Investigation of Anterior Open Bite Malocclusion by Means of Dental Arch Measurements, Cephalometrics and Cinefluorography of Deglutition

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INVESTIGATION OF ANTERIOR OPEN BITE MALOCCLUSION BY MEANS OF DENTAL ARCH MEASUREMENTS, CEPHALOMETRICS AND CINEFLUOROGRAPHY OF DEGLUTITION

BY

CHARLES H. FINK

A THESIS SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL OF LOYOLA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

JUNE 1968
Charles Henry Fink was born in Madison, Wisconsin on April 19, 1939.

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ACKNOWLEDGEMENTS

I wish to extend my sincere appreciation to my co-advisor, Dr. Douglas C. Bowman, Professor of Physiology, for his conscientious effort and display of interest in the composition and experimental method of this thesis.

I wish to thank my co-advisor, Dr. Donald C. Hilgers, Chairman, Department of Orthodontics, for his help in obtaining the cinefluorograph and the materials used in this study.

I wish to thank the members of my thesis advisory board, Drs. Bowman, Hilgers and Kiely for their helpful suggestions and refinement regarding this thesis.

I will always be deeply indebted to Dr. Joseph R. Jarabak, my teacher, and the Loyola-Jarabak Foundation, for their foresight and the deep scientific interest necessary to install and finance the cinefluorograph in the Orthodontic Department of Loyola University Dental School.

I am very grateful to my parents for their encouragement and financial support throughout the duration of my schooling.

I am most grateful to my wife, Carole, for her loyalty, hard work, and the sacrifices she made for four years. With her support and devotion, I was able to continue my education.
TABLE OF CONTENTS

Chapter                                                                 Page

I.  INTRODUCTION AND STATEMENT OF THE PROBLEM .....  1

II. REVIEW OF THE LITERATURE .................................  4

   A. Cinefluorography - History and Technique
   B. Methods of Quantitative Cinefluorography
   C. Studies of Swallowing Patterns
   D. The Hyoid Bone - Anatomy and Physiology
   E. Open Bite - Studies and Etiology
   F. Cephalometrics of the Cranial Base, Hyoid Position and Movement

III. METHODS AND MATERIALS .................................  38

   A. Introduction
   B. Radiation Output
   C. Radiation Dosage to the Operator
   D. Open Bite Population and Normal Sample
   E. Medical and Dental History
   F. Dental Casts
   G. Photographs
   H. Cephalograms
   I. Cinefluorographic Film Sequences
   J. Cranial Landmarks and Method of Analyzing Hyoid Movement

IV. FINDINGS .................................................  64

   A. Medical and Dental History
   B. Dental Casts
   C. Photographs
   D. Cephalometrics
   E. Hyoid Motion Analysis
   F. Observation of the Swallowing Pattern

V. DISCUSSION ..................................................  81

VI. SUMMARY AND CONCLUSIONS .................................  94

APPENDIX .....................................................  97

BIBLIOGRAPHY ................................................  99
## LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>The Cinefluorograph</td>
<td>40</td>
</tr>
<tr>
<td>2.</td>
<td>The Profile Shield</td>
<td>41</td>
</tr>
<tr>
<td>3.</td>
<td>Bjork Analysis</td>
<td>48</td>
</tr>
<tr>
<td>4.</td>
<td>The Optical Cephalostat</td>
<td>52</td>
</tr>
<tr>
<td>5.</td>
<td>Analytical Projector and Projection Cabinet</td>
<td>56</td>
</tr>
<tr>
<td>6.</td>
<td>The H 1 Angle</td>
<td>59</td>
</tr>
<tr>
<td>7.</td>
<td>The H 2 Angle</td>
<td>60</td>
</tr>
<tr>
<td>8.</td>
<td>The H 3 Angle</td>
<td>61</td>
</tr>
<tr>
<td>9.</td>
<td>The Occlusal Plane H Angle</td>
<td>63</td>
</tr>
<tr>
<td>10.</td>
<td>Normal Swallowing Pattern</td>
<td>73</td>
</tr>
<tr>
<td>11.</td>
<td>Hyoid Patterns</td>
<td>77</td>
</tr>
<tr>
<td>12.</td>
<td>Bird's Head Silhouettes</td>
<td>79</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cast Measurements of Functional Open Bites Compared to Values From Pont</td>
<td>66</td>
</tr>
<tr>
<td>2.</td>
<td>Cast Measurements of Skeletal Open Bites Compared to Values From Pont</td>
<td>67</td>
</tr>
<tr>
<td>3.</td>
<td>&quot;t&quot; Comparisons Between Group II and III</td>
<td>68</td>
</tr>
<tr>
<td>4.</td>
<td>Angular and Linear Values of Bjork Analysis in Group II and III and Their &quot;t&quot; Comparisons</td>
<td>70</td>
</tr>
<tr>
<td>5.</td>
<td>Angular Values of Hyoid Motion in Group I, II and III and Their &quot;t&quot; Comparisons</td>
<td>71</td>
</tr>
</tbody>
</table>
CHAPTER I
INTRODUCTORY REMARKS AND STATEMENT OF THE PROBLEM

The literature is filled with statements as to the etiology of the anterior open bite malocclusion. Anterior open bite has been defined as "an open vertical dimension between the incisal edges of the maxillary and mandibular anterior teeth. While this situation exists, some of the buccal teeth are in definite occlusal contact."

Various habits, diseases, and aberrant growth patterns are some of the conditions that have been suggested as responsible for the development and maintenance of the anterior open bite malocclusion. Some of these suggestions have been based upon sound observation and scientific reasoning; others have not.

It is evident that no single factor is the sole cause of the problem. There is more than one type of anterior open bite malocclusion from the standpoint of etiology.

Many authors have described these malocclusions as associated with habits such as non-nutritive sucking and tongue thrusting. Others have mentioned skeletal growth patterns as responsible for the malocclusion. Some have discussed the problem from the standpoint of treatment.
An attempt must be made to classify the open bite malocclusion as to factors of its etiology and maintenance. Many attempts have been made in the treatment of the malocclusion; some have been successful, and others have not. Many clinicians will never attempt its treatment. It is a malocclusion of great renown as to its difficulty of treatment and retention.

It is no wonder that investigators know so little of its cause and effect relationship. Until recently, there have been no real specialized diagnostic tools that could probe into the internal mechanism of the animal body. Early investigators could only speculate etiology from observations of stone models or dry skulls. Cephalograms came later, but even then there were no recognized norms of skeletal morphology, growth and development.

The necessary number of sophisticated diagnostic instruments have been unavailable for the segregation and observation of synchronous movement and pressure equilibrium associated with various functions of the animal body. Only in the last fifteen years has an instrument, the cinefluorograph, been developed that could show internal movements of the animal body, record these movements permanently, and still not expose the body to undue amounts of radiation or damage during a specified period of time. Although cinefluorographic technique is far
from being of a precision quality, it does, however, provide a means of exploring internal motion.

Clinical treatment, to be successful, of necessity, demands an accurate diagnosis and understanding of the etiology and mechanism of the malocclusion. According to de Coster (1936) only 16.7% of the treated open bites can be considered to demonstrate clinically excellent results. Open bites can almost always be closed, yet successful results are determined only by successful retention. Relapse denotes treatment failure and this sometimes is not evident for many years.

The purpose of this investigation is to study the anterior open bite malocclusion from the standpoint of etiology so as to relate form and function in the establishment of treatment objectives.

Through the use of lateral cephalograms, the open bite cases will be divided into two groups: skeletal and functional. Movement of the hyoid bone during swallowing will be examined primarily with respect to the mandible and cranial base.

Movement of the tongue will also be observed with respect to the hard palate, and the anterior teeth.
CHAPTER II
REVIEW OF THE LITERATURE

A. Cinefluorography - History and Technique

Cinematography describes the production of the illusion of motion with the aid of the motion picture. Indirect and direct roentgen cinematography are the two basic methods of making motion pictures with x-rays. These two methods were investigated by Macintyre in 1897. The direct method of roentgen cinematography consists of making multiple, sequential exposures on x-ray film with or without the aid of radiographic intensifying screens.

Rapid serial radiography is an example of a direct method. Serial film changers that permit the making of as many as twelve exposures per second on film as large as 14 x 14 inches in size are utilized. Upon copying such serial radiographs onto motion picture film, an illusion of motion is created. This low frequency, however, is not compatible with modern standards.

Seventy millimeter double emulsion film exposed by the direct roentgen beam at camera speeds of fifteen frames per second has been termed cineradiography and does meet modern requirements.
An example of indirect roentgen cinematography is the photography of fluorescent moving images. This procedure has become known as cinefluorography, but it was not until the development of practical x-ray image intensifiers in 1953 that cinefluorography has been able to assume a useful place in roentgen diagnosis. This was due to the reduction in radiation to the patient.

The basic components for any modern image-intensifier cinefluorographic method are: a source of x-ray energy, the patient, the x-ray beam after differential absorption in the patient, the input phosphor, an image intensification device, an intensified image on the output phosphor, a lens and film transport system.

The image intensifier, described simply, consists of an evacuated glass envelope containing a fluorescent screen at one end called the "input phosphor". When the x-ray beam strikes the input phosphor, a conventional fluoroscopic image is formed, which frees electrons from a photocathode placed in intimate contact with the input phosphor. The number of electrons emitted at any point from the photocathode is proportional to the light intensity at a corresponding point in the fluoroscopic image. An electron image is thus formed on the surface of the photocathode. These electrons are
accelerated to high speed and are also electrostatically reduced in size and focused on a second fluorescent screen, the viewing screen or "output phosphor", contained within the anode. The combination of these two factors, acceleration and reduction, results in increased brightness of the image on the output phosphor by a factor of between four and five thousand times. A variety of viewing systems is available for fluoroscopy alone, for simultaneous use of a motion picture camera, and closed circuit television camera.

The earlier image intensifiers had a field size of five inches, but modern image intensifiers now have a field size of nine and eleven inches.

Synchronization of the power source to the x-ray head with the cine camera allows emission of x-rays only when each successive frame of cine film is in position for exposure. This produces a pulsating x-ray beam which when compared to a continuous beam, with the time remaining constant, reduces the total radiation exposure to the patient.

Research in developing the cinefluorographic technique began as early as 1929 by Warren and Bishop at the University of Rochester School of Medicine.

Since 1946 many cinefluorographic studies have been reported dealing with the anatomy and physiology of normal and
abnormal hearts, the urinary tract, the esophagus, the stomach and small intestine, the cerebral circulation and various joints. In addition to routine clinical studies, special investigations have been reported dealing with the swallowing mechanism, the production of sounds by laryngectomized patients and the function of the organs of speech. The majority of studies have been concerned with the mechanism of swallowing, the function of the heart, and the function of the urinary tract.

B. Methods of Quantitative Cinefluorography

Men investigating swallowing, speech patterns, and patterns of hyoid movement have developed methods to measure quantitatively movement with respect to fixed cranial landmarks. Sloan et al (1963) presented an analysis originally described by Bench (1963) wherein a cephalometric tracing of fixed cranial landmarks is superimposed over a cinefluorographic image. Both roentgen ray magnification errors were compensated for by fastening objects of known dimension to the patient and thereby evaluating movement on the cinefluorographic record with respect to the cephalometric tracing.

Berry and Hofmann (1959) made a cinefluorographic study of the movement of the temporomandibular joint. To determine
the degree of roentgenographic enlargement and thereby calibrate the actual anatomic excursions, a metal ball bearing (a round image can not be elongated or foreshortened) of 4.8 mm diameter was attached to the patient's face directly above the joint to be examined. This ball bearing becomes magnified to the same extent as the joint structures. A wire grid with 10 mm openings was placed in contact with the receiving screen of the image amplifier and was not subject to enlargement. Therefore, on the finished film, a simple ratio between the size of the shadow of the ball bearing and the grid meshes determined the actual anatomic measurements.

The analysis of movement can be accomplished with an instrument known as a Boscar. Single frames appear on a large screen and by digital manipulation, two cross hairs are positioned on the specific point to be plotted. A reference line is then constructed on the face of the Boscar tangent to the shadow of the ball bearing and the superior border of the external auditory canal. This tangent serves as a fiducial or orienting mark, and on all readings of succeeding frames the tangent line is superimposed over the reference line on the Boscar. The center of the shadow of the ball bearing was chosen as the center of the coordinate system. When the cross hairs are positioned over the selected point, a beam of light
activates an IBM punch-card machine, and the X and Y coordinates of the point (with reference to the center of the ball) are punched, and their numerical equivalent is typed simultaneously on another paper. X and Y readings are carried out in this manner for each of eight preselected points around the condyle in each frame.

The next step is to plot these readings. The punch cards are fed into an Electroplotter which automatically marks the X and Y position of each point on graph paper. By connecting these points, the outline of the condyle is produced. When the same procedure is repeated for succeeding frames, condylar movement becomes apparent.

In order to quantitate cinefluorographic records other grid systems have been used. These provide a graphic record of movement, coordinated plotting that results in arithmetical data which can be programmed, and a means of testing the reliability of the selected morphologic static points. Some of these grids have been oriented on the Frankfort plane using the plane as the X axis and a perpendicular to it as the Y axis.

All of the quantitative methods of cinefluorographic analysis of motion have been based on the development of analytical projectors which enable the viewer to preview the cine sequences by means of slow motion and pulse viewing and the
final selection of a cine frame representing the limit of motion in some direction. This selected frame is then projected for an unlimited period of time while its image is traced or compared to a subsequently prepared tracing. The unlimited dwell of the selected frame is made possible by means of a fire gate shutter or accessory blower so as not to damage the film.

Recently, Cleall (1966) has used the Vanguard Motion Analyzer in his study of head posture in relation to deglutition. The motion analyzer consists of a vertical projecting analytical projector attached to a projection stand or rear projection screen. On the face of the screen, individually adjusted and manually crank operated cross hairs representing the X and Y coordinates can be moved. These coordinates are accurate to the nearest one thousandth of an inch. Other accessories such as an angle measuring device are available. The angle measuring device is accurate to the nearest quarter degree. The motion analyzer can be coupled to automatic read-out equipment which will activate IBM card punch and magnetic tape equipment for subsequent computer analysis.

C. Studies of Swallowing Patterns

Saunders, Davis and Miller (1951) using high speed cineradiography studied the mechanism of deglutition. Their
Paper is summarized by Grant and Basmagian: "Swallowing begins as a voluntary movement and continues as an involuntary one. Thus, the lips are closed and the Buccinators are pressed against the teeth. The lingual muscles pass the bolus of food backward on the dorsum of the tongue to the palatoglossal arch, and there, at the entrance to the pharynx it may rest, the voluntary stage of deglutition being completed."

"If, however, some saliva, fluid or portion of food enters the pharynx, the involuntary stage is started reflexly by stimulation of the glossopharyngeal nerve."

"The jaws are held closed by the Masseters and Temporals, while the hyoid bone and the larynx rise, as by palpation you can determine on yourself (probably by the action of the Di-gastrics). The tongue, like a piston thrust forcefully backward and upward against the soft palate, forces the bolus into the pharynx (by the action of the intrinsic muscles of the tongue, the Mylohyoids and the Styloglossi), whereupon a peristaltic wave propels it through the pharynx and into the esophagus. During this phase the larynx rises slightly more (by the action of the Stylopharyngei)."

"The erect epiglottis, inclined slightly backwards by the backward movement of the tongue, is now swept farther backward by the oncoming bolus which fills the valleculae. In fact,
it is swept backward and downward until it covers the laryngeal aperture like a lid. Since the aryepiglottic folds can be seen to shorten, it is not unlikely that the Aryepiglottic muscles pull the epiglottis while the bolus pushes it."

"The entrance to the larynx and the vestibule are tightly closed by the sphincteric muscles which also tilt the apices of the arytenoid cartilages against the tubercle of the epiglottis and approximate the vocal cords. Although the epiglottis closes like a lid, the sphincteric mechanism is alone sufficient to prevent the entrance of food into the larynx."

"The movements that take place during the act of swallowing are too rapid for the eye to perceive. For example, the epiglottis bends from the erect position to 60° below the horizontal and recovers in about 1/15 of a second. Hence, high speed cinefluorography using 30 and 60 frames per second was employed by Saunders, Davis and Miller, who in more ways than one have thrown new light on the mechanism of deglutition."

Cleall (1963), in his study of the form and function of deglutition, performed a cinefluorographic analysis on 28 adolescents with skeletal and normal Angle Class II division I malocclusions, and 27 tongue thrust subjects with Class II and Class I malocclusions, including several openbites. These
samples were balanced with respect to age.

In this analysis a cinefluorographic sequence was studied during the nondemand deglutition of saliva, and motion was compared by means of an analytical projector, tracing cabinet, and a tracing of a standard fixed reference taken from a cephalometric film.

Cleall states, "The assumed interrelationship between the movements of the tongue, lips and mandible during swallowing, and the form of the surrounding hard structures has given rise to the concepts of 'normal' and 'abnormal' swallowing. 'Normal swallowing' is said to be occurring when the lips remain in repose, the posterior teeth make contact, and the tongue remains within the confines of the oral cavity; swallowing is said to be 'abnormal' when the behavior is such that an adverse effect on the dentition can be demonstrated or assumed to be present." However, in this study of the normal sample he found that in approximately twenty per cent there was an actual lip separation even during stage two of deglutition. Forty per cent showed no interocclusal contact at any phase of deglutition.

In the Class II group, the hyoid bone was found to be higher and more posterior, and the posterior aspect of the tongue with the soft palate resting upon it was also found to
be in a dorsicranial position. When related to the lower incisor, the tongue tip was also observed to be further forward in the Class II group. At rest, the lips were parted in approximately twice as many subjects in the Class II group as in the normal sample, while sixty per cent did not achieve occlusal contact during deglutition. Most of the important differences appeared to be related to the marked dental disharmony present in the Class II group.

The movements of the functioning organs and structures during deglutition were smoothly synchronized in the normal and Class II groups, but in the tongue thrust group the movements were erratic. The movements were also inconsistent between swallows within one given individual. "No attempt was made to break the tongue thrust group down into subgroups and to investigate such factors as tongue size, skeletal or dental open bite, 'endogenous' tongue patterns or habit manifestations."

In the tongue thrust group, a greater distance from the palatal plane to the tip of the lower incisor was found. A consistent finding was that the tongue tip at rest was lower in the tongue thrusters. A longer period of time was required for the tongue tip to move from rest to the second stage of swallowing. Sixteen per cent of this group rested with the
tongue tip anterior to the lower incisor, and the tongue tip was found to move much further forward during swallowing. Lip separation was greater both at rest and in function. At rest the hyoid bone was found to be more posterior in the tongue thrust group when compared to the normal group and it was found to be lower than in the Class II group. In function, this bone was also found to be situated more posteriorly than normal. Mandibular movements were more erratic and no correlations were found between movements of the tongue tip and the mandible itself as could be found in the other groups. In the tongue thrust group, the mandible moved upward and backward as compared to upward and forward in the other two groups. The tongue thrusters were found to swallow in an erratic manner with an abnormal amount of head movement.

Cleall made a secondary experiment in the tongue thrust group. In twenty of the twenty seven cases, a palatal crib was worn for six months after the initial cinefluorographic records and study models were taken. At the end of this period new records were made, the palatal cribs were removed, and a second cinefluorographic recording was made. After two months, a final set of study models and cinefluorographic records were made. The dental casts were analyzed for changes in the occlusal status during the time interval (eight months) that
had elapsed between the initial and final records.

Comparing the initial recordings and the six month recordings showed that the crib appeared to "basket" the tongue tip and influence it to function in a more posterior position. The hyoid bone also was found to be in a more posterior position in rest and in function. The swallowing patterns after six months were consistent and showed none of the initial erratic motion. Following removal of the crib, the initial erratic pattern was observed and the tongue tip tended to seek its initial position as did the hyoid bone. The final records showed that most of the subjects reverted to their old habits, however, eight subjects showed a consistent reduction in the forward excursion of the tongue after therapy. Five of these eight subjects showed marked change in their anterior occlusal relationships. The intercanine distance was reduced and lingually directed lip forces became unopposed causing crowding in some cases.

Cleall stated "While it is possible that the positions of the structures at rest may be partly controlled by the inherent elasticity of the muscles and the position of the muscle attachments, there is also the possibility that tactile sensory receptors in the lingual and oral mucosa, the oral surface of the lips, and the periodontal ligaments may strongly
influence the postural relationships of structures in this region. Furthermore, it is possible that during swallowing movements a sensory 'feedback' from these structures may influence the finer details of the movements. The erratic postural and movement patterns observed after removal of the crib appliance were thought to be due to the loss of the established sensory clues, which also may be evidence that a strong tactile sensory 'overlay' is required for good neuromuscular coordination."

Hedges, McLean, and Thompson (1965) state that the evidence concerning the frequency of teeth-together swallows is not well documented and simultaneous lip movement during deglutition is rather vague. Tulley (1956) attributed this to the difficulty in obtaining a true lateral view of a subject without a head positioner. Cleall (1963) refrained from using a head positioner in his study and had the patient watch a small light positioned at eye level. He stated that fixation of the head during swallowing was not physiologic. In the study of tongue patterns in function by Hedges, McLean and Thompson, a cephalostat was used and they found that fifty-three per cent of the non-demand saliva swallows were of the teeth apart variety.
D. The Hyoid Bone - Anatomy and Physiology

The hyoid bone is a horse-shoe shaped bone located high in the neck. The legs of the bone encircle the larynx just above the thyroid cartilage.

Brodie (1950) called attention to the fact that the hyoid's role as a functional part of the skeletal system has been a recent evolutionary development associated with man assuming an upright posture.

Orban (1957) stated that the hyoid develops from the second and third branchial arches. The posterior portion of the tongue also develops from these two arches.

Sicher (1960) stated that the hyoid bone can be designated as the skeleton of the tongue.

Parson (1909) reported the hyoid bone to have become completely ossified by the age of fourteen years. He also found the greater horns to have grown one centimeter in the first year, another centimeter to puberty, and a third centimeter between puberty and the age of twenty-five years.

Bench (1963) in his study of the cervical vertebrae and related structures found that the hyoid bone moves downward in conjunction with cervical vertical growth. King (1952) found that in the infant, the hyoid bone was positioned well above the symphysis. The downward progress of the hyoid bone is
rapid during early childhood and then slower until puberty when it takes a spurt downward and forward to be found at a level between the third and fourth cervical vertebrae. Bench (1963) reports the level of the hyoid bone to be at the level of the fourth cervical vertebra. Stepovich (1965) was the first to measure the hyoid angle and the hyoid plane as described by him also was found to be at the level of the third cervical vertebra.

The hyoid bone is divided into three parts: an unpaired middle part, the body, and the paired greater and lesser horns. Mainland (1945) has likened the hyoid bone to a platform. By flexing one set of muscles, the platform is stabilized so that other muscles can act from it.

The following 11 major muscles are attached to the hyoid bone.

- Geniohyoid
- Mylohyoid
- Omohyoid
- Sternohyoid
- Stylohyoid
- Digastric
- Thyrohyoid
- Chondroglossus
- Hyoglossis
- Genioglossis
- Middle Pharyngeal Constrictor

The hyoid bone through these muscles is attached to the mandible, the base of the skull, the sternum, the scapula, and
the pharynx. It might be said further that the thyroid cartilage also is attached to the hyoid bone.

The relative lengths of the sets of muscles attaching to the hyoid bone determine the anteroposterior relation of the hyoid bone to the vertebral column and the superio-inferior relation to the sternum and the mandible or maxilla.

Thompson (1941) noted that mandibular movements were influential upon the position of the hyoid.

Cleall (1966) noted a definite statistical correlation between movements of the tongue tip, mandible and hyoid bone in his cinefluorographic study of swallowing in a "normal" group.

Sloan et al (1963) prescribed methods of quantitative cephalometric-cinefluorographic analysis. By coupling adequate stabilization of the head and maintenance of a standard distance between source, subject, and pickup, they were able to obtain standardized cinefluorographic film. Complementary cephalometric roentgenographs were then traced and related to the cine material.

They studied forty-five subjects averaging twelve years of age. Three groups of equal number representing Class I; Class II, Division I; and Class II, Division II type malocclusions were presented. Two distinct hyoid movement patterns
were found; a circular pattern and an oblique, elliptical pattern. In all three groups the anterior-posterior location of the hyoid was found consistently near the anterior root of the pterygoid plates. The Class I malocclusions showed significantly lower and more posterior hyoid locations. The Class II malocclusions showed higher and more forward hyoid patterns with greater ranges of movement than were found in the Class I subjects.

In a cinefluorographic study by Cleall (1965) of the form and function of deglutition, the hyoid bone in his Class II subjects was found to be in a higher and more posterior aspect than his group of "normal" swallowers.

Shelton, Bosma and Sheets (1960) found in their cinefluorographic study that the hyoid bone moved cephalad, the larynx was elevated and that the pharyngeal portion of the tongue moved dorsally in Phase I of deglutition. In Phase II, the hyoid moved ventrad or ventrad and cephalad with concomittant elevation and closure of the larynx. The pharyngeal portion of the tongue was obscured on its dorsal surface by a radio-opaque bolus. In Phase III, the hyoid bone descended either obliquely dorsad and caudad, or dorsad and caudad and then more directly caudad. Ventrad movement of the pharyngeal portion of the tongue and descent and opening of the larynx
also was observed. They stressed the concept of a unified tongue-hyoid-larynx column as useful and perhaps essential in understanding the myology of the pharynx.

Durzo and Brodie (1962) concluded that while the hyoid bone is positioned superio-inferiorly at a level opposite the lower portion of the third and upper portion of the fourth vertebrae, its position anterio-posteriorly depends on the relative length of those muscles running to it from the base of the cranium bilaterally and from the region of the mandibular symphysis. It is thus controlled by a three point suspension. Its position is probably further modified by the pharyngeal and infra-hyoid muscles and by gravity acting upon the larynx.

During the period of growth, the hyoid descends as the cervical vertebrae increase their height and the posterior cranial base and the mandible descend and move away from each other. This descent, however, is of such a nature that the relative position of the bond does not change.

E. Open Bite - Studies and Etiology

Rodgers (1927) observed that open bites were seldom seen in the deciduous dentition. He observed that this mal-development usually appeared later in life, and developed most
rapidly during the period of transition between the shedding of the deciduous teeth and their replacement by the permanent teeth.

He believed that an explanation for the cause of some open bites was that the tongue found itself in a changing environment, and in its exploratory movements, it discovered unstable deciduous teeth and repeatedly tested the stability of these teeth and as a consequence developed a thrusting habit. He prescribed facial muscle exercises and exercises to provide an awareness of tongue position and to promote proper swallowing procedure. In some cases he prescribed fixed palatal rake appliances in order to limit tongue movements.

Hellman (1931) compared three negro skulls with open bites to forty-one negro skulls with the full complement of teeth in normal occlusion. He found that the open bite skulls demonstrated a greater total face height. The ramus length was significantly shorter in the open bite skulls. He also found the bizygomatic, bicondylar, mandibular bicanine, and minimum palate widths narrower than the normal skulls while the nasal and posterior narial widths were greater. He found that the palate and mandible as a whole, were smaller anteroposteriorly than normal. It was also noted that, while the face as a whole is longer in the skull with malocclusion, the
ramus and body of the mandible are shorter. This would produce a more obtuse gonial angle than normal.

In order to check the preceding observations, Hellman again compared open bite skulls to twenty-five normal skulls in a collection of white European male skulls from Hungary. He again found that a short ramus and body of the mandible were related to open bite malocclusion.

"That the short ramus and short body of the mandible are causally related to open bite cases may also be shown by negative evidence. One skull had a dentition in Class I malocclusion, but the incisors and canines were in an excessive overbite relationship. In this skull, the total face height was shorter than normal, but the ramus height was greater than the standard. The effect on the bite was consequently reversed."

In summary, the following statements were made:

"The reason for success or failure in treatment is not known. The habit of finger-sucking and breaking of the habit may be part of the problem."

The study of skeletal material revealed the fact that the occlusal disturbance known as open bite is in constant relationship with an absolutely or relatively short ramus and body of the mandible and not with an arresting of development in the incisor region.
The short ramus, in the course of individual development, may increase in size by the natural process of growth and this growth coincidently, often improves the open bite condition.

When growth changes are favorable, the prognosis of open bite cases is excellent and may require no orthodontic treatment; when unfavorable, the outcome of treatment is questionable.

De Coster (1936) examined one hundred open bite cases. Seventy-five were examined by means of orthodontic models and twenty-five by means of models and teleradiographs analyzed with mesh diagrams. He found that in a great many of the cases, the arch form was in the shape of a lyre with a narrowing in the premolar area. He divided the seventy-five model cases into five groups according to the maximum midline open bite aperture:

<table>
<thead>
<tr>
<th>Group</th>
<th>Anterior Vertical Opening</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>15 mm+</td>
<td>7</td>
<td>9.3%</td>
</tr>
<tr>
<td>II</td>
<td>10 mm+</td>
<td>10</td>
<td>13.3%</td>
</tr>
<tr>
<td>III</td>
<td>5 mm</td>
<td>20</td>
<td>26.6%</td>
</tr>
<tr>
<td>IV</td>
<td>3 mm</td>
<td>28</td>
<td>37.7%</td>
</tr>
<tr>
<td>V</td>
<td>2 mm</td>
<td>8</td>
<td>10.6%</td>
</tr>
</tbody>
</table>

In comparing open bite occlusion he found that 54.3% were Angle Class I, 39.2% were Angle Class II and 3.39% were Angle Class III. He found, in measuring the mesio-distal width of all the teeth on the models, that there was evidence of
90.66% 'atresia' of the molars and premolars.

The open bite extended to the molars 4.7% of the time and to the premolars 66.97% in Group I and Group II. Premolar infraocclusion was 86.95%, and molar infraocclusion 13% in Group IV. The infraocclusion was always limited to the premolars in Group V. The totals for all groups were 72.8% premolar infraocclusion and 37.1% molar infraocclusion.

The depth of the palatine vault was measured and found to be an average of 20 mm in Group I and 19 mm in Group II.

Accentuated protrusion of the anterior teeth was found in 86.4% of the cases, while 13.5% exhibited either abnormal occlusion of the incisors or retrusion.

Teleradiographs revealed many cases with a shortened ascending ramus protruding anteriorly. In certain cases the ascending ramus ran so far posteriorly that it resulted in a receding condyle in the articulation and in an inferior distal position of the mandible. Shortening was the variation most frequently found in the body of the mandible. The mandibular angle with few exceptions, was greater than normal and had remained infantile.

Rix (1946) and Ballard (1945) describe a tongue position reminiscent of the neonatal tongue-lip contact. The tongue
rests constantly against the lower lip and thrusts or spreads forward to meet the contracting lower lip in swallowing and speech. A lisping speech accompanies this behavior and may be found in several members of the family. The speech therapist may overcome the lisp but fails to change the basic pattern of tongue behavior. This is a poor prognostic sign when an attempt is being made to treat an open bite.

Seipel et al (1954) and Anderson et al (1954) found that open bite in the Rhesus monkey was associated with endocrine imbalance, systemic diseases and aberrant growth and development.

Tully (1956) states that the tongue readily fills any open bite created by finger or thumb sucking habits and that these habits may be eliminated with mechanical treatment of the malocclusion. The resting position of the tongue is important. The question is, how often is its resting position primary or secondary to dental arch form?

Duration, frequency and intensity, of the sucking habit must qualify conclusions of the psychiatrist, pediatrician and orthodontist (Graber, 1958). Jarabak (1959) states that most medical, dental and child guidance authorities agree that if a thumb sucking habit is of short duration and it is broken before the child is four years old, little damage is done to the
permanent dentition. He states that sucking is one of the first neuromuscular reflexes seen in the newborn. According to Gesell (1943) sucking is limited to the control of feeding as well as sleep. "When the linkage to feeding is primary, the sucking may run a short course ... If however, for personality or other reasons, it establishes a main linkage with sleep, it is likely to continue longer and the tie-up with sleep will become rather more than less tenacious. The latter is probably the reason mothers will say 'my child sucks his thumb only at bedtime.'"

Jarabak states that malocclusions due to thumb sucking usually have similar characteristics. The upper teeth are protrusive and spaced. If the habit is indulged in for any length of time, the curvature of the anterior segment of the upper arch is skewed to the side in which the thumb is held. The posterior teeth are in cross bite in the permanent dentition more often than in the deciduous dentition. This cross bite occurs on the side to which the upper anterior teeth are skewed because the buccinator muscle activity is greater on this side. The bite is usually open in the anterior region and the lower teeth are inclined lingually.

Protrusion of the maxillary anterior teeth results in a shortened and hypotonic upper lip. Conversely, the lower lip muscles and mentalis muscle become hypertonic. They act jointly
and with increased vigor to create an anterior seal that is needed to establish the swallowing vacuum.

Jarabak states that the forces of the tongue, perioral musculature, buccinator mechanism plus force upon the teeth and jaws from thumb or finger pressure all contribute to this malocclusion.

Swindler and Sassouni (1962) found that non-nutritive thumb and or toe sucking habits in Rhesus monkeys were directly related to the formation of an anterior open bite in monkeys born in captivity and subsequently separated from their mothers. Wild born controls and observed wild monkeys demonstrated no observable thumb or toe sucking habits.

Subtelny and Sakuda (1964) define anterior open bite as "an open vertical dimension between the incisal edges of the maxillary and mandibular anterior teeth. While this situation exists, some of the buccal teeth are in definite occlusal contact." They state that unfavorable growth or genetic determinants of a malocclusion, including open bite, can not be altered or removed successfully. They believe a pattern of complexly interrelated causal factors is projected as the best reference from which to diagnose. "For example, it is difficult to find an open bite and a thumb sucking habit without also observing a fronting tongue activity."
The age gradient is an important factor in open bite malocclusions. Kantrowicz and Korkhaus (1926) reported that 4.2% of a population of six year olds had open bites while only 2.5% of fourteen year olds had open bite malocclusions. The decrease in frequency of open bites due to age factor is thought to be brought about by the decrease in finger or thumb sucking habits and pubertal growth spurts. Open bites found at an early age are usually caused by sucking habits. Subtelny states that it is his clinical impression that, in most instances, the tongue is adapting to its own environment; that is, the thumb or fingers created the orthodontic problem, and subsequently, the tongue has adapted to that problem.

Abnormal tongue posture and function due to excessively enlarged pharyngeal and or palatine tonsils may cause open bites. When lymphoid tissue is removed, the tongue assumes a new posture and function and subsequently the open bite is seen to close.

Subtelny states that the tongue is disproportionately large in relation to the jaws at birth. If this discrepancy persists for a considerable time, the disproportionately large tongue could cause and maintain an open bite provided skeletal growth does not relieve the condition.
A cephalometric study of twenty-five open bite patients and thirty subjects with normal occlusion yielded the following findings; both groups were over twelve years of age.

1. In the open bite group, the dimension of the posterior cranial base (S-Ba) was statistically shorter at a 5% level of significance.

2. SNA was smaller in the open bite cases at a 5% level of significance.

3. Previously, it had been surmised that there was an inadequacy in dentoalveolar development in open bite cases. This had been considered an etiological factor. The opposite was found. There was greater dimension. A greater eruption of the maxillary molars and incisors was found. There was a greater dimension from the nasal floor to the occlusal surface and incisal edge in the maxillary molars and incisors.

4. Steep mandibular planes were found to be highly significant in the open bites.

5. A trend towards a short ramal height was observed.

6. The relationship of the ramus to the body was distorted.

7. The gonial angle was more obtuse.
8. The mandible was found to be significantly more retruded with respect to the cranial base.

9. The open bites had a significantly greater vertical dimension to the skeletal face restricted to the lower face region from the nasal floor to the lower border of the symphysis.

Subtelny states that "aberrant skeletal development must be considered a very definite factor in the development of a persistent open bite." He refers to a 'skeletal' open bite as one in which the gonial angle of the mandible is oblique, a predominantly vertical growth pattern is evident, and the vertical dimension from nasion to the lower border of the mandible is large. This length is restricted to the lower face region; specifically from the nasal floor to the lower border of the symphysis. This is not true in the posterior region of the face, since the vertical dimension in the molar region was the same in both groups. "The discrepancy in size and shape of the mandible in the open bite subjects seemed to be most greatly expressed in the anterior part of the skeletal face."

The hyoid bone in these groups was measured horizontally with respect to the lingual aspect of the mandibular symphysis and vertically relative to the palate. No differences were
found between the two groups.

Subtelny (1965) stated that until more information is provided, tongue-thrust can not be established as the cause of defective speech and/or malocclusion. Of itself, tongue-thrust may be merely symptomatic of some other primary problem such as skeletal growth deficiency.

F. Cephalometrics of the Cranial Base, Hyoid Position, and Movement

Bjork (1947), in his anthropological x-ray investigation of Swedish children and military conscripts, found the correlation between the vertical over bite and the total facial height to be significant. His regression calculations indicated that if the vertical over bite diminishes, the total facial height will diminish by an average length of 0.89± 0.18 mm; i.e. by an equal amount within the limits of the standard error. The converse of this should also be true.

The angle between the occlusal plane and the mandibular plane was significantly larger when compared to those with vertical over bite exceeding the mean value in cases of vertical over bite below the mean value.

"Hence the mechanics of increased depth of bite was, as anticipated, that the jaws close more intimately, causing the
face to appear somewhat compressed. In prognathic structures the average facial height is also reduced as previously mentioned. Combined prognathism and deep bite will therefore, on an average, have a pronounced effect on the facial height."

According to Bjork, (deduction by means of reverse application),

1. If the saddle angle at sella turcica increases, the jaw joint will be displaced posteriorly, with the secondary effect of a similar displacement of the jaws which is accompanied by a decrease in the angle of prognathism.

2. An increase in the joint angle (articular angle) would be accompanied by an equal decrease in the degree of prognathism as the ramus and profile are nearly parallel. An increase of the articular angle would have the secondary effect of increasing the frontal facial height. Another effect would be to make the jaws more divergent with respect to the cranial base.

3. A possible change in the jaw angle would have little effect on the degree of prognathism and hence little effect on the degree of retrognathism.
"It is evident that if all dimensions undergo proportional changes the net effect will be nil. It will merely mean a reduction or an enlargement, as the case may be, of head and face. It is therefore only relative changes that are of interest, and in the following the assumption is made that all other dimensions remain unchanged."

4. An increase of the anterior horizontal portion of the cranial base from nasion to sella turcica is accompanied by a pronounced decrease in the angle of prognathism if the length of the facial structures remains unaltered.

5. If the increase in length of the cranial base occurs in its posterior vertical portion, increasing the distance between sella turcica and the jaw joint, the face will become more retrusive and the angle of prognathism will decrease, causing a secondary increase in the height of the face. These changes are conditional upon the joint angle remaining unaltered.

6. Decreased height of the ramus causes a decrease in the mandibular prognathism.

7. A decrease in the length of the jaw is naturally accompanied by a pronounced decrease in prognathism.
8. Increased height of the anterior region of the face may possibly be evenly distributed or may be larger in one facial section than in the others. An increment in the height of one segment will, in some measure, increase the prognathism of the segment below it, in the case of a bent facial profile. This effect, however, is slight. The relationship remains unaffected, whether or not changes in the height of the anterior part of the facial skeleton are accompanied by a corresponding change in the ramus height. If the height of the posterior part remains unaltered, the secondary effect will be to change the parallelism of the jaws relative to the cranial base.

King (1952), Smith (1956), Grant (1959), Andersen (1963), Bench (1963), and Stepovich (1965) related the hyoid bone to cranial landmarks by means of various angles and planes.

Cleall (1965) recorded the movements of the hyoid bone cinefluorographically and analyzed individual cinefluorographie frame tracings. This analysis was based on the palatal plane and was registered either at the pterygomaxillary fissure or at Point A.
Sloan et al (1967) also recorded the movement of the hyoid bone cinefluorographically and used a Cephalometric-Cinefluorographic Analysis. A Cephalometric-Morphological Analysis, and a Cephalometric-Hyoid Analysis in order to analyze movement and position of the hyoid bone with respect to cranial landmarks, and dentoalveolar structures.

Mills (1967) developed an optical method of head positioning for cephalometry. Radiographs were obtained of the patient with the head oriented optically with respect to the true vertical, and the true vertical line was recorded on the cephalogram.
CHAPTER III
METHODS AND MATERIALS

A. Introduction

A standard technique of cinefluorography was first developed in order to provide cine records of consistently high quality.

After becoming familiar with the cinefluorograph, it was decided to operate the machine with the automatic brightness control in phase. This control allowed the cinefluorograph to fluctuate between 40 and 90 kilovolts peak at a constant milliamperage of 40 during cine or 4 during fluoroscopy. This automatic kilovoltage adjustment is dependent upon the thickness and density of the tissue under fluoroscopy and results in standardized cine film of uniform average density.

Kodak Shellburst and Kodak Plus X film were compared for differences in contrast, detail and grain size. Kodak Plus X (Reversal Type 7276, 16 mm, PXR 449) was chosen for its detail, lack of grain and satisfactory contrast. In order to use this film, the lens was set at f 2.8 and focus at infinity.

Automatic film developing machines and standard medical x-ray film dip tanks were used for development at first. It
was decided, however, because of the inaccessibility of an automatic developing machine, and limited time and convenience, to develop the film by hand using spiral developing reels and tanks.

A Kindermann one hundred foot, 16 millimeter spiral reel, loading stand and film guide were used. Three 5 gallon plastic tanks were used to hold developer, fix and water bath. Kodak D-11 developer was used for eight minutes at 68°F. Standard Kodak fixing solution then was used for 5 minutes and finally the film was washed for 10 minutes. The film was then wound on a drying rack, and when dry, was wound onto a one hundred foot reel.

A cephalostat was developed and attached to the cine-fluorograph so that it could be adjusted in toto with respect to the image amplifier (Figure 1). The cephalostat was modified so that only one ear rod was adjustable. The ear rod adjacent to the image amplifier remained fixed so that a constant subject-film distance could be maintained once the cephalostat was fixed in a rigid position. The cephalostat was further modified to carry an aluminum profile shield (Figures 1 and 2). The profile shield allowed the investigator to obtain a soft tissue profile, protect the image amplifier from bursts of raw radiation, and allow the automatic brightness control to be
Figure 1

THE CINEFLUOROGRAPH

with Cephalostat and Profile Shield
Figure 2

THE PROFILE SHIELD
used to its greatest efficiency. The shield, in effect, provided a uniform radiographic subject from profile or anterior part of the face to the posterior area of the skull. The shield allowed the investigator to observe the movement of the lips, tongue, and profile outline with respect to the anterior skeletal profile. The profile shield was attached to the cephalostat in such a manner that it was adjustable in all directions. The shield was one inch thick at its thickest part and tapered in step wedge fashion to 1/8 inch. It consisted of a scalloped design of one 5/8 inch piece and three 1/8 inch pieces of hard tool aluminum bolted together and contoured to the average anterior skeletal profile.

An adjustable two way mirror and stand were fabricated along with a rear projection cabinet. The function of these will be described later.

A distortion measuring wheel which turned on an axle with concave ends was constructed of 1/8 inch plexiglass. Number nine lead shots were placed every 5 millimeters along the radius for a distance of 72 millimeters from the center of the wheel toward the periphery. The distortion wheel was placed in the cephalostat approximating the average patient midsaggital plane. The ear rod axis was adjusted to be concentric with the optical center of the image amplifier and the optical center of
the amplifier was marked with a piece of lead taped to its surface. A cine record was made of the spinning wheel. When this image was projected and adjusted so that the distance between the center lead shot was 5 millimeters, then peripheral x-ray distortion could be computed by measuring the distance between the peripheral segments of lead shot anywhere in the image circle.

The cine record from the distortion wheel was projected and adjusted by means of the zoom lens so that the distance between the third and fourth lead shot was exactly five millimeters from center to center as measured with fine pointed dividers. The image of the first two lead shot was obliterated by the image of the axle of the distortion wheel.

The distance from the center of the third and the center of the most peripheral (fifteenth) lead shot was measured several times in all four quadrants of the circle. The average distance on the image was computed and compared to the actual distance between the third and fifteenth lead shot on the distortion wheel. The distortion from center to periphery (7 cm.) was found to be eight per cent.

Even though this distortion is small, linear measurements would have to be adjusted and they were discarded on the cine records in favor of angular measurements. Angular measurements
and linear ratio are more important since they demonstrate relationships between parts with respect to size and position.

B. Radiation Output

A thimble type ionization chamber was attached to the cephalostat ear rod nearer the x-ray head. The ear rod was adjusted so as to measure the average skin dosage that would be absorbed by the average patient. The distance from the focal spot to the ionization chamber metering point was two feet twenty-six inches. The x-ray head was energized for five seconds at a time so as to limit heat build up in the x-ray head and to preserve the image amplifier. The image amplifier was set on manual and a specific kilovolts peak was applied. The ionization chamber was removed and placed in the reading instrument. After recording the meter reading the dosage meter was re-calibrated and the test was repeated on the cinefluorograph. An average of five readings is recorded as follows:
RADIATION OUTPUT FOR THE PICKER CINEFLUOROGRAPH

Cine (During cine, the milliamperage is constant at 40)

<table>
<thead>
<tr>
<th>KVP</th>
<th>Aluminum Filtration</th>
<th>Frames/sec</th>
<th>Rate/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>2 1/2 mm</td>
<td>60</td>
<td>20</td>
</tr>
<tr>
<td>90</td>
<td>1 1/4 mm</td>
<td>60</td>
<td>23</td>
</tr>
<tr>
<td>60</td>
<td>1 1/2 mm</td>
<td>60</td>
<td>8.8</td>
</tr>
<tr>
<td>50</td>
<td>1 1/4 mm</td>
<td>60</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Fluoroscopy (During fluoroscopy, the milliamperage is constant at 4.)

<table>
<thead>
<tr>
<th>KVP</th>
<th>Aluminum Filtration</th>
<th>Rate/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>2 1/2 mm</td>
<td>3 1/2</td>
</tr>
<tr>
<td>90</td>
<td>1 1/4 mm</td>
<td>4 1/2</td>
</tr>
<tr>
<td>60</td>
<td>1 1/2 mm</td>
<td>1 1/4</td>
</tr>
<tr>
<td>50</td>
<td>1 1/4 mm</td>
<td>1 1/4</td>
</tr>
</tbody>
</table>

The cephalometer was also measured for radiation output. The ionization chamber was placed on the ear rod nearest the x-ray head. The ear rod was adjusted so as to measure the average skin dosage absorbed by the average patient. The distance from the focal spot to the ionization chamber metering point was 4 feet and 7 1/2 inches. At 90 kilovolts peak and 50 milliamperes with 2 millimeters of aluminum filtration the radiation output of the cephalometer was calculated to be one quarter Roentgen per second.
C. Radiation Dosage to the Operator

The operator wore a film badge clipped outside the lead apron during all the cinefluorographic procedures. This included approximately 40 thirty second cine sequences, and 40 one minute fluoroscopic examinations over the period of two and one half months. The total x-ray, gamma and neutron dosage for this period was .033 REM which is the equivalent of 33 MREM. The maximum permissible weekly dosage for radiation workers (dentists included) is 100 mr. (100 MREM) per week.

D. Open Bite Population and Normal Sample

Patients with normal occlusion and patients with anterior open bite malocclusion were selected for investigation. Anterior open bite was characterized by an open vertical dimension between the incisal edges of the maxillary and mandibular anterior teeth, while some of the buccal teeth are in definite occlusal contact.

The patients were divided into three groups. Group I consisted of ten patients with normal occlusion and swallowing habits. Group II consisted of six patients who had anterior open bites supposedly caused by habits such as tongue thrusting, and finger or thumb sucking. Group III consisted of ten patients who had anterior open bites that were judged to be of
of a skeletal nature. The Bjork cephalometric skeletal analysis was used to divide the open bite patients into these two groups (Figure 3).

Anterior open bite patients who have single angular measurements of the gonial angle or articular angle equal to or greater than the normal value plus two standard deviations or a combination of both angles equal to or in excess of the combined normal values plus two standard deviations were considered skeletal open bites. An anterior open bite subject with the combination of a large articular angle with a short posterior cranial base and a Class II or III mandible was considered as a skeletal open bite. Anterior open bites with an anterior cranial base length to mandibular body length ratio equal to or greater than 1 to 1.24 were considered skeletal open bites.

For each patient, the following examinations were performed:

1. Medical and dental history
2. Impressions of the maxillary and mandibular dental arches
3. Frontal and lateral photographs
4. Lateral cephalograms
5. A cinefluorographic sequence of swallowing
Figure 3

BJORK ANALYSIS

1. Ant. Cranial Base
2. Post. Cranial Base
3. Ramus Length
4. Body Length
E. Medical and Dental History

A simple medical and dental history was recorded for each patient. Specific questions were asked regarding congenital deformity of the body, hearing impairment, and temporomandibular joint symptoms. A clinical evaluation of the patient's swallowing habits was recorded.

F. Dental Casts

Impressions were taken, dental models constructed, and the following values were determined for the casts:

1. Midline vertical dimension of open bite
2. Horizontal dimension of overjet
3. Inter first molar width in each arch
4. Inter first premolar width in each arch
5. Molar relation according to Angle
6. Mesio-distal width of each maxillary incisor

All dimensions were taken with sharp pointed dividers and recorded in millimeters to the nearest one-half millimeter. The measuring points are the distal end of the occlusal grooves of the first premolars and the mesial pits on the occlusal surface of the maxillary first molars. The points used in the mandibular teeth are the disto-buccal marginal angle on the first premolars and the highest point in the middle cusp of the buccal cusps of the first permanent molar.
G. Photographs

Frontal and lateral head photographs were taken with Kodak Panatomic X thirty-five millimeter film from a distance of 2½ feet. Prints of 2-3/4 x 4 inches were obtained from the negatives. The photographs were taken with the patient oriented in a natural and physiologic head position for deglutition to be described later.

H. Cephalograms

Lateral head cephalograms were taken with a focal point to subject distance of 5 feet and a subject to film distance of 12 centimeters using a standard cephalometer. An exposure of 0.8 seconds at 50 milliamperes and 90 kilovolts peak using intensifying screens and a Lysholm grid was used. Dupont Cronex 8 x 10 inch x-ray film was used. The usual development time of five minutes at 68° F. was followed. The patients wore a knee length protective apron with a five millimeters of lead equivalent rating.

The patient's profile was outlined with a ribbon of barium sulfate placed in the midline, and a number nine lead shot was taped over the left infraorbitale. The patient was positioned in a cephalostat with the ear rods loosely positioned. The head was left free to move so that the chin
could be raised or lowered and the head able to pivot slightly from side to side.

A plumb bob suspended by a cord upon which were fastened two lead shot was positioned so that the cord bisected the patient's face in the midsaggital plane. The patient observed the image of his eyes in a mirror placed four or more feet away at eye level and oriented with the plane of the mirror parallel to the x-ray beam. The patient moved his head slightly so as to bisect his own face with the plumb bob cord by observing his image in the mirror. By means of this "optical cephalostat" (Figure 4), cephalograms of the patient oriented in the natural head position were obtained. The two lead shot were recorded on the x-ray and a line connecting the centers of the shot represented the true vertical.

The mirror was a two way mirror (Mirropane) and was mounted in a frame on an adjustable stand. The stand was on castors and the mirror could be adjusted vertically to the patient's own eye level or moved around the room to any desired position and was used also for head orientation in the cinefluorographic studies. A hole was drilled in the wood frame backing at right angles to the mirror surface. Since this was a two way mirror, the operator could position the plane of the mirror parallel to the principle x-ray beam by placing one mirror between the ear rods of the cephalostat, which were
The patient is adjusted vertically so that his head is properly related to the cassette and instructed to bisect his face with the plumb line by looking into the mirror.
oriented so that the plane of the mirror was parallel to the central x-ray beam.

The lateral and frontal photographs were taken with the patient oriented in this optical cephalostat.

I. Cinefluorographic Film Sequence

A Picker cinefluorograph with a high gain image intensifying tube was used for the cinefluorographic sequences (Figure 1). The output phosphor had a diameter of nine inches and the input phosphor had a diameter of 0.8 inches. This gave a demagnification of 11 to 1 and a brightness gain of about 3,000 to 5,000 X. The x-ray head and the image amplifier with the camera and optical system were mounted on each end of a "C" arm which was adjustable and capable of being locked in any vertical position so that the patient could be examined while in the standing position. A cephalostat was attached to the "C" arm in close relation to the input phosphor of the image tube. An aluminum profile shield was devised and attached to the cephalostat in order to produce a soft tissue image while a definite skeletal contrast was preserved (Figure 2).

The patient was observed under fluoroscopy while the cephalostat was adjusted in order to assure a good record of the patient's swallowing pattern. Sometimes pieces of lead were taped to the input phosphor in order to block areas of
excessive radiation. The adjustable mirror was then aligned so that its surface was parallel to the primary x-ray beam.

The tip and middle of the tongue were dried with gauze and a mixture of Orabase and barium sulfate crystals was applied to the middle, tip and under surface of the tongue with a cotton tipped swab.

A sixty frame per second cinefluorographic film of swallowing a radiopaque bolus of barium sulfate (Esophotrast) was obtained using Kodak Plus X film and a 16 millimeter two speed cine camera with a 35 millimeter f 1.0 lens. The swallowing of water was recorded several times. The patient was placed as close to the input phosphor as possible with his head in the cephalostat loosely held in place by the ear rods and in the natural head position oriented by means of the plumb bob and mirror as previously described. The actual x-ray head to subject distance was 55½ inches and the subject to input screen distance was 5½ inches.

During each cinefluorographic sequence and during the cephalometric exposures, the patient and operator each wore a lead apron.

The operator wore a radiation monitoring film badge during all x-radiation exposure. All of the x-ray equipment was located in a room lined with lead panels.
Fixed cranial landmarks were selected from the cephalograms and tracings of these landmarks were made on tracing paper. The cinefilm image was projected by means of a 16 millimeter Bell and Howell Selecta-Frame analytical projector (Figure 5). The analytical projector is capable of continuous projection in single frame dwell without a reduction in image brightness and also will project in pulse fashion from one frame per second to full cine. The projector has a frame counter and a 1½ inch f 1.6 lens with a zoom attachment.

The projected image was focused into a custom projection cabinet (Figure 5) consisting of the cabinet frame, a custom made quartz hardened front surface mirror of very high optical quality and an 18 inch square Polacoat formula LS75 1/8 inch glass lenscreen. The lensscreen was a high gain rear projection screen designed for a directional beam and low intensity projection systems where wide angle viewing is not required as for projection microscopes and profile projectors. The lenscreen was oriented in the cabinet with its image reflecting surface outward. This surface was covered with a sheet of 0.003 inch mylar plastic. Therefore, all tracings were made 0.006 inches away from the actual image since the tracing paper was also 0.003 inches thick. This method reduced error or distortion due to parallax.
The image was adjusted so as to be of the same scale as the image on the cephalogram. This was accomplished by using the sella turcica point, the infraorbital lead shot, and the area being observed such as the mandible. Movement of various parts of the head and neck as seen in the cinefilm average of the points of origin and insertion of the muscles forming the hyoid triangle were selected primarily because of the ease in consistently locating them on cephalometric and cinefluorographic films. They are: Basion-representing an average of the points, (1) digastric groove on the temporal bone nearest of the

**Figure 5**

ANALYTICAL PROJECTOR AND PROJECTION CABINET
The image was adjusted so as to be of the same scale as the image on the cephalogram. This was accomplished by using the sella turcica point, the infraorbitale lead shot, and the area being observed such as the mandible. Movement of various parts of the head and neck as seen in the cinefilm image were plotted against the fixed cranial reference points of the cephalometric tracing on the face of the projection cabinet. Distortion and magnification were taken into consideration.

J. Cranial Landmarks and Method of Analyzing Hyoid Movement

Muscular points of origin and insertion of the primary muscles influencing the hyoid bone closely describe a triangle with its base cephalad and its apex caudad. It is within this triangle that movement of the hyoid bone must therefore be limited.

Suggested trial cranial landmarks that represent an average of the points of origin and insertion of the muscles forming the hyoid triangle were selected primarily because of the ease in consistently locating them on cephalometric and cinefluorographic films. They are: Basion-representing an average of the points, (1) digastric groove on the temporal bone near the base of the mastoid process, (2) base of the
styloid process. **Menton** - determined by drawing a line tangent to the outer cortical plate of the inferior border of the mandibular symphasis from the point gonion and representing an average of the attachments of the geniohyoid, anterior belly of the digastric and the anterior fibers of the mylohyoid muscle. **Hyoid Point** - representing an average of all the muscles attaching to the hyoid bone. The hyoid point will be determined by a point where the superior and ventral aspects of the hyoid meet forming almost a right angle on the radiopaque outline of the body of the hyoid bone.

The angle H 1 (Hyoid inferior - Basion-Hyoid superior) denotes the movement of the hyoid bone from its most inferior position to its most superior position as measured from Basion (Figure 6).

The angle H 2 (Basion - Hyoid inferior - Menton) will denote the angle of the muscles attaching to the hyoid bone in its rest position or more inferior position (Figure 7).

The angle H 3 (Basion - Hyoid superior - Menton) will denote the angle of the muscles attaching to the hyoid bone in its most superior position (Figure 8).

The Occlusal Hyoid angle is constructed by drawing a perpendicular line to the hyoid point when the hyoid bone is in its most inferior position from the occlusal plane and
Figure 6

THE H 1 ANGLE
Figure 7

THE H 2 ANGLE
Figure 8

THE H 3 ANGLE
another line from the point where the perpendicular intersects the occlusal plane to the hyoid point in the hyoid bone's most superior position (Figure 9). This angle represents the movement of the hyoid bone in an anterior direction with respect to the occlusal plane. The occlusal plane is constructed by drawing a line between points representing one half of the incisor over bite or open bite and one half the cusp height of the last occluding molars.
Figure 9

THE OCCLUSAL PLANE H ANGLE
CHAPTER IV
FINDINGS

A. Medical and Dental History

The medical and dental history revealed that none of the open bite patients had subjectively recognized symptoms of temporomandibular joint pathology.

In the functional open bites (Group II), one 16 year old, white male had multiple congenital defects, spherocytosis and 80% vision loss in one eye. One 23 year old white female had had an attack of kidney stones which resulted in the surgical removal of one kidney.

In the skeletal open bites (Group III), three patients had a history of non-specific ear trouble and one of these patients also had allergic manifestations including an organic heart murmur. This same patient had a skeletal Class II mandible resembling a rheumatoid arthritic condition. Another patient had a gastro-intestinal tract malformation, while still another patient was mentally retarded. One patient had a medical history of hyperthyroidism, and had undergone a subtotal thyroidectomy.
B. Dental Casts

Pont (1909) compared the combined width of the maxillary incisors to the inter-premolar and intermolar widths, Tables 1 and 2 show these measurements for the subjects of this research. The variation of these measured values from those reported by Pont are also included.

The Student's "t" test was used to compare the measurements between the two experimental groups of this study. These "t" values are shown in Table 3.

C. Photographs

The facial photographs demonstrate the tonus and configuration of the perioral musculature, the shape of the face and skull, as well as any asymmetries and midline deviations. A mentalis habit is recognized by the dimpled, bulging mentalis muscle. This muscle accomplishes the raising of the lower lip to meet the upper lip in order to effect closure of the lips over the anterior teeth.

In the functional open bite population (Group II), two patients demonstrated tight perioral musculature and a mentalis muscle habit. One patient demonstrated loose perioral musculature and open lips. One patient had a long triangular dolichocephalic face. The rest were either ovoid or square faced.
Table 1

Cast Measurements of Functional Open Bites Compared to Values From Pont

<table>
<thead>
<tr>
<th>Case</th>
<th>Spaced or Crowded Teeth</th>
<th>Max. Incisor Width (mm.)</th>
<th>Max. Inter Premolar Width (mm.)</th>
<th>Max. Inter Molar Width (mm.)</th>
<th>Mand. Inter Premolar Width (mm.)</th>
<th>Mand. Inter Molar Width (mm.)</th>
<th>Molar Relation</th>
<th>Open Bite (mm.)</th>
<th>Over Jet (mm.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>normal</td>
<td>30</td>
<td>39 (37.5)*</td>
<td>45 (46.8)</td>
<td>36 (37.5)</td>
<td>55 (46.8)</td>
<td>II</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>crowded</td>
<td>34</td>
<td>42 (43)</td>
<td>48 (53)</td>
<td>40 (43)</td>
<td>49 (53)</td>
<td>I</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>normal</td>
<td>32</td>
<td>41 (40)</td>
<td>0</td>
<td>39 (40)</td>
<td>50</td>
<td>IIIsub</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>crowded</td>
<td>30</td>
<td>33 (37.5)</td>
<td>40 (46.8)</td>
<td>38 (37.5)</td>
<td>47 (46.8)</td>
<td>II</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>spaces</td>
<td>32.5</td>
<td>40 (40.5)</td>
<td>47 (50.8)</td>
<td>40 (40.5)</td>
<td>49 (50.8)</td>
<td>I</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>crowded</td>
<td>37</td>
<td>36 (46.2)</td>
<td>44 (57.8)</td>
<td>40 (46.2)</td>
<td>50 (57.8)</td>
<td>I</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>(mean)</td>
<td>32</td>
<td>38.5</td>
<td>44.8</td>
<td>38</td>
<td>50.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SX</td>
<td>(std. deviation)</td>
<td>2.44</td>
<td>3.11</td>
<td>6.23</td>
<td>1.46</td>
<td>2.45</td>
<td>.094</td>
<td>1.63</td>
<td></td>
</tr>
</tbody>
</table>

* The values in parenthesis indicate the values Pont found for the corresponding maxillary incisor width.
Table 2

Cast Measurements of Skeletal Open Bites Compared to Values From Pont

<table>
<thead>
<tr>
<th>Case</th>
<th>Spaced or Crowded Teeth</th>
<th>Max. Incisor Width (mm.)</th>
<th>Max. Inter Premolar Width (mm.)</th>
<th>Max. Inter Molar Width (mm.)</th>
<th>Mand. Inter Premolar Width (mm.)</th>
<th>Mand. Inter Molar Width (mm.)</th>
<th>Molar Relation</th>
<th>Open Bite (mm.)</th>
<th>Over Jet (mm.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>crowded</td>
<td>36</td>
<td>39 (45)*</td>
<td>42 (56.4)</td>
<td>40 (45)</td>
<td>52.5 (56.4)</td>
<td>II</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>crowded</td>
<td>32.5</td>
<td>33 (40.5)</td>
<td>45.5 (50.8)</td>
<td>0</td>
<td>48 (50.8)</td>
<td>II</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>spaces</td>
<td>32</td>
<td>0</td>
<td>44</td>
<td>0</td>
<td>46.5</td>
<td>I</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>spaces</td>
<td>31.5</td>
<td>42 (39.5)</td>
<td>50 (49.2)</td>
<td>47 (39.5)</td>
<td>58 (49.2)</td>
<td>I</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>0</td>
<td>33</td>
<td>44</td>
<td>37</td>
<td>0</td>
<td>?</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>crowded</td>
<td>34</td>
<td>43</td>
<td>49 (53)</td>
<td>36 (43)</td>
<td>52 (53)</td>
<td>III</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>crowded</td>
<td>28</td>
<td>35</td>
<td>39</td>
<td>48</td>
<td>53 (53)</td>
<td>III</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>crowded</td>
<td>36.5</td>
<td>33 (45)</td>
<td>41 (56.4)</td>
<td>31.5 (45)</td>
<td>42.5 (56.4)</td>
<td>I</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>9</td>
<td>spaces</td>
<td>31</td>
<td>44.5 (39)</td>
<td>50 (48.4)</td>
<td>44 (39)</td>
<td>53 (48.4)</td>
<td>I</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>crowded</td>
<td>34</td>
<td>30 (43)</td>
<td>42 (53)</td>
<td>38 (43)</td>
<td>47 (53)</td>
<td>I</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>(\bar{x}) (mean)</td>
<td></td>
<td>33.4</td>
<td>36.95</td>
<td>44.25</td>
<td>39.06</td>
<td>49.72</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SX (std. deviation)</td>
<td></td>
<td>1.9</td>
<td>6.17</td>
<td>4.43</td>
<td>4.48</td>
<td>4.32</td>
<td>1.36</td>
<td>2.87</td>
<td></td>
</tr>
</tbody>
</table>

*The values in parenthesis indicate the values Pont found for the corresponding maxillary incisor width.
Table 3
"t" Comparisons Between Group II and III Cast Measurements

<table>
<thead>
<tr>
<th>Measurement</th>
<th>&quot;t&quot; Value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary Incisor Width</td>
<td>.020</td>
<td>P &gt; .45</td>
</tr>
<tr>
<td>Maxillary Inter-Premolar Width</td>
<td>.752</td>
<td>.35 &gt; P &gt; .20</td>
</tr>
<tr>
<td>Maxillary Intermolar Width</td>
<td>.189</td>
<td>.45 &gt; P &gt; .40</td>
</tr>
<tr>
<td>Mandibular Inter-Premolar Width</td>
<td>.082</td>
<td>P &gt; .45</td>
</tr>
<tr>
<td>Mandibular Intermolar Width</td>
<td>.136</td>
<td>.45 &gt; P &gt; .40</td>
</tr>
<tr>
<td>Open Bite</td>
<td>.140</td>
<td>.45 &gt; P &gt; .40</td>
</tr>
<tr>
<td>Overjet</td>
<td>1.10</td>
<td>.10 &gt; P &gt; .05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Comparison</th>
<th>&quot;t&quot; Value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary Intermolar Width vs.</td>
<td>1.284</td>
<td>.15 &gt; P &gt; .10</td>
</tr>
<tr>
<td>Mandibular Intermolar Width in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maxillary Intermolar Width vs.</td>
<td>1.800</td>
<td>.05 &gt; P &gt; .025</td>
</tr>
<tr>
<td>Mandibular Intermolar Width in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group III</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maxillary Inter-Premolar Width vs.</td>
<td>.891</td>
<td>.20 &gt; P &gt; .15</td>
</tr>
<tr>
<td>Mandibular Inter-Premolar Width</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width in Group III</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In the skeletal open bite population, (Group III), five patients demonstrated tight perioral musculature and a mentalis muscle habit. Four patients demonstrated loose perioral musculature or open lips. Nine patients had long dolichocephalic faces of the long triangular or long ovoid form.

D. Cephalometrics

Table 4 gives the mean and standard deviation for the Group II and Group III cephalometric angular and linear values. The "t" values for comparison between Group II and Group III of these cephalometric angular and linear values are also included in this table.

E. Hyoid Motion Analysis

Table 5 gives the mean and standard deviation for the angles of the hyoid movement in Group I, II and III. The "t" comparison between Group I and II, Group I and III and Group II and III are also included in this table.

A rank correlation study comprising Groups I, II and III was performed between various angles in the Hyoid Motion Analysis.

Angle H 1 (Hyoid inferior - Basion - Hyoid superior) was very significantly and negatively correlated to angle H 2
Table 4

Angular and Linear Values of Bjork Analysis in Group II and III and Their "t" Comparisons

Mean ± 1 Standard Deviation

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Group II</th>
<th>Group III</th>
<th>&quot;t&quot; Comparison (Group II vs III)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>19 ± 7.92</td>
<td>15.4 ± 4.43</td>
<td>--</td>
</tr>
<tr>
<td>SA</td>
<td>124.66 ± 3.41</td>
<td>123.2 ± 2.89</td>
<td>.854</td>
</tr>
<tr>
<td>AA</td>
<td>146.33 ± 5.80</td>
<td>151.2 ± 6.19</td>
<td>1.458</td>
</tr>
<tr>
<td>GA</td>
<td>128.5 ± 3.61</td>
<td>134.4 ± 8.20</td>
<td>1.56</td>
</tr>
<tr>
<td>Sum</td>
<td>399.5 ± 2.65</td>
<td>408.8 ± 6.60</td>
<td>3.089***</td>
</tr>
<tr>
<td>ACB</td>
<td>72.33 ± 5.85</td>
<td>68.3 ± 4.01</td>
<td>1.526</td>
</tr>
<tr>
<td>PCB</td>
<td>34.66 ± 3.64</td>
<td>34.3 ± 2.69</td>
<td>.211</td>
</tr>
<tr>
<td>RL</td>
<td>47.16 ± 4.22</td>
<td>42.7 ± 5.83</td>
<td>1.532</td>
</tr>
<tr>
<td>BL</td>
<td>81.0 ± 3.21</td>
<td>83.2 ± 7.53</td>
<td>.638</td>
</tr>
<tr>
<td>ACB/BL Ratio</td>
<td>1: 1.11 ± .0585</td>
<td>1: 1.22 ± .030</td>
<td>2.397**</td>
</tr>
</tbody>
</table>

Group II Articular Angle vs. Bjork's 281 conscript group
"t" = .939

Group III Articular Angle vs. Bjork's conscript group
"t" = 3.06***

Group III Gonial Angle vs. Bjork's 281 conscript group "t"=1.62

** significant at the 5% level
*** significant at the 1% level

SA, Saddle Angle; AA, Articular Angle; GA, Gonial Angle; ACB, Anterior Cranial Base; PCB, Posterior Cranial Base; RL, Ramus Length; BL, Body Length; ACB/BL, Anterior Cranial Base to Body Length Ratio. Angular Values are in degrees, Linear values are in millimeters.
Table 5

Angular Values of Hyoid Motion in Group I, II and III and Their "t" Comparisons

Mean ± 1 Standard Deviation

<table>
<thead>
<tr>
<th>Measurement (in degrees)</th>
<th>&quot;t&quot; Comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I vs. II</td>
</tr>
<tr>
<td>H 1 10.8 ± 3.2</td>
<td>.6695</td>
</tr>
<tr>
<td>H 2 119.6 ±13.2</td>
<td>2.64**</td>
</tr>
<tr>
<td>H 3 140.3 ±29.7</td>
<td>.871</td>
</tr>
<tr>
<td>H3-H2 31.6 ±10.7</td>
<td>1.012</td>
</tr>
<tr>
<td>Occ. Plane H Angle</td>
<td>17.50± 4.1</td>
</tr>
<tr>
<td>* significant at the 10% level</td>
<td></td>
</tr>
<tr>
<td>** significant at the 5% level</td>
<td></td>
</tr>
</tbody>
</table>

H 1, Hyoid inferior - Basion - Hyoid superior angle

H 2, Basion - Hyoid inferior - Menton angle

H 3, Basion - Hyoid superior - Menton angle

H3-H2, The difference between angle H 3 and angle H 2

Occ. Plane H Angle, This angle represents the movement of the hyoid bone in an anterior direction with respect to a perpendicular drawn to the occlusal plane from the hyoid inferior position.
(Basion - Hyoid inferior - Menton) \( r = -0.601 \) (\( P < .01 \))

Angle H 1 (Hyoid inferior - Basion - Hyoid superior) was positively but not significantly correlated to angle H 3 (Basion - Hyoid superior - Menton) \( r = +.243 \) (\( P > .10 \))

Angle H 1 (Hyoid inferior - Basion - Hyoid superior) was significantly and positively correlated to the Occlusal Plane Hyoid angle \( r = +.443 \) (\( .05 > P > .01 \))

Angle H 2 (Basion - Hyoid inferior - Menton) was positively but not significantly correlated to angle H 3 (Basion - Hyoid superior - Menton) \( r = +.336 \) (\( .10 > P > .05 \))

Angle H 3 (Basion - Hyoid superior - Menton) was very significantly and positively correlated to the Occlusal Plane Hyoid angle. \( r = +.522 \) (\( P < .01 \))

F. Observation of the Swallowing Pattern

The swallowing pattern was divided into three phases:

1. The voluntary phase, 2. The reflex phase, and 3. The visceral phase (Figure 10).

The Voluntary Phase

1. The tip and anterior portion of the tongue approximated the anterior teeth and the incisive and anterior region of the hard palate. The hyoid bone rose and came forward slightly.
NORMAL SWALLOWING PATTERN

Figure 10

As the tongue and the bolus backward progressively move posteriorly and notome the hyoid bone, the base of tongue forward and now the hyoid bone dropped slightly. Thus the sphincteric action of the tongue against the hard palate, and usually had forced the bolus backward and downward.

Reflex Phase

As the tongue, as the mid-palate, as the soft palate rose and contact with the posterior of the pharynx in order to accomplish the velopharyngeal seal. The tongue made contact with the entire length of the hard palate. As the soft palate raised to fill the entire space, in some cases, the entire all of the tongue to come in touch with the hyoid bone to rise only partially. In some cases of swallowing smooth and semisolid bolus, the bolus traveled so far as the level of the epiglottic vallecula before the soft palate was raised. In this
2. The tongue propelled the bolus backward as it progressively made contact with more and more of the hard palate.

3. As the anterior and middle portion of the tongue progressively rose, in a wave like and fluid motion, to contact the hard palate, the base of the tongue came forward and then the hyoid bone dropped slightly. Thus far, sphincteric action of the tongue against the hard palate, and gravity had forced the bolus backward and downward.

The Reflex Phase

4. As the bolus approximated the middle of the soft palate, as seen in the sagittal fluoroscopic view, the soft palate rose and made contact with the posterior wall of the pharynx in order to accomplish the velopharyngeal seal. The tongue made contact with the entire length of the hard palate and part of the soft palate and seemed to fill the entire oral cavity. In some cases, the posterior wall of the pharynx was seen to come forward slightly. The hyoid bone was seen to rise only if it had previously dropped when the base of the tongue came forward. In some cases of swallowing liquid and semisolid boli, the bolus traveled as far as the level of the epiglottic vallecula before the soft palate was raised. In this
phase, the teeth may or may not make occlusal contact.

5. Usually, the bolus passed the raised soft palate to reach the level of the epiglottic vallecula before the hyoid bone was seen to move upward and forward.

6. The hyoid continued forward and the epiglottis closed as the bolus passed the hyoid-epiglottic level and the base of the tongue and posterior wall of the pharynx made contact above the bolus. The middle and anterior portions of the tongue also made contact with the anterior teeth, the entire length of the hard palate and parts of the soft palate.

The Visceral Phase

7. The hyoid bone then descended and the soft palate and tongue both relaxed and dropped as the bolus entered the esophagus.

When observing the movement of the hyoid bone, it must always be remembered that as the hyoid bone moves so must the larynx move.

When the hyoid bone began to move up and forward to any great extent, the mandible had to be stabilized in order for the supra-hyoid muscles to gain mechanical advantage. During swallowing, the mandible must be stabilized by occlusal contact with the maxilla through action of the muscles of mastication
or the tongue must be interposed resulting in an open occlusal swallow or, in other words, no occlusal contact of the teeth during swallowing as noted by Cleall (1965). Four of the subjects in Group I swallowed in the open occlusal manner and this was especially noticed when swallowing liquid.

The shape of the hyoid pattern was observed on the tracings and could be classified into ovoid, triangular or vertical patterns (Figure 11).

In Group I, five subjects showed triangular, three showed ovoid, and two showed vertical patterns.

In Group II, two subjects showed vertical and four showed ovoid patterns. There were three open occlusal swallowers in this group.

In Group III, six subjects showed vertical, three showed ovoid, and one showed triangular hyoid hyoid pattern. There were four open occlusal swallowers in this group.

The swallowing patterns seen in Groups II and III were basically the same as that seen in Group I except for the position and action of the tongue and lower lip.

In both groups the tongue, lower lip or both were used to effect an oral seal during swallowing.

In Group II, two subjects effected a tongue seal, two a lower lip seal and two a combination of tongue and lower lip
Figure 11
HYOID PATTERNS

OVOID

TRIANGULAR

VERTICAL
seal.

In Group III, three subjects effected a tongue seal, two a lower lip seal and five effected a combination seal.

In both groups, the subjects effecting a primary seal with the lower lip and those that showed hyper lip activity also had noticeable mentalis muscle bulging and mentalis activity.

The tongue seal resembled a "Bird's Head" silhouette (Figure 12). The anterior and middle portions of the tongue made contact with the hard palate during swallowing as in Group I except for a portion of the tongue that protruded through the anterior teeth to affect a seal.

At no time in any of the cine sequences did the tongue appear to thrust forward during swallowing. The tongue always seemed to fill this anterior oral defect even during rest.

The muscular activity of the lips, and the grimace seen when observing the subject from the frontal exterior view, and the momentary protruding of the lips as if being pushed from behind by the tongue, were not seen in the sagittal fluoroscopic view during swallowing. In the sagittal fluoroscopic view, the tongue seemed to be voluntarily placed in order to effect an oral seal, and the excessive muscular activity in the perioral area came during the latter part of
Phase I or at the beginning of Phase II. This so-called "tongue thrust" or "reverse swallow" was not a thrusting forward as one might image, but compensatory muscle activity resulted to effect an anterior oral seal during the day. In some instances, the lower lip was substituted in order to effect an oral seal.

Figure 12

BIRD'S HEAD SILHOUETTES
Anterior Tongue and Lip Sealing
Phase I or at the beginning of Phase II. This so-called "tongue thrust" or "reverse swallow" was not a thrusting forward as one might imagine from the name, but compensatory muscle activity resulting in an attempt to effect an anterior oral seal during the swallowing act. In some instances, the lower lip was substituted for the tongue in order to effect an oral seal.
CHAPTER V
DISCUSSION

It is evident from the radiation output of the cinefluorograph that the average patient received no more radiation during one minute exposure at a maximum KVP (90) than he would experience for a full mouth series of intraoral periapical radiographs. A full mouth periapical series exposes the patient to approximately 20 to 50 Roentgens, while a one minute cine series at 90 KVP exposes the patient to 20 Roentgens. Further, it is unusual to run the cinefluorograph constantly for one minute. Usually, the cinefluorograph is run for approximately thirty to forty seconds, using ten second bursts. This technique allows the patient to be examined during different types of swallowing, and reduces wear to the x-ray head. It also should be noted that the radiation dose to the operator is minimal.

The cinefluorographic distortion was found to be 8% and is similar to the amount of distortion found in cephalograms, but is of a greater amount due to the shorter focal point to subject distance of the cinefluorograph. The cinefluorograph will become more useful as it is refined and modified to record the entire radiographic density range of the human head and neck in more detail. In this thesis, the cinefluorograph was
useful only because the cinefluorographic technique was modified to accomplish this end.

Symptoms of temporomandibular joint dysfunction do not seem to be evident consistently in open bite patients. However, many of these patients complain of 'earaches'. It is not known if these earaches are actually a symptom of the anterior open bite. However, many orthodontists have noted that anterior open bite patients seem to have an abnormal number of 'earaches'. This seems to be especially true in the skeletal anterior open bite patient.

Pont related interpmolar and intermolar width in each arch to the total mesio-distal width of the maxillary incisors. He believed that wide teeth require wide arches for proper alignment. In this study, the open bite population, in most instances, was noted to have interpmolar and intermolar widths smaller than the average values reported by Pont. This was found in arches with spaced, crowded or normally aligned teeth. It has been said, however, that Pont only measured subjects with normal but broad arches. It would seem that the arches would be equal to or greater than the arch widths found by Pont due to the excessive muscular force of the tongue. The excessive action of the buccinator muscles, and the perioral musculature may cause a constriction in arch width as these
muscles perform a lip seal over the open bite during swallowing. The smaller than normal arch width may also be consistent with the large number of dolichocephalic cranial configurations found in this study.

Of the sixteen open bite subjects, nine showed crowding, four spacing, two were normal, and one was unclassifiable due to extractions. The arch width in the open bite population was smaller than Pont's norms but not necessarily smaller than the true population normal. More crowding was observed than spacing and this may contribute significantly to the formation of anterior open bites. This condition alone or along with habits such as finger or thumb sucking is probably the causative factor of anterior open bite in Group II. The crowding of teeth due to inadequate arch length seems to be associated with an excessive curve of Spee, protruding incisors and excessive overjet. This condition predisposes to tongue or lower lip habits. Tongue and lower lip sealing is necessary to obtain an oral seal during swallowing in these subjects.

The "t" test used to compare cast values between each group showed no significant differences between measurements, although the difference in overjet approached significance. In Group II, the mean open bite was 3.66 and the mean overjet was 4.0. In Group III, the mean open bite was 4.6 and the mean
overjet was 2.7. The mean open bite was always greater than the mean overjet in Group III.

In Group III it was found that the mandibular intermolar width was significantly greater \( (0.05 > P > 0.025) \) than the maxillary intermolar width. This difference may be attributed either to a small maxilla or to a large mediolateral dimension of the mandible. This finding is consistent in skeletal Class III facial configurations where the middle face is small in relation to a normal mandible, where the mandible is larger than normal, or where the maxilla is small and the mandible is larger than normal. In these subjects, the anterior facial height was large in relation to the posterior facial height.

The photographs demonstrated the fact that all Group III subjects except one had long dolichocephalic faces, demonstrating the average extreme anterior vertical dimension shown by this group. Nine of these patients demonstrated abnormal perioral musculature. In contrast most of the subjects in Group II were round or square faced and only one subject demonstrated extreme vertical dimension. Three of these subjects demonstrated abnormal perioral musculature.

In comparing the cephalometric values, the mean articular angle and mean gonial angle in Group III were larger than those of Group II \( (0.15 > P > 0.10) \). In comparing the articular angle of
Group III with Bjork's group of 281 Swedish conscripts, it was found that the articular angle of Group III was significantly larger (\( .01 > P > .001 \)).

The gonial angle of Group III was larger than Bjork's group (\( .15 > P > .10 \)).

As the articular and gonial angles increase, the anterior portion of the face tends to increase in size with respect to the posterior portion of the face and a tendency toward anterior open bite develops.

Bjork did not include statistical values for the sum of the cranial base angles in his original work. When the mean values of these angles are added the sum is 397.5 degrees, the mean for Group II was 399.5 degrees and for Group III was 408.8 degrees. When the sum of the Group II and III cranial base angles were compared it was found that the difference was significant (\( .01 > P > .001 \)). These significant findings demonstrate the fact that the Group III population of this study can be considered separate and distinct from Bjork's normal group and from the Group II population of this study with respect to cranial base configuration. The angular measurements clearly show a small posterior vertical dimension with respect to the large anterior vertical dimension of the splanchnocranium in Group III. The cranial base configuration
of Group II was normal with respect to these measurement values.

When comparing linear values growth is a factor, and one must consider the age of the subject with respect to the part being measured. One should not compare the length of the mandibular ramus when the age range is great, however, one is justified in comparing the length ratio of parts that are growing at the same relative rate within the same subject. Bjork did not include statistical values for a ratio between the anterior cranial base length and the length of the mandibular body in his original work. It stands to reason however, that if the anterior cranial base remains small with respect to a large mandibular body, all other factors remaining constant, then the degree of prognathism will increase. If the mandibular ramus is short, and if the sum of the cranial base angles is large, then along with the high anterior cranial base/body length ratio, an anterior open bite will be present. This is fact describes the skeletal Class III open bite.

The ACB/BL ratio between Groups II and III, was found to be statistically significant (P< .05). This demonstrated the fact that there were a high percentage of skeletal Class III open bites in Group III.
The cephalometric analysis revealed that Group III was significantly different from Group I and Group II with respect to cranial configuration. The cranial configuration in Group III contributed greatly if not totally to the anterior open bite. This could be attributed to the size shape and relationship of the mandible with respect to the maxilla and cranial base. Configuration with respect to size was demonstrated by the anterior cranial base to mandibular body length ratio. Configuration with respect to shape was demonstrated by the gonial angle, mandibular ramus and mandibular body lengths. Configuration with respect to relationship was demonstrated by the articular angle.

A statistical evaluation of angle H I of the hyoid motion analysis revealed that the hyoid bone rose a similar amount with respect to Basion in all three groups.

In Group II, angle H 2 was significantly larger than in Group I (P < .05) and larger than the same angle in Group III (.10 > P > .05). Angle H 2 (Basion - Hyoid inferior - Menton) is essentially a measurement of the hyoid bone in the rest position. The difference between Group I and III would seem to indicate that either the hyoid bone is at a higher level in Group II or that Basion and Menton are farther apart indicating a facial skeleton of greater depth. Also, the
muscle tone may be greater in this group, causing the hyoid to be suspended at a higher level with respect to the mandible and cranial base. This would effect a higher tongue position and thereby facilitate the sealing of the anterior oral defect.

The Occlusal Plane Hyoid angle was very similar in all three groups indicating that the hyoid bone moved about the same amount anteriorly with respect to the occlusal plane in each of the three groups. However, the range was greatest in Group III and one patient had an angle of 33 degrees.

The swallowing pattern was basically the same for each of the three groups, except for the position and action of the tongue and lower lip. In Groups II and III, the tongue, lower lip or a combination of the two were positioned so as to form an anterior seal in order for the swallowing mechanism to take place. A characteristic "bird's head" silhouette was formed by the tongue when viewed from the saggital aspect. This "bird's head" was outlined by the radiopaque media coating the tongue.

No "tongue thrusting" was observed at anytime during any cine sequence of Groups II or III. The tongue thrust phenomenon was observed when examining the patient from a clinical exterior aspect. This tongue thrust phenomenon appears to be an abnormal and excessive pushing and expansion of the tongue.
tip during swallowing in an effort to produce an anterior seal. If one tries to observe the tongue thrust with the lips parted in an anterior open bite subject, it stands to reason that the tongue tip will come forward to fill the anterior void in order to form a seal and initiate the swallowing reflex by the sphincteric squeezing of saliva, food or water into the pharynx. An anterior open bite subject with his lips closed can be seen to push from behind with his tongue, and his perioral musculature constricts during the first phase of the swallowing cycle. The action of the tongue in both instances is a definite habitual placement of the tongue into an anterior defect so that the swallowing mechanism can be initiated. Cleall stated that he noticed tongue thrusting in his cinefluorographic examination. However, he did not outline the tongue tip with barium and he did not develop a profile shield in order to best observe the soft tissue such as the lower lip.

The action of the tongue in no way resembles "reverse swallowing" or "infantile swallowing". There is nothing "reverse" about the open bite swallow. The "infantile swallow" is a swallow produced in conjunction with sucking on an object or the creation of an intraoral vacuum. Thrusting forward of the mandible, forming a trough with the tongue, lowering of the
floor of the mouth and placing the tongue between the mandibular anterior teeth and a nipple while the maxillary anterior teeth or gum pads remain above the nipple are all actions found in the infantile swallow. These same actions are not found in anterior open bite swallowing.

The tongue and lip movement during the swallowing cycle in anterior open bite subjects is better termed "anterior tongue and/or lip sealing".

Even though the tongue seemed to rest at a lower position in some subjects of Group III, it always rose to make contact with the entire length of the hard palate during deglutition.

It was noted from the cephalometric-cinefluorographic tracings that the hyoid pattern could be classified into ovoid, triangular and vertical patterns described in the findings. The ovoid and triangular patterns were noted most often in Groups I and II. Six vertical patterns were noted in Group III. The vertical patterns noted in Groups I and II were associated with subjects exhibiting more than the normal anterior vertical dimension of the splanchnocranium. Ricketts noted two hyoid motion patterns during swallowing: a circular and an elliptical. The triangular pattern found in this study contains a definite forward horizontal movement of the hyoid bone as the bone reaches the height of its pattern of movement.
It can be inferred from this study that hyoid movement patterns are not related to the action of the tongue in open bite patients from the standpoint of etiology. The hyoid motion pattern directly involves the motion of the larynx as it moves up and forward to make room for an expanding esophagus during the last phase of swallowing. Tongue action involving the sealing of an anterior open bite takes place during the first phases of swallowing. The hyoid bone is seen to move during the last phases of swallowing as the larynx is brought forward. The relationship of the hyoid bone with respect to the cranial base and mandible in its initial static position should relate directly to tongue movement in swallowing.

A correlation study involving movement of the hyoid bone with respect to the cranial base and mandible has proved the basic triangular theory of hyoid motion. The hyoid inferior - basion - hyoid superior angle is significantly inversely correlated to the basion - hyoid inferior - menton angle. The basion - hyoid superior - menton angle is significantly positively correlated to the occlusal plane hyoid angle.

Other investigators, Cleall and Ricketts, have related hyoid movement to the palatal plane and other cranial landmarks. This is fine for observing a static relationship,
however, a moving relationship requires that one relates the moving object to its own references or attachments.

From observation, open occlusal swallowing appears to be a normal occurrence in each group. It does not appear to have any abnormal effect on the form and function of the organs involved in the swallowing mechanism. Cleall noted open occlusal swallows in forty percent of his normal patients and a similar percentage was noted in this study.

In view of the findings of this study, treatment from the standpoint of etiology in Group III would require adjustment of the skeletal configuration by means of preliminary orthodontic treatment in order to consolidate and align the arches and then mandibular surgery. Usually, the surgery would involve changing the gonial angle, and lengthening the mandibular ramus. Few cases would involve reduction of mandibular body length by means of body surgery alone. Genioplasty, if necessary, would be a concomittant procedure with mandibular surgery. Final orthodontic treatment would obtain an ideal occlusion.

In Group II, treatment from the standpoint of etiology would necessitate extraction of teeth to relieve crowded conditions and to close the bite. Placement of habit appliances, correction of tongue, lip and thumb habits in
conjunction with regular orthodontic treatment would be the treatment of choice in this group. Spaced conditions would require consolidation and treatment of tongue, lip and thumb habits.
CHAPTER VI
SUMMARY AND CONCLUSIONS

The swallowing pattern was investigated by means of cinefluorography in twenty-six subjects. Ten of the subjects had normal occlusion and were designated as the normal group or Group I. Sixteen of the subjects demonstrated an anterior open bite. These sixteen subjects were divided into two groups by means of the Bjork cephalometric analysis. Six of the anterior open bite subjects were designated as functional open bites or Group II. Ten of the subjects were designated as skeletal open bites or Group III.

In the open bite groups, dental models, photographs, cephalograms, and a medical and dental history were taken along with the cinefluorographic examination. Angular and linear measurements involving the dental models, cephalograms and the movement of the hyoid bone were compared within and between the groups. Observation of the photographs, the medical and dental history and the swallowing pattern were also compared.

The cinefluorograph was shown to be a useful tool in the diagnosis of tongue and lip habits associated with the swallowing mechanism.
It was shown that the movement of the hyoid bone was not significantly different between Groups I, II and III. The H 2 angle (Basion - Hyoid inferior - Menton) was significantly different between Group II and Group I and between Group II and Group III. However, the H 2 angle is not an angle of movement.

The triangular method of analyzing hyoid movement was developed and three distinct patterns of hyoid motion were found.

Observation of the swallowing pattern revealed no difference between the two open bite groups in tongue and lip movement. Both Group II and Group III were different from Group I in relation to tongue and lip movement during swallowing.

The cephalometric analysis revealed that Group III was significantly different from Group I and Group II with respect to cranial configuration. The cranial configuration in Group III contributed greatly if not totally to the anterior open bite. This could be attributed to the size, shape and relationship of the mandible with respect to the maxilla and cranial base.

The dental models demonstrated that the mandibular intermolar width was greater than the maxillary intermolar
width in Group III. This further demonstrates the relationship of the mandible to the maxilla with respect to size.

Crowding of teeth was found most often in both Group II and Group III.
APPENDIX I

Individual Cephalometric Measurements

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## APPENDIX II

### Individual Hyoid Analysis Measurements

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Mills, P.B.: "A Grid and Optical Head Positioning as Adjuncts to Cephalometric Analysis", Harvard School of Dental Medicine, Forsyth Dental Center, Boston, Mass.


APPROVAL SHEET

The thesis submitted by Charles Henry Fink 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 Master of Science.

May 22, 1968
DATE

Donald C. Hilgers
Signature of Co-Advisor

May 22, 1968
DATE

Douglas C. Bowman
Signature of Co-Advisor