THE CLAVICLE AND SCAPULA OF THE NEWBORN INFANT

DISSERTATION

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By

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>The Clavicle</td>
<td>3</td>
</tr>
<tr>
<td>The Scapula</td>
<td>5</td>
</tr>
<tr>
<td>MATERIALS</td>
<td>7</td>
</tr>
<tr>
<td>METHODS</td>
<td>10</td>
</tr>
<tr>
<td>RESULTS</td>
<td></td>
</tr>
<tr>
<td>Description</td>
<td>20</td>
</tr>
<tr>
<td>The Clavicle</td>
<td>20</td>
</tr>
<tr>
<td>The Scapula</td>
<td>56</td>
</tr>
<tr>
<td>Osteometrical</td>
<td>74</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>84</td>
</tr>
<tr>
<td>The Clavicle</td>
<td>85</td>
</tr>
<tr>
<td>The Scapula</td>
<td>135</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>157</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>164</td>
</tr>
<tr>
<td>ILLUSTRATIONS</td>
<td>173</td>
</tr>
</tbody>
</table>
INTRODUCTION

The purpose of this study is to present the osteometry, gross anatomy, roentgenology, and functional analysis of the neonatal clavicle and scapula. Presently, gross anatomical data upon these bones is not available while the osteometry and radiology is inadequate for the establishment of norms and standards directly applicable to the neonate. Such norms and standards are of great significance in the analysis of growth as they allow the comparison of the neonatal stage with the fetus and the adult.

Many delicate skeletal details occur before they are roentgenologically discernable. The absence of such detail limits the recording of the slow, minute but important changes which occur in bone growth (Noback, 1954). Forensic medicine and paleontology share an obvious interest in the details of neonatal osteology for which at present no study or guide is available. Recent advances in the study of the physiology (Smith, 1956), pathology (Potter, 1954) and surgery (Gross, 1955) of the newborn anticipate the foundation of a more complete study of newborn anatomy such as that existing for the human adult.
Although the neonatal skeleton has been used in longitudinal studies of the growth of the skeletal system, relatively few newborn specimens have been used. Most of these studies are obstetrical in nature and deal with the external dimensions of the skull.
The Clavicle

There is no study devoted to the neonatal clavicle, although the fetal and adult condition of the bone has been described. The most pertinent study of the fetal clavicle is that of Rudinsky (1929) in which the method for the osteometric description and analysis of the developing clavicle was established. No application of this classification was made to the neonate nor were data for the neonate presented. The status of the clavicle in embryos of nine to twenty-two centimeters is presented by Brandt (1935) in which the changes in the shape of the clavicle from a predominant "S" shape in the fourth month to an "axe-shaped" type at six months are demonstrated.

Stocaada (1924) presented an analysis of the human adult clavicle and described it in a triad manner following the method of Henke (1875) and others. The clavicle has been studied in relation to humeral length (Pasteau, 1879) and in relation to the superior thoracic aperture (Lissitzyn, 1925). Rachman (1928) established a classification of the adult clavicle on the basis of the height of the curvature in relation to the chord of the curvature. Sternal, intermediate, and acromial types were established and correlated to positions of fracture.
No study of the gross anatomical relationships of this bone has been made in any of the early developmental stages. Consequently there are no correlations of muscular, fascial, and arthrological characteristics in the previously mentioned papers excepting for the consideration of fractures and other injuries.
The Scapula

Little information applicable to the early development of the scapula is available. Lewis (1902) presents data pertaining to the early development of scapular form at the eleven, fourteen, and eighteen millimeter stages. The radiographic studies of Hess (1917) indicate that the ossification center for the scapular body occurs at the eighth or ninth week. At the approximate age of 64 days and in fetuses of crown-rump length of 38 millimeters, the scapula is present in osseous form when the alizarin red staining technique is used (Noback, 1944). He found that the change in the form of the scapula during fetal existence was due to the absolutely faster growth of the vertebral border than the axillary border.

Textbooks of gross anatomy generally do not illustrate the scapula of the newborn though other newborn bones are pictured. An idea of the size and shape of the neonatal scapula is available from the radiographic study of Smith (1924) and that of Noback (1944).

Presently there is not only an absence of data upon the scapula at birth in the terms of gross anatomy but also there is little information bearing on the osteometry of the scapula at this stage. Wolf (1925)
presents the changes in form, scapular index, and topographical position of the scapula during the stages of crown-rump length 18.5 mm. to 157 mm. Frey (1923) has traced the growth of the breadth of the scapula and the scapulo-humeral index from the fetal period to the adult stage.

A similar study of the scapular index of the neonate was carried out by Vallois (1932) with the retention of the cartilaginous portions of the scapulae. Although only three subjects were used in this study, the value of the index is quite similar to that of the present study.
MATERIALS

The clavicles and scapulae analyzed were obtained from still-born neonates of both clinical and private patients. An assessment of maturity was made following the criteria for classification of the Chicago Lying-In Hospital (Potter and Adair, 1948). By these standards an infant may be defined as a neonate when:

a. the crown-heel length is from 470 to 540 mm.

b. the body weight is from 2500 to 4500 grams.

c. the period of gestation has lasted from thirty-nine to forty-two weeks.

These criteria were used by the author in association with a judgment of maturity which eliminates specimens which deviate from the normal newborn by any gross discrepancy of morphological maturity.

The selection of the material was completely at random and represents a sample of the stillborn population of Columbus, Ohio, and environs during the years 1954, 1955, 1956, and 1957. It should be noted that in each case there was a failure of the defrayment of the burial expenses by the parents, and so the sample may bear the bias of origin from a single socio-economic group.
All the specimens were readily identifiable as to sex. The possibility of miscegenation in the sample was thought to be rather slight; however, there is concrete proof of this. The assessment of the racial purity of the sample is admittedly inaccurate and is limited by the method of procurement.

The clavicle series under investigation contains seventy neonatal clavicles or thirty-five pairs of bones. Fifteen of the pairs were from colored cadavers (42%); twenty from white (58%). Nineteen of the pairs are male (54%), while the remaining are female (46%). The higher proportion of male clavicles is representative of the greater mortality rate of males in the neonatal. Since the neonatal mortality rate for colored infants exceeds that of white infants by thirty-eight per cent, the population exhibits some bias from being a typical sample of neonatal cadavers (Potter and Adair, 1950).

The scapula series contains sixty neonatal scapulae, or thirty pairs of bones. These specimens are equally divided as to sex and color.

All of the material used in this study was previously autopsied. The method of post-mortem examination in present use requires that the thoracic cage be opened anteriorly. In this technique often times the clavicle is cut and the bone damaged so as to be
useless in the present study. However, whenever possible the clavicle was used so that no statistic presented herein is based on less than sixty specimens. There was no damage to the scapula or its muscles of attachment.

The cadavera, kept in cold storage before and after autopsy, were embalmed with intra-muscular syringe injections of a phenol-glycerine-alcohol solution. In some instances the bodies were stored in four percent formalin prior to embalming. The color, age, crown-rump, and crown-heel lengths were noted by the usual method.
METHOD

Each bone was dissected from the cadaver and notations on the gross anatomical relationships were made. An electric needle was used to demarcate the muscular and fasical relationships. The clavicles and scapulae were placed in four percent formalin following the dissection to preserve the cartilaginous parts with a minimum of shrinkage.

A compilation of the standard osteometric measurements was made from Frazer (1913), Hrdlicka (1952), Terry (1932), and Martin (1928) to establish a form sheet upon which the individual measurements were recorded. A standard machinist's sliding caliper with one-fiftieth of a millimeter accuracy was used in all linear measurements excepting that of the clavicular circumference at the mid-point. The form of the shaft at the mid-point is generally smooth, so that the measurement has an accuracy to the tenth of the centimeter. Measurements of the scapular angle were taken to the nearest degree by the use of a machinist's compass with a vernier scale. All measurements were carried out to the nearest millimeter.
Clavicular Measurements

The clavicular measurements carried out were (Fig. 1A):

1. maximum length (A & B)
2. width of the inner end
3. width at the inner angle
4. width at the conoid tubercle
5. the minimum width
6. width at the acromial third
7. depth at the middle point
8. depth at the inner end
9. depth at the conoid tubercle
10. depth at the least outer depth
11. circumference at the mid-point
12. index of the inner end
13. length/thickness index
14. medial angle (gamma)
15. lateral angle (delta)
16. index of curvature (14 + 15)

The maximum length measurement was taken from the furthest medial projection of the medial end of the bone to the furthest lateral projection of the bone with its orientation in the horizontal plane. The size of the bone allows this measurement and those subsequent to be
taken on a caliper with the same accuracy as that obtained with adult bones on a standard osteometric board.

The measurements of the widths of the clavicle are in reality those of its horizontal plane. The width at the inner or medial end is the width at the plane of the bony annulus and is the greatest available at this portion. That at the inner angle is the width at the furthest forward convexity of the bone while the minimum width is the width at the middle of the bone. The measurement of the width at the conoid tubercle was a measurement which was taken at the lateral angle of the bone since there is no conoid tubercle in the neonatal bone. The width at the acromial third of the bone is the greatest width of the lateral extremity of the fourth quadrant.

The term "depth of the clavicle" means the size of the sagittal diameter of the bone. These measurements were taken at the same positions as those of the horizontal diameter. The depth at the least outer depth is a measurement of the superior-inferior height at the lateral flaring of the extreme end of the bone.

It should be pointed out that when the circumference at the mid-point of the bone was taken, it was measured at right angles to the true and not the
osteometric axis of the bone.

These measurements were used in the calculation of what are the most commonly used and referred to indices of the clavicle.

Indices of the Clavicle

Parson's index of the inner end (1913) which is the ratio of the sagittal (x 100) to the horizontal diameter and the length (x 100) to the thickness at the mid-point were calculated. A few measurements were made of the articular discs in both medial and lateral dimensions. These were recorded when the measurements were thought to be of some validity and the values are given for them to give some idea of their thickness. They are generally in proportion to the discs at the extremities of the adult bone.

Foramina of the Clavicle

Each bone was examined for nutrient foramina. A count of these foramina was made. The bones were also inspected for clavicular perforations, rhomboid pits, and conoid and trapezoid facets.

Curvatures of the Clavicle

Parsons (1913) established the standard method for the expression of an estimated curvature of the clavicle. With one exception, the method of projection
of the image of the bone, his method has been followed in this paper. While Parsons employed a dioptograph for the drawing of an accurate contour of the bone, in this study a photographic enlargement projector was used to project the contour of the bone which was traced onto paper. Both of these methods seem superior to that of Terry (1932) in which paper tracings were made directly from the bone. From the contour drawing, the central points of the medial and lateral ends were established and united by a straight line (Fig 1A). This line is the osteometric horizontal axis of the bone. The central axis was then established by the drawing of a line the length of the bone which is equidistant between the anterior and posterior borders of the bone. The points of greatest anterior and posterior convexity are then fixed in this central axis. By the uniting of these two points with the end points of the horizontal osteometric axis, two angles are formed: an outer, delta, and an inner, gamma. These angles are measured by means of a protractor and the sum of the medial and lateral angles is taken as the index of curvature of the clavicle.

There are two inherent difficulties in this method. The projection of the superior surface in this bone is belabored by the torsion which exists
throughout its length. The accuracy of the entire measurement is dependent upon the positioning of the bone prior to its projection. This applies not only to the single specimen but also to the consistency of alignment of all of the specimens. Terry (1932) points out the second variable of this procedure which is the careful selection of the acromial and sternal end mid-points of the bone. The establishment of these points is "sometimes difficult to determine". This measurement is an estimate or approximation of the curvature and serves to give some idea of it.

**Scapular Measurements**

Scapular measurements (Fig. 12) taken were

1. height (C-D)
2. breadth (A-B)
3. length of the axillary margin (D-1)
4. length of the superior margin (C-G)
5. height of the infraspinous fossa (D-B)
6. height of the supraspinous fossa (C-B)
7. length of the spine and the acromion process (A-F)
8. length of the base of the spine
9. gross height of the acromion (B-F)
10. length of the acromion
11. greatest length of the coracoid process
12. length of the glenoid cavity
13. breadth of the glenoid cavity
14. axillo-spinal angle (ADI)
15. axillo-glenoidal angle (GID)
16. superior angle
17. inferior angle

Indices established were:

1. scapular index (breadth \times 100/length)
2. infraspinal index (infraspinous fossa length \times 100/length)
3. supraspinal index (supraspinous fossa length \times 100/length)
4. marginal index (axillary length \times 100/scapular height)
5. spinal fossa index (fossa \times 100 \text{ length of } \text{the infraspinous fossa})
6. length/breadth index of the glenoid cavity.

The vertebral border of the scapula was classified in each specimen according to the classification of Hrdlicka (1952) in which the border may be described as being triangular, biconcave, or convex; these are the three main shapes or types of scapulae.
The measurement of the height of the scapula was accomplished by the measurement of the distance from the superior angle to the inferior angle (Fig. 12, C to D). The breadth of the bone was measured from the vertebral border at the point of approximation of the spine of the scapula to the vertebral border of the glenoid fossa (Fig. 12, A to B). The length of the axillary border is the distance from the inferior angle to the inferior lip of the glenoid fossa (Fig. 12, D to I); while the length of the superior border (Fig. 12, C to G) is the distance from the superior to the inferior lip of the glenoid cavity. The height of the supraspinous fossa (Fig. 12, E to C) was measured from the vertebral border at the site of the approximation of the spine to the superior angle; and the height of the infraspinous fossa (Fig. 12, B to D) is that from the vertebral border at the level of the spine to the inferior angle. The length of the spine and acromion was established by the measurement of the distance from the vertebral border at the level of the spine to the most lateral extent of the acromion process (Fig. 12, A to F). The length of the base of the spine is taken from the vertebral border at the level of the spine to the end of the spine at the acromial notch. The measurement of the height of the acromion process was taken from the floor of the supraspinous fossa and is the
maximum elevation of the acromion from this floor.
The distance from the acromial notch to the lateral end of the acromion process was measured and is described as the length of the acromion process.
The medial half of this process is bony while the lateral half of the acromion process is cartilaginous.
The length of the glenoidal cavity is its vertical dimension, while the breadth of the glenoid cavity is its horizontal dimension.

The axillo-spinal angle is the angle of the spine of the scapula with the axillary border, (angle GID, Fig. 12) while the axillo-glenoidal angle is the angle of the axillary border with the superior and inferior aspects of the glenoidal borders. The superior angle is the angle of the lines connecting the superior portion of the glenoidal cavity and the superior angle with the vertebral border at the point of intersection with the spine of the scapula. The inferior angle is the angle formed by the vertebral border and the axillary border. It is measured at the intersection of the lines connecting the inferior angle to the inferior rim of the glenoidal cavity and to the vertebral border at the level of the spine of the scapula.
Scapular Relationships

The differences in the origin and insertion of muscles of the scapula were noted in dissection and catalogued. Likewise the facial relationships of the bone were studied. The portions of the bone which are cartilaginous were established and a notation made of their size.

The interest of the pediatric radiologist to date has been in the establishment of growth standards for the early stages of development. Numerous lists of data upon the time of appearance of ossification centers and their synostosis have accumulated (Lenz, 1956). Particular interest has been paid to the sutures and fontanelles of the calvaria, the teeth, and external dimensions of the cranium. But little has been done in the classic roentgenographic description of extra-cranial bones. This lack of attention may be related to the complementary histological studies which parallel the general skeletal disturbances of the neonatal and the interest which has been particularly focused upon disturbances of the normal growth of the skull.
Description and Relationships

The Clavicle

The neonatal clavicle is topographically in a similar position as in the adult. It is a horizontally placed strut which serves to unite the pectoral girdle to the axial skeleton, and serves for the attachment of appendicular muscles. Its position in the horizontal body plane is an oblique inclined plane (Noback, 1944), which is typical for the prenatal stages of the bone. This position is relatively higher than in the adult and is associated with the elevated position of the neonatal shoulder which later in life descends to the adult position. Also, it is more anterior than in the adult due to the rotundity of the thorax in the neonatal (Scammon, 1929).

The bone lies under five millimeters of superficial fat which contains the diverging filaments of the supra-clavicular nerves (C3-C4), that emerge from the lateral border of the sternocleidomastoid muscle and then radiate over the bone. They are found deep in the superficial fascia.

The clavicle of the newborn infant (Fig. 3) exhibits the same general shape and configuration as that of the adult. The double curvature, from which the bone has received its name in the adult stage
(L. clava; key), is present. One can readily distinguish the traditionally described basic divisions of the adult clavicle in that of the neonatal, namely a so-called medial prismatic and a lateral flattened area.

A "two part" system of description, that is, the designation of a medial prismatic and lateral flattened areas, of this bone is certainly not amenable to the concise description of the clavicle either of the adult or neonatal. Neither is the widely used "three part" system, which is justifiable somewhat on the basis of the attachments of the pectoralis major, deltoid, and trapezius muscles. This latter system, however, has no relationship to the other muscular attachments of the bone and is poorly correlated with other osteological divisions. The origin of this "three part" description is related to the description of the adult clavicle and is not in conformity with a developmental or osteometric analysis.

The arrangement of the muscles on the clavicle prohibits a satisfactory geometric or osteometric division of the bone on the basis of the delimitation of its muscular attachments.

Although these various divisions may be made out of the newborn bone, it is evident from a closer inspection of the surface planes that four osteological regions are present. A more minute inspection of the
neonatal clavicle leads to the employment of a quartile or "four part" system of description (Fig. 1A). The basis of the quartile system lies in the presence of two flattened areas between two regions of the bone which approximate a triangular outline in sagittal section and are henceforth referred to as prismatic. These areas are obvious upon palpation of the bone. Each half of the bone has under the quartile system a triangular or prismatic portion which lies medial to a relatively flattened area. Passing medially from the sternal to the acromial end, these four regions are respectively in cross section: prismatic (the sternal end), flattened, prismatic, and flattened (the acromial end). The prismatic nature of the bone is particularly distinct in the thinnest part of the bone - the medial portion of the outer curvature or the second prismatic region.

In the following description these four quadrants are assigned numbers and are numbered from medial to lateral: one, two, three, and four. Thus, the medial prismatic region is number one, the adjacent flattened area is number two, the prismatic region lateral to this is number three, while the flattened acromial end is number four (Fig. 1A). These four regions correspond to quarter lengths of the bone, hence, this descriptive system is a quartile one.
Although this bone demonstrates some torsion throughout its length, the greatest amount of torsion occurs near the mid-point of the bone. This is the area between the medial flattened area (the second region) and the lateral prismatic region (the third region).

The prismatic regions generally have three borders and three surfaces while flattened regions have two borders and two surfaces. The surfaces may be smooth or granular, that is, showing pitting of the bone due to the attachment of the periosteum. With but one exception, the muscle attachments to the clavicle do not produce the rough irregular surfaces seen in the adult bone. This is related to the heavy thickness of the periosteum in most regions, the insertion of the muscle into the periosteum, and the loose attachment of the periosteum to the bone. Indeed in the process of autolysis of the newborn, the clavicle, with the exception of its ends, may easily be enucleated from its periosteal covering.

(I) The first quadrant (the medial one-quarter) contains the sternal articulating end and is that portion from the sternal end to the flattening of the bone at the point one-quarter of the bone length laterally. The lateral demarcation of this region is just a few millimeters medial to the point gamma or the medial
angle of the clavicle. The enlargement of this end for the articulation with the sternum results in an increased size of this portion so that in relation to the other parts of the bone it is much greater in the neonatal than in the adult. In the neonate this medial quarter has the greatest volume of the other three regions. (See osteometry and height/width index).

This region extends in a medial-lateral direction and is higher than it is wide. Four surfaces are present: anterior, posterior, superior, and inferior.

(I-A) The anterior surface of this region is triangular in outline, (6mm x 6mm x 8mm) flattened in the frontal plane, and gives rise to the clavicular part of the pectoralis major. From the inferior border of this triangular surface the costo-clavicular ligament has part of its attachment. This ligament is also attached to the inferior surface. The bony annulus, which occurs on the other three surfaces, is absent on this anterior surface due to the prolongation of the origin of the pectoralis major muscle over the entire anterior surface of the bone and the capsular ligament. The inferior border is longer, so that the triangle is based upon it, while the medial border of the triangular
surface is rounded and less acute than those of the other surfaces. It bears a small portion of the anterior surface.

The superior, posterior, and inferior surfaces of this region taken together form a fairly evenly curved surface so that in reality this end of the clavicle is rounded with a flattened anterior portion and is not exactly prismatic. The entire medial margin of this convexity serves for the attachment of the ligaments of the sternoclavicular articulation. The attachment of these fibers is so close to the bone that a bony annulus is left upon their removal from the bone. This bony collar is present a distance of two millimeters from the medial margin and is due to the attachment of the periosteum, which is lateral to the edge of the annulus and is loosely adherent to the bone while in the region of the origin of the sternoclavicular and capsular ligaments, it is closely attached. The annulus coincides with the medial margin of the sternocleido-mastoid and pectoralis major muscles. It is also present on the posterior aspect of the bone in the region which overlies the cervical fascia and the sternohyoid muscle. The area lateral to the annulus exhibits diffuse granularity resulting from the attachments of the periosteum. This granularity naturally is
absent on the articular surfaces of the bone.

(I-B) The superior surface which slants to the posterior surface, on its anterior border gives origin to some of the clavicular head of the pectoralis major muscle while over the remainder of its surface it provides for the attachment of the clavicular head of the sternocleido-mastoid muscle. This origin is wider on the medial aspect of this surface and so corresponds with the form of the bone. Since there is no definable posterior margin to the superior surface, and it becomes continuous with the posterior surface. This surface is on the same plane as the sternal notch. Palpation of the joint will in reality place the investigator's finger on the lateral aspect of the head of the medial clavicle; specifically on the superior and anterior surfaces of this first quadrant.

(I-C) The posterior surface is rounded and triangular shaped. The apex of the triangle is the shaft of the clavicle while the base is the bony annulus mentioned above. The annulus is especially well marked on the posterior surface. The remainder of the posterior surface lateral to the annulus is occupied by the cleidal head of the sternocleido-mastoid muscle. The attachment of these fibers is tangential to the medial axis of the bone and passes
over the posterior aspect of the capsule. Commonly there is a ridge between the two parts of the clavicular heads of muscle, which roughly corresponds to a posterior boundary between the superior and posterior surfaces.

(I-D) The inferior surface is rounded and bears the superior attachment of the costoclavicular ligament and the inferior sternoclavicular ligament. The costoclavicular ligament is prominently developed, three to four millimeters wide, and is continuous medially with the anterior sternoclavicular ligament. Its attachment to the medial quarter of the clavicle forms a definite roughened area on the inferior surface of this portion of the clavicle. Its inferior attachment to the first rib is overlapped by the subclavius muscle, which inserts on the clavicle anteriorly to the ligament. The bony annulus of the joint is well defined in this portion. This surface projects inferiorly and the plane of its surface faces ventrolaterally.

(I-E) The medial articular surface of the clavicle articulates with the clavicular notch of the manubrium sterni in a complex saddle-type of joint (Steindler, 1956). A meniscus intervenes in the joint and bears a shape intermediate between that of the articulating surfaces. This sternal articulating
surface is convex, and is directed anteriorly and medially. The form of the articular surface is ellipsoidal with the long axis in a superior-inferior plane. The point of greatest convexity lies on the lower portion of the surface. The form of the surface limits the movement at this joint, particularly, in restricting the elevation of the clavicle. The convexity lies in the posterior plane of the joint and so limits movement in an antero-posterior plane. This point is below the horizontal axis of the bone and on the lower third of the articular surface. Moreover, the articular surface of the sternal end of the clavicle is prolonged onto its anterior surface and thus extends the mobility of the joint in an antero-superior direction.

The medial surface of the articular disc follows the surface of the joint and is oblique to the horizontal plane and is smaller than that of the medial head of the clavicle. It is attached about its periphery to the capsule of the joint, especially to the postero-inferior portion of the capsule. The size of this disc is generally proportional to that of the adult and is similar, in that it is thinnest at its central portion.

Just as the articulating surface of the sternal end of the clavicle is directed antero-medially,
so the articular surface of the clavicular notch of the manubrium is directed postero-laterally.

The sterno-thyroid muscle passes posteriorly to the sterno-clavicular joint and the medial end of the clavicle. A lateral extension of the muscle originates from the posterior aspect of the joint capsule by fibrous attachments; it is too short for sternal attachment.

(II) The second quadrant (the medial flattened zone) contains the medial angle of the clavicle and is that portion situated between the flattened part of the first quadrant to the beginning of the prismatic third quadrant. It approximates a quarter of the length of the clavicle. The lateral boundary of the region is coincidental with the mid-point of the bone and the origin of the inferior margin.

This second region presents two surfaces, superior and inferior, and two borders, anterior and posterior. Structurally it is simple due to the absence of any definitive bony markings, with the exception of the granularity of the periosteal attachment. The shaft of the bone, however, assumes a gentle arc which contains and forms the medial angle of the clavicle. This angle approximates the same angulation as that of
the adult. This region is intrinsically strong and bears one of the greatest widths seen in the shaft of the bone.

(II-A) The anterior border presents a smooth rounded edge. The origin of the clavicular portion of the pectoralis major muscle is continued onto it and onto both the superior and inferior aspects. The lateral margin of the origin of this muscle almost coincides with the lateral border of the second quadrant.

(II-B) The superior surfaces of this region gives origin to two muscles, the clavicular portion of the pectoralis major and the sternocleidomastoid. A slight ridge is often present on this surface although it does not bear any relationship to the line of origin of these two muscles. The pectoralis major muscle originates from only the anterior quarter of this surface and extends further laterally than does the sternocleidomastoid muscle. This origin causes some granularity of the anterior border and of the superior surface. The origin of the sternocleidomastoid muscle extends laterally for but one-half of this region and does not extend to the posterior border but leaves a smooth area on the posterior quarter of this surface. This area has no muscular relation but
is enveloped by thick periosteum and may be considered a "bare" area. There are thus two areas on the superior surface: a granular anterior "muscular field" on the anterior portion and a smooth area posteriorly. They differ slightly in that most of the muscular portion has a forward slant while the posterior area is slanted posteriorly. The bare area is present behind the lateral origin of the sternocleidomastoid muscle and posterior to the origin of the pectoralis major which is over the entire superior surface.

(II-C) The posterior border is rounded and yet more acute than the anterior border. It serves as the site of attachment of the vaginal layer of the cervical fascia.

(II-D) The inferior surface is flattened area which is tranversely trisected throughout its length by the lines of attachment of the clavipectoral fascia which envelops the subclavius muscle. Thus the inferior surface is divided longitudinally into three approximately equal parts. The middle is that of the insertion of the subclavius muscle; it shows no bony markings to demarcate the attachment of the muscle. The anterior and posterior thirds of this region are smooth and in direct relationship to the deep enveloping clavipectoral fascia and periosteum.
This fascial relationship is a condition which is invariably found.

The pectoralis major origin occupies the anterior portion of the inferior surface and thus the subclavius muscle and fascial relationships are better demonstrated in the lateral portion of the second quadrant.

(III) The third quadrant (the lateral prismatic region) forms one of the most important regions of the bone in that it bears the most acute angle of the clavicle, contains the foramen for the nutrient vessels of the bone, and is the site of most obstetrical damage, i.e. fracture and complete breakage. It contains the lateral angle of the shaft; begins medially at the mid-point of the clavicle; and may be demarcated morphologically at the medial origin of the inferior border of this region by the increasing depth of the bone. It extends to the flattening of the border into the inferior surface of the fourth quadrant. This lateral boundary coincides with the commencement of the straight portion of the posterior border of the fourth quadrant. Three borders and three surfaces may be distinguished. They are the superior, posterior, and inferior surfaces; and the anterior, posterior, and inferior borders. The inferior surface is readily
distinguishable and is the widest at its intersection with the inferior surface of the fourth quadrant while the superior and posterior surfaces are more irregular in outline.

(III-A) The superior surface presents two areas, a roughened lateral area for muscle attachment and a medial smooth area. A part of the clavicular head of the deltoid muscle arises from the roughened area anteriorly extending its origin from the anterior border onto the superior surface. Behind this and occupying the posterior two-thirds of this area, the fibers of the trapezius muscle insert onto the bone in a tangential manner. The bare area of this surface is a continuation of the bare area of the second quadrant. In contrast to the presence of a deltoid tubercle on the adult clavicle, the neonatal clavicle rather bears a depression at the site of origin of the deltoid fibers. This depression is the most notable secondary character of the neonatal clavicle and is the only one with any significant development. This deltoid origin is not limited to the groove it makes but occurs anterior to the bare area also.

(III-B) The posterior surface is smooth and free of muscle attachment. It is related to the vaginal
layer of the cervical fascia, and to the fat in this fascia. The lateral portion of this surface receives the fibers of the trapezius and consequently has a roughened surface. There is no definite border between this surface and the superior surface, however, the two are distinguishable by the plane of their surfaces. The superior surface, with the exception of the deltoid depression, faces postero-superiorly while the posterior surface is posteriorly positioned.

(III-C) The inferior surface is concave, faces antero-inferiorly and provides insertion for the subclavius muscle and for the attachment of the clavipectoral fascia anterior and posterior to this muscle. In contrast to the adult clavicle, this area is smooth. It does, however, show laterally some indication of the attachment of the muscle. This surface is divided, as is a portion of the second quadrant, into three areas by the subclavius muscle and the clavipectoral fascia. It should be noted that, as in the adult, the insertion of the subclavius muscle has no casual relationship to a subclavian groove or its neonatal precursor. There is no evidence of a subclavian groove on the inferior surface of the neonatal clavicle while the insertion of the subclavius muscle then is into the entire inferior surface excepting the extreme lateral
end, and the medial one-quarter of the clavicle.

(III-D) The anterior is concave and with a markedly acute edge, which is the line of demarcation of the inferior margin of the origin of the deltoid muscle.

(III-B) The posterior border is rounded, convex, and hardly distinguishable except at the lateral portion where it is joined by the prolongation of the inferior border. It serves for the attachment of the deep cervical fascia on the lower part of the curvature. This border and the adjacent posterior portions of the superior and inferior surfaces are very smooth and bear no muscular attachments. It is in this area which is in contact with the axillary fat over the brachial plexus.

(III-F) The inferior border is sharply defined and forms the posterior border of the attachment of the subclavius muscle. It arises from the center of the inferior surface at the lateral boundary of the third quadrant and passes posteriorly on this surface to join in the formation of the posterior border of the fourth quadrant. About one millimeter lateral to its origin a constantly occurring foramen for the nutrient vessels of the bone perforates the cortex of the bone perpendicularly. Thus, the nutrient
foramen of the neonatal clavicle lies at its thinnest diameter, in a prismatic region of the bone, and adjacent to the site of most clavicular fractures. This is the principal nutrient foramen of the clavicle and was present in all of the series. The foramen may be single, double, or compound. This latter condition is quite rare.

(IV) The fourth quadrant (the lateral flattened portion) is the lateral fourth of the clavicle. The medial boundary is at the level of the medial commencement of its straight posterior border and is coincident with the end of the inferior border of the third quadrant. The fourth quadrant extends laterally without any notable curvature, as was the case with the first quadrant. The region is flattened and presents anterior, posterior, and lateral borders, and superior and inferior surfaces. It bears the lateral articular surface of the clavicle which partakes in the acromio-clavicular joint.

(IV-A) The anterior border is concave and rounded. The origin of the deltoid muscle is continued along it excepting for the flattened extreme lateral portion which serves for the attachment of the capsular fibers of the acromio-clavicular joint.

(IV-B) The superior surface is flattened and wider laterally than medially. This surface has muscle
and capsular ligament attachments. The deltoid muscle is attached to the anterior quarter of the surface but it does not cause any depression. Its origin is detectable by a roughening of the area of origin while most of the remaining surface is occupied by the fibers of insertion of the trapezius. A diffuse granularity of the bone results from this fleshy insertion. The lateral portion of this surface is covered by the fibers which pass over the acromio-clavicular joint and which take part in the formation of the capsule of this joint. Whereas, the articular surface is on the anterior aspect of the lateral border, the capsular fibers are attached to the antero-lateral superior surface. The posterior border is straight and rounded and is involved in the insertion of the trapezius fibers. At the extreme lateral edge some of the fibers of the acromio-clavicular ligament are attached.

(IV-C) The inferior surface is the same shape and size as the superior. Like the inferior surface of the third quadrant, it faces slightly anteriorly. In the medial central area of this surface the subclavius muscle has its lateral insertion. This muscle extends to the conoid ligament and attaches on it for one-half millimeter. About this insertion the
conoid and trapezoid divisions of the acromio-clavicular ligament attach in the form of a laterally directed "V". The conoid ligament forms the long posterior arm of the "V" and causes a heavier granulation of the bone. In contrast to the adult this ligament is not oblique in the newborn and is more difficult to separate from the trapezoid ligament. Its continuity with the trapezoid ligament is present near the apex of the "V" where the trapezoid ligament is firmly attached. The anterior arm is a continuation of the trapezoid ligament in an anterior relationship to the subclavius muscle and forms no bony markings.

The area lateral to the coraco-clavicular ligament is relatively smooth and its concavity is related to the convexity of the fleshy fibers of the supraspinatus muscle. Some of the fibers of the trapezius muscle intertwine with the periosteum in this region. This portion serves as the superior part of the bony arch through which the supraspinatus muscle passes.

(IV-D) The lateral border is a wide rounded arc two to three millimeters high. On the anterior aspect of this arc is found the oval articular surface, the longitudinal axis of which runs antero-posteriorly and is inclined inferiorly. This incline allows a
displacement of the clavicle up and over the articular surface of the acromion process. This luxation is easily demonstrated in the fresh cadaver and may be of some importance in parturition where a lateral pressure is placed upon the shoulder. In such a situation the clavicle follows the incline of its articular surface and the scapula moves under it. As in the sterno-clacicular joint, no muscle fibers pass over the acromio-clavicular joint.

The acromial end of the clavicle is enmeshed for the remainder of the surface by dense connective tissue. These fibers attach the clavicle to the acromion process. They are attached to the entire circumference of the acromial end of the clavicle and about the acromial process the articular surface of which is small. The articular surface looks laterally, anteriorly, and is inclined downwards very slightly to form a very mobile joint.

**Comparison to the Adult**

It is interesting to compare the morphology of the neonatal clavicle to that of the adult in order to define the topographical and developmental changes which take place in the growth of the clavicle from a high anterior relationship to the lower and more posterior one typical of the adult.
The four quadrants which are distinguishable in the neonate are present in the adult and are as easily defined as in the neonate. The differences which are present will be discussed as they are noted in each quadrant.

(I) While the boundaries of the first quadrant are the same in the adult as in the neonate, the preponderant size of the entire medial quarter which exists in the neonate is lost in the adult. The adult medial quarter is more consistent in size with the remainder of the bone, and, in particular, the similarity of the superior-inferior size in this medial quarter to the same portion of the second quarter is greater in the adult than in the neonate. Whereas, in the neonate this region is generally as high as it is long; in the adult the length of the medial quarter exceeds length.

In this paper four surfaces of the first quadrant of the new-born clavicle have been discerned. Whereas, the anterior surface is readily discernible, the superior, posterior, and inferior form in the newborn a gentle arc which is expressed on the medial surface of the bone. The adult clavicle shows this pattern but expresses both a prismatic three-sided form, and the four surfaces described.
In the adult clavicle the anterior surface retains its triangular outline and flattened frontal plane for the origin of the pectoralis major. The triangular outline is altered and variable, but distinguishable. While this surface in the neonate is restricted to the medial quarter, it extends more laterally in the adult and onto the anterior surface of the second quarter. The roughened area on the anterior surface, to which the anterior fibers of the costo-clavicular ligament attach, appears in the adult as the impression for the attachment of the costo-clavicular ligament. The only indication for this attachment in the newborn is a roughening caused by the fibrous attachment to the bone. It is quite usual to find the anterior surface bearing part of this tubercle or depression. Whereas, the surface is continuous with the articular surface in the neonate, and continuous with it by very rounded borders; in the adult the two areas are discrete as the articular surface is elevated above it. The border is generally distinct and articular lipping is common.

The attachment of the capsular ligaments in both age groups is to the circumference of the periphery of the medial end. There is formed in the newborn a distinct elevated annulus, which is absent in the adult.
Rather the mature bone has no distinctive border but does bear a roughening over the entire medial border.

The superior surface slants posteriorly in both the adult and the neonate. The elevated medial aspect of this bone is absent in the adult though prominent in the neonate. The adult bone shows some small tubercles for the origin of the sternocleidomastoid muscle which are absent in the neonate. There is no vagueness of the posterior border on this surface, and generally the superior and posterior surfaces are distinct.

This posterior surface is of the same shape in both the neonate and the adult. The two differ in that the neonatal surface has a much greater concavity than the adult bone. The absence of the bony annulus in the adult, exaggerates this concavity. This surface may contain in the adult a portion of the tubercle for the costoclavicular ligament.

The inferior surface of this portion is small in both age groups. Essentially it is the area of attachment for the costoclavicular ligaments. In the adult bone this area is very evident by its markings. In contrast, the neonatal bone while not bearing these extuberances does show a marking or "granularity" not only of these surfaces but also of the superior,
posterior, and inferior surfaces. Just as the inferior surface serves completely for the attachment of the costoclavicular ligament in the neonate, it functions similarly in the adult where a flattening of the surface results.

The sternal articulating surface is more prominent in the neonate than in the adult due to its generally larger size, and the bone annulus about it. While the articular surfaces of both are convex and ellipsoidal, the anterior-inferior portion of the adult bone is markedly developed so that one-sixth to one-fourth of the articulating surface faces antero-inferiorly. This projection generally is raised above the surface of the bone and may show articular lipping. The surface is evidence of the change caused by elevational movements of the clavicle.

In addition, the neonatal clavicle shows little of the variations seen in this articular end of the adult bone (Toff and D'Errico, 1928), where the end may be convex, plane or concave, and is quite variant in outline. The articular disc is similar to that of the adult in corresponding to the plane of the joint.

(II) The second quadrant (the medial flattened bone) undergoes little change in its form.
The pectoralis major origin is changed in position so that the anterior border is rounded. Sectionally this region may approximate a semicircular appearance due to the depression inferior to the anterior border. Bony markings are not remarkable in either age group and the angulation of this region is the same in both groups. In the adult the width of this quadrant is more proportional to the other quadrants than is that of the newborn. The site of origin of the sternocleidomastoid changes little in relative size from the neonate to the adult. But this area in the newborn is a flattened area, while in the adult it is convex and may bear a few roughenings on its surface due to muscular attachment. The origin of the pectoralis major is now over the anterior one-half of this superior surface. Both the exterior and posterior borders are of the same approximate curvature in the adult, while in the neonate the posterior border is a little more prominent than the anterior.

The inferior surface of the second quadrant changes from a convex surface in the neonate, in which the convexity is near the mid-line, to the adult condition where the entire surface is flattened and faces postero-inferiorly. No bony demarcation exists between the pectoralis major origin and that of the
subclavius in the adult. This is distinguishable, however, in the neonate because of the granularity imposed by the origin of the pectoralis major. The major growth change occurring on this surface is the extension dorsally of the pectoralis major, so that the clavipectoral attaches to the posterior border. The insertion of the subclavius muscle is restricted in the adult second quadrant to the posteromedial portion of this area, while the attachment of the clavipectoral fascia is united to the posterior border of the surface. There is an apparent restriction of the medial attachment of the subclavius with increasing age.

(III) **The third quadrant** (the lateral prismatic region) is the site of most fractures in both the neonatal and the adult bones. It is interesting to note that the form of this portion is still prismatic in the adult, though somewhat altered by the suppression of the inferior border and the formation of a definitive subclavian groove. The newborn bone has three regions which, though present in the adult bone, are not equilateral, as in the neonatal bone.

The medial margin of the third quadrant is the neonatal coincides with the origin of its inferior
border. In the adult this border commences at about
the middle of the region and is neither sharp nor
distinct in appearance. The lateral border is also
less easily distinguished. Either the conoid tubercle
or the commencement of the straight portion of the
posterior border may be used.

In contrast to the inferior surface of this
portion of the neonatal clavicle that of the adult
bears the markings of the subclavian groove and the
anterior slope of this plane is much less than in the
neonate.

The superior surface of the third quadrant
of the adult is similar to that of the neonate in
bearing a medial smooth area and a lateral area
roughened by the insertion of the trapezius. While
these markings on the neonatal bone are not remarkable,
those for the adult are quite distinct. The deltoid
depression on the neonatal clavicle generally changes
to a pronounced deltoid tubercle in the adult stage
and the anterior border on which it develops is more
acute in the neonate.

The posterior surface of both the neonate
and adult is smooth and bears no muscular attachment.
Its relative size is reduced in the adult. The
nutrient foramen typically occurs on this surface or
upon the inferior border of this quadrant.

The inferior surface of the adult bone is less convex than that of the neonate, while the neonatal clavicle bears no impression for the subclavius muscle and shows none of the roughenings which result from the attachments of the conoid ligament. The inferior border is much less prominent in the adult bone and may serve as the posterior border of the subclavian groove.

(IV) The fourth quadrant (the lateral flattened portion) is strikingly different in the adult, due to the complex bony extuberances upon the adult bone in this region which are absent in the neonate. While the lateral border of this bone forms a smooth curve in the neonate, in the adult it has a variable pattern of rough and smooth edges of many shapes, but, the general form of the quadrant is the same.

The concavity of the anterior border is generally reduced and the superior surface is rougher in the adult. The posterior border is not straight as in the neonate but bears a dorsal arc along its length.

The inferior surface of the adult bone bears the same general topography of attachment as the neonatal bone. While the neonatal bone surface is
not smooth, the adult bone exhibits exostoses along the course of attachment of the rhomboid ligament. In the neonatal no impression is made by the anterior portion of this ligament which passes medially towards the anterior border from the trapezoid tubercle. The concavity for the passage of the supraspinatus muscle is identical in disposition in each one. Both supraspinatus areas serve to attach the fibers of the rhomboid ligament.

The adult bone differs from the neonatal bone also in that the lateral end of the clavicle is shaped that the articular surface forms the greater part of the end of the bone and is not conformant to a lateral arc as in the case in the neonatal. The articular surface of the adult clavicle remains to become oval in form and shows the typical age changes which occur on a joint surface.

The presence of an articular disc at this joint is only in the realm of one percent (Steindler, 1956) in the adult. None were observed in the present series.

Radiography

Radiographs of the dry neonatal clavicle were taken from two aspects (Fig. 5). A superior-inferior view demonstrates the arrangement of the
trabeculae in the horizontal plane; while the anterior-posterior view shows the disposition of the trabeculae in the sagittal plane. The relationship of the compact to the trabecular bone is easily seen and the disposition of the nutrient canal to the medullary cavity is quite obvious.

The clavicle at the neonatal stage is undergoing both patterned apposition of bone and modeling reabsorption. There is no radiographic trace of the primary ossification or of other growth processes which take place in this bone.

The division of the clavicle into four morphological regions is discernable in the radiographs of the newborn clavicle. While the medial and lateral quarters of the bone show the pattern of the spongy trabeculae with a very thin cortical layer of bone, the medial quadrants are more mature in their construction, they bear a heavy outer cortex of compact bone, and have no discernable trabeculae. The medullary cavity is seen to pass through the central axis of the bone and to expand on each end. Other trabeculae are very distinguishable in the lateral ends and demonstrate the torsion of the clavicle. They parallel the central axis of the bone when the lateral end is viewed from the superior aspect and the medial end is
inspected from the anterior aspect.

(I) The medial quarter has previously been described from gross observations as bearing a very thin granulated cortical layer. The thinness of this layer is demonstrable in an x-ray and allows a clear visualization of the trabeculae which are typical of a growing immature bone in their coarseness, irregularity in form, and wide range of thickness. This heterogeneity is marked in the lateral portion of the quadrant but is not distinct at the articular end of the bone. Here their orientation in many directions causes a loss of the linear pattern. The thinness of the compact bone, which is apposed to the articular cartilage and the compact nature of the many fine trabeculae present are demonstrated. In contrast, just lateral to the bony annulus, the longitudinal pattern of the trabeculae is marked. By a comparison of the superior and anterior views of these trabeculae their orientation to the medial end and central axis of the bone may be distinguished. From the anterior view the trabeculae are seen to extend in the plane of the central axis. The lines vary in length according to their relationship to the periphery of the bone; the central trabeculae are the longer
and extended the length of the quadrant; those which originate from the region of the annulus are shorter. In contrast the superior view demonstrates the radiation of the trabeculae in a trajectory of "functional" pattern. They flare to the entirety of the medial end of the bone. The orientation of these trabeculae loses its distinctness on the articular end of the quadrant in both antero-posterior and supero-inferior views. The entirety of this medial quadrant bears internally the medial flaring portion of the medullary cavity, while the cortical bone about the cavity is for the most part very thin. The anterior half of this quadrant contains the thickened anterior border of the bone. From the superior aspect this compact bone assumes up to one-half of the width of the bone; the anterior view shows that this layer of cortical bone is about one-quarter of the depth of the bone. By examination of the surface markings of the bone and the pattern of this surface as seen in the roentgenogram this compact portion of the bone bears a horizontal orientation of its fibrillar elements. This linearity is not discernible at the medial angle of the bone because of the thickness of the bone. In conclusion, the medial quadrant is
compact in nature only at its antero-medial portion while the remainder of its substance is essentially composed of spongy bone.

This quadrant by its thin cortex and heavy trabeculae demonstrates some of the fundamental morphological characteristics of growing tubular bones. The process of the longitudinal growth of a bone involves a progressive removal and addition of bone to its growing end. This modeling is responsible for a wide terminal segment which is followed by a concentrically contracted shaft (Caffey, 1956). In this quadrant of the clavicle the structure of the bone is adapted to the mechanical forces which are applied to it, and yet has a structural composition which is readily modifiable.

(II) The second flattened quadrant of the bone is radiographically of a typical "collar" composition. The compact bone forms the outer two-thirds of the bone. Some linearity of its elements is discernable. Passing through the center of the bone is the medullary cavity which is quite discernable on an x-ray by its greater translucency. The cavity does not follow exactly the morphological axis of the bone. It passes on the anterior plane from an upper medial position to one lower and lateral. From the superior
aspect it is seen to follow the curvature of the bone. The contour of the medullary cavity is regular in outline; however, the horizontal and vertical dimensions change throughout their course in the bone. The cavity appears larger toward the medial portion of this quadrant excepting for its central enlargement.

(III) The third prismatic portion of the clavicle is similar to that of the second quadrant. It too is tubular in composition and contains a definitive medullary cavity. The cavity is centrally placed in its antero-posterior relationships but in its horizontal plane is somewhat inferiorly placed. The opening of the nutrient foramen into this medullary canal is evident as a deficiency in the inferior portion of the cortex. The shadow of the foramen is larger in the x-ray than in gross observation and is also demonstrable from the superior view as a darkened area in the medullary cavity whose shadow is approximately the size of the medulla cavity. The antero-posterior view demonstrates that at the level of the nutrient foramen, one-half of the roentgenological shadow is darkened by the continuity of the nutrient foramen and the medullary cavity. The significance of this disparity

53
in the continuity of the cortex of the bone is that this region is most frequently involved in clavicular fracture.

(IV) The lateral quadrant (the lateral flattened area) is very similar in general plan to the first quadrant. Medially there is a cone of compact bone from which trabeculae flare laterally. These trabeculae are not as well defined linearly as are those of the medial end, and generally less dense. Their arrangement is parallel to the central axis of the bone when viewed from the superior aspect. The trabeculae are large and distinct proximally, while distally they are shorter, small, and less well defined. At the articular surface they are not definable and form the loose trabecular bone characteristic of the lateral articular end. The intertrabecular spaces are larger in the medial portion of the bone than further laterally. These trabeculae diminish in size gradually and continuously, follow the path of a trajectory, and are oriented so as to dispose the end to withstand horizontal or lateral strain. The path of the trabeculae is a gentle displacement inferiorly, but this is not as distinct as in the medial end. The medullary cavity appears to be less spongy, is more translucent in outline and passes
inferiorly in this region. It is covered on its medial portion by the compact bone of the anterior border. This region demonstrates the typical configuration of the growing end of a long bone which is disposed structurally so as to undergo progressive concentric constriction of the shaft away from the wider epiphyseal plate.

It should be noted that as seen in the x-ray of the newborn clavicle (Fig. 5) there is no evidence of the more mature bony projections which are characteristic of the adult bone. There is no rhomboid depression, conoid tubercle, subclavian groove or groove for the first rib either on external or internal examination. The bone is morphologically immature and demonstrates the flaring ends of a growing tubular bone. The size of the medullary cavity is quite different from that of the adult. The adult bone exhibits a clearly delineated central cavity with an outer wall of dense cortical bone. The compact bone in the adult is generally less than one-quarter of the diameter of the bone while it is approximately two-thirds of the thickness of the neonatal bone. The spongy trabeculae of the adult bone is limited radiologically to the medial and lateral ends and is not as profusely developed as in
the neonate.

Obviously, the presence of the nutrient foramen of this bone at the thinnest portion of the bone with the subsequent vacancy in the cortex may be correlated by means of the radiograph with a weakened condition in this portion. The x-ray vindication of an apparently weakened disposition of the third quadrant, however, must not detract from the observation that this region is prismatic in form and that its elements are arranged according to the maximal strength they impart.

The Scapula

The form of the scapula at birth (Fig. 12,13) may be regarded as a miniature of the adult bone. Though the lower angle, vertebral border, coracoid process, the lateral half of the acromion process, the lateral half of the neck and the entirety of the head of the bone are cartilaginous, the shape of these elements is the same as that of the adult. The bone at birth is more compact and relatively thicker when compared to adult specimens which generally are quite translucent in their flattened areas. The relative dimensions of the coracoid and acromion processes, and the distances between these
processes and the glenoid cavity are similar to that of the adult while the glenoid cavity is seemingly relatively larger in the neonate.

The neonatal scapula exhibits the same variations which have been demonstrated in the adult. In accordance with a general principle of osteogenesis, the variations present in early stages are less obvious than they are in the adult due to a smaller possible range of size variation and the relative absence of extrinsic formative forces related to muscular activity and orthograde posture. Close visual inspection of the bone, both of its osseous and cartilaginous parts allows the definition of the classic scapular types (Graves, 1910) and of the other descriptive features of the scapula (Hrdlicka, 1942).

The study of juvenile scapulae by Hrdlicka (1942) presents the following conclusions concerning the form of the scapula and its changes in form in later life:

"The whole evidence shows that the juvenile scapula is far from finished in its form, but that it changes in many respects during the growth, and perhaps even during the earlier adult period.

As the scapula is almost totally dependent on the muscles which are attached to it, it seems safe to conclude from the
above indications that much of the ultimate form which the body of the bone achieves is of functional nature and due to muscular activity.”

(Hrdlicka, 1942; pg. 85)

These conclusions are based upon the following data:

<table>
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<th>Percent Angular</th>
<th>Percent Concave</th>
<th>Percent Convex</th>
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<tr>
<td>Juvenile (22)</td>
<td>9.1</td>
<td>9.1</td>
<td>68.2</td>
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<tr>
<td>Adult, female (18)</td>
<td>77.8</td>
<td>5.6</td>
<td>16.7</td>
</tr>
<tr>
<td>Adult, male (29)</td>
<td>62.0</td>
<td>13.8</td>
<td>20.7</td>
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These data permit both of the above quoted conclusions. They also allow the observation that the angular variety increases with age; while the convex form decreases with age.

The present study demonstrates, however, that the maintenance of the cartilages of the scapulae during the preparation of the bones for this study allows for an entirely different interpretation of the age changes of the scapula. Had Hrdlicka preserved the cartilaginous portions of the scapula which he studied and limited the material to the neonatal stage, the results would have approximated the following obtained in the present study:
These data are surprisingly more similar to those which Hrdlicka found for the adult series rather than for his juvenile specimens. The percentage of the neonatal angular variety is identical with that of the adult female, while the percentage of convex types is identical with the percentages given for the adult male.

This similarity of form of the neonatal and adult scapulae completely negates the conclusion of Hrdlicka, quoted above, in that the neonatal and juvenile scapulae are quite similar to the finished adult form when the totality of the bone, both cartilaginous and osseous, is considered.

Other data presented by Hrdlicka (1942) tend to show that the scapula does change postnatally, for in his study of a large series of scapulae of both sexes from the United States, Germany, Italy, and other countries he obtained the following results:

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<tr>
<th></th>
<th>Percent</th>
<th>Percent</th>
<th>Percent</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Angular</td>
<td>Concave</td>
<td>Convex</td>
</tr>
<tr>
<td>Neonatal (60)</td>
<td>76.6</td>
<td>3.3</td>
<td>20.</td>
</tr>
<tr>
<td>Male scapulae  (1285)</td>
<td>41.3</td>
<td>10.7</td>
<td>37.8</td>
</tr>
<tr>
<td>Female scapulae (511)</td>
<td>49.3</td>
<td>9.0</td>
<td>30.7</td>
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</table>
Ten percent of the scapulae were too indefinite for classification. This quantity in consideration with the normal ranges of variation allow the data to be interpreted as similar to that of the neonate. Certainly it is evident (Fig. 10, 11) that the scapula at birth is very similar in form to that of the adult. The limited amount of change which can take place in the form of the scapula limits attempts to correlate scapular form to adult occupations as attempted by Fick, (1923).

The neonatal scapula exhibits none of the crista and other secondary bony markings typical of the adult bone. Whereas the vertebral border is cartilaginous, there is no osseous rim on the ventral surface of the vertebral border of the neonate. The axillary border of the neonate is rounded in contrast to the rather sharp border of the adult while it does bear the adult thickening of the bone along this border.

As in the adult, the neonatal axillary border is in reality a secondary border formed after the development of the "ventral bar" (Frazer, 1948), which parallels this border.

The adult scapula typically exhibits upper and lower borders along the dorsal spine which pass
superiorly and inferiorly at their junction with the vertebral border of the bone. These borders are absent in the neonate and the spine of the neonate is but slightly elevated at its junction with the vertebral border of the bone.

While the adult scapula bears evidence of the underlying relationships of the subscapularis and serratus anterior muscles to it, the neonatal scapula has neither the oristae typical of the adult subscapular fossa nor the flattened areas which are present at the angles of the adult bone due to the underlying digitations of the serratus anterior muscle. The major differences in the origin and insertion of the neonatal muscles which gain attachment to the scapula are as follows:

1. The serratus anterior muscle inserts into the cartilaginous portion of the vertebral border.

2. The insertion of the levator scapulae muscle is only into the inferior half of the supraspinatus portion of the vertebral border.

3. The origin of the subscapularis muscle is variable in relation to the cartilaginous portion of the bone. In the neonate, the origin of the subscapularis at the upper medial angle is lateral
to the cartilaginous rim while at the lower medial angle it passes over the cartilage and attains somewhat the same origin as it does in the adult.

4. The subscapularis muscle does not extend over onto the dorsal surface of the scapula in the neonate as in the adult; in the neonate the origin of the subscapularis muscle is limited to the osseous portion of the ventral surface of the scapula.

It has been proposed that the spino-glenoid ligament is formed by the fusion of the fascial sheaths of the supraspinatus and infra-spinatus muscles (Frazer, 1948). In the neonate there is little indication that this ligament is formed by such a fusion; the ligament is quite distinctly developed with little fascial relationship to these muscles.

The position of the major nutrient foramen is the same in the neonate as in the adult; likewise the diameter of the nutrient foramen is relatively similar, in that the foramen of the supraspinatus fossa is larger than that of the infraspinatus fossa. The number of nutrient foramina in the supraspinatus fossa is generally greater in the adult. The neonate bears only one nutrient foramen in this fossa.
The neonatal scapula is on the average 4.4 centimeters long and 3.3 centimeters wide. The acromion process is approximately 1.3 centimeters long while the spine and the acromion process together are 4.25 centimeters long. Its position in the neonate is similar to that of the adult excepting that the neonatal scapula is located at the level of the first and sixth ribs while that of the adult is located at the level of the second and seventh ribs. This elevation of the scapula in relation to the bony thorax is a topographical remnant of the descent of the scapula during the fetal period.

As in the adult there are two surfaces, three borders, and three angles on the body of the neonatal scapula. The costal surface of the neonatal scapula has a shallow sub-scapular fossa, lacks lineae musculares, and is covered by a heavy, thick periosteum. While the origin of the sub-scapularis is from the entirety of this fossa, it is restricted to the osseous portion of the costal surface excepting at the inferior angle of the bone which is cartilaginous in its lower centimeter.

The dorsal surface is convex as in the adult and is divided by the dorsal spine into two fossae, the supraspinous and infra-spinous. Contrary to
Frazer (1948), these are approximately proportionate in their size to the fossa of the adult (see osteometry). The origin of the supraspinatus muscle from the supraspinatus fossa is similar to that of the adult, and, as in the adult, it originates from the base of the acromion process and from the superior aspect of the spine of the scapula.

The infraspinatus fossa in the adult is alternately concave and convex. The convexity is due to the prominent "ventral bar" along the axillary border of the bone, which is smaller in the neonate, so that the infraspinous fossa is flatter than that of the adult. Both the convexity and concavity of the fossa are less marked in the newborn. The infraspinous muscle originates from the infraspinous fossa but lacks a fibrous attachment to the inferior surface of the dorsal spine. The origin of the teres minor is restricted in the neonate to a narrow region on the dorsal surface of the infraspinous fossa which parallels the axillary border. The origin of the teres major is from the middle third of the axillary border and dorsal surface of the cartilaginous portion of the inferior angle. The remainder of this surface inferior to the dorsal spine serves for the attachment of the infraspinous
muscle. Both the supra-spinatus and infra-spinatus muscles extend to the periphery of the cartilaginous vertebral border.

The notch of the scapular neck is similar in shape and position in both the neonate and the adult. In the neonate it is about four millimeters wide and is almost completely filled by the spino-glenoid ligament. Between the gleno-scapular ligament and the notch, the suprascapular nerve and accompanying transverse scapular vessels pass from the supra-spinous to the infra-spinous fossa. As opposed to the adult scapula, the vessels and nerves do not groove the neonatal scapula.

Of the three borders of the neonatal scapula, superior, vertebral, and axillary, only the vertebral is cartilaginous. The superior border of the neonatal scapula is thin as in the adult. It bears a scapular notch about one millimeter in depth, and the superior transverse ligament which bridges it, is well developed at this stage. As in the adult, the inferior belly of the omohyoid muscle originates from this ligament and from the superior border lateral to it. In the neonate, however, the origin of this muscle overlaps onto the ventral surface of the border more than onto the dorsal surface.
The vertebral border, which bears a cartilage one millimeter wide in its upper half and 2-3 millimeters wide in its lower half, is triangular in the neonatal. Its muscular attachments allow for the same topographical divisions of the vertebral border which have been in use for the adult. Thus, the levator scapulae muscle inserts into the vertebral border between the medial angle and the spine; the rhomboideus major at the junction of the spine with the border; and the rhomboideus minor into the border below the level of the spine. This later attachment is not by means of fibrous insertion of the muscle into the cartilaginous border as is true of the levator scapulae and rhomboideus major; rather it inserts by means of fibrous connective tissue which is attached to the cartilaginous border. The chief difference in the attachment at this border in the neonatal is found at the insertion of the levator scapulae muscle, which inserts into the lower half of the border above the spine, while in the adult the insertion is into the vertebral border above the spine.

The axillary border of the neonate lacks an infraglenoid tuberosity for the attachment of the long or scapulae head of the triceps muscle. The
superior sixth of the border gives origin to the long head of the triceps, while the remainder of the dorsal portion of the border gives origin to the teres major muscle. As the serratus anterior muscle overlaps onto the tip of the inferior angle, it gains a partial insertion onto the most inferior portion of the axillary border.

The medial angle of the neonatal scapula is either square or rounded, as in the adult. The lateral portion is cartilaginous where it is in continuity with the vertebral border of the bone. The anterior surface of this angle gives insertion to the fibers of the serratus anterior muscle.

The inferior angle presents all of the variant forms seen in the adult scapula. It, too, receives fibers of the serratus anterior.

The superior angle like other angles of the neonatal scapula, is cartilaginous. Most of the neck and all of the head of the scapula are also cartilaginous. The glenoid cavity is similar in shape and orientation as in the adult. The supraglenoid eminence is entirely cartilaginous and is continuous with the fibrous attachment of the tendon of the long head of the biceps muscle. The ligaments of the joint, while not conspicuously defined, are discernible in the neonate. The glenoid labrum is
from attachments only along the superior dorsal aspect of its circumference.

The spine of the scapula differs in the neonate in that definitive osseous superior and inferior flanges are about at its intersection with the vertebral border at the so-called apex, or "spinal point" (Hrdlicka, 1952), prolongations of these flanges are lacking along the vertebral border. The spine contributes to the formation of the supraspinatus and infraspinatus fossae as in the adult. Likewise both of these surfaces bear vascular foramina, which though singular in the neonate, are frequently compound in the adult. The trapezius inserts into the superior "flange" and the deltoid muscle originates from the respective superior and inferior "flanges" of the posterior border of the spine. The insertion of the trapezius in the region of the deltoid tubercle is identical with that of the adult.

The acromion of the neonate is similar to that of the adult in form, although only its lateral half is cartilaginous in the neonate. Contrary to most descriptions of this bone, the lateral portion is cartilaginous at birth (i.e., Morris, 1956). The
ossification of this cartilaginous portion later in life leaves only the articular surface as a remnant of the cartilaginous model. The superior surface is smooth and not roughened as it is in the adult although it gives origin to fibers of the deltoid muscle as in the adult. The inferior surface is smooth and concave as in the adult. Its apical portion gives origin to some fibers of the coraco-acromial ligament. Though present, there is no marked development of the subacromial bursa in the neonate.

The medial border of the acromion receives the insertion of the trapezius, while further laterally it bears the small oval articular surface for the clavicle. There is little concavity to this facet in the neonate and the border shows no premonition of any roughenings or elevations typical of the adult bone. The coraco-acromial ligament is attached to the medial border and tip of the acromion process.

The lateral border of the acromion in the neonate is smooth in contrast to the condition in the adult in which the border bears three or four tubercles with intervening depressions. At the neonatal stage there is no distinct indication of the prominent tendinous septa characteristic of
the adult deltoid muscle which are responsible
for the formation of the tubercles and depressions.

The coracoid process which is entirely
cartilaginous in the neonate follows the adult
form of an ascending and a horizontal portion.
The angulation of these two parts is at a right
angle as in the adult. The corac-humeral
ligament attaches to the lateral aspect of the
ascending portion, while the transverse scapular
ligament is attached medially. The conoid ligament
is attached to the superior surface of the ascend­ing
portion and a small portion of it passes onto
the medial border.

The horizontal part of the coracoid in
the neonate receives at the anterior half of its
medial border and over its superior aspect, the
tendon of the pectoralis minor muscle. The
trapezoid ligament occupies the superior aspect of
the posterior portion of this horizontal part. As
in the adult, the lateral border gives attachment
to the coraco-acromial and coraco-humeral ligaments,
however, this border in the neonate is cartilaginous
and smooth. The free apex in the neonate bears the
fibers of attachment of the conjoint tendon of the
coracobrachialis and the short head of the biceps
muscle. This process in the neonate does not bear
the roughenings of its surface which are distinctive
in the adult.

It is of value to list the significant
anatomical differences between the scapula of the
neonate and the adult:

1. The vertebral border is cartilaginous
and the serratus anterior muscle is restricted in its
insertion to this cartilaginous portion.

2. There is no specialization of structure
for the origin of the teres muscles.

3. The glenoid mass is cartilaginous.

4. The insertion of the levator scapulae
is only from the inferior one-half of the supraspinous
portion of the vertebral border.

5. The axillary border is rounded.

6. The coracoid process is entirely
cartilaginous.

7. The conoid tubercle is absent in the
neonate.

8. The glenoid tubercles are cartilaginous
in the muscle.

9. There is no ventral osseous rim on the
costal surface.
10. The origin of the subscapularis at the superior angle is lateral to the cartilaginous rim while at the inferior angle it passes over the cartilage and attains somewhat the same origin as it does in the adult.

11. The costal surface is not wide in relation to the digitations of the serratus anterior muscle.

12. The origin of the subscapularis muscle is limited to the osseous portion of the ventral surface of the scapula.

13. The subscapular fossa of the neonate is completely smooth and exhibits no secondary ridges.

14. There is no groove for the circumflex scapular vessels on the axillary border of the scapula.

15. The lateral half of the acromion process is cartilaginous in the neonate.

16. There are no distinct flanges on the upper and lower portions of the posterior border of the spine of the acromion and consequently there is no ridge at the meeting of the spine with the vertebral border in the neonate.

17. The ventral bar while forming the definitive lateral border of the bone in the fetus is in its adult position in the neonate, and the
lateral border of the neonate is in reality a secondary border.

18. In comparison with the scapula of the adult, the neonatal scapula may be considered as quite rugged in its structure. There are no thin areas such as occur in the adult.
Clavicular and Scapular Osteometry

The results of the measurements of the clavicles have been tabulated with the compilation of the mean, standard deviation, and coefficient of variation for the right and left sides and for the combined right and left sides. These measurements serve to set a standard for the size and dimensions of the clavicle at the end of gestation. They are indicative of the variation which is present in this sampling of the neonatal clavicle and demonstrates the nature of the population. The clavicle in the newborn stage exhibits the same pleomorphism which is characteristic of the adult clavicle as demonstrated by the overall high values of the standard deviation in comparison to the mean measurements of the bone. That the neonatal clavicle is even more variable than the adult bone is seen in the higher values of the coefficient of variation for the neonate. The statistics of Terry (1932) generally give variances for the adult clavicle which are almost one-half that which are reported herein for the neonate. In spite of this variation there is no major difference in the dimensions of the right and left clavicles. Bilateral dimorphism is easily accountable to errors of measurement, preparation, and natural intrinsic size differences.
The variance in the time of interception of the rapid development in utero by the birth process and the variable rate of growth in this period combine to present a wide range of size not only in overall development of the neonate but also in the parts of the newborn as well. The variability of the bones in the neonate must be associated with the fact that the individual bones normally grow in constant relation to the total body growth (Potter, 1956). The variability of body size is much greater at birth than in the samples of the adult population generally used in osteometric mensuration. One is not surprised to find therefore that the dispersion of the neonatal clavicular measurements is large in the neonate. The measure of this dispersion, the range, is indicative of the largest and smallest values occurring in this sample. In the present population under study the lower values seem to be concentrated in a few individuals which are included in the neonatal classification by minimal adherence to criteria previously cited.

The standard deviation (s) was calculated by the machine formula:
While the standard deviation will measure the absolute dispersion within the series, a measure of the relative dispersions within the group may be calculated by the establishment of the coefficient of variation, \( V \).

\[
V = \frac{S}{\bar{X}}
\]

This coefficient is usually expressed as a percentage.

The use of the above statistical methods allows for the formulation of the expected values to be found in populations on neonatal clavicles and scapulae. The nature of the biological variation of these bones will limit the use of the date for the absolute establishment of age of the individual bone. An additional restriction of the date is the lack of correlation of the major osteometric measurements with the body length of the neonate. The nature of the material obtained has limited the use of correlation of these major measurements with the body weight. The body weight of the neonate is a variable which is correlated with the general growth pattern of the neonate and is presumed to bear the same relationship to the major osteometric measurements as was observed with body length.
As mentioned previously, the scapulae at birth exhibit the same pleomorphism which is characteristically found in the adult scapulae. There are no coefficients of variation in the literature to enable a comparison of the variability expressed by adult and neonatal scapulae.
Osteometry of the Neonatal Clavicle

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<th></th>
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<th>LEFT</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
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<td>152.23</td>
<td>149.42</td>
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<tr>
<td>Standard Deviation</td>
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<td>6.08</td>
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<tr>
<td>Coefficient Variation</td>
<td>7.63</td>
<td>5.94</td>
<td>4.06</td>
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<tr>
<td>Range</td>
<td>131°</td>
<td>140° - 171°</td>
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</table>

**LATERNAL ANGLE:**

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<tbody>
<tr>
<td>Mean</td>
<td>138.69</td>
<td>140.56</td>
<td>139.58</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>8.17</td>
<td>8.00</td>
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<td>Coefficient Variation</td>
<td>5.89</td>
<td>5.94</td>
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<tr>
<td>Range</td>
<td>122° - 159°</td>
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</table>

**INDEX OF CURVATURE:**

<table>
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<tr>
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<th>RIGHT</th>
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<tbody>
<tr>
<td>Mean</td>
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<td>292.80</td>
<td>289.17</td>
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<tr>
<td>Standard Deviation</td>
<td>13.00</td>
<td>10.35</td>
<td>12.09</td>
</tr>
<tr>
<td>Coefficient Variation</td>
<td>4.54</td>
<td>3.53</td>
<td>4.18</td>
</tr>
<tr>
<td>Range</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Osteometry of the Neonatal Scapulae

HEIGHT:
Mean 4.4 cm.
Standard Deviation .56 cm.
Coefficient of Variation 12.7%
Range 3.6 - 5.4

BREADTH:
Mean 3.4 cm.
Standard Deviation .10 cm.
Coefficient of Variation 12.2%
Range 2.7 - 4.0

LENGTH OF AXILLARY MARGIN:
Mean 3.5 cm.
Standard Deviation .43 cm.
Coefficient of Variation 12.2%
Range 2.6 - 4.2

LENGTH OF THE SUPERIOR MARGIN:
Mean 2.4 cm.
Standard Deviation .54 cm.
Coefficient of Variation 22.5%
Range 1.8 - 3.1

LENGTH OF THE INFRASPINOUS FOSSA:
Mean 3.5 cm.
Standard Deviation .52 cm.
Coefficient of Variation 14.8%
Range 2.8 - 4.2

LENGTH OF THE SUPRASPINOUS FOSSA:
Mean 1.7 cm.
Standard Deviation .55 cm.
Coefficient of Variation 32.1%
Range 1.1 - 2.4

LENGTH OF THE SPINE:
Mean 4.2 cm.
Standard Deviation .53 cm.
Coefficient of Variation 14.4%
Range 3.3 - 4.9

LENGTH OF THE BASE OF THE SPINE:
Mean 2.4 cm.
Standard Deviation .28 cm.
Coefficient of Variation 11.5%
Range 2.0 - 2.9

HEIGHT OF THE ACROMION PROCESS:
Mean 1.3 cm.
Standard Deviation .22 cm.
Coefficient of Variation 16.4%
Range 1.0 - 1.7
LENGTH OF THE ACROMION PROCESS:
  Mean 1.6 cm.
  Standard Deviation .33 cm.
  Coefficient of Variation 19.5%
  Range 1.1 - 2.2

LENGTH OF THE CORACOID PROCESS:
  Mean 1.4 cm.
  Standard Deviation .22 cm.
  Coefficient of Variation 14.9%
  Range 1.1 - 1.9

LENGTH OF THE GLENOID CAVITY:
  Mean 1.0 cm.
  Standard Deviation .21 cm.
  Coefficient of Variation 19.0%
  Range .9 - 1.4

BREADTH OF THE GLENOID CAVITY:
  Mean .76 cm.
  Standard Deviation .14 cm.
  Coefficient of Variation 18.4%
  Range .6 cm. - .9

AXILLO-SPINAL ANGLE:
  Mean 46.8°
  Standard Deviation 7.61°
  Coefficient of Variation 16.2%
  Range 39° - 55°

AXILLO-GLENOIDAL ANGLE:
  Mean 138.7°
  Standard Deviation 8.24°
  Coefficient of Variation 5.04%
  Range 125° - 151°

SUPERIOR ANGLE:
  Mean 98.2°
  Standard Deviation 13.34°
  Coefficient of Variation 13.58%
  Range 75° - 139°

INFERIOR ANGLE:
  Mean 47.0°
  Standard Deviation 5.96°
  Coefficient of Variation 12.6%
  Range 34° - 58°

MEANS OF SCAPULAR INDICES:
  Scapular index .781
  Infraspinal index .79
  Supraspinal index .38
  Marginal index .79
  Spinal Fossa index .48
  Length/Breadth index of the glenoidal cavity .78
  Length/Circumference index 26.38
DISCUSSION

The neonatologist is in a favorable position not only to draw conclusions from the newborn material itself, but also to compare the newborn state with embryonic and fetal conditions. Likewise he is able to make comparisons of newborn morphology with detailed anatomical knowledge of the adult body. The interpretations made possible by the comparisons of these different stages enables the neonatologist to present a more complete idea of the changes of form and structure throughout the entire developmental period of the individual from conception to maturity.

The synthesis of a longitudinal concept of an anatomical structure from embryological, neonatological, and adult studies is not without difficulty. The techniques of study used at these various stages must be accommodated to the differences in size, shape, structure and relationships which accompany growth and development at the stages studied. Since the results of research in these different stages are used for many purposes, which may be foreign to each other, their application to the newborn often will result in the amalgamation of ideas from many fields of research such as embryology, gross anatomy, anthropology, histology, obstetrics and pediatrics.
NEONATAL CLAVICLE

Comparison of Pre-natal with the Neonatal Clavicle

The establishment of a valid scientific theory of newborn morphology requires a thorough description of the anatomical features of the neonate. From this description, the differences and similarities of the neonate and the fetus may be established. Thus, for example, in the case of the clavicle Brandt (1935) describes its status in fetuses of crown-rump length varying from 9.8 centimeters to 22 centimeters. He studied eighty right clavicles which he classified into the following groups:

<table>
<thead>
<tr>
<th>Group</th>
<th>Crown-rump Length</th>
<th>Clavicle Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>9.8-14.3 cm.</td>
<td>1.6-2.0 cm.</td>
</tr>
<tr>
<td>Group II</td>
<td>13.4-16.0 cm.</td>
<td>2.1-2.5 cm.</td>
</tr>
<tr>
<td>Group III</td>
<td>16.2-22.0 cm.</td>
<td>2.6-3.0 cm.</td>
</tr>
</tbody>
</table>

In addition to a correlation of clavicle length with crown-rump length, he also noted change in the form of the clavicle in these groups. He found that in group I the clavicle was predominantly "S" shaped; in the second group there was a decrement of the "S" form, while in the third group the "axet-type" clavicle form is
The transition consisted of straightening of the central axis of the sternal half with a subsequent decrease in its curvature. The "change in elevation" is mathematically expressed as a shortening of the greatest sternal and acromial distance between the central and horizontal osteometric axes. The "S"-shaped type is correlated with a greater sternal elevation, while the "axe-shaped" type with a smaller sternal elevation. In determining these elevations the anterior border rather than the central axis was used. Gardner (1956) concurs with Brandt regarding the occurrence of the "S" shaped clavicle. Brandt noted a straightening of the posterior border of the fourth quadrant in the transition from the "S" type to the "axe-shaped" type.

In the present study the neonatal clavicle was found to exhibit typically the straight type of posterior border. The change in shape noted by Brandt was observed in only thirty-one per cent of the neonates. The occurrence of the "S" shape, in the adult, as claimed by Parsons (1913), is further evidence that this shape is characteristic not only of the neonate but also throughout later post-natal stages of development.

The neonatal clavicle has advanced in thickness at the midpoint from its fetal dimensions as seen
in the increasing value of the vertical diameter.

Brandt gives the values of the sagittal diameter for his three groups as .12 mm, .14 mm, and .18 mm. In the present study of the neonatal clavicle this value was found to be .29 mm. (Fig. 9B).

In Brandt's group three the ratio of the mid-point depth to the length of the bone is 1:15.88. Since the value of this ratio is 1:15.44 for the neonatal clavicle it would appear that there is a slight change in the relation of length to girth of the bone during the latter part of its development. However, the growth of the bone in length and width is proportionate, as is shown by the equality of these two ratios.

Comparison of the neonatal osteometry with that of the adult, which was determined by Terry (1932), shows that this ratio maintained throughout post-natal development and is very stable.

In the following table is an analysis of the results reported in the present study and those by Brandt:

<table>
<thead>
<tr>
<th></th>
<th>Brandt Group I</th>
<th>Brandt Group II</th>
<th>Brandt Group III</th>
<th>Newborn Present Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>mid-point sagittal</td>
<td>.12</td>
<td>.14</td>
<td>.17</td>
<td>.29</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>clavicular length (cm)</td>
<td>1.8</td>
<td>2.3</td>
<td>2.7</td>
<td>4.48</td>
</tr>
<tr>
<td>sagittal diameter</td>
<td>15.0</td>
<td>16.4</td>
<td>15.88</td>
<td>15.44</td>
</tr>
<tr>
<td>length index</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The peak of the ratios of the sagittal diameter to the length is reached when the clavicular length attains 2.3 centimeters (Brandt group II), after which the ratio is followed by a subsequent decline. In view of the relative smallness of this change the interpretations may be made that after the mature shape of the clavicle is reached, the bone undergoes little change in its relative proportions.

The mean weights of the clavicle in the three groups studied by Brandt (1935) were 25, 50, and 89 grams. The weight increase from the first to the second group was two times and from the second to the third group, 1.78 times. In the present study it was found that the mean weight of the neonatal clavicle is 705 milligrams, showing an accretionary rate of 7.92. When these weights are related to the length of the bone in the fetus, as determined by Brandt (1935) the results are as follows:

<table>
<thead>
<tr>
<th>Brandt Group</th>
<th>Brandt Group</th>
<th>Brandt Group</th>
<th>Neonatal</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>II</td>
<td>III</td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td>25 mg.</td>
<td>50 mg.</td>
<td>89 mg.</td>
</tr>
<tr>
<td>length</td>
<td>1.8 cm.</td>
<td>2.3 cm.</td>
<td>2.7 cm.</td>
</tr>
<tr>
<td>index</td>
<td>.072</td>
<td>.046</td>
<td>.050</td>
</tr>
</tbody>
</table>
The weight/length index is seen to decline through the period of intrauterine existence (Fig. 9A). The weight/length graph for the fetal and neonatal clavicle assumes the shape of a typical curve of growth. There is, however, only the duplication of the initial portion of the curve in which the rate of acceleration of growth is the greatest.

It may be concluded from these observations that the pre-natal clavicle changes in form during its intra-uterine development. This change is not entirely completed by birth, as it is observable in a small percentage of neonates, while generally the gross form of the bone is established by the 22 cm. stage.

The osteometric data show a homogeneity in the general range of values for the coefficient of variation. It may be deduced from these data that there is a variation of about thirteen percent in the measurements of the newborn clavicle. Future analysis of the other bones in the neonatal skeleton should be correlated with these data. The variability of the neonatal clavicle ranges from 4.06 percent in the measurement of the medial angle to 23 percent in the measurement of the width at the conoid tubercle. The mean variability for the sixteen measurements and indices employed is 12.96. This is a high value when
compared with that computable from the results of Terry (1932) in which the value of the mean variability for the adult clavicle is 8.67.

**Comparison of Neonatal Clavicle to the Neonatal Femur**

In the only modern study of the bones of the neonatal extremities, Ingalls (1928) found that the mean variability of the femur in the neonate is 4.87 while that of his adult femur series was 6.43. These data apparently lead to the conclusion that the adult clavicle is more variable in its morphology than the femur. However, there is an inverse relationship in the development of this diversity. While the variability of the clavicle decreases from the newborn to the adult stage, the mean variability of the adult femur increases. It may be assumed that the basis of this difference in development lies in the functional adaptations which occur in these two bones. Whereas the femur is a bone which undergoes changes in its form to serve the functions of locomotions and support, the clavicle remains throughout its existence as a bone serving for muscular attachment and as a brace which tends to restrict movement of the scapula. The role of the extrinsic factors which regulate the remodeling of bony architecture seems
to be acting in two different directions in these two bones. In the clavicle there is a tendency towards a more permanent form, while the femur tends to become more diverse in its morphology in post-natal life.

Ingalls (1927) found that there was a rather marked difference in the relative variability of the different parts of the adult femur, the epiphyses being the most constant part of the bone while the diaphysis was the most variable. Only faint indications of such variability of this bone was exhibited in neonate, in which Ingalls found that the least, as well as the most variable, features were diaphyseal in character; epiphyseal characteristics being somewhat scattered.

A comparison of the data presented in this study with those of Ingalls is restricted by the nature of the material. For example, the epiphyses of the neonatal clavicle are very minute and in no way reach the relative dimensions of those of the neonatal femur studied by Intalls. Even so, it should be noted that the variability of the ends of the neonatal clavicle generally is greater than
that of the shaft of the bone. The measurements of the shaft, particularly in terms of maximum length, circumference at the mid-point, and its angles are restricted in their variability when compared with the higher values of the coefficient of variation found in the measurements of the ends of the bones. Inasmuch as the ends of the clavicle undergo a greater relative remodeling than the shaft, this result may be expected.
Racial and Sexual Differences of Clavicle

Two measurements are less variable in their coefficients of variation; namely, the maximum length of the clavicle and the circumference of the bone at its mid-point. The constancy of the development of the length of the bone is significant as shown by Parsons (1913) who found a sexual difference in the length of the clavicle, that of the male generally being lower than that of the female. Terry (1928) noted that the difference in the length of the clavicle of the American Negro and that of whites may possibly be significant. From the present series it seems reasonable to assume from the constancy of the length of the clavicle that such a difference does not exist at birth. Likewise the finding by Parsons (1913) of a marked sexual difference in the circumference of the adult clavicle probably cannot be related to a difference at birth due to the small amount of variation shown by the osteometric values of the neonatal clavicle. However, comparisons on a larger sample of bones than analyzed in this study may show significant sexual differences which are not perceivable in the present series. Terry's finding (1932) of a difference in the width of the acromial
extremity of the clavicle of the American Negro, and whites may account for the high degree of variation in the measurements of the medial end of the neonatal clavicle in this series of mixed races and sexes. There is no basis, however, from the studies of Terry, for supposing that the racial factors may cause variability in other measurements of the neonatal clavicle. They may be ascribed to the inherent variability of the series and the subject material.

Angulation of Neonatal Clavicle

The results of the measurement of the angulation of the neonatal clavicle show that the medial angle is larger than the lateral angle as it is in the adult. But contrary to the studies of Terry (1932) on the adult, the medial angle in the neonate is more variable than is the lateral angle. There is approximately a ten degree difference in these two angles; the medial angle is generally 149 degrees while the lateral angle is about 139 degrees. Likewise in the adult there is a similar ten degree difference in these two angles; the means being 142 for the lateral...
angle and 152 degrees for the medial angle. The absolute difference in the angles is only in the realm of three degrees. It is not surprising then to find that the index of curvature, which is approximated by the summation of these two angles, is but six degrees higher in the adult (292.26 mean) than in the neonates.

Another remarkable similarity in the measurements of the angulation of the clavicle is found in the comparison of the means of the right and left sides. In the present neonatal series the medial and lateral angles on the left side were found to be larger than those on the right side. Of course, the index of curvature for the left side was larger than that on the right. It is interesting that Terry (1932) likewise found a similar situation on the adult clavicle, namely a higher index of curvature on the left side.

No date exist for the angulation of the clavicle during its embryonic and fetal stages. The maintenance of the primitive form of the clavicle is well demonstrated by the very slight changes (three and seven degrees) which take place in this characteristic from birth to adulthood. While this difference is summed in the comparison of the indices of curvature, the difference of six percent is still very small.
**Length-circumference Index**

It is not in these measurements of angulation alone that the neonatal clavicle approximates an adult morphology. The calculation of the length-circumference index (circumference x 100/maximal length of the clavicle) reveals similar results for both the neonate and the adult. The mean of the length/circumference index in the adult as established from the figures of Terry (1932) is 25.24, while that for the neonate is 26.30. The neonate is much less variable in this index than is the adult. However, in both groups there is no significant difference between the right and left sides.

**Clavicular Chords**

It is possible to measure the distance from the horizontal or osteometric axis to the point of greatest curvature of the bone which is furthest from the osteometric axis in a perpendicular direction (Brandt, 1935, Fig. 5). This distance is termed the chord. There is the possibility of two chords in the osteometry of the clavicle due to its double curvature. Brandt (1935) has noted that the acromial chord is always present in fetuses ranging in size from nine to twenty-two centimeters in crown-heel length.
Furthermore, with the assumption of an "axe-shape" in the group from sixteen to twenty-two centimeters, there is an increase of the acromial chord and a disappearance of the sternal chord in the older specimens. This is merely an osteometric method to describe the straightening of the sternal half of the clavicle.

In the present series of neonatal clavicles the acromial chord is present in all of the bones studied. In 69 percent of the neonatal clavicles the stern chord reappears and is present in the clavicles of adult whites (Parsons, 1913). Although there are no data for the negro clavicle, the representatives illustrated by Terry (1913) do show its presence.

The absence of the sternal chord in the older series studied by Brandt (1935) is undoubtedly representative of a transitory stage in the morphogenesis of the clavicle.
Classification of Clavicles

Clavicles have been classified according to the position of intersection of the horizontal or osteometric axis and the true or central axis of the bone. When this intersection occurs to the eternal side of the mid-point of the bone, the bone is classified as "sternopetal"; when the intersection occurs to the acromial side of the mid-point of the bone, it is classified as "acromiopetal" (Rudinsky, 1929, Fig. 12). Rudinsky applying this classification to the clavicles of embryos and adults, reports the following results:

Embryo (5-22 cm.)

<table>
<thead>
<tr>
<th>Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>sternopetal</td>
<td>69.3%</td>
</tr>
<tr>
<td>intermediate</td>
<td>12.8%</td>
</tr>
<tr>
<td>acromiopetal</td>
<td>17.9%</td>
</tr>
</tbody>
</table>

Adult

<table>
<thead>
<tr>
<th>Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>sternopetal</td>
<td>30.0%</td>
</tr>
<tr>
<td>intermediate</td>
<td>19.0%</td>
</tr>
<tr>
<td>acromiopetal</td>
<td>51.0%</td>
</tr>
</tbody>
</table>

The results from the compilation of these statistics from the neonatal series under study are as follows:

Neonate

<table>
<thead>
<tr>
<th>Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>sternopetal</td>
<td>36.0%</td>
</tr>
<tr>
<td>intermediate</td>
<td>62.2%</td>
</tr>
<tr>
<td>acromiopetal</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

The discrepancy in these results is more apparent than actual. The intermediate type of clavicle is distinguished arbitrarily by Rudinsky as the form of the clavicle in which the sternal chord equals the acromial chord. Reference to the results
presented by Rudinsky demonstrates that there is a normal distribution of the values with some skewness to an increased size of the sternal chord. It is apparent that in the newborn the same condition exists. The arbitrary separation of the types according to this system merely confused the fact that the intersection of the true and osteometric axes of the neonatal clavicle is generally at or near the mid-point of the bone.

It should be pointed out that this classification of the neonatal clavicle emphasizes essentially the presence of the sternal chord of the bone, (Brandt, 1935). Since the intermediate type of Rudinsky is determined by the proportionality of sternal and acromial chords, the presence of the sternal chord is naturally necessary for its establishment. So as the sternal chord occurs in 69 percent of the neonatal clavicles, the intermediate type of clavicle occurs 62 percent of the time. Likewise its absence in 31 percent of the neonatal clavicles compares with the finding of 36 percent of the sternopetal type of clavicles in this study.
Bi-acromial Diameter as Related to Clavicle

The measurement of the bi-acromial diameter may be correlated with the growth of the clavicle. The bi-acromial diameter is the length of a straight line in the transverse plane between the most lateral points of the acromial eminences of the growing fetus. Since it is the clavicle that helps to maintain the lateral position of the scapula, which lies in the anatomical plane of this measurement, it is interesting to study the growth of this diameter. The dimension is not affected by formalin artefacts in contrast to the measurement of the bi-deltoid diameter which changes seven percent in the first month (Scammon, 1929). This is a further indication that the measurement of the bi-acromial diameter is essentially based upon osteological factors, particularly the dimensions of the clavicle.

According to Scammon and Calkins (1929) the bi-acromial diameter bears a linear relationship to the crown-heel length. The major deviations from this relationship occur in the group of neonates. The range of the diameter for the neonates studied is from 10.7 to 12.2 centimeters. The extensiveness
of this range correlates well with the range of coefficients of variability demonstrated for the neonatal clavicle. While Scammon associated "these high terminal variations" with the effect of birth moulding upon the shoulder girdle, the data do relate well to the variation observed in the present study of the clavicle. Methods for determining the bi-acromial diameter generally are made with the shoulders abducted so as to minimize any birth moulding which may occur.

The establishment by graphic presentation of the change in the means of clavicular lengths to the crown-heel length of the fetus (Brandt, 1929) and newborn allows duplication of the graph presented by Scammon and Calkins (1929) for the bi-acromial diameter. When the same method of five centimeter intervals is employed in both graphs, the slope of the two graphs is nearly the same (Fig. 4). The only possible deviation to be expected may be present in the smaller fetal lengths.

The measurement of the bi-acromial diameter may be related to the length of the clavicle in the subject measured. The basis for this lies not only in the anatomical factors involved but also in the
similarity of the deviation of the bi-acromial diameter, the close resemblance of the graphs of the bi-acromial diameter and the mean length of the clavicle to crown-heel length. It may be concluded from these comparisons that the fetal clavicle grows in a harmonious relationship to the size, dimensions, and form of the thorax. Noback (1944) noted that at the time of birth, the cartilage bones, with the exception of the ribs, have not reached proportionate forms. It is logical to assume that during the development of the neonatal clavicle it not only grows in harmony with its future adult form but also grows in unison with the ribs throughout the fetal period. This is evident when a comparison is made of the agreement in growth rate of the bi-acromial diameter with the diameters of the growing fetal thorax (Scammon and Calkins, 1929, Fig.42).

The entire period of growth of the ribs and the clavicle may be placed, according to the classification of Noback (1943), in the "period of construction" during which the linear osseous growth rate increases approximately equally to that of the body segment with which it is associated. The adherence of the clavicle to linear osseous growth and to growth proportionate to the fetal thorax is demonstrated graphically (Fig.2).
Bony Markings on Neonatal Clavicle

The deltoid muscle attachment which is the sole distinctive bony marking for muscle attachment of the clavicle at birth, can be distinguished as a series of small ring-shaped depressions on the anterior border of the lateral quadrant. Throughout development this border and its tuberole change in shape and form. At the time of birth the depression is enlarged and well defined. Later in life the bony marking is drawn out to form a tubercle, which generally bears a concave surface in the adult. However, there is granularity on other surfaces of the bone which are associated with muscle attachments. The fetal clavicle lacks all other specializations of the surface; the neonatal clavicle in contrast shows the beginnings of nearly all of the adult surface characteristics, with the exception of points of attachment for the conoid and trapezoid ligaments. These pits are developed later in the more mature stages of osteogenesis. In several instances the neonatal clavicle was found to contain perforations for the supraclavicular nerves which are similar to those sometimes present on the adult bone.

The amount of epiphyseal cartilage present
on the sternal end of the newborn clavicle is usually greatly over-estimated (Fig. 7). This is due to the appearance in anatomy texts of illustrations of this bone, which though supposedly representing the neonatal stage, in reality depict the bone at seven and eight months of age (Piersol, 1907) (Renauld and Renier, 1887). Throughout the early months of development of the clavicle an appreciable amount of cartilage is present at the epiphysis but diminishes so that at the time of birth it is extremely thin.
Stability of Form of Neonatal Clavicle

During the growth period from 10 to 22 centimeters (crown-heel) the clavicle assumes a form which persists throughout the fetal period. The change in form is from an extremely curved "S" shape to the more mature "axe-shape" which is reached by the middle of the fetal period when the bone has passed its greatest rate of development. At the time of birth the clavicle has already assumed its mature form. This quality of form is seen in the entire series of bones. It does not exclude the variability of the surfaces, angles, and borders for the single individual bone. The data available and the study of the form of the neonatal clavicle allows the conclusion that in the relationship of the horizontal axis and the diameter of the bone there is a constant growth occurring which is essentially the same during the latter half of development in utero. In its growth this bone retains the same three dimensional form during the major portion of its existence. The bone seems to be extremely conservative during the developmental change in certain of its osteometric indices such as length-width, length/circumference.
In the values of the medial and lateral angles, and their sum, the index of curvature, there is a similar stability of form which is even more constant. The study of this material permits such a conclusion, but an individual serial study would provide more positive proof of this phenomenon. The method of compilation of the means through various age groups has been the usual method for the substantiation of growth phenomenon since vertical studies of individuals are expensive and difficult to perpetuate in human population.

The overall increase in the length, width, and thickness of the bone which occurs throughout the stages of its metamorphosis does not affect its general form, with the exception of changes at the ends of the bone, in that the rather massive features of these parts become reduced, as is typical of a growing long bone. The predisposition of the bone to this change has been noted in the radiographs.

When a comparison is made of this index from the time of its earliest recognition to the adult stage, an even more striking conservation of the index is evident. Brandt (1935) finds an index
of 15.0 for the clavicle of mean length of 1.8 centimeters while Terry's report (1932) yields a value of 14.20 for the index for clavicles the mean length of which is 14.98 centimeters (Fig. 9). It is evident, therefore, that the clavicle increases its length some 830 percent, while the index changes only seven percent at a maximum.

**Factors Determining Form of Clavicle**

The gross form of developing bones is under the direction of factors which are intrinsic. This has been known for a relatively long period of time (Braus 1909, 1910; Brandt 1927) with work on grafts, and in tissue culture work (Fell and Conti, 1934). These factors have been acknowledged to be insufficient in themselves to explain entirely the development of a functional skeleton. Thus, deviations from the norm in which extrinsic forces, such as the growth pressure of neighboring parts, are lost or displaced result in an abnormal model. It has been found that the intrinsic forces are determinative in the early stages, while the extrinsic factors change their role from relatively passive
modifiers in these early stages to active molders of the adult form in the later stages. As regards a bone, such as the clavicle, in which its definitive form is maintained throughout the major part of life, several conclusions may be reached in accordance with the above theory.

The intrinsic factors regulating the form of the early fetal model of the clavicle are the most important in the formation of the embryonic, fetal, and post-natal form of the bone. The role of the extrinsic factors governing the morphology, such as formation of tubercles and grooves, cannot be minimized.

With reference to the extrinsic and intrinsic developmental factors which govern the shape of the clavicle, a modern theory of the varying relative importance of these factors should be considered. It is possible that the seemingly greater role of intrinsic factors in the development of the clavicle may be related to the anatomical position and functional role of the bone. While the clavicle certainly undergoes internal and external strain by virtue of its muscular attachments and because of its role in the limitation of motion of the upper extremity, nevertheless, it does not serve to transmit much of the
stress of body activity, i.e., the maintenance of the orthograde posture. In this regard it is unlike the calcaneus, the outer and inner architecture of which depend upon conditions of stress encountered in normal stance and gait for proper development (Weidenreich, 1922).

In the study of the clavicle one is lead to the conviction that the clavicle retains a primitive or embryonic form. The basis for such beliefs are the established facts that it is the first bone to form a trabecular system (Brandt, 1935); it accompanies the dermal bone of the mandible in initial development of an ossification center (Hanson, 1919), and it assumes its morphological characteristics early in development. However, in comparison with the mandible there are several significant differences in post-natal development. The mandible after birth undergoes marked changes in shape and dimensions due to the influence of the forces of mastication (Logan, 1935) and is an exception to the rule that bones formed earliest in gestation are relatively stable in their morphology. In this regard it is not to be inferred that the
clavicle is not affected by muscular and other external forces. In the case of the clavicle, these forces are effective primarily in the alternation of the bone externally and apparently mechanical forces allow for its increased growth of size without inducing change in general form, atrophy, or hypertrophy. However, it seems that the conservative nature of the form of the clavicle undoubtedly limits its adaptability to new stresses and strains.

Although this bone is characteristically pleomorphic, when group comparisons are made (Strauss, 1939), the individual bone is quite homogeneous in its general form. It may be regarded as a structure, which, though subjected to a multiplicity of forces, is nevertheless unlike other bones which meet new tensions and pressures with a characteristic change in structure. Wolff's new law of transformation of structure to meet new demands of function is not greatly exemplified by the clavicle for its static nature apparently is based on an early development of the architecture and form of the bone which is already adapted to the environmental stimuli which later play upon it. The perfection of this condition which
might be termed -ontogenetic preadaptation - is exemplified by the static nature of the bone throughout its growth and supports the hypothesis that mechanical stresses and strains are not the principal factors which govern its morphology.

The development of the architecture of bone is generally considered in two phases: a primary phase which is intrinsic in quality and a secondary phase which the definitive architecture is formed (Murray, 1936). This secondary phase is thought to occur either directly or indirectly in response to a pattern of mechanical stress. The presence of the secondary pattern in the pre-natal clavicle is opposed to the assumption that this pattern, which is a miniature replica of the adult bone, is exclusively a product of mechanical stress. Weidenreich (1923) regarded the mechanical stimulus as being mediated through the vascular system of the bone. He believed that changes in the caliber of the blood vessels reach expression in alterations in the architecture of the bone. It is possible, of course, that the mature status of the neonatal clavicle is due to the existence within it of a vascular system, the pattern of which
would result from tension and strain of mechanical forces.

On the other hand it might be argued that the intrinsic factors governing the development of the primary phase of the clavicle may induce a general form of the bone (secondary phase), which in turn determine the amount and nature of the mechanical forces which play upon it. It should be pointed out that, if such is the case, only bones in the anatomical position of the clavicle could be of such a self-determinative nature.

Perhaps the best example of the maintenance of the general form of the clavicle throughout development is the constancy of the index of the diameter to the length (Fig. 4). As previously discussed this index changes very little during the intra-uterine period. A compilation of the means for this index from the work of Terry (1932), in which there are data for negro males and females and only white males, results in an index of 14.29. This index was found to be 15.44 in the neonate so that there is a deviation of approximately seven percent during the entire post-natal life.

Viewed in the light of the growth in length of the bone some four times its length at birth,
and, with the acknowledgment of post-natal forces such as muscular forces acting upon it, the fact that this index is maintained is remarkable. The forces or factors of resorption and apposition effect the bone as if there was a strict inner control of their action.

The conservative quality of the clavicle can be seen in the form of the bone. In the comparison of the gross form of the bone it is possible to find in the adult the four external regions which are described for the neonate clavicle. The alternation of prismatic, flattened prismatic, and flatter quadrants is, with few exceptions, the pattern which occurs in all stages of the post-natal growth of the bone.

The clavicle resembles a growing tubular bone in that it shows a reduction in the relative size of its ends. However, this change in the neonatal condition is minimal in comparison to the reduction of the epiphyseal size which occurs in the other long bones such as the humerus and the femur.
Classification of the Bones of the Newborn Skeleton

The bones of the developing skeleton can be classified as to the time of appearance of their adult morphology. The calcaneus is an example of a bone that is slow in the assumption of the adult form, and, since it is partially cartilaginous at birth, it fails to exhibit the adult form at this time. It may be categorized as a bone which requires the action of mechanical forces for its development. Such bones show no anticipation of the adult form in their neonate morphology. As contrasted to the clavicle, in this class of bones the secondary forces are of greater import in the establishment of the final form of the bone, for which reason such bones may be called "post-natally mechanically determined" bones.

An intermediate classification is exemplified by the neonate femur, which is partially demonstrative of the adult condition (Ingalls, 1927), in that it is a miniature model of the adult bone but which undergoes some structural modification during its post-natal growth. It is only secondarily affected by the extrinsic factors in its fetal existence. However,
with the advent of actual use and active functioning, these same external forces, such as muscle pull and tension of ligaments, cause decisive post-natal changes in the morphology of the bone, which are adaptive in nature. From the studies of Ingalls (1927) it might be expected that bones of this class are relatively restricted in their variability at birth but that the variability increases with its modification brought about by post-natal external forces. Such bones may, therefore, be called "bones of compromise" in that their adult form is a compromise of pre-natal and post-natal forces.

The clavicle at birth exemplifies a third class of neonatal bones, since its morphology is already fixed at birth and undergoes little change in form during the post-natal period. The adult morphology of this bone is present at birth, the only essential post-natal changes being increments in the size of the bone in its later life.

To relate this classification to neonatology is relatively simple and is a concept that has not been stated previously in the literature. The establishment of a comprehensive neonatology in the future will demand that the attention of the
neonatologist be focused not only upon the neonate as a stage in man's life history, but also that the neonate be studied in relation to its past and future growth and development. In such a study two approaches are possible by the morphologist; either a traditional study can be made of the gross anatomical structures of the neonate in a biometrical study of the characteristics of its structure. Thus, for example, a study of the neonatal clavicle with the view to determining the presence of its bony markings may be an objective while a statistical analysis of such features as its angulations may constitute another objective.
Neonatal Patterns of Growth

Other structures and characteristics of the neonate may be classified in somewhat the same manner as neonatal bones. While the neonate is adapted mechanically to parturition and is equally well adapted to post-natal existence, its structure and characteristics are not homogenous in the range of development exhibited. The neonate exhibits some effects of the cranio-caudal growth axis and is well cephalized. These fundamental patterns of growth in the newborn are not without exception. Indeed, the skeleton at this stage, and at even earlier stages of development, shows discrepancies from total or organismic patterns of growth, in which the morphology is related to the development of regional characteristics (Noback, 1943).

So it is that in the neonatal stage the structures and characteristics may be classified as to the future changes in their qualities. This classification is an expression of the realization of the potentials of growth and development during the first two extra-uterine weeks of the neonatal
period.

The neonatal clavicle exhibits features which may be used for the extension of this idea in that the angulation of the clavicle changes little through ontogeny and the mature structural and functional form is achieved remarkably early. The paucity of change of this characteristic post-natally leads to its definition as an "ontogenetically static characteristic". Likewise, the form of the bone itself leads to the description of it as an "ontogenetically static structure".

The phenomenon of immutability of form in spite of the assumption of new or different functions is not restricted to the clavicle or the skeleton. There are numerous examples of ontogenetic stasis in the neonate, notably Bichat's fat pad, the structure of the eye, the occurrence of tertiary gyri in the cerebral cortex, and the relationship of the cricopharyngeus muscle to the level of the sixth cervical vertebrae. To date no attempt has been made to analyze the neonate in terms of the relative maturity of the totality of its morphology.
Yet if the predisposition of the neonate to its future functioning is to be known, such a survey will be necessary.

Opposing this phenomenon of stasis is the lability of some structures and characteristics of the neonate. It has been mentioned previously that the calcaneus is relatively immature at birth. The changes which it undergoes post-natally are those which really determine its adult form. Both the structure and the characteristics of the neonate calcaneus are labile or changeable. Another example of a labile structure which has been previously mentioned is the general form of the neonatal mandible. One may also compare the neonatal femur and its post-natal changes which are based on the interplay of extrinsic and intrinsic forces to the formation of the neonate sacrum in which the mere elements of the adult structure are present at birth. It is obvious that the lability of neonate structures is within wide limits and that these structures are easily definable as "ontogenetically labile".

119
The terms "labile" and "static" as used here are in reality a method of classification which is based upon the potential of the early formative forces to form an embryonic or fetal structure which is adapted not only to a harmonious integration with the development of the individual and the process of parturition, but is also relatively resistant to changes due to the post-natal forces of muscular contraction, altered function, ortho-grade posture, etc.

In summary the structures and characteristics of the neonate may be categorized as being either "ontogenetically labile" or "ontogenetically static". An "ontogenetically labile" structure or characteristic is one which exhibits changes in complexity in its post-natal existence; an "ontogenetically static" structure or characteristic is one which at birth shows the complexity which is diagnostic of its maturity.
Noback's Classification

Noback (1943) has proposed three developmental periods in the morphogenesis of the bones of the embryonic, fetal, and circumnatal osseous skeleton. The time of the appearance of the ossification centers is termed the "period of differentiation". The time of the rapid extension of ossification into unossified regions is termed the "period of proliferation" where the linear growth of the bone proceeds at a higher rate of increment than that of the corresponding body segment, and when the morphological features characteristic of each bone appear. The third period is a period of "osseous reorganization" of each bone, and of linear osseous growth at a rate of increment approximately equal to that of the body segment with which it is associated.

Unfortunately, while this system is well adapted to the description of the changes in alizarin stained specimens in various stages of embryonic and fetal life, it is of limited value in the description of the bones of the neonate.

The classification which is employed here attempts
to relate the condition of the neonatal bones to the mature status they will assume later in life and to determine the status of each bone in terms of its organization. It relates the neonatal stage to the adult stage and does not deal with the relation of the bone to the growth which is occurring in the region.

Noback's classification in which the second period of the period of proliferation is termed a period in which "the morphological features characteristic of each bone appear" is hardly specific enough in the classification of the bones of the neonatal skeleton. Many bones undergo primary growth under intrinsic factors which form a structure which is subsequently altered by the external forces to produce the morphological characteristics of the bone, as for example, the calcaneus. It is oftentimes not until these secondary forces come into play that the "morphological features characteristic of each bone appear" (Noback, 1944).

Noback in his theory of the period of construction, considers that in this period there
is "the assumption, by the bones, of an area or length". The study of the neonatal clavicle and its earlier stages demonstrates that it is not necessary that this period of construction, which according to definition, involves the osseous reorganization of the bone, be the period in which the proportionality or the adult form of the bone be assumed.
Clavicular Fractures

The function of the clavicle as a horizontal strut and the anatomical orientation of the bone to this function renders it susceptible to injury from lateral pressure during the passage of the shoulder through the birth canal (Mauss, 1903). The pressure produced in cephalic presentation between the anterior shoulder of the child and the symphysis pubis is held accountable for injury of the bone (Reither, 1902). Hauch (1905) demonstrated the importance of proper obstetric techniques for the reduction of the incidence of fractures of the neonatal clavicle, recommending the exertion of gentle extra-uterine pressure in contrast to traction upon the fetal head during delivery. However, the occurrence in nature of disparities between the breadth of the neonate shoulder and the diameters of the pelvic outlet limit the effectiveness of such techniques for the complete elimination of obstetric injury to the clavicle.

Although the clavicle is one of the most frequently injured bones at birth, there is some debate as to whether the neonatal fractures of the
clavicle are more numerous than those of the humerus. Most writers on the injury of the neonatal skeleton state that fractures of the humerus are more numerous than those of the clavicle (Naujoke, 1934; Staffier, 1915; Truedell, 1917; Watson-Jones, 1946; and Adler, 1928). However, the opinion is not unanimous, (Grulee and Eley, 1952; and Madsen, 1955). The latter study is the most recent and perhaps the most complete upon the subject. In the examination of 786 cases of injury to the extremities in 105,119 subjects occurring over a thirty year period, the incidence of fracture was 0.75 percent of births. Clavicular fracture composed 92.4 percent of these injuries, or an incidence of clavicular fracture in the neonate of 0.70 percent. These percentages are not the highest recorded, as Muns (1903) found a frequency of 1.5 percent in 1700 neonates delivered in the vertex position. The range in reporting the incidence of clavicular fracture in the neonate is demonstrated by the results of Moyisch (1934), who, in the examination of 23,215 neonates, found only eight fractures, an incidence of 0.038 percent. The variance in occurrence, recording, and detection of these injuries is related to the obstetric
techniques in use, the frequency of radiographic
examination and the exercise of due care in the
delivery and examination of the neonate.

It is impossible to establish any definite
statistic for the frequency of clavicular fracture
rate, although it may be considered to be generally
in the realm of 0.50 to 0.75 percent. Since there
is little deformity and practically no impairment
of movement in neonatal clavicular fracture, the
early detection of this injury is often missed in
examination (McEnery, 1945). The absence of pro­
nounced clinical signs and symptoms undoubtedly is
responsible for much of the variation in the reporting
of the injury.

It has been definitely established and
confirmed (McEnery, 1945; Madsen, 1955) that fractures
of the clavicle are more numerous, relatively and
absolutely, in cases of spontaneous vertex presentation
than in cases of breech presentation. Likewise the
higher incidence of fracture of the anteriorly
presented clavicle (Muns, 1903; and Hauch, 1905)
has been substantiated (Madsen, 1955).

In the numerous papers written upon fractures
of the clavicle in the neonate, there is an apparent
unanimity of agreement in the general site of the fracture. The quartile system proposed in this paper should provide a more definitive system for the description of these injuries. Presently the literature is confusing as to the exact location to the point of curvature of the bone. The general agreement is that typically the fracture occurs at the junction of the middle and outer thirds. Ehrenfest (1922) states that this is the weakest point of the bone. The radiographic evidence reported in the present study demonstrates that this region exhibits the greatest disparity of the substantia compacta while the osteometric results show this region to be the narrowest in width.

It is interesting to note that the location of a fracture of the neonatal clavicle is the same as that described for the adult. This similarity of traumatic reaction may be used to demonstrate further the approximation of the neonatal morphology of this bone to that of the adult. The forces which produce fracture of the adult clavicle by lateral pressure upon it are similar in action to those which are encountered by the neonatal clavicle in its traumatization against the public symphysis. The neonatal
clavicle responds mechanically in the same manner as does the adult clavicle.

Little information is available in the literature concerning any correlation of the site or healing of fracture of the neonatal clavicle with the nutrient foramen of the bone or with the position of the fracture in terms of the curvatures of the bone. In the description of the third quadrant of the neonatal clavicle it was pointed out that this region is prismatic in shape. Hence this quadrant is mechanically shaped to resist lateral pressures. It was also pointed out that the size of the nutrient foramen in the neonatal clavicle is relatively larger than in the adult. This size factor, as well as its position, are of importance to the liability of obstetric trauma. It is generally acceded that healing of a fracture is faster when the site of the fracture is well vascularized, whereas fracture sites removed from the vascular supply heal with a slowness which is proportional to their access to the vascular supply. The site of clavicular fracture in the neonate is invariably proximate to the nutrient foramen of the bone. Moreover, the trabeculae are seen roentgenologically to be discontinuous in
this region. On the other hand, in terms of the healing of the fracture it is also true that the fracture site is well vascularized and hence the fracture heals quickly and the prognosis for neonatal clavicular fractures is always excellent (Madsen, 1955).

Most of the fractures of the clavicle are described as of the greenstick variety. Undoubtedly the thick periosteum enveloping the bone tends to limit displacement of the parts. There has been only one attempt to duplicate the fracture of the neonatal clavicle. Hauch (1905) found that a lateral pressure of 5 to 16 kg. would produce a fracture.

The limited interest in fracture of the neonatal clavicle may be due to the difficulty of diagnosis of the condition and to the fact that it heals with rapidity and with little or no difficulty; no therapeutic limitation of movement is necessary; shortening never occurs; and only rarely does temporary paralysis of the arm occur (Madsen, 1955; and McEnery, 1945).
The conclusion reached from the study of the data of the fracture of the neonatal clavicle is that under traumatic conditions this bone mimics the traumatic reaction typical of the adult. The fracture of the neonatal clavicle is very clearly related to the cortex and to the presence of the nutrient foramen at the thinnest portion of the bone. On the other hand, it is interesting to note, that this thin portion of the bone exemplifies what is perhaps the strongest type of molding possible, namely, the prismatic form. In this regard it should be pointed out that no analysis of the clavicular fractures of the newborn have been related to the change from the prismatic form of the third quadrant to the flattened form of the second quadrant. It would seem that mechanically this portion of the bone would be the most prone to fracture for it is the region in which the lateral forces of stress within the bone undergo the greatest torque in passing to the flattened portion of the bone.
Functional Role of Clavicle

As has been mentioned, the clavicle functions as a support of the scapula and for the attachments of muscles (Inman and Saunders, 1946). The inner architecture of the bone with its longitudinally arranged traveculae permits this action of the bone in meeting both the longitudinal pull of the muscles which attach to it and the horizontal pressure of the scapula. In forms such as the artiodactyls, i.e. the horse, this longitudinal pressure is limited, due to the restriction of fore-limb action to pendular movements. The absence or rudimentary nature of the clavicle in these forms is not due to its failure to restrict movements by the clavicle but rather to a decrement in lateral forces which appear to actuate the presence of the clavicle. It is quite understandable to find that the clavicle is well developed in organisms in which there is lateral movement of the limbs (Frazer, 1948).

The question arises concerning the function of the clavicle in man. There is no doubt that the functioning of the upper limb of man places the shoulder apparatus in the functional group in which
there is a decided diversification of the movements of the girdle in contrast to the pendular type locomotion found in the artiodactyIs. The movements of the shoulder region are free and not restricted in the movements of extension and flexion. This may be a sufficient reason to explain the existence of the clavicle.

However, the issue is not so clear. The strong development of the clavicle in the mammals has long been associated with prehensile activities of the limb (Bateman, 1955). Particularly amongst the primates, the clavicle has been regarded as a strut which has developed in the functioning of the upper extremity in brachiation (Hooton, 1949). The function of the clavicle may limit the adduction of the shoulders in the act of brachiation. As a stabilizer of the girdle, a strong clavicle has been closely associated with brachiating primates. The early theories of human evolution, which related men's ancestry to the living primates, considered the clavicle of man as a bone of brachiation, which it is in most anthropoids. However, it is not necessary that the bone be so associated in man.
Man is unique among the primates in the possession of a complete bipedal gait and erect posture (Hooton, 1949). The presence of a well developed clavicle in man is not necessarily related to brachiation but may be equally well related to its function in the alternating bipedal gait. The movements of the shoulder in locomotion constantly exhibit the loss and recovery of equilibrium which is characteristic of the human gait. In locomotion the movements of the hip and shoulder are directly opposite in direction. As the hip line ascends and descends, the frontal plane of the shoulder respectively descends and ascends about three-fifths of the former distance. The movements of the horizontal plane of the shoulder are about two-fifths that expressed by the hip line. With forward movements of the hips, the shoulder moves backwards; and with backward movements of the hips, the shoulder moves forwards. The exactness of these shoulder movements allow the formation of the paths of their movements (Steindler, 1956).

It can readily be appreciated that the movements of the shoulder are harmonious with those of
the hips in the bipedal gait. The action of the clavicle is in the restriction of not only forward projection of the scapula but also in providing the attachment for the pectoralis major muscle which provides for the final extension of the humerus.

The conclusion from this analysis is that the clavicle is necessary in the functioning of the shoulder in locomotion. The limitation of the forward movement of the shoulder is particularly evident in running and sprinting. It is proposed that the clavicle is of functional significance in man not because of a primate ancestry from an arboreal progenitor but due to its functioning in the bipedal locomotion of man.

This theory is quite in agreement with the modern anthropological view of man's ancestry from a terrestrial non-brachiating ancestor (LeGros Clark, 1956). By it the clavicle achieves a status of not only a bone of brachiation but also of a bone developed in association with the bipedal gait. Its occurrence in the primates may be due to either of these causes and is not necessarily restricted to brachiation.
THE NEONATAL SCAPULA

Gross Form of the Neonatal Scapula

The analysis of the gross anatomy of the neonatal scapula (Fig. 10, 11) demonstrates that, as is the case with the neonatal clavicle, the bone is generally mature in its form, in the attachment of the muscles which originate from and insert onto it, and in the form of its articular surfaces and attachment of ligaments.
Secondary Markings

As is characteristic of neonatal bones, there is an absence of secondary bony markings. While there is muscular movement of the fetus in utero, (Windle, 1940), this activity does not produce the cristae and other markings evoked by post-fetal activity. This condition is a result of both the limited muscular activity of the fetus and the strong intrinsic forces which influence the bone during its development to the adult form. At the time of birth the acromion process arises from the end of the scapular spine and is similar to the adult acromion. Likewise, the coracoid process at the end of gestation arises from the superior border of the scapula and is of similar shape and direction as in the adult.

There seems to be a gross over-estimation of the portion of the neonatal scapula which is cartilaginous at birth. Smith (1924) established radiographically the early occurrence of ossification centers in the coracoid process at the time of birth. Grossly, the coracoid is cartilaginous, the medial half of the acromion, and the medial portion of the neck of the scapula are osseous. The amount of cartilage present on the vertebral border is limited and is generally disproportionately large in illustrations of the bone at birth, e.g. Morris (1956) and Piersol (1907).
Age Changes

Graves (1922) has established that the age changes of the scapula are manifestations of two diametrically opposed forces; namely the ossification process and atrophic processes. As a result of the study of the scapula at the neonatal stage it is observed that while the scapula is undergoing even the final fetal stages of its development and when the scapula has almost reached relatively adult proportions in its borders and processes, there is no evidence to substantiate an early appearance of age changes due to the ossification process. The age changes which may be attributed to the ossification process are truly post-natal and are attributed to muscular forces and to the extension of ossification into the cartilaginous portions of the bone.

The structure of the bone at birth apparently is dominated exclusively by the nature of the intrinsic forces of osteogenesis. Its compact and thick nature rule against atrophic changes such as atrophic spots, buckling, pleating, or distortion.
Changes in the basic structure and form of the scapula at birth are the resultant of pre-natal changes due to aplasia or hypoplasia and other changes in the intrinsic factors. Thus, Brailsford (1914) demonstrated that the normal glenoid fossa is made up of three osseous components; one from the main body of the scapula, one from the region of the base of the coraoid, and one from the inferior portion of the glenoid. These three are present in a cartilaginous form by the 18 millimeter stage but are unossified. The failure of the development of either of the cartilaginous primordia, particularly the inferior one, will result in bilateral glenoid hypoplasia (Owens, 1953).

Such manifestations of the failure of the precartilage to develop are rare (Owens, 1953), so that the power of the inherent forces which lead to the development of the scapula may be considered as very strong.

The neonatal scapula may show all of the variations of border and single structure which have been noted in the adult. These variations in size and occurrence are never complicated by the
process of parturition. The bone and its muscles are so rarely traumatized at birth that no mention of such injuries are ever made in the standard texts of obstetrics. Occasionally, the descent of the scapula from its position at the level of the fourth cervical vertebrae is arrested, resulting in a deformity (Sprengel's) marked by an unusually high scapula. At the time of birth the scapulae are topographically one vertebral level higher than in the later stages of growth.
Comparison of the Pre-natal and Neonatal Scapula

No study is available which traces the growth of the scapula through its entire fetal stages. Neither are there any studies in which any of the specific osteometric measurements or indices have been applied to the fetus or newborn. Wolf (1925) studied the changes in the position and scapular index in a series of eleven embryos and fetuses, ranging in size from 1.85 to 15.7 centimeters, i.e., from the second to the fifth month. Her results are as follows:

<table>
<thead>
<tr>
<th>CROWN-RUMP LENGTH</th>
<th>AGE UPON THE DATA OF STRYBER (1920)</th>
<th>SCAPULAR INDEX</th>
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<tr>
<td>1.85</td>
<td>second month</td>
<td>127.5</td>
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<td>63.1</td>
</tr>
<tr>
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<td>69.0</td>
</tr>
<tr>
<td>14.3</td>
<td>fourth month</td>
<td>72.5</td>
</tr>
<tr>
<td>15.6</td>
<td>fourth month</td>
<td>81.5</td>
</tr>
<tr>
<td>15.7</td>
<td>fourth month</td>
<td>78.0</td>
</tr>
</tbody>
</table>

These data show a striking change in the scapular index during the second month. The decline from 127 to 79 is followed in the next two months by a further decline. Wolf's data show an apparent
increment of the index during the latter part of the fourth month. Unfortunately, the number of specimens used does not allow for a complete assumption of an interphase in the growth of the scapula during the fourth month.

That there is a decline in the value of the scapular index during the early fetal period is apparent from the observation of the scapula in its early stages; and is verified by the data of Vallois (1932). Though he used only a few specimens, the index was found to diminish from 83.3 in the second month to 73.7 at birth. Vallois did not use specimens from the fourth month so that there is no verification of the interphase which may occur somewhere in the fourth month. Such an interphase has been demonstrated about this time for the parietal bone (Moss and Noback, 1955). The data of Vallois are as follows:

<table>
<thead>
<tr>
<th>NUMBER OF SUBJECTS</th>
<th>AGE IN MONTHS</th>
<th>INDEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>2</td>
<td>83.3</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>76.4</td>
</tr>
<tr>
<td>2</td>
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<td>81.0</td>
</tr>
<tr>
<td>3</td>
<td>6/7</td>
<td>76.6</td>
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<tr>
<td>3</td>
<td>8/9</td>
<td>79.0</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>73.7</td>
</tr>
</tbody>
</table>
These data do not include a crown-rump measurement of the specimens used; nor is there any statistical analysis of the data. However, in conjunction with the data of Wolf, they show a definite decrement in the scapular index during osteogenesis and the fact that during the middle of gestation the index is in the high 70's and low 80's. The only available data showing the value of the scapular index for the newborn (73.7) is by Vallois (1932). He gives no description of the neonates used, no statistical information about the data, nor whether the number of specimens he used were sufficient for anything but a longitudinal growth study. His value for the neonate (73.7) is lower than that obtained from the present collection but is within the normal range of variability.
Age, Racial and Sexual Differences of Scapula

In comparing the scapular index of the neonate with that of the adult it is seen that it continues to decline throughout the post-natal period of growth. Martin (1928) compiled the values for the scapular index according to races. The range in value is from 60.3 for the Tasmanians to 72.5 for the Senoi and Semang (Negrito tribes of the upper Malayian Peninsula). The values by other investigators for the peoples of western Europe range as follows: 65.2 (Flower), 65.9 for males, 64.9 for females (Broca), 63.5 (Dwight), 63.1 for males, 76.4 for females (Livon), and 65.3 (Turner). In the present study it was found that the value for the neonatal scapular index is well above the extremes of variability given for the adult human as an entire group and for the adult from Western Europe.

Rather, the value for the scapular index of the neonate (78.1) falls close to the class of values available for three of the major members of the anthropoids, namely, the gorilla, (72); orang-utan (74), and the chimpanzee, (Martin, 1928). However,
The scapula of these anthropoids exhibits a more elongated axillary border and larger infraspinous fossa than would allow for any comparison of these scapulae to that of the neonatal.

It is interesting to note that both Vallois (1932) and Wolf (1925) found, as was the case in the present study, that no significant differences in the measurements could be related to sex or to laterality of the bone.
Scapular Indices

Values of the length and the breadth for the neonatal scapula are obtainable from the work of Vallois (1932) and Frey (1923).

Vallois (three specimens)
length 4.65 cm. breadth 3.4 cm.

Frey (ten specimens)
length 3.9 cm. breadth 3.0 cm.

The present study (60 scapulae)
length 4.4 cm. breadth 3.4 cm.

As the value for the length of the Frey series was not given, it has been derived from the values for the supra- and infraspinous indices. The lower value of the Frey series may be due to the removal of the cartilaginous portions of the bone as the method of preparation is not mentioned in his paper. Vallois apparently maintained the cartilaginous portions of the bone in his studies.

Frey (1923) studied the breadth of the scapula, the scapulo-humeral index, the index of the spinal fossae, and the supra- and infraspinous index. A series of scapulae from different age groups was used, including ten newborn specimens; however, he failed to indicate the body size and other criteria
necessary for the definition of the neonatal stage. The method of preparation of the specimens is likewise omitted.

In the present study the value arrived at for the breadth of the neonatal scapula is 3.4 centimeters. This compares favorably with the findings of Frey, who found in his series the value to be (3.0). The differences may be accounted for on the assumption that the specimens used by Frey lacked the cartilaginous portions of the bone. However, the difference does not negate Frey's finding that the breadth of the scapula increases with a steady increment through the first twenty-two years of life and that the rate of growth of scapular breadth in the female specimens during the period of puberty. A similar though steeper curve has been obtained in the measurements of the growth of the humerus, showing that the scapulohumeral index is 40 at the neonatal stage, with a decrement by the age of two to 35 and to 33 by adulthood. This index is 40 during the entire gestational period from the fourth month to the neonatal period (Frey, 1923).

The infraspinal index of the present series is 79.7, while that found by Frey is 87.
The supraspinal index is 38.7 in the present study, while that of Frey is 35. The absence of cartilage at the lower angle of the scapula and at the head of the bone in Frey's specimens could account for this difference in infraspinal index and lower supraspinal index. The lower value for the infraspinal index and the infraspinal index and the finding by Frey that the index by the age of 2-3 years has achieved an adult proportion of 115 in this region demonstrates the large amount of post-natal growth that occurs in this region. The growth of the supraspinal index is slower than that of the infraspinal index and does not reach the adult value of 39 until 9-11 years.

From the supra- and infraspinal indices given by Frey (1923) it is possible to derive mathematically the heighth of the bone though it is not given. The calculated value obtained in this study (3.95 cm.) is lower than that of the present series (4.4 cm.).

With the exception of these supra- and infraspinal and scapular indices calculated by Frey, no other data are available to compare with the
results of the present neonatal osteometry. It is possible to obtain an idea of the growth of the scapula from birth to adulthood by the use of the data for the adult scapula in which the morphological breadth of the bone is 10.5 centimeters and the length 16.0 centimeters (Martin, 1928). The width of the bone increases 3.18 times while its length increases 3.63 times from the neonatal stage to adulthood. When a comparison is made of the grouped data for the growth in length in the neonate to the adult, the value found was 3.40 times. It is obvious from these data that the osseous elements of the shoulder, that is, the scapula and clavicle, maintain a harmonious development. The data for the growth of the scapula may be compared to the growth of the external dimensions of the shoulder (Scammon and Calkins, 1929). (Graph 4).
The Supraspinous Fossa

The greatest change which takes place in the morphology of the scapula during its osteogenesis is the development and increment in size of the supraspinous fossa. From the early occurrence of this fossa at 18 mm. fetal length, the fossa increases in size greatly. At the time of birth this increment is still taking place as is shown by the index of the fossa. Frey (1923) demonstrated that the spinal fossa index in the adult is 34 for males and 35 for females, the range of the index being from 25 to 45. His data for the neonate fall within the range of variation for the adult of 41. The data presented here (48.6) indicate that there can be no question but that the spinal fossa index is distinctly lower in the adult and that there is an increment in the relative size of the supraspinous fossa after birth. Since this fossa is directly related to the size of the area of the attachment for the supraspinatus muscle, it follows that the muscle and its attachment into the fossa reach a mature status later than does the infraspinatus muscle and fossa.
As regards the index for the spinal fossae, the neonatal scapula tends more towards the values for the anthropoids and primates, in which the index for the orangutan is 36, the gorilla 68, the chimpanzee 73, gibbon 77, and the baboon 40 (Frey, 1923).
The Glenoid Fossa

The glenoid fossa of both the neonatal and adult scapula is ellipsoidal in shape. The length-breadth index (72.3) is similar to that of the adult (72.2) (Dwight, 1908, Hrdlicka, 1942). Thus, during post-natal osteogenesis of the bone, little change occurs in relative dimensions of the glenoid fossa.

Liven (1879) and Schuck (1910) found that in the adult the right scapula is shorter than the left. This difference is not evident in the neonate. The difference being only three-tenths of a scapular index unit. Frey (1923) has discerned that the breadth of the scapula is six percent of the body length in the neonate. In the present study the scapular breadth is 6.96 percent of the body crown-heel length, (4.4 cm./48.8 cm.); the scapular length in relation to the crown-heel length is 9.01 percent (3.4 cm./48.8 cm.)
Scapular Coefficient of Variation

It should be noted that corresponding with the little change which occurs in the length/breadth index of the glenoid fossa, the axilloglenoidal angle has a coefficient of variation three times less than that of the other angles whose coefficients of variation are similar to those of other measurements of the bone. The coefficients of variation for this series of clavicle are from the same collection of cadavers. Likewise, the coefficients of variation for this series of scapulae are similar to each other in having values in low tenths of percentages. The rather high coefficient for the length of the superior margin (22.5 percent) coincide with the embryological evidence that it is this portion of the bone which undergoes the greatest morphological changes during the later part of osteogenesis. The low coefficient of variation for the breadth of the scapula (2.9 percent) may be explained on the basis of the biological principle that the form of the progeny in utero coincides generally with the available dimensions of the birth canal. The width of the shoulder when measured at the bi-acromial diameter, is constant throughout the fetal period, being 22.5 per cent of the total crown-heel length (Scammon and Calkins, 1929).
The apparent control of body size of the fetus in the maintainence of dimensions compatible with parturition has been a subject of little academic discussion. The basis of a concept of "parturitional proportions" in the shoulder region may be illustrated by the low coefficient of variability in the breadth of the scapula. This coefficient is the least variable measurement of the neonatal scapula and agrees with the low variability of the length of the clavicle. The lowest coefficients of variability of any of the dimensions of the bones of the neonatal shoulder exhibit limitations in their size corresponding with the breadth of the shoulder. The dimensions of the neonatal shoulder girdle, which are the most important as regards the future birth and survival of the fetus, are the least variable.

It may be seen that the greatest validity in the estimation of the breadth of the neonatal shoulder lies in the correlation of the breadth of the scapula to shoulder measurements. The median breadth of the neonatal scapula (3.4 cm.) corresponds to a bi-acromial...
diameter of 10.5 cm.

It has been pointed out previously that the mean coefficient of variation for the neonatal clavicle was 15% and that the majority of clavicular measurements were closely grouped about this figure. The situation is similar in the neonatal scapula, in which the mean of the coefficient of variability is also 15%. With the exception of the low variations exhibited by the breadth of the scapula (2.9%) and the high coefficient of variability for the length of the supraspinous fossa (32.1%), the values of this coefficient in the neonatal scapula are grouped about 15% as they are in the neonatal clavicle.

The mean variability of the neonatal femur is 4.87%, while that of the adult femur is 6.43% (Ingalls, 1928). These data indicate that the neonatal scapula, like the neonatal clavicle, is more variable in its morphology than the femur at birth. The basis for this difference in variability may lie in the adaptability of the bone to future functional demands. Like the clavicle, the scapula serves primarily as a bone for muscular attachments. The femur, however, is subjected not only to the strain and stress of its muscular attachments but also to the forces imposed by the orthograde posture.
Comparison of the Neonatal Clavicle to the Scapula

The scapula differs from the clavicle during its osteogenesis in that the general form of the clavicle is maintained from its early stages of development while the scapula changes its form throughout its fetal existence. This may be explained on the basis that the scapula is a long bone with no large flattened areas serving for muscular attachments.

Though the scapula does not coincide with the clavicle in the extremely conservative nature of pre-natal changes, still at the time of birth it is relatively mature in its form. The similarity of the early assumption of the adult form in these two bones may be explained on the basis that both bones are highly self-determinative and are anatomically located as to be free of strong postural stress.

The neonatal scapula is not definitely fixed in its final form and yet does not have to undergo changes, such as occur in bones like the calcaneus and innominate, where there is little anticipation of the adult form at birth. The scapula may then be placed in an intermediate classification along with
the neonatal femur in which the bone at birth is
identifiable as a miniature model of the adult
bone and yet which undergoes some structural
modification during its growth. This class of
neonatal bones is secondarily affected by extrinsic
factors post-natally.

In association with the definition of the
neonatal clavicle as an ontogenetically stable
structure, the changes which occur in the neonatal
scapula are not great enough to consider it as
labile following birth and so it too may be considered
as ontogenetically static.

Noback's (1943) classification may be applied
to the neonatal scapula, namely, that the scapula
changes its indices post-natally, and, so the post-
natal period is the "period of construction" in
which there is osseous reorganization of the bone,
and linear osseous growth, at a rate of increment
approximately equal to that of the body segment with
which it is associated.
CONCLUSIONS

1. This is the first study of the anatomy of the newborn skeleton in which the criteria of the neonate are used. All neonates were: 47 to 54 centimeters in crown-heel length, 2500 to 4500 grams in weight, and of 39 to 42 weeks gestational age.

2. When the cartilaginous portions of the neonatal bones are retained, it is possible to carry out all of the standard osteometric measurements usually employed on adult bones.

3. The neonatal clavicle is topographically inclined on an oblique plane as in the adult but due to the rotundity of the neonatal thorax, it lies more anteriorly. It exhibits the same shape and configuration as that of the adult. The posterior border is typically straight in the fourth quadrant.

4. The clavicle of the neonate and the adult is best described by the use of four quadrants which are based upon the geometric shape of the different regions and are applicable to all stages of clavicular morphogenesis. Two prismatic and two flattened regions occur.
5. Neonatal bones are enveloped in a thick periosteum and exhibit few of the rough irregular surfaces associated in the adult bone with muscle and ligamental attachment.

6. The index of the length to the sagittal diameter of the clavicle remains centered about a value of 15.0 from fetuses of eleven centimeters crown-rump length to the adult state. There is a 7% change in the index from birth to adulthood in face of a 400% to 500% increase in the length of the bone.

7. The weight/length index declines through intrauterine existence and assumes the shape of a typical logarithmic growth curve.

8. Both the neonatal scapular and clavicular measurements have a variation of about 15%. The variation of the clavicle ranges for 4.06% in the measurement of the medial angle to 23% in the measurement of the width at the conoid tuberole.

9. The mean variability of the neonatal clavicle is 12.98 in comparison to that of the adult clavicle, 8.67.

10. The variability of the end of the neonatal clavicle is greater than that of the shaft of the bone, while the maximum length and the circumference...
of the clavicle at the midpoint are the two measurements with the least variability.

11. No sexual or racial differences are evident in the neonatal clavicle or scapula.

12. As is the case with the adult, the medial angle of the neonatal clavicle is larger than that of the lateral angle. However, in contrast to the adult, the medial angle of the neonate is less variable than is the lateral angle.

13. The index of curvature is six degrees larger in the adult (292.26°) than in the neonate. Both age groups are similar in that the index of curvature is higher on the left side than on the right.

14. The length/midpoint diameter index of the neonate (26.3) is similar to that of the adult (25.24) and is less variable than that of the adult.

15. In its growth the clavicle retains the same three dimensional form during the major part of its existence, i.e. in length/width, length/circumference, and curvature indices. Wolff's law of transformation of structure to meet new demands of function is not exemplified by the clavicle because its static nature is apparently based upon the early development of the architecture and form of the bone which is already suited to the environmental
stimuli which later act upon it.

16. The acromial chord is present in all of the clavicles studied and the sternal chord in 69% of the bones. This is in correspondence with the occurrence of the "S" shape of bone.

17. Following the classification of Rudinsky (1929), the intermediate type of clavicle is the more common (62.2%) than the sternopetal type (36.0%). The acromiopetal type is rare (1.6%).

18. The high terminal variations of the neonatal bi-acromial diameter previously reported (Scammon, 1929), correlate with the coefficients of variation of the neonatal clavicle. The growth of clavicular length corresponds with the growth of the bi-acromial diameter as demonstrated by the correspondence of the slopes of their growth curves. The measurement of the bi-acromial diameter is really a measurement of clavicular length.

19. The growth of the fetal clavicle corresponds with that of the fetal thorax.

20. The deltoid depression is the sole distinct bony marking for muscle attachment on the neonatal clavicle; the beginnings of nearly all of the other adult surface markings are distinguishable.
21. The epiphyseal cartilages in the neonatal clavicle are small and have been greatly overestimated in the past.

22. A classification of neonatal bones into three groups according to their attainment at birth of forms corresponding to: 1) the adult form, 2) approaching the adult form, and 3) of little resemblance to the adult form, is proposed and applied to the neonatal clavicle, scapula, femur, and calcaneus. Other examples of morphological maturity at birth - ontogenetic stasis - are discussed.

23. The classification of Noback is of limited value when applied to neonatal bones.

24. Fracture of the clavicle at birth is related to the apparent weakness of the bone at the third quadrant due to the changes in angulation of the bone and the location of the nutrient foramen. The similarity of the neonatal and adult clavicle is evident in the identical nature of their traumatic reaction.

25. The function of the clavicle in the restriction of forward flexion of the humerus and adduction of the shoulders during the orthograde alternating bi-pedal gait is emphasized.
SCAPULA

26. The neonatal scapula is generally definitive in form and position of muscle attachments. The vertebral and glenoid borders of the bone are cartilaginous.

27. There is no evidence in the neonatal scapula of age changes due to ossificational or functional influences. The neonatal scapula may show all of the variations of border and angular structure which have been recorded in the adult.

28. The scapular index of the neonate is 73.7 and represents the lowest index during the gestational period. The neonatal index is greater than that of the adult specimens and is closer in the values of the anthropoids.

29. The neonatal to adult growth increment of clavicular length (3.4) and scapular length (3.6) indicates a harmonious development of these elements.

30. The growth of the supraspinous fossa, as indicated by the supraspinous index, is still taking place in the neonate.

31. No change occurs in the length-breadth index of the glenoid fossa during post-natal osteogenesis. Corresponding with the
consistency of this index, the axilloglenoid angle has a coefficient of variation three times smaller than that of the other angles.

32. The median breadth of the neonatal scapula (3.4 cm.) corresponds to a bi-acromial diameter of 10.5 cm. of the neonatal shoulder.

33. The scapula, like the clavicle, is structurally and osteometrically more variable than the neonatal femur.
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Fig. 1 (A). A drawing of the osteometrical clavicle showing the median axis of the bone as dotted line, the horizontal axis of the bone as a solid line, and the method of determining the medial angle (delta) and the lateral angle (gamma). The medial points on the ends of the bone are indicated by the point alpha, (medial) and the point beta (lateral).

The division of the bone into four quadrants is indicated.

Fig. 1 (B). Superior and inferior views of the neonate clavicle showing the portions of these surfaces which have muscular and fibrous attachments. The key to these illustrations is as follows:

A.C. ........ lateral articular capsule.
M.C.L. ........ medial capsular ligament.
Cl. M........ cleidomastoid muscle.
D. ........ deltoid muscle.
P. M. ........ pectoralis major.
R. L. ........ rhomboid ligament.
Sc. M. ........ subclavius muscle.
T. ........ trapezius muscle.
QUADRANTS

SUPERIOR

INFERIOR
Fig. 2. - Anterior and posterior views of the neonate clavicle demonstrating the surface attachments of the bone. The key to the outlined areas is as follows:

A.S. articular surface.
C.C.L. costo-clavicular ligament.
D. deltoïd muscle.
F. fat.
P.M. pectoralis major.
S.C. sternocleidomastoid muscle.
S.H. sternohyoid muscle.
T. trapezius muscle.
Fig. 3. Photograph of the superior aspect (above) and the inferior aspect (below) of the neonate clavicle. The deltoid depression may be seen on the superior aspect of the bone in the fourth quadrant. The nutrient foramen is visible on the inferior aspect in the third quadrant.
Fig. 4. A graph of the relationship of the bi-acromial diameter, and clavicular length to the crown-heel length of the fetus. The square symbol represents clavicular length; the round symbol represents the bi-acromial diameter.
Fig. 5. Radiographs of the neonate clavicle; on the left, the superior-inferior view; on the right, the anterior-posterior view.

Both ends of the bone demonstrate the predominant horizontal orientation of the brabeculae. The superior view demonstrates the relative size of the modullary cavity of the bone. The anterior view shows the large size of the nutrient foramen.
Fig. 6. Photograph of a dry ground section of the adult clavicle in which is demonstrated the continuity of the cancellous bone throughout the length of the bone and the widened medullary cavity.
Fig. 7. A photograph of a dry ground section of the neonate clavicle in which is demonstrated the discontinuity of the cancellous bone in the medulla.
Fig. 8. Photograph of dry ground section of a neonate clavicle demonstrating the relative size of the medullary cavity and the small size of the lateral epiphysis (superior).
Fig. 9. (A). Table of the increment of clavicular weight and length, and the length/weight index decrement during gestation.

Fig. 9. (B). Table of the increment of the sagittal diameter and the sagittal diameter index during gestation.
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<th>II</th>
<th>III</th>
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Fig. 10. Photograph of the dorsal aspect of the neonate scapula. The cartilaginous vertebral border and inferior angle of the bone are obvious. The lateral half of the acromion process and the glenoid cavity are also cartilaginous.

The surface of the bone shows the radiating character of the trabeculae, more obvious on x-ray. Excepting for the small size of the supraspinous fossa, this bone is a miniature model of the adult.
Fig. 11. Photograph of the ventral aspect of the neonate scapula. The cartilaginous nature of the coracoid process is seen as is the radiating pattern of the bone on the ventral surface.
Fig. 12. Drawing of the dorsal aspect of the neonatal scapula with the principal points of osteometric reference lettered (see text, pg. 11).

A. Vertebral point.
B. Dorsal point of the glenoid fossa.
C. Superior point.
D. Inferior point.
E. Intersection of height axis with scapular spine.
F. Acromial point.
G. Superior point of the glenoid fossa.
H. Inferior point of the glenoid fossa.
Fig. 13. Outline drawing of the ventral aspect of the neonate scapula.
Fig. 14. Radiograph of the dorsal aspect of the neonate scapula demonstrating the radiating nature of the trabecula in the flattened portion of the bone. The base of the spine is not radio-translucent while no ossification center is present in the coracoid process.
Fig. 15. Superior view of the neonate clavicle and scapula in articulation. The acromio-clavicular articulation faces medial and posterior.
Fig. 16. Photograph of the superior view of the neonate scapula demonstrating the supra-spinous fossa of the bone. This fossa is small in the neonate and in superior view, is rectangular. The relative distance between the acromion and coracoid processes is similar to that of the adult.
Fig. 17. Lateral view of the glenoid fossa demonstrating its relationship to the acromion process. The size of the glenoid fossa and the distance to the acromion process are relatively the same in both the neonate and the adult.
I, Gilbert Edward Corrigan, was born in Cleveland, Ohio, May 3, 1929. My secondary education was in the public and parochial schools of Cleveland and East Cleveland. I attended Adelbert College of Western Reserve University, where I majored in biology and served as assistant to the late Dr. Amos H. Hersh. Following graduation in 1951, I received graduate training in biology at the University of Notre Dame, studying genetics under Dr. Edward O. Dodson. A Master of Science was awarded me in June, 1953, while I was in attendance at The Ohio State University. From September, 1952, to the present, I have been in graduate study in anatomy, during which time I have held teaching assistantships and in the year 1956-57 an assistant instructorship in the department. My graduate study here has been under the advisership of Dr. Linden F. Edwards. In June, 1958, I was appointed Instructor in Anatomy at Wayne State College of Medicine.