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Hyoid Positioning Following Forced Distal Positioning of the Tongue During Swallowing

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HYOID POSITIONING FOLLOWING FORCED DISTAL POSITIONING OF THE TONGUE DURING SWALLOWING

by

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AUTOBIOGRAPHY

Gary Samuel Cuozzo was born in Montclair, New Jersey on April 26, 1941, the second son of a dentist and his wife, Dr. and Mrs. Pasquale John Cuozzo. The author has an older brother John, an M.S. and an orthodontic graduate of Loyola University (1965), and a younger sister, Patricia, a dental hygiene student from the University of Pennsylvania (1966).

Gary graduated from Glen Ridge High School in Glen Ridge, New Jersey, in 1959.

He received an athletic scholarship from the University of Virginia, and graduated with a Bachelors of Arts Degree in 1963. In 1963 he signed a professional football contract with the Baltimore Colts and played four years there. The following six years in professional football were divided amongst three teams: New Orleans Saints (1), Minnesota Vikings, (4), and Saint Louis Cardinals (1).

During the off-seasons of the first seven years in professional football, Dr. Cuozzo attended the University of Tennessee Dental School and graduated in 1970.

In 1970, he began his studies in Oral Biology and Orthodontics at Loyola University of Chicago.

Dr. Cuozzo was married to Margaret Taylor in 1965, and they have four children: Kimberly 7, Gary Jr. 5, Patrick 4, and Jeffrey.

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I will always be deeply indebted to Loyola University and Drs. Hilgers, Madonia, Rapp and Jensen who have made my graduate education possible in coordination with my professional football career.

I am very grateful to my parents who have helped me strive for high goals through their constant encouragement.

No words can express the admiration and appreciation I have for my wife, Peg, who in the last seven years, has blessed me with four wonderful children and helped us move sixteen times to keep our family from being separated due to the combination of our football and dental education.

Last of all, I would like all readers of this acknowledgement to know that I thank God for blessing me with the talent to accomplish these things in my first thirty-two years of life.

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I. INTRODUCTORY REMARKS AND STATEMENT OF THE PROBLEM

The purpose of this study was to determine the amount of change in positioning of the hyoid bone during deglutition following forced distal positioning of the tongue by a tongue crib.

The hyoid bone is completely suspended by muscular and ligamentous attachments resulting in an ability to alter its positioning due to surrounding musculature tensions. The study is two fold:

A. Cinefluorographic sequences of deglutition were taken before and twenty-four hours after insertion of a crib to reposition the tongue distally.

B. A myometric study was done to measure the anterior force of the tongue during normal swallowing without a crib, and the force immediately upon insertion of the distally displacing tongue appliance as well as twenty-four hours after insertion.

II. REVIEW OF LITERATURE

A. The Hyoid Bone

The hyoid bone is shaped like a horseshoe and referred to by Sicher (1970) as the skeleton of the tongue. It is located just above the thyroid cartilage in the middle sagittal third of the neck between the third and fourth cervical vertebrae. Embryologically, according to Orban (1962), the hyoid develops from the mesoderm of the second and third brachial arches. The hyoid is divided into three parts: an unpaired middle part, the body, and the paired greater and lesser horns. The greater horn and majority of the body are derived from the third arch; the lesser horn and medial part of the body are derived from the second arch. The bone is ossified from six centers: two within the body, and one within each horn. Ossification begins in the greater horn near the end of the fetal life; in the body, shortly afterward; in the lesser horns, during the first or second year after birth.

According to Gray (1956) the lesser horns are conical in shape and arise superiorly at the junction of the body and greater horns. The stylohyoid ligament attaches to the lesser horn. The body is quadrilateral in form and anteriorly is divided by a transverse ridge into superior and inferior portions. The superior surface serves for muscle attachments of the geniohyoid, condroglossus and genioglossus muscles. The inferior surface anteriorly gives insertion for the sternohyoid, mylohyoid and omohyoid muscles. The posterior surface of the body is smooth and separated from the epiglottis by the hyothyroid membrane and some loose areolar tissue. The superior border is rounded, and gives rise to the hyothyroid membrane. Dorsolaterally, the stylohyoid, thyrohyoid, and digastric muscles insert into the anterior two thirds of the greater horn. The greater horn, superiorly, gives origin to the middle pharyngeal constrictor; and, inferiorly, to the hyoglossus muscle.

A hyoid is a non-articulating bone, suspended entirely by ligaments and tendons attaching to these several structures. (See Figures II 1 and 2).

1. tongue (via the hyoglossus and genioglossus muscles)
2. mandible (via the mylohyoid, geniohyoid, genioglossus and digastric muscles

FIG. II 1

HYOID BONE

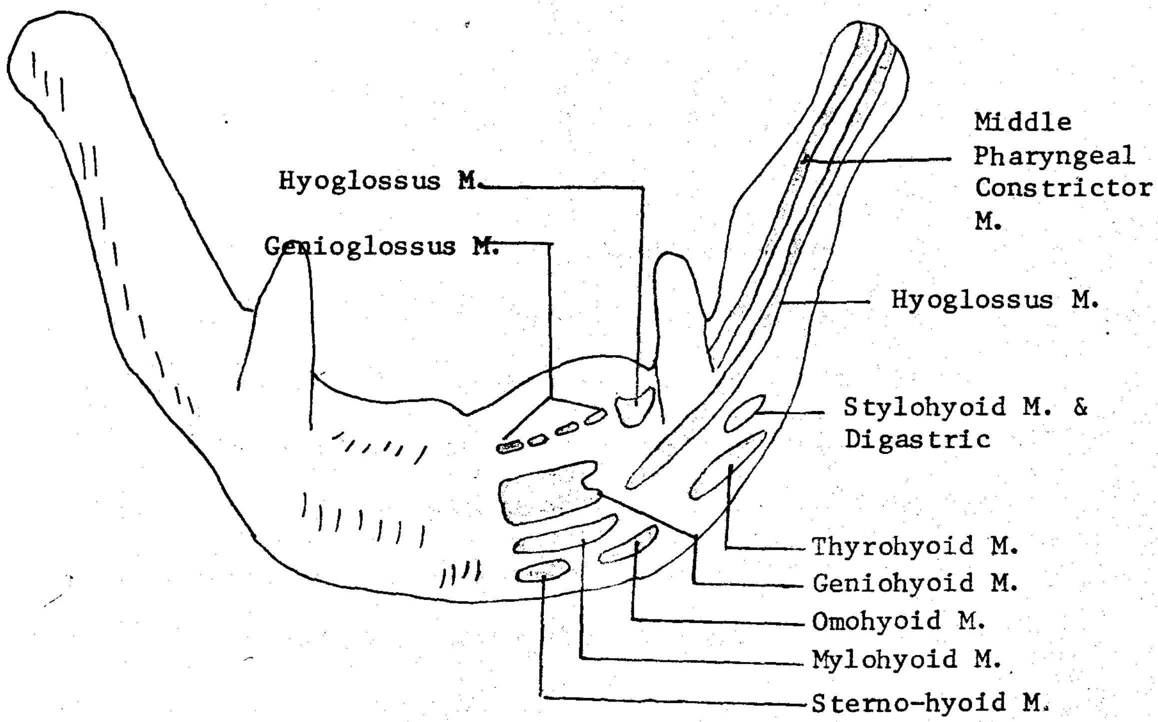
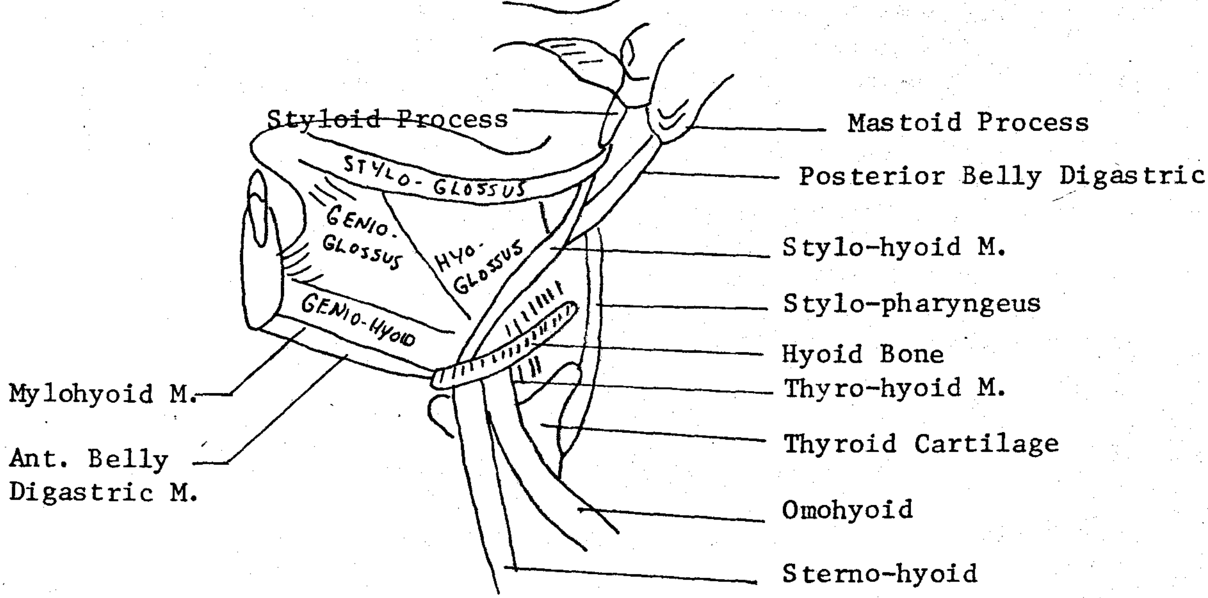


FIG. II 2

TONGUE AND HYOID MUSCULATURE



From Stepovich (1965)

3. base of skull (via the stylohyoid ligament and digastric muscles
4. sternum (via sternohyoid muscles)
5. scapula (via omohyoid muscles)
6. thyroid cartilage (via hyothyroid membrane and ligament)
7. pharynx (via middle pharyngeal constrictor)

Prior to 1950, there were very few references to the hyoid bone in the literature. The early descriptions were anatomical and very little was written about its functional movements.

Most comparative anatomists feel the hyoid bone is witness to the fact that there is a decrease in the number of bones and an increase in the complexity of those remaining. In the lower forms of life, the hyoid is referred to as an apparatus for laryngeal scaffolding and tongue support.

The hyoid bone serves as a scaffold largely responsible for mouth opening and deglutition. The hyoid musculature is divided into those muscles above the bone (suprahyoids) and those below (infrahyoid).

Let us examine the suprahyoids and the combined action of this group. The digastric, stylohyoid, mylohyoid, and geniohyoid act in combination for two very important functions. During deglutition, the hyoid bone is raised along with the base of the tongue by the suprahyoids, and in the mouth opening, when the hyoid is fixed by its depressors, the suprahyoid muscles open the mandible. In the first stage of swallowing, the hyoid bone is driven up and forward by the combined action of the geniohyoid, anterior bellies of the digastric, and the mylohyoid muscles. Once the bolus has passed through the pharynx,the posterior bellies of the digastric and the stylohyoid pull the hyoid posteriorly which assists in preventing the food from returning to the mouth.

The infrahyoids (sternohyoid, sternothyroid, thyrohyoid and omohyoid) depress the larynx and hyoid following the superior anterior movement in swallowing. During mouth opening, this group fixes the hyoid enabling the suprahyoids to depress the mandible. The omohyoid not only depresses the hyoid, but also carries it backward to either side. This muscular control of the suspended hyoid bone lends it to ranges of physiologic adaptability through cooperative constriction and relaxation of attaching muscles.

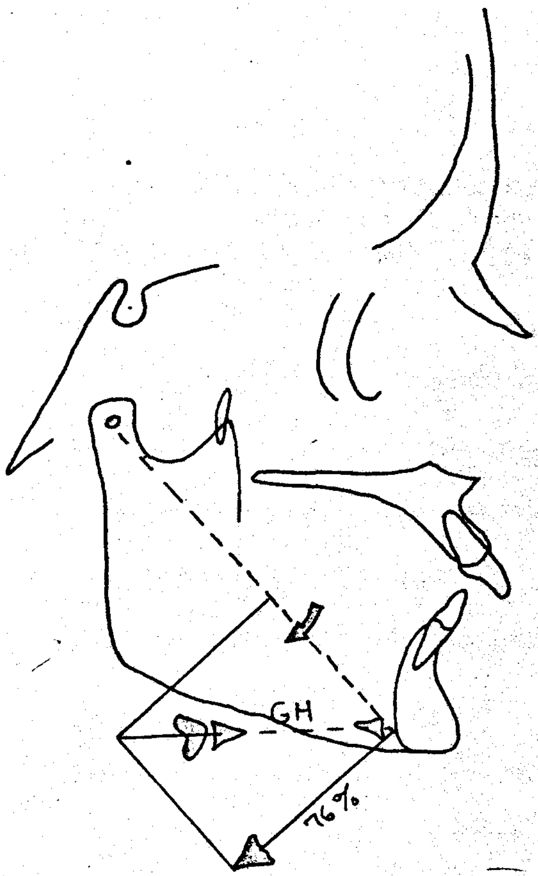
The stylohyoid ligament, attaching from the base of the skull to the lesser cornu of the hyoid, does have a limiting effect on any large amount of change.

Thurow (1970) in a vector analysis of mandibular opening demonstrated a lessening of the load on the geniohyoid in individuals with a low mandibular plane angle. The illustrations number II 3A and II 3B point out this phenomenon. The contraction of the geniohyoid aids in opening the mandible by its attachment at the genial tubercle. Based on an opening centered at the condyle, illustration II 3A shows the vector analysis to be 76% of the contracting force while in figure II 3B, the steep mandibular plane case shows 98% contracting force. The steeper mandibular plane also requires greater contraction of the geniohyoid to maintain the same amount of opening as illustrated in figure II 4. This happens because the hyoid is stabilized on mouth opening to prevent respiratory embarrassment.

It is accepted that the geniohyoid is largely responsible for carrying

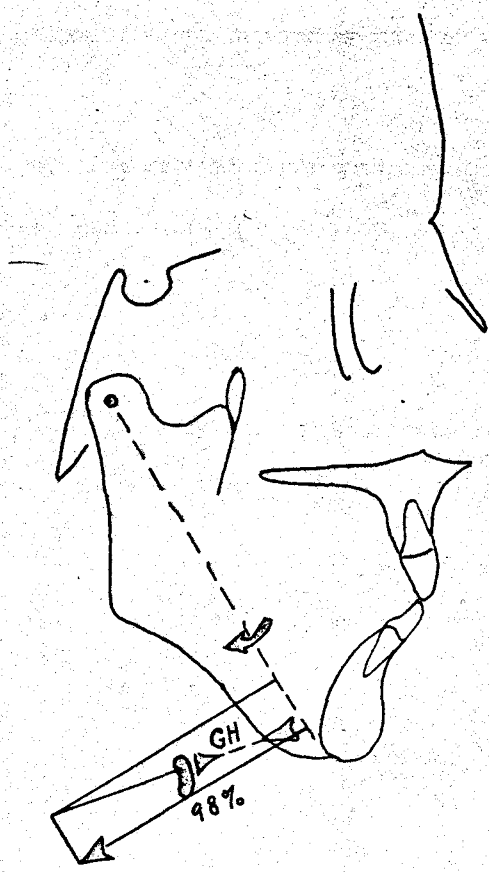
FIG. II 3

(A)



Effect of geniohyoid action on mandibular opening in a patient with a relatively low mandibular plane angle.

(B)

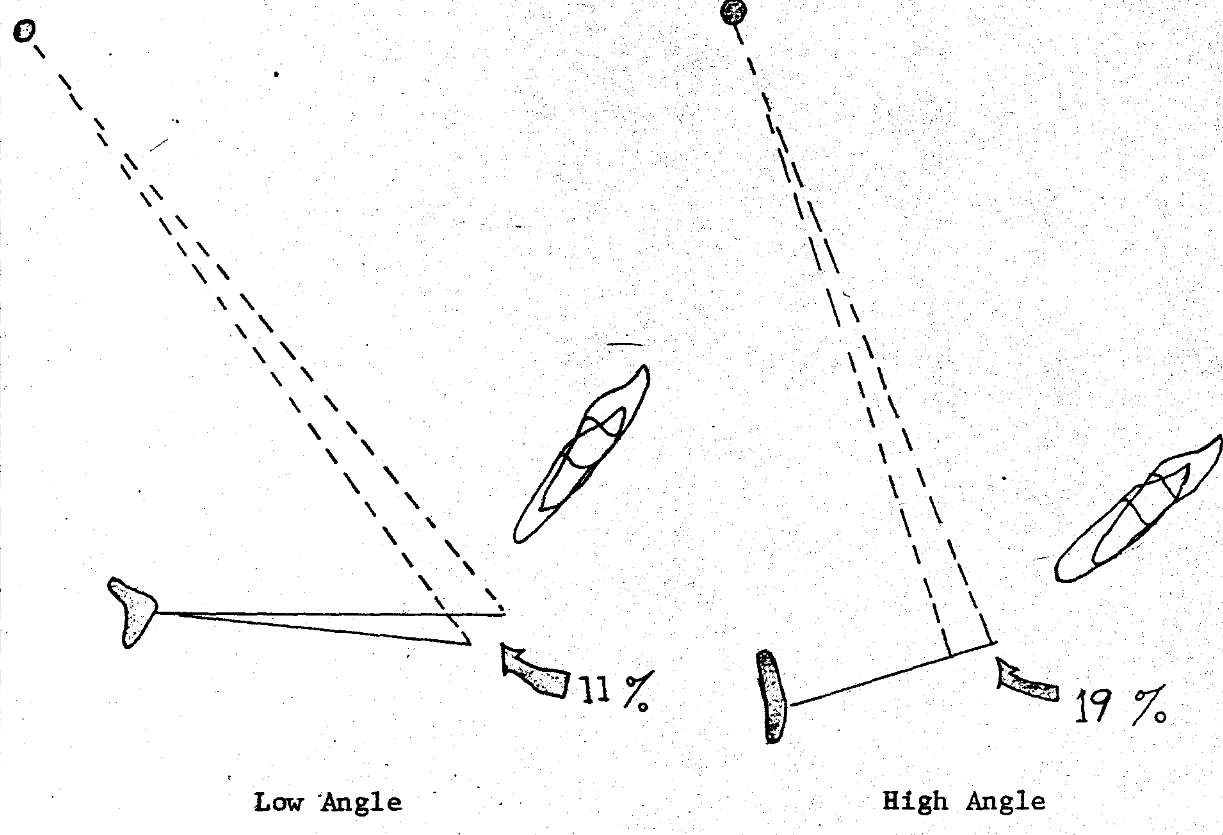


Geniohyoid with steep Mandibular plane

Illustrations from Thurow (1970)

FIG. II 4

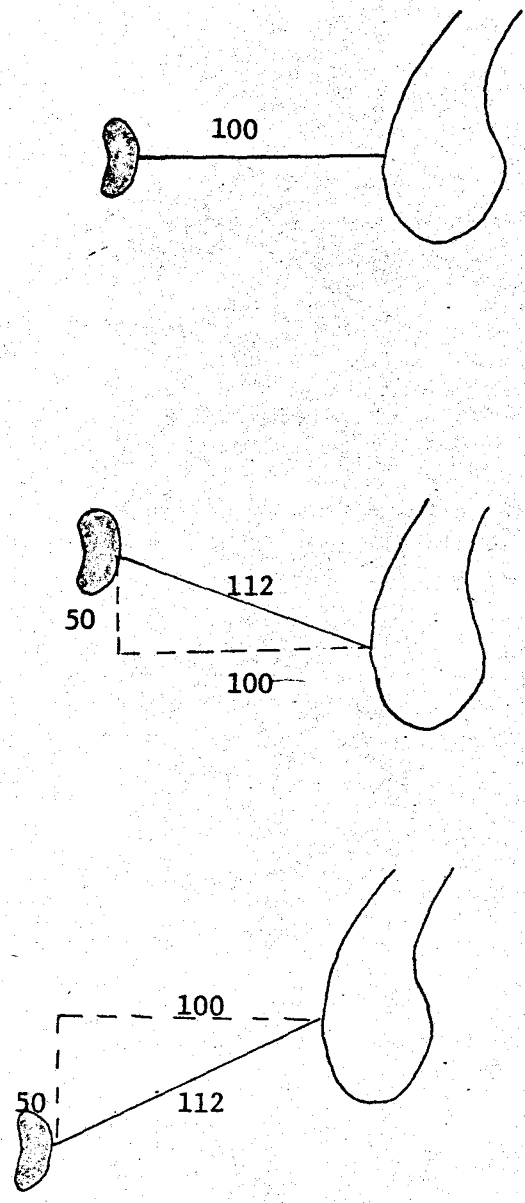
Low mandibular plane angle showing 8% less contraction for the same amount of opening as high mandibular plane angle.



Illustrations from Thurow (1970)

FIG. II 5

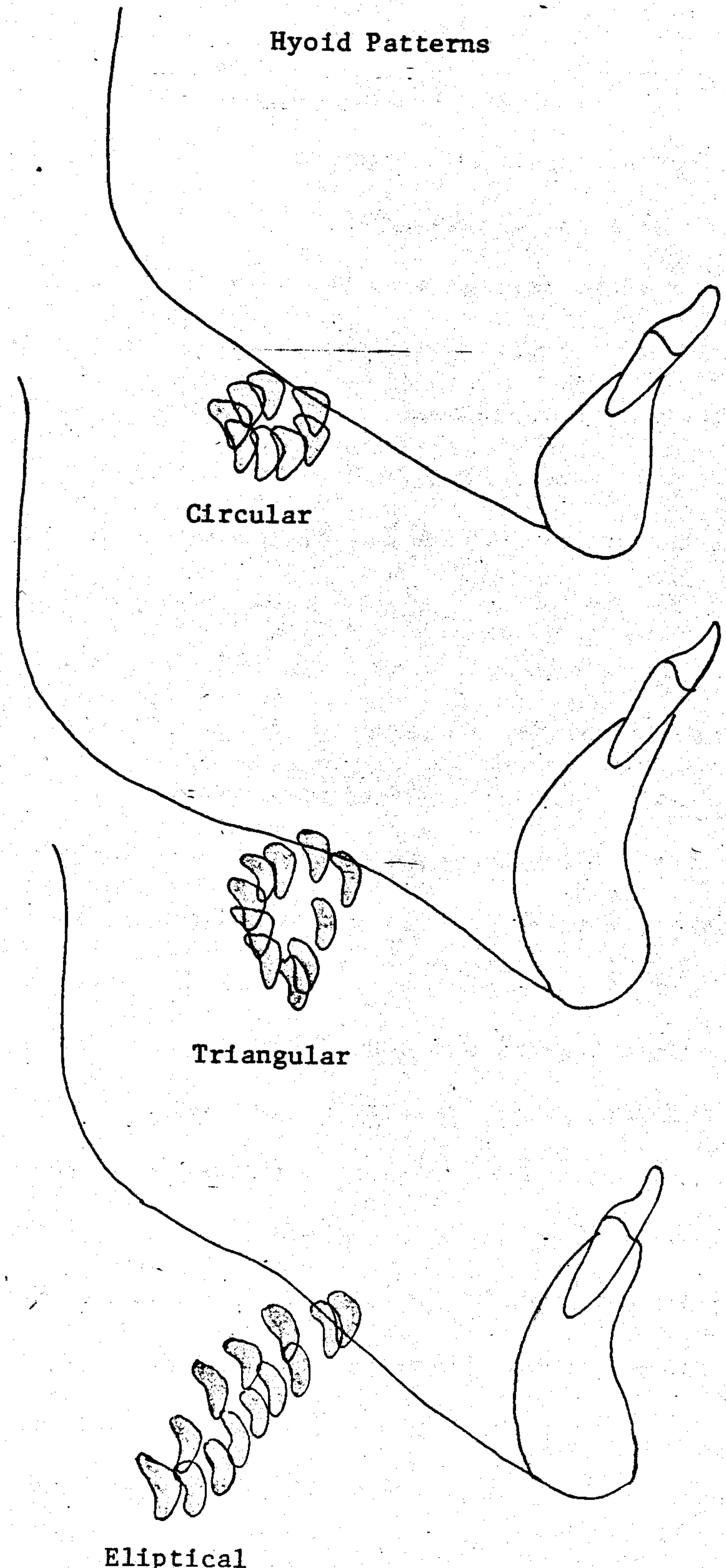
Mechanical Advantage of a Horizontal
Hyoid Genial Tubercle Relationship



Illustrations from Thurow (1970)

FIG. II 6

Hyoid Patterns



the tongue forward. A hyoid in line with the genial tubercle will have the greatest mechanical advantage in this action as shown in figure II 5.

For long periods of time the hyoid circle was never clearly demonstrated. Sloan, et al. (1965) described two variations in hyoid patterns during deglutition: a circular and an eliptical pattern. Fink in 1968 described a third pattern as triangular. Illustration II 6 shows these three patterns. Fink's triangular pattern demonstrated a definite horizontal movement following elevation to its highest point. The hyoid motion pattern was directly involved with the larynx which moved up and forward to make room for an expanding esophagus.

In 1930, Negus published his work on the throat structures. He described the hyoid of many of the lower vertebrates of having a closer relationship with the larynx than in higher orders. The larynx, although not intimately united with the hyoid was indirectly attached to it, and certain muscles pass from one to the other. Negus believed both the hyoid bone and larynx were influenced by head position. As the height of the face increased the mandible was carried down and forward with the tongue and hyoid being carried in the same direction. As the mandible became shorter in man, the tongue was not permitted to grow forward and was literally forced down the throat with both the hyoid and larynx similarly depressed.

Thompson (1941) reported that the hyoid was influenced by mandibular movements. Thompson found on mouth opening, the hyoid did not move down but moved slightly backward.

Mainland (1945) described the hyoid as a platform which can be fixed by one set of muscles, while another group of muscles acted on it.

In a roentgenographic study of pharyngeal growth, King (1952) showed that the distance between the hyoid bone and the cervical vertebrae was constant until puberty when the hyoid bone moved slightly anteriorly.

In 1956 Wood correlated the hyoid with movements of the head. He related an elevated hyoid in dorsiflextion, and a depressed hyoid in ventriflexion. Smith (1956) later investigated the hyoid and its movement from centric position to protrusion, and from centric position to maximum opening. The hyoid moved slightly forward on protrusion and slightly backward on maximum opening.

During scrutinization of hyoid pattern in Class I, II, and III malocclusions Grant (1959) concluded the hyoid pattern was constant in the three types of occlusions; and the musculature, not the occlusion, determined the position of the hyoid.

Shelton, Bosma, and Sheet (1960) reported cinefluorographic observations of the tongue, hyoid, and larynx during deglutition and phonation. Deglutition was divided into three phases. In Phase I of deglutition, the larynx was elevated and the pharyngeal portion of the tongue moved dorsally. Phase II consisted of the hyoid moving ventral and cephalad with a concomitant elevation and closure of the larynx. In Phase III, the hyoid bone descended either obliquely dorsad and caudad, or dorsad and caudad, and then more directly caudad. Swallowing in the supine position resulted in a similar hyoid cycle.

Durzo and Brodie (1962) reviewed cases where growth was arrested, or as a result of an accident, there was abnormal position of one of the points of suspension of the hyoid bone. The hyoid shifted accordingly; but, such shifting, was limited by compensatory muscle reaction which insured patency of the airway. Brodie further stated that due to forward migration of the foreman magnum and marked flexion of the cranial base, (due to man gaining an upright position) the larynx and trachea were no longer held away from the upper respiratory tract by gravity. Patency of the tract was maintained by contraction of the muscles anterior to the hyoid bone, via, geniohyoids and mylohyoids. Concomitant with this was the growth of the chin. In a case study of micrognathia, the anterior suspensory point (genial tubercle) of the hyoid, was posterior to its normal position; and this resulted in a drop of the hyoid bone, but a compensatory increase in the contraction of anterior suprahyoids caused a swelling between the symphysis and hyoid. Brodie interpreted this as an involuntary response to maintain patency of the airway.

In studying growth of the cervical vertebrae and related structures Bench (1963) found the hyoid moved downward in conjunction with cervical vertebral growth. Bench revealed the hyoid bone descended gradually from the third cervical vertebra at age 3 to a position opposite the fourth cervical vertebra in adulthood.

Sloan (1965) et al., described methods of quantifying cinefluorographic techniques. They studied forty-five subjects averaging twelve years old; equal groups of Class I, Class II, Division I, and Class II, and Division II were studied. They postulated to distinct hyoid movements: a circular pattern and an oblique pattern (eliptical). In all three groups, the hyoid was found near the anterior root of the pterygoid plates. Contrary to this, Grant (1959) reported the hyoid in Class I malocclusions showed a significantly lower and more posterior position while the Class II showed a higher more anterior position with greater ranges of movement in deglutition than the Class I.

One of the most extensive studies reporting cinefluorographic analysis of swallowing was by Cleall (1965). Using a tongue crib on tongue thrusting patients, the sensory cues were changed which modified the resting posture and movements of the glossopharyngeal structures during swallowing. These adaptive changes occurred rapidly and were also reversible. Cleall felt this supported the concept of a strong tactile sensory component in the neuromuscular control of deglutition. Cleall generalized that positional changes occurring during swallowing are largely in accord with the dictates set by the local skeletodental configuration.

In measurement of the hyoid bone in three positions: vertically, horizontally and angularly, Stepovich (1965) found it difficult to measure the hyoid without totally eliminating movement of the head in swallowing.

Cleall, (1966) after studying head posture and its relationship to deglutition, concluded that all subjects showed slight head extension in the early act of swallowing, but no conclusive differences were observed in the head posture of subjects with normal occlusion and those with Class II malocclusions.

Ingervall (1970) viewed the changes in location of the hyoid bone with change in mandibular positions. He studied 144 subjects, viewing the hyoid bone and the mandible in retruded contact position, intercuspal position and postural position. He observed the hyoid moving downwardly backwardly when the mandible moved from intercuspal position to retruded contact position. In the postural position the hyoid bone occupied a more superior position than in the intercuspal position.

Fink (1968) studied cinefluorographically the hyoid position in three types of individuals: normal occlusion, functional open bites, and skeletal open bites. His work demonstrated the hyoid bone positional movement was not significantly different in these three groups.

During cinefluorographic research on the hyoid during swallowing before and after mandibular resection, Wolk (1969) discovered the hyoid cycle structure unchanged, but the whole cycle moved downward and backward postsurgically. Wickwire (1972) verified these results, and reported the stability of a surgical result in mandibular resection appeared to be associated with the stability of the hyoid position. Takagi (1967) also reported this mandibular hyoid change relationship. The new assumed positional change protected the pharyngeal airway and also reduced the tongue mass within the oral cavity. The patient would have been unable to confine the mass of soft tissue within the surgically decreased oral cavity without this reflex adjustment.

In 1970, Cleall cinefluorographically examined changes that occurred in posture and function of the oropharyngeal structures during the transitional dentition state. The results demonstrated the oropharyngeal structures possessed the marked ability to adapt to a change in local dental environment. During deglutition, when the deciduous central incisors had been exfoliated, the tongue was postured forward. After the maxillary permanent incisors had erupted, the tongue was retracted. The tongue, hyoid, and mandible appeared to work as an integrated unit. The hyoid position mirrored the tongue tip position in swallowing, but not in speech. The hyoid and the tongue were forward when no central incisors were present, and backward, when incisors erupted into occlusion. The hyoid moved progressively downward through this transitional dentition period. In speech, the tongue tip functioned independently of the hyoid bone, but in swallowing, the tongue tip and hyoid were vitally associated in respiration.

Once again in 1970, Ingervall, studied the hyoid bone; but this time, he related positional changes to facial and dental morphology. He reviewed 76 girls with Class II Division I malocclusions. Movements of the mandible from intercuspal to postural position proved to be correlated with facial and dental arch morphology. The vertical movement of the hyoid bone on movement of the mandible from intercuspal to postural position was negatively correlated with the height of the face. In other words, if the height of the face was small, the hyoid moved inferiorly when the mandible went from intercuspal to rest position; while if the facial height was great, the hyoid moved superiorly. The horizontal movement of the hyoid bone during mandibular movement from intercuspal to rest position was positively correlated with the sagittal apical base difference between upper and lower jaw.

B. Studies on Intraoral Forces of the Tongue

In 1873, Tomes suggested that the tooth position is determined by a balance of forces between the tongue and perioral musculature. The long acceptance of this theory was questions after myometric and electromyographic results were evaluated.

Winders, (1958) showed by means of resistance tranducers on the teeth, the tongue in function exerted much greater force upon the teeth than the perioral muscles. Again, in 1962, Winders demonstrated the resting pressures of the tongue ranged from 0 to 15 gm/cm. Swallowing pressure ranged from 10 to 150 gm/cm. Tongue thrusters measured as high as 207 gm/cm. Maximum effort pressure was measured up to 2000 gm/cm.

Gould and Picton (1962) studied forces on the teeth from the tongue and perioral musculature. They found the pressure transducers should be no more than 2 mm from the surface of the tooth, or the force would be greater than normal.

Kydd, et al., (1962) measured the magnitude and duration of forces exerted on the teeth during deglutition. They studied orthodontic patients, 6 subjects with tongue thrust and anterior open bite, 5 subjects with no tongue thrust or open bite. The mean tongue pressure of anterior open bite sample was twice that of normal. Tongue thrusters showed longer duration of tongue and lip pressures than non-thrusters.

In studying the tongue pressure on mandibular anterior teeth in open bite cases, Neff and Kydd (1966) postulated that tongue pressure from the tonic passive position may cause the open bites more than the pressure during deglutition.

In order to examine the adaptability of the labiolingual musculature to changes in incisor position, McNulty (1968) constructed four different partial dentures for patients with missing maxillary central and lateral incisors at different labio-lingual positions. These partial dentures contained pressure transducers. Results indicated the perioral muscle force increased labially and decreased lingually on first experience; but after 24 hours, the muscles appear to have adapted to the new hard tissue architecture.

This rapid adaptability of perioral musculature prompted the study of tongue adaptability for this same 24 hour period.

Lear (1969) measured buccolingual muscle force and dental arch form. His estimate of the 24 hour muscle forces on the dental arches gave support to the century old hypothesis that normal occlusion was due to over-all counter-balance between tongue and cheek forces.

In 1969, Jacobs, emphasized the need to evaluate muscle tonus as well as contractile forces in maintaining muscle balance equilibrium. Since the tongue exerted greater pressure in swallowing than the perioral musculature, the balancing factor was the buccal tonic forces counter-balancing the dynamic forces exerted by the tongue which showed lesser tonic forces.

In an effort to correlate functional lingual pressure and oral cavity size, McGlone and Profitt (1972) studied nine children with oral cavities varying greatly in size. The results suggested functional activities contributed only in a limited extent to the overall growth of the oral cavity. They used the phrase "semi-functional matrix" meaning that resting, longer acting forces were more significant to arch formation, than were intermittant intense forces like swallowing and speaking.

Posen (1972) evaluated the influence of maximum perioral and tongue force on the incisor teeth. Maximum tongue strength was shown to range from 600 to 2500 grams. There was a significant relationship between maximum strength and force of the lips, and the final position and angulation of the maxillary and mandibular incisor teeth; but not a significant relationship between tongue force and incisor position. This study indicated the role of the tongue in determining final incisor position was minimal except in abnormal swallowing or abnormal positioning at rest.

C. Cinefluorographic Literature

The earliest cinefluorographic work was done in 1929 by Warren and Bishop at the University of Rochester. In the last 20 years, cinefluorography has developed into a useful tool for study of motion of the oral pharyngeal structures.

Cinematography is the production of an illusion of motion with the aid of the motion picture. Motion pictures taken by means of x-rays can be accomplished in two different ways, direct and indirect. Indirect roentgen motion pictures, cinefluorography, are made by photographing the fluorescent image on the motion picture film. Direct roentgen cinematography involves taking multiple, sequential exposures on x-ray film. These serial radiographs are then copied onto motion picture film creating an illusion of motion. Since the frequency is so low, this method is not as graphic as modern methods.

In 1953, the x-ray image intensifier was developed thus making cinefluorography useful in roentgen diagnosis due to the reduction in patient radiation.

D. Methods of Quantitative Cinefluorography

In 1959, Berry and Hoffman studied the temporomandibular joint (TMJ) cinefluorographically. In order to calcuate the degree of roentgenographic enlargement a metal ball bearing of known dimensions was attached to the face. A round image can not be elongated or foreshortened. The ball bearing became magnified to the same degree as the joint structures. A wire grid with 10 mm openings was placed on the receiving screen of the image amplifier and was not subject to enlargement. Later, the size of the shadow of the ball bearing and that of the grid meshes on the film determined the amount of magnification.

Movement in the films was viewed on analytical projectors which enable quantitation. The viewer was able to watch the film frame by frame, and measurements were made by digital manipulation of two cross hairs and superimposition of frames by tracing. The projector had an accessory blower which enabled unlimited examination of a single frame without damage to the film.

Sloan et al., (1967) presented an analysis originally developed by Bench (1962) in which cephalometric tracings of fixed cranial landmarks were superimposed over a cinefluorographic tracing.

The hyoid bone has a characteristic cycle of movement during swallowing. Comparative measurements of this cycle can be made by relating the positions of the hyoid to cranial landmarks.

Sloan's cephalometric analysis of the hyoid position used the following landmarks: a) cranial base (represented by the saddle angle, measured from nasion-sella turcica-basion; this indicates the relationship of anterior to posterior cranial base by angulation, b) mandibular plane (lower border of the mandible,) c) angle of facial convexity (measures the procumbency of the jaws), d) facial height (linear, nasion-menton line), e) height of the cervical vertebrae, f) vertical height of the dens, g) distance from the hyoid bone to the mandible, h) distance from the hyoid bone to the genial tubercle, i) level of hyoid with respect to cervical vertebrae, j) distance of the hyoid point to a vertical line drawn from pterygoid root.

Sloan's cinefluorographic analysis was composed of the following measurements: a) hyoid to posterior nasal spine at rest, b) hyoid bone in posterior most position to posterior nasal spine, c) hyoid bone in anterior most position to posterior nasal spine. Angular measurements were made at these positions using the hyoid as the apex and posterior nasal spine as one leg, and the vertical line from the orbit upon the palatal plane as the other leg.

Cleall, (1966) used a cinefluorographic analysis different than Bench's analysis. The angular measurements were the following: a) tongue tip to palatal plane at posterior nasal spine, b) hyoid to palatal plane at posterior nasal spine, c) soft palate to hard palate at posterior nasal spine, d) tongue tip to palatal plane, e) lower incisor to palatal plane at point "a" intersection, f) pogonion and palatal plane. Linear measurements in Cleall's study were the following: a) tongue tip to palatal plane, b) lower incisor to palatal plane, c) dorsum of tongue to palatal plane, d) hyoid to palatal plane, e) lip separation, f) molar separation, g) tongue tip to lower incisor (horizontal), h) hyoid to posterior pharyngeal wall.

E. Swallowing

The experimental psychologist, Magendie (1783-1855), divided swallowing into three stages (as compared to Boerhaave's five stages from the early 1700's).

Swallowing can still be divided into the classic three stages:

(1) the voluntary stage, which initiates the swallowing process, (2) a pharyngeal state, which is involuntary, and constitutes passage of food through the pharynx into the esophagus (3) the esophageal state, also involuntary, which promotes the passage of food from the pharynx to the stomach.

First, the voluntary stage involves squeezing or rolling the bolus posteriorly by pressing of the tongue up and back against the palate. The bolus is forced into the pharynx by the tongue. The lips are closed and the buccinators are forced against the teeth. Once this point in swallowing is reached, it normally cannot be stopped. The bolus now passes into the pharynx past the palato-glossal arch, and the second stage of swallowing process. The swallowing receptor areas are stimulated by areas located around the opening of the pharynx and impulses pass to the brain stem which initiate involuntary pharyngeal muscular contractions, as follows: 1) posterior nares closed by the soft palate being pulled upward (prevents food from entering nasal passages), 2) palato-pharyngeal folds are pulled medialward to closely approximate each other. This sagittal slit is selective in bolus size passage, 3) the vocal cords of the larynx are strongly brought together and further protection of laryngeal airway is due to the epiglottis swinging backward over the superior opening of the larynx. A person can exist without an epiglottis; but destruction of the vocal cords or the muscles that approximate the cords, will result in strangulation, 4) the entire larynx and hyoid are pulled upward and forward by the supra-hyoid musculature; and simultaneously, the hypopharyngeal sphincter around the esophageal entrance is relaxed. The bolus usually passes on either side of of the epiglottis, adding another protective device to the laryngeal airway, 5) simultaneous with the raising of the larynx and relaxation of the hypopharyngeal sphincter, the superior constrictor of the pharynx contracts setting off rapid peristaltic waves passing down the pharynx into the esophagus.

This, entire pharyngeal state, according to Guyton (1956) takes one to two seconds. The sensory nerves stimulation of the pharyngeal stage is through the glossopharyngeal and trigeminal nerves transmitting to the region of the medulla oblongata closely associated with the tractus solitarius, which receives almost all sensory impulses from the mouth. The successive stages of swallowing are controlled in the reticular substance of the medulla and lowest portion of the pons. These areas are collectively called the swallowing center.

The pharyngeal stage of swallowing interrupts respiration for only a fraction of a usual respiratory cycle. The portion of the medulla responsible for respiration is inhibited by the swallowing center for this 1 to 2 second period.

The third state, esophageal, is a 5 to 10 second period primarily conducting the bolus from the pharynx to the stomach. The peristaltic waves of the esophagus are controlled primarily by the vagal reflexes. The musculature of the pharynx and upper one third of the esophagus is skeletal muscle. The lower two thirds of the esophagus is smooth muscle.

Movements in swallowing are too rapid for the eye to perceive. Thus, high speed cinefluorography, using 30 to 60 frames per second, is the only way to visualize this movement.

Saunders, Davis and Miller (1951) using high speed cinefluorography studied deglutition.

Ramsey (1955) did a cinefluorographic study on deglutition on 300 individuals, about half of whom were considered normals. He postulated that initially a larger bolus size will cause the hyoid to move forward more than upward, as in small bolus swallow.

In a study of swallowing by the cinefluorographic technique on Class II Division I malocclusions without tongue thrust and on Class II and I tongue thrusters, Cleall (1965) found 20 percent of the normal sample did not have the lips together in swallowing, and 40 percent showed no occlusal contact during swallowing. Both of these facts conflicted with opinions prior to his study.

In 1970, Subtelny reported that 2 of 10 normal subjects had a tooth together swallow. This study attempted to answer the following question: If there was an abnormal oral or dental environment and a concomitant abnormal pattern of muscle activity, did the muscular structures create the abnormal environment or was the environment present and the muscles simply adapted to it? His conclusion was that successfully treated orthodontic cases were the ones which the environment was corrected and the muscle forces became adapted to it, and case failure resulted when the muscle force which caused the environment lack the adaptive capacity, even though the environment was corrected (teeth brought to good occlusion orthodontically).

This lack of adaptability showed the need for myofunctional therapy following treatment to correct deviate swallowing habits and strengthen perioral musculature.

III. MATERIALS AND METHODS

A. General

1. Ten female subjects ranging in age from 19 to 30 were selected from volunteers. All subjects had a Class I molar relationship and aside from minor rotations, occlusion was good.

2. Description of Procedure in order:

   a. A myometric analysis of tongue pressure was done during normal deglutition.

   b. Cinefluorographic sequences of normal deglutition were taken.

   c. An orthodontic crib was fashioned to restrain the tongue distal to its normal position.

   d. A myometric analysis of tongue pressure was done immediately following insertion of the crib with the plate 2 mm distal to the crib.

   e. Following 24 hours of crib wear, another myometric analysis of the tongue pressure was taken with the plate 2 mm distal to the crib.

   f. Following 24 hours of crib wear, another cinefluorographic sequence of deglutition with the crib in place was taken.

B. Crib Construction and Placement Details (See Fig.III 2 and 3)

The tongue crib, used to restrain the tongue in a posterior position was made of .036 stainless steel wire and soldered to form a basket. The crib was held in the mouth by soldering it to orthodontic bands placed on the maxillary canines. Impressions were taken of the subjects' mouths with the orthodontic bands in place. The bands were removed and placed in the impression material prior to pouring plaster into the impressions for fabrication of the appliance. The appliance was constructed on the plaster models with the crib 15 millimeters distal to the incisal edge of the maxillary incisors. Extension arms from the crib were contoured to contact the gingival one third of the maxillary incisors during deglutition. This contact enabled normal physiologic feedback during swallowing. In normal swallowing, the tongue tip contacted the incisive papilla with minimal pressure to the gingival one third of the maxillary incisors.

Patients with deviate swallowing habits place their tongue between the maxillary and mandibular incisor during deglutition. These patients often have an anterior open bite and strained facial grimmace during swallowing. None of the subjects displayed a true anterior open bite, but two of the subjects appeared to have other characteristics indicative of a deviate swallow.

C. Cinefluorographic Equipment, Technique and Analysis.

A Picker cinefluorograph with a high image intensifying screen was used for the deglutition film sequence. The output phosphor on the machine had a diameter of 9 inches and the input phosphor had a diameter of 0.8 inches. The resulting demagnification was 11 to 1 and the brightness gain was about 3,000 to 5,000 X. On opposite ends of a "C" arm were the x-ray head and the image amplifier with camera and optical system. The"C" arm was adjustable and capable of being locked in any vertical position. The cephalostat was attached to the "C" arm in close relation to the input phosphor of the image tube. The ear rod nearest the image amplifier was fixed so that the subject film distance was constant.

The patients were seated in the cephalostat in a comfortable position and allowed to assume a natural head position while looking straight ahead into a mirror. An adjustable stand was used to measure the exact chin level, so that this position could be duplicated in the cinefluorographic x-ray before and after insertion of the tongue crib. This stand rested passively under the chin during the swallowing procedure.

The Picker Dental Cinefluorographic machine was used in this study and was a pulsed unit provided with aluminum filtration. The unit was monitored prior to this research by Mr. Ted Fields, of the department of radiology at the Loyola Medical Units. An ionization chamber was used to calibrate the exposure. This chamber was placed in the direct beam of radiation, and following exposure, was placed in a reading instrument. The following recordings were made:

KVP	mA	FRAMES PER SECOND	ROENTGEN PER 20 SECONDS
90	13	60	.50
90	13	30	.40
100	12	60	.50
100	11	30	.35

Each exposure was taken at 90 Kilovolt peak and 13 milliamperes since this provided the best picture. Each subject received approximately fifteen seconds exposure in each film sequence at .025R per second. The total radiation in both exposures combined per subject was approximately .75R.

Barium sulfate was placed on the subject's nose and lips to outline the soft tissue profile prior to filming. A comfortable amount (2 to 4 cc) of barium sulfate was introduced into the subject's mouth from a beaker. The patient was asked to swallow the radiopaque bolus. A sixty frame per second cinefluorographic film was taken during the act of deglutition with 16 mm Kodak Shellburst film and a 35 mm F_1 lens. The film was developed on a Profexray automatic film developing machine. Two swallows were recorded for each patient at each testing period.

The films were analyzed on a Vanguard Motion Analyzer. The machine had manually operated cross hairs which superimpose on the film. Measurements with this Vanguard unit were accurate to .001 inch linearly and $1/4^{\circ}$ angularly, but due to a lack of detail in cinelfuorographic films this degree of accuracy was not needed. There was a variable speed adjustment on the motion analyzer which enabled viewing in the range of 5 to 30 frames per second. Long term single frame viewing was also possible since there was a blower to prevent damage to the film. A metered frame counter allowed the viewer to identify individual frames.

The cinefluorographic film sequences of the ten subjects were analyzed. The swallow was divided into four states, and the hyoid movement traced in these following positions: (See Figure III 1).

STAGE 1 Rest - The bolus was not introduced yet, and the teeth were together.

STAGE 2 Hyoid bone in the most posterior superior position. This position coincides with the bolus at the level of the soft palate.

STAGE 3 The hyoid at its most anterior superior position coinciding with the bolus at epiglottis level.

STAGE 4 The hyoid returned to rest position and the bolus had passed out of the picture through the esophagus.

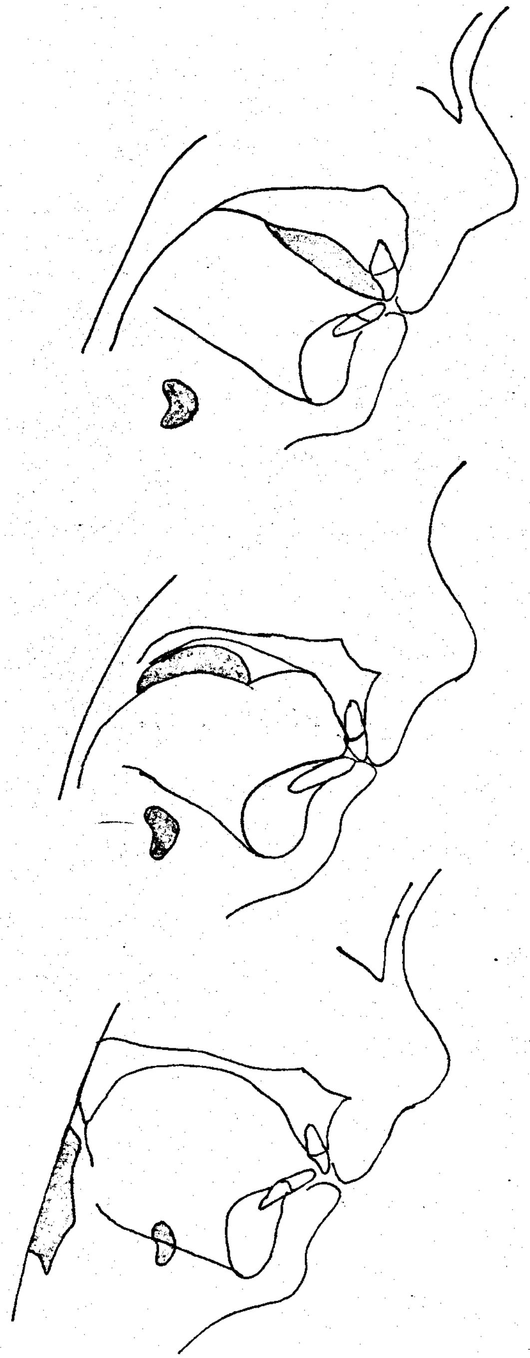
The individual sequences were viewed frame by frame with the Vanguard Motion Analyzer. Tracings of the subjects were made on acetate paper placed on the screen by tracing the hyoid bone, mandibular symphysis, lower border of the mandibular body, incisor teeth, (maxillary and mandibular) and maxilla. A template was made for the hyoid bone, and by using the inferior border of the hyoid the bone was drawn. The incisor teeth were also drawn from a template placed on the edge and the labial surface of the teeth. By superimposition of these points in the four stages of deglutition, it was possible to visualize the movements of the hyoid bone before and after insertion of the tongue crib.

D. Measurement of Tongue Thrust

To measure the force of the tongue during swallowing a small plate was placed in the vicinity of the incisive papilla. An .014 guage wire

FIG. III 1

Stages of Deglutition



Stage 1 and Stage 4

a) Rest position of hyoid and tongue

Stage 2

a) Hyoid superior and posterior in position

b) Bolus begins to move backward

Stage 3

a) Hyoid in anterior and superior-most position

b) Bolus at level of epiglottis

 = bolus

(.016 in 2 subjects) was welded to this plate and this was slipped above the contact between the maxillary central incisors. The .014 wire attached to a female socket which was soldered to an extension arm of the pressure transducer. The pressure transducer was a Myograph C manufactured by Narco-Bio Systems with a range from 0-500 grams and maximum sensitivity of 1 centimeter deflection for 5 grams of force.

The plate used to measure in the mouth extended 2 millimeters from the papilla in the pre-appliance measurements and 2 millimeters from the crib in the post-appliance measurements. The pressure from the tongue onto the plate was transferred to the pressure transducer which recorded on the graph paper of a polygraph (Physiograph-Narco Instrument Company) by pen deflections. Calibration was done following each writing since different sensitivities were used in the measurements. (See Fig. III 4 and 5).

The recordings were made with the subject's head stabilized by the head rest of a dental chair. Water was introduced by a cup when the patient did not have adequate saliva to swallow.

Approximately ten swallows were recorded at the three different sittings. On occasion, a rubber band had to be placed between the contact area of the maxillary incisors to prevent the .014 wire from binding in the embrasure.

E. Myometric Analysis

The swallowing recordings were studied for each subject. The five most representative swallows were chosen from each sitting for analysis.

The swallows produced pen deflections from a base line on the physiograph. These amplitudes were measured in millimeters and converted to grams following calibrating with the standard force.

Fig. III 2 Tongue Crib Used To Restrain Tongue

Fig. III 3 Extension Arms From The Appliance To Maxillary Incisors

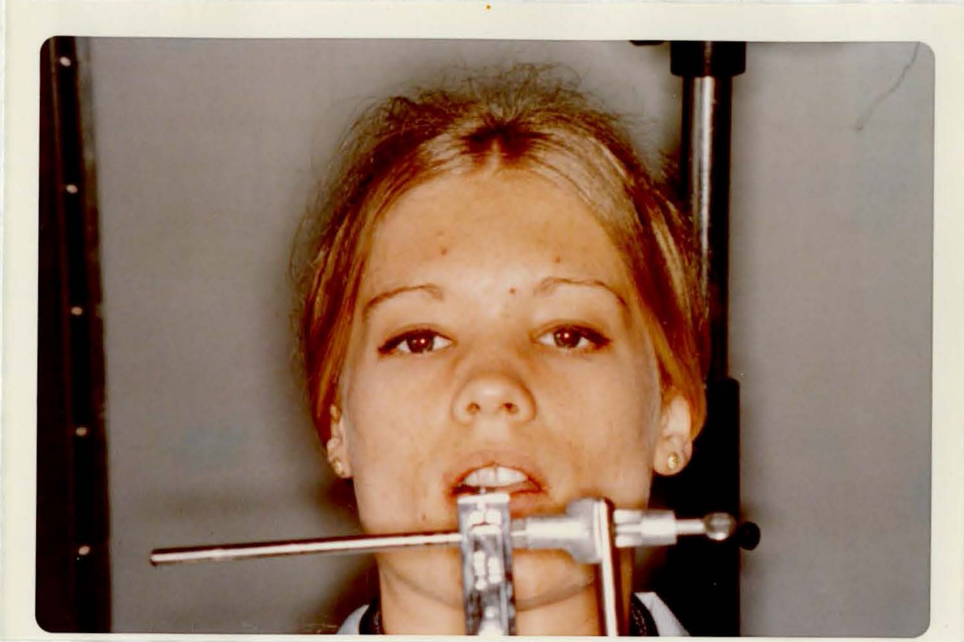


Fig III 4 Subject During Reading of Tongue Pressure with Myograph

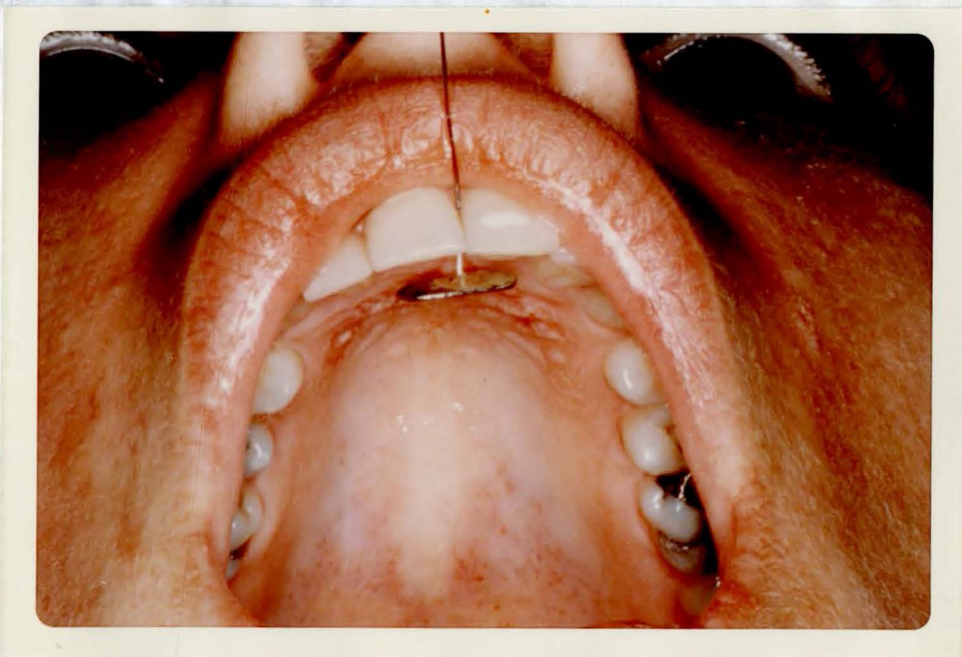


Fig. III 5 Pressure Plate Used In Measurement of Tongue Pressure

IV. RESULTS

A. Cinefluorographic Results (See Tables 1 and 2)

After evaluating the tracings of the hyoid cycle, the ten subjects were divided into three patterns. Six of the subjects had cycle re-positioning following crib insertion. Three subjects made no accommodation at all, and one subject made no accommodation at rest position, but the cycle was smaller. One of the six subjects showing accommodation, differed significantly in amount and direction from the other five.

1. Subject L.L. See Figure IV 1

The hyoid at rest was repositioned 4.5 mm backward and 4 mm downward. The hyoid did not anteriorize as far as the original position during swallowing. The most posterior-superior position remained the same. A perpendicular distance from the mandibular plane to the lowest point on the body of the hyoid at rest prior to crib insertion was 18 mm.

2. Subject G.J. See Figure IV 2

The hyoid at rest was repositioned 6 mm backward and 4 mm downward. The entire cycle appeared to remain the same, but shifted posteriorly and inferiorly. The distance from hyoid to mandibular plane was 24 mm at rest position prior to crib insertion.

3. Subject K.B. See Figure IV 3

This adaptation was very similar to subject 2. The entire cycle repositioned posteriorly and inferiorly. The primary movement was posterior (7.5 mm), and there was slight change inferiorly (1 mm). The original rest measurement from the mandibular plane was 20 mm.

4. Subject P.C. See Figure IV 4

The hyoid cycle was entirely repositioned in the posterior and inferior direction, (4 mm) downward and backward. The original rest hyoid position was 15 mm from the mandibular plane.

5. Subject M.J. See Figure IV 5

Similar to the previous four subjects, the hyoid cycle went down and back. There was a 3 mm change posteriorly and a 7 mm change inferiorly in the resting hyoid position. The original perpendicular distance of the hyoid from the mandibular plane was 17 mm.

5. Subject C.C. See Figure IV 6

The hyoid resting position and cycle remained the same. The rest measurement of the hyoid to mandibular plane was 29 mm.

7. Subject S.A. See Figure IV 7

The hyoid rest position and cycle remained the same. The rest measurement of the hyoid to mandibular plane was 38 mm.

8. Subject K.K. See Figure IV 8

The hyoid rest position and cycle remained the same. The rest measurement of the hyoid to the mandibular plane was 31 mm.

9. Subject M.R. See Figure IV 9

The hyoid rest position did not change, but the accommodation did occur in the posterior superior position of the hyoid, as well as the anterior most position. Both these positions were inferior and posterior when the crib was worn. The rest measurement of the hyoid to the mandibular plane was 35 mm.

10. Subject P.B. See Figure IV 10

The hyoid did show accommodation in this subject, but the inferior change of 11.5 mm was the most significant variance in this direction; and instead of posterior accommodation, there was 3 mm. of anterior change. The original resting hyoid measurement from the mandibular plane was 23 mm.

B. Myometric Results (See Table 3)

After analyzing the data from the myometric measurements, the ten subjects were categorized into 3 types: The first type (7 subjects) showed an initial rise in myometric pressure following crib insertion, and an accommodation after 24 hours. The second type (2 subjects) showed a rise in pressure following insertion, and an even higher rise after 24 hours. The third type (1 subject) showed an immediate rise in myometric pressure, and a similar reading after 24 hours.

TYPE I SUBJECTS: L.L., G.J., K.B., P.C., M.J., S.A., K.K.

All these subjects showed a rapid rise in tongue swallowing pressure on immediate insertion of the appliance, and an accommodation following 24 hours of wear.

TYPE II SUBJECTS: M.R., P.B.

These subjects showed an immediate increase following insertion of the crib and a greater rise following 24 hours of crib wear.

TYPE III SUBJECT: C.C.

This subject showed an immediate rise in tongue pressure and a failure to accommodate after 24 hours. Basically, this subject's pressures were very close in all three readings.

TABLE I

AMOUNT OF HORIZONTAL AND VERTICAL HYOID ADAPTATION IN REST POSITION BASED ON A PERPENDICULAR MEASUREMENT FROM THE MANDIBULAR PLANE (MENTON-GONION)

SUBJECT	IN MILLIMETERS HORIZONTAL	IN MILLIMETERS VERTICAL
1. L.L.	-4.5	-4
2. G.J.	-6	-4
3. K.B.	-7.5	-1
4. P.C.	-4	-4
5. M.J.	-3	-7
6. C.C.	0	0
7. S.A.	0	0
8. K.K.	0	0
9. M.R.	0	0
10. P.B.	+3.5	-11.5

TABLE 2

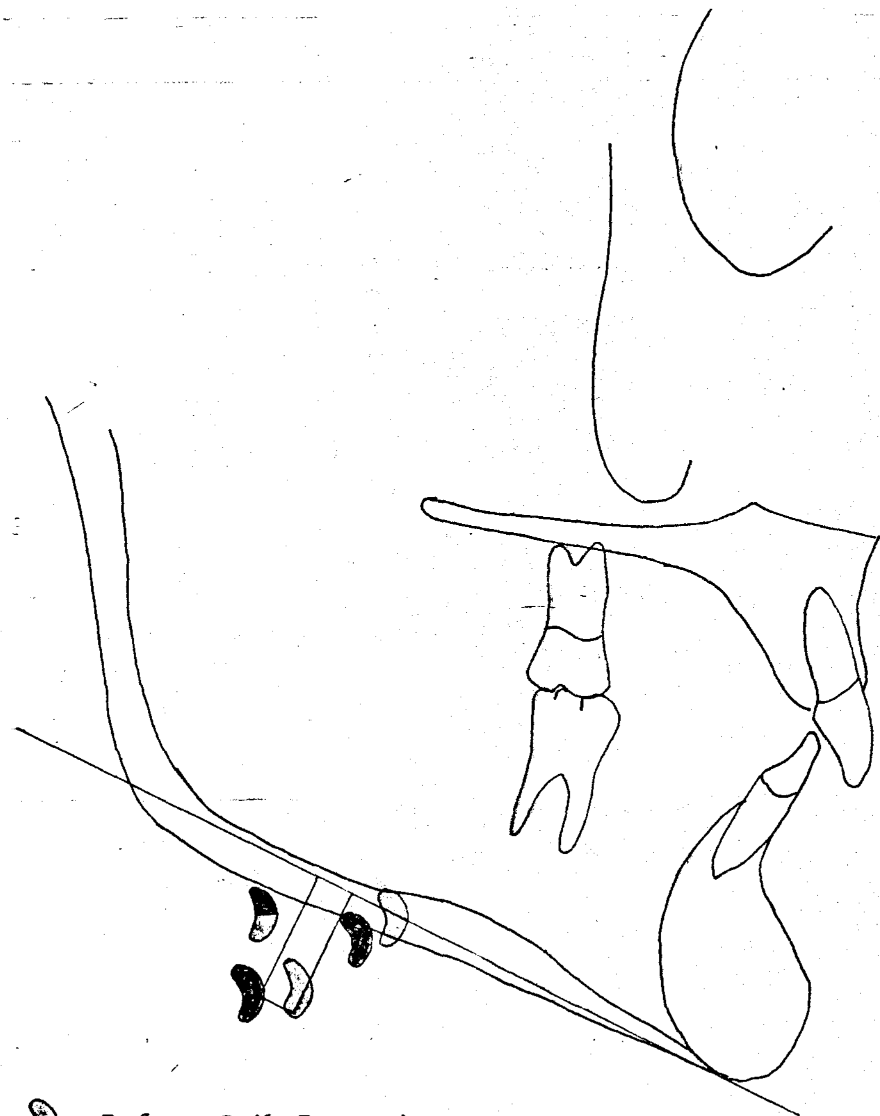
PERPENDICULAR HYOID DISTANCE FROM THE MANDIBULAR PLANE IN REST POSITION PRIOR TO CRIB INSERTION

SUBJECT	DISTANCE IN MILLIMETERS
1. L.L.	18
2. G.J.	24
3. K.B.	20
4. P.C.	15
5. M.J.	17
6. C.C.	29
7. S.A.	38
8. K.K.	31
9. M.R.	35
10. P.B.	23

TABLE 3

MYOMETRIC MEASUREMENTS OF TONGUE PRESSURE IN GRAMS

SUBJECT	INITIAL	IMMEDIATELY FOLLOWING CRIB INSERTION	24 HOURS FOLLOWING CRIB INSERTION
1. L.L.	18.9	60.8	32.1
2. G.J.	79.8	110.2	79.9
3. K.B.	95.3	148.0	118.0
4. P.C.	75.3	120.8	105.3
5. M.J.	26.7	97.6	67.8
6. C.C.	87.2	95.0	95.2
7. S.A.	40.3	94.9	72.0
8. K.K.	50.5	83.3	55.5
9. M.R.	48.0	70.0	160.0
10. P.B.	65.7	108.4	151.7



= Before Crib Insertion

= After Crib Insertion

= Before and After In Same Position

FIGURE IV 2

G.J.

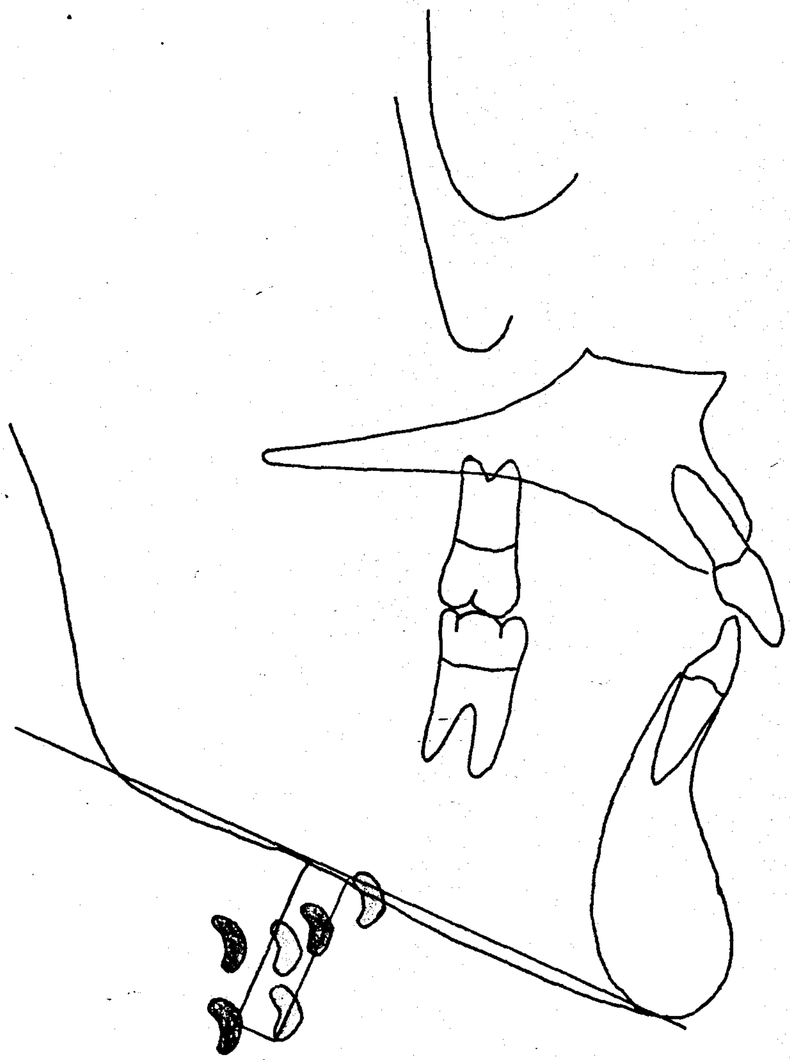


FIGURE IV 3

K.B.

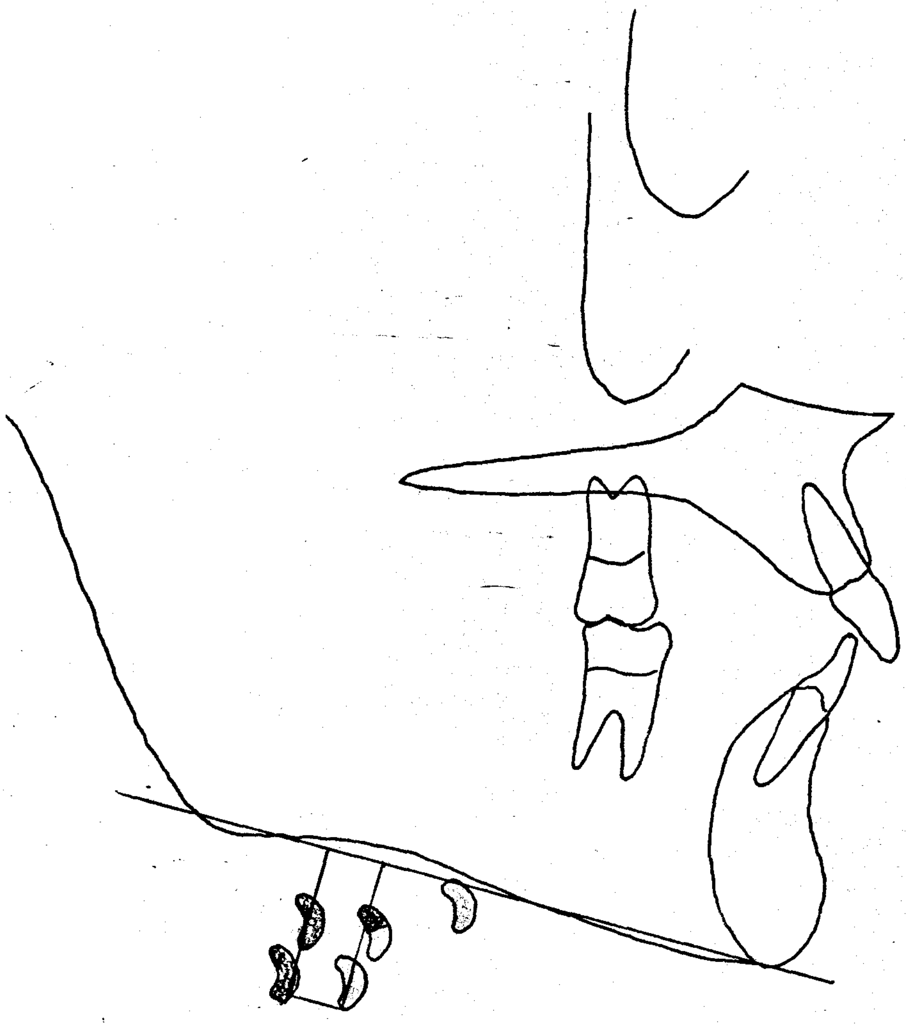


FIGURE IV 4

P.C.

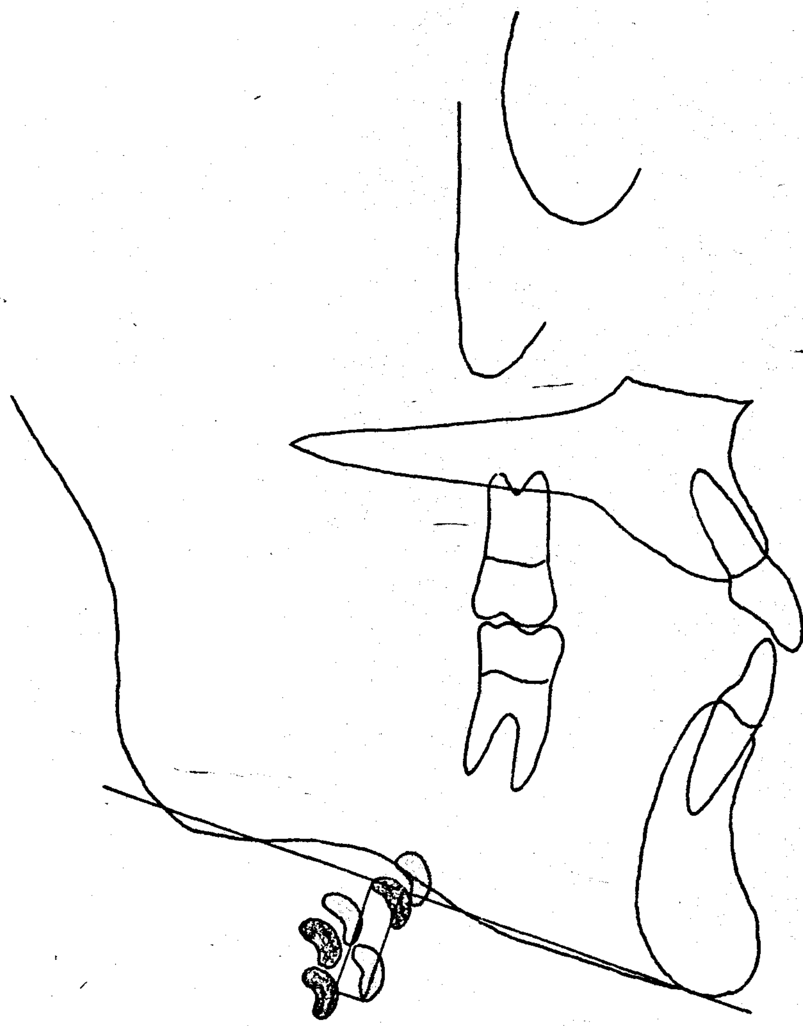


FIGURE IV 5

M.J.

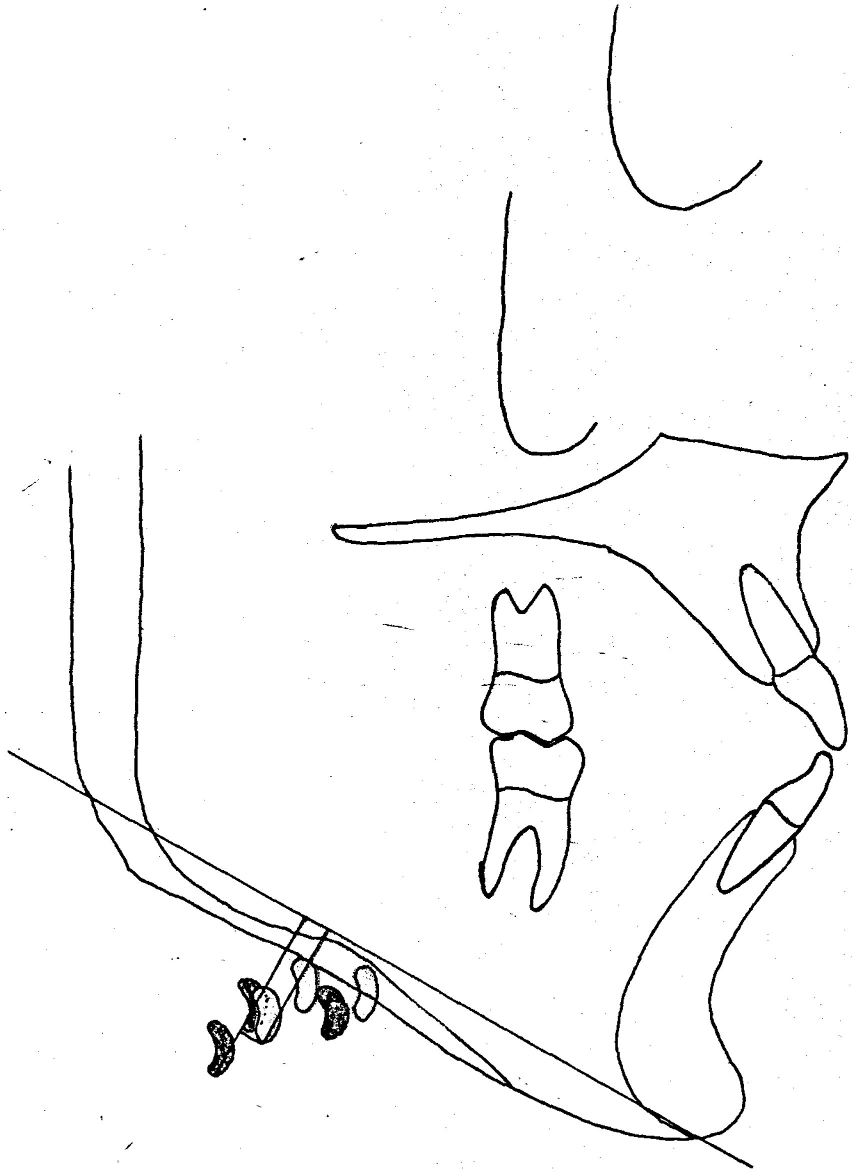


FIGURE IV 6

C.C.

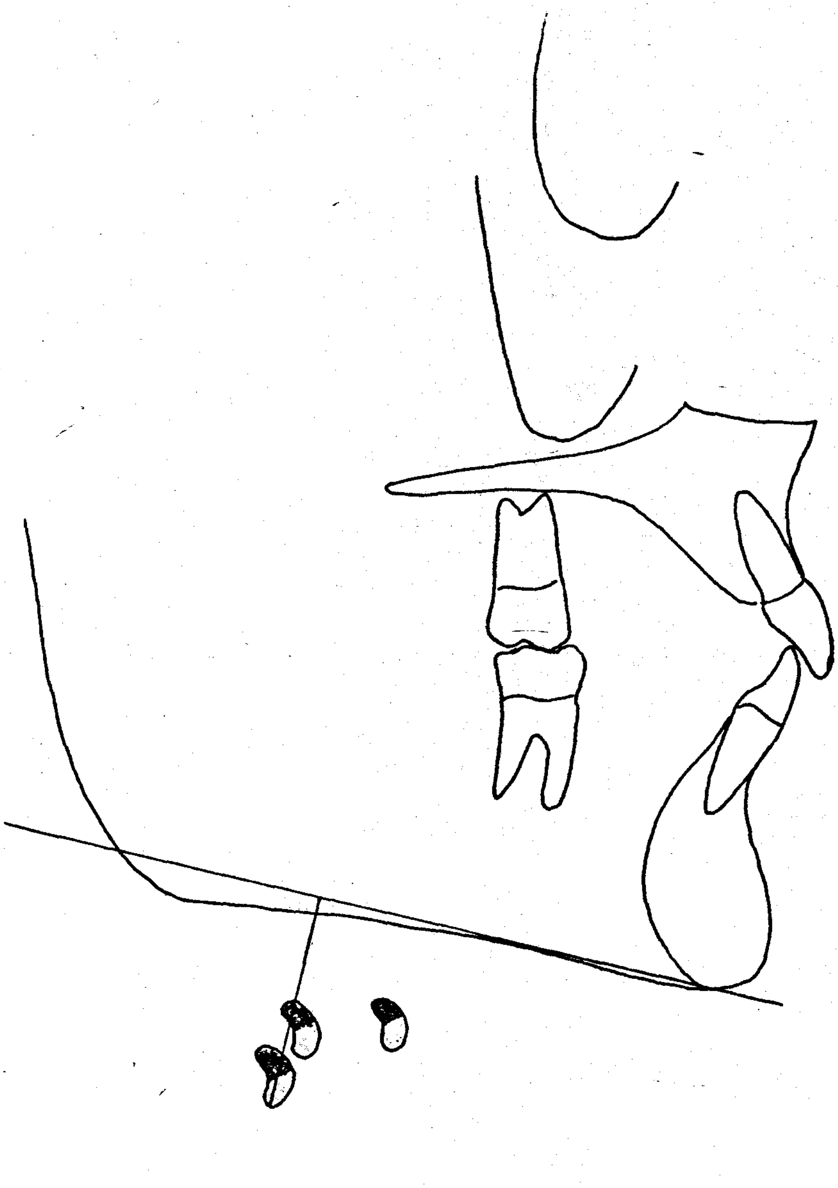


FIGURE IV 7

S.A.

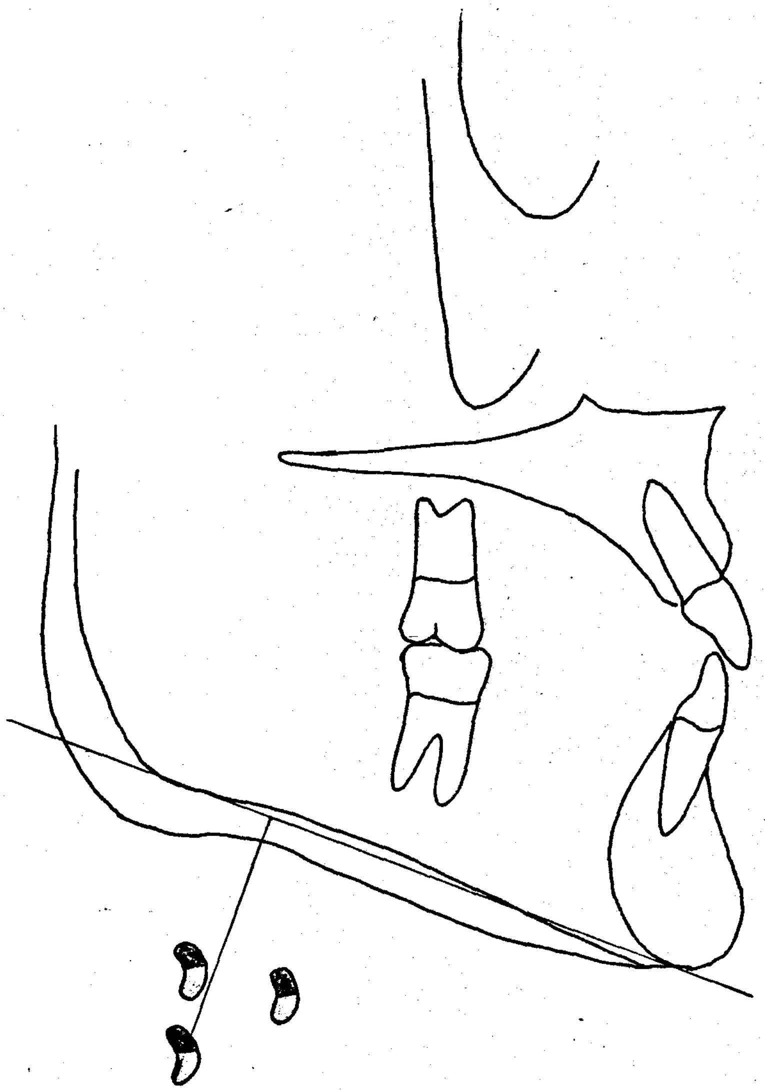


FIGURE IV 8

K.K.

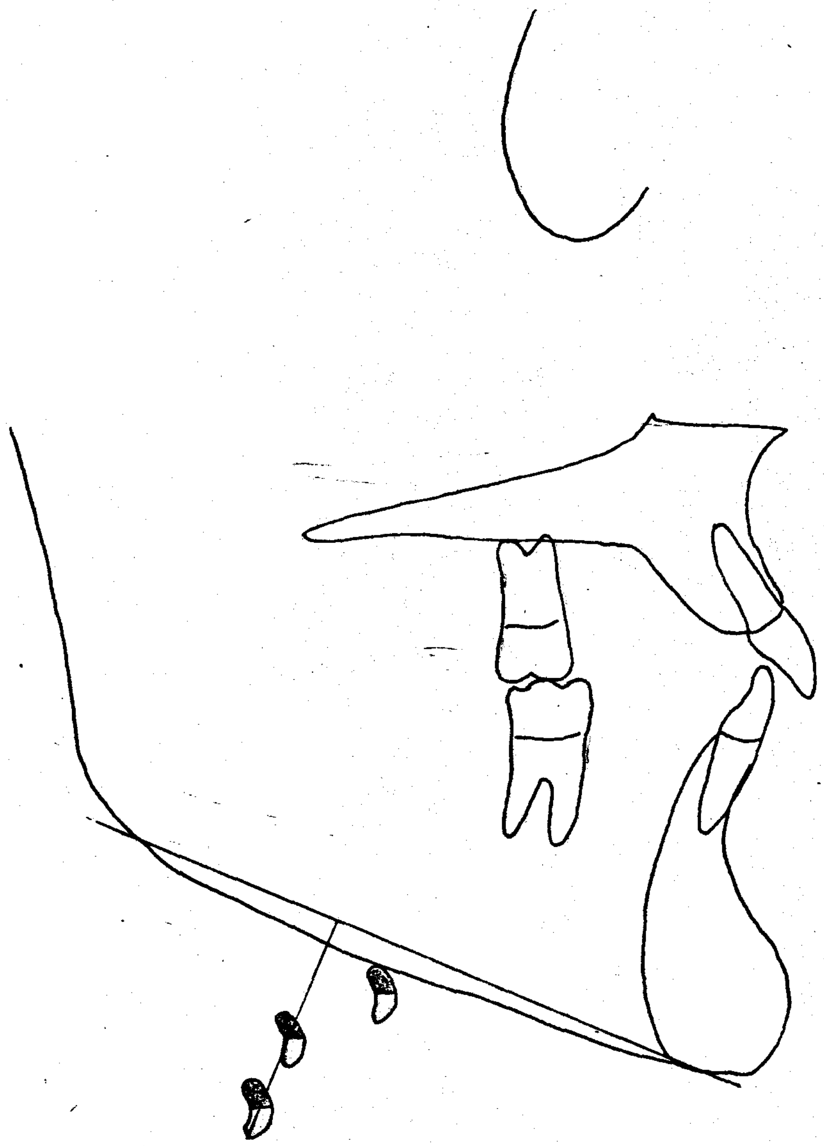


FIGURE IV 9

M.R.

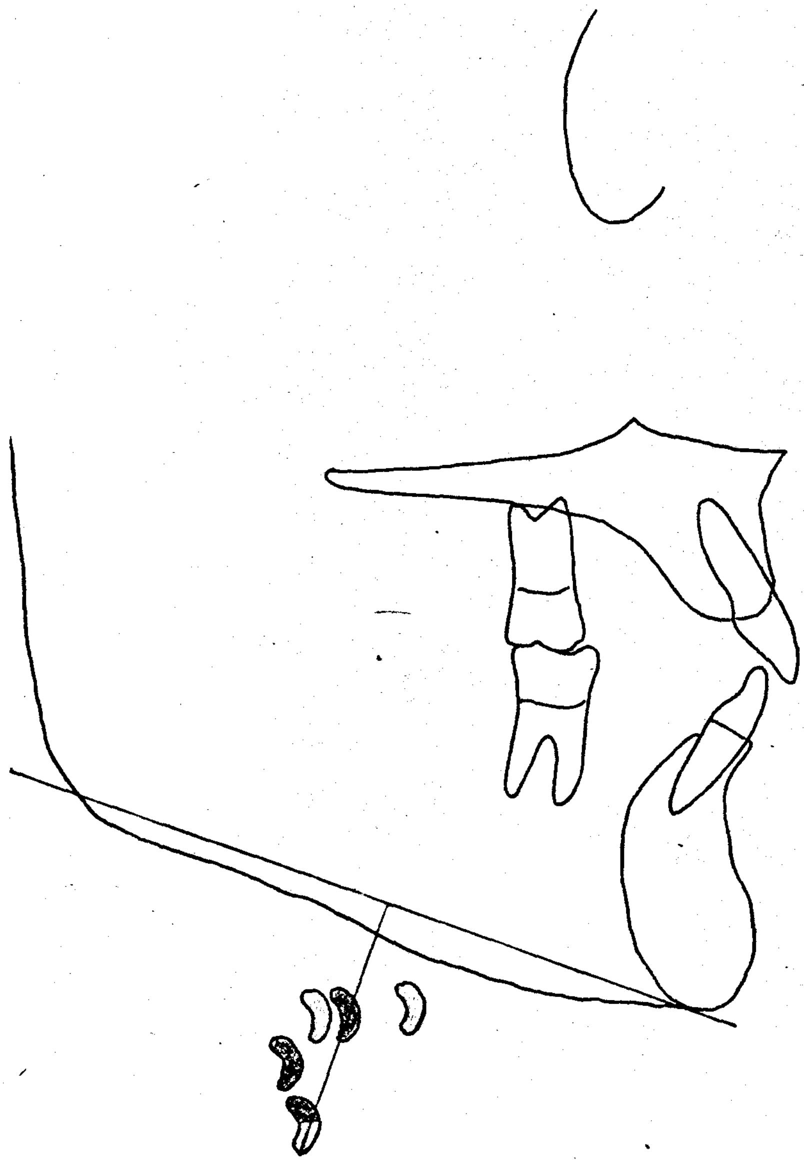
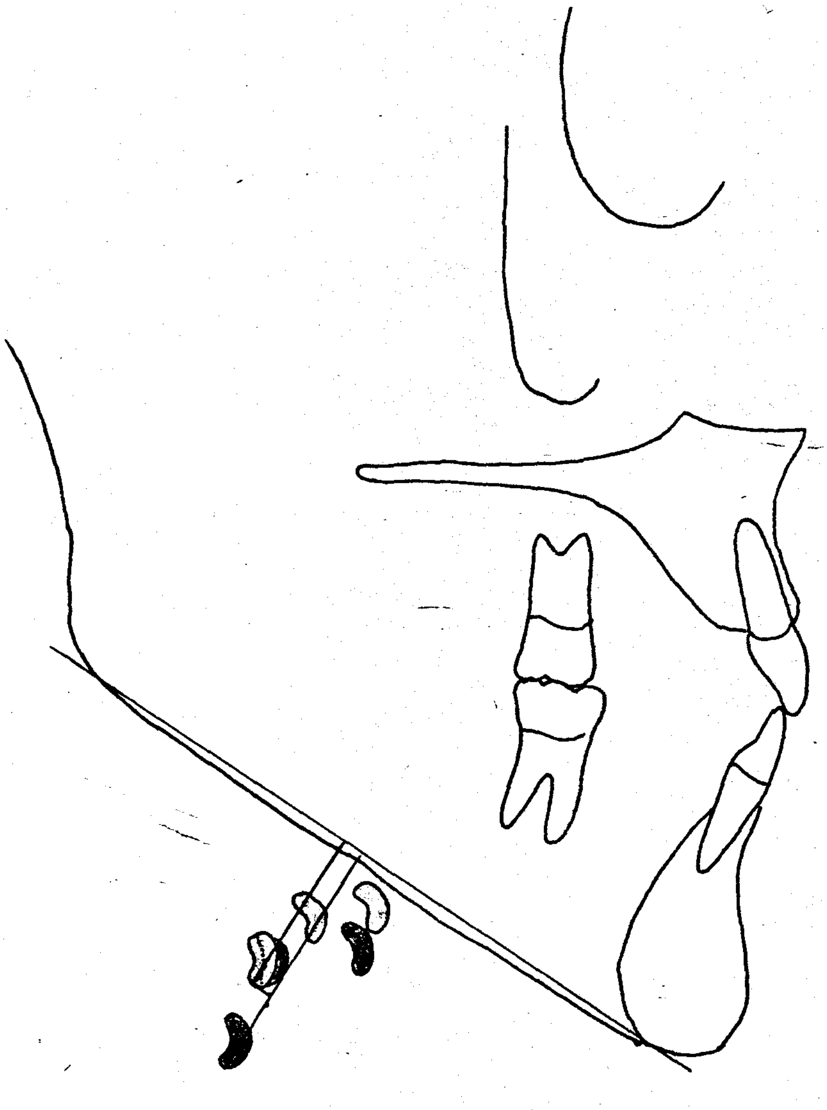


FIGURE IV 10

P.B.



V. DISCUSSION

An attempt was made in this study to determine the amount of change in positioning of the hyoid bone during swallowing following forced distal positioning of the tongue by a tongue crib. Myometric readings of tongue pressure were also recorded, and an attempt was made to correlate hyoid position with tongue force.

Following analysis of the cinefluorographic film and myometric readings, the ten subjects were divided into three groups for discussion. The first group (A) showed horizontal and vertical adaptation of the hyoid at rest and during the entire cycle, as well as tongue force adaptation after 24 hours. The second group (B) showed no hyoid change at all, and a varied response to tongue force adaptation. The last group (C) showed some hyoid adaptation; but, instead of a decrease in tongue force after 24 hours, there was an increase.

Group A consisted of 5 subjects, (L.L., G.J., K.B., P.C., M.J.) all showing downward and backward adaptation of the hyoid bone (See Table 1). These five subjects also showed tongue pressure increase on insertion of the crib, and a decrease following 24 hours of crib wear. None of these five subjects returned to the initial tongue force measurement prior to crib insertion, but there was a definite tendency to accommodation. It would have been presumptuous to assume that all of the myometric adaptation resulted from the adaptation of the hyoid bone in a posterior inferior direction, but this must have contributed to a portion of the change.

The entire hyoid cycle of these five subjects was displaced inferiorly and posteriorly. All five of these subjects measured a shorter distance than the other groups between the initial resting hyoid position and the mandibular plane. (See Table 2). The perpendicular distance in this group from the hyoid to the mandibular plane (a line through menton and gonion) ranged from 15 mm to 24 mm.

Earlier in this thesis the hyoid was described as a bone completely suspended by musculature and ligamentous attachments. When accommodation of the hyoid bone was considered, it was necessary to assume an increase in tonus of the infrahyoid musculature and a decrease in tonus of suprahyoid musculature, allowing the hyoid to accomodate to this new forced distal tongue position which was uncomfortable to the subject. There was a limiting factor in the amount and direction of accommodation that these muscular forces could have moved the hyoid bone. The limiting factor was the stylohyoid ligament which originated from the styloid process at the base of the skull and inserted onto the lesser horn of the hyoid bone. Any adaptation that occurred had to arc on the radius of this powerful ligament. Another possible means of accommodation could have come by rotation of the body of the hyoid downward and a raising or lowering of the greater horns. Cinefluorographic films did not show the outline of the greater horns, so it was impossible to determine if this occurred.

It was interesting to observe that Group A, with an initial higher hyoid position in relation to the lower border of the mandible, showed the ability to move the hyoid body inferiorly and posteriorly; while those with a lower hyoid position, were unable to do this.

Group B consisted of 3 subjects, (C.C., S.A., K.K.) and they showed no accommodation of the hyoid position. Myometric measurement of tongue pressure in two of the subjects (S.A., K.K.) did show adaptation after 24 hours, but the other subject (C.C.) remained very close to the initial crib insertion pressure. The tongue force decrease in these two subjects could only be explained by an adaptation of the intrinsic muscles of the tongue since there was no concommitant hyoid adaptation. All three of this group began with larger hyoid mandibular plane distance than Group A. The measurements here ranged from 29 mm to 38 mm. This distance appeared to be very important in hyoid accommodation.

Durzo and Brodie (1962) reviewed cases where growth of the mandible was arrested or there was an abnormal position of one of the points of suspension of the hyoid bone and the hyoid shifted accordingly. They found that this shifting was limited by compensatory muscle reactions which insured patency of the airway.

Patency of the airway appeared to be a major force in the amount of possible hyoid accommodation. In the hyoid positions close to the mandible, there appeared to be more room for accommodation of the hyoid and base of the tongue inferiorly without respiratory embarrassment. In those subjects with a lower hyoid mandibular body relationship, there seemed to be little accommodating ability due perhaps to encroachment on the patency of the airway.

Since there was accommodation of subjects with the hyoid closer to the inferior border of the mandible, it could have been the tonus of suprahyoid musculature that allowed change. In other words, if the hyoid was at a level closer to the mandibular plane then the suprahyoid musculature would have more ability to stretch.

The third group (C) consisted of two subjects (M.R., P.B.). These two were grouped together for one reason: both of them showed an increase in tongue pressure on crib insertion, and a further increase 24 hours after insertion. Subject P.B. had a large hyoid accommodation, but this was the only subject that moved anteriorly and inferiorly. She started 23 mm from the mandibular border, and moved 11.5 mm downward and 3.5 mm forward. The forward movement of the hyoid helped explain the increase in tongue force following 24 hours of crib wear. Subject M.R. had no accommodation of the rest hyoid position, but her cycle became smaller indicating an expected decrease in tongue force. There was no decrease in tongue force, but on the contrary, a violent increase. Based on the previous findings, this subject appears to be the exception. Speculation on the possible cause of this deviation was necessary. This subject was examined orally, and she had a large tongue which could account for the rise in tongue force. The subjects were instructed to hold their tongues behind the crib all the time, and this subject had a unique means of "slurping" to gather the saliva anterior to the crib rather than tipping her head backwards. This prolonged 24 hours of "slurping" may have increased tongue force though the same intrinsic muscles that made possible the accommodation for the two subjects of Group B who showed no hyoid adaptation, but myometric tongue force decreases.

An overall analysis of the results indicated a physiological variability in the adaptive capacity of the hyoid bone, but a definite potential in some individuals to perform this accommodation.

VI. SUMMARY AND CONCLUSIONS

Ten female subjects with Class I occlusions were studied to determine the amount of change in positioning of the hyoid bone during deglutition following forced distal positioning of the tongue by a tongue crib. A myometric study was done to measure the anterior force of the tongue during normal swallowing, and the force immediately following insertion of the distally displacing tongue appliance as well as twenty four hours after insertion.

The procedure was the following:

a) A myometric analysis of tongue pressure was done during normal deglutition

b) Cinefluorographic sequences of normal deglutition were taken

c) An orthodontic crib was fashioned to restrain the tongue distal to its normal position

d) A myometric analysis of tongue pressure was done immediately following insertion of the crib

e) Following 24 hours of crib wear, another myometric analysis of tongue pressure was taken

f) Following 24 hours of crib wear, another cinefluorographic sequence of deglutition with the crib in place was taken

Analysis of myometric and cinefluorographic results placed the ten subjects in three groups. Group A (5 subjects) showed posterior and inferior adaptation of the hyoid position at rest and during the entire cycle, along with tongue force accommodation after 24 hours of wearing the crib. Group B (3 subjects) showed no hyoid change at all, and a varied response to tongue force adaptation. Group C (2 subjects) showed hyoid adaptation, (One subject's rest position remained constant and the cycle became smaller. The other subject showed anterior movement as well as inferior movement of the hyoid at rest and in cycle) but a further increase in tongue force following 24 hours of crib wear.

It appeared that the subjects with an initial hyoid position close to the lower border of the mandible had the potential to accommodate in the posterior inferior direction. Those subjects in which the hyoid was at a greater distance from the lower border of the mandible failed to accommodate. The failure to accommodate in these subjects may be due to encroachment on a patent airway by the base of the tongue which attaches to the hyoid.

This field of study on the accommodation potential of the tongue pressure and hyoid position is of great importance to the orthodontist retracting teeth in the oral cavity as well as the prosthodontist, and oral surgeon whose reconstruction work may influence the size of the oral cavity.

There were many variables such as tongue size related to oral cavity size, lymphoid tissue involvement, deviate swallowing patterns, and other physiological variables, which were not considered in this paper, that merit further study.

An overall analysis of the results indicated a physiological variability in the adaptive capacity of the hyoid position, but a definite potential in certain individuals to make this accommodation.

BIBLIOGRAPHY

Bench, R.W., "Growth of the Cervical Vertebrae as Related to the Tongue, Face, and Denture Behavior", American Journal of Orthodontics 49: 183-214, 1963.

Berry, H.M., and Hoffmann, F.A., "Cineradiographic Observations of Temporomandibular Joint Function", Journal of Prosthetic Dentistry, 9: 21: 33, 1959.

Boucher, L.J., Van Scotter, D.E., Charlebois, H.J., "The Use of Cinefluorography in Dentistry", Greater Milwaukee Dental Bulletin, 306-319, Sept.

Cleall, J.F., "Deglutition: A Study of Form and Function" American Journal of Orthodontics, 51: 566-594, 1965.

Cleall, J.F., Alexander, W.J., McIntyre, H.M., "Head Posture and Its Relationship to Deglutition", The Angle Orthodontist, 36: 335-350, 1966.

Cleall, J.F., Milne, I.M., "Cinefluorographic Study of Functional Adaptation of the Oropharyngeal Structures", The Angle Orthodontist, 40: 267-283, 1970.

Durzo, C.A., Brodie, A.G., "Growth and Behavior of the Hyoid Bone", The Angle Orthodontist, 32: 193-204, 1962.

Fink, C.H., "Investigation of Anterior Open Bite Malocclusion by Means of Dental Arch Measurements, Cephalometrics, and Cinefluorography of Deglutition", Unpublished Master's Thesis, Loyola University, 1968.

Gould, M.S.E., Picton, D.C.C., "A Method of Measuring Forces Acting on The Teeth From The Lips, Cheeks, and Tongue", Brit. Dental J., 112: 235-242, 1962.

Grant, L.A., "A Radiographic Study of the Hyoid Bone Position in Angles Class I, II, and III Malocclusions", Unpublished Masters Thesis, University of Kansas City, 1959.

Gray, H., Anatomy of the Human Body, ed. 26, Philadelphia, Lea and Febiger, 1956.

Guyton, A.C., Textbook of Medical Physiology, ed. 2, W.B. Saunders, Company Philadelphia, 1956.

Ingervall, B., "Positional Changes of the Mandible and Hyoid Bone Relative to Facial and Dental Arch Morphology", Acta Odontologica Scandinavica, 28: 867-894, 1970.

Ingervall, B., Carlsson, G.E., Helkima, M., "Change in Location of Hyoid Bone with Mandibular Positions, Acta Odontologica Scandinavica, 28: 337-361, 1970.

Jacobs, R.M., "Muscle Equilibrium: Fact or Fancy" The Angle Orthodontist, 39: 11-20, 1969.

King, E.W., "A Roentgenographic Study of Pharyngeal Growth", The Angle Orthodontist, 22: 23-27, 1952.

Kydd, W.L., "Tongue and Lip Forces Exerted During Deglutition in Subjects With and Without Anterior Open Bite", J. Dent. Research, 42: 858-867, 1962.

Lear, S.C. and Moorrees, C.F.A., "Buccolingual Muscle Force and Dental Arch Form", Am. J. Orthodont., 56: 379-393, 1969.

Magendie, F., A Summary of Physiology, Baltimore, Straub Publ. 1822.

Mainland, D., Anatomy as a Basis for Medical and Dental Practice, New York, Paul Hoeber and Co., 1945, p. 580.

McGlone, R.E., Profitt, W.R., "Correlation Between Functional Lingual Pressure and Oral Cavity Size", Cleft Palate Journal, 9: 229-235, 1972.

McNulty, E.C., "Measurement of Labiolingual Forces on Central Incisors in Normal and Protrusive Positions", Am. J. Orthodont. 53: 137, 1968.

Neff, C. Wayne, Kydd, W.L., "The Open Bite: Physiology and Occlusion," The Angle Orthodontist, 36: 351-357, 1966.

Negus, V.E., The Mechanism of the Larynx, St. Louis, The C.V. Mosby, Co., 1930.

Orban, B.J., Orban's Oral Histology and Embryology, ed. 5, St. Louis, The C.V. Mosby, Co., 1962.

Posen, A.L., "The Influence of Maximum Perioral and Tongue Force on the Incisor Teeth", The Angle Orthodontist, 42: 285-308, 1972.

Ramsey, G.H., Watson, J.S., Gramiak, R., Weinberg, S.A., "A Cinefluorographic Analysis of the Mechanism of Swallowing", Radiology, 64: 498-518, 1955.

Saunders, J.B., Davis, C., Miller, E.R., "The Mechanism of Deglutition as Revealed by Cineradiography", Annals of Otology, Rhinology, and Laryngology, 60: 897, 1951.

Shelton, R.L. Jr., Bosma, J.F., Sheets, B.V., "Tongue, Hyoid and Larynx Displacement in Swallow and Phonation", Journal Applied Physiology, 15: 283-288, 1960.

Sicher, H., DuBrul, E.L., Oral Anatomy, ed. 5, St. Louis, The C.V. Mosby Co., 1970.

Sloan, R.F., Bench, R.W., Mulick, J.F., Ricketts, R.M., Brummett, S.W., Westover, J.L., "The Application of Cephalometrics to Cinefluorography: Comparative Analysis of Hyoid Movement Patterns During Deglutition in Class I and Class II Orthodontic Patients", The Angle Orthodontist, 37: 26-33, 1967.

Sloan, R.F., Ricketts, R.M., Brummett, S.W., Bench, R.W., Westover, J.L., "Quantified Cinefluorographic Techniques Used in Oral Roentgenology" Oral Surg. 20: 456-463, 1965.

Smith, J.A., "A Cephalometric Radiographic Study of the Hyoid Bone in Relation to the Mandible in Certain Functional Positions", Unpublished Master's Thesis, Northwestern University, 1956.

Stepovich, M.L., "A Cephalometric Positional Study of the Hyoid Bone", American Journal of Orthodontics, 51: 882-900, 1965.

Subtelny, J.D., "Malocclusions, Orthodontic Corrections and Orofacial Muscle Adaptation", The Angle Orthodontist, 40: 170-201, 1970.

Takagi, Y., "Postural Change of the Hyoid Bone Following Osteotomy of the Mandible", Oral Surg. 23: 688, May, 1967.

Thompson, J.R., "A Cephalometric Study of the Movements of the Mandible", J.A.D.A., 28: 750-761, 1941.

Thurow, R.C., Atlas of Orthodontic Principles, St. Louis, The C.V. Mosby, Co., 1970.

Tomes, C.S., "The Bearing of the Development of the Jaws on Irregularities, Dental Cosmos., 15: 292-296, 1873.

Wickwire, N.A., White, R.P., Profitt, W.R., "The Effect of Mandibular Osteotomy on Tongue Position", Journal of Oral Surgery, 30: 184-190, 1972.

Winders, R.V., "Forces Exerted on the Dentition by the Perioral and Lingual Musculature", The Angle Orthodontist, 28: 226-235, 1958.

Wolk, R.S., "A Cinefluorographic, Electromyographic, and Myometric Study of Muscular Activity During Swallowing In Patients with Mandibular Resection", Unpublished Master's Thesis, Loyola University, 1969.

Wood, B., "An Electromyographic and Cephalometric Radiographic Investigation of the Positional Changes of the Hyoid Bone in Relation to Head Posture", Unpublished Master's Thesis. Northwestern University, 1956.

APPROVAL SHEET

The thesis submitted by Gary Samuel Cuozzo has been read and approved by members of the Department of Oral Biology.

The final copies have been examined by the Director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Masters of Science.

May 11, 1973
DATE

Douglas C. Bowman
SIGNATURE OF THE ADVISOR