EFFECTS OF DISTAL MANDIBULAR TRACTION IN THE RABBIT: A CEPHALOMETRIC, HISTOLOGIC, ELECTROMYOGRAPHIC STUDY

by

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The purpose of this study was to investigate the effect of a distal direction of traction on the mandible in young growing rabbits. Twelve, four to five week old rabbits were divided into two experimental and two control groups. Group 1 consisted of four animals in which "heavy" traction forces were exerted, and Group 2 consisted of four animals in which "light" traction forces were exerted. Group 3 consisted of two animals which had identical experimental appliances but without application of traction force. Group 4 consisted of two animals which had no experimental appliances and no force application. The animals were weighed and metallic implant markers were placed in the mandible, maxilla, frontal, nasal and occipital bones prior to the initiation of the experiment. The mandibular distal traction appliances consisted of an intraoral mandibular splint and an acrylic collar brace fitted to the animal's neck. The intraoral and extraoral portions of the appliances were connected with orthodontic elastics, which exerted the distal force. The experimental period of force application was 30 days. The traction forces were classified as "heavy" and "light" according to the level of response to the force by the lateral pterygoid muscle. A force level causing

slight deviation of the electromyographic picture of the lateral pterygoid muscle was classified as "light." "Heavy" forces were those that caused total deviation of the silent electromyographic picture.

Radiographs were taken and vital dyes were administered at three time intervals: day one, day 15 and day 30 following force application. Electromyograms of the lateral pterygoid muscle were taken every second day throughout the entire period.

Cephalometric analysis of mandibular growth and histologic examination of the condyle and the ramus were performed for each animal. A histochemical study for ATPase and succinic-dehydrogenase activity in the lateral pterygoid muscles from two control and two experimental animals receiving "heavy" forces was also conducted. This study was carried out to test different levels of contractile activity in the lateral pterygoid muscles of control and experimental animals subjected to "heavy" forces.

It was found that the lateral pterygoid muscle in experimental Group 1 was in a continuous contractile state throughout the entire experimental period. The electromyographic activity of the lateral pterygoid muscle in experimental Group 2 was slightly different from that in the control group. There were, however, no differences in the muscle activities of the lateral pterygoid muscles in Groups 3 and 4.

The posterior ramal height and the condylar and ramal height along the ramus axis were measured in all animals. An analysis of variance of these measurements demonstrated that there was a significant difference (p 0.01). The performed t-tests showed a significant difference (p 0.05) between Groups 1 and 2. The t-test was also significant (p 0.05) between both Groups 1 and 2 and the control Group. The condylar remodeling pattern was similar in Groups 2, 3 and 4, but showed a histologic reversal pattern in Group 1. Microscopic examination of the disc and the condyle also revealed significant histologic differences between the experimental and control groups. The histochemical findings demonstrated different activity between control lateral pterygoid muscles and muscles of animals subjected to "heavy" forces.

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INTRODUCTION

Facial growth has been one of the orthodontist's most interesting and exciting areas of research. It has also proven to be quite perplexing clinically in that the process of facial growth is one of the most difficult things to control. Since facial deformities are usually associated with dental malocclusions the clinician should therefore attempt to treat both problems concurrently.

Factors involved in control of the growth process include genetic control, differential cellular responses, membrane control, neurotrophic control, oxygen tension, bioelectric potentials, pH levels, temperature effects, chalone-like inhibitors and stimulators, cyclic AMP, vasomotor control, nutrition and enzymatic and hormonal factors. The important question is which are the specific trigger factors and which are the subordinate or secondary ones (Enlow, 1973).

Mandibular growth is presumably regulated by specific combinations of all the above factors that control the mandible's size, morphology and position in the craniofacial skeleton. For many years the condyle was thought to be the most important control center of the mandible, and a great deal of research was directed to attempts to prove or disprove its primary regulatory role in mandibular growth. Two basic theories which have arisen

from the historic controversies regarding mandibular growth suggest that the condyle is either the major growth center controlling overall mandibular growth or that the condyle is simply another local growth site that contributes only regionally to overall mandibular growth.

Extraoral orthopedic manipulative forces represented one of the initial clinical therapeutic approaches to the various skeletal problems of the face. As early as 1803, Fox and Cellier used extraoral forces to manipulate various skeletal problems involving the jaws. This trend continued into the 20 century when Case, Oppenheim, Kloehn, King and Fischer (Graber, 1975) and others recommended the use of extraoral types of appliances for the correction of dento-facial abnormalities. Treatment of Class III malocclusions or mandibular prognathism can be quite resistant using conventional orthodontic therapy as practiced today. Treatment can become more difficult as a child grows older, as Graber (1975) recognized, since as a general rule the Class III face tends to have a predominant horizontal growth direction becoming more severe with increasing age.

Chin caps have been used to constrain mandibular growth, presumably inhibiting chondrocytic proliferation of the condyle and thereby retarding the extent of mandibular growth and forward and downward translative growth. Although chin caps have been used in a large number of patients by many

practitioners, there is no sufficient evidence that chin caps can consistently produce significant clinical alterations. The questions then must be asked:

1. is the biologic rationale underlying use of the chin cap valid, and
2. if so, why does not its use provide satisfactory and consistent results?

REVIEW OF THE LITERATURE

Overview of Mandibular and Condylar Growth

Presently there are two principal theories regarding mandibular growth. Sicher (1947) suggested that the growth of the mandible is regulated by signals that arise from the condylar center. Mandibular growth is known to be a result of both extensive remodeling that occurs in all parts of the mandible as it undergoes displacement in space (Enlow, 1973).

Hunter (1771), using vital stains, first showed that the ramus grows backward by bone deposition onto its posterior border with simultaneous resorption from its anterior aspects. Humphrey (1864) inserted small metal rings on both the anterior and posterior borders of the growing pig's mandibular ramus. The rings implanted on the posterior margin of the ramus were more deeply embedded whereas the rings on the resorptive anterior surface became sloughed during subsequent mandibular growth.

Brash (1933) stated that bone growth is a surface phenomenon carried out by surface deposition and surface resorption. While studying the pig's mandibular growth Brash found that osseous surface changes in the three dimensions of vertical, horizontal and oblique contributed equally to the growth phenomenon. The three dimensional growth pattern also involves the

major growth areas (symphyseal, alveolar, ramal, condylar, coronoidal) and together constitute the composite of mandibular growth. These areas are simply sites of growth that follow the general principles of surface deposition and resorption. The mandible thereby grows in length both anteriorly and posteriorly. The oblique direction of the upward and backward growing condyle significantly contributes to the total length of the mandible. The increase in mandibular body depth was believed to be due mainly to upward alveolar bone growth.

Rushton (1944) evaluated patients who sustained injury or infection in the condylar area and observed resultant mandibular hypoplasia. He stated that, "in the early years it is the function of the condylar growth center to promote continual advancement of bone upon which subperiosteal additions and remodeling can be exercised." The hypoplasia was explained by Rushton as a result of no advancement of bone within the periosteum, and because the subperiosteal bone is abnormally localized instead of proportionately distributed.

Sicher (1947) suggested that mandibular growth is the product of cartilaginous condylar growth and associated osseous tissue replacement. He distinguished condylar cartilage from epiphyseal and articular cartilages and stated that the mandibular condyle possesses a different form of cartilage that has the ability to grow both appositionally and interstitially. He believed that

growth of the mandible and, primarily, growth of the condylar cartilage determine the development of the entire face. Persons with a wide type of facial appearance presumably have slow cartilaginous growth that results in reduced facial height and a wider, shorter face. People with a narrow, long face presumably possess cartilage that grows relatively fast and which thereby determines this specific type of facial form.

Robinson and Sarnat (1955) studied the growth pattern of the pig mandible in nine female Hampshire pigs at approximately eight weeks of age. The average period of the experiment was twelve weeks. Amalgam implants and serial roentgenography were used to study the mandibular growth pattern. They observed that the condyle appeared to be the most active mandibular growth site, contributing about 80% to total ramus height and to some degree to the mandibular body length. The posterior border of the ramus was the second most active growth site and also contributes to the total length of the mandible. The interior, anterior and alveolar borders and lateral surfaces of the mandible were believed to be less important sites of appositional growth.

Scott (1959) stated that growth of the condylar cartilage thrusts the mandible downward and forward from its contact in the glenoid fossa. The resorption of bone at the anterior border of the mandibular ramus is a compensatory mechanism whose role is to maintain the proper relationship between the zygomatic arch and the anterior edge of the ramus.

Moss (1960) refined a theory of functional analysis and functional cranial components. Each functional component was described by him as consisting of two parts: the functional matrix and its skeletal unit. The matrix consists of all muscles that are attached to the mandible, all arteries, veins and nerves in that region, salivary glands, teeth, skin, adipose and connective tissues, the tongue and the oral and pharyngeal cavities (Moss, 1960).

The mandible is not a unitary biological object, but rather is composed of several independent functional cranial components. The skeletal units of the mandible that correspond to the above mentioned functional cranial components are the alveolar processes, the coronoid process, the angular process, the mandibular corpus, the condylar process and the chin. The primary morphogenetic event in mandibular growth control is the volumetric expansion of the oral functioning space and the oral capsular matrix (Moss and Salentijn, 1971). The above growth process, presumably, also results in the passive displacement of the mandible.

The changes in the form (remodeling) of the skeletal units are described as secondary, compensatory and mechanically obligatory (Moss, 1971). Moss and Salentijn (1969) reject the proposition that the mandibular condylar cartilages are primary sites of mandibular growth control. The condyles are believed to

be loci at which secondary, compensatory growth occurs.

Bjork (1963) presented preliminary data on the growth of the mandible in a sample of 45 Danish male volunteers who were followed annually by radiographs utilizing tantalum implant pins. He found that a pronounced area of remodeling occurs anterior to the angle of the mandible. The direction of condylar growth in the sagittal plane was found to vary widely, but the most frequent direction was slightly forward in relation to the posterior tangent to the ramus.

Enlow and Harris (1964) studied remodeling changes in the human mandible during the growth period. They showed that the basic remodeling principles of area relocation, activity at surfaces determined by regional directions of growth, and the "V" growth principle occur "throughout all parts of the mandible." These authors also demonstrated that there are consistent patterns of remodeling in the condylar neck, the coronoid process, the ramus, the body, the chin and the alveolar processes.

Enlow (1975) analyzed in specific detail the mandibular growth process. Remodeling and displacement are the two principal types of movement involved in mandibular growth. In displacement the whole mandible is moved in a forward and downward manner. In remodeling the compponent parts that constitute each region of the entire bone undergo histologic alterations that bring them into new positions to provide for the bone's enlarge-

ment and functions.

The mandibular condyle is not regarded by Enlow as a growth "center." It does not possess any special regulatory role on growth of the mandible as a whole. Nor is there believed to be any genetic programming for condylar control of lower jaw growth. As Enlow (1975) states the condyle is only a regional field of growth that provides an adaptation for its own localized growth circumstances. The growth of the mandible is the result of a composite of many different regional factors and functional agents that act to produce the final complex shape of the lower jaw.

There is a question regarding the existence of a special type of cartilage in the condylar head. That special cartilage is a functional adaptive response to applied compressive forces on the condyle. "An intramembraneous type of growth could not operate because the periosteal mode of osteogenesis is not pressure adapted" (Enlow, 1975).

The condylar cartilage is actually a secondary type of cartilage, and its function is to provide regional adaptive growth (Enlow, 1975). The condyle because of this specialized cartilage has a special multidirectional capacity to grow and remodel according to the various mandibular displacements and/or rotations. This can be explained with the histologic picture of the four different layers (capsular, proliferative, hypertrophied,

bone). The daughter cells in the above zones are not arranged into linear columns, but rather their manner of alignment reflects the capacity for multidirectional proliferation and growth. The proliferation of these cartilage cells produces the upward and backward growth movement of the condyle. The condylar cartilage actually moves by prechondroblast cell division on the articular side with an equal amount of cartilage removed from the opposite internal side (Enlow, 1975).

Enlow (1980) states that rather than "condylar growth" we should refer to "ramal" growth because it is the entire ramus that remodels and adjusts continuously, allowing the lower dental arch to function reasonably with the upper arch and the glenoid fossa. The condyle and whole ramus provide the exceedingly critical function of progressive adaptation without which mandibular fit to the maxillae and cranial base would not be possible (Enlow, 1980).

Koski (1967) also stated that the condyle is not the leading center of mandibular growth. This was supported in Koski's view by the fact that the condylar cartilage is an embryologic latecomer. It is not an actual articular cartilage, nor an epiphyseal plate. This secondary type of cartilage does not posses any inherent intrinsic growth forces, nor does it grow in nonfunctional sites as has been demonstreated by transplantation experiments.

Baume (1961) and Baume and Derichsweiler (1961) advocated that condylar cartilage is responsive to functional stimuli, a property that makes it distinct from epiphyseal plate cartilages. Baume (1969) categorized the condylar cartilage as a skeletal growth "center." He regarded the condylar cartilage as the particular growth center of the mandible, pointing to very distinct differences from epiphyseal and synchondrosal centers. To support this interpretation, he referred to the embryological ability of condylar cartilage at about the twelfth foetal week to assume all the functions of a growth center "namely endochondral ossification well concerted with cartilage proliferation."

Limborgh (1972) considered cartilage as highly independent of local epigenetic and environmental factors. Intrinsic genetic factors were described by him as much more important in cartilaginous growth. The above statements are supported by the contentions that the cranial base remains practically normal in congenital malformations such as hydrocephalus and anencephalus, and cartilaginous growth is not restricted by compressive or stretching muscle forces.

Meikle (1973) transplanted complete mandibular joints as isografts into the brain of littermate rats and concluded the following:

1. The cells of the proliferative zone can form either bone or cartilage depending on the environmental factors;

2. The proliferative zone's cells differentiate into chondroblasts only in a functional environment that provides articular movements; and

3. Mandibular growth is not dependent upon condylar growth. The condyle, however, is essential for normal mandibular growth.

McNamara (1973) carried out experiments using monkeys in which an intraoral appliance was inserted to produce forward mandibular position. At the end of the experiment, he observed changes in the growth pattern of the condylar head and compensatory integration of the dentition. He did not find any significant increase in the rate of bone deposition along the posterior border of the ramus. He did observe alterations at the angle of the ramus and the angle of the condyle in relation to the occlusal plane. He concluded that there were adaptations and functional alterations in the mandibular skeletal units, the dentition and the mandibular muscles in order to serve functionally better the new mandibular posture.

Carlson, McNamara, Graber and Hoffman (1980) stated that the temporomandibular joint region of young growing individuals has the ability to adapt to environmental changes.

> Increased function or displacement of the joint may lead to an increase in the rate of mandibular growth, whereas decreased function or immobilization may lead to a reduction in the rate of mandibular growth.

Thus, the TMJ components and especially the condyle are believed to have the potential to adapt and either enhance or reduce mandibular growth.

Experimental Evidence

Condylar resections

Several studies of condylar resection have been carried out in order to ascertain the role of condylar cartilage in mandibular growth. Sarnat (1957) operated on eight-month old monkeys that weighed from 2 to 2.5 kg. The animals were divided into unoperated controls, animals in which the right mandibular condyle was removed and animals in which bilateral condylectomy or condylotomy had been performed. The postoperative survival period was as long as thirty-five months. Sarnat's conclusion that the condyle is the pacemaker and organizer of mandibular growth was supported by the following observations. In the operated sides of the animals, the ramus was wider and shorter, and the coronoid process was wider and relatively higher, than on the unoperated side. In addition the superior surface of the ramus was irregular. When viewing the animals anteriorly, a marked asymmetry was noted in those animals in which one condyle had been removed. Examination of the skulls from the lateral aspect of the operated side demonstrated a decreased facial height and length compared to the unoperated. Sarnat and Muchnic (1971) performed condylectomies in growing and adult monkeys and they concluded that the important factor for the resultant skeletal changes is loss of integrity of the temporomandibular joint rather than loss of a growth site.

Jarabak et al. (1949) performed condylectomies on rats. Immediately after the operation there was a deflection of the mandible to the operated side, and postoperative occlusal compensations also occurred. There was indication of rapid growth activity in the operated areas as well as in the lateral surface of the mandible opposite the mandibular foramen. The above mentioned readjustments in the operated mandible as well as adjustments in the temporal portion of zygomatic arch compensated for the new functional situations of the animals.

Das et al. (1965) used forty-eight male albino rats of the Charles River strain for their experiments. Thirty-five day old animals were operated and sacrificed at specific times after condylectomies. All animals received intraperitoneal injections of Alizarin Red S ten days prior to sacrifice. The combined use of alizarin and roentgenograms showed that normal developmental growth apparently does not occur in the absence of the condyle. Adjustive growth had occurred, and it resulted in mandibles that had normal overall size but distorted shapes.

Gianelly and Moorrees (1965) performed bilateral condylectomies on forty-two Holtzman albino rats weighing 40-50 g. They compared the operated animals with ten sham-operated and twenty-seven control animals. Their findings showed that the mandibles of the condylectomized group were 2 mm shorter than the mandibles of the control group. The overjet and overbite of

the operated animals were unaffected and a scar tissue type of response was noted in the operated area. They concluded that condylar growth was of an adaptive nature in the rat.

Pimenidis and Gianelly (1972) performed condylectomies on one day old Holtzman albino rats according to Giannelly and Moorrees' procedure. Their findings showed that the condylectomized mandibles doubled in size compared to the control ones that only grew approximately 125 to 130% of their original length. These findings also supported the theory that the condylar growth is of an adaptive nature in the rat.

Transplantations

Ronning (1966) inserted mandibular condyle transplants composed of cartilage or cartilage with adjoining bone into the brain tissue of five day old littermate rats. Out of 111 transplants, 55 were recovered. The transpants were attached to the calvaria by means of a fibrous or bony union. They closely resembled tubular bones and less than half of the recovered transplants displayed any cartilaginous structures.

Duterloo and Wolters (1969) performed a series of four different experiments in which they implanted isologous condylar and angular cartilages intracerebrally in one day old rats. They concluded that the angular implants showed less growth, less chondrogenesis and advanced ossification in comparison to the

angular cartilages. Transplantation of angular or condylar cartilage from a littermate donor to a condylectomized host resulted in the formation of a new condyle. Thus, Duterloo and Wolters concluded that articular function provides an extrinsic, stimulating chondrogenetic factor for the growth of the secondary cartilages of the mandible. They further stated that secondary cartilage is only maintained if articular function is present.

Meikle (1973) transplanted the mandibular joint as an isograft into the left cerebral hemisphere of seven day-old littermate rats. He observed that the cells of the proliferative zone differentiated into osteoblasts and not chondroblasts due to their multipotential capability. Meikle therefore concluded that the extrinsic mechanical stresses associated with functional activity of the mandibular joint provided the stimulus for the normal differentiation of the cells of the proliferative zone into chondroblasts.

Engelsma et al. (1980) transplanted 112 mandibular condyles from four day old rats to the site of the resected fourth distal metacarpal epiphysis of seven day old inbred host rats. The transplants became attached to the metacarpal diaphyses, and well-defined condyles developed. Articular function appears to be an essential factor for the maintenance of chondrogenesis, and, thus, the growth and development of the mandibular condyle.

Mandibular retraction

Janzen and Bluher (1965) applied a constant retracting bilateral force of 150 grams against the mandible through a retracting mechanism in four growing rhesus monkeys 19-23 months of age. The experimental period was 140 days. The retracting force affected not only mandibular growth but the growth of the total facial complex as well. A slight increase in ramus height, a decrease in the mandibular angle, a reduced maxillary alveolar development and hypertrophy of the external pterygoid muscles were among the anatomic changes noted. The condyle was not allowed to reach its fullest growth potential.

Petrovic et al. (1973, 1975) used chin caps in growing rats and arrived at the following conclusions:

1. The use of chin cap appliances diminished the rate of mandibular growth.
2. There was a decreased proliferation of the condylar cartilage, prechondroblasts and a decrease in the length between the posterior border of the condyle and the mental foramen.
3. The number of the serially arranged sarcomeres of the lateral pterygoid muscle was increased after the use of direct retracting force.

Rats wearing chin caps in which the whole lateral pterygoid muscle had been resected demonstrated significantly diminished mandibular growth rate than rats in which either the meniscal part of the lateral pterygoid muscle of the meniscotemporal elastic frenum had been resected.

The mandibular growth rate of the chin cap treated animals followed the circadian and circannual cycle. The response to the action of an active retropulsor occurred to a greater extent when the condylar cartilage was in a rapid growth stage.

Control of Mandibular Posture

The control of the active and rest positioning of the mandible involves information that passes from the central nervous system and is relayed to the peripheral motor units and musculature. Signals from proprioceptors in the temporomandibular joint capsule play an important role in the feedback information to the central nervous system. Monosynaptic and polysynaptic neurologic pathways are involved in mandibular posture and can counteract any tendency of deviation from the anatomically and functionally established position.

Electromyographic studies of mandibular rest position

Jarabak (1957) studied the electrical activity of the muscles of mastication in individuals with the mandible placed in rest position. It was assumed that for a subject with normal occlusion, mandibular rest was synonymous with electromyographic silence in the digastric, masseter and temporal muscles. In edentulous patients wearing dentures causing increased interocclusal distance, a hyperactivity of the above muscles was found. This hyperactivity heightened as the interocclusal distance was increased.

Garnick and Ramfjord (1962) acknowledged that there is a resting activity or tonus of the jaw muscles during the rest position. The resting activity of the muscles is dependent upon

the stretch reflex of the muscles, the gamma efferent system as influenced by the central nervous system and peripheral impulses from occlusal disharmony of the teeth.

Wyke (1974) rejects the suggestion that the rest position of the mandible is determined solely by counterbalanced static elastic forces exerted by the supramandibular and inframandibular muscles on the mandible in relation to prevailing gravitational forces acting on the mandible. He contends that the rest position of the mandible involves some degree of continuous motor unit activity in the mandibular musculature.

Møller (1975) accepts the possibility of a servo-mechanism involved in the control of mandibular posture because patients show different muscular activity in the upright versus the supine positions. On the other hand, eye closure or local anesthetic injection is followed by an obvious reduction of postural activity of the muscles of mastication.

Thilander (1975) states that both depressors and elevators are under some degree of contraction during the postural mandibular position. That postural contraction of the supra and inframandibular muscles balances the gravitational forces exerted upon the mandible.

Temm (1975) indicates that mandibular posture results from a state of equilibrium determined by gravity and tissue elasticity. The physical properties of the tissues are responsible

for the basic position, and that the degree of contraction of the jaw muscles controlled through sensory feedback is not a major factor.

Evidence of electromyographic activity in the lateral pterygoid muscles

Moyers (1950) studied the contraction pattern of the lateral pterygoid muscle in Angle Class II Division 1 malocclusions. The electrical activity of the muscles in Angle Class II Division 1 subjects was different than that in normal patients. The difficulty of approaching the lateral pterygoid led to questionable results of the muscle electromyograms.

McNamara (1973) also investigated the role of the lateral pterygoid muscle in rhesus monkeys utilizing electromyographic recordings. He found that the inferior head of the muscle acts synergistically with the suprahyoid muscle group in opening movements of the mandible. The superior head is antagonistic to the suprahyoid muscles during closing movements and during deglutition. The two heads of the lateral pterygoid muscle show different electromyographic activity in various movements, and they can be regarded as two functionally distinct muscles.

On the other hand, Lehr and Owens (1980) could not support any separate roles for the superior and inferior heads of the lateral pterygoid muscles during their electromyographic investigation. They found that the lateral pterygoid muscle is active in protrusion but is not active in retrusive movements.

Proprioceptive Mechanisms of Masticatory Muscles

Muscle spindles

Histomorphology of the Muscle Spindles

Sherrington (1894) and Ruffini (1898) described details of the structure of muscle spindle. The spindle was shown to contain two to 12 intrafusal fibers, each being 6 to 28 in diameter. The intrafusal fibers of the central third are surrounded by a fluid-containing capsule. The fusiform shape of the spindle is due to the presence of the above mentioned capsule and fluid. The intrafusal muscle fibers are striated at their polar end, and they possess many nuclei in their central regions. Boyd (1962) described the most recently acceptable picture of the muscle spindle in which two types of intrafusal muscle fibers exist: the nuclear-bag fibers that contain an aggregation of nuclei in the central region of the muscle spindle; and the muclear-chain fibers that present a single line of nuclei lying in a chain. The bag fibers receive motor innervation from motor fibers, whereas the chain fibers receive motor innervation from $_2$ motor fibers. A muscle spindle is composed of both bag and chain fibers.

Function of the muscle spindles

Matthews (1964) believes that muscle spindles play a role in the subconscious control of muscular contraction. They purportedly provide the nervous system with information about the

contractile state of the muscle during movement or steady contraction. Kawamura et al. (1958, 1959, 1960, 1974) showed that impulses from the muscle spindles in a jaw-closing muscle are transmitted to the midbrain trigeminal nucleus when the muscles are stretched. The impulse then goes to neurons of jaw closing muscles in the trigeminal motor nucleus, and as a final result, the closing muscle contracts. This describes a monosynaptic reflex arc. Eccles (1951) elucidated the interrelationship of control impulses of the muscle spindles to synergistic and antagonistic muscles. The control impulses could be the pathway of information to the mandibular depressors (Kawamura, 1974) from the jaw closing muscles. This information will be induced via a polysnaptic neuron arc. Cooper and Fillenz (1955) discuss the existence of "stretch receptors" in the extrinsic eye muscles of the cat even though they don't contain any spindles.

Existence of Muscle Spindles in the Lateral Pterygoid Muscle

The existence of neuromuscular spindles in the lateral pterygoid muscle has been a controversial point. It seems that the muscles which close the jaw possess a certain number of muscle spindles whereas the depressor muscles of the jaw are generally void of muscular spindles. Cipollone (1897) and Portela-Gomes (1963) noted the existence of some muscle spindles in the rabbit's lateral pterygoid muscles, whereas Smith and

Markarian (1967) and Franks (1964) could not identify their presence. Freimann (1954) did not find any muscle spindles in the lateral pterygoid muscle of one human subject investigated. Baum (1900) and Gill (1971), however, did observe neuromuscular spindles in the human lateral pterygoid muscles they investigated. Karlsen (1969) counted 13 muscle spindles in the middle region of the lateral pterygoid muscle of one Macacus irus monkey. Karlsen (1965) and Maier (1979) did not find any muscle spindles in the rat's lateral pterygoid muscles, but Christensen (1967) and Tsaknakis and Karakasis (1972) reported their presence in the lateral pterygoid muscles of the miniature swine and guinea pig. Thilander (1964) studied the nerve fibers of the lateral pterygoid nerve, and she concluded that if spindles are present in the lateral pterygoid muscle, they must be fairly few in number.

TMJ Mechanoreceptors and Neuromuscular Control Patterns

Thilander (1961) described the innervation of the temporomandibular joint. Articular branches of the auriculotemporal, deep temporal and masseter nerves enter into the capsule of the joint where they divide into smaller branches. These extend into the periphery of the articular disc. The branches from the deep temporal and masseter nerves innervate the anterior parts of the joint, while those from the auriculotemporal nerve innervate the posterior parts.

In regard to the types of receptors in the temporomandibular joint capsule, Greenfield and Wyke (1964) and Klineberg et al. (1970) found Type I and Type II nerve endings in the fibrous capsule. Type III nerve endings were present in the temporomandibular ligament, and Type IV were most dense in the posterior capsule of the joint. Clark and Wyke (1975) categorize the mechanoreceptors as Type I low threshold--slowly adapting mechanoreceptors; Type II low threshold--rapidly adapting mechanoreceptors; Type III higher threshold--slowly adapting mechanoreceptors; and Type IV mechanoreceptors which comprise the receptor system of the articular tissues. The same authors mention that the Type I low threshold slowly adapting mechanoreceptors located in the posterior region of the joint capsule play an important role in the reflex regulation of mandibular posture. Wyke (1974) believes that the awareness of mandibular posture is similar to the awareness of the spatial orientation of other parts of the body. That type of awareness does not depend upon information that reaches the central nervous system through muscle spindle afferent systems, but it is very much dependent upon the information to the brain from the Type I mechanoreceptors. These receptors lying in the posterior region of the joint capsule are active when the joints are immobile.

Kawamura (1974) feels that since different types of sensory receptors exist in the temporomandibular joint the

different kinds of sensory information possible originate from these receptors in the joint capsule. Thus, movements of the condyle are inhibited at a conscious level because of pain sensation existing in the temporomandibular joint area.

Thilander (1975) stated that the free and proprioceptive nerve endings of the joint capsule control the mandibular position, and that they transmit signals during large opening movements as a protective function. The sensory information from the joint is transmitted into the same areas of the central nervous system that innervate the muscles of mastication. As a result, the information from the joint regulates the muscular activity. Larrson and Thilander (1964) applied pressure over the TMJ and demonstrated that the ability of the TMJ to detect position was enhanced.

Lund and Matthews (1979) identified 11 units as temporomandibular joint receptors in rabbits. They found that there was a relationship between excitement of the receptors and a combination of rotation and horizontal displacement of the jaw. Additionally, a correlation was noted between firing frequency and chin displacement. Five of the units were active during depression of the mandible, and the other six were active during mandibular movement in a horizontal plane. Six of the units were adapting rapidly.

Abe et al. (1973) demonstrated that sensory impulses from mechanoreceptors in the TMJ capsule make a significant contribution to the reflex coordination of masticatory muscle activities during jaw movements. The TMJ mechanoreceptors modify the excitatory level of the masseter motor neurons during jaw opening and function to harmonize the movements of the jaw.

Smith et al. (1967) utilized monkeys and cats to determine that depression of the mandible evoked potentials in the ipsilateral and contralateral mesencephalic nuclei. Tension applied to the isolated medial and lateral pterygoid muscles initiated the same result as that of mandibular depression. They believe that these potentials represent impulses carried through a polysynaptic chain from the neuromuscular spindles, Golgi tendon organs, and TMJ mechanoreceptors. All of these structures project bilaterally and serve to regulate the function of the masticatory muscles.

Greenfield and Wyke (1966) showed that discharges from the joint mechanoreceptors contribute significantly to the reflex coordination of masticatory muscle activity during jaw movements in all directions. They concluded that changes in articular reflex activity should contribute to the production of abnormal jaw relationships and to different responses of the muscles of mastication during different types of orthodontic treatment.

Kawamura and Majima (1964) recorded the activities of the sensory and motor nuclei of the trigeminal nerve in cats whose

jaw muscles were totally detached from the bone and with the mandible divided at the symphysis. They demonstrated that impulses in the motor and sensory nuclei of the trigeminal nerve during condylar movement was the result of information from temporomandibular joint receptors.

STATEMENT OF THESIS

The purpose of this study is to investigate the effects of a distal direction of traction on rabbit mandibular growth. The study will attemtp to answer the following questions:

1. Do different levels of retrusive force exerted on the mandible selectively result in different kinds of condylar and ramal growth responses, both in the direction and the extent of resultant growth?

2. If so, does the action of the lateral pterygoid muscle relate to these possible differences?

3. Does the lateral pterygoid muscle function to relieve discomfort in the TMJ by attempting to draw the condyle away from its articulation, thereby actually decreasing the force level exerted on the condyle and actually stimulating condylar growth rather than inhibiting it?

4. If so, does a level of retrusive force exist that can (a) cause a pressure effect on the condyle, but (b) not trigger strong contractile activity of the lateral pterygoid muscle, thus successfully result in growth inhibition of the condyle?

MATERIALS AND METHODS

Twelve albino New Zealand rabbits (Oryctolagus cuniculus) were utilized in this study. The animals were obtained from the Animal Resource Center of Case Western Reserve University and upon receipt they were four to five weeks old and newly weaned. The initial (pre-experimental) weights ranged from 445 to 830 grams (Table I).

The rabbit was selected as the experimental animal in this investigation for the following reasons:

1. It is a relatively large animal, thus facilitating fabrication of custom-made appliances for mandibular traction.
2. It is a docile animal and can be easily handled.

The sample was divided into four different groups, two experimental and two control:

Group 1 (experimental) included rabbits #5, 6, 14 and 16 which had continuous mandibular retraction with "heavy" forces.

Group 2 (experimental) included rabbits #4, 7, 8 and 9 which had continuous mandibular retraction with "light" forces.

Group 3 (control) included rabbits #18 and 20 which had similar appliances as the animals in the experimental groups but without traction.

Group 4 (control) included rabbits #10 and 12 which had no appliances and no force.

TABLE I

INITIAL AND FINAL WEIGHT DATA

Group	Rabbit	Initial Weight (grams)	$\bar{X}$ (grams)	S.D. (grams)	Final Weight (grams)	$\bar{X}$ (grams)	S.D. (grams)
1	5	590	608.75	18.83	1200	1405	120.31
	6	590			1440		
	14	630			1500		
	16	625			1480		
2	4	810	696	75.71	1545	1450	118.37
	7	597			1280		
	8	685			1400		
	9	692			1575		
3	10	580	580	0	1535	1567.5	32.50
	12	580			1600		
4	18	690	655	35.00	1700	1665.0	35.00
	20	620			1630		

Experimental Procedure

Each animal was weighed and impressions of the mandibular dental arch and neck were taken in order to fabricate the appliances. On the first experimental day, metallic implant markers were inserted and initial lateral cephalometric radiographs were taken. At the same time the initial vital dye was administered. The appliances were placed on the animals and electromyograms were taken to record the force level of applied traction. At the end of the 15th experimental day, a second vital dye was administered. This was followed by another set of lateral cephalometric radiographs. A third vital dye was administered one day before sacrifice and the final set of lateral cephalometric radiographs was taken immediately prior to sacrifice. The entire experiment lasted for a period of 30 days during which time electromyographic recordings of the lateral pterygoid muscle were made every second day (Table II).

Design and Construction of the Appliance

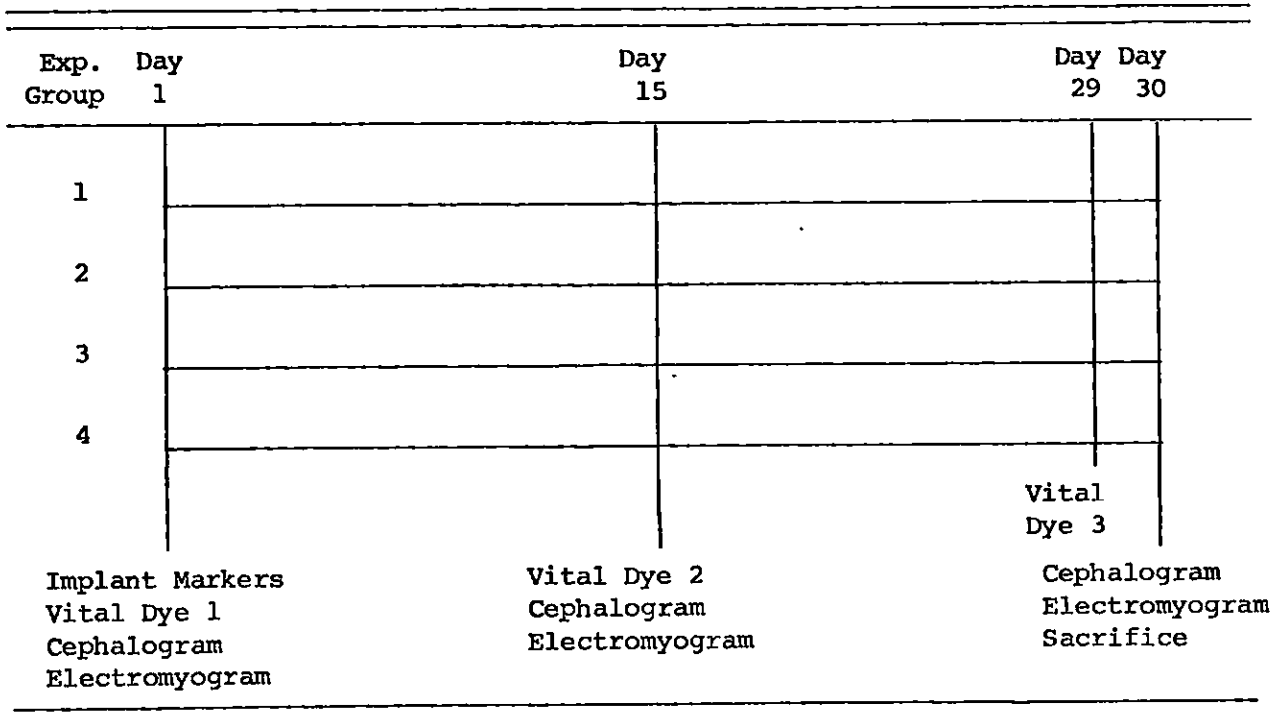
The appliance that was used to exert retrusive forces on the mandible consisted of two main components:

1. an intraoral mandibular splint, and
2. an anchoring neck brace.

These two parts were connected with elastic rubber traction.

TABLE II

EXPERIMENTAL PROCEDURE



Xantopren/Optosil (Unitek Co., Monrovia, California) impressions of the mandibular arch of both experimental and control animals were taken with custom-made acrylic trays previously constructed using mandibles from dry rabbit skulls at comparable ages. The final impressions were poured in Velmix Stone. The mandibular splint was waxed and extended over the molars, premolars, incisors and the attached gingiva of the lower dental arch. A wax bar, having a transverse dimension similar to the buccal-lingual width of the posterior dental segment, connected the posterior and anterior teeth. The wax was cast using Type II casting gold. Extraoral extensions in .050 inch wire were soldered on the anterior aspect of the splint in a 90° angle to the long axis of the anterior teeth. The extensions were 25 mm long and possessed a circular hook at the end for the elastic traction (Plate I).

The anchoring neck brace was fabricated in cold cure acrylic on a mold of utility wax (The Hygienic Co., Akron, Ohio). The acrylic brace consisted of two equal halves which could be wired together with orthodontic steel ligatures around the neck of the rabbit to form a complete collar. On the dorsal aspect of the collar, two .050 inch stainless steel wires were embedded in the acrylic and directed towards the temporomandibular joint area. These wires had circular hooks fashioned at the free ends which served as posterior attachments for the elastic traction (Plate II).

PLATE I

Intraoral mandibular splint

PLATE II

Neck Brace Apparatus

Anesthesia

An adequate level of anesthesia was obtained using an intramuscular injection of 5 mg/kg body weight of Xylazine (Rompun, Bayvet Division, Cutter Laboratories, Inc., Shawnee, Kansas) followed in 10 minutes by an intramuscular injection of 30-50 mg/kg body weight of Ketamine HCl (Ketaset, Veterinary Products, Bristol Laboratories, Syracuse, New York). To sustain anesthesia, subsequent intramuscular Ketamine HCl injections (10 mg/kg body weight) were administered at 10 minute intervals.

Insertion of the Appliances

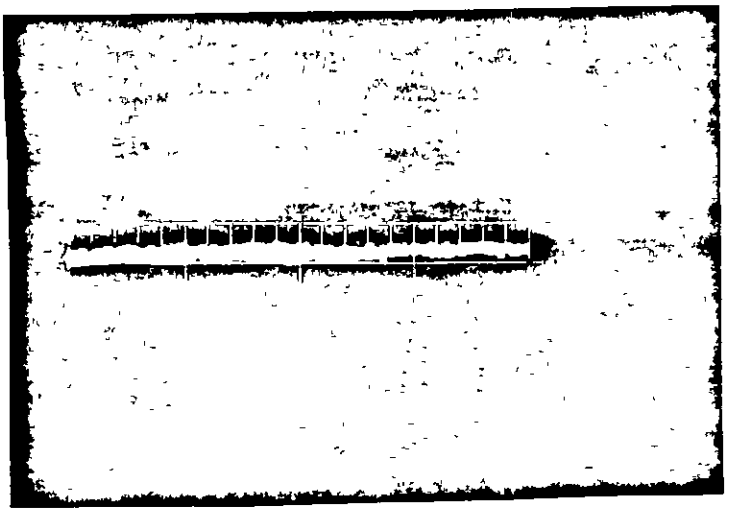
Under anesthesia, the lower intraoral splint was cemented onto the lower dental arch of each animal using orthodontic bonding concise material (Dental Products, 3M, St. Paul, Minnesota). The two halves of the collar were fitted around the neck and wired together. The animals were subsequently allowed to adjust to the appliances for 48 hours. Thereafter, the period of extraoral force application was started.

Application and Measurement of the Forces

The animals in Group 2 received a force that produced an electromyographic picture of the lateral pterygoid muscle that deviated only slightly from that of the resting muscle (Plate III). This force was considered to be of "threshold" level and consequently designated as "light." With "trial and error" method it

PLATE III

Electromyogram: lateral pterygoid muscle activity immediately after application of "light" distal traction force.



was found that a standard 3/4" orthodontic latex elastic (Unitek Corp.) generated such a force. The magnitude was determined with a Haldex precision force gauge to be approximately 25 grams.

A force of 65 grams, also measured with the Haldex precision force gauge was applied to the animals in Group 1. Orthodontic 3/8" elastics (TP Lab, Inc.) generated this force when stretched between the splint and the collar hooks. This force level produced an electromyographic picture of the lateral pterygoid muscle that was totally different from that of the silent electromyographic picture (Plate IV). The 65 gram force was classified as "heavy." The elastics were changed at two-day intervals, and at the same time the force level was measured. Electromyographs of the lateral pterygoid muscle were also taken.

Elastic thread (Power Thread, Orvnco, Inc.) was used to passively connect the mandibular splint hook with the collar hook in the animals of Group 3.

Electromyography

The electromyographic apparatus used for this study was the TECA Electromyograph Model B-2 (Teca Corp., White Plains, New York) which has a frequency range of 0.5 to 50 cycles per second. A polaroid camera (Model 350) was used to photorecord the signals (Plate V).

PLATE IV

Electromyogram: lateral pterygoid muscle activity

immediately after application of "heavy"

distal traction force.

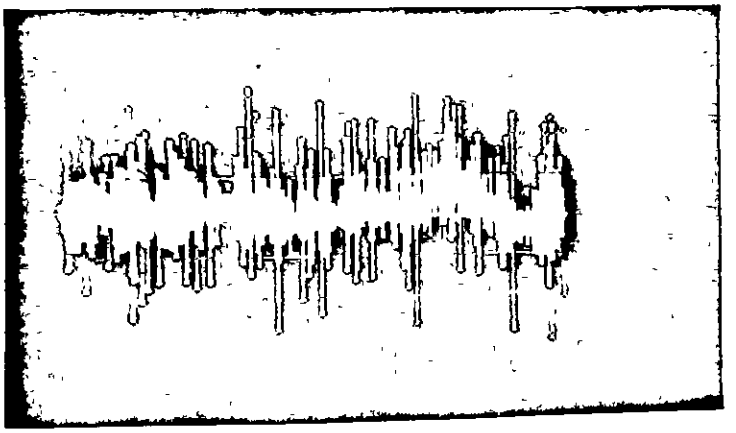


PLATE V

Animal under electromyographic procedure

Concentric needle electrodes (Type CF25, Teca, Pleasantville, New York) were used. These electrodes consist of a simple stainless steel hypodermic needle which contains an insulated wire in its barrel. The tip of the wire is bared and acts as one electrode while the barrel of the needle acts as the second electrode. The outer needle is insulated except for the tip. In this study needle electrodes were required, rather than surface electrodes, because of the deep anatomic location of the lateral pterygoid muscle. Metalic plate surface electrodes (Teca Corp.), however were used for ground connection. The needle electrodes were sterilized in ethanol baths for several hours prior to use.

The equipment was operated with a microvolt/cm setting at 200 Hz. In the range between 20 and 200Hz amplifier noise, general non-muscular tissue noise and movement artifacts are largely eliminated without significant loss of motor unit potentials (Hayes, 1960). The Time Base was set at 30 milliseconds per division, and the 60 cycle filter was turned off. The Audio Volume was at its maximum setting. The vertical position (visual picture) was adjusted so that the pattern of the electromyographic picture was vertically centered on the screen.

During the electromyographic recordings, the animals were under Ketamine HCl anesthesia. Muscle tonus of the animals was not altered since this drug is not a muscle relaxant. Hair was shaved from all insertion areas, and the Keratin layer of the

skin along with its protective oils were removed to lower electrical resistance. Electrical contact was improved at the electrode surface by the use of a saline electrode jelly (Redux Paste, Medical Products Group, Waltham, Massachusetts). The ground (surface) electrode was applied over the frontal bone close to the sagittal suture and were kept in position by adhesive strips. The concentric needle electrode was inserted through the skin 3 mm anterior to the external auditory meatus at the level of the zygomatic arch in a direction pointing towards the mandibular condyle. The needle was then carefully pushed medially and inferiorly to the condylar surface to a depth of 12 mm. Each electrode was then connected to the input plug box of the electromyograph (Plate V).

The electromyographic procedures were carried out in a large shielded cage, which consisted of a wooden frame covered with grounded copper screen. The use of this cage significantly diminished electromagnetic and electrostatic interferences. The experimental animals, cables or the electromyographic apparatus itself can act as an antenna for undesired signals, such as the ubiquitous electromagnetic effects from power lines (Basmajian, 1978). The laborarory room itself should also be isolated from any undesirable signals originating from the atmosphere and surrounding electrical fields. The room used in this study was entirely lead-lined.

Radiographic Method and Procedure

A special cephalometer was designed consisting of a plexiglass base with plastic uprights, upon which two ear posts were mounted and an anterior post for centering and holding the upper anterior teeth of the animal (Plate VI). A metal collar was attached to the cone of the x-ray unit and it incorporated a telescopic measuring pin to allow for standardization of target-object orientation and target-film distance. The film was placed in a specially constructed plexiglass holder located at a fixed distance from the midsagittal plane. Thus, fixed object-film and target-film distances were obtained. These were 7 cm and 57 cm respectively.

Lateral cephalometric radiographs were taken at the beginning, middle and end of the experimental period on Kodak X-Omat TL Ready Pack film at 0.6 seconds, 15 milliamperes and 70 kilovolts. To insure maximum clarity all the films were manually developed with a developing time of 5 minutes and a fixing time of 8 minutes. The films were washed for one hour after fixation and air-dried overnight.

Implants

At the beginning of the experiment tantalum implants with a size of 1.5 x 0.5 mm (Appolonia Dental Aktieselskab-Lersoparkalle, 109 DK 2100, Kobenhavn) were placed in cortical bone at

specific locations of the skull. The Holst implant gun was utilized (Aronson et al., 1974). Each rabbit received three implants in the body of the mandible, two implants in the maxilla, one implant in the frontal bone, one implant in the nasal bone and one implant in the occipital bone (Figure 1).

Administration of Vital Dyes

A series of three different vital dyes was administered in each rabbit at different times during the experimental period. At the beginning of the experiment 50 mg/kg body weight Oxytetracycline was administered intramuscularly (Terramycin Oxytetracycline ampules of 2 ml intramuscular solution 250 mg/ml, Pfizer Laboratories Division, Pfizer, Inc., New York, N. Y.). On the 15th day, 30 mg/kg body weight of Alizarin Complexon (Eastman Kodak Co., Rochester, New York) mixed in 2% $NaHCO_3$ solution (1 cc per kg body weight) was administered intraperitoneally. Fifteen mg/kg body weight of DCAF (2,4 BIS) N, N'DI (Carboxymethyl) (Aminomethyl Fluorescein) (Life Sciences Group of ICN Pharmaceuticals, Inc., Cleveland, Ohio) mixed in 2% $NaHCO_3$ solution were administered intraperitoneally in each rabbit 24 to 48 hours prior to sacrifice.

Weight of the Animals

The animals were weighed at the beginning of the experiment (Table I) and every third day thereafter. The final

Figure 1. Implant location.

M_1, M_2, M_3: Mandibular corpus

Z: Zygomatic process of maxilla

MC: Maxillary corpus

F: Frontal bone

N: Nasal bone

O: Occipital bone

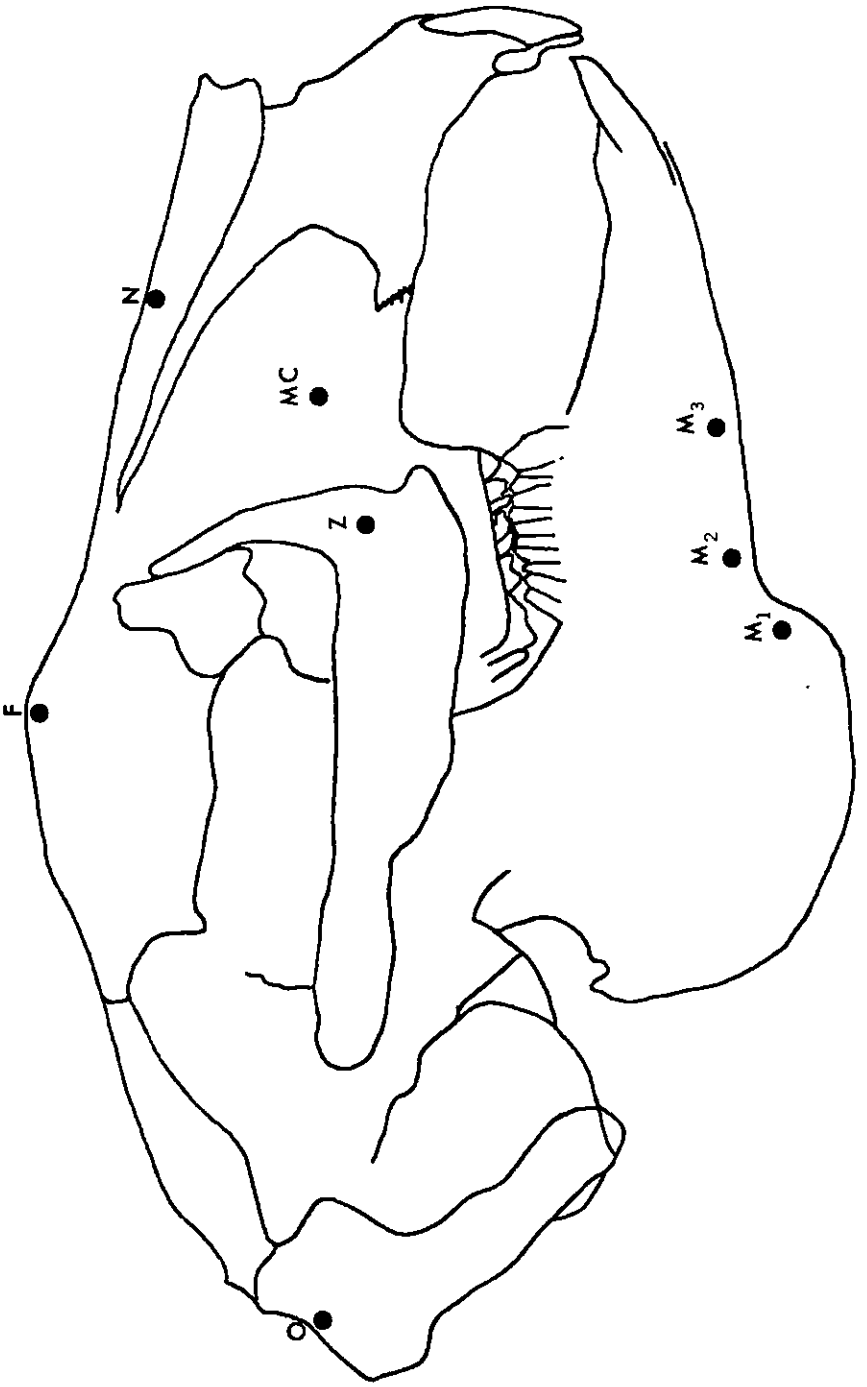

N
MC
N
F
O
M3
M2
M1

PLATE VI

Cephalometer

body weight was determined immediately prior to sacrifice (Table I).

Histologic Procedures

The animals were perfused with 10% formalin through an intra-cardiac route. In addition to Ketamine HCl and Xylazine, one ml of Pentobarbitol Sodium per kg body weight was also administered intraperitoneally in order to attain surgical level of anesthesia. The skulls were hemisectioned and the right half was used for decalcified sections while the left half was used for ground sections.

The mandibular condyle, glenoid fossa, and associated tissues were dissected out from the right hemisection of each animal and placed in 10% buffered formalin for two weeks. The specimens were then decalcified in a 4% solution of formic acid. The tissues were radiographically examined periodically to determine degree of decalcification. The tissue specimens were then dehydrated in a series of alcohol baths. Following this, they were placed under vacuum in a solution composed of equal parts of absolute alcohol and toluene for two hours and later in toluene for another two hours. The tissues were then placed in two baths of liquified paraffin, two hours in each. Finally the tissues were placed in premelted paraffin for an additional 2 to 4 hours under vacuum and then embedded in paraffin blocks for sectioning at 6 m.

The mandibles of the left hemisections were cleaned of all soft tissue and embedded in Bio-Plastic (Ward's, Rochester, New York). The Bio-Plastic embedding process consisted of the following steps:

1. Rinsing fixed and cleaned specimens in running tap water for 2 to 8 hours.
2. Dehydration in 70%, 95% and absolute alcohol (12 hours in each solution).
3. Dehydration in absolute alcohol for another 24 hours.
4. Placement of the specimens in acetone for 24 hours.
5. Placement of the specimens in fresh acetone solution for an additional 48 hours.
6. Placement of the specimens in uncatalyzed Bio-Plastic I (Resin without hardener) for 48 hours.
7. Draining and then placement of the specimens in catalyzed Bio-Plastic (mixture of resin and hardener).
8. The Bio-Plastic was allowed to cure in 60° C for 48 hours.

Serial condylar and ramal ground sections, 120 m thick, were prepared from the mandibles embedded in Bio-Plastic.

Histochemical Procedures

Lateral pterygoid muscle tissue from two control and two experimental rabbits subjected to "heavy" forces were prepared for histochemical study. Biopsies, 3-5 mm thick, were excised from the superior, middle and inferior portions of the muscle, and then quick frozen in acetone cooled with dry ice. Serial cross-

sections 14 m thick were cut from the frozen blocks in a cryostat (International Cryostat, IEC, Model CTI, Needham Heights, Massachusetts). The sections were collected directly from the microtome blade onto warm, clean glass slides and kept in the cryostat until used for histochemical processing as described below.

Method for Calcium-activated ATPase

The procedure utilized is described by Chayen et al. (1969) and involves the following steps:

1. Sections are incubated in freshly prepared reaction medium at 37°C for 10-20 minutes. Reaction medium: 0.1 M sodium barbiturate solution (2.06 g/100 ml), 20 ml; ATP, 152 mg; 2,4 dinitrophenol, 60 mg; calcium-chloride solution (10.5 g, $CaCl_2.2H_2O$/100 ml), 10 ml; distilled water, 70 ml.
2. Wash in three changes of 1% calcium chloride for two minutes in each bath.
3. Transfer to 1% cobalt nitrate solution for 2 minutes and then wash in two changes of the same solution for two minutes.
4. Wash in distilled water to remove adsorbed cobalt for 1 minute.
5. Place in dilute ammonium sulphide (0.5%v/v) for 1 minute.
6. Wash in distilled water for 2 minutes.
7. Mount the sections with gelatin.

ATPase activity is shown by a brown-black precipitate of cobalt-sulphide. Control: the reaction may be controlled by incubating

a serial section under the same conditions but with glycerophosphate in place of the adenosine triphosphate.

Tetrazolium-Formazan Method for Succinic-Dehydrogenase

The method described by Lillie and Fullmer (1976) was followed for succinic dehydrogenase activity. The procedure involves the following steps:

1. Incubate sections in the freshly prepared reaction medium at 37°C for 15 minutes. Reaction medium: dissolve 10 mg nitroblue tetrazolium in 30 ml 0.1 M phosphate buffer of pH 7.6 and add 30 ml 0.1 M sodium succinate. The 0.1 M phosphate buffer of pH 7.6 was taken by mixing 13% of 0.1 M monobasic phosphate solution and 87% of 0.1M dibasic phosphate solution.
2. Wash tissues for 1 minute in distilled water.
3. Mount tissues with gelatin.

Sites of succinic dehydrogenase activity stain blue. Controls: immerse sections for 30 minutes in 0.01 M iodoacetate (185 mg iodoacetic acid in 100 ml 0.01 N(NaOH). This leads to complete inactivation.

Cephalometric Procedure

A cephalometric analysis was performed to determine patterns of regional remodeling and displacement for the mandible in each individual rabbit. Tracings of initial and final cephalograms were superimposed on the mandibular implant markers to identify areas of directional remodeling. In addition, tracings of

each rabbit's initial and final cephalograms were superimposed on the cranio base in order to test for mandibular displacement.

Two measurements were taken from each rabbit's cephalograms: posterior ramal height and ramal height along the mid-condylar-ramal axis. These two measurements were determined as follows: a neutral vertical axis was constructed through the mandibular ramus. The neutral axis is a line perpendicular to and centrally located between every point on the anterior ramal aspect and their corresponding points on the posterior ramal aspect. However, in this study not all points on the anterior aspect of the ramus had corresponding points on the posterior border of the ramus, which were perpendicular to, and equidistant from, the neutral axis. Therefore, the neutral ramal axis was constructed in a manner which allowed the greatest match between the anterior and posterior points. In order to achieve the most accurate location of the neutral ramal axis, an error of inspection was involved.

The mandibular plane was defined as the plane connecting the two most inferior points tangent to the lower mandibular border. Ramal height along the condylar-ramal axis was defined as the distance from the intersection point of the neutral axis and the condyle to the intersection point of the neutral axis and the mandibular plane. Posterior ramal height was defined as the perpendicular distance from the intersection point of the neutral

axis on the condyle to an intersection point on the mandibular plane (Figure 2).

Figure 2. Cephalometric Landmarks and Analysis.

A. intersection point of the neutral axis and the condyle.

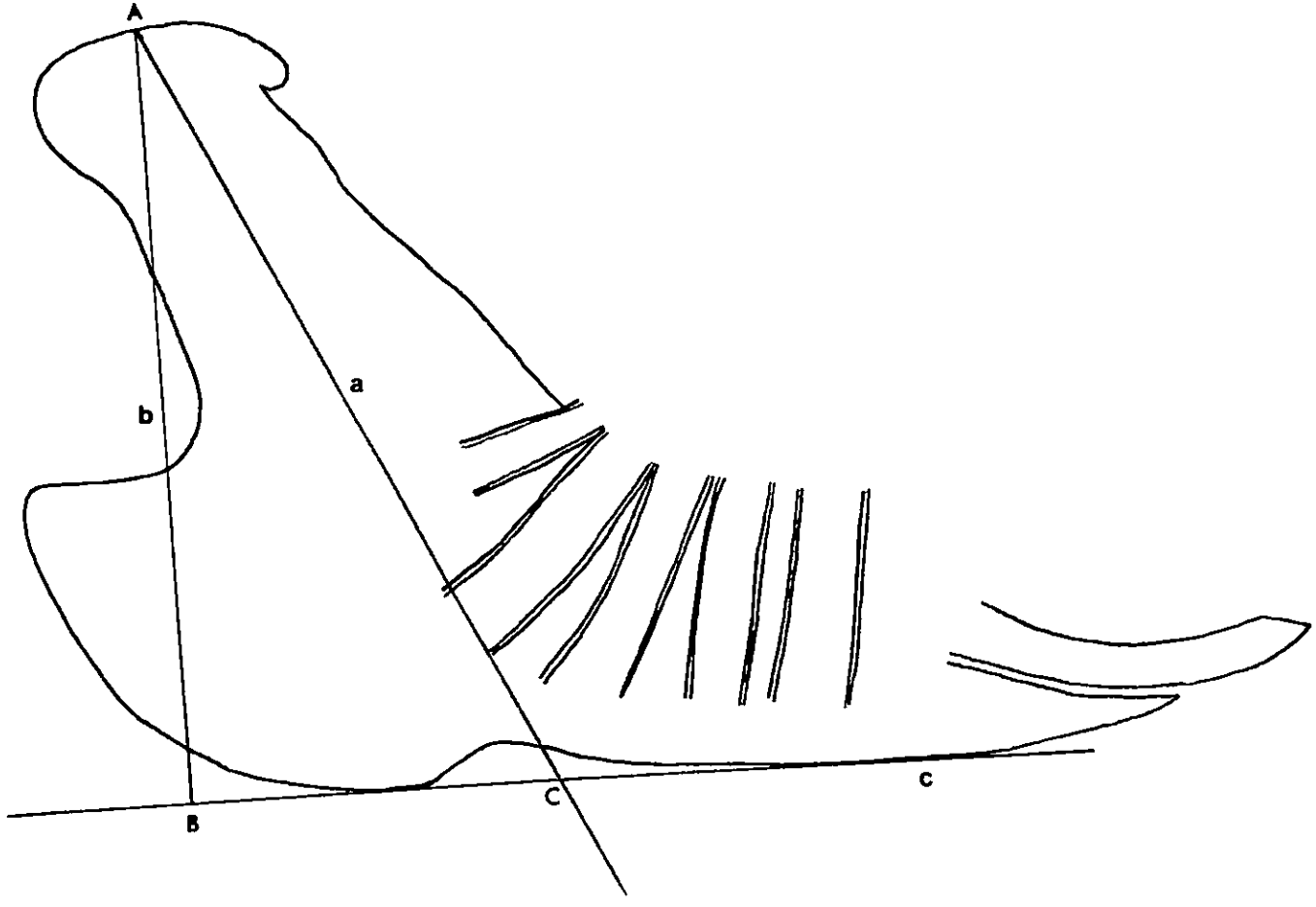
B. intersection point of the mandibular plane and a perpendicular line to the mandibular plane dropped from point A.

C. intersection point of the neutral axis and the mandibular plane.

a. neutral axis
b. perpendicular line from point A to the mandibular plane
c. mandibular plane.

AC: Ramal height along the condylar-ramal axis.

AB: Posterior ramal height.


A
a
b
B
C
c

RESULTS

Weight Gain

There were individual differences in animal weight gain throughout the experimental period, but the analysis of variance did not show any significant weight differences between groups at the 5% level of confidence (Table I).

Skull Inspection

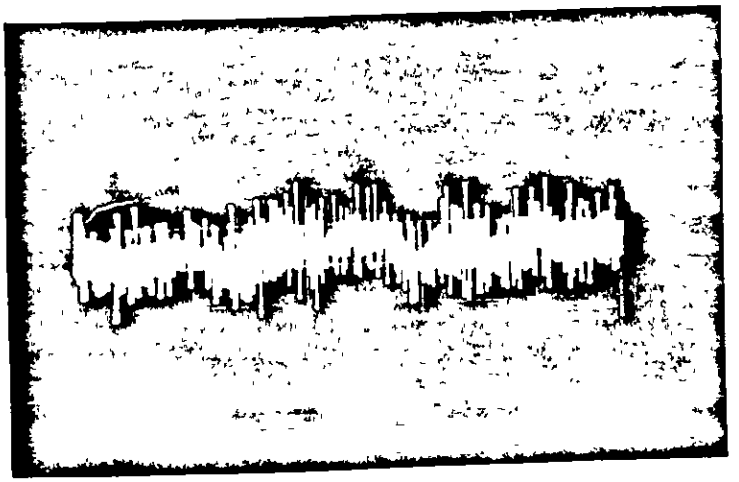
As soon as the animals were perfused and sacrificed, the skulls were dissected from the overlying skin and were inspected for gross skeletal malformations and dental malocclusions. All rabbits exposed to "heavy" traction forces revealed a severe anterior overjet resulting from a marked extent of mandibular retrusion. Rabbits exposed to "light" traction forces revealed only a very slight overjet. Rabbits with appliances but without force had a bite similar to that in rabbits exposed to "light" traction forces. Control rabbits without appliances revealed a normal end-to-end bite.

Electromyographic Results

The electromyographic pattern of the lateral pterygoid muscles exposed to "heavy" forces was identical throughout the entire experimental period (Plate VII). This pattern severely deviated from the electromyographic electrical activity of the

PLATE VII

Electromyogram: lateral pterygoid muscle activity for the "heavy" force group at the termination of the experiment



normal resting lateral pterygoid muscle. The motor unit peaks associated with the "heavy" traction forces were 1.5 cm high, which were 15 times higher than in the normal resting muscle.

The electromyographic pattern of the lateral pterygoid muscles exposed to "light" traction forces deviation much less sharply from that of the normal resting muscles, and this continued throughout the entire experimental period. The motor unit peaks were about twice the height of those of the normal resting muscle (Plate VIII).

The electromyographic patterns of the lateral pterygoid muscles from both control groups with and without appliances were very similar (Plate IX).

Cephalometric Analysis

Regional cephalometric superimposition revealed the following mandibular remodeling patterns:

1. With rabbits exposed to "heavy" forces, the condyle and the superior one-third of the ramus displayed new bone depository activity on the anterior aspect and resorptive activity on the posterior aspect. The lower two-thirds of the ramus was depository on the anterior aspects and no bone deposition or resorption could be identified on the posterior aspects. There was a depository field on the gonial angle area (Figure 3).

2. With rabbits exposed to "light" forces and all control rabbits the condylar and ramal remodeling patterns were identical: The condyle and the superior one-third of the ramus were resorptive on their anterior aspects and depository on their posterior aspects. The lower two-thirds of the ramus were depository on the anterior and posterior aspects. There was also a depository field on the gonial angle area (Figure 4).

PLATE VIII

Electromyogram: lateral pterygoid muscle activity for the "light" force group at the termination of the experiment.

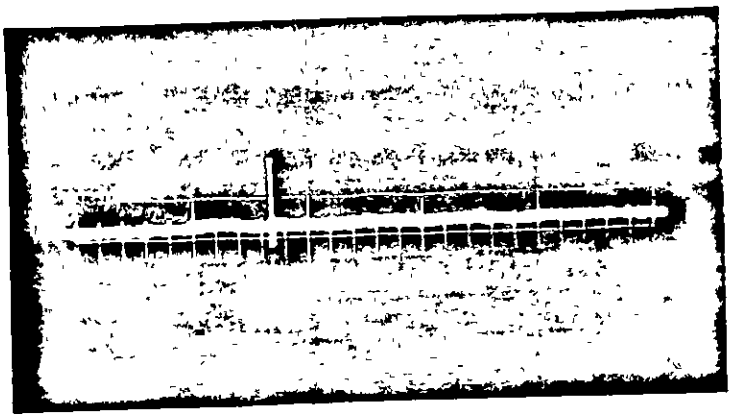


PLATE IX

Electromyogram: Normal activity of the rabbit resting lateral pterygoid muscle.



Figure 3. Superimposition on mandibular implant markers of the initial and final cephalometric radiographs from "heavy" force subject.

 Periosteal deposition

 Periosteal resorption

------ Initial cephalogram

_____ Final cephalogram

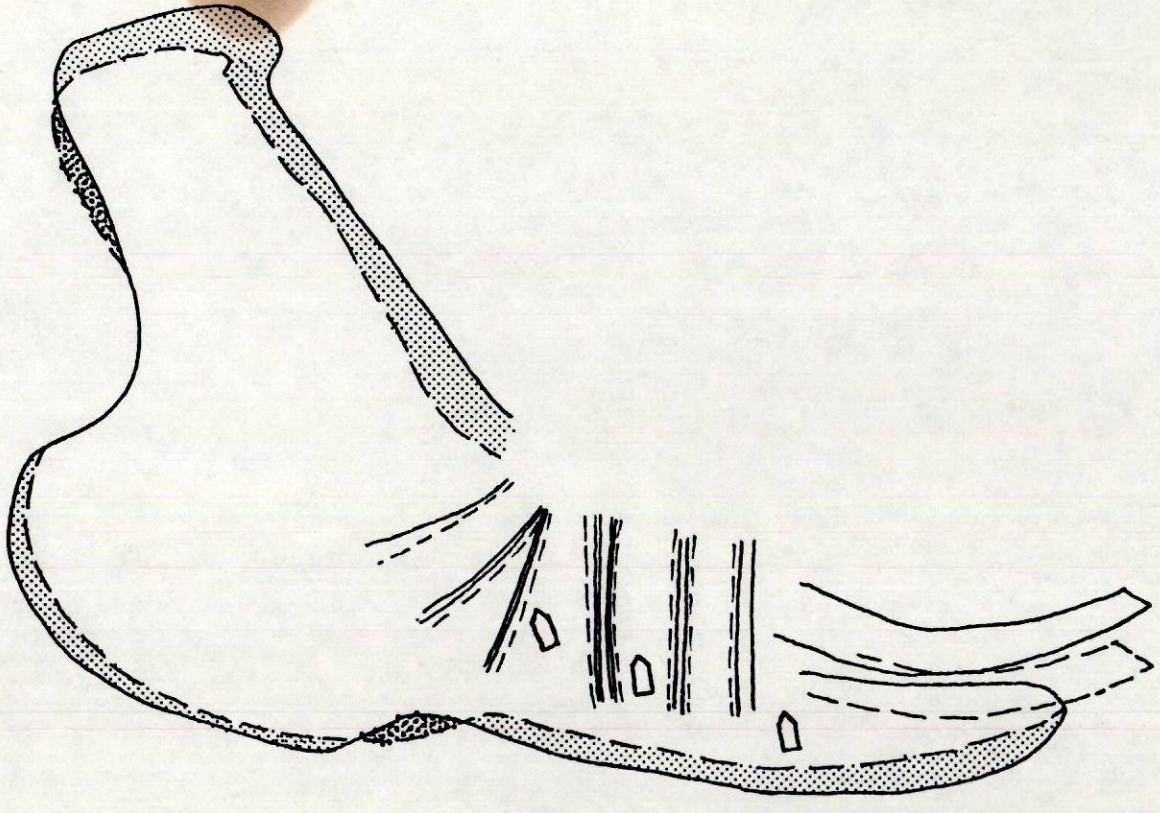


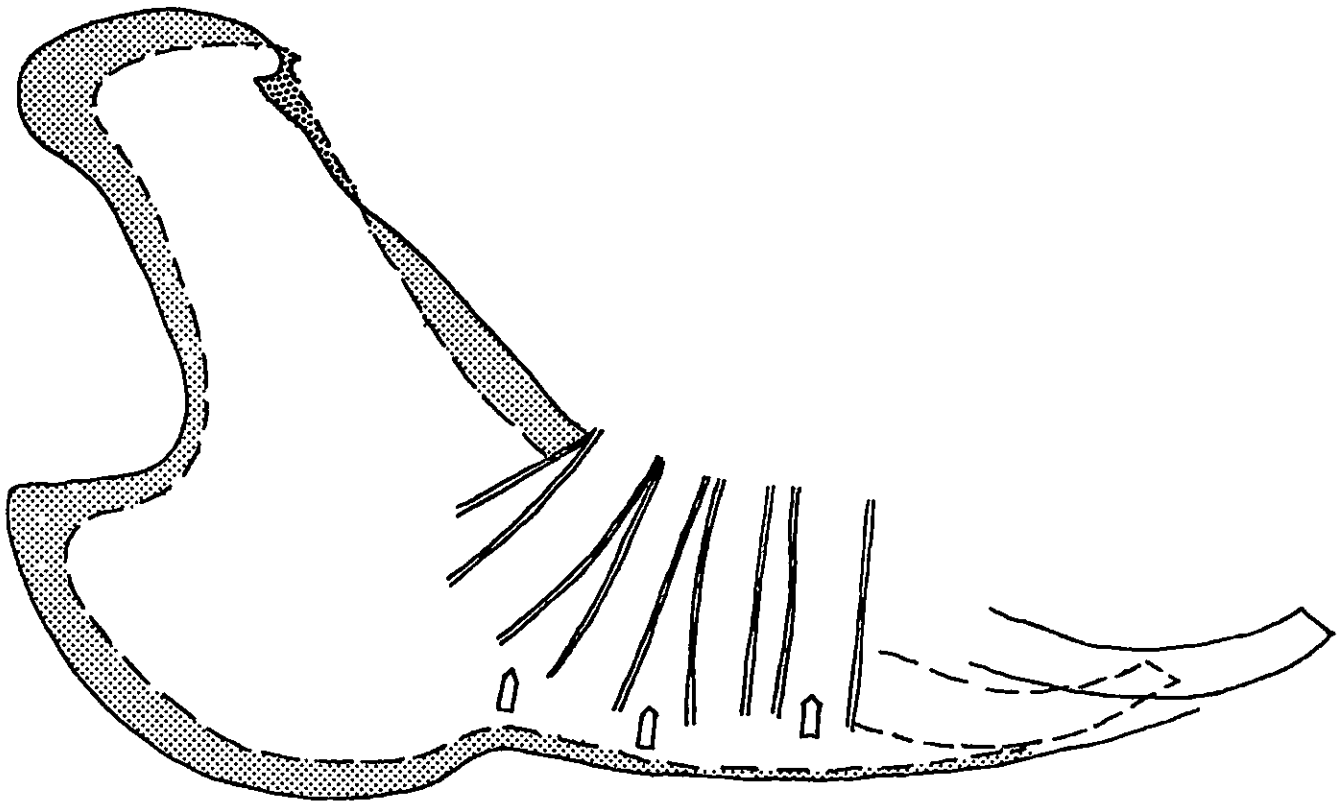
Figure 4. Superimposition on mandibular implant markers of the initial and final cephalometric radiographs from "light" force subject.

 Periosteal deposition

 Periosteal resorption

------ Initial cephalogram

_____ Final cephalogram



Growth changes in the posterior ramal height and the ramal height along the condylar-ramal axis from the initial and funal radiographs of all rabbits were determined (Tables III and IV). The analysis of variance showed that there were significant differences (p 0.01) between the groups (Tables V and VI). Using the paired t-test, it was shown that there were significant differentss (p 0.05) in ramal height between all groups (Tables VII and VIII).

Histologic Results

Serial ground sections from experimental and control animals injected with vital dyes showed the following features. The remodeling patterns of animals exposed to "light" forces and those of the control animals were essentially similar. The posterior margin of the entire ramus was found to be depository in both groups. There was also simultaneous resorption along the anterior border of the superior one-third of the ramus. The lower two-thirds of the anterior margin was depository. The lingual surface of the ramus was predominantly depository while the contralateral side was largely resorptive (Figures 5 and 6).

The animals exposed to "heavy" forces showed essentially opposite remodeling patterns in the ramus, as compared with controls and animals exposed to "light" forces. The posterior margin of the condyle and the superior one-third of the posterior

TABLE III

CHANGES IN RAMAL HEIGHT ALONG THE CONDYLAR-RAMAL AXIS

Group	Rabbit	Initial (cms)	Final (cms)	Difference (cms)	$\bar{X}$	S.D.
1	5	10.20	10.76	0.56	0.38	0.28
	6	10.36	10.46	0.10		
	14	11.77	12.40	0.66		
	16	11.59	11.77	0.18		
2	4	11.05	11.96	0.91	0.92	0.20
	7	10.27	11.02	0.75		
	8	11.20	12.03	0.83		
	9	10.04	11.24	1.20		
3	10	10.48	12.37	1.89	1.80	0.12
	12	11.12	12.84	1.72		
4	18	12.46	14.41	1.95	1.89	0.08
	20	11.94	14.18	1.83		

TABLE IV

CHANGES IN POSTERIOR RAMAL HEIGHT

Group	Rabbit	Initial (cms)	Final (cms)	Difference (cms)	$\bar{X}$	S.D.
1	5	8.50	9.17	0.67	0.54	0.18
	6	8.93	9.37	0.44		
	14	11.25	11.96	0.71		
	16	10.97	11.31	0.34		
2	4	9.85	10.65	0.80	0.87	0.17
	7	9.36	10.20	0.84		
	8	9.54	10.26	0.72		
	9	9.35	10.46	1.11		
3	10	9.12	10.37	1.25	1.395	0.21
	12	10.18	11.72	1.54		
4	18	11.13	12.69	1.56	1.45	0.16
	20	10.56	11.89	1.33		

TABLE V

STATISTICAL ANALYSIS: CHANGES IN RAMAL HEIGHT ALONG THE CONDYLAR-RAMAL AXIS

ANALYSIS OF VARIANCE

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Between Groups	4.45	3	1.48	29.6
Within Groups	0.37	8	0.05	
Total	4.82	11		

Significant difference at p .01

TABLE VI

STATISTICAL ANALYSIS: CHANGES IN POSTERIOR RAMAL HEIGHT

ANALYSIS OF VARIANCE

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Between Groups	1.5896	3	0.53	17.67
Within Groups	0.25	8	0.03	
Total	1.8396	11		

Significant difference at p .01

TABLE VII

STATISTICAL ANALYSIS: CHANGES IN RAMAL HEIGHT ALONG THE CONDYLAR-RAMAL AXIS

t-tests

Group	Group 1	Group 2	Group 3	Group 4
1		t = 3.51 p .05	t = 7.47 p .05	t = 7.94 p .05
2			t = 4.63 p .05	t = 5.10 p .05
3				t = 0.41 p .05
4				

TABLE VIII

STATISTICAL ANALYSIS: CHANGES IN

POSTERIOR RAMAL HEIGHT

t-tests

Group	Group 1	Group 2	Group 3	Group 4
1		t = 2.62 p .05	t = 5.52 p .05	t = 6.07 p .05
2			t = 3.53 p .05	t = 3.86 p .05
3				t = 0.30 p .05
4				

Figures 5 and 6. Rabbit ramus. Figure 5 is a lingual view and Figure 6 is a buccal view of a rabbit ramus exposed to "light" traction force.

 Periosteal deposition

 Periosteal resorption

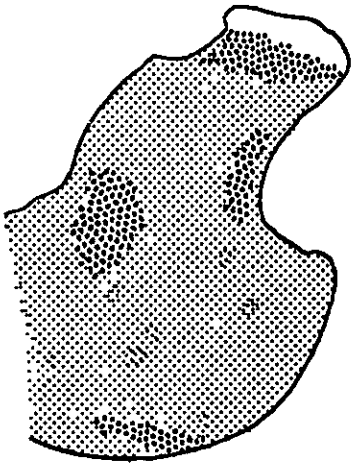


Figure 5

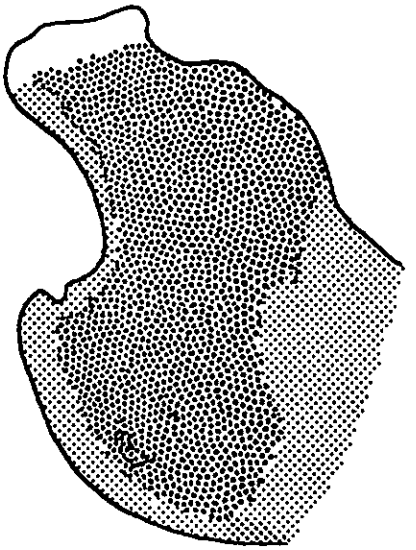


Figure 6

margin of the ramus was resorptive, whereas the corresponding portion of the anterior border was depository. The posterior margin of the lower two-thirds of the ramus was inactive, but the corresponding segment of the anterior border was actively depository. The lingual side of the condyle and the superior one-third of the lingual surface of the ramus was resorptive, while the corresponding buccal surface was depository. The lingual surface of the lower two-thirds of the ramus was predominantly depository, and the buccal side was resorptive (Figures 7 and 8).

Examination of serial decalcified sections of the condyle and the associated joint tissues revealed the following. The meniscus of animals exposed to "heavy" forces was approximately double the thickness of control discs. The increased thickness was not, however, primarily due to significant increase in collagenous fibers because the collagen bundles of the wider discs appeared less dense than those of the control animals. The TMJ discs of animals exposed to "light" forces were similar in thickness and density to those of the control animals.

The prechondroblastic condylar layer of the condyle was less active in animals exposed to "heavy" forces as compared to the control animals. The area below the prechondroblastic layer was more active in the "heavy" traction force animals. There was no organization and hypertrophy of cells corresponding to the

Figures 7 and 8. Rabbit ramus. Figure 7 is a lingual view and Figure 8 is a buccal view of a rabbit ramus exposed to "heavy" traction force.



Periosteal deposition



Periosteal resorption

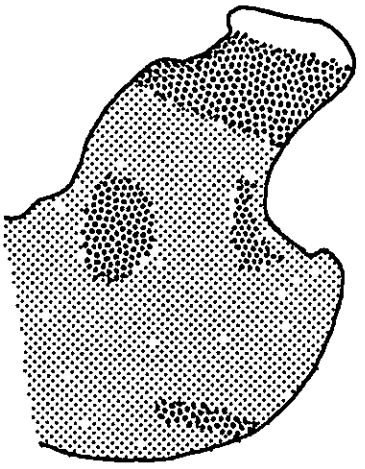


Figure 7

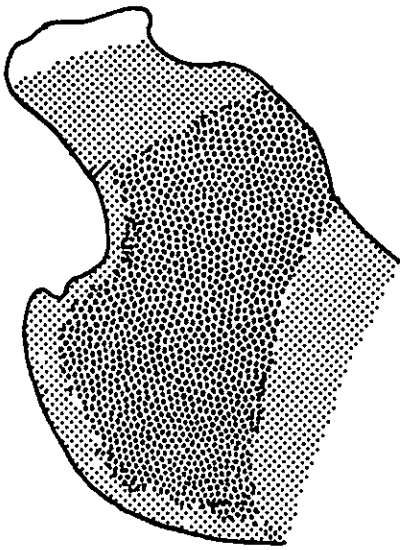


Figure 8

hypertrophied layer of the controls. The prechondroblastic condylar layer in animals exposed to "light" forces was more active than that in animals exposed to "heavy" forces but less active in the control animals.

DISCUSSION

The purpose of this study was to investigate the effects of a distal mandibular traction utilizing a chin cap appliance, on the process of mandibular growth. Previous studies (Jansen and Bluher, 1965; Petrovic et al., 1975) used retracting forces on the mandible without any attempt to classify the magnitude of the applied forces and their subsequent effects on surrounding biologic tissues. To provide insight into the biological basis for the use of retracting orthodontic forces, we attempted to correlate the level of such forces with the activities of the lateral pterygoid muscle. The study was based on the hypothesis that as mandibular retrusive forces are applied against the temporomandibular joint surfaces, the lateral pterygoid muscles immediately contract to prevent contact with the superior and posterior boundaries of the fossa. Such a contractile muscular response would presumably serve as a protective mechanism preventing pathology and discomfort in the temporomandibular joint. Such an action, however, would result in a change in the intended nature of the force being applied to the condyle. Consequent changes in the nature of growth responses could thereby be expected.

The design and construction of a mandibular traction appliance was of primary concern because its use should not

interfere with the animal's normal feeding regimen. In our pilot studies various trial appliances were fabricated and experience with them led to the selection of features and properties of the final design. The portion of the appliance exerting the direct retrusive force against the mandible must be fixed within the oral cavity. In order to avoid postoperative surgical complications, surgical wiring of the appliance around the mandible would be inappropriate. Thus, the intraoral part of the appliance was cemented onto the lower dentition. The anchoring portion of the appliance should ideally be behind the posterior border of the mandibular ramus and located in such a manner that the force would be exerted in a direction pointing posteriorly from the mandibular symphysis toward the temporomandibular joint. The possibility of using implanted metal posts within the rabbit's skull was rejected because this would jeopardize the animal's survival. Rather, an acrylic collar was placed around the rabbit's neck to provide an anchor for force exertion.

It was found that a close interrelationship exists between applied retrusive forces onto the mandible and the activity of the lateral pterygoid muscle. In animals having "heavy" distal traction forces, the lateral pterygoid muscle was in a continuous contractile state throughout the entire experimental period. The electromyographic picture of the lateral pterygoid muscle in animals with "light" forces was only slightly different from that of the resting muscle in control animals.

McNamara (1973) stated that induced retrusive function of the mandible in monkeys increased the activity of the superior head of the lateral pterygoid muscle. Petrovic et al. (1975) concluded that stretching the lateral pterygoid muscle by means of a chin cap appliance does elicit a weak, short-lived, myototic reflex because the resultant level of muscle contraction is not sufficient to stimulate increased condylar growth. These investigators based their conclusions on the fact that smaller numbers of neuromuscular spindles exist in the lateral pterygoid muscle. Petrovic and his co-workers also referred to the presence of Golgi tendon organs within the articular disc. These structures provoke the inhibition of motor neuron activity in the lateral pterygoid muscle and thereby result in a decrease of contractile muscle tension. In contrast to Petrovic's hypothesis we found strong, continuous lateral pterygoid contraction in the myographic patterns of the animals subjected to "heavy" retrusive forces. In the animal group subjected to "light" retrusive forces the electromyographic pattern was also constant throughout the 30 day experimental period but with only a very slight divergence from that of the resting muscle in control animals. Frank's (1964) statement that: "the frequent clinical sign of hyperactivity in the lateral pterygoid muscle may be related to spindle absence if this is confirmed in primates", would appear to support our findings.

Type I low threshold-slowly adapting mechanoreceptors in the fibrous joint capsule working together with Type II higher threshold-slowly adapting mechanoreceptors in the temporomandibular ligament (Greenfield and Wyke, 1964) send proprioceptive information to the central nervous system. The central nervous system then sends appropriate messages to the peripheral musculature for the protection of the temporomandiublar joint from any distortion resulting from distal mandibular traction. That would support the idea of a protective contractile function for the lateral pterygoid muscle, especially in "heavy" force mandibular retrusions. Our findings were also supported by Larsson and Thilander's (1964) observation that pressure applied to the TMJ enhances its ability to detect mandibular position, due to the role of cutaneous receptors over the joint. Our histochemical findings demonstrated a different level of contractile activity of the lateral pterygoid muscles in animals subjected to "heavy" force distal traction compared to control animals.

Tantalum implants inserted into the mandibles drifted out of position during the experimental period and therefore caused a problem in accurate superimposition and interpretation of the cephalometric radiographs. Nevertheless, ground sections showing vital dye lines gave us the necessary information needed to be able to analyze patterns of ramal and condylar remodeling. The remodeling patterns of the animals subjected to "light" forces

and the control animals were essentially similar. The posterior margin of the entire ramus was found to be depository. There was also simultaneous resorption along the superior one-third anterior border of the ramus. The medial surface of the ramus was predominantly depository, while the lateral side was resorptive in nature. The ramus as a whole drifted posteriorly. These findings are in agreement with those of Bang and Enlow (1967) and Seiton and Engel (1969). Concurrently, the entire mandible was displaced forward and downward. On the other hand, the animals subjected to "heavy" forces followed to a large entent, opposite remodeling patterns from those animals subjected to "light" forces and the control ones. The displacement of the mandible as a whole was also basically different, in that this occurred in a posterior direction in animals subjected to heavy forces. The different remodeling pattern is most likely due to the altered activity of the lateral pterygoid muscle and the destructive pathology in the joint following application of "heavy" distal traction forces. The opposite displacement is probably due to the fact that the lateral pterygoid muscle although being in a constant contractile state could not overcome the "heavy" retrusive forces. Since there is an extreme freedom in the rabbit temporomandibular joint the mandible could grow in a posterior and distal direction. Measurement of the actual ramal height indicate that the growth of the ramus was significantly decreased in animals subjected to mandibular retraction.

SUMMARY AND CONCLUSIONS

Twelve albino New Zealand rabbits were used to study the effect of distal traction on the growth of the mandible. The animals were divided into four groups, two experimental and two control. Experimental Group 1 consisted of four animals exposed to "heavy" force application. Experimental Group 2 consisted of four animals having "light" force application. Control Group 3 consisted of two animals with experimental appliances but without force. An inactive elastic was used to connect the two parts of the appliance in this group. Control Group 4 consisted of two animals which had neither experimental appliances or force application. The experimental period lasted for thirty days.

The experimental procedure included: placement of tantalum implants in the mandible, maxilla, frontal, nasal and occipital bones; taking of cephalometric radiographs of the animals on the 1st, 15th and 30th experimental days; administration of vital dyes on the 1st, 15th and 28-29th experimental days; and, electromyograms of the lateral pterygoid muscle at the beginning and on alternate days throughout the 30-day experimental period. Cephalometric analysis of the radiographs were performed. Two different measurements of ramal heights were analyzed with inferential statistics. Histology of serial ground and decalcified

sections was carried out. A histochemical study for ATPase and succinic dehydrogenase activity in the lateral pterygoid muscle from two control and two experimental animals receiving "heavy" forces was also conducted. This study was carried out to test different levels of contractile activity in the lateral pterygoid muscles of control and experimental animals subjected to "heavy" forces.

Analysis of the cephalometric, histologic, electromyographic and histochemical data led to the following conclusions: The "heavy" traction forces diminished mandibular growth ($p < .05$). "Heavy" forces resulted in a muscular imbalance expressed by continuous contractile activity of the lateral pterygoid muscle and the condyle and portions of the superior aspect of the ramus demonstrated opposite remodeling patterns compared to control animals. There was a definite change in the structural and cellular morphology of the meniscus and the condylar cartilage in animals exposed to "heavy" forces compared to the control ones. "Light" traction forces also diminished mandibular growth ($p < .05$). Nevertheless, there was a difference in the ramal height of animals subjected to "heavy" forces as compared to those subjected to "light" forces ($p < .05$). "Light" traction forces did not cause any significant electromyographic pattern deviation as compared to the resting muscles' electrical activity. "Light" traction force condylar and ramal remodeling

was similar to that of the control group. There were histological and morphological changes in the articular disc of "light" traction force animals but the structural and cellular pictures were more similar to the control group.

Thus, it is concluded that "light" traction forces are preferable for inhibiting control of mandibular growth. They significantly diminish the extent of mandibular growth without causing any significant destructive changes in the joint. "Light" forces have the added advantage of avoiding muscular over-reactions. In contrast, "heavy" traction forces diminish growth of the lower jaw, but create serious functional and structural imbalances in the surrounding parts and tissues. Additionally, "heavy" forces cause destructive changes in the temporomandibular joint. Thus, a level of retrusive force exists (25 grams in our experiments), that can (a) cause a pressure effect on the condyle, but (b) not trigger strong contractile activity of the lateral pterygoid muscles, thus successfully resulting in growth inhibition of the condyle.

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