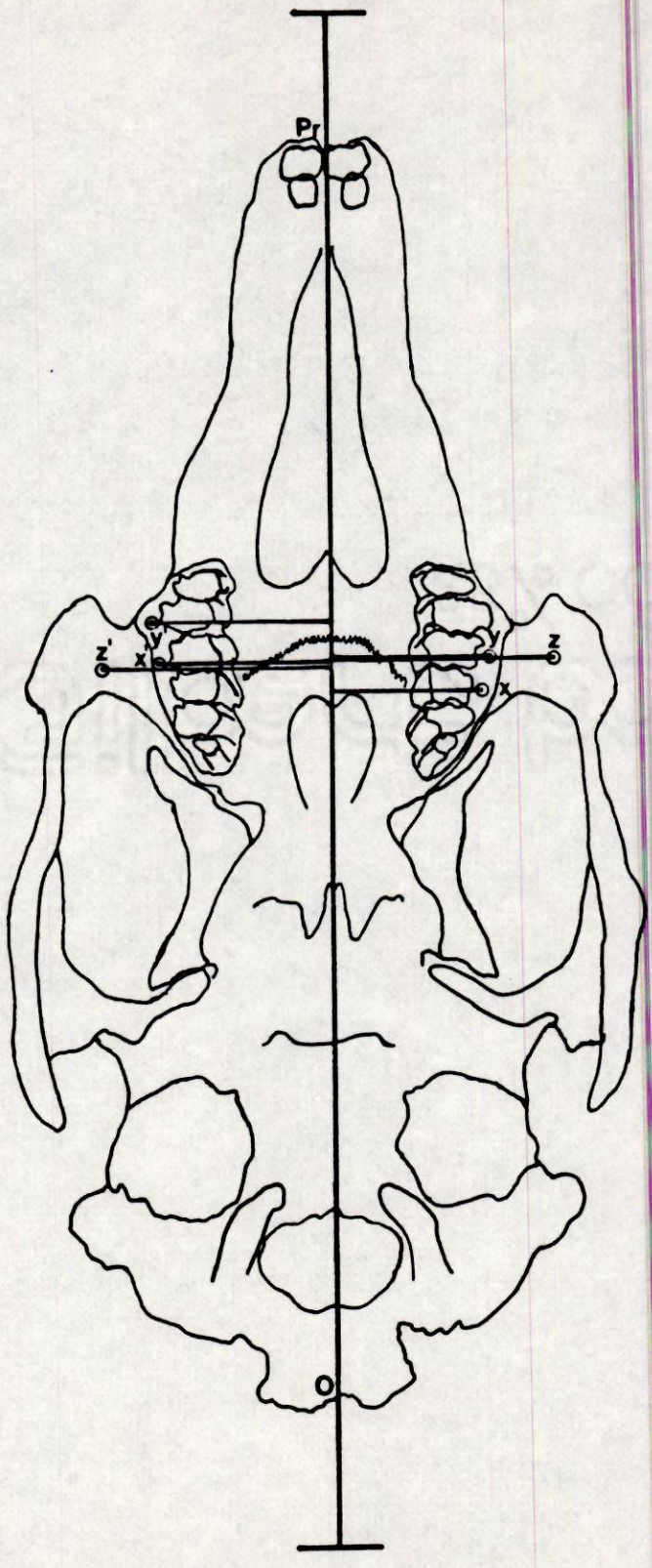

Pr
Z'
X'
Y'
Y
Z
X
O

Figure 5. Cephalometric Analysis: Anatomical Measures

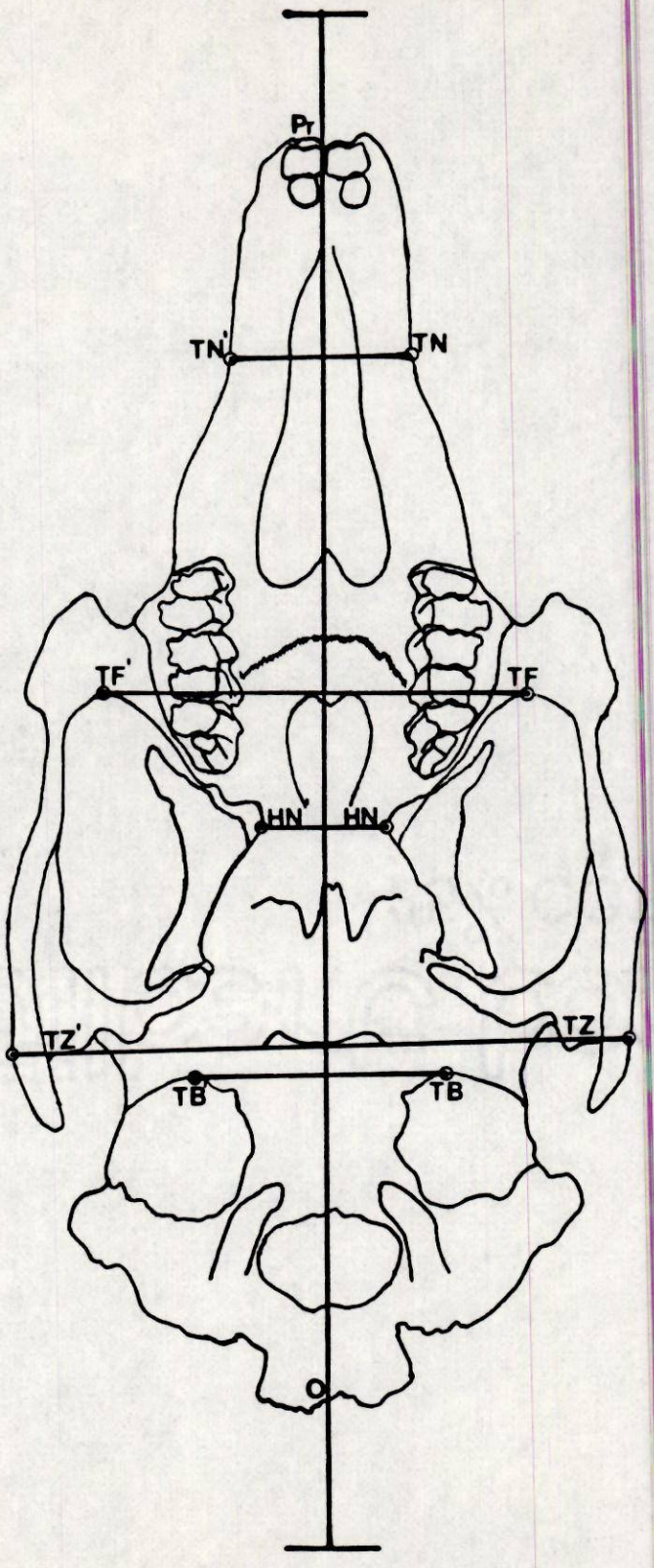

Pr
TN'
TN
TF'
TF
HN'
HN
TZ'
TZ
TB
TB
O

TABLE III

CEPHALOMETRIC ANALYSIS

	Measure	Landmarks Employed
I.	Transverse cranial base development	TB - TB'
II.	Bizygomatic width	TZ - TZ'
III.	Posterior maxillary width	HN - HN'
IV.	Mid-maxillary width	TF - TF'
V.	Anterior maxillary width	TN - TN'
VI.	Transverse maxillary	x' - Pr·O
VII.	development posteriorly	x" - PR·O
VIII.	Transverse maxillary	y' - Pr·O
IX.	development anteriorly	y" - Pr·O
X.	Transverse maxillary	z' - Pr·O
XI.	development	z" - Pr·O

Model Analysis

Increases in the width of the dental arches were measured on the dental casts. Measurements were taken between all premolars and molars that were erupted at the start of the experiment and recorded as the greatest distance between buccal surfaces at the gingival level. Values were obtained on two different occasions with the average of these values recorded.

Histological Evaluation

The animals were divided into two groups, each having a representative number of experimental and control individuals. Decalcified coronal sections, 8-10 microns in thickness, were made on three of the animals and stained with hematoxylin and eosin.

The remaining skulls were prepared for ground sectioning so that vital dye markers could be evaluated. Block sections of the maxillary midpalatal suture region and the right and left premolar and molar region, including the buccal and lingual cortical plates were embedded in Bioplastic (Wards, Inc., Rochester, New York). The blocks were then thin-sectioned in the coronal plane to a thickness of 100-125 microns and examined under a fluorescence microscope using an ultraviolet light source.

Data Reduction

In order to detect possible significant differences between control and treatment groups the student's t-test was used to compare group mean changes.

Uncontrolled environmental conditions, such as the differences in skeletal growth and weight gain as a result of variations in food intake, may affect estimates of treatment results. Due to highly significant differences in skeletal growth and weight gain, an adjustment factor, R, was incorporated in the calculation of mean values for treatment and control groups. The adjustment factor, R, was obtained by formulating a ratio between treatment and control group mean final tibial length.

The formula for the calculation of the t-value is given by:

$$t = \frac{\bar{X}_{ic} - \bar{X}_{ie}}{S\sqrt{\frac{1}{n_c} + \frac{1}{n_e}}}, \text{ where}$$

$\bar{X}_{ic}$ = the mean change for the control group variable,

$\bar{X}_{ie}$ = the mean change for the treatment group variable,

n_c = the number of measurements for the control group,

n_e = the number of measurements for the treatment group,

S is the pooled variance = $\sqrt{\frac{S_1^2 (n_c-1) + S_2^2 (n_e-1)}{n_c + n_e - 2}}$

d.f. = $n_c + n_e - 2$.

$$R = \frac{\bar{X}_{ct}}{\bar{X}_{et}} \text{ where,}$$

$\bar{X}_{ct}$ = control group mean final tibial length,

$\bar{X}_{et}$ = treatment group mean final tibial length.

RESULTS

The results of the present study are presented under the following headings: weight gain, dental cast examination and analysis, cephalometric evaluation, and histological analysis.

Weight Gain

The final weight values were markedly different between treatment and control groups (Table IV). At the termination of the experiment the two groups did show statistically significant ($p < .01$) difference in weight as determined by the t-test. Similarly, the computed weight gain per day for the control group was much greater than for the treatment animals (Table V).

Dental Cast Examination and Analysis

Visual observation of initial and final casts revealed varying degrees of change for both treatment and control groups. The characteristic biconcave shape of the buccal segments of the maxillary dental arch was altered in the treatment group. Final dental casts of this group demonstrated a straight and parallel arrangement between the posterior teeth. No asymmetries were noted in either group.

Transverse dental measurements, recorded on initial and final casts, did demonstrate arch dimension differences between

TABLE IV

INITIAL AND FINAL WEIGHT DATA
(in grams)

Rabbit	Initial Weight	$\bar{X}$	S.D.	Final Weight	$\bar{X}$	S.D.
8[e]	723			918		
9[e]	607			681		
10[e]	616	666.4	47.9	820	857.0*	106.4
12[e]	673			866		
4[e]	713			1000		
11[c]	588			1600		
13[c]	596	741.0	210.7	1858	1752.0*	110.2
3[c]	1039			1798		

* Significant difference at $p<.01$.

e Experimental group.

c Control group.

TABLE V

AVERAGE WEIGHT GAIN PER DAY
(in grams)

Rabbit	Weight Gain	$\bar{X}$	S.D.
8[e]	5.6		
9[e]	2.1		
10[e]	5.8	5.44	1.95
12[e]	5.5		
4[e]	8.2		
11[c]	28.9		
13[c]	36.1	28.90	5.88
3[c]	21.7		

e Experimental group.

c Control group.

groups. Changes in maxillary transverse dimension for the controls were all positive. The treatment group did not experience a uniform increase in width between teeth. Arch increases were smaller than those recorded for controls in areas that did increase but actual reductions in dental arch width were recorded for the third premolar, first molar and the second molar for all subjects in the treatment group except animal four (Tables VI and VII).

Width increase for the treatment group was greatest in the region of the maxillary first premolar teeth. The calculated changes in transverse arch dimension demonstrate maximum positive changes in the region where the appliance was most rigid bilaterally and least susceptible to flexion medially due to muscular forces.

The results of the t-test are presented in Table VIII. Mean changes in transverse arch dimension for the maxillary first premolar and the maxillary second premolar exhibit no significant difference at $p<.05$. Significant differences ($p<.01$) were noted for the maxillary third premolar and the maxillary first and second molar teeth. The adjustment factor, R, was incorporated in the calculations of the test statistic for all variables considered in the dental cast analysis.

Tibial and Cephalometric Evaluations

Direct linear measurements were performed on the tibial

TABLE VI

CHANGES IN MAXILLARY DENTAL ARCH TRANSVERSE DIMENSION FOR THE MAXILLARY FIRST AND SECOND PREMOLARS

Rabbit	Tooth					
	MP_1	$\bar{X}$	S.D.	MP_2	$\bar{X}$	S.D.
8[e]	+2.80			+1.42		
9[e]	+2.44			+1.71		
10[e]	+3.18	+2.47	0.37	+1.53	+1.46	0.41
12[e]	+1.38			+0.72		
4[e]	+2.56			+1.94		
11[c]	+3.10			+4.25		
13[c]	+3.11	+2.55	0.62	+3.72	+3.11	1.26
3[c]	+1.45			+1.35		

e Experimental Group

c Control Group

TABLE VII

CHANGES IN MAXILLARY DENTAL ARCH TRANSVERSE DIMENSION FOR THE MAXILLARY THIRD PREMOLAR AND THE MAXILLARY FIRST AND SECOND MOLARS

Rabbit	Tooth								
	MP_3	$\bar{X}$	S.D.	MM_1	$\bar{X}$	S.D.	MM_2	$\bar{X}$	S.D.
8^e	-0.78			-0.98			-0.19		
9^e	-0.25			-0.87			-0.15		
10^e	-0.04	-0.11	0.47	-0.26	-0.33	0.62	-0.38	-0.16	0.57
12^e	-0.16			-0.32			-0.92		
4^e	+0.68			+0.76			+0.85		
11^c	+3.64			+3.59			+3.68		
13^c	+2.57	+2.60	0.83	+3.26	+3.11	0.63	+3.81	+3.21	0.76
3^c	+1.60			+1.89			+2.13		

e Experimental Group

c Control Group

TABLE VIII

STATISTICAL ANALYSIS: TRANSVERSE DENTAL CHANGES

t-test

Measure	Control			Experimental			t
	Sum of Squares	Variance	n_c	Sum of Squares	Variance	n_e	
MP_1	1.83	0.91	3	2.50	0.63	5	-0.60
MP_2	12.70	4.23	3	1.07	0.21	5	+0.97
MP_3*	2.08	1.04	3	1.09	0.22	5	+5.11
MM_1*	1.74	0.87	3	4.85	0.97	5	+4.47
MM_2*	1.75	0.58	3	1.95	0.39	5	+12.10

* Significant difference at $p<.01$.

radiographs obtained at the start of the experiment and the conclusion of the experimental period. The adjustment factor, R, was obtained by formulating a ratio between treatment and control group mean final tibial lengths. The tibial measurements are listed in Table IX. Statistical evaluation of the mean changes in tibial length between treatment and control groups proved significantly different at $p < .01$ (Table XI).

The implant measurements were designated X, Y and Z according to implant location, with X inserted into the maxillary corpus superior to the roots of the maxillary molars, Y inserted superior to the root of the maxillary first premolar and the Z implants placed into the zygomatic process of the maxilla. Measurements for right and left implants were summed (x' + x"; y' + y"; z' + z") to obtain a measure of total transverse dimension change. Mean changes for the grouped implant changes (X, Y, Z) and the anatomical measurements are presented in Table X. The implants placed in the anterior maxilla were not used due to implant movement.

The results of the t-tests are presented in Table XI. Implant measurements for X, Y and Z failed to show significant differences at the $p < .05$ level. Similarly, measures for the cranial base (TB-TB'), the bizygomatic width (TZ-TZ'), and the temporal fossa (TF-TF') could not be shown to be significantly different at the $p < .05$ level. The data for growth changes in transverse snout width (TN-TN') did prove to be significantly different

TABLE IX

TIBIAL GROWTH

(in millimeters)

Animal	Initial	$\bar{X}_i$	S.D.	Final	$\bar{X}_f$	S.D.	Change	$\bar{X}$	S.D.
8	59.5			73.5			14.0		
9	55.0			65.0			10.0		
10	56.0	57.2	2.11	71.0	69.6	4.09	15.0	13.4	1.74
12	55.5			64.5			14.0		
4	60.0			74.0			14.0		
11	53.0			77.5			24.5		
13	56.0	56.6	5.19	83.5	83.3	4.69	27.5	25.7	1.31
3	64.0			89.0			25.0		

$$R = \frac{\bar{X}_{ct}}{\bar{X}_{et}} = 1.19$$

TABLE X

MEAN CHANGES: RADIOGRAPHIC AND CEPHALOMETRIC VARIABLES

(in millimeters)

Measure	Animal Group		
	$\bar{X}$ Control	$\bar{X}$ Experimental	
		$\bar{X}_e$	$\bar{X}_e$ (R)
Tibial length	25.70	13.40	15.80
TB - TB'	8.44	3.83	4.56
TZ - TZ'	17.73	9.06	10.78
HN - HN'	0.27	4.90	5.83
TF - TF'	13.06	10.07	11.98
TN - TN'	6.33	1.66	1.98
X	4.63	2.88	3.43
Y	4.59	3.71	4.41
Z	5.05	3.91	4.65

TABLE XI

STATISTICAL ANALYSIS: TIBIAL AND CEPHALOMETRIC MEASUREMENTS (in millimeters)

Measure	t-test						
	Control			Experimental			
	Sum of Squares	Variance	n_c	Sum of Squares	Variance	n_e	t
Tibial length*	5.20	2.6	3	15.40	7.70	5	9.04
TB - TB'	23.40	11.70	3	24.77	6.19	5	1.89
TZ - TZ'	32.43	16.41	3	107.34	26.84	5	1.99
HN - HN**	0.15	0.08	3	35.18	8.79	5	-3.11
TF - TF	15.62	7.81	3	39.53	9.88	5	1.35
TN - TN'*	10.44	5.22	3	1.78	0.45	5	6.15
X	10.54	2.10	6	47.00	5.22	10	1.15
Y	5.77	1.44	5	29.86	4.27	8	0.69
Z	3.74	0.75	6	23.18	2.90	9	0.57

* Significant at $p<0.01$

** Significant at $p<0.05$

($p<.01$). Similarly, the interhamular notch measure (HN-HN') was significantly different ($p<.05$). This latter finding was the only measured variable which demonstrated greater growth change in the treatment group. All other variables tested were greater for the control group.

Fluorescent Microscopy

Ground, serial coronal thin-sections were prepared for both the control and treatment groups. Under ultraviolet light all three vital dyes were readily apparent for the control group sections, but examination of treatment group preparations only revealed the uptake of tetracycline and calcein green. The alizarin marker was not visible for the treatment group, but recognition of endosteal and periosteal bone remodeling activity was still possible because the initial and final dyes were readily identifiable. Examination of the prepared sections revealed no marked differences between treatment and control groups. The patterns of osseous remodeling and sutural growth activity were essentially identical in location, and quantitative differences could not be discerned.

For both groups, the remodeling pattern on the buccal surfaces of the alveolus remained constant anteroposteriorly and was uniformly depository in nature. A reversal line marking a conversion to endosteal deposition and periosteal resorption was

present at the apex of the osseous vestibular fold area and was evident throughout the length of the dentition. The alveolar crest, both bucally and lingually, demonstrated active deposition. Due to the very thin nature of the cortical plate, quantification of incremental osseous accretion was not feasible. Markers indicating active osteogenic activity were evident in the cortical bone forming the tooth sockets but remodeling patterns indicating dental buccolingual drift were not seen in any of the sections examined.

The osseous palate of the rabbit is composed of paired maxillary palatal processes and the horizontal processes of the palatine bone. The midpalatal suture is only present in that portion of the hard palate comprised of the paired maxillary palatal processes, and this suture extends posteriorly to the mesial of the maxillary third premolar. Posterior to this area the palate is divided by bilateral maxillopalatine sutures which are located at the junction of the horizontal and vertical walls of the palatal vault.

Serial sections of the hard palate in the region of the midpalatal suture demonstrated active periosteal deposition on the palate and the nasal floor for both groups. The distances between markers on the palate were relatively equal but an increased activity was apparent at the junction of the vertical and horizontal walls of the palatal vault. The sutural osteogenic

activity was uniform bilaterally and vertically in both treatment and control sections.

Coronal sections through the third premolar and first molar revealed a different remodeling pattern than for the area of the first and second premolars. Identical changes were found for the two groups. The palate maintained the same pattern and was depository, but remodeling reversals were evident on the nasal floor along the midsagittal plane. This region was resorptive as evidenced by lack of calcein green uptake. Laterally this pattern was reversed and active periosteal deposition was evident. The maxillopalatal suture behaved quite differently than the midpalatal suture. Examination revealed more active sutural growth activity on the medial sutural margin indicating different rates of sutural growth between the palatine bone and the maxilla in this area. This pattern of remodeling was the same for all coronal sections through the maxillary third premolar area of both the control and treatment group specimens.

In the region of the first and second molars the pattern of activity in the maxillopalatal suture remained constant. The resorptive nature of the nasal floor became more pronounced laterally although depository surfaces were seen on the extreme lateral boundaries of this region. Active periosteal deposition was still present in the midline of the hard palate, but the pattern of remodeling lateral to the midline indicates a marked reversal of

activity. Between the median palatal zone of periosteal deposition and the depository lingual alveolar cortical plate a zone of periosteal resorption was found.

Figures 6, 7 and 8 represent a diagrammatic mapping of the remodeling activity of the maxilla. Figure 6 characterizes the local growth processes active in the region of the maxillary first and second premolars. The pattern of remodeling activity for the third premolar area is presented in Figure 7 and for the first molar area in Figure 8.

Light Microscopy

Serial, coronal, decalcified and stained sections spanning the length of the maxilla were taken from tissue blocks and examined under a light microscope. Examination revealed a similar pattern of histologic anatomy for both groups. The sutures of both groups were patent and no areas of pathology or hyalinization were evident for either series. The periodontal membrane appeared normal in both groups coronally but the connective tissue pattern changed radically in the apical zone. The parallel arrangement of the fibers became more diffuse and irregular in the region of the crypt.

For both the control and the treatment group sections, lamellar bone deposition was evident in those areas described as depository in the previous section. In those zones undergoing

Figure 6. Frontal view: local growth processes in the maxilla in the region of the maxillary first and second premolars. Arrows indicate directions of bone remodeling. Arrows pointing away from bone surfaces denote areas of bone deposition; arrows pointing into bone surfaces represent areas of periosteal bone deposition. The (+) signify active bone deposition on sutural surfaces. 1) Buccal alveolar wall; 2) Osseous vestibular apex; 3) Palate; 4) Lingual alveolar wall; 5) Nasal floor (medial); 6) Nasal floor (lateral); 7) Midpalatal suture.

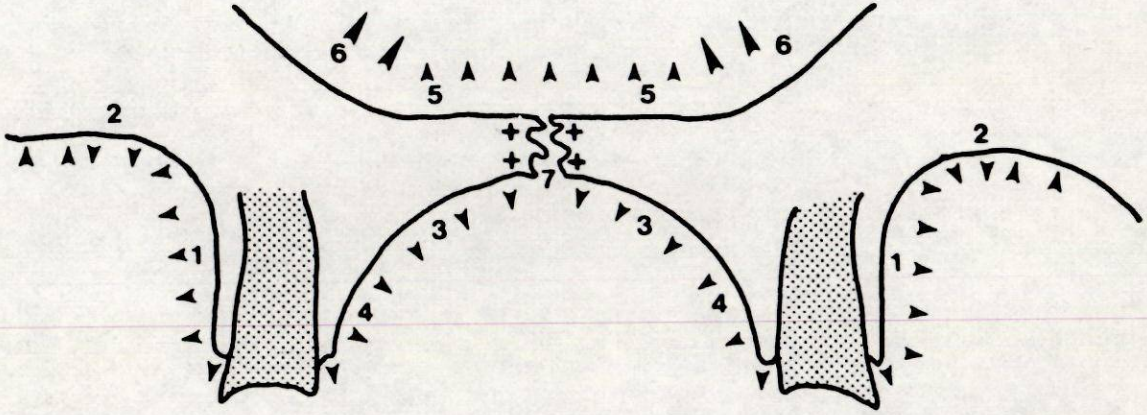

6
6
5
5
2
2
1
1
3
3
4
4
7

Figure 7. Frontal view: local growth processes in the maxillary and palatine bones in the region of the maxillary third premolar. Arrows indicate directions of bone remodeling. Arrows pointing away from bone surfaces denote areas of bone deposition; arrows pointing into bone surfaces represent areas of periosteal bone resorption. The (+) signify active bone deposition on sutural surfaces. 1) Buccal alveolar wall; 2) Osseous vestibular apex; 3) Palate; 4) Lingual alveolar wall; 5) Nasal floor (medial); 6) Nasal floor (lateral); 7) Palatomaxillary suture(s).

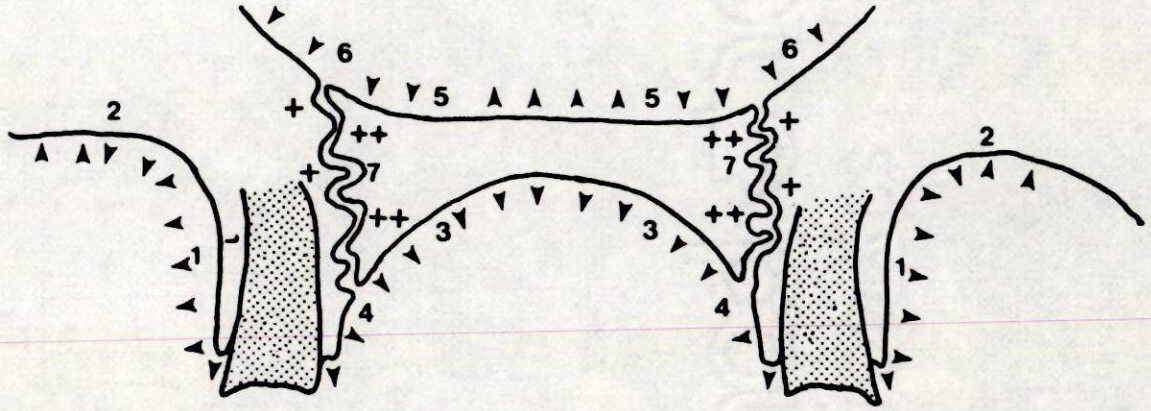
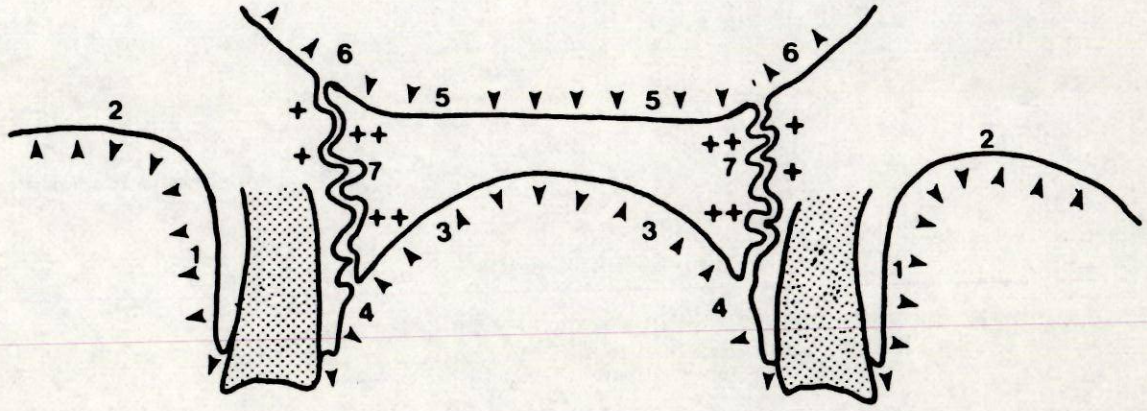

6
5
5
6
2
2
1
1
7
7
3
3
4
4
+
+
+
+
+
+
+
+

Figure 8. Frontal view: local growth processes in the maxillary and palatine bones in the region of the maxillary first molar. Arrows indicate directions of bone remodeling. Arrows pointing away from bone surfaces denote areas of bone deposition; arrows pointing into bone surfaces represent areas of periosteal bone resorption. The (+) signify active bone deposition on sutural surfaces. 1) Buccal alveolar wall; 2) Osseous vestibular apex; 3) Palate; 4) Lingual alveolar wall; 5) Nasal floor (medial); 6) Nasal floor (lateral; 7) Patatomaxillary suture(s).


6
5
5
6
2
2
7
7
3
3
1
1
4
4

active bone resorption multinucleated cells were present, and conversely, dark staining osteoblasts were identified in zones of osteogenic activity.

DISCUSSION

The objective of the investigation was to assess the effect of vestibular shields on the transverse growth of the maxilla using the New Zealand white rabbit. The shields were placed in order to eliminate contact between the cheeks and the lateral aspects of the maxilla, and to induce tension in the region of the mucobuccal fold. The transverse growth and development of the maxilla was then studied both macroscopically and microscopically and compared with control groups. This approach was intended to provide for a descriptive analysis of possible differences in remodeling changes.

Animal age at the commencement of the experiment was either 35 or 45 days. This age range in the rabbit is said to parallel the skeletal maturation timing for six to seven year old humans (Heikl, 1959). The experimental time of 35 days is presumably equivalent to a period of three to four years in the human, thus corresponding to the human mixed dentition phase of development, which has been suggested as the most opportune time to implement functional therapy utilizing vestibular shields (Frankel, 1966). During this time period the maxilla is actively involved in remodeling growth (Enlow, 1975), and sutural growth activity is very patent (Björk and Skieller, 1976). In addition,

the succadaneous teeth are physiologically spreading from their original crowded position at this time and it has been suggested that the vestibular shields can intercept restraining forces of the perioral musculature and allow the teeth to maximize their role as agents of the functional matrix contributing to the growth control of the alveolar processes (Frankel, 1971).

The method of appliance fixation was designed to most closely simulate the clinical application of vestibular shields. Circumzygomatic ligation of the appliance served to eliminate potential growth interferences which would result if the teeth or the maxilla were used to support the shields in place. Similarly, it was decided to maintain 24 hour per day appliance insertion in order to maximize the soft tissue functional alteration during the period of rapid skeletal growth. However, resultant tibial length and weight data suggested that significant nutritional impairment occurred, most probably due to poor masticatory function. The two groups were significantly different in comparative skeletal growth and weight gain. Ghafari and Shanfeld (1981) reported similar growth impairment using a rat model. It is suggested that there is a direct cause-effect relationship betweem full-time appliance wear and generalized skeletal growth retardation when using laboratory animals. In this experiment, the treatment group did not eat as vigorously.

Dental cast examination demonstrated an alteration of the characteristic biconcave shape of the rabbit maxillary arch in the treatment group as viewed in the horizontal plane. It has been previously demonstrated in humans that vestibular shield therapy affects the dimensions and configurations of dental arches (Frankel, 1971, 1974; Eirew, 1969; Pac, 1970). In the present study, the posterior teeth of the treatment group, viewed in the horizontal plane, assumed a straight and parallel arrangement. A positive increase in transverse dental arch dimension was recorded for all animals in the region of the maxillary first and second premolars and mean changes between the two groups were not statistically significant. In the treatment group, actual reduction in transverse dental arch dimension was exhibited in the maxillary third premolar and molar regions and these changes were significantly different when compared to the control group which had uniformly positive gains in transverse arch dimension in these regions. Ghafari and Shanfeld (1981) reported significant increases in transverse arch dimension following 15 days of vestibular shield wear in the rat, but noted, however, that these differences did decrease with time. Importantly, they did note maxillary arch expansion as early as five days after appliance insertion. Organ (1979), however, failed to demonstrate increases in transverse arch dimension using a primate model.

In the present experiment, appliance design can be directly related to the reductions in transverse arch dimension posteriorly. Bilateral stability of the shields was greatest in the anterior region where the connecting palatal bar was placed. Reductions in posterior dental transverse dimension may have been caused by a compressive effect of the buccal soft tissues on the posterior, free ends of the shields.

The cephalometric part of the present study revealed non-significant growth changes between treatment and control groups in those areas of the maxilla directly associated with the appliance. Similar results were noted for measures which reflect cranial base and bizygomatic width change. However, significant differences were noted for snout width, which reflected the extent of maxillary transverse growth anterior to appliance placement. Thus, the severe growth retardation experienced by the treatment group did not affect maxillary growth uniformly. The data suggest that those areas of the maxilla directly associated with appliance location grew more normally than maxillary structures anterior to appliance placement. Transverse skeletal growth retardation is significant with regard to the snout, but not the maxillary corpus.

Björk and Skieller (1976) have stressed the important role the midpalatal suture plays in maxillary transverse growth. The nonsignificant difference between the groups examined in this

study, with respect to transverse growth of the maxilla, suggests maintenance of midpalatal suture growth even under conditions of nutritional deprivation. Light microscopic examination failed to detect differences in cellular activity in the sutures which contribute to increases in transverse dimension and the vital dye patterns in these regions were similar for both groups. Sheridan and Yoshikawa (1981) used inter-rugae measurements to study the contribution of the midpalatal suture to transverse growth changes in the maxilla after Function Regulator treatment. It was concluded that changes in the growth increments of the midpalatal suture account for a significant portion of the maxillary arch width increase observed in patients treated with this appliance.

Observations of anteroposterior growth changes between groups displayed marked differences in maxillary arch length. It is suggested that control subjects experienced larger increments of growth in the maxillo-premaxillary suture. There is no immediate explanation for these observed cephalometric results although a possible explanation may be inferred from the work of Enlow (1975) in his discussion of counterparts. The anterior cranial fossa is the template for the nasomaxillary complex and, due to the "perinatal brain development" of the rabbit (Harel et al., 1972), nutritional deprivation may affect to a lesser degree those anatomical structures whose boundaries are prescribed by cranial base dimensions. Under conditions of malnourishment,

skeletal elements not directly associated with cranial templates may be more severely affected. Previous studies on the sutural growth rate of rabbit cranial sutures have concluded that the various sutures grow differentially and those sutures which contribute to increases in snout length are most active during the growth period (Selman and Sarnat, 1955; Erickson, 1958; Hong et al., 1968; Ikeda and Honma, 1961). It is suggested that, sutures contributing to increases in cranial transverse dimension were less active during the experimental period, than sutures responsible for snout length increases, and therefore, the latter would be more severely affected by malnourishment.

There is no satisfactory explanation for the significant difference in inter-hamular notch width. This measure proved to be greater for the treatment group. Ness (1957) postulated that stress on the rabbit dentition may affect skull structure to a greater extend than in man due to the more significant activity of continuous root development. It is plausible that medial appliance flexion posteriorly produced coronal restriction and apical divergence of the teeth resulting in altered dimension in this area. Such an explanation is highly speculative because the implant data and histological results do not clearly support the view presented.

The remodeling pattern displayed by the palate and floor of the nasal cavity in the rabbit suggests a mode of regional

growth activity previously described (Enlow, 1975) as a compensatory remodeling mechanism in response to displacement mechanisms operative in the nasomaxillary complex. Enlow (1975) and Björk and Skieller (1976) ascribe this counterclockwise pattern of palatal and nasal floor remodeling as a response to clockwise displacement mechanisms operative for the maxilla.

SUMMARY AND CONCLUSIONS

The vestibular shield has been used extensively as an integral component of functional appliances. Data accumulated from this clinical use suggests a direct cause-effect relationship resulting in alterations of the maxillary dental arch transverse dimension. Previous investigators have postulated that transverse growth changes obtained through the application of vestibular shields may be due to periosteal deposition on the apical walls of the buccal alveolar plates. Sutural growth changes have also been cited as a possible mechanism underlying maxillary growth alterations.

The purpose of the present study was to assess the morphogenic and histogenic effects of vestibular shields on the transverse growth of the maxilla utilizing a laboratory model. Buccal shields were inserted in the oral cavity of five actively growing New Zealand white rabbits and were maintained in position by means of bilateral circumzygomatic ligature fixation. The treatment group was evaluated after a period of 35 days and compared to a sham control group of three age-similar animals.

Several categories of data were collected. Dental casts, obtained at the beginning and at the end of the experimental period, were used to compare differences in transverse dental

arch dimensions. Results suggest a maintenance of normal dental arch increases in those specific areas in which undesired flexion of the vestibular shields, caused by a compressive effect of the buccal soft tissues, was not possible. Regions distal to the maxillary second premolar, however, exhibited actual reduction in transverse dental arch dimension, and it is postulated that undesired impingement caused by buccal soft tissue pressure on the appliance produced a constrictive effect on lateral dental growth movements. Histologic evaluation did not provide evidence of any remodeling differences in regional alveolar and palatal remodeling between the control and experimental groups.

An analysis of general body growth using tibial length standards, supported by body weight comparisons, revealed gross differences in overall body and skeletal development between the groups related to feeding interferences caused by the appliances. However, cephalometric analyses suggest that retarded body growth affects maxillary and basicranial maturation to a somewhat lesser degree than post-cranial regions. Anatomic and radiographic variables used as indicators for differences in transverse cranial base and maxillary growth suggest that growth boundaries such as those prescribed by the cranial base cannot be significantly exceeded, but growth under compromised nutritional conditions may fall short of the growth field boundaries. In the present study, the counterpart relationship between the anterior

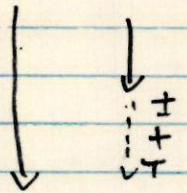
2-50 , 2-49 ص 39

2-53 ص 40

(c) ص ٤٢

3-21 , 3-20 , ص ٤٢

Most important بالترتيب ص ١٢٤



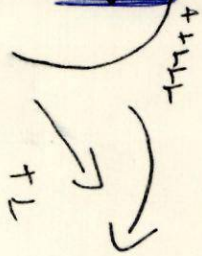
→

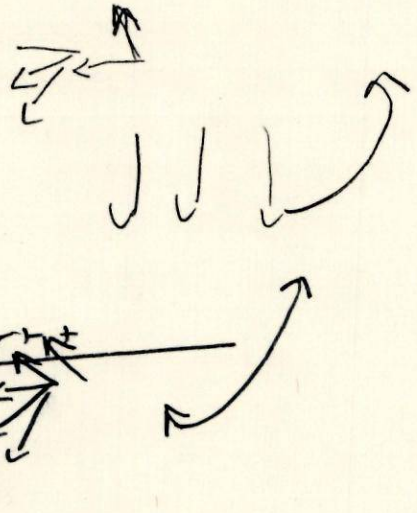
upward + forward Rotation

Counterclockwise rotation

↗

[redacted] complex





381-2670

449-4373

cranial fossa and the nasomaxillary complex was not altered significantly under conditions of experimental functional modification of the perioral soft tissue. Results obtained in this study, therefore, suggest that normal skeletal relationships between the maxilla and its counterpart, the anterior cranial fossa, cannot be altered beyond prescribed growth boundaries through the application of vestibular shields as utilized in the present investigation.

Results obtained clinically demonstrate increased maxillary transverse dimensions. Perhaps the design of the appliance and the animal model used in this study failed to simulate the actual mechanisms of action produced by vestibular shields. In addition, future studies should attempt to design an experimental model which does not produce severe growth retardation between treatment and control groups.

LITERATURE CITED

Adams, C. P.: An investigation into indications for and the effects of the Function Regulator. Trans. Eur. Orthod. Soc., 45: 293-312, 1969.

Angle, E. H.: Malocclusion of the Teeth. 7th ed., Philadelphia: S. S. White Dental Manufacturing Co., 1907.

Bassett, C. A. L. and Becker, R. O.: Generation of electric potentials by bone in response to mechanical stress. Science, 137: 1064-1065, 1962.

Bassett, C. A. L.: Electrical effects in bone. Sci. Amer., 213: 18-25, 1965.

Björk, A.: Sutural growth of the upper face studied by the implant method. Acta Odont. Scand., 24: 109-127, 1966.

Björk, A.: Timing of interceptive orthodontic measures based on stages of maturation. Trans. Europ. Orthod. Soc., 48: 61-74, 1972.

Björk, A. and Skieller, V.: Growth in the width of the maxilla studied by the implant method. Scand. J. Plast. Reconstr. Surg., 8: 26-33, 1974.

Björk, A. and Skieller, V.: Postnatal growth and development of nasomaxillary complex. In: Factors Affecting the Growth of the Midface, J. A. McNamara, Jr. (ed.). Monograph #6, Craniofacial Growth Series, Center for Human Growth and Development, The University of Michigan, Ann Arbor, Michigan.

Brady, W. J.: The influence of heredity on malocclusion. P.A. S.O., 1905.

Brash, J. C.: Some problems in the growth and development mechanics of bone. Edinburgh Med. J., 41: 305-387, 1934.

Brodie, A. G.: Analysis of change during and subsequent to orthodontic management of Class III malocclusions. Angle Orthod., 8: 330-350, 1938.

Brodie, A. G.: The growth of alveolar bone and the eruption of the teeth. Oral Surg., 1: 342-345, 1948.

Brodie, A. G.: The apical base: zone of interaction between the intestinal and skeletal systems. Angle Orthod., 36: 136-151, 1966.

Eirew, H. L.: Dynamic-functional appliances. Dent. Practit., 19: 287-291, 1969.

Engdahl, E.: Bone regeneration in maxillary defects. Scand. J. Plast. Reconstr. Surg., Suppl. B, 1972.

Enlow, D. H.: A study of the postnatal growth and remodeling of bone. Am. J. Anat., 110: 79-88, 1962.

Enlow, D. H.: A morphogenetic analysis of facial growth. Am. J. Orthod., 52: 283-291, 1966.

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

Enlow, D. H.: Handbook of Facial Growth, Philadelphia: W. B. Saunders Co., 1975.

Enlow, D. H. and Bang, S.: Growth and remodeling of the human maxilla. Am. J. Orthod., 51: 446-464, 1965.

Erickson, L. C. and Ogilvie, A. L.: Aspects of growth in the cranium, mandible and teeth of the rabbit as revealed through the use of alizarin and metallic implants. Angle Orthod., 28: 47-56, 1958.

Frankel, R.: The theoretical concept underlying the treatment with function correctors. Trans. Eur. Orthod. Soc., 42: 233-250, 1966.

Frankel, R.: The functional matrix and its practical importance in orthodontics. Trans. Eur. Orthod. Soc., 45: 207-218, 1969.

Frankel, R.: The guidance of eruption without extraction. Trans. Eur. Orthod. Soc., 46: 303-315, 1971.

Frankel, R.: Decrowding during eruption under the screening influence of vestibular shields. Am. J. Orthod., 65: 372-406, 1974.

Frankel, R.: A functional approach to orofacial orthopaedics. Brit. J. Orthod., 7: 41-51, 1980.

Ghafari, J. and Shanfeld, J.: Effect of removing buccal muscular pressure from the rat maxilla. J. Dent. Res., 60: 432, 1981.

Harel, S., Watanabe, K., Linke, E., Schain, R. J.: Growth and development of the rabbit brain. Biol. Neonate, 21: 381-399, 1972.

Heikl, H. V.: On ossification and growth of certain bones of the rabbit; with a comparison of the skeletal age in the rabbit and in man. Acta Orthop. Scand., Suppl. 39, 1959.

Hong, Y. C., Yen, P. K. J., and Shaw, J. H.: An analysis of the growth of the cranial vault in rabbits by vital staining with lead acetate. Calc. Tiss. Res., 2: 271-285, 1968.

Howes, A. E.: Case analysis and treatment planning based upon the relationship of the tooth material to its supporting bone. Am. J. Orthod. and Oral Surg., 33: 499-517, 1947.

Hoyte, D. A. N. and Enlow, D. H.: Wolff's Law and the problem of muscle attachment on resorptive surfaces. Am. J. Phys. Anthrop., 24: 205-214, 1966.

Hunter, J.: The Natural History of the Human Teeth, 2nd ed.: London, J. Johnson, 1771.

Ikeda, J. and Honma, R.: Postnatal growth of the cranial vault in the rabbit. Acta Med. Biol. (Niigata), 9: 91-103, 1961.

Keith, A. and Campion, G. G.: A contribution to the mechanism of growth in the human face. Dent. Rec., 42: 61-88, 1922.

Krebs, A.: Midpalatal suture expansion studied by the implant method over a seven-year period. Trans. Europ. Orthod. Soc., 40: 131-142, 1964.

Latham, R. A.: The development, structure and growth pattern of the human mid-palatal suture. J. Anat., 108: 31-41, 1971.

Logan, R. W.: The clinical management of the Frankel appliance, F. R. I. Dent. Practit., 21: 205-211, 1971.

Lowrance, E. W.: Roentgenographic record of skeletal growth in relation to age and body weight of the rabbit; calcaneous and tibia. Growth, 17: 183-189, 1953.

Lundstrom, A.: Malocclusion of the teeth as a problem in connection with the apical base. Int. J. Orthod., Oral Surg., 11: 591-1109, 1925.

Melsen, B.: Palatal growth studied on human autopsy material. A histological micro-radiographical study. Am. J. Orthod., 68: 42-54, 1975.

Moorrees, C. F. A., Gron, A. M., Lebret, L. M. L., Yen, P. K. J. and Frolich, F. J.: Growth studies of the dentition: A review. Am. J. Orthod., 55: 600-616, 1969.

Moss, M. L.: The differential roles of periosteal and capsular functional matrices in oro-facial growth. Trans. Eur. Orthod. Soc., 45: 193-206, 1969.

Moss, M. L. and Greenberg, S. N.: Functional cranial analysis of the human maxillary bone: I. Basal bone. Angle Orthod., 37: 151-164, 1967.

Moss, M. L. and Young, R. W.: A functional approach to craniology. Am. J. Phys. Anthrop., 18: 281-292, 1960.

Ness, A. R.: Cephalometric analysis of hereditable incisor malocclusion in the rabbit. Brit. Dent. J., 102: 439-449, 1957.

Organ, G. M.: An experimental model to study the effects of the Function Regulator in the Macaca monkey. Thesis, Faculty of Dentistry, Department of Orthodontics, University of Toronto, 1979.

Pac, J.: The early treatment of Class III malocclusion by the vestibule-plate. Trans. Eur. Orthod. Soc., 46: 239-248, 1970.

Richardson, E. R. and Brodie, A. G.: Longitudinal study of growth of maxillary width. Angle Orthod., 34: 1-15, 1964.

Roux, W. (1895). Cited from: Adams, C. P. The Design and Construction of Removable Orthodontic Appliances, Baltimore: The Williams and Wilkins Co., 1970.

Sachs, P.: Personal communication, 1980.

Scott, J. H.: Growth at facial sutures. Am. J. Orthod., 42: 381-387, 1956.

Scott, J. H.: The analysis of facial growth. Part II. The horizontal and vertical dimensions. Am. J. Orthod., 44: 585-593, 1958.

Selman, A. J. and Sarnat, B. G.: Sutural bone growth of the rabbit snout: a gross and serial roentgenographic study by means of metallic implants. Am. J. Anat., 97: 395-408, 1955.

Sheridan, L. and Yoshikawa, K.: Midpalatal sutural change associated with use of the Frankel appliance. J. Dent. Res., 60: 540, 1981.

Skieller, V.: Expansion of the midpalatal suture by removable plates, analysed by the implant method. Trans. Europ. Orthod. Soc., 40: 143-158, 1964.

Strang, R. W.: The fallacy of denture expansion as a treatment procedure. Angle Orthod., 19: 12-23, 1949.

van der Klaauw, C. J.: Size and position of the functional components of the skull. Arch. Neer. Zool., 9: 1-599, 1948-51.

Weisbroth, S. H. and Fudens, J. H.: Use of ketamine hydrochloride as an anesthetic in laboratory rabbits, mice and guinea pigs. Lab. Anim. Science, 22: 504-508, 1972.

Wolff, A. 1895: Cited from: Enlow, D. H.: Handbook of Facial Growth, Philadelphia: W. B. Saunders Co., 1975.

GENERAL BOOKBINDING CO
31 0 7
21105 104 T
QUALITY CONTROL MARK