GROWTH AND DEVELOPMENT OF THE HUMAN FETAL HIP JOINT

A STUDY OF THE GROWTH AND DEVELOPMENT
OF THE
HUMAN FETAL HIP JOINT

By

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ABSTRACT

Congenital hip disease (CHD), a condition in which the head of femur may be partially or completely separated from the acetabulum, is detected in one to 4 infants per 1,000 live births. At birth the hip joint is cartilaginous and underdeveloped. In cases of CHD the acetabulum is shallow, the femoral head is small and aspherical, the ligament of the head of femur (LHF) is elongated, and the femoral angles are abnormal. These are measureable characteristics. However, no previous studies have given quantitative data for several dimensions of this joint in a sample of fetuses, at regular intervals of age, throughout the fetal period.

The pattern of normal growth and development was studied in 280 hip joints from 140 fetuses between 12 weeks and term. Measurements were taken of acetabular depth, diameter, femoral head diameter, the length and width of the LHF, and the femoral torsion and neck-shaft angles. Histological studies of ossification and labrum structure were undertaken on a number of acetabula at intervals throughout the fetal period.

Acetabular depth was shown to be the slowest growing variable at the hip joint. The study confirmed previous reports that the acetabulum tends to become shallower towards term but suggested that the greatest amount of change in shape may occur early in the fetal period. In a sample of femoral heads a tendency for the head to become less spherical with age was revealed. With the exception of the neck-shaft angle all variables demonstrated a moderate to high positive correlation with age. Variables were best fitted by a regression model which included a polynomial on age. Only for left LHF length and right LHF width was growth a simple interest function. The velocity of growth for all dimensions, except the neck-shaft angle, was highest between 12 and 18 weeks. After this period a deceleration in the growth rate was noted, most noticeable in acetabular depth.

No significant differences were detected between males and females, or between the right and left sides. This indicates that the higher incidence of CHD in females, and the greater involvement of the left hip must be explained by factors other than the growth of cartilage and bone.

The LHF was shown to be variable in shape throughout the fetal period. It was not a distinctly linear structure in normal or abnormal hip joints. A strong correlation with acetabular dimensions was not evident.

Both femoral angles demonstrated variability throughout the fetal period and values reported are lower than those currently accepted for the newborn. Since the angles demonstrated poor to moderate correlation with the other hip dimensions, neither angle alone appears to provide a useful indicator of normal development. A change in the orientation of the lesser trochanter with age, correlated with the increase in torsion was observed. This is considered pertinent to the reading of femoral angles on radiographs.

In 65 hip joints from 46 fetuses variation from descriptions of normal hip joint morphology was detected. Measurements of these joints did not differ significantly from those of normal hip joints. It is suggested that a number of these variants are microforms of CHD. An unexpected number of variants and abnormal socket features were localized to the anterosuperior quadrant and anterior socket wall.

Comparison of data from abnormal joints (18) with data from the normal growth study permitted a more precise evaluation of the abnormality. From this comparison underdevelopment of apparently "normal" joints was detected.

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INTRODUCTION

At birth the human hip joint is cartilaginous, underdeveloped and potentially unstable. The head of femur may be partially or completely dislocated from the acetabulum. Congenital dislocation of the hip (CDH) has incidence rates between 0.65 to 1.0 per 1,000 live births. These rates rise four-fold when neonatal cases are included (Carter 1969, Warkany 1971, Wilkinson 1972). It was considered that a comprehensive study of the developmental trends of the hip joint would give greater insight into possible mechanisms of congenital hip disorders than the investigation of one or two facets of its organization. While the hip joint is one of the most intensively studied joints in man, most of the reported work on its development has been concerned with certain isolated characteristics, and/or has been based on small sample sizes (Table 1).

The leg limb bud first appears at day 28, Streeter's (1951) horizon 12 embryo. The embryonic development of the limb bud and the hip joint are well documented in a number of studies (Bardeen and Lewis 1901, Bardeen 1905, Strayer 1943, 1971, Gardner and Gray 1950, 1970, O'Rahilly 1967, Gardner and O'Rahilly 1972, Rooker 1975). Skeletal differentiation in the lower limb begins in the region of the hip and extends distally and proximally. Most of the main structures in the leg may be distinguished by the end of the seventh week.

Table 1: Reported studies of the prenatal development of the human hip joint. Blanks = no data, + = more than, # = single hips.

Reference	Number	Age (weeks)	CRL (mm)	Type of Study
Humphry (1888-9)	11	9 - 42		neck-shaft angle
Le Damany (1904, '08, '12)	23+	12 - 42		measurement, torsion depth, diameters
Rogers (1934)	5			torsion (radiographs)
Morville (1935)	12	stillborn children		anthropography
DeSanto & Colonna (1939)	6	6 - 30		histology
Strayer (1943, 1971)	6+ illustrations	embryos	45 - 237	histology
Badgley (1949)	illustrations		8 - 58	morphology, posture
Gardner & Gray (1950)	52	6 - 42	12 - 370	histology
Cheynel & Huet (1952)	10 black 40 white	23 - term - term		measurement, depth, diameter, torsion
Felts (1954)	53		31 - 495	femoral dimensions, angles, ossification
Andersen (1962)	30		30 - 121	histology
Stanisavljevic & Mitchell (1963) Stanisavljevic (1964)	120 150	16 - 40		histology, anatomy, morphology
Kobayashi & Mizuno (1965)	32	7 - 40	7.5 - 362	torsion, acetabular angles, histology
Laurenson (1965)	14		40 - 300	radiographic measurements, histology
Sasada (1968)	35	4 - 40		labrum histology
Dunn (1969)	22	13 - 40		morphology
Gardner & Gray (1970)	40		26 - 342	femoral ossification
Gardner & O'Rahilly (1972)		6 - 8		histology
Ralis & McKibbin (1973)	13+	11.5 - term	55 on	depth, diameter, measurements, index
Watanabe (1974)	144	up to 2[illegible]	1[illegible] - [illegible]	measurements of torsion, histology
[illegible] (1974)	[illegible]	2[illegible] - term		[illegible]
Rooker (1975)	[illegible]		5 - 43	histology
Crelin (1976)	26	32 - term		[illegible] strength, mobility, [illegible]

The skeleton develops from condensed mesenchyme which undergoes chondrification to form hyaline cartilage models. The growth of cartilage, the mechanism of perichondral and endochondral ossification of bone are well described (Vaughan 1970, Royer 1974, Moore 1973, Warwick and Williams 1973, Bloom and Fawcett 1976). Irregular bones, such as the bones of the pelvis, develop in a manner similar to that of a long bone epiphysis.

The structure of fetal bone differs from that seen in the postnatal period. Embryonic bone is characterized by an irregular arrangement of collagenous fibres, a high degree of mineralization and abundance of osteocytes. With fetal aging, lamellar bone, which is less mineralized and contains fewer osteocytes, forms along the length of the bone producing the compact cortex of fetal bone. Royer (1974) noted that a surprisingly small amount of osseous remodelling occurs in prenatal life.

Chondrification in the femoral shaft has been observed in stages 17 and 18 embryos. However, at term the trochanters and the head of the femur remain cartilaginous (Gardner and Gray 1950, 1970, Gardner and O'Rahilly 1972). Many investigators concur with Watanabe (1974) that the femoral head forms as a spherical structure and does not change in contour throughout the growth phase. However, several investigators have commented on the globular shape of the femoral head. From measurements, Ralis and McKibbin (1973) stated that the head represented 80 percent of a true sphere in the embryo but that the head was closer to a hemisphere at birth. Tests with precise measuring tools have shown that the adult femoral head is aspherical and that a sex difference in the degree of asphericity was present (Clarke and Amstutz 1975). Despite the number of observations on the unchanging sphericity of the head, there is no study reported in which precise tools have been used to assess fetal femoral head shape and its variability.

Felts (1954) noted that the head grows out of proportion to the neck of the femur, and considered that " . . . the possibility existed of discrete but as yet unmeasured differences in growth rates of very localized areas of cartilage." While Bardeen (1905) and de Santo and Colonna (1939) described the presence of a defined neck, several investigators have commented on the shortness of the femoral neck at term (Morville 1936, Felts 1954, Gardner and Gray 1970, Crelin 1976). No linear measurements were located at any stage in the prenatal period.

The neck-shaft angle (Fig. 1) and the torsion angle (Fig. 2) are two commonly measured variables of femoral development. Comparability of studies is reduced by the variation in methods used to measure these angles. Frequently the techniques employed were based on the assumption of a spherical head centred on the neck, and the use of the head to align the neck axis. Felts (1954) commented on the tendency for investigators to ignore the neck-shaft angle, and considered that this was due to difficulties of measurement in small fetuses. There is agreement that this angle decreases in fetal life (Humphry 1888-9, Strayer 1943, Felts 1954, Andersen 1962). Stanisavljevic (1964) reported average values of 140° to 145° at term. Because of the method employed, these values may be high. There is a discrepancy between the values reported for fetuses by Felts (1954), Stanisavljevic (1964) and Watanabe (1974). Since Stanisavljevic's values are generally accepted, further

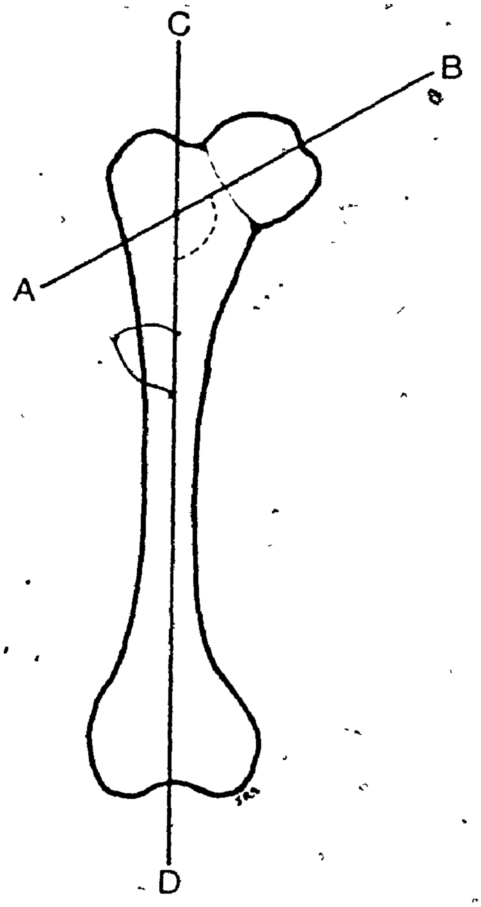


Figure 1: The neck-shaft angle of the fetal femur

Measurement of this angle in fetuses is complicated by the shortness of the femoral neck. Line AB should be centred on the neck, not the mid-point of the head. Line CD is the long axis of the femur.

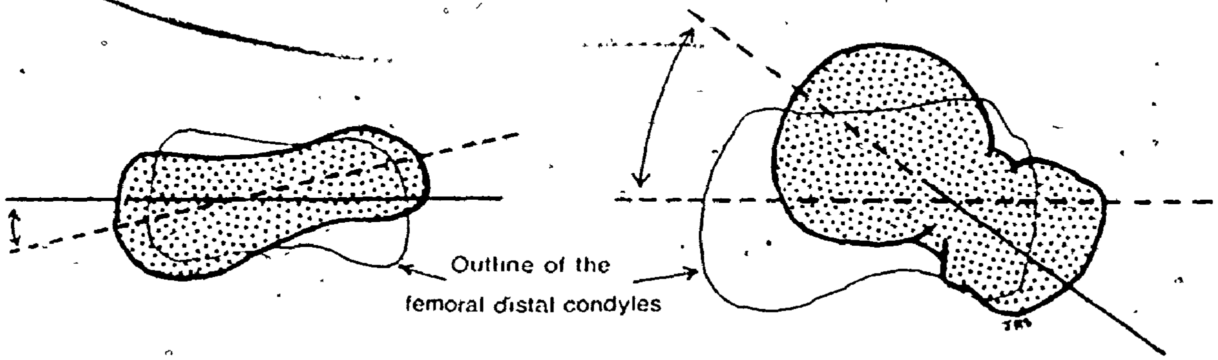


Figure 2: Femoral torsion

On the left negative torsion (retroversion) considered typical of the early fetal period.
On the right positive torsion (anteversion) in a near term femur. (after Gardner 1972)

study is necessary to validate his findings, and to determine if this angle is changing in the period from 12 weeks to term. Furthermore, no study on the fetal femur has given limits of normal variation for this angle. Since this angle is easily determined in infants on radiographs, it is important to determine whether it is correlated with other hip variables, such as acetabular depth.

Le Damany (1904), later supported by a number of other workers (Milch 1943, Kingsley and Olmsted 1948, Watanabe 1974), theorized that positive torsion developed in the second half of fetal life. However, Felts (1954) concluded that the increase in torsion was characteristic of the whole prenatal period. Despite the common usage of "anteversion of the neck of the femur" there is general agreement with Le Damany's theory that torsion does not occur between the neck and the femoral shaft, but is a torsion of the distal end of the shaft in relation to the proximal end (Felts 1954, Kingsley and Olmsted 1948). It is therefore important to determine the true longitudinal axis of the neck of the femur. Kingsley and Olmsted (1948) in a largely postnatal sample, noted that 68.7 percent of all femora had the head displaced either anteriorly or posteriorly. Le Damany thought that mechanical factors such as internal rotation of the flexed thigh caused by pressure of the uterine wall produced positive torsion, while Badgley (1949) hypothesized that muscular forces were responsible. From macroscopic and microscopic studies, Strayer (1943) and Gardner (1972) were unable to explain the mechanisms producing angulation of the femur. A remodelling process, different to normal growth processes of bones, say in length, was hypothesized. As in the neck-shaft angle, none of the studies on the fetal femur have given the variation about the means, other than ranges, nor has the correlation of torsion with several hip variables been reported.

Histological studies of chondrification have provided evidence that the head of femur anlage appears about three days before the concave acetabular anlage is observed (Strayer 1943, Gardner and Gray 1950, Andersen 1962, Gardner and O'Rahilly 1972, Wosko 1974). Figure 3 demonstrates the fetal development of the os innominatum and the acetabulum. Ossification commences in the ilium, followed by centres in the ischium then the pubis. However, at birth there is a predominance of bony elements over cartilage only in the roof of the acetabulum.

The question of whether the depth of the acetabulum is constant throughout fetal life, or whether, in relation to the socket diameter, depth progressively decreases so that the socket is shallow at birth is not completely settled. A deep concavity has been observed in early fetuses (De Santo and Colonna 1939, Strayer 1943, Andersen 1962, Ralis and McKibbin 1973, Watanabe 1974). Several investigators have noted that the head fits normally into the concavity of the acetabulum at term (Gardner and Gray 1950, Stanisavljevic and Mitchell 1963, Gardner 1972). However, Le Damany (1904) claimed that the acetabulum was shallowest at term and Ralis and McKibbin (1973), from direct measurements, supported this theory. Only these two investigators, with Watanabe (1974) have measured the socket. There is general agreement that the osseous roof, or osseous socket is flat at term (Morville 1936, Laurenson 1965, Hadziselimovic and Secerov 1968). Concavity of the osseous roof was observed to commence in the seventh postnatal month (Hadziselimovic and

Figure 3: Prenatal development of the os innominatum

Stippled areas indicate ossification

a) Primary centres of ossification

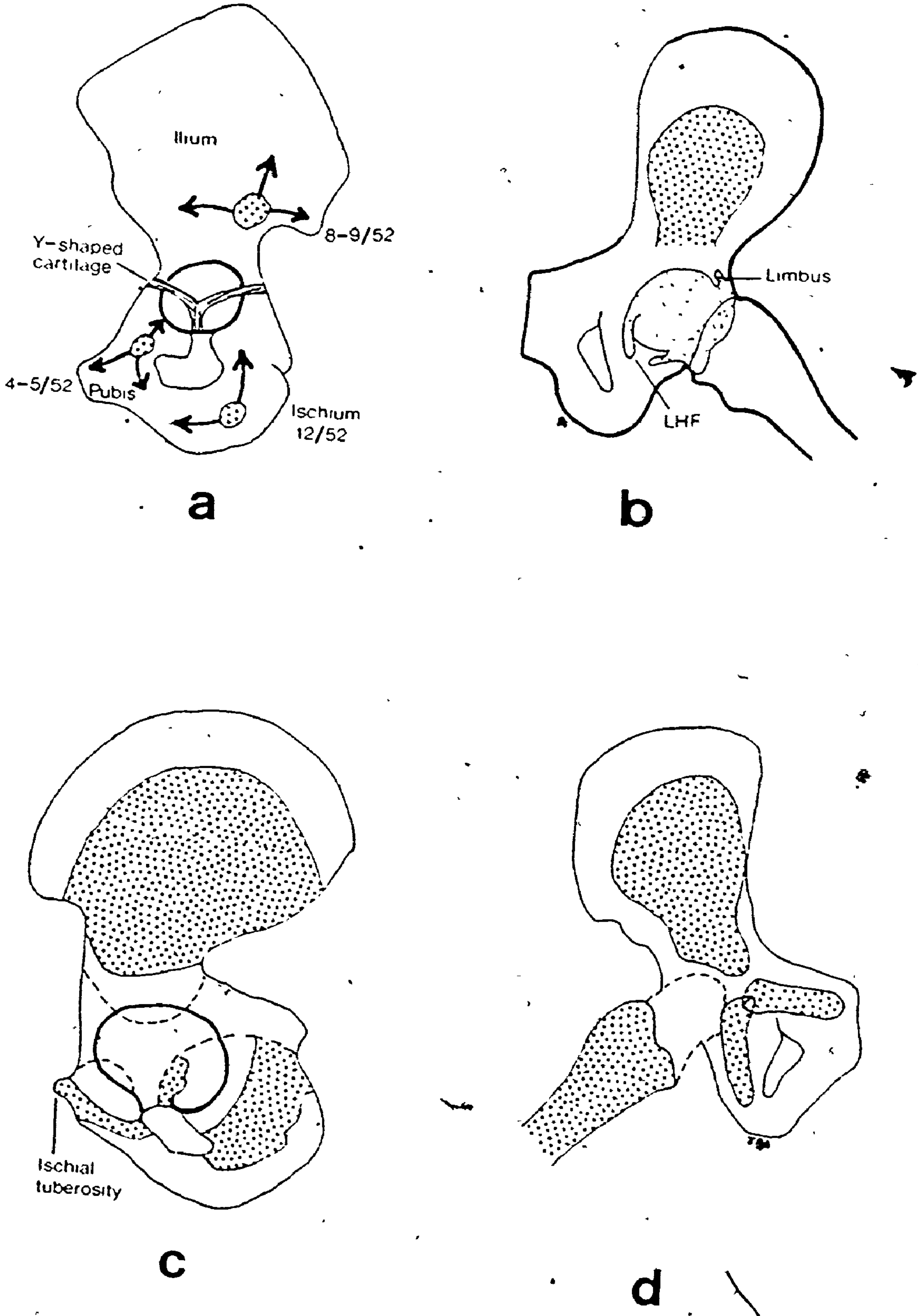
b) Diagram of the 14 week fetal hip showing arthrogram features*

c) Os innominatum at birth. The ossified part of the ischium is shown in the floor of the acetabulum.

R. Warwick & P. L. Williams. 1973 Gray's Anatomy, Fig. 3, p. 351, Churchill Livingstone. With permission.

d) Diagram of a term fetal hip showing typical radiographic appearance. The osseous roof of the acetabulum is sloping. The cartilaginous roof which is congruous with the femoral head is not visible.*

*after Laurenson (1965)


Ilium
8–9/52
Y-shaped cartilage
4–5/52
Pubis
Ischium 12/52
a
Limbus
LHF
b
Ischial tuberosity
c
d

Secorov 1968). Controversy around Morville's claim that the hip joint is vastly underdeveloped at birth and that a flat socket is normal at term, appears related to lack of distinction between the osseous roof and the normal shaped cartilaginous acetabulum. Few of the observations on acetabular depth have been based on actual measurements in an adequate sample of hips. The two largest samples studied, Stanisavljevic's (1964), 300 hips, and Watanabe's (1974), 288 hips, add very little since the former did not measure depth and in the latter the data are inadequately presented. There are no reports on the variability in depth at different age points. Individual case values (Le Damany 1904) or means (Watanabe 1974) may be misleading.

Laurenson (1965), in his histological studies, observed at term that the medial outer perichondral border projected further than the lateral perichondral border. The inner endochondral portion was less advanced. From measurements of the angular values of the cartilaginous acetabulum and the labrum, Kobayashi and Mizuno (1965) support the opinion that the acetabulum does become shallower towards term, and that the labrum plays a role in hip stability.

Since Cheynel and Huet (1952) reported a 3.5 mm difference in acetabular depth between Black and White newborns, there is a suggestion that growth studies should not be based on racially mixed samples. The matter requires further investigation.

The formation of the interzone, present in fetuses between 20 - 25 mm crown rump length (CRL) is well documented (Moser 1892, Strayer 1943, Haines 1947, Gardner and Gray 1950, Andersen 1962, Gardner and O'Rahilly 1972). By 47 mm CRL the cavity extends along the femoral neck and by five to six months it ends as an outpouching near the greater trochanter. Dislocation of the joint cannot occur until the joint cavity is fully opened. Watanabe (1974) noted the head of femur readily dislocated at eleven weeks (9.1 mm CRL).

A perennial question, still subject to debate, is whether a shallow socket, dysplasia, is primary or secondary to subluxation or dislocation of the femoral head. Tissue culture studies have shown that the femur, in the chick embryo, will attain normal form when isolated. However, concave facets when isolated initially deepen but then flatten out as the culture proceeds (Fell and Robison 1929, Fell 1938, Chen 1952). This is evidence that a normal acetabulum may not develop without the pressure stimulus of the head of the femur. It is not established at which stage the femoral head and the acetabulum are interdependent for normal growth.

Movement is thought to play an important role in development of the joint, especially once cavitation of the interzone to form the future joint cavity has commenced, and in the final modelling which is marked in the first year of life (Hadzeselimovic and Secerov 1968, Drachman 1969). Badgley (1949) considered the changing position of the limb bud, prior to separation of the joint cavity, to be a possible mechanism in the production of the neck-shaft angle of the femur. Delayed leg folding and persistence of the breech posture of hip flexion, internal rotation and adduction with knee extension (Fig. 4) is claimed to be an important factor in the etiology of congenital hip disorders (Wilkinson 1966).

Early in development, the labrum acetabulare (limbus, limbus

Figure 4: Theoretical development of the intra-uterine posture

Stage 1: The breech posture of flexed hips and extended knees, considered common in all fetuses at eight to twelve weeks.

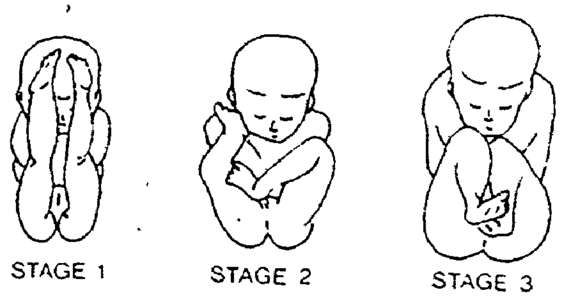
Stage 2: The folding mechanism of the legs which occurs with innervation of the knee flexors.

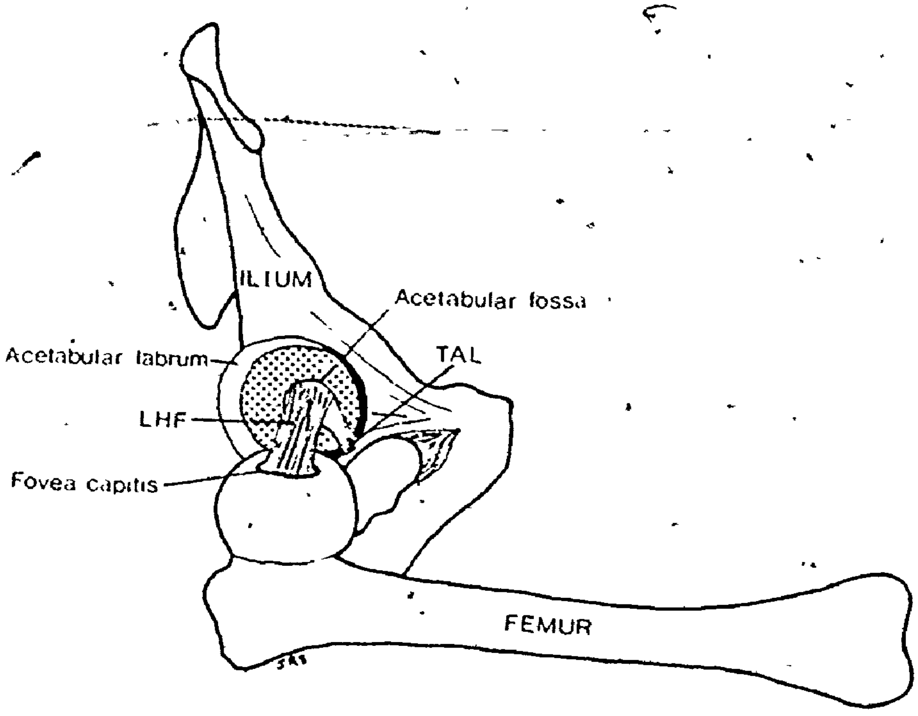
Stage 3: The typical vertex posture with knee flexion which is adopted between 26 and 40 weeks.

(Wilkinson 1966:1107. With permission.)

Figure 5: The acetabular labrum, ligament of the head of femur (LHF), the transverse acetabular ligament (TAL)

The stippled area represents the horseshoe-shaped cartilaginous portion of the socket. Note that the labrum merges with the TAL inferomedially. The LHF is shown attached to the fovea of the head of femur (fovea capitis) and the acetabular fossa. The ligament may take attachment up to the TAL. When the capsule is removed, the intact LHF permits greatest motion of the head from the acetabulum inferiorly, with adduction.


STAGE 1
STAGE 2
STAGE 3


ILIUM
Acetabular fossa
TAL
Acetabular labrum
LHF
Fovea capitis
FEMUR

horn, cotyloid ligament) covers more degrees of the arc of the acetabulum and will, therefore, contribute more to the stability of the joint (Strayer 1943). While the labrum is frequently described as being fibrocartilaginous (Ralis and McKibbin 1973, Grant 1958, Crouch 1972, Francis and Martin 1975, Gardner, Gray and O'Rahilly 1975), Gardner and Gray (1950) and Sawada (1968) emphasized that no cartilaginous cells of tissue similar to adult fibrocartilage are found. Sawada (1968), who has reported the only study confined to the labrum at all ages, considered the labrum to be fibrous in origin. He observed that cartilaginous cells were not found in the labrum at any age. It is not clear to what Gardner and Gray (1950) refer to in their distinction between "cartilaginous labrum" and the "fibrous acetabular lip."

Regional differences in the labrum have been described (Gardner and Gray 1950, Andersen 1962, Sawada 1968). Gardner and Gray (1950) observed a lining of cartilage-like tissue, present on the inner surface of the labrum and continuous with the adjacent hyaline cartilage in a 60 mm CRL fetus. Sawada (1968) only noted this at 24 weeks of fetal age. Several investigators have reported the presence of blood vessels at the periphery of the labrum which in older specimens may penetrate the fibrous labrum, occasionally being traced to its free margin (Andersen 1962, Gardner and Gray 1950, Sawada 1968). The mature labrum is composed of collagenous fibres with a density similar to menisci, is wedge-shaped with a sharp free edge, encircles the socket and is separated from the capsule by a small recess (Fig. 5). In the infant hip, Ogden (1974) noted that the peripheral portion was composed of fibrocartilage while the bulk of the labrum was hyaline cartilage, as was the acetabulum proper. Sawada's histological studies do not support this viewpoint, since he observed cartilaginous cells to be only present, at any age, at the articular margin. Matles (1967), however, concluded from a study of nonformalin-fixed term labra that differences in histologic findings are due to the technique of preparation rather than histodifferentiation.

With a shallow socket, an abnormally long ligament of the head of femur (LHF) and simple capsular laxity are factors cited in the etiology of neonatal and infantile hip subluxation and dislocation. However, in one study of operative findings in CDH cases, 20 percent of cases had congenital absence of the LHF (Scaglietti and Calandriello 1962). No data are yet available on the length of the LHF and its variability at different ages. It is not established whether the elongated LHF observed in abnormal hips (Stanisavljevic 1964, Dunn 1969, Watanabe 1974) reflects a ligament that was originally longer than "normal," or whether the length reflects lengthening due to stress of the abnormal position of the head of femur relative to the socket.

Ligamentum capitis femoris is the official term (International Anatomical Nomenclature Committee 1966) and the anglicized abbreviation LHF will be used herein. Crelin (1976) noted in 26 stillborn infants that the LHF was a flat band of connective tissue as in the adult. Thus the former terms, ligamentum teres or round ligament, are "descriptively erroneous." In the literature attention has been given to the shape of this ligament only when some pathology was present.

There is general agreement that LHF develops in situ (Schuster 1878, Bardeen 1905, Walmsley 1917, Strayer 1943, Haines 1947, Gardner and

Gray 1950, Andersen 1962) and no support exists for the earlier theories that the LHF was first part of the joint capsule or originally part of the tendon of pectineus that migrated into the joint (Sutton 1883, Moser 1892, Parsons 1900, Keith 1933, Frazer 1940). The morphological development of the LHF has been described by a number of investigators, however uncertainty still exists as to the function of this ligament. As early as 1834 Sandifort discounted this structure's role as a ligament. The most consistent function attributed to the LHF is to convey blood vessels to the head of femur. While Haines (1947) considered his data gave support to this hypothesis, Andersen (1962) and Gardner and Gray (1950) found that few vessels actually entered the fetal head of femur. Crelin (1976), from a study of hip stability in term stillborn infants, concluded that the LHF and not the capsule was the most important structure preventing posterosuperior dislocation of the head of femur.

Gardner and Gray (1950) observed the capsule was not a definite entity until 49 - 50 mm CRL. There is increasing density of collagenous fibres thereafter, but the increase is not uniform, and regional differences may be apparent until term. Inferior to the zona orbicularis the fibrous capsule is reported to be less developed (Gardner and Gray 1950, Andersen 1962).

The labrum blends with the transverse acetabular ligament (TAL). Strayer (1943) observed in the region of the TAL that cartilage was not present in the socket and at the time of joint opening the TAL does not enclose the head of femur beyond its greatest diameter. The site of the TAL has been considered the weakest point in the structure (Strayer 1943, Watanabe 1974). Figure 5 shows the relative positions of the LHF, the labrum and the TAL.

The typical posture of the newborn is one with flexion and abduction of the thighs, flexion of the knees with the feet in equinus and adduction (Crelin 1976). At term muscle development is not uniform. The adductor group is quite large in relation to the abductor group, which with the external rotators are poorly developed (Ogden 1974). Extension of the hip is limited at term due to the flexed fetal posture and the dominance of the flexor muscle groups.

The hip joint, potentially unstable at birth, improves functionally during postnatal life. With growth, ossification spreads to the rim replacing the cartilage. The Y-shaped portion of the acetabular cartilage commences to ossify from the 12th year and ossification is completed between the 20th and 25th year. The forward inclination of the acetabulum (anteversion) increases from a neonatal value of 7° to an adult value of 17° (McKibbin 1970). One of the main postnatal changes in the femur is the development of a true neck. Equilibrium of forces acting on the proximal femoral growth plate will determine the neck-shaft angle (Ogden 1974). This angle gradually decreases to an average adult value of 125°. Torsion angle values also decrease from an average of 35° ~~at~~ birth to the 10° to 15° average found in adults (Le Damany 1914, Whitman 1923, Rogers 1934, Felts 1954). The sharpest decrease between any age group is reported to occur in two- year old infants (Dunlap et al. 1953). Table 2 demonstrates the small variation in average values for the neck-shaft angle reported from anatomical sample based studies on adult femora. The variability seen in adult torsion angle values is demonstrated in Table 3. The newborn hip range of motion which exceeds 60° in abduction, but is limited in extension and

Table 2

Neck-shaft angle values reported for adult femora, in degrees.
*SD = standard deviation

Reference		n	Mean	Range	Study Type
Parsons	(1914)	300	126.4	112-140	13-14th century femora
Pearson & Bell	(1919)	800	130.2 127.3	(SD* 6.68) 106-149	17th century femora modern Homo sapiens
Ingalls	(1924)	100	127.1	106-145	anatomical collection
Pick <u>et al</u>.	(1941)	150	126.4	104-147	anatomical collection

Table 3

Torsion values reported for adult femora, in degrees

Reference		n	Mean	Range	Study Type
Soutter & Bradford	(1903)	154	14.3	-9 to +40	anatomical collection
Parsons material	(1914)	300	15.5	-17 to +40	13-14th century
Durham	(1915)	200	11.9	0 to +35	anatomical collection
Pearson & Bell	(1919)	800	15.3	(SD 8.08)	17th century collection
Ingalls	(1924)	100	9.73	-14 to +27	anatomical collection
Pick <u>et al</u>.	(1941)	152	14.0	-18 to +41	anatomical collection
Elftman	(1945)	35	11.86	0 to +26	anatomical collection, rights only
Kingsley & Olmsted	(1948)	630	8.02	-20 to +38	anatomical collection

internal rotation, will evolve into the adult range of motion: abduction 45°, adduction 15°, flexion 125°, extension 5-15°, external and internal rotation 45° (American Academy Orthopaedic Surgeons 1965).

Gardner (1972:151) from his histological studies concluded that there were:

> . . . no morphological features of normal prenatal development which provide a significant clue to the etiology of CDH. Nor is there any valid reason to support the thesis that this condition is a primary embryonic development defect.

Metabolic defect(s) in development and formation of connective tissue, especially collagen, may be involved in the etiology of CDH (Wynne-Davies 1970, Fredensborg and Uden 1976). Dunn, in a number of papers (1965, 1969, 1971a,b, 1972, 1974, 1976a,b,c) has produced considerable evidence to support the hypothesis first proposed by Dennis Browne (1936, 1955) that congenital postural deformities are caused by mechanical factors. The hip joint is frequently involved when dislocation of a joint occurs, in isolation, or as part of a complex of congenital abnormalities. Distinction is made between malformations which arise in the embryonic period and congenital postural deformities " . .. deformities . . . which arise in later fetal life and are alterations in the form and structure of a previously formed part" (Dunn 1976a). Deformities such as talipes and CDH are rarely observed before the 20th week of gestation (Nishimura 1970). This confirms the belief that these anomalies arise in late pregnancy. Several investigators have reported cases of congenital hip disease (CHD) in stillbirths or cases of perinatal death (Stanisavljevic and Mitchell 1963, Stanisavljevic 1964, Laurenson 1964, Dunn 1969, Watanabe 1974). In many of these cases CHD was a single entity, and the morphological features of these hips were similar to that observed during corrective surgery of CHD infants. However, Barlow (1966) suggested that autolytic changes were responsible for certain reported cases of abnormal hip morphology in stillborn fetuses.

It is recognized that many cases of dysplasia in liveborns are probably unrecognized since dysplasia involves to a greater degree the cartilaginous socket, not visualized on ordinary radiographs. The relationship between infantile hip dysplasia and adult ostoearthritis (Putti 1929, Morville 1936, Wiberg 1940, Hart 1942, Salter 1968, Gofton 1971, Pappas 1973) requires longitudinal studies. In addition, there is a need to develop a technique which will permit visualization of the cartilaginous socket without exposure of infants to unnecessary radiation hazards. The present arthrogram is unsuitable for population studies.

Huxley (1932) commented that underlying growth processes ". . . can be better understood when descriptive data can be stated as quantitative expressions which may be indispensible to making certain systematic and biological deductions." Reported studies of the developing hip joint have been restricted to descriptive statistics and univariate analysis. Only Felts (1954) in his detailed study of the prenatal femur has analysed the data in terms of growth rates. Le Damany (1904) first demonstrated the close relationship between the femoral head, acetabular size and shape and femoral torsion. Felts (1954) concluded that the proportional increase in the femoral head should obviously be studied in relation to factors other than the femur alone. The availability of computer programs now permits the usage of multivariate analysis which can handle correlation between variables. A degree of correlation may be expected between the dimensions of the hip joint. If univariate analysis only is employed, greater differences than actually exist may be predicted, for example, between males and females (Morrison 1967, Kramer 1972, Zar 1974).

The first trimester of prenatal life is characterized by rapid growth and differentiation while in the fetal period developmental changes are relatively slow and continuous. The third trimester is marked by a greater increase in mass than an increase in length. The incremental model used by Scammon and Calkins (1929) and Felts (1954) therefore will not give best fit through the entire fetal period. This linear model implies that the increase in the measured dimension is constantly proportional to the increase in age during the fetal period. Both of these investigators found, for some variables, that the lines of best fit were not rectilinear but were better demonstrated by a parabolic or hyperbolic curve.

Johnson et al. (1975) commented that due to their non-linear nature, growth curves are often difficult to fit statistically to a set of measurements. These authors considered that there was little guidance yet available for estimating general growth curves, or for determining which growth curve is the most appropriate for a set of data. Huxley (1932) observed that some of Scammon and Calkin's data was better fitted by his allometric formula, $y = ax^b$. This formula is based on the assumption that growth is essentially multiplicative, and changes in self-multiplication affect all parts of the body equally. However, since bone length does not increase by self-multiplication of tissue, that is an overall increase in mass, a correction factor is needed.

Felts (1954) did not examine his data for sex and side differences. Scammon and Calkins found no sex differences, but they noted that no detailed study was made of possible sex differences. The need to examine hip joint growth data for possible sex and side differences is indicated by the demonstrated higher female to male, and left to right side involvement in reported cases of CHD (Walker 1973). Dunn (1974) related the left hip predominance in CHD to the position in utero.

Since no comprehensive growth study was located on the fetal hip joint, in the present study measurements will be made of a number of variables with an adequate sample at two-weekly periods from 12 to 42 prenatal weeks. Variables to be measured bilaterally on each fetus are acetabular depth and diameter, femoral head diameter, the LHF length and width, and the femoral torsion and neck-shaft angles.

Statistical analysis will be performed with consideration of correlation between variables and investigation of the possible differences between the sexes and the right and left sides. Growth rates will be determined and expressed graphically. Any abnormal hip joints detected will be retained in the study but will be analysed separately from normal joints. An attempt will be made to elicit the characteristics which may typify congenital hip disease.

On a limited number of acetabula the development of ossification in the acetabular roof and the morphology of the acetabular labrum will be investigated at the histological level.

Chapter 2

MATERIALS AND METHODS

Specimens

Human fetal material in the age range 12 weeks to term was obtained from several sources in Canada and U.S.A. Specimens were the products of elective abortion (62.2%), stillbirths (23.7%) and perinatal deaths (14.1%). Specimens with a gestational age greater than 20 weeks or an equivalent crown-rump length (CRL) measurement (Canada) or 24 weeks (U.S.A.) were obtained from bequeathals to Anatomy departments. The sample by source and by type of abortion or age of death is given in Appendix A.

Criteria for inclusion into the normal growth study were:

1. an absence of external congenital malformations (including internal if an autopsy was performed);
2. minimal maceration, graded according to Streeter (1920);
3. postnatal viability not greater than 24 hours;
4. Caucasian;
5. gestational age between 12 weeks to 42 weeks, or the equivalent crown-rump length measurement of 8.7 cm to 40 cm (Moore 1973);
6. normal hip joint morphology.

Of the 158 fetuses or paired fetal hip joints collected, 140 were suitable for inclusion in the growth study. Eighteen fetuses were excluded but will be reported separately. Of these, four were rejected due to a postnatal age greater than 42 weeks; six due to the presence of a congenital malformation; and seven due to the presence of abnormal hip joint morphology. One was excluded as death occurred at 35 days post birth. Premature infants who lived a number of days were not included as it is considered that the intensive care received in neonatal units may cause deviation in the normal growth patterns.

Specimen Quality

Specimens of CRL less than 16 cm were received shortly after the abortion. Specimens with a CRL greater than 16 cm had, for the most part, been stored in fixative for variable time periods, the majority not greater than five years. One had been stored for 20 years. In 22 cases only the pelvis and femora were received. Macerated specimens were not accepted. Eighty-seven percent of fetuses could be classified as Grade 1 and 13 percent as Grade 2 of Streeter's (1920) classification of fetal material. Fetuses that had been kept in small containers were rejected as inadequate fixation and post-fixation compression effects may be suspected.

Ethnic Group

Cheynel and Huet (1952) reported apparent differences in several hip joint measurements between Black (Senegal) and White fetuses. An attempt was made to restrict the sample to Caucasians. However, since the sample was derived partly from two American sources both with a sizable Black population, the sample may contain a mixture of racial types. No known Blacks were included but a percentage may be suspected since in many cases of elective abortion the father is listed as unknown.

Currently, race is not always recorded since it is considered discriminatory. Family data were generally unavailable for anatomy department derived specimens. Bracken and Swigar (1972) reported racial proportions of induced abortions at the Yale-New Haven Hospital to be 70.4 percent White or Spanish American, with 29.6 percent Black. Thirty-nine percent of the specimens in the present study were derived from this source. In cases where family data were unavailable, fetuses were rejected if Negroid physical characteristics were present.

Sample Size

The initial objective was to obtain for the normal growth study a minimum of 15 fetuses for each two-weekly age period from 12 to 20 weeks. A minimum of five fetuses (or paired hip joints) was the objective for each two-weekly period after 20 weeks, the legal age for a reportable stillbirth requiring formal bequeathal. This objective was not met for fetuses in the third trimester. Only one normal fetus was collected for each of the age groups 28 and 36 weeks. Table 4 presents the total number of fetuses collected (158) by two-weekly age groups and presents a breakdown for the normal growth study (140) and others (18) which will be reported separately.

Sex

Of 158 fetuses, 74 (46.8%) were male, 82 (51.9%) were female and in two sex was unknown (1.3%).

Individual Data

When available the following data were collected for each case: date of birth and/or date of death, cause of death, crown-rump length,

Table 4

The number of fetuses by age groups with mean values and range of crown-rump lengths

Age Group (weeks)	CRL* (mean) cm	CRL Range*		Growth Study		Others	Total
		min.	max.	with CRL	missing CRL		
12	10.5	8.7	11.9	16	0	1	17
14	12.9	12.0	13.9	18	0	-	18
16	14.9	14.1	15.9	18	0	-	18
18	17.7	16.0	18.7	19	0	2	21
20	19.9	19.0	20.8	15	0	1	16
22	21.7	21.0	22.5	12	0	-	12
24	23.8	23.0	24.7	8	1	-	9
26	25.1	25.0	25.5	8	0	-	10
28		27.5		1	0	-	1
30	28.3	28.0	28.9	5	2	2	9
32	30.0	30.0		2	0	-	2
34	32.5	32.0	33.0	2	1	1	4
36		34.0		1	0	2	3
38	36.0	36.0		2	0	-	2
40	37.8	37.5	38.0	3	2	3	8
42	39.3	38.5	40.0	2	2	-	4
<50	unknown	-	-	-	-	1	1
>50	unknown	-	-	-	-	3	3
				132	8	18	158
				(140)			

* for growth study group only

birth weight, parental age, racial group, autopsy findings if performed, type of birth and the estimated gestational age based on the last menstrual period.

Specimen Age Determination

The crown-rump measurement (cm) was used to assess the age of fetuses. Eight fetuses (5.7%) lacked this data (Table 4). In these cases birth weight (corrected by 5% when weighed in the fresh state) and/or estimated gestational age was utilized. Vernier scaled anthropometric calipers were used and the fetal spine was straightened but not extended (Streeter 1920). Fetuses were measured after two weeks in fixative as there is a small increase in CRL immediately after simple preservation in formalin (Schultz 1919, Streeter 1920, Scammon and Calkins 1929).

The CRL measurement was selected as the standard for estimation of the age of specimens since it remains widely used and is therefore more frequently recorded. Further, use of the CRL permits comparison of this study with previous reports of hip joint development. Gardner and Gray (1970) noted that the CRL measure was still regarded as " . . . . the most useful index of the growth of fetuses." There is, however, considerable variability in the CRL reported for different gestation ages (Streeter 1920, Scammon and Calkins 1929, Potter 1952, Potter 1961, Moore 1973, Potter and Craig 1975). Appendix B demonstrates this variability. Developmental horizons which are available for the embryo, based largely on the work of Streeter (1942, 1945a, 1945b, 1951), are not yet available for the fetus. It is recognized that Streeter underestimated CRL in young embryos (Gardner and Gray 1970). Moore (1973) has presented main characteristics with CRL, weight, foot length and estimated age. While Moore's CRL mean values exceed those reported by other investigators, they are within reported standard deviations for age of CRL. Böving (1965) commented that uncertainty in age estimates vary from one week at 17 weeks to four weeks at term. Potter and Adair (1949) presented weight group means with mean CRL which correlated with those given by Moore (Appendix B). There is closer correlation to Moore's standards than to Streeter's, which is the most widely used standard, when an age estimate by ultrasound is available for specimens. The study population which includes therapeutic abortions is more similar to Moore's population than that of Streeter (1920) and Scammon and Calkins (1929). For the reasons given above, the CRL means reported by Moore (1973) were selected as the standard for age groups in this study. The present series of fetuses have a CRL range from 8.7 cm to 40 cm. By Moore's standards this is an age range from 12 weeks to post-term. Establishment of age groups permitted inclusion of eight third trimester fetuses that lacked CRL data. The means and range of CR lengths for each age group in the normal growth study sample are given in Table 4.

Fixation

The majority of fetuses were received prefixed in neutral 10% formaldehyde (formalin) and were transferred to neutral formalin buffered to pH 7.0 (Lillie 1954). Inadequate fixation is suspected since many fetuses were initially immersed in a small quantity of fluid. Whole fetuses were measured and weighed after two weeks in fixative. The larger fetuses were immediately measured, weighed, and the hip joints dissected down to the level of the joint capsule to improve fixation.

Limb Posture

The posture of the lower limbs was recorded with the presence or absence of lower limb crossing. The level at which the lower limbs were crossed - toes, foot or leg - was noted.

Dissection

Dissection to expose the hip joint was carefully performed in order to observe any abnormal soft tissue morphology, such as absence of a specific muscle or variation in size or position of muscles. Mobility of the hip joint was assessed before and after ablation of the joint capsule at room temperature (20°) without prior warming of the specimen. The push-pull test (Babb and Sundberg 1970) was used to assess the tendency for the femoral head to dislocate. The capsule was then divided close to the femoral neck attachment to observe the presence and development of the capsule retinacula, and the presence or absence of a sulcus between the capsule and the acetabular labrum rim. Avoiding detachment of the ligament of the head of the femur (LHF) mobility of the joint was again assessed noting the capacity for subluxation or dislocation of the femoral head and the direction in which this could occur. Coverage of the femoral head by the acetabulum was noted in different joint positions.

The LHF was then carefully detached from the acetabulum using a pair of fine curved blade dissection scissors. In small specimens the detachment was performed under the dissecting microscope.

MEASUREMENTS

A Wild stereoscope fitted with a 10X wide field measuring eyepiece with a 12 mm scale in 120 divisions was used to measure the maximum length of the LHF, the maximum width of the free portion of the LHF, the maximum transverse diameter of the acetabulum, the maximum transverse diameter of the femoral head and the depth of the acetabular socket.

All measurements were repeated consecutively three times with the specimen moved and repositioned each time. The decision to use n = 3 was based on trials which showed a maximum difference of 0.1 mm in the means for sets of n = 3, 5, 10 and 15 measurements. Means of these measurements, adjusted for the ocular scale, were recorded (Appendix C). All measurements were recorded in millimeters. The total number of specimens measured for each variable, and the total by age category for the specimens included in the growth statistics (n = 140) is given in Appendix D. Specimens were kept moist during all measurements. When the specimen was received with the joint previously dislocated, measurements were not taken of the LHF width and length.

LHF Length

To limit any effects of tissue contraction the LHF was measured immediately following its detachment from the acetabular fossa. Length and width were measured with the LHF attached to the fovea of the femoral head. Maximum length was recorded from the junction of the ligament with the cartilage of the femoral head (see Fig. 5) to the free acetabular end. Initial attempts to record the maximum length of the free portion of the ligament resulted in poor reproducibility of measurements due to lack of precision in locating the exact point the ligament was free from the fovea capitis.

Length measurements were adjusted for taking a linear measure on a curved surface, the femoral head, by the following formulae:

$$s/d = \sin (x°)$$

$$L \text{ (mm)} = (2x°/360) \times d$$

where $s < L$, s = microscope measurement of LHF length, L = corrected length, and d = microscope measurement of the maximum transverse diameter of the femoral head. The shape of the femoral head was assumed to be spherical.

LHF Width

The maximum width of the free portion of the ligament was measured. Where the ligament appeared unusually thick, depth (= thickness) was recorded but not coded onto the computer forms.

Acetabular Diameter

Acetabula were orientated prior to measurement by lining up the anterior inferior iliac spine and the ischial tuberosity on the vertical hair of the ocular. The maximum transverse diameter between the inner surfaces of the anterior and posterior labrum rims was measured. The relationship between the vertical, transverse and oblique diameters (determined with respect to the anatomical position) was investigated. Where the vertical or oblique diameter exceeded the transverse this was recorded but not coded onto the computer forms.

Femoral Head Diameter

To investigate the relationship between the femoral head and acetabular diameters the maximum transverse diameter of the femoral head was measured. Vernier scaled calipers were used to measure postnatal femoral heads whose diameters were outside the range of the microscope ocular.

Acetabular Depth

The mechanical stage of the microscope was fitted with a Vernier side scale, three cm in length. The scale read one mm on the major and 0.1 mm on the minor (Fig. 6a). New control knobs were fitted. A pointer, adjustible in position and length, was fitted to the microscope head. The scale gave direct measurement values.

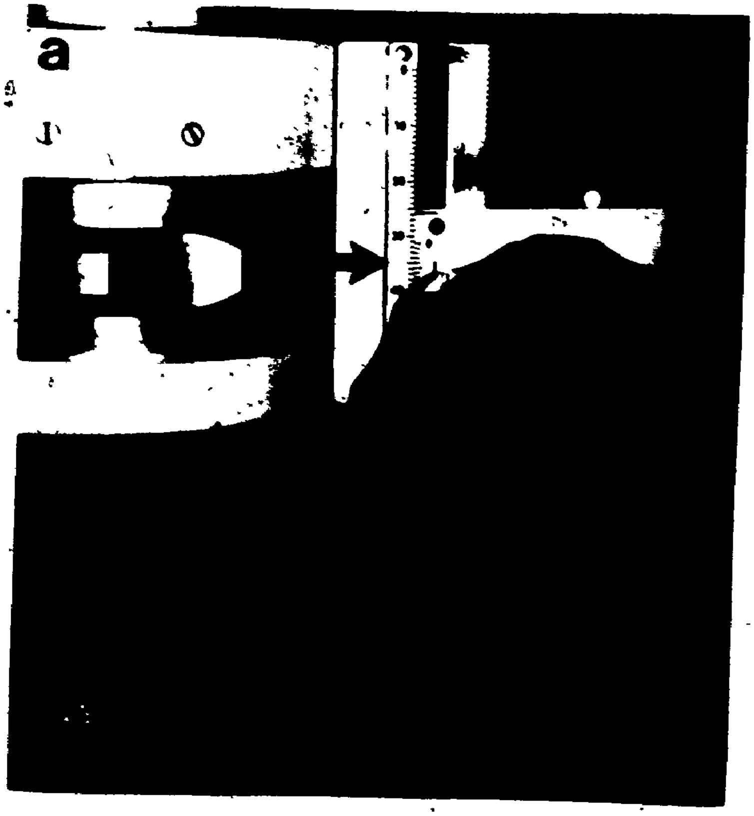
Prior to the depth measurement, the anterior and posterior rims of the acetabula were levelled by checking that the pointer made minimal contact with the superior edge of both rims. The position of the acetabulum was maintained with plasticine. Levelling of the rims ensured that measurement of depth made from either the anterior or posterior rim (determined by the specimen, right or left) would be identical. This was necessitated by location of the pointer on the right hand side of the microscope. When the pointer made contact with the rim the sliding scale was read (Fig. 6b). The acetabulum was then positioned over the centre of the socket (Fig. 6c). The pointer was then lowered to contact the lowest visible portion of the acetabular cartilage. This point was read off the sliding scale. Depth equalled the difference between the first and second measurement.

Figure 6: Acetabular depth measurement

a) A vernier side scale is shown mounted to the mechanical stage of a dissecting microscope. The pointer used in the depth measurement is visible in the lower left hand corner.

b) The pointer, attached to the microscope head and adjustable in position and length, is shown in contact with the rim of the acetabulum. Prior to taking the first of two readings to obtain the depth measurement the rims of the acetabulum are levelled by ensuring that the pointer makes contact with both rims. The position of the acetabulum is maintained by plasticine.

c) The tip of the pointer is in contact with the lowest point of the acetabular cartilage, in line with the rim reading. The difference between the rim (b) and the floor reading is the depth recorded.


a

Care was taken to ensure the pointer did not penetrate the labrum rim or the acetabular cartilage. This technique had high reproducibility (maximum range in sets of 3 measurements = 0.4 mm). It was easier to perform than the technique described by Ralis and McKibbin (1973) and appears simpler and more accurate than taking plaster of paris casts (Le Damany 1904).

Arthrograms

Injection of contrast material into the joint cavity permits visualization of joint morphology in the cartilaginous fetal hip. Morville (1936), Laurenson (1965), Nakamura (1968) and others have utilized arthrograms in studies of the developing hip and in cases of CDH. Laurenson (1965) reported measurements of acetabular depth and length of the femoral head in ten fetuses but noted that these measurements were not accurate.

Mammograph film (Kodak RP-M, X-Omat) and Renografin contrast material (0.5 cc) was used to determine whether this technique could be employed to obtain precise, reproducible measurements of acetabular depth, femoral and acetabular diameters. The results were unsatisfactory. It was not possible to obtain a constant position for arthrography in the formalin-fixed fetuses. Since it was anticipated that only locally obtained fetuses would be fresh material, the technique had to also be suitable for fixed material. The junction of the femoral head cartilage with the neck can only be determined by inference from the zona orbicularis constriction of the capsule. The quality of specimens obtained from diverse sources together with the variability in length of time in fixative may have contributed to the results obtained.

While arthrography clearly reveals the relationship of the head of the femur to the acetabulum, the distance of bone from the acetabulum, and other features, this technique is unsatisfactory for precise reproducible measurements of the variables under study.

Angles of the Proximal End of the Femur

The extreme shortness of the fetal femoral neck necessitates thorough stripping of soft tissues around the neck prior to measurement of the neck-shaft and torsion angles. Three measurements were taken on each bone for each angle, with the femur removed and repositioned for each measurement (Appendix C). The mean was entered onto the computer forms. Femora were measured in series of 10 right, 10 left, and the total sample was measured in two large series (#1-108, 109-159). To reduce possible bias due to a practice effect, 30 femora from each side were measured prior to recording any values for each series.

The Neck-shaft Angle

The femur was supported in the mid-shaft on a perspex block so that both extremities were free (Figs. 7 and 8). Plasticine was used to maintain the proximal extremity of the bone in the same plane as the shaft (Fig. 8a). An oblong piece of perspex (26.5 cm x 18 cm) with protractor markings for 180° was placed directly over the femur and rested on the measuring frame (Fig. 8b). After alignment of the vertical line with the long axis of the femoral shaft, the angle formed between the neck and shaft was read (Fig. 8c). The angle values were 5 cm from the edge of the protractor frame, ~~and~~ could not be easily read during alignment of the angle axes. This is considered to reduce possible bias in consecutive measurements.

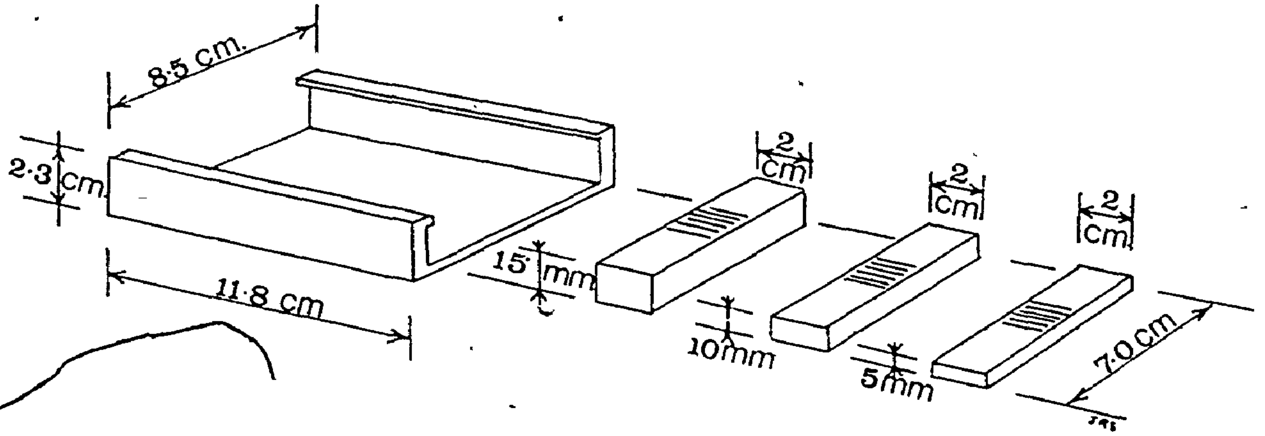


Figure 7: Neck-shaft angle measurement. Perspex frame and blocks

The three different heights of blocks are shown on the right. The blocks permit femora of varying size and torsion to be positioned with the head in the same plane as the shaft, assessed visually, and with the proximal and distal ends free. The protractor will rest on the superior ledge of the frame on the left. In a few cases the torsion angle in term femora necessitated positioning the protractor some distance above the frame.

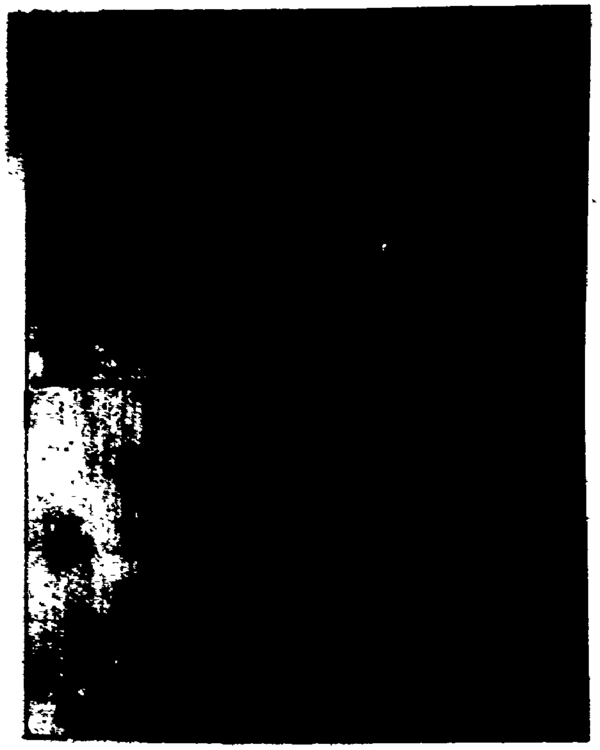
Figure 8: Neck-shaft angle measurement

a) The femur is positioned so that the head is in the same plane as the shaft. Perspex blocks are used to ensure the proximal and distal ends of the femur are free. Plasticine (p) is used to hold the femur in place.

b) A piece of perspex with angle divisions at the periphery is placed on the perspex frame. The long axis, 0° or 180°, is aligned with the long axis of the femoral shaft.

c) A straight-edge protractor is superimposed and aligned with the midpoint of the long axis of the neck of the femur. Note the shortness of the femoral neck.

a



c

The extreme shortness of the fetal femoral neck creates difficulties in the measurement of the neck-shaft angle which are not present in measurement of adult femora. Figure 9 shows that only the superior border of the neck is clearly delineated from the head in young fetal femora. This morphology of the femoral neck may persist to term. The fetal femoral head may be more elliptical than spherical. Pearson and Bell (1919) used the term "capito-collar" axis to imply that the head was not central on the neck of the femur. The line E-F bisecting the long axis of the femoral shaft (Fig. 9) must be at right angles with the transverse diameter of the neck, line A-B in the same figure. Where the head and shaft formed an almost straight line on the inferior (medial) surface of the neck, the inferior margin of the neck was taken as the inferomedial limit of the femoral head hyaline cartilage. Alignment of the neck axis at right angles to line C-D of the head as opposed to line A-B of the undeveloped femoral neck resulted in consistently higher values for the neck-shaft angle in fetal femora. In this study the first series of 108 femora was repeated due to initial faulty alignment of the axes.

Femoral Torsion

The angle of torsion is formed by a twisting of the proximal extremity of the femur in relation to the fixed bicondylar axis of the distal extremity. The angle to be measured is the angle between the plane of the central axis of the neck and the plane of the femoral condyles. When the femur rests on a level horizontal surface with the posterior surfaces of the distal condyles and the greater trochanter in

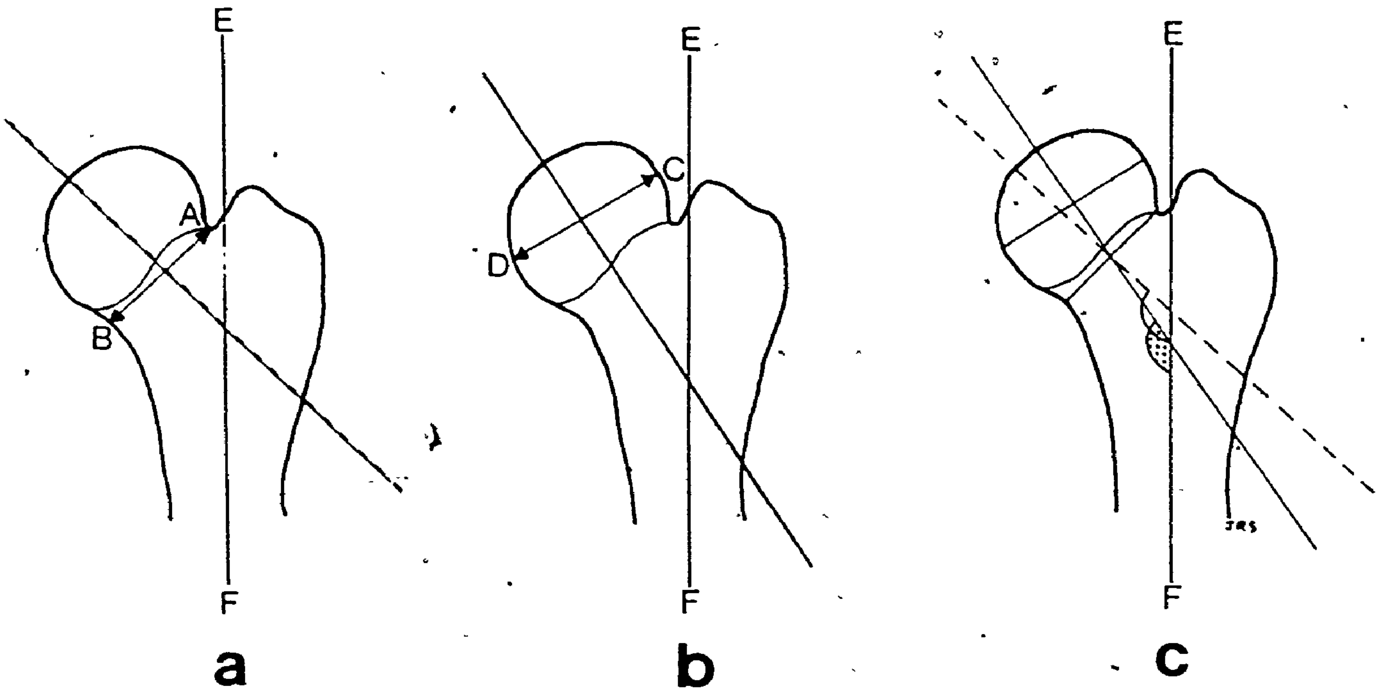


Figure 9: Diagrammatic representation of the neck-shaft angle, axes alignment in fetal femurs

Line E-F represents the long axis of the femoral shaft.

a) The neck axis is at right angles with the transverse axis of the neck, line A-B.

b) The neck axis is incorrectly aligned with the transverse axis of the head, line C-D. Only when the head is exactly centred on the neck could the head be used to determine the neck axis.

c) Comparison of neck axes aligned with the transverse axes of the head and neck. It can be seen that when the head is not exactly centred on the neck, the neck-shaft angle is larger when the neck axis is taken to be at right angles to the mid-point of the transverse axis of the head.

contact, the angle formed between the level of the supporting surface and the central axis of the neck is the torsion angle.

As previously noted, fetal femora present problems in determination of the long axis of the neck due to the virtual absence of a neck with true length and a well-delineated neck in relation to the head of the femur. In measurement of this angle in postnatal femora, Dunlap et al. (1953) aligned one arm of a goniometer with the long axis of the femoral neck, while Kingsley and Olmsted (1948) superimposed the goniometer arm over the long axis of the femoral neck. In the hands of this author and a fellow researcher, both methods were associated with an unacceptable error rate on repeated measurements of fetal femora.

In the chosen method, each femur was positioned so that it rested on the posterior surfaces of the condyles and greater trochanter. Of the total 315 femora, trochanter size could be assessed in 293 femora and the lesser trochanter was more prominent than the greater trochanter in 84 pairs of femora (168, 57.3%) and unilaterally in 33 femora (11.3%) (21 left, 7.2%; 12 right, 4.1%). In 92 femora (31.4%) the greater trochanter was more prominent. To ensure proximal support of the greater trochanter, these femora were positioned on perspex blocks (60 mm thick) so that the lesser trochanter was free. These blocks were also used for those femora in which a negative angle was present (retroverted, Fig. 10a). Unsupported, a femur with a negative angle rests proximally on the head (Fig. 10b).

Two celluloid 360° protractors were mounted on a shelf at eye level. One protractor was level with a block identical in thickness to that used to support femora with either a retroverted neck or a lesser

Figure 10: Measurement of torsion

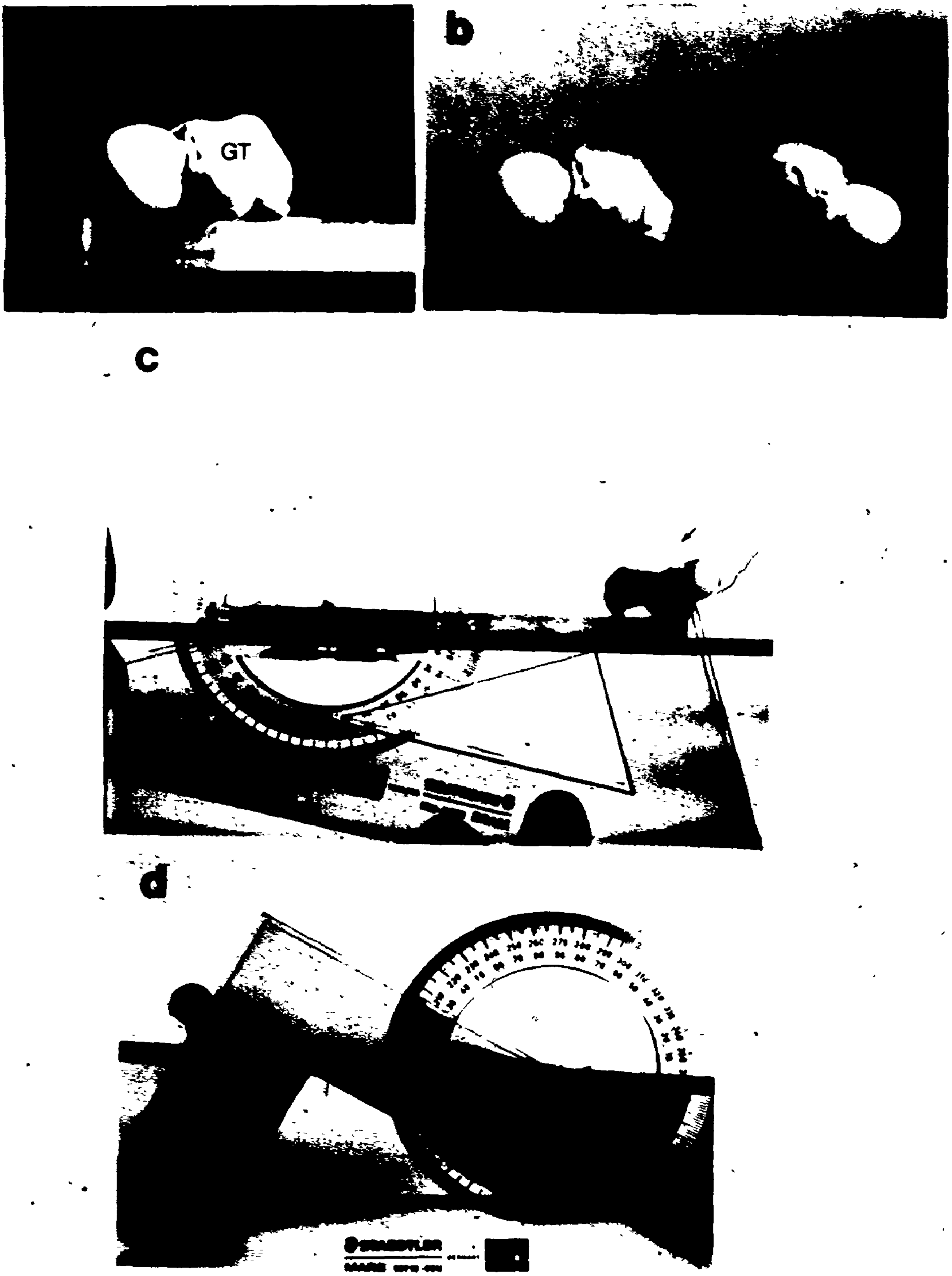
a) A right femur is shown positioned on a perspex block to ensure that the proximal point of contact is the greater trochanter (GT). The arrow indicates the lesser trochanter.

b) In this pair of term femora the right (R) femur rests naturally on the lesser trochanter (torsion = -8°). The left (L) femur with a negative torsion angle of -32° rests on the head. Blocks are required to ensure proximal support by the greater trochanter. Note that the neck lacks appreciable length. This pair of femora were from a stillborn term infant with multiple congenital abnormalities.

c) Measurement of torsion in a femur which naturally rested on the lesser trochanter. Perspex blocks have been placed under the distal condyles and the greater trochanter. The circular protractor is mounted on a block of identical height to that used for the femur. The short side (arrow) of the protractor is aligned with the transverse axis of the neck. The oblique side of the protractor is parallel with the long axis of the neck. The head of the femur is off-centre, tilted anteriorly, in relation to the neck.

d) Measurement of torsion in a femur which naturally rested on the greater trochanter. The circular protractor is mounted level with the shelf on which the femur rests.

To facilitate alignment of axes and reading the angle a shelf at eye level was used. In these four photographs variability in the femoral head shape is visible, as is the short femoral neck.


GT
b
c
d

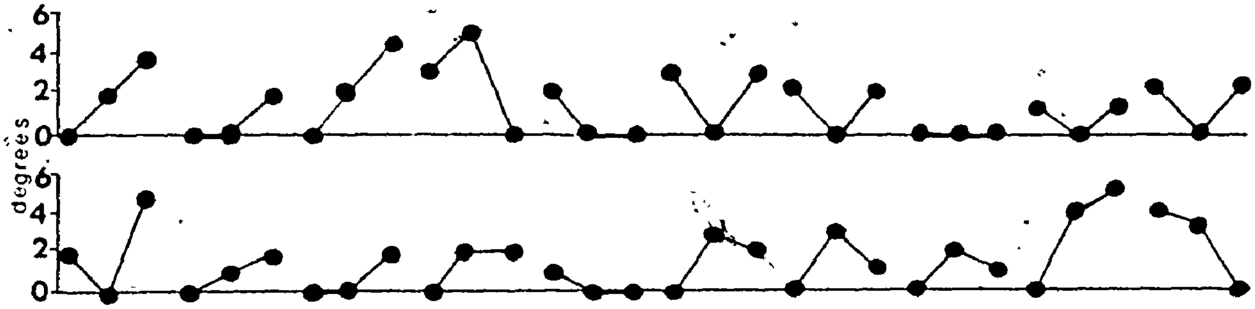
trochanter more prominent posteriorly than the greater trochanter (Fig. 10c). To reduce error in alignment due to the shortness of the neck, a small dot (India ink) was placed at the junction of the head and the superior border of the neck and at the termination of the hyaline cartilage of the head on the inferior border. As the head frequently is not centered on the neck it is important to use the mid-point of the neck, not the mid-point of the head, in alignment of the neck axis.

Femora were positioned approximately 5 cm from the edge of the circular protractor to facilitate determination of the central axis of the neck. The longer edge of a triangular celluloid protractor was aligned with the central protractor (Fig. 10d). Where a negative angle was present an unyielding piece of thin steel rod with a 90° angle at one end replaced the triangular protractor.

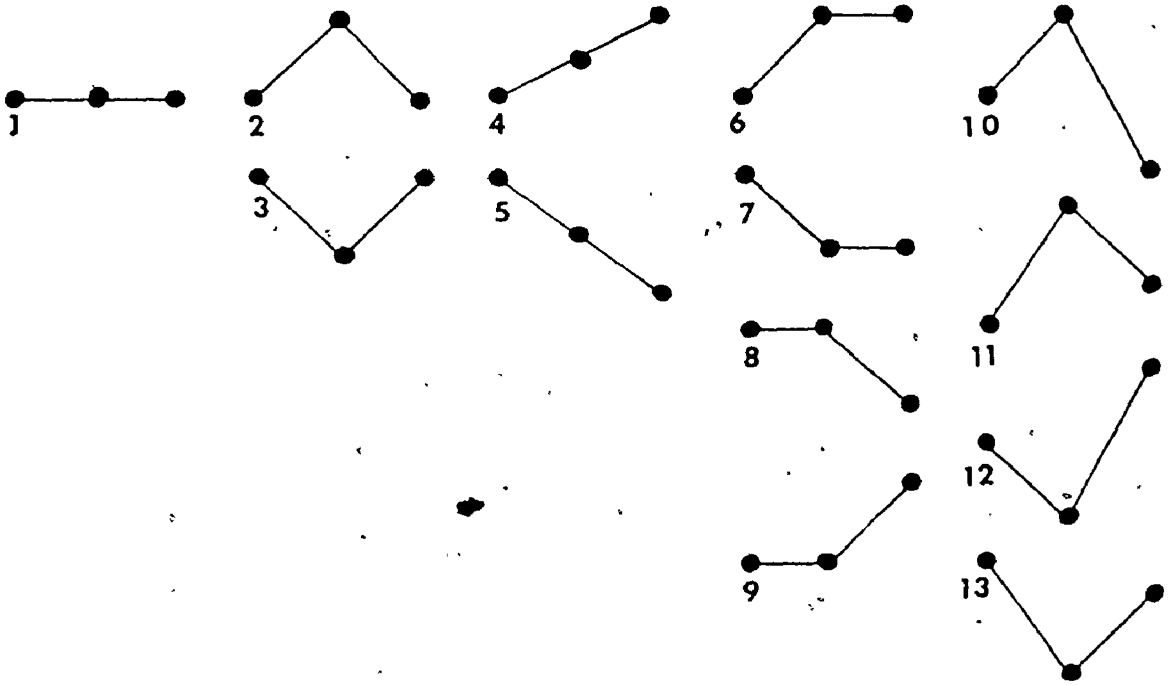
The torsion angle was not measured in 12 cases (24 femora) since only the proximal halves of the femora were received and no reliability could be placed on positioning the shaft in the absence of the femoral condyles. Obliquity of the shaft, less in fetal femora than in adult femora, was disregarded as this has been shown to contribute an error of only 0.2° in determination of the torsion angle in postnatal femora (Campbell 1940).

Femoral Angles Measurement Error

Bias may exist in a measurement series within each set of three measurements, between sequentially measured bones or between the left and right sides. This potential for bias was examined first by plotting against a base line (Fig. 11a) each set of three measurements per femur,



a: Patterns in femoral torsion angle measurement for cases 1 to 20. Values were plotted against a baseline to assess randomness of three consecutive measurements.



b: The thirteen patterns seen in series of three consecutive measurements of each femur for the neck-shaft and torsion angles. Patterns 1, 4 to 9 exhibit a trend whereas patterns 2, 3, 10 to 13 exhibit no definite trend.

Figure 11: Patterns in femoral angles measurement

in the total sample, in the sequence in which the femora were measured. Thirteen patterns were present (Fig. 11b). If no bias is present each pattern may be expected to have an equal probability of occurence. A chi-square test was employed to test the null hypothesis that the measurements were independent of side, i.e. that the distribution of patterns was random. For the neck-shaft angle the null hypothesis was not rejected ($X_{12}^{2} = 15.09$; $p = .2379$). However, the null hypothesis of randomness of patterns in torsion angle measurements was rejected ($X_{12}^{2} = 30.99$; $p = .0025$). For this angle the test statistic indicated that some bias was present in performing three measurements consecutively on each bone with a possible carry-over effect between bones.

To detect this bias the patterns were grouped in two ways. In the first comparison, patterns were separated into patterns in which a trend in the three measurements was present, that is, all values were the same or angle values either increased or decreased from the first measurement to the third. There were seven patterns in this set (Nos. 1, 4, 5, 6, 7, 8, 9, Fig. 11b). The second set of patterns exhibited no definite trends (Nos. 2, 3, 10, 11, 12, 13, Fig. 11b). In the second comparison patterns exhibiting a trend were subdivided into those with a definite trend (Nos. 1, 4, 5, Fig. 11b) and those patterns in which at least two consecutive measurements were in the same direction (Nos. 6, 7, 8, 9, Fig. 11b). In both groupings chi-square tests were not significant ($X_{1}^{1} = 0.19$; $p = .6641$, $X_{1}^{2} = 0.29$; $p = .8667$, for $n = 159$). The null hypothesis that no systematic trend was present within the sets of three measurements was not rejected.

To test the measurement precision, 10 right and 10 left femora were measured twice with a six-month interval between the two sets of measurements. Analysis of variance was performed to test the null hypothesis that the measurements on the six runs were equal against the alternate hypothesis that at least one inequality was present on the six runs. A one-sided variance ratio test was employed. The null hypothesis of equality of measurements over six runs was not rejected for the right and left femoral torsion angles (right F = 0.63; p = .6770; left F = 1.24; p = .3061) but was rejected for the right and left neck-shaft angles as both F values were greater than the critical value (right F = 3.15; p = .0158; left F = 5.35; p = .0006). For both angles the F statistic for between-femora variance was significant at less than 0.001 (Appendix E). This result was expected since the femora were selected to give variation in bone size and with this it was anticipated the sample would contain variation in ages and angle values.

The within-measurements variance was partitioned a number of ways (Appendix E) to detect which of the six runs contributed to the inequality between the runs. Partition of effects for the torsion angle revealed no significant F values at 0.05. Partition of effects of the neck-shaft angle demonstrated significant differences in the means for the first and second set of measurements but not within each set. As the neck-shaft angle was measured in the fetal femora, in a sample of ten from both sides, the method lacks precision. In part this is due to a subjective element that could not be removed in any of the methods attempted, that of visually aligning the neck axis in femora which lacked a clearly defined neck. Further variability between the two sets may be due to the observer's initial lack of critical awareness of the malalignment between the head and the neck and the asphericity of the head. A practice effect was identified and to discount this, 30 femora from each side were each measured three times each before any single values were recorded. Over all sets of three, the maximum range of deviations between individual measurements for the torsion angle was 7° with a mean of 3.53, and for the neck-shaft angle the maximum range was 7° with the mean 2.33° (for n = 1818).

Geometry of the Femoral Head

Initially the shape of the femoral head was only assessed subjectively. However, since a number of heads appeared to be nonspherical the decision was made to obtain objective data on a randomly selected sample. A random number program was used to generate a sample of at least 65 pairs. When a head could not be measured on the Talyrond because it was too "out-of-the-round" the next number in sequence was selected. A Model 50 Talyrond (Rank Taylor Hobson) roundness measuring machine normally used in precision engineering was used (Blowers, Elson and Korley 1972). The Talyrond stylus rotates about a vertical axis by precision spindle. Electrical measurements are made of the motion of the stylus, which has a blunt hacket point and is held against the specimen by a light spring. If the specimen is not completely circular, or is not centrally placed, the stylus moves relative to the carrier and an

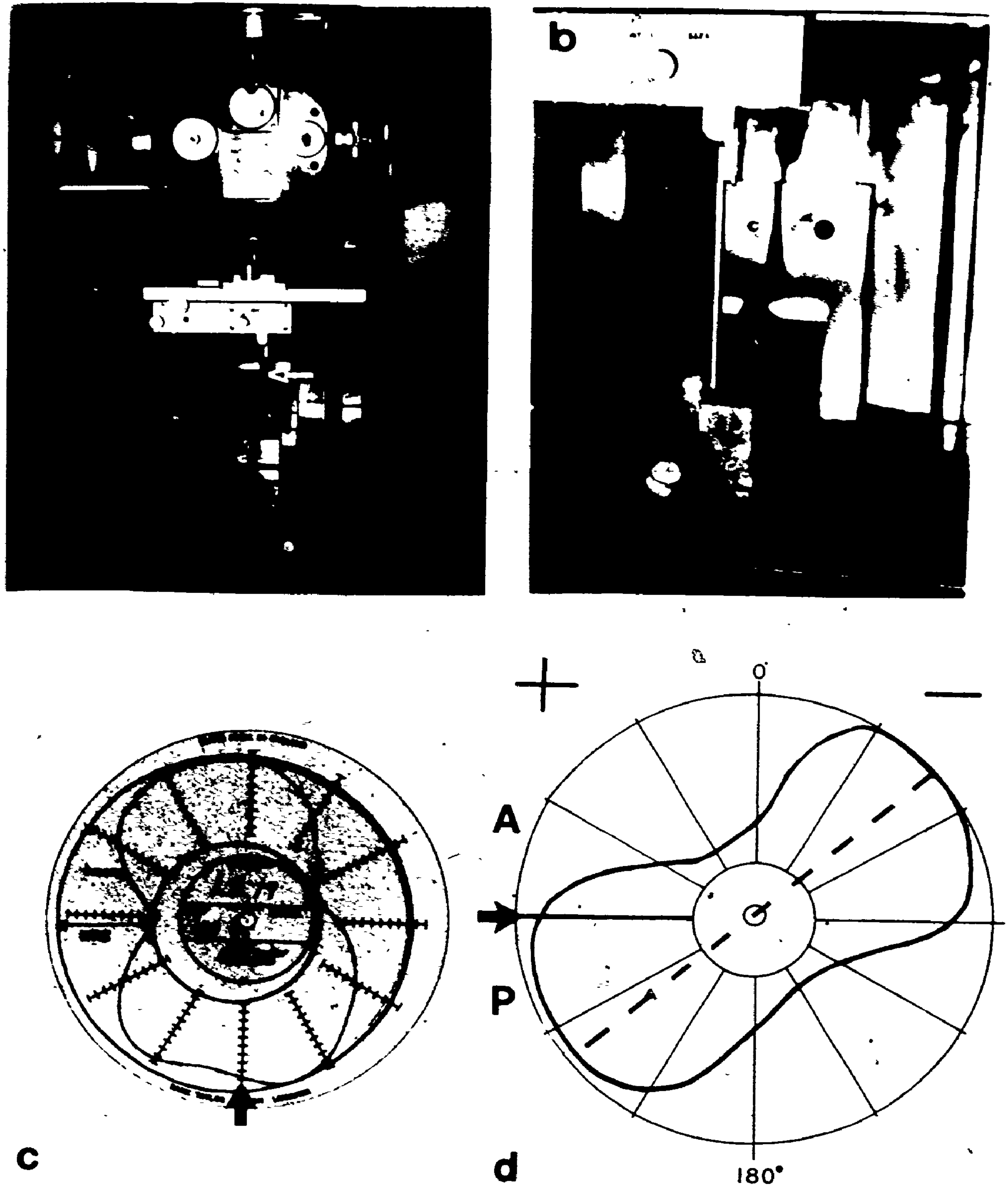
Figure 12: Assessment of femoral head sphericity in one contour

a) Talyrond roundness measuring machine. Arrows indicate the polar graph (upper left), the stylus and the femur held in a metal clamp. Small femora were held in plasticine inside the clamp.

b) Close-up view of the femur and stylus point. Femora were positioned so that the medial surface faced anteriorly. The degree to which this was achieved was dependent on obtaining a level 360° contour of the head.

c) Minimum radial zone (MRZ). This is the minimum spacing found by which the femoral head trace is entirely bounded by two concentric circles (*). At 100 times magnification each circle separation of 2 mm represents 0.02 mm. Arrow points to the region of the medial surface of the femur. On a left femur the lesser trochanter is to the left of this arrow, the anterior surface of the femur to the right. In polar graphs the actual size of a specimen is not represented and only the radial deviations are magnified.

d) The approximate angle of inclination on ellipse-shaped graphs. The head is viewed as from inside the pelvis. The arrow head indicates the medial surface of the femur. A = anterior half, P = posterior half of the femur head. The angle is positive (+) when the upper half of the ellipse, that is the anterior surface, is inclined forwards, and is negative (-) when the upper half of the ellipse is inclined backwards as shown in this diagram.


b
+
0°
—
A
90°
P
c
d
180°

electrical signal proportional to this relative movement is recorded on a polar graph (Fig. 12a).

Femora held in a metal clamp were positioned with the medial surface facing anteriorly and the head in the horizontal plane (Fig. 12b). Only one contour of the head could be examined through a continuous 360 degrees due to the smallness of the heads and the narrow band of cartilage between the line of capsule retinacular attachment and the fovea. The LHF was not detached but when the ligament overlay the contour to be examined it was cut. The contour examined was equivalent to the zone of maximum diameter of the head. A stylus with 100 times magnification was normally used. In older specimens because of the irregularity of these heads a long stylus was required to reduce the magnification to the minimal level of 50 times.

The Talyrond roundness measuring machine was selected as it provides a precise measure through 360°. Hammond and Charnley (1967) and Blowers _et al_. (1972) had experimented with a number of other methods of assessing femoral head sphericity but found most of them unsuitable. The latter authors used a Talyrond.

The minimal radial zone (MRZ, the minimum radial separation, as specified in the ANSI B89.3.1, American Standard Association 1972) was calculated to assess roundness. By use of a template on which each circle separation represents two mm (at 100 times magnification 2 mm = 0.02 mm), the minimum spacing is found by which the graph is entirely bounded by two concentric circles (Fig. 12c). The MRZ centre may not necessarily coincide with that of the centre of the graph. Assessment of the MRZ with a template was checked on a number of graphs with compass measurements. In a perfectly round specimen the MRZ would be zero. In the polar graphs actual size of a specimen is not represented and only the radial deviations are magnified. Magnification of the radial deviations leads to distortion of shape, for example, an ellipse becomes dumbbell in shape. In seven femoral heads (age 32-42 weeks) the radial deviations exceeded the measuring capacity of the instrument (560 μm at 50 times magnification) and these were not measured.

In addition, the approximate angle of inclination was estimated from the contour of the polar trace, using the centre of the graph (Reason 1966). The extent to which a segment of the trace has a constant diameter can be checked by direct measurement through the centre of the graph. Each head was viewed as from within the pelvis. The angle of inclination was positive when the upper half of the ellipse was inclined forwards, and was negative when the upper half of the ellipse was inclined backwards (anterolaterally, Fig. 12d). In this manner the sign of the angle of inclination is comparable between sides.

The femoral head traces were also assessed for the number of degrees, of the total 360°, that the trace exactly coincided with a template circle, as a measure of the extent to which part of the heads were circular.

HISTOLOGICAL TECHNIQUES

A number of paired acetabula at each two-week age period from 12 to 42 weeks were decalcified, embedded and stained to permit microscopic analysis.

Decalcification

Specimens were decalcified at room temperature (18 - 22°C) by the immersion method using 5% formic acid in distilled water (Lillie, 1954) following washing (30 min) to remove fixative. Decalcifying fluid was agitated by hand two to three times daily to ensure dispersion of decalcification products through the fluid. The end point of decalcification was determined by Armin's (1935) method based on the absence of calcium salts from the solution. Decalcifying fluid was changed on alternate days then daily as the end point was approached. Decalcification time varied from 10 to 25 days with the size of the specimen. Tissue was retained in a fresh change of decalcifying fluid 12 to 24 hours after no precipitate had formed, as a precaution against a false negative test. For some specimens the calcein (fluorescein bismethylene-imino-diacetic acid) test of Eastoe (1964) was utilized. This author did not find that absence of fluorescence was any easier to determine than the absence of a faint precipitate in Armin's method.

Tissue Embedding

Tissues were washed overnight in gently running water to remove the decalcifying fluid. Excess bone around the acetabulum was removed with a sharp knife once some decalcification had occurred. Specimens were then prepared for embedding in either paraffin wax (Paraplast +) or celloidin (Parlodion). Specimens were embedded in celloidin when:

(i) specimens were 28 weeks or older;

(ii) the specimens had been stored for months to years in fixative;

(iii) It was known that intra-uterine death had occurred days prior to delivery.

This method was selected following collapse of three acetabula during paraffin wax embedding.

Tissue embedded in Paraplast were dehydrated through 50%, 70% and 90% ethanol (EtOH) for four hours each, through three changes of 100% EtOH (8 h, 12 h, and 15 min) then cleared in two changes of 1,4-dioxane (diethylene dioxide) for two hours each and infiltrated with three changes of Paraplast (56°, 1 h, 2 h, 2 h) under moderate vacuum. Tissues were then embedded in a fresh change of Paraplast with L-shaped perspex molds and base plates used as embedding frames.

Tissues embedded in celloidin were dehydrated through two changes each of 70%, 80%, 95% and 100% EtOH with 12 hours for each change. The tissue was then transferred to absolute anhydrous ether for eight hours and through four changes of celloidin (3%, 6%, 12% each one month). The nitrocellulose strips were diluted in equal parts of EtOH and ether. After the second change of 12% celloidin the glass jars were opened daily inside a glass desiccator and the celloidin allowed to set. Blocks were then cut free, trimmed and stored in 80% EtOH (Chaplin 1975).

Celloidin-Paraffin Embedding

For photography, one pair of hips at each four-weekly age interval from 12 to 42 weeks was cleared in methyl salicylate following dehydration in graded steps of EtOH. These specimens were kept in 1% celloidin and methyl salicylate solution until clear (Brain 1966), and then infiltrated and embedded in Paraplast in the manner previously described.

Sectioning

Paraplast blocks were cut at 10µ on an AO Spencer 20 microtome. Every tenth section was saved and mounted on albuminized slides using a 37° solution of 0.1% sodium chromate as a flattening medium (Andersen 1962). Celloidin blocks were sectioned on a Jung sledge microtome with a plano-concave knife at 10µ to 25µ. The sections saved were stored in tissue paper sleeves in 80% EtOH. To reduce the amount of tissue to be sectioned several blocks were divided at the mid-point of the acetabulum in the horizontal plane on an electric fret saw. This procedure resulted in considerable trauma to the tissue, even at the 1/4 way mark (Fig. 13). Subsequent blocks were completely sectioned with sections saved from the previously measured and marked 3/4, 1/2 and 1/4 way levels.

In both celloidin and Paraplast blocks the acetabulum was positioned vertically and sectioned in the horizontal plane.

Staining

Two changes of xylene (5 min and 3 min) were used to remove paraffin from the sections which were then hydrated through 100%, 95%, 85%, 75%, 60%, 50% EtOH and distilled water (each 3 min). Sections were first stained in filtered fresh Alcian Blue 8GS in 3% acetic acid (HoAc), transferred to 3% HoAc (5 min), rinsed in water, stained with van Gieson (100 mg acid Fuchsin in 100 ml saturated aqueous picric acid) and differentiated in 95% EtOH and two changes of 100% EtOH. Sections were finally cleared in two 2-minute changes of picric-xylene, one change of acidified xylene and cover-slipped with permount.

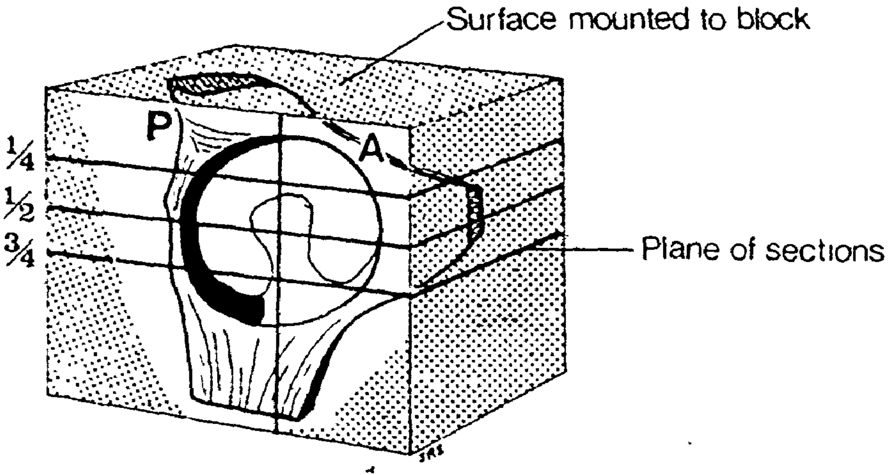


Figure 13: Positioning of the acetabulum in celloidin blocks P = posterior; A = anterior. The face of the acetabulum is vertical. Sections were taken from the marked 3/4-, 1/2-, and 1/4-way levels of the acetabulum.

Free celloidin sections were individually stained following hydration in 75%, 50% EtOH and distilled water (3 min each). Staining times in Alcian Blue and van Gieson were greatly reduced from times used for paraffin sections due to the higher affinity of celloidin sections to take up stains (Brain 1966). Sections were mounted on glass slides in 75% EtOH after van Gieson staining, and a "drip and blot" method was used through 85%, 95% EtOH, two changes of isopropyl alcohol to assist flattening on the slide, then xylene, and cover-slipped with Depex. Some slides were completely immersed in Depex (diluted in xylene 1 in 2) and warmed to 37° for three to five minutes to improve penetration of celloidin (Drury 1975).

Alcian Blue with 3% glacial acetic acid stains acid and sulphated mucopolysaccharides in the cartilage matrix blue, and stains nuclei red.

Van Gieson stains osteoid and woven bone bright red, mature lamellar bone yellowish-pink, mature collagen fibres deep red, and muscle, cytoplasm, red blood cells and fibrin yellow.

Chemical reagents were obtained from recommended commercial sources.

DATA ANALYSIS

Measurements were adjusted for the ocular scale and the mean values recorded on the data forms. The information on these forms was then transferred onto two 80 column Hollerith cards utilizing an IBM-029 keypunch. Analysis of the growth data was done on a CDC 6400 computer at McMaster University. The SPSS (Statistical Package of Social Scientists) system of computer programs was utilized. The data were coded with card no. 1 for the right hip and card no. 2 for the left hip in each case. Computer raw data is presented in Appendix F.

Statistical Analysis

The following abbreviations will be used in reporting statistical tests:

SD = standard deviation

SE = standard error

n = number of observations

– = in tables indicates no observations at that point

p = the probability associated with an observed value; in table headings, P(≥F) indicates the probability of observing a value greater than or equal to an F value

ANOVA = analysis of variance

MANOVA = multivariate analysis of variance

df = degrees of freedom

cfm = corrected for the mean

SS = sum of squares

MS = mean sum of squares

SSM = sum of squares model

SSR_m = sum of squares regression (corrected for the mean)

SSE = sum of squares (error) residual (SSE = SST - SSM)

SST = sum of squares total

SST_m = sum of squares total, corrected for the mean

SSPE = sum of squares pure error

SSLF = sum of squares lack of fit

R^2 = raw coefficient of determination (SSM/SST)(100), expressed as a percentage

R^2_m = raw coefficient of determination, corrected for the mean $(SSR_m/SST_m)(100)$

Q^2 = modified coefficient of determination, (SSM/(SST-SSPE))(100)

Q^2_m = modified coefficient of determination, corrected for the mean, $(SSR_m/(SST_m - SSPE))(100)$(Goldsmith 1974)

When frequencies are given, the percentage follows in brackets. Similarly, the mean is followed by one standard deviation in brackets. Ranges are given as the minimum and maximum values observed. The exact probability of a chi-square (Chi-square Basic Program) or F statistic (Texas Instrument 1976) is given; however, the critical level used throughout is 0.05.

In all computations decimal places were carried to the accuracy of machines. Figures were rounded off in tabular presentations.

The adequacy of regression models was assessed by checking MSLF/MSPE with central F distribution with p - k and n - p degrees of freedom. When pure error is present R^2 or R_m^2 cannot achieve 1 or 100%. The modified coefficient of determination corrected for the mean, Q_m^2, will be reported when pure error is present to express the total amount of variation explained by the model, corrected for the mean (Goldsmith 1974).

Since measurements of the femur, acetabulum and ligament of the head of the femur have been obtained from the same unit, they are correlated and should be analysed simultaneously by multivariate analysis of variance. The SPSS MANOVA subprogram uses " . . . . the least squares criterion to estimate the p-regression coefficients for the univariate multiple linear regression model, and the matrix of p x q regression coefficients for the multivariate regression model" (Cohen and Burns 1976). Tests of significance will be reported for departure from the null hypothesis

$$Ho : \beta_1 = \beta_2 = . . . = \beta_p = 0$$

in the case of univariate linear regression, and

$$Ho : \underset{\sim}{B} = \underset{\sim}{0}$$

in the case of the multivariate linear regression model, where $\underset{\sim}{B}$ and $\underset{\sim}{0}$ are (p - 1) x q matrices, p is the number of independent variables, and q is the number of dependent (measurement) variables. The subprogram MANOVA performs " . . . . multivariate analysis on a vector of dependent variables simultaneously, instead of on a single dependent variable . . ." (Cohen and Burns 1976) as in univariate ANOVA.

In MANOVA it is assumed that observations follow a multivariate normal distribution with unknown matrix. The test statistics, largest root criterion (LRC) and/or Hotelling's trace criterion (HTC), will be reported with parameters s, m, n, where s (total number of eigenvalues) = Min (n_h, q) where n_h = hypothesis degrees of freedom and q is the number of response variables; and m, n, are functions of n_h, n_e where n_e is the error degrees of freedom (Cohen and Burns 1976). When s = 1 the LRC and HTC reduce to an F test which rejects if the statistic exceeds the $(1 - \alpha)$ fractile of the F distribution [df = (2m+2), (2n+2)] (Potthof and Roy 1964).

The theoretical bases of statistical programs employed are given in SPSS manuals (Nie *et al*. 1975, Cohen and Burns 1976).

Photography

The majority of photographs were taken by the author using an Asahi Pentax camera with extension tubes and/or bellows. Kodak panchromatic-X and high speed Ektachrome film were used.

Chapter 3

RESULTS

Classification of Cases

Based on the hip morphology or the presence of congenital abnormalities, and prior to any statistical analysis, cases were placed in one of four groups.

1. Normals. These cases did not deviate from the expected morphology of the hip joint (n = 98).
2. Dysnormals. These cases exhibited one or more minor variants from the expected hip joint morphology (n = 46).
3. Abnormal cases demonstrated obvious abnormality of the hip joint(s) and were excluded from the growth study. These seven cases will be reported separately.
4. Congenital abnormality cases. Despite the study exclusion criteria six cases were received which had one or more congenital abnormalities. Since the hip morphology in these cases is of interest these cases were measured and will be reported separately.

Normal cases will be described following consideration of dysnormal cases.

Dysnormal Cases

In 46 cases (65 hips) one or more variants from the expected morphology of the acetabulum were observed. Variants from the normal were:

1. a rounded labrum rim (9 hips)
2. flattening of the labrum rim (14 hips)
3. localized dips in the socket rim which only involved the labrum (20 hips)
4. folding of the labrum which partially overhung the acetabular cartilage (6 hips)
5. capsular fold projecting into the joint space (4 hips)
6. extension of the pulvinar pad spreading outwards from the acetabular fossa over the acetabular cartilage (6 hips)
7. a noncircular socket rim (9 hips)
8. abnormal LHF morphology (7 hips)
9. absence of the normal sulcus between the acetabular capsule attachment and the labrum (5 hips)
10. hemorrhage in the joint cavity (1 hip)

Commonly a combination of variants were observed in a single hip joint, for example, case #39 in which bilateral flattening of the anterosuperior quadrant of the acetabular rim was observed together with a small capsular fold at the same site, underdevelopment of the sulcus and a slight labrum overhang. Only in 28 hips were these variants single in appearance (this does not imply unilateral hip involvement). Table 5 presents the frequency of these variants by four age groups, sex and variant type.

In the 46 cases there were 25 males (54.3%) and 21 females (45.7%). Twenty-four hips (36.9%) were in the 12 to 20 week group, 21 hips (32.3%) were in the 22 to 30 week group, 16 hips (24.6%) were in the 32 to 42 week group (26.1% including the one hip with hemarthrosis), and three hips (4.6%) were postnatal cases aged 50 and 58 weeks.

Table 5

Frequency of variants in hips, by age groups, sex and variant type*

Age (weeks)	Males (%)	Females (%)	Variant Type							Total Hips %
	n=46		1	2	3	4	5	6	9	
12 - 20	12 (26.1)	7 (15.2)	2	7	10	2		3		24 (36.9)
22 - 30	7 (15.2)	8 (17.4)	4	5	6	3		2	1	21 (32.3)
32 - 42	4 (8.7)	6 (13.0)	2	2	4		3	1	4	16 (24.6)
>42	2 (4.3)	0	1			1	1			3 (4.6)
	25 (54.3)	21 (45.7)	9	14	20	6	4	6	5	64** (98.4)

* Types 7 and 8 were excluded from this table as these two types were only seen in combination with another type

** One hip with hemorrhage into the joint cavity omitted

Side involvement by sex is given in Table 6. In 27 cases (58.7%) with unilateral involvement there were 15 right hips (32.6%) and 12 left hips (26.1%). Bilateral hip involvement was present in 19 cases (41.3%). The se[illegible] by side involvement was not significant ($\chi^2_1 = 0.164$).

No pattern was detected when side involvement was compared to the birth leg posture and the pattern of leg crossing. However, in 17 cases (37%) the leg position was unknown due to receipt of only the hip joints.

Variants as dips, rounded rims, flattening of the labrum, labrum fold with overhang, sulcus absence and capsular folds tended to be

Table 6

Side involvement by sex for all types of variants, by cases

	Unilateral			Bilateral	Total
	Right	Left			
Male	9	5	14	11	25
Female	6	7	13	8	21
Total %	15 (32.6)	12 (26.1)	27 (58.7)	19 (41.3)	46

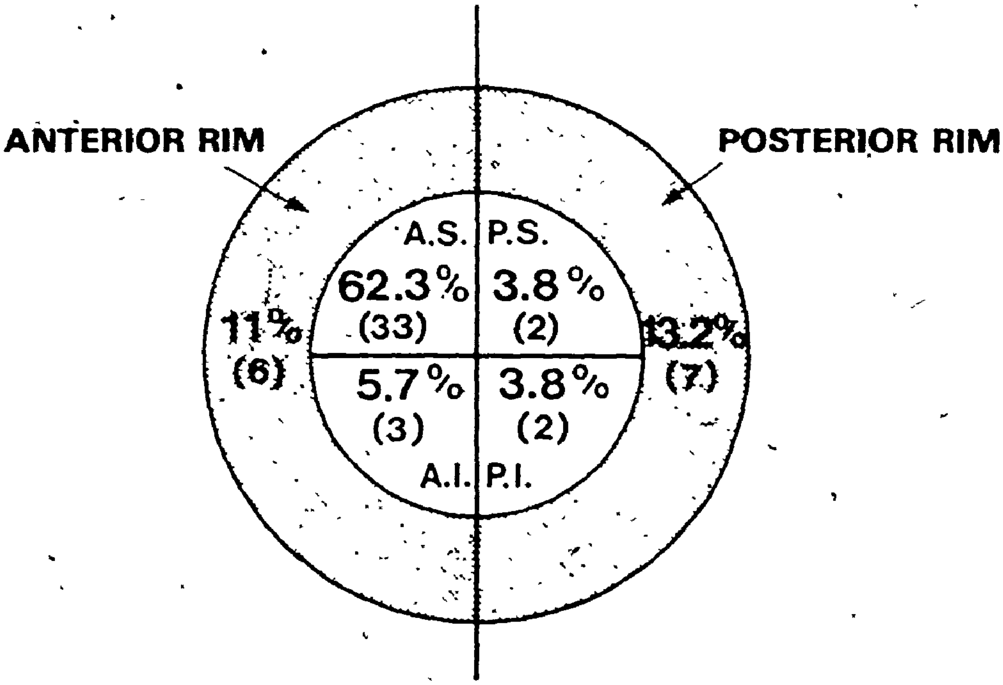


Figure 14: Frequency and percentage of localized variants in hip joints by rim and quadrant of the acetabulum (n = hips)

localized to a particular area of the socket rim. For descriptive purposes the socket rim was subdivided into four quadrants. The frequency of variants by rim, anterior or posterior, and by quadrants is given in Figure 14. In these 53 hips (81.5%) the anterior rim was involved in 42 hips (79.2%) and the posterior rim was involved in 11 hips (20.8%). A chi-square goodness of fit test was used to test the null hypothesis that anterior or posterior rim involvement is random. This hypothesis was rejected ($\chi^2_1 = 18.13$; $p < .0001$).

Rounded rims or flattening of the rim involved the entire anterior rim in six hips (11.3%) and the entire posterior rim in seven hips (13.2%). In 33 hips (62.3%, see Fig. 14) the variant was localized to the anterosuperior quadrant of the acetabulum, while in seven hips (13.2%) the variants were localized in one or more of the other three quadrants of the acetabulum. A chi-square goodness of fit test rejected the hypothesis that variants are randomly distributed in the four quadrants ($\chi^2_3 = 70.60$; $p < .0001$).

Instability was not detected in any of the hips in this group prior to divison of the capsule, nor was any abnormality of hip joint musculature observed. In all cases the head of the femur was located within the acetabular socket. No degree of subluxation was noted.

Variant Characteristics

Type 1, a rounded rim

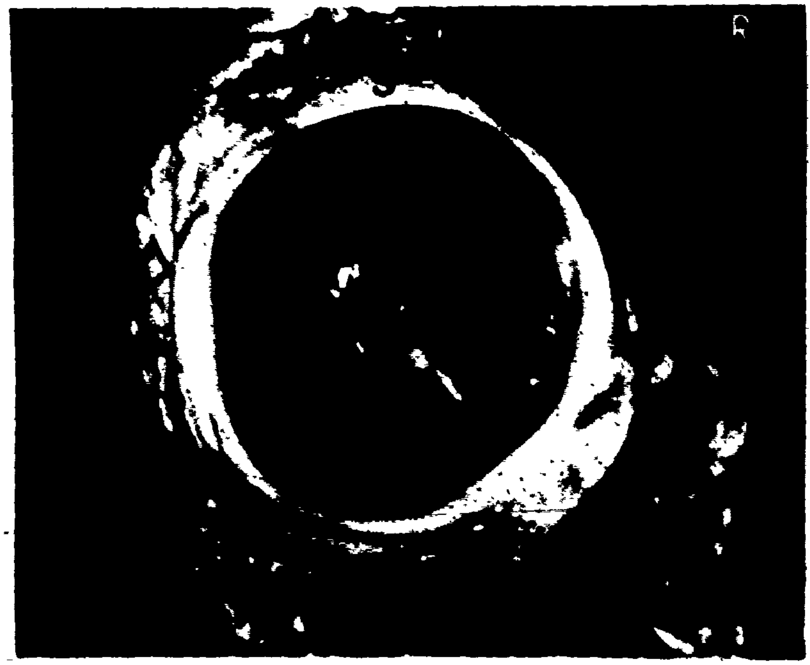
This occurred as a single variant in 7 of 14 hips. The rim involvement was variable, affecting the entire rim, one half, or only one quadrant (Fig. 15). When the area affected was localized the remainder

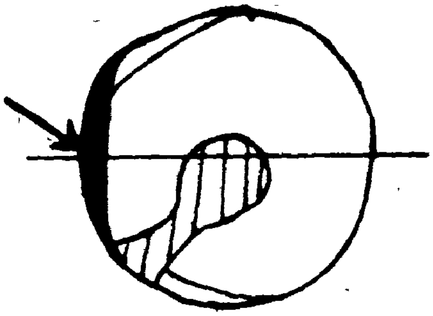
Figure 15: Rounded labrum rim

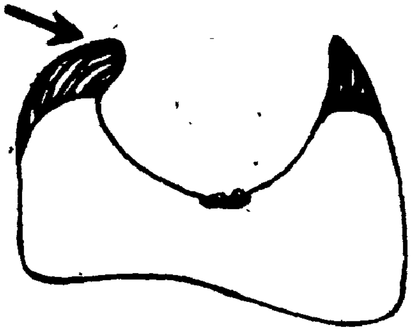
The socket rim is rounded in the middle section of the posterior (P) rim in a right (R) hip (arrow). Note that the superior (S) and inferior portions of the rim have the normal sharp appearance. The anterior rim is considered to be within the normal range of variation. (X 4.2)

Figure 18: Diagram of a labrum fold with overhang

A frontal view of the socket is shown on the left. The shaded area in the floor of the socket is the acetabular fossa and the non-articular area of the socket. The region of the labrum fold is marked by an arrow. The cross section of the socket on the right is taken at 90° to the line through the socket on the left. Note the normal pointed apex of the labrum on the right side and that the labrum overhangs the articular cartilage on the left side of the right diagram.


R





of the rim showed a normal pointed apex. Rounding of the rim was seen in association with a noncircular socket rim, absence or underdevelopment of the sulcus, asphericity of the head of the femur, capsular folds and the presence of a dip. In the region of the dip the labrum had more of a flattened than a rounded appearance.

Type 2, flattening of the labrum rim.

In four of nine hips this was the only variant seen, and the posterior rim was involved in only two hips. Flattening of the labrum was associated with a noncircular socket rim in which the vertical diameter exceeded the transverse, a thick LHF, labrum overhang and aspherical head of the femur (Fig. 16).

Type 3, dips.

Dips were depressions of variable extent which only involved the labrum and occurred as a single variant in nine of 20 hips (Fig. 17). The labrum in the region of the dip had variable morphology from the normal pointed apex to rounded or flattened. In several cases the labrum in the region of the dip appeared thinner than that of the remainder of the rim. The capsular sulcus was frequently underdeveloped or absent in the region of the dip. Multiple dips on one socket or a single dip were noted.

Type 4, labrum fold with overhang.

In this type there was a localized region of variable extent of labrum flattening (width range 0.4 mm to 0.6 mm) which in this region overhung the acetabular cartilage so that the labrum projected slightly into the socket (Fig. 18). A slight ledge was produced instead of the normal smooth transition between the inner surface of the labrum and the

Figure 16: Flattening of the labrum

a) A flattened area (arrow) with a width of 0.9 mm and a length of 4.6 mm on the anterior (A) rim of a left hip. The limbs of this fetus were in the breech posture. S = superior. (X 7)

b) The greater trochanter was observed to be in contact with the localized area of flattening on the posterior rim (arrow) when the capsule was removed. This right hip was in a flexed and abducted position. There was poor socket coverage of the anteromedial aspect of the head. The flattened area had a width of 2.0 mm. SA = sacrum, IS = ischial tuberosity. (X 3.5)


S
A


SA
IS
b

Figure 17: Dips in the labrum rim

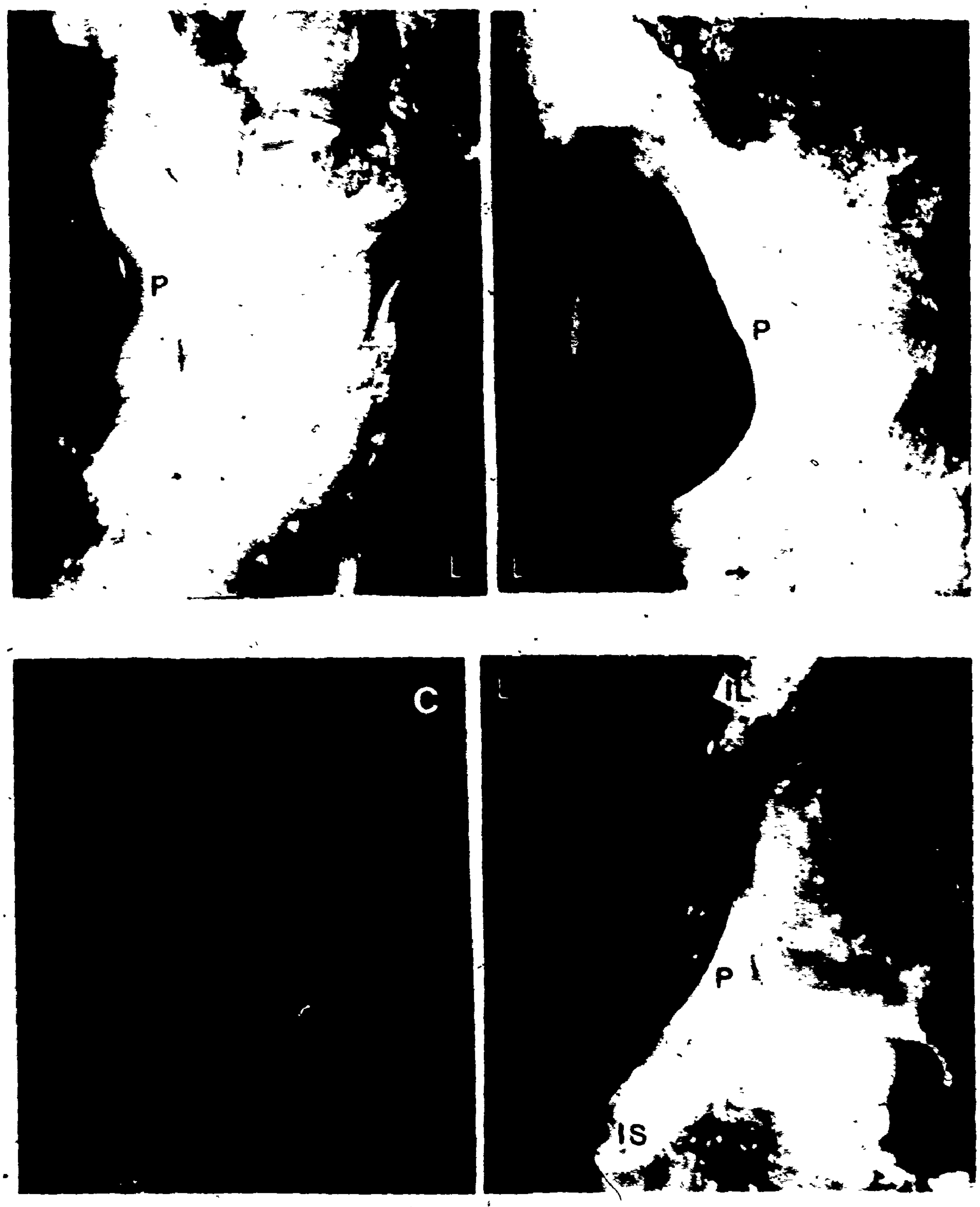
L = left, P = posterior, A = anterior, IL = ilium, the anterior inferior iliac spine, IS = ischium, OF = obturator foramen. Figures a) to d) are all left (L) acetabula.

a) side view of an irregular-shaped socket with a dip in the anterosuperior quadrant. (X 5)

b) side view of a socket with dips in the anterosuperior, anteroinferior and posteroinferior quadrants. (X 4.5)

c) frontal view of the socket shown in d). The region of the dip is visible on the anterosuperior quadrant. (X 2.8)

d) Note that the labrum inner surface is less smooth in the region of the dip in the anterosuperior quadrant. (X 2.8)


P
L
L
P
C
L
IL
P
IS

cartilage socket surface. The anterior rim was affected in five of the six hips. In two hips there was a lack of circularity of the socket rim with the transverse diameter exceeding the vertical diameter.

Type 5, capsular fold.

This variant was seen in four hips of three infants, two term stillbirths and one infant death at 58 weeks. In all four hips the fold was located in the anterosuperior quadrant of the acetabulum, and in this region the labrum was flattened or rounded in appearance (Fig. 19). In case #142 aged 58 weeks, a male, the hips were in flexion. No subluxation of the femoral heads occurred when the capsule was divided due to a short LHF with a tent-like attachment to the tissue of the acetabular fossa and the acetabular ligament. Bilaterally the vertical diameter of the acetabulum exceeded the transverse diameter by 1.3 mm. Case #39, a female, had the legs uncrossed in approximately 70° of flexion. There was an underdeveloped sulcus and slight labrum overhang due to flattening of the rim in the region of the small fold.

In case #52, a male, the fold was present bilaterally in the same location. No telescoping of the hips occurred prior to division of the capsule which was well developed with a prominent zona orbicularis. Histological examination of the fold showed loose bundles of collagenous fibres with a number of capillaries (Fig. 19c-e). In horizontal section the left fold was found to have two components (Fig. 19f-h). However, it is considered that only the fold connected to the capsule was observed directly or under the dissecting microscope. Both folds appeared to have similar consistency, contain loose fibrous tissue, and were distinctly different to the structure of the labrum or the capsule. While

Figure 19: Capsule fold

R = right, P = posterior, SA = sacrum, IS = ischium, CS = capsule

a) The capsular fold is visible projecting into the joint cavity in the anterosuperior quadrant. This fold was present at the same location in both hips of this term fetus. Neither hip was subluxated. Note the flattened globular appearance of the head. (X 2)

b) The socket of the hip shown in a). The labrum had a dip in the region of the fold (arrow) and was rounded in appearance. A thin film of fibro-fatty tissue is seen covering the anterior wall of the socket. (X 2)


R
P
C

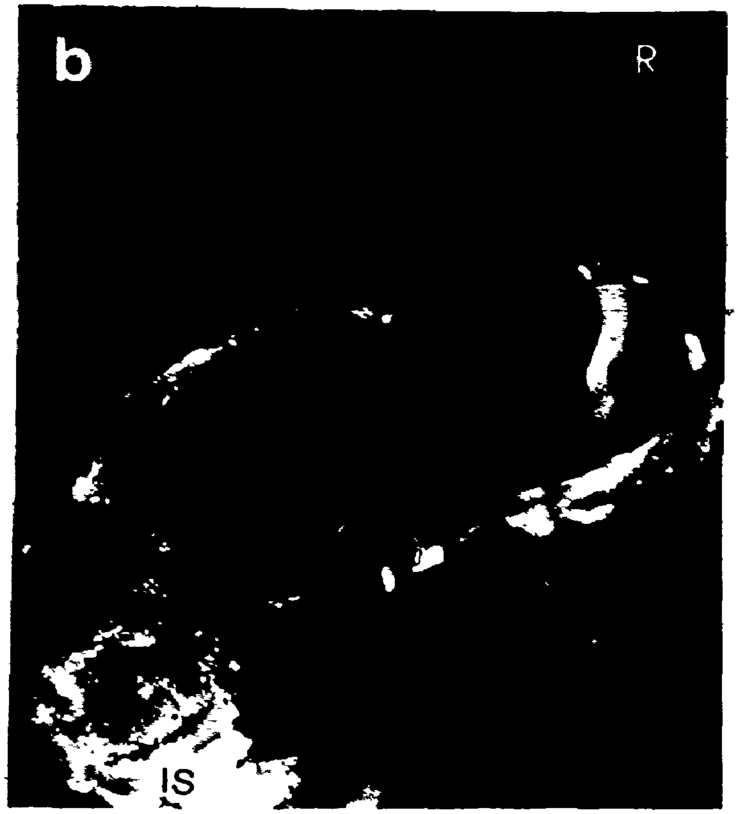

b
R
IS

Figure 19 cont.

c) Cross section of an acetabulum with a capsular fold similar to that shown in Figs. 19a and b. In the region of the fold the labrum is distinctly rounded (arrow). This region is shown in d). Alcian Blue and van Gieson (AB and VG), 25μ section, (X 2).

d) The rounded labrum (c) is composed of compact collagenous fibres, typical of term acetabula. 25μ section, AB and VG, (X 25).

e) Histological appearance of a capsule fold. Collagenous fibres are shown in cross section. A capillary is visible in the upper right hand side. 6μ section, AB and VG, (X 125).

c

d

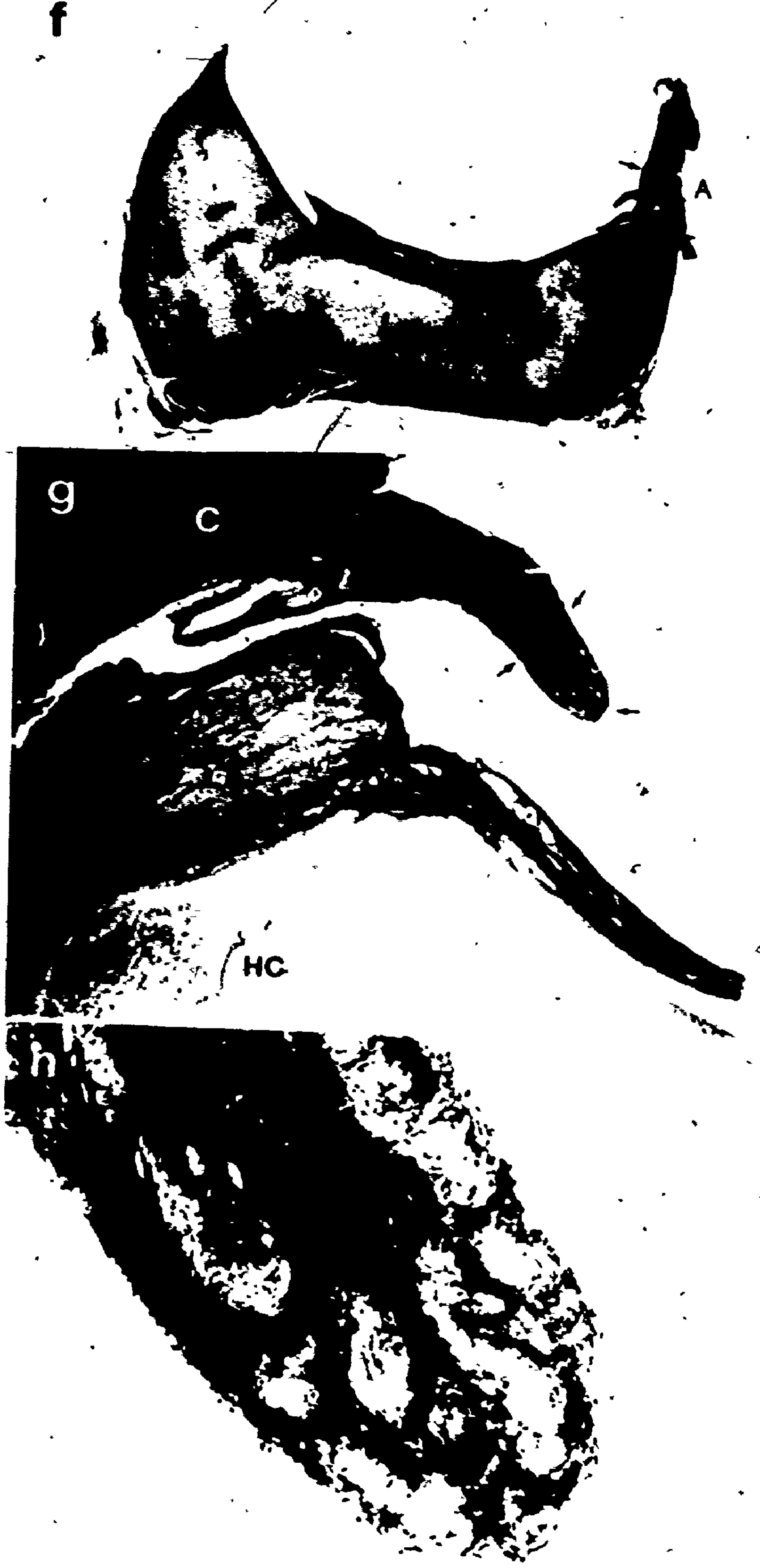
Figure 19 cont.

f) to h) are from the left hip of case #52; the right acetabulum of this fetus was shown in c) to e). Both hips had a similar appearance. In the left, the capsule fold was not detached prior to embedding. 20 μ sections.

f) In cross section, the capsule fold on the anterior (A) rim is seen to be composed of two folds. One is attached to the capsule (thin arrows) and one extends into the socket from the labrum. This region is shown magnified in g). AB and VG, (X 2).

g) Photomicrograph of the two folds shown in f). Neither fold has a composition identical to that of the capsule (C) or the labrum (LA). Collagenous fibres are more compact in the labrum than in the capsule. Note that the free end of the capsular fold (magnified in h) and indicated by arrows) has a similar structure to the fold attached to the labrum. AB and VG, (X 25).

h) The free end of the fold attached directly to the capsule (see f) and g)) is seen to be composed of loosely arranged bundles of collagenous fibres with several capillaries. AB and VG, (X 160).


f
A
g
c
HC
h

macroscopically both folds seemed to be the same size, on histological sections the right labrum is considerably more rounded than on the left side.

Type 6, extension of the pulvinar pad

In six hips a thin and relatively avascular sheet of tissue was connected centrally with the tissue in the acetabular fossa, extended over the acetabular cartilage and had a free peripheral edge (Fig. 20). This sheet of tissue was the only variant seen in four of the hips, and in five it covered a wide area of the acetabular cartilage, especially the superior half. It had the appearance of being interposed between the acetabulum and the head of the femur and was not connected to the coverings of the LHF other than by virtue of its attachment centrally to the pulvinar of the fossa from which the ligament also takes origin.

Type 7, noncircular socket rim.

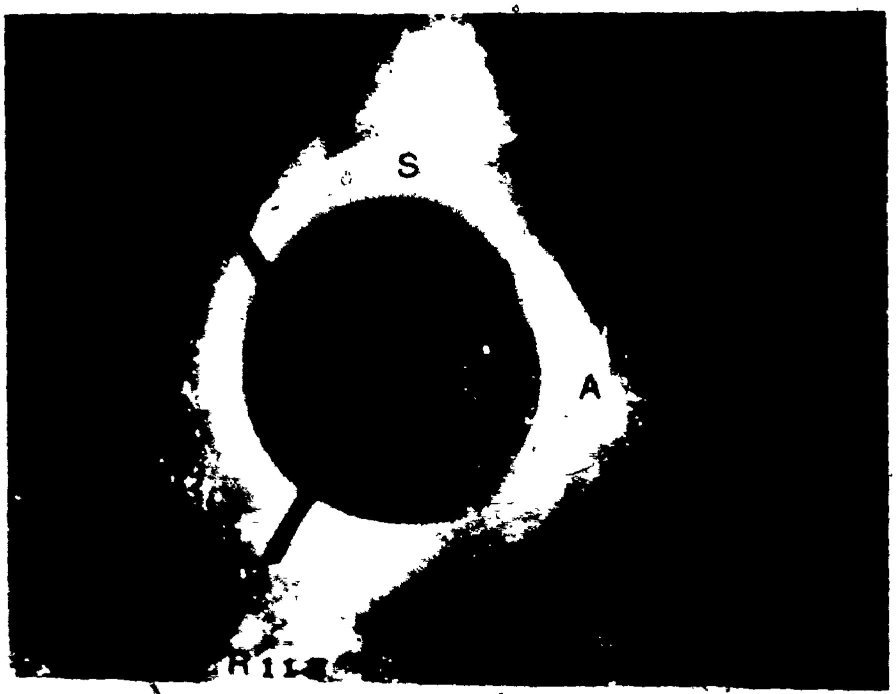
Circularity of the rim was not specifically measured. It is suspected that this type was underdetected since early in the study the vertical or oblique diameters of the acetabulum were measured only when it was macroscopically obvious that the diameters may not be equal. This variant was seen in a total of 15 cases of which nine were categorized as dysnormal. In these nine the abnormal shape was always associated with at least one other variant, such as a dip or rounded rim. If the socket rim is circular, the vertical (AB), transverse (CD) and oblique (EF) diameters should be of equal length (Fig. 21). A vertical diameter greater than the transverse diameter was the most frequent type seen; the difference was generally less than 1 mm (range: 0.1 mm to 1.32 mm). The

Figure 20: Extension of the pulvinar pad

S = superior, A = anterior. In both sockets loose thin fibro-areolar tissue extended outwards from the acetabular fossa to cover part of the hyaline cartilage surface of the socket. This tissue did not appear to be attached to the coverings of the ligament of the head of femur. This variant was observed in six sockets and was a single variant in four hips. Note that neither socket rim is completely circular.

a) Right (R), (X 4.3).

b) Left (L), (X 4.5).


S
A
R11


L
A

Figure 21: Socket rim shape.

A = anterior, S = superior, L = left, R = right
a) and b) are from the same fetus (9.7 cm CRL)

a) a typical circular-shaped socket rim. The transverse and vertical diameters are equal. (X 9)

b) The transverse diameter (C - D) exceeds the vertical diameter (A - B) by 0.32 mm (mean value). The lack of circularity appeared to be localized to the anterior half of the socket with the posterior half being hemicircular in shape. The head of femur showed a similar distortion. (X 9)

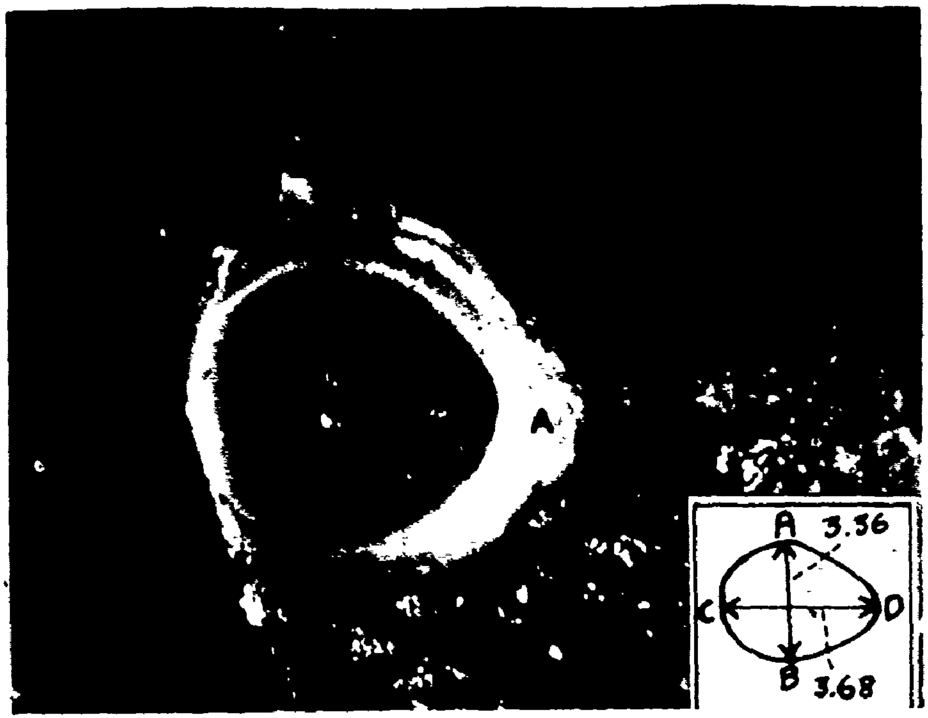
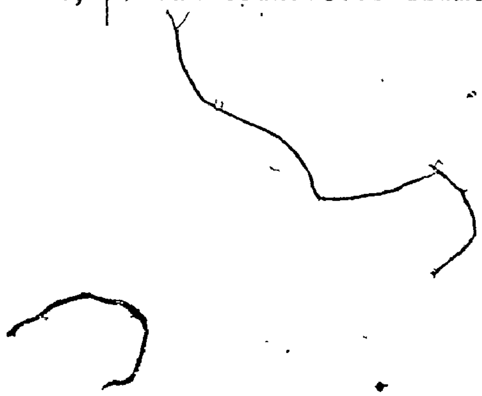
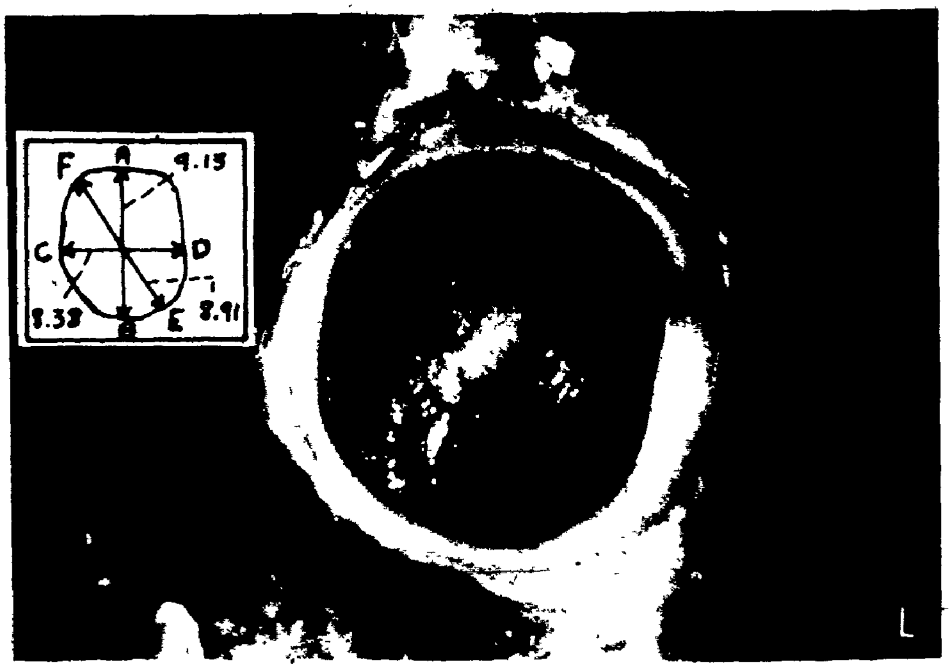

A
A
3.36
C
D
B
3.68

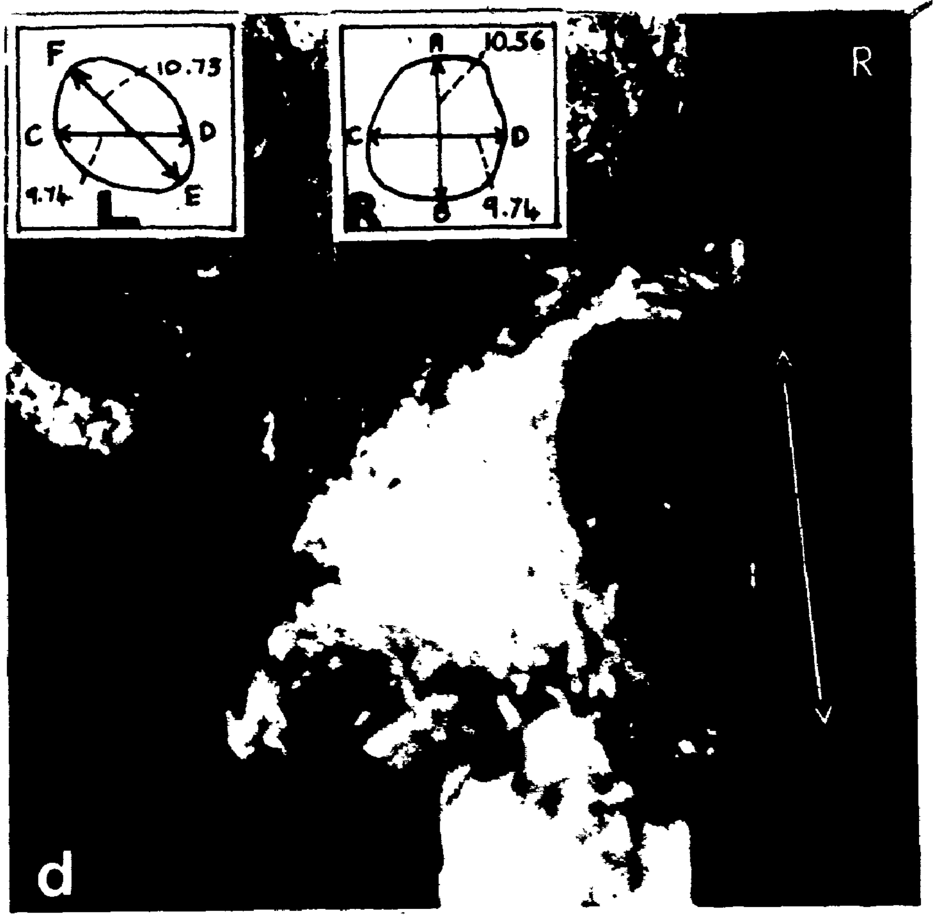
Figure 21 cont.

c) This left (L) socket rim outline is irregular. The vertical (A - B, ↑) diameter exceeds the oblique (F - E, ↑) and transverse diameters. (X 4.8)



d) In both sockets of this fetus the vertical (R = right) or oblique (L = left) diameters exceeded the transverse diameter. The right socket is shown in an oblique view (X 4). Inset diagrams give the diameter dimensions. The left socket of this pair of hips was the only socket observed in which the largest diameter was the oblique diameter (F - E). Transverse (C - D), vertical (A - B).


F
A
9.15
C
D
8.38
B
E
8.91
L


F
10.73
C
D
9.74
L
E
A
10.56
C
D
R
B
9.74
R
d

heads of the femora were congruent with the acetabula and revealed asphericity.

Type 8, abnormal morphology.

An obvious kink affecting the total length of the ligament was observed in eight hips, of which seven were associated with at least one other type of variant and were classified as dysnormal. In these seven hips there were two bilateral cases. Kinking occurred either at the femoral or acetabular end of the ligament and was more frequently seen at the acetabular end (Fig. 22a). In two hips there were labrum flattening and labrum dips. Case #127 was unusual in that removal of the capsule revealed poor socket coverage of the anteromedial aspect of the femoral head such that the LHF was visible on the medial side (Fig. 22b). No significant differences were seen when the length and width of these ligaments were compared with the means and SD for their age group. In one unilateral case both LHF lengths exceeded the mean plus two SD, and in the left LHF of a bilateral case the width was less than the mean minus three SD.

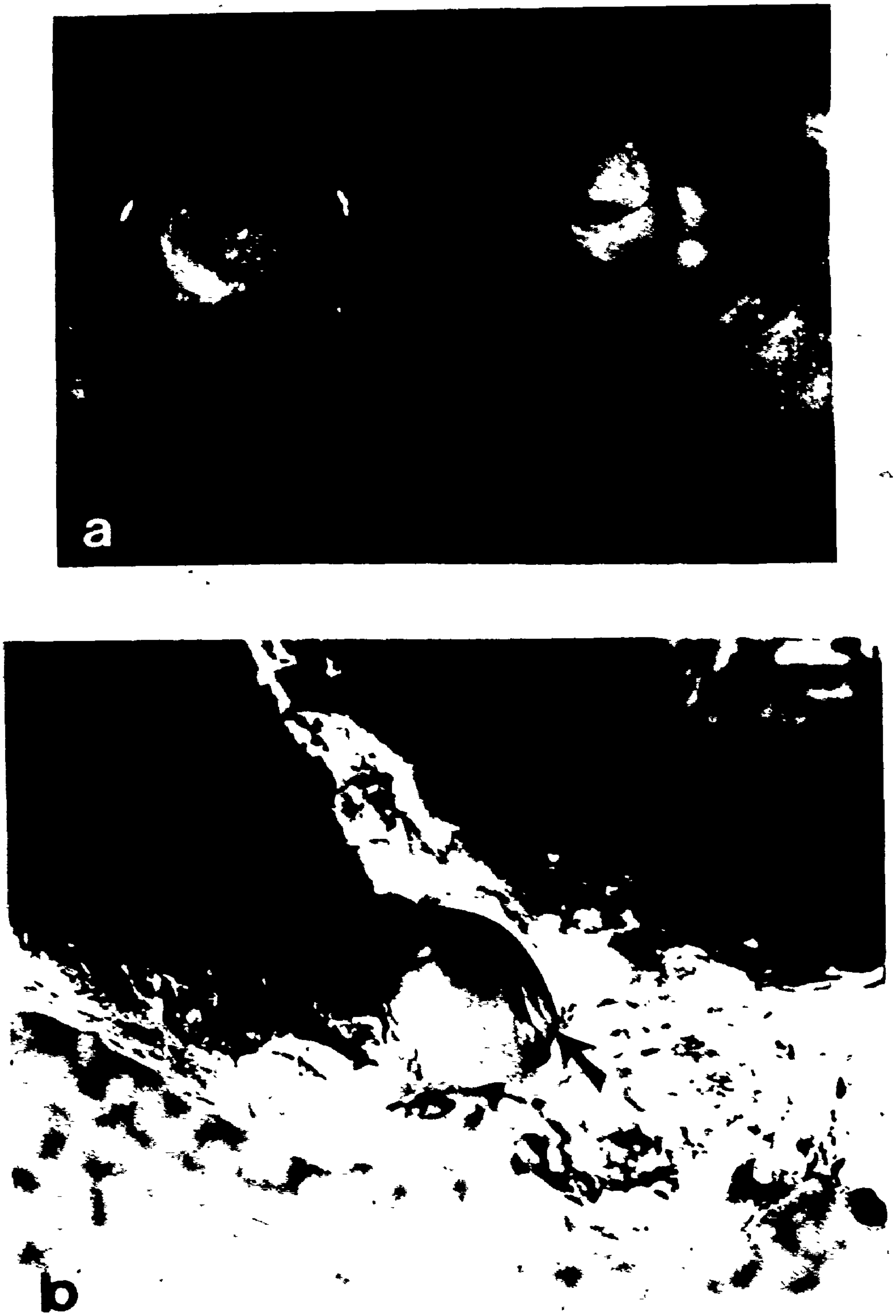
Type 9, sulcus absence.

Absence of a sulcus was seen in five hips but in only one was the sulcus absent for the entire rim perimeter. This type is shown in Figure 23. In two of these hips the labrum width differed on the anterior and posterior rims (one case), and in one, the involved hip had a socket depth 0.9 mm shallower than the normal opposite hip. In the involved hip slight telescoping was possible after ablation of the hip muscles and prior to division of the capsule.

Figure 22: Abnormal ligament of the head of femur (LHF) morphology

a) Both ligaments in this fetus (28.0 cm CRL) were kinked and twisted in appearance. (X 2.7)

b) In fetus #127 removal of the capsule revealed poor socket coverage of the anteromedial aspect of the head such that the LHF was visible on the medial side (arrow). Normally the ligament is not seen until the head is withdrawn from the socket. The tissues of this fetus had a dry and matted appearance. (This hip was shown in Figure 16b. A flattened area of the labrum was also noted.) (actual size)


a
b

A small underdeveloped sulcus was frequently observed in association with the presence of dips, flattening or rounding of the labrum.

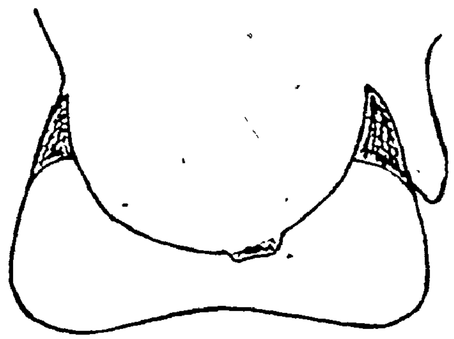


Figure 23: Diagram of sulcus absence. In normal hip joints a sulcus (groove) is present between the outer surface of the labrum (shaded area) and the capsule which is attached below the level of the labrum (right side). When no sulcus is present the capsule is attached up to the tip of the labrum as shown on the left side. (See also Figure 48a).

Analysis of the Significance of the Dysnormal Cases

Dysnormal cases were numerous and it was hypothesized that the variants may only represent the normal range of morphological variation. Therefore, analysis was conducted to test whether a significant difference existed between the means of normal and dysnormal cases.

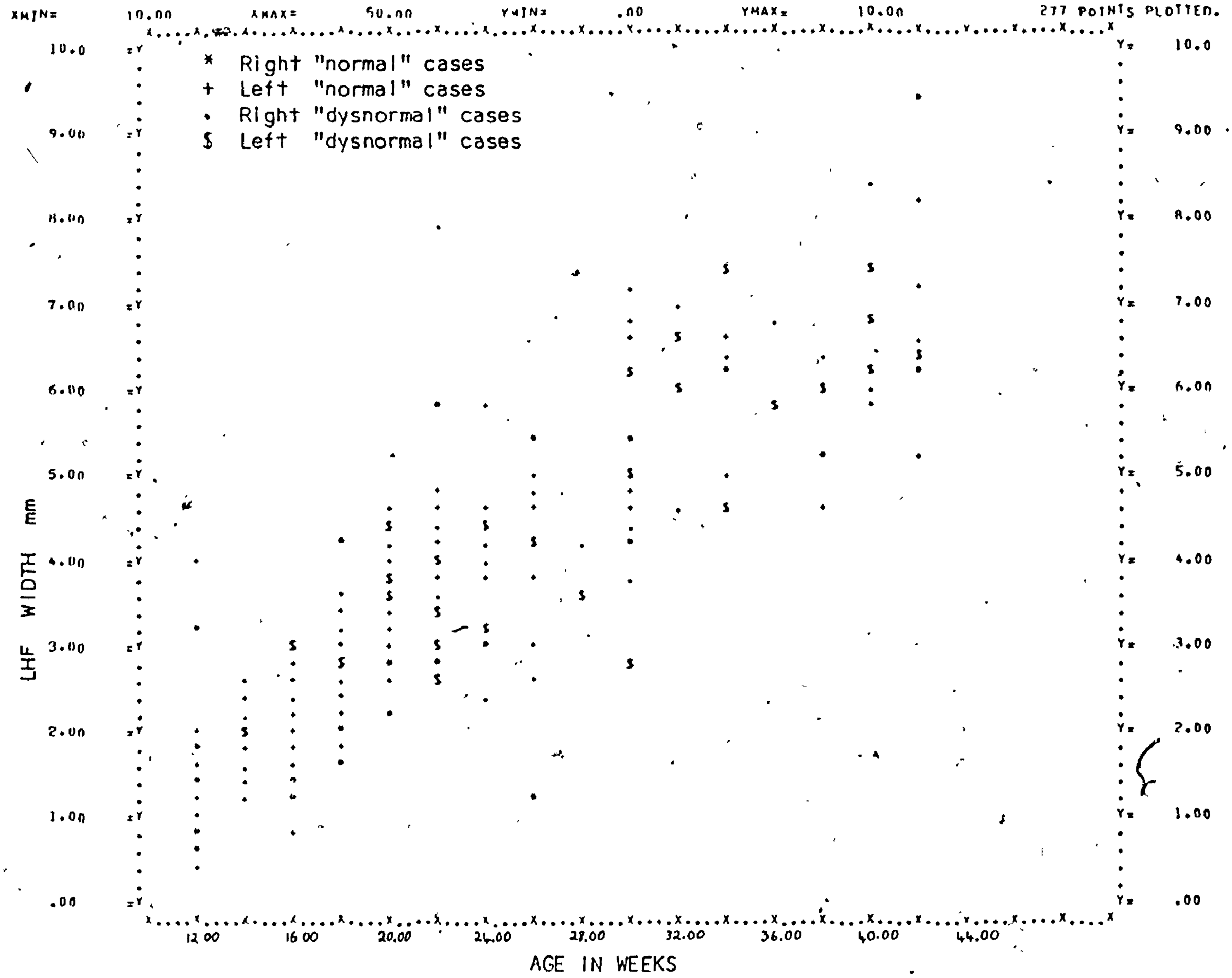
A chi-square contingency test was used to test the hypothesis that the frequency of dysnormal cases was unrelated to age. This hypothesis was not rejected ($\chi^2_4 = 3.48$; $p = .5172$). Dysnormal cases formed 23 percent of all cases less than 28 weeks of age and 55 percent of all cases greater than 28 weeks. A chi-square test of linear trend with five age groups, however, indicated that the distribution of dysnormal cases was not randomly distributed with respect to age ($\chi_1^2 = 7.36$; $p = .0069$).

Examination of scatterplots of normal and dysnormal cases, by side, for each measurement, revealed no tendency for clumping of either normal or dysnormal cases (for an example see Fig. 24 and Appendix G). Both groups appeared randomly distributed at all age categories. Analysis of variance to test for significant difference between the means for each variable gave, as expected, significant F values when the effect of age was not adjusted for. However, the amount of variability explained by comnorm, the normality variate (both hips normal = 1; at least one hip ≠ 1 = 2), was not greater than 11 percent. When adjustment was made for the effect of age, only small differences in the means for each variate between normal and dysnormal cases were revealed by multiple classification analysis. This suggested that there was no significant degree of interaction between normal and dysnormal cases. Table 7 presents the results of the ANOVA and multiple classification analysis for comnorm. From this table it can be seen that both femoral head diameters and the left torsion showed the highest variance of interaction between normal and dysnormal means. After adjustment for age the largest differences between means for normals and dysnormals were present in both torsions (2.68° right, 3.77° left) and the right acetabular diameter (1.1 mm). Only in left torsion was the interaction significant at less than 0.05.

Since the probabilities of the F values for the different variates, with the exception of left torsion, were greater than or equal

Figure 24

Example of a scatterplot of values for "normal" and "dysnormal" cases, by side, for ligament of the head of femur width. The frequency of values at each specific coordinate is not given. Scatterplots for the remaining six variables are given in Appendix G.



XMIN= 10.00 XMAX= 50.00 YMIN= .00 YMAX= 10.00 277 POINTS PLOTTED.
* Right "normal" cases
+ Left "normal" cases
• Right "dysnormal" cases
$ Left "dysnormal" cases
LHF WIDTH mm
10.0
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
44.00
AGE IN WEEKS

Table 7

Results of ANOVA and MCA for the comnorm factor with age as a covariate
MCA = multiple classification analysis, LHF = ligament of the head of femur

	ANOVA, main effects of Comnorm				MCA	
Variable	n - 2	SS*	F	P(≥F)	σ^{2}**	Differences***
Right femoral head diameter	131	.15	.21	.6491	.11	0.07mm
Left femoral head diameter	131	.44	.60	.4388	.11	0.13mm
Right acetabular diameter	141	2.29	1.73	.1904	.07	1.1mm
Left acetabular diameter	141	3.68	2.92	.0896	.08	0.35mm
Right acetabular depth	141	.15	.42	.5160	.06	0.07mm
Left acetabular depth	141	.56	1.40	.2385	.07	0.13mm
Right torsion	131	188.50	2.52	.1147	.08	2.68°
Left torsion	131	372.87	4.87	.0290 †	.11	3.77°
Right neck-shaft angle	136	14.49	1.08	.3003	.01	0.72°
Left neck-shaft angle	136	.96	.12	.7274	.01	0.19°
Right LHF width	135	.57	.93	.3368	.08	0.15mm
Left LHF width	135	.08	.13	.7190	.07	0.06mm
Right LHF length	135	1.77	1.15	.2861	.08	0.25mm
Left LHF length	135	2.84	1.43	.2330	.08	0.32mm

* df = 1

** Variance of the interaction between normals and dysnormals (Eta^{2})

*** Differences between means for normals and dysnormals after adjustment for age

† = $p < .05$

to 0.1 the null hypothesis of no difference in means between the two groups was accepted. The normal and dysnormal cases were pooled to create one group of 144 cases, hereafter termed normals, for the growth study. In these 144 cases four were excluded since their ages exceeded 42 weeks. "Dysnormal" cases form 32.9 percent of the "normal" group.

Estimation of the Age of Specimens

The crown-rump length (CRL) was used as the standard for placement of specimens in two-weekly age groups. Except for specimens in which only the hip joints were received all fetuses were measured by this investigator. Where a discrepancy existed between the reported CRL and that measured, the latter value was recorded. In two cases where only the hip joints were received the crown-heel length (CHL) was given. Scammon and Calkin's (1929, p.48) formula was used to convert the CHL to CRL (CRL = 0.66 CHL + 0.5 cm).

CRL data were missing in eight cases in the growth study group (n = 140). Three of these eight also lacked birth weight data. However, all had an estimated gestational age (GA) and age group placement was made by GA. These eight cases are in the following age groups: one in 24 weeks, two in 30 weeks, one in 34 weeks, two in 40 weeks and two in 42 weeks. In two of these eight cases the birth weight was, by several authors, more appropriate to a younger age group (difference 6 weeks).

In 13 fetuses a discrepancy existed between the estimated gestational age and the study age by CRL. Unless otherwise stated it was presumed that the estimated gestational age was based on the last menstrual period. The estimate of age by birth weight was closer to the estimate of age by CRL than for the calculated gestational age, except in three of the 13 fetuses. Data for these cases are given in Table 8.

A scatterplot, for 132 cases, of age by CRL is given in Figure 25. As expected, a strong correlation is present between age and CRL ($r^2 = .984$, $p < .0001$). Age increases by 1.01 (0.011) weeks for every 0.673 (0.232) cm increase in CRL (SE 0.915 weeks). The mean study age, sexes combined, was 21.04 (7.976) weeks with a SE of 0.674 weeks.

Birth Weight

Birth weight data were present for 87 of the 140 cases (62.1%). Means and standard deviations for birth weight by sex, age and CRL are given in Table 9. The means for males tend to exceed the female means. Age groups 24, 34, 40 and 42 weeks have the largest standard deviations. Up to 28 weeks birth weight means in this sample exceed values given by Moore (1973) for equivalent CRL, while after 28 weeks the means are either smaller or in the same range as Moore's data. The mean for males in age group 42 weeks is high, either indicative of large-for-dates infants, or incorrect aging by CRL. This group contains two postmature infants (#99, #100, see Table 8) whose birth weights exceeded normal term range values. By CRL, case #38 was placed in the 24 week group. However, by estimated gestational age and by birth weight, by both Moore (1973) and Streeter (1920), this fetus would belong in the 34 week group. In fetuses where a discrepancy was present in age group placement by CRL, weight, or gestational age, weight estimates were closer to the age estimate by CRL than the estimated gestational age except for the cases noted. This may indicate that cases in which a discrepancy existed were small-for-dates fetuses.

Table 8

A comparison of CRL, gestational age and study age in selected cases. F = female, M = male, GA = gestational age, CRL = crown-rump length, ND = no data.

Case Number	Sex	GA weeks	CRL cm	Weight (g)	Study Age Group
001	M	29	25.0	1,170.79	26
026	F	28	24.7*	414.85	24
037	M	term	28.0	1,634.06	30
038	M	34	24.7	2,351.63	24
072	F	35	30.0	1,800.75	32
082	F	38	32.0	ND	34
097	F**	30/31	25.0	1,131.48	26
099	M	43	38.5	5,491.50	42
100	F	43	37.5	4,725.03	38
113	F	25	20.0	831.45	20
114	F	30	25.0	1,008.00	26
157	F	48	38.0	2,131.50	40

* calculated from crown-heel length
** twin

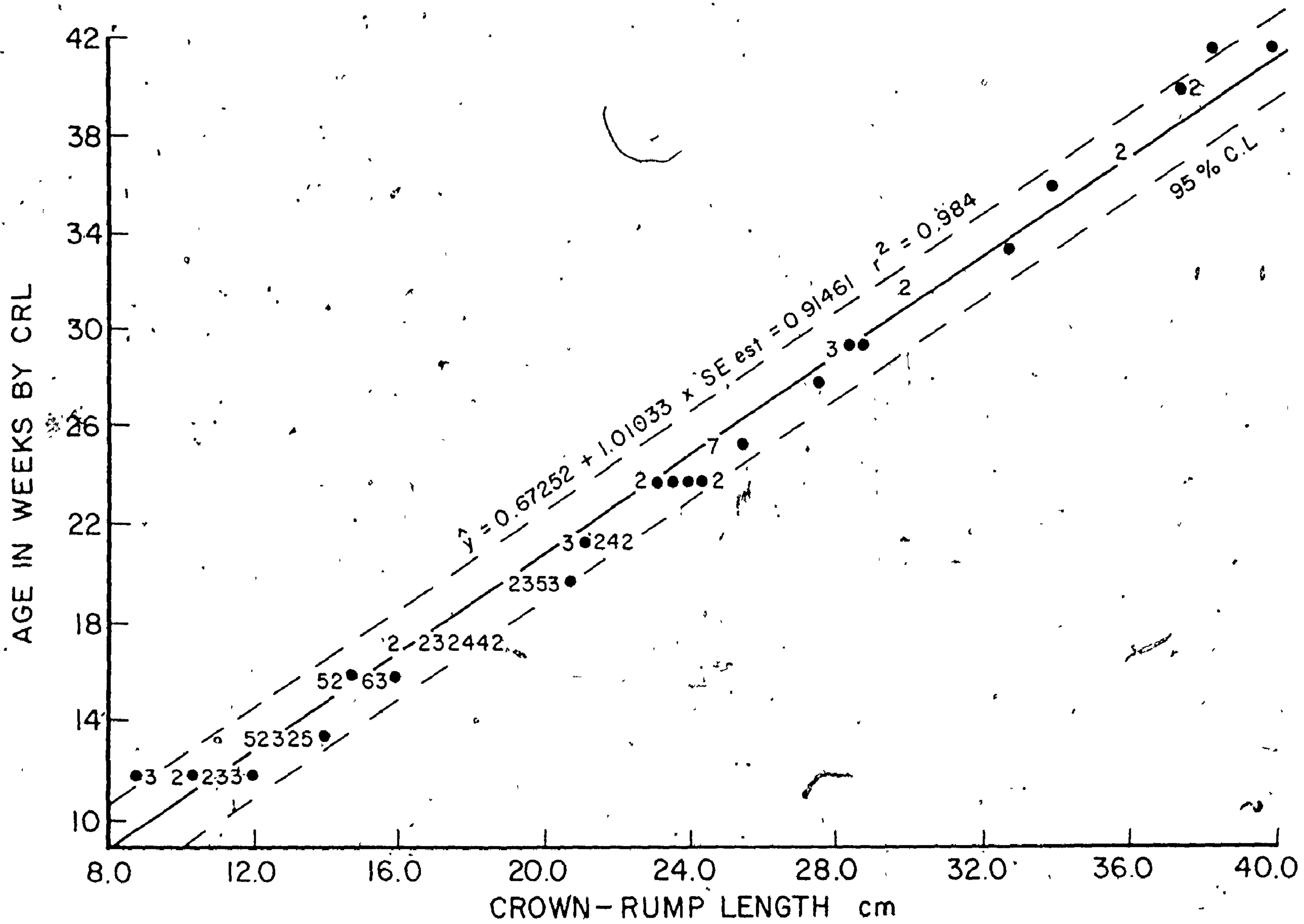


FIGURE 25: STUDY AGE BY CROWN-RUMP LENGTH, n =132

Table 9: Birth weight means and standard deviations (g) in normals* by age group and sex. n = sample frequency, suprascript = actual n with birth weight data, ND = no data

CRL cm, $\bar{x}$	AGE GROUP (WEEKS)	SEXES COMBINED n	SEXES COMBINED $\bar{x}$	SEXES COMBINED SD	MALES n	MALES $\bar{x}$	MALES SD	FEMALES n	FEMALES $\bar{x}$	FEMALES SD
10.5	12	16	88.04	32.50^{10}	8	94.08	41.06^{5}	8	82.00	24.49^{5}
12.9	14	18	184.20	44.24^{10}	5	150.07	34.63^{3}	13	198.83	40.99^{7}
14.9	16	18	240.75	79.08	10	231.18	53.76	8	252.71	105.71
17.7	18	19	374.80	98.90^{12}	10	387.27	52.53^{7}	9	357.34	148.68^{5}
19.9	20	15	561.33	113.98^{9}	4	587.67	188.98^{3}	11	548.17	76.66^{6}
21.7	22	12	751.95	195.54^{4}	6	696.40	0.00^{1}	6	770.47	235.15^{3}
23.8	24	9	1121.55	846.64^{4}	6	1595.80	1068.86^{2}	3	647.30	329.09^{2}
25.1	26	8	1185.43	149.96^{6}	5	1247.07	138.56^{3}	3	1123.80	160.09
27.5	28	1	-	-	1	ND		0	-	-
28.3	30	7	1619.98	345.32^{4}	2	1634.10	0.00^{1}	5	1615.27	422.78^{3}
30.0	32	2	1735.10	92.77	1	1669.50	0.00	1	1800,75	0.00
32.5	34	3	-	-	0	-	-	3	2163.00	920.65^{2}
34.0	36	1	-	-	0	-	-	1	ND	
36.0	38	2	-	-	2	3357.70	0.00^{1}	0	-	-
37.8	40	5	3428.25	1833.88^{2}	2	ND		3	3428.25	1833.88^{2}
39.3	42	4	-	-	4	4382.43	1080.03^{3}	0	-	-
	TOTAL	140	87 (62.1%)		66	40		74	47	

* missing 37.9% of 140 cases

The possibility existed that cases which lacked weight data may be a different group to cases which had weight data. The former group was chiefly derived from anatomy department collections and also lacked data related to family and birth history. Analysis was conducted to test if there was any association between weight (present or absent), age (in three categories: 12-20, 22-30, 32-42 weeks) and sex. Since this was not significant ($X_4^2 = 5.89$; $p = .2071$) it was concluded that the two birth weight groups did not differ significantly from each other.

Parental Age

Maternal age was known for only 18 of the 140 cases (12.9%). The mean maternal age of these 18 cases was 24.61 (8.27) years, with a sample range from 14 to 45 years. Paternal age was generally not available.

Birth Presentation

Data on birth presentation were scanty, being known for 11 cases (7.9%). Six of these were a vertex presentation, four were breech births and one was a caesarian delivery. Due to the diversity of sample sources no attempt was made to locate birth history when it was absent on pathology department reports or study record forms.

Sex and Side

In the 140 cases there were 66 males (47.1%) with a mean age of 21.76 (8.58) weeks and 74 females (52.9%) with a mean age of 20.41 (7.40) weeks. In the pooled means for each variable (Table 10) there is a general trend for the male means regardless of side, right or left, to be larger than that for females. On the right side this is reversed for

Table 10

Pooled means and standard deviations for sex and side, n = 140. LHF = ligament of the head of femur, FH = femoral head, in mm, angles in degrees.

		RIGHT		LEFT	
Variables		Male	Female	Male	Female
LHF width	$\bar{x}$	3.22*	3.28	3.36	3.25
	SD	1.81	1.73	1.77	1.60
LHF length	$\bar{x}$	5.63*	5.57	5.56	5.53
	SD	3.08	2.72	3.19	2.26
FH diameter	$\bar{x}$	8.95	8.44	8.91	8.39
	SD	3.93	3.33	3.95	3.31
Acetabular diameter	$\bar{x}$	9.00	8.45	8.95	8.45
	SD	4.04	3.28	3.94	3.31
Acetabular depth	$\bar{x}$	3.82	3.63	3.81	3.63
	SD	1.47	1.29	1.48	1.31
Torsion	$\bar{x}$	10.82*	13.27	12.30*	14.21
	SD	10.12	10.61	11.14	10.80
Neck-shaft angle	$\bar{x}$	123.77*	125.83	124.65	123.38
	SD	15.90	3.68	2.65	2.91

* ♂ < ♀

LHF width and length, and in torsion the bilateral pooled means were smaller than that for the females. Similarly, the male pooled mean for the right neck-shaft angle is less than that for the females, but it is associated with a large standard deviation. Overall, the standard deviations in males are larger than those for females. However, some inconsistency is evident in both femoral angle standard deviations. Scatterplots for the right and left sides for each variable, with distinction between normal and dysnormal cases, were presented in Figure 24 and Appendix G.

Analysis of covariance was used to test the null hypothesis that there were no significant differences in the means between males and females, or between the right and left sides. In this analysis age was a covariate in order to remove any confounding effects of age. The frequency of males and females by age groups is given in Table 11. Due to the unequal cell frequencies for sex in the 16 age categories, in the analysis of covariance the parameters cannot be estimated independently of each other so that the main effects are not independent of each other, nor are the interaction effects independent of the main effects. Since the largest root criterion (parameters: s = 1, m = 2 1/2, n = 133 1/2) for sex, side, and sex given side and the Hotelling's trace criterion (Table 12) were all less than $F_{0.05}(7,269) = 2.34$, the multivariate tests provided no evidence to reject the hypothesis that $\mu = \mu_0$, and indicated that no significant difference existed between males and females, or between the right and left sides.

Table 12

Multivariate analysis of covariance for sex and side significance, controlling for age. HTC = Hotelling's trace criterion, LRC = largest root criterion.

Effect	HTC	LRC	F	P(≥ F)
Sex by side	0.1594	.01569	.61	.7455
Side	0.0119	.01176	.46	.8649
Sex	0.3540	.03421	1.36	.2220

Parameters: s = 1, m = 2 1/2, n = 133 1/2 or F (7,269)
(Potthoff and Roy 1964)

Table 11

Frequency of males and females in the normal group by age

Age Groups (weeks)	Males	Females	Total
12	8	8	16
14	5	13	18
16	10	8	18
18	10	9	19
20	4	11	15
22	6	6	12
24	6	3	9
26	5	3	8
28	1	0	1
30	2	5	7
32	1	1	2
34	0	3	3
36	0	1	1
38	2	0	2
40	2	3	5
42	4	0	4
Total	66	74	140
> 42	3	0	4*
Grand Total	69	74	144

* one case sex unknown

In the multivariate analysis of effects none of the F values were significant at 0.1, and only the F value for the effect of sex, when age was controlled, approached 0.1. In the univariate F tests without controlling for age, all variables had F values significant at less than 0.001 with the exception of the neck-shaft angle. Thus all of the variables measured, as expected, increase in value with age except for the neck-shaft angle which showed no significant effect of age even at the 0.1 level. However, in the analysis of the effect of sex by side with the effects of age controlled, the neck-shaft angle was the only variable in univariate tests to suggest any significant effect (F=2.87, p = 0.091). The least nonsignificant univariate test in the same analysis was FH diameter.

In univariate tests for the effect of side, controlling for age, none of the variables had F values significant at 0.1 but again both angles showed a slight trend towards this level (torsion: F=1.09, p = 0.298; neck-shaft angle: F=0.79, p = 0.372). Acetabular depth had the least nonsignificant univariate test for the effect of side.

In univariate tests for the effect of sex, controlling for age, acetabular depth again had the least nonsignificant F value. However, F values for LHF width and length and torsion were all significant at less than 0.1. The F values for these three variables are given in Table 13.

Since the more sensitive multivariate tests failed to provide any evidence to reject the null hypothesis of no significant differences in the means between the sexes or between the sides, and only torsion, in a univariate test, showed significance at 0.01 for the effect of sex, the sexes were pooled for the greater part of the hip joint growth analysis.

Table 13

Analysis of covariance, univariate F tests (1, 275) for the effect of sex

Variable	F	P (≥ F)
LHF width	3.09	.0798
LHF length	2.94	.0877
Torsion	6.64	.0105

Hip Joint Growth Statistics for the Normal Group (n = 140).

Strong correlation was present between intra-side acetabular and femoral head variables (Table 14). Raw coefficients of determination for between the right and left sides (Table 15), with the exception of the neck-shaft angle, were high (min.: 0.769 for torsion to max.: 0.988 for acetabular diameter (acediameter)) and significant at less than 0.001. The analysis was therefore conducted on 140 cases instead of regarding each hip joint as a separate unit making 280 cases. The correlations between sides for acetabular depth, acediameter and FH diameter remained highly significant after adjustment for age, but were lower for the LHF variables and torsion. The neck-shaft angle r values were not significant after adjustment for age. These data are presented in Table 16. After adjustment for age, the highest correlation coefficients exist between acediameter and FH diameter (r = .860). Correlation coefficients for LHF length and width were strongest with FH diameter, as was the r for torsion.

The means and one standard deviation (SD) by sex, side and age group for each variable, with the frequency of observations, are presented in Tables 17 - 23. Age group means with one SD for the sexes combined, by side (right then left for each age group) for each variable

Table 14

Coefficients of determination between variables by side. R = right, L = left, n = 140, acediameter = acetabular diameter, FH = femoral head.

	R^2
R depth, R acediameter	.894
L depth, L acediameter	.884
R acediameter, R FH diameter	.982
L acediameter, L FH diameter	.986
R depth, R FH diameter	.889
L depth, L FH diameter	.880

Table 15

Coefficients of determination for variables between sides. R = right, L = left. *$p < .001$, acediameter = acetabular diameter, FH = femoral head, LHF = ligament of the head of the femur.

	R^2	n
R depth, L depth	.936*	140
R acediameter, L acediameter	.988*	140
R FH diameter, L FH diameter	.995*	140
R torsion, L torsion	.769*	133
R neck-shaft, L neck-shaft angle	.133	139
R LHF length, L LHF length	.862*	138
R LHF width, L LHF width	.845*	138

are shown in Figures 26 - 32. A comparison of size between variables within each age group, by sex and side is given in Appendix H. Placement of cases in two-weekly age groups produces an artificial clumping of cases at each age group point so that larger standard deviations are obtained for the means of each variable by age in two-weekly groups than by CRL. When cases are plotted by CRL a steady continuum of cases is seen. Scatterplots for each variable by CRL are presented in Figure 33 and Appendix I.

Table 16

Correlations of variables between sides adjusted for age as a covariate

Standard deviations* are given on the diagonal, acediameter=acetabular diameter, FH = femoral head, LHF = ligament of the head of femur.

Right across / Left down	depth	acediameter	FH diameter	LHF width	LHF length	neck-shaft angle	torsion
depth	.60*						
acediameter	.637	.89*					
FH diameter	.618	.860	.85*				
LHF width	.222	.319	.343	1.01*			
LHF length	.242	.347	.407	.589	1.71*		
neck-shaft angle	.103	.086	.088	.003	.041	8.20*	
torsion	.340	.341	.431	.181	.273	-.032	9.61*

* in mm except for the neck-shaft angle and torsion which are in degrees.

Table 17: Acetabular depth (mm) by age, sex and side, n = 140

CRL	Age Group	Sexes Combined			Males			Females		
cm, $\bar{x}$	(weeks)	n	Mean	SD	n	Mean	SD	n	Mean	SD
10.5	12	16	*1.90	0.31	8	1.84	0.36	8	1.95	0.27
			1.84	0.29		1.87	0.33		1.81	0.25
12.9	14	18	2.42	0.38	5	2.53	0.42	13	2.37	0.38
			2.41	0.32		2.36	0.23		2.43	0.35
14.9	16	18	2.92	0.40	10	2.82	0.36	8	3.04	0.45
			2.91	0.42		2.77	0.40		3.07	0.41
17.7	18	19	3.60	0.37	10	3.48	0.44	9	3.73	0.24
			3.61	0.47		3.50	0.42		3.72	0.52
19.9	20	15	3.95	0.56	4	3.83	0.51	11	3.99	0.60
			4.00	0.48		3.95	0.40		4.02	0.52
21.7	22	12	4.02	0.45	6	4.25	0.43	6	3.79	0.36
			4.03	0.49		4.21	0.55		3.85	0.37
23.8	24	9	3.88	0.50	6	4.10	0.30	3	3.43	0.58
			3.87	0.47		4.13	0.21		3.34	0.42
25.1	26	8	4.76	0.45	5	4.57	0.37	3	5.09	0.42
			4.81	0.58		4.59	0.55		5.17	0.52
27.5	28	0	-	-	1	5.40	0.00	0	-	-
						5.50	0.00			
28.3	30	7	4.95	0.64	2	5.17	0.52	5	4.87	0.74
			5.01	0.63		5.23	0.14		4.92	0.74
30.0	32	2	5.45	0.78	1	4.90	0.00	1	6.00	0.00
			5.40	0.33		5.17	0.00		5.63	0.00
32.5	34	0	-	-	0	-	-	3	5.80	1.02
									5.44	0.67
34.0	36	0	-	-	0	-	-	1	5.33	0.00
									5.26	0.00
36.0	38	0	-	-	2	5.89	0.48	0	-	-
						5.27	0.63			
37.5	40	5	6.33	0.92	2	6.47	0.80	3	6.23	1.15
			6.49	1.10		6.50	0.71		6.49	1.48
39.3	42	0	-	-	4	7.02	1.56	0	-	-
						7.07	1.40			

* The first number in each pair is for the right hip, the second is for the left hip.

Table 18: Acetabular diameter (mm) by age, sex and side, n = 140

CRL cm, $\bar{x}$	Age Group (weeks)	Sexes Combined			Males			Females		
		n	Mean	SD	n	Mean	SD	n	Mean	SD
10.5	12	16	*4.04	0.71	8	3.82	0.74	8	4.27	0.64
			4.10	0.29		3.90	0.77		4.31	0.70
12.9	14	18	5.44	0.60	5	5.23	0.70	13	5.52	0.61
			5.41	0.58		5.31	0.56		5.45	0.60
14.9	16	18	6.32	0.55	10	6.14	0.51	8	6.54	0.54
			6.30	0.53		6.14	0.49		6.50	0.54
17.7	18	19	8.00	0.63	10	7.92	0.66	9	8.08	0.62
			7.93	0.60		7.87	0.71		8.01	0.47
19.9	20	15	9.74	0.66	4	8.35	0.81	11	8.88	0.58
			8.71	0.66		8.39	0.83		8.93	0.59
21.7	22	12	9.37	0.74	6	9.66	0.73	6	9.09	0.70
			9.37	0.76		9.69	0.64		9.04	0.77
23.8	24	9	9.78	0.68	6	10.06	0.62	3	9.22	0.45
			9.72	0.73		9.97	0.49		9.22	0.99
25.1	26	8	10.98	0.89	5	11.10	1.00	3	10.78	0.81
			11.01	0.88		11.13	0.99		10.80	0.82
27.5	28	0	-	-	1	13.20	0.00	0	-	-
						13.20	0.00			
28.3	30	7	12.59	1.40	2	13.94	0.98	5	12.04	1.19
			12.60	1.10		13.14	2.18		12.37	0.64
30.0	32	2	13.58	1.94	1	12.21	0.00	1	14.96	0.00
			13.28	1.28		12.38	0.00		14.19	0.00
32.5	34	0	-	-	0	-	-	3	14.25	1.34
									14.23	1.32
34.0	36	0	-	-	0	-	-	1	13.53	0.00
									15.35	0.00
36.0	38	0	-	-	2	13.94	0.35	0	-	-
						13.78	0.35			
37.5	40	5	17.37	1.16	2	18.01	1.21	3	16.94	1.12
			17.15	1.27		17.82	1.32		16.70	1.27
39.3	42	0	-	-	4	18.14	1.15	0	-	-
						17.74	1.34			

* The first number in each pair is for the right hip, the second is for the left hip.

Table 19: Femoral head diameter (mm) by age, sex and side, n = 140

CRL	Age Group		Sexes Combined			Males			Females	
cm, $\bar{x}$	(weeks)	n	Mean	SD	n	Mean	SD	n	Mean	SD
10.5	12	16	*4.02	0.73	8	3.83	0.81	8	4.21	0.63
			4.00	0.74		3.81	0.81		4.20	0.67
12.9	14	18	5.41	0.56	5	5.36	0.52	13	5.43	0.52
			5.36	0.60		5.22	0.53		5.41	0.64
14.9	16	18	6.29	0.55	10	6.10	0.53	8	6.52	0.51
			6.22	0.53		6.07	0.50		6.40	0.52
17.7	18	19	8.01	0.72	10	7.99	0.83	9	8.04	0.61
			7.95	0.75		7.90	0.85		8.00	0.68
19.9	20	15	8.67	0.56	4	8.48	0.77	11	8.74	0.49
			8.60	0.60		8.35	0.76		8.70	0.54
21.7	22	12	9.43	0.62	6	9.52	0.60	6	9.34	0.73
			9.45	0.57		9.60	0.65		9.31	0.50
23.8	24	9	9.75	0.45	6	9.94	0.26	3	9.38	0.57
			9.73	0.45		9.93	0.24		9.31	0.56
25.1	26	8	10.99	0.83	5	11.13	1.00	3	10.74	0.52
			11.02	0.76		11.14	0.94		10.82	0.39
27.5	28	0	-	-	1	12.71	0.00	0	-	-
						12.71	0.00			
28.3	30	7	12.43	1.27	2	13.01	1.21	5	12.20	1.19
			12.37	1.59		13.04	1.17		12.10	0.99
30.0	32	2	13.26	1.48	1	12.21	0.00	1	14.30	0.00
			13.28	1.75		12.05	0.00		14.52	0.00
32.5	34	0	-	-	0	-	-	3	13.81	1.27
									13.62	1.52
34.0	36	0	-	-	0	-	-	1	15.02	0.00
									15.35	0.00
36.0	38	0	-	-	2	14.85	1.40	0	-	-
						15.13	1.01			
37.8	40	5	16.98	1.07	2	16.77	1.63	3	17.12	0.94
			16.83	1.38		16.67	2.57		16.94	0.68
39.3	42	0	-	-	4	17.95	1.47	0	-	-
						17.83	1.58			

* The first number in a pair is for the right hip, the second for the left hip

Table 20: Femoral torsion (degrees) by age, sex and side, n = 133 right, n = 134 left

CRL	Age Group	Sexes Combined			Males			Females		
cm, $\bar{x}$	(weeks)	n	Mean	SD	n	Mean	SD	n	Mean	SD
10.5	12	§15	*0.65	4.88	§7	1.51	7.04	8	-0.11	1.96
		16	-0.69	6.76	8	-1.04	7.43		-0.35	6.52
12.9	14	18	4.43	7.15	5	0.98	1.63	13	5.76	8.04
			4.42	4.58		3.40	1.22		4.81	5.36
14.9	16	18	7.53	5.69	10	5.96	4.02	8	9.49	7.06
			9.19	6.10		7.65	5.99		11.13	6.04
17.7	18	19	16.25	8.90	10	13.33	8.94	9	19.50	8.11
			19.13	9.37		16.11	9.63		22.49	8.32
19.9	20	15	15.49	8.39	4	13.90	12.16	11	16.07	7.27
			18.80	6.20		19.00	9.40		18.73	5.23
21.7	22	§11	17.63	9.81	5	*19.06	12.28	6	16.43	8.26
			20.05	10.70		20.52	14.07		19.65	8.37
23.8	24	9	17.47	10.43	6	14.82	11.79	3	22.77	4.97
			15.62	8.00		13.15	8.22		20.57	5.69
25.1	26	8	17.69	6.93	5	14.72	6.04	3	22.63	6.03
			18.79	5.02		17.14	4.17		21.53	5.97
27.5	28	0	-	-	1	16.30	0.00	0	-	-
						22.30	0.00			
28.3	30	§5	23.04	10.40	2	12.80	3.96	§3	29.87	5.80
			21.30	5.28		18.45	1.63		23.20	6.40
30.00	32	2	30.80	0.71	1	31.30	0.00	1	30.33	0.00
			33.15	3.04		31.00	0.00		35.33	0.00
32.5	34	0	-	-	0	-	-	§2	25.15	7.28
									29.15	3.04
34.0	36	0	-	-	0	-	-	1	23.33	0.00
									25.33	0.00
36.0	38	0	-	-	2	24.85	3.04	0	-	-
						26.00	0.99			
37.8	40	5	17.92	6.32	2	19.15	10.11	3	17.10	5.11
			24.10	7.53		29.30	11.31		20.63	2.05
39.3	42	0	-	-	§2	15.50	5.37	0	-	-
						10.70	12.73			

§ missing data proximal end of femur only

* The first number in a pair is for the right hip, the second for the left hip.

Table 21: Femoral neck-shaft angle (degrees) by age; sex and side, n = 139 right, n = 140 left

CRL	Age Group	Sexes Combined			Males			Females		
cm, $\bar{x}$	(weeks)	n	Mean	SD	n	Mean	SD	n	Mean	SD
10.5	12	§15	*125.14	5.64	§7	124.49	4.42	8	125.71	6.79
		16	126.05	3.64	8	127.31	1.53		124.79	4.73
12.9	14	18	128.52	3.75	5	129.56	1.74	13	128.12	4.28
			124.91	2.13		126.12	1.30		124.44	2.24
14.9	16	18	126.49	3.45	10	126.28	4.54	8	126.75	1.54
			125.09	3.15		125.82	3.08		124.18	3.19
17.7	18	19	124.16	2.54	10	124.97	2.58	9	123.27	2.31
			123.16	1.75		123.67	1.50		122.60	1.92
19.9	20	15	126.72	2.81	4	128.40	2.40	11	126.11	2.79
			124.19	1.59		124.48	2.43		124.08	1.31
21.7	22	12	126.29	3.04	6	127.00	3.75	6	125.58	2.26
			121.97	2.79		122.57	3.22		121.35	2.42
23.8	24	9	124.46	3.30	6	124.03	3.45	3	125.30	3.48
			122.93	3.98		123.75	3.46		121.30	5.24
25.1	26	8	123.95	2.56	5	124.02	2.94	3	123.83	0.68
			123.46	2.42		123.24	2.62		123.83	2.54
27.5	28	0	-	-	1	123.60	0.00	0	-	-
						126.60	0.00			
28.3	30	7	124.16	3.90	2	122.15	5.87	5	124.96	3.37
			122.77	1.73		123.80	0.28		122.36	1.93
30.0	32	2	123.15	2.62	1	125.00	0.00	1	121.30	0.00
			120.80	3.11		123.00	0.00		118.60	0.00
32.5	34	0	-	-	0	-	-	3	124.77	0.68
									121.20	1.06
34.0	36	0	-	-	0	-	-	1	128.00	0.00
									123.60	0.00
36.0	38	0	-	-	2	124.80	0.71	0	-	-
						121.45	0.21			
37.8	40	5	125.42	3.88	2	123.45	4.46	3	126.73	3.70
			124.30	3.34		124.95	0.50		123.87	4.63
39.3	42	0	-	-	4	126.90	4.40	0	-	-
						125.23	1.53			

§ missing datum

* The first number in each pair is for the right hip, the second for the left hip.

Table 22: Ligament of the head of femur length (mm) by age, sex and side, n = 138 right, n= 139 left

CRL cm, $\bar{x}$	Age Group (weeks)	Sexes Combined n	Sexes Combined Mean	Sexes Combined SD	Males n	Males Mean	Males SD	Females n	Females Mean	Females SD
10.5	12	16	*2.20	0.83	8	1.97	0.92	8	2.44	0.70
			2.07	0.74		1.86	0.90		2.28	0.52
12.9	14	18	3.36	1.02	5	2.63	0.55	13	3.64	1.04
			3.24	0.64		3.11	0.51		3.29	0.69
14.9	16	18	3.88	0.74	10	3.96	0.74	8	3.78	0.71
			4.18	0.41		4.10	0.65		4.27	0.87
17.7	18	19	5.14	1.02	10	4.94	1.01	9	5.37	1.05
			5.13	1.12		4.90	1.03		5.37	1.21
19.9	20	15	5.27	0.95	4	5.37	0.96	11	5.04	0.91
			4.87	0.98		4.41	1.14		3.31	0.67
21.7	22	12	6.88	1.27	6	6.45	1.34	6	7.30	1.15
			6.76	1.63		5.90	1.10		7.61	1.69
23.8	24	9	6.70	1.66	6	6.74	1.37	3	6.62	2.52
			6.22	2.31		6.47	2.70		5.72	1.60
25.1	26	8	7.81	1.97	5	6.95	1.84	3	9.25	1.38
			7.45	1.63		7.05	0.97		8.11	2.52
27.5	28	0	-	-	1	10.39	0.00	0	-	-
						10.93	0.00			
28.3	30	§ 6	9.46	1.22	2	10.31	2.19	§ 4	9.03	0.37
		7	8.84	1.59		10.41	0.04	5	8.22	1.44
30.0	32	2	9.65	3.15	1	7.42	0.00	1	11.88	0.00
			8.33	2.80		6.35	0.00		10.31	0.00
32.5	34	0	-	-	0	-	-	3	9.57	0.40
									9.90	1.59
34.0	36	0	-	-	0	-	-	1	9.53	0.00
									9.41	0.00
36.0	38	0	-	-	2	11.10	2.95	0	-	-
						11.02	2.05			
37.8	40	§ 4	10.75	1.38	§ 1	11.29	0.00	3	10.57	1.64
			11.05	2.02		11.81	0.00		10.80	2.39
39.3	42	0	-	-	4	11.65	1.04	0	-	-
						11.83	3.45			

§ missing 1 case/received dislocated

* The first number in each pair is for the right hip, the second for the left hip.

Table 23: Ligament of the head of femur width (mm) by age, sex and side, n = 138 right, n = 139 left

CRL cm, $\bar{x}$	Age Group (weeks)	Sexes Combined			Males			Females		
		n	Mean	SD	n	Mean	SD	n	Mean	SD
10.5	12	16	*1.34	0.69	8	1.13	0.59	8	1.56	0.76
			1.44	0.77		1.51	1.07		1.36	0.34
12.9	14	18	1.78	0.24	5	1.75	0.34	13	1.79	0.21
			1.78	0.35		1.72	0.48		1.81	0.31
14.9	16	18	2.11	0.41	10	2.17	0.39	8	2.04	0.71
			2.13	0.47		2.09	0.51		2.19	0.41
17.7	18	19	3.08	0.63	10	3.00	0.81	9	3.16	0.39
			2.99	0.52		2.82	0.58		3.17	0.40
19.9	20	15	3.37	0.64	4	3.55	0.59	11	3.31	0.67
			3.61	0.56		3.95	0.44		3.49	0.56
21.7	22	12	3.98	0.83	6	3.70	0.79	6	4.26	0.85
			3.81	0.76		4.04	0.77		3.58	0.74
23.8	24	9	3.85	0.67	6	3.65	0.75	3	4.25	0.25
			4.33	0.67		4.29	0.83		4.43	0.23
25.1	26	8	4.24	1.33	5	3.85	1.60	3	4.90	0.23
			4.06	0.92		4.08	1.02		4.04	0.96
27.5	28	0	-	-	1	4.16	0.00	0	-	-
						3.52	0.00			
28.3	30	§6	4.99	1.22	2	4.29	0.63	§4	5.34	1.36
		7	5.25	1.40		5.85	1.12		5.01	1.55
30.0	32	2	5.87	1.72	1	4.65	0.00	1	7.08	0.00
			6.31	0.51		5.95	0.00		6.67	0.00
32.5	34	0	-	-	0	-	-	3	5.88	0.75
									6.18	1.44
34.0	36	0	-	-	0	-	-	1	6.75	0.00
									5.78	0.00
36.0	38	0	-	-	2	5.80	0.92	0	-	-
						5.27	1.00			
37.8	40	§4	7.19	1.38	§1	8.38	0.00	3	6.80	1.38
			6.59	0.67		7.36	0.00		6.33	0.53
39.3	42	0	-	-	4	7.08	1.51	0	-	-
						6.73	1.26			

§ received dislocated, not measured
* The first number in a pair is for the right hip, the second for the left hip.

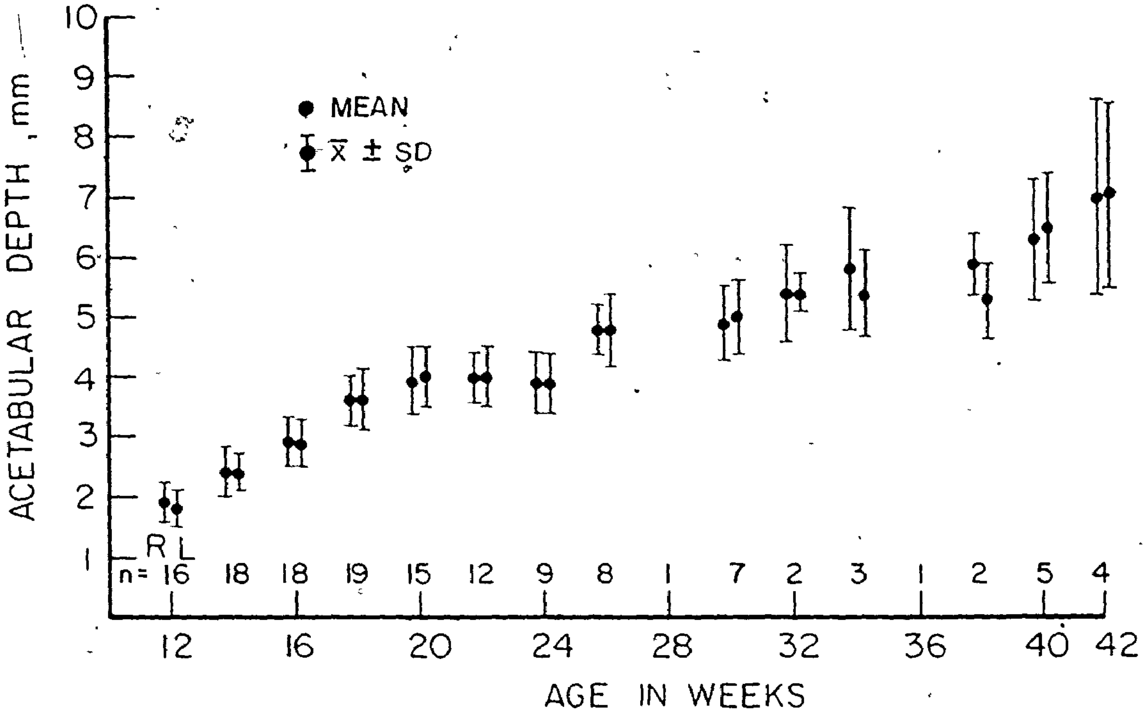


Figure 26 : Acetabular depth, mean values and standard deviations, sexes combined, by side, for n=140.

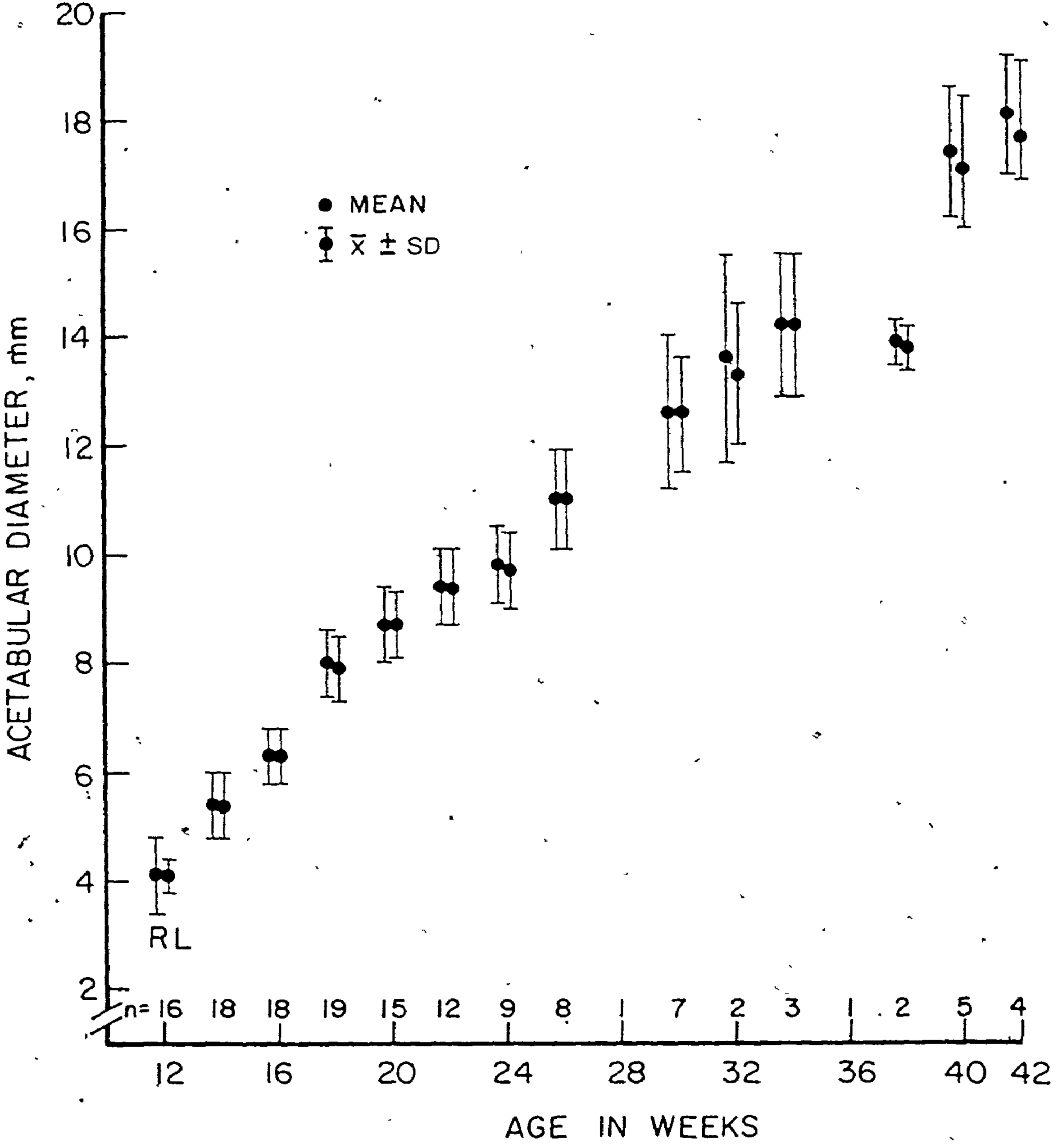


Figure 27 : Acetabular diameter, mean values and standard deviations, sexes combined, by side, for n = 140.

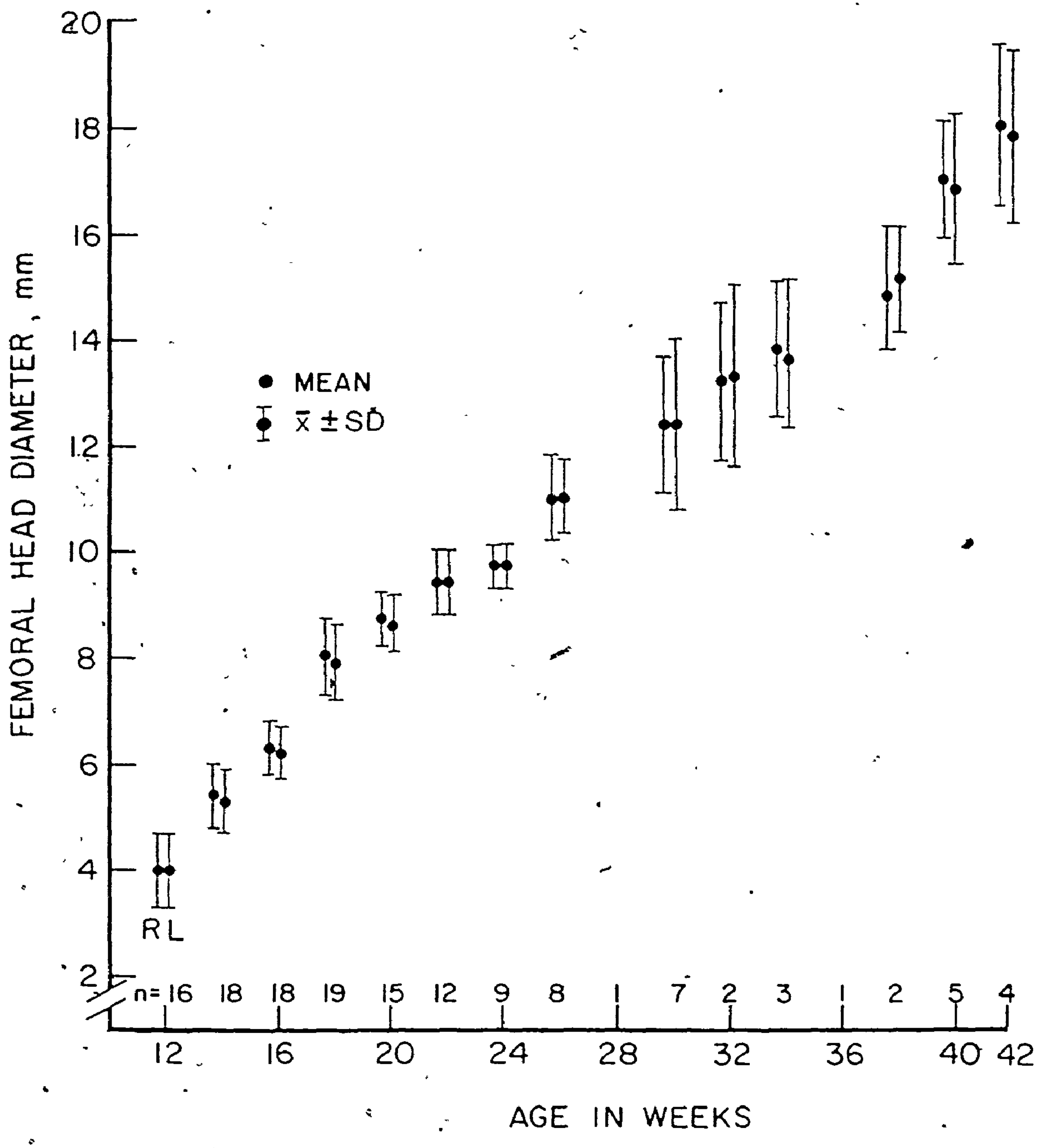


Figure 28 : Femoral head diameter, mean values and standard deviations, sexes combined, by side, for n = 140.

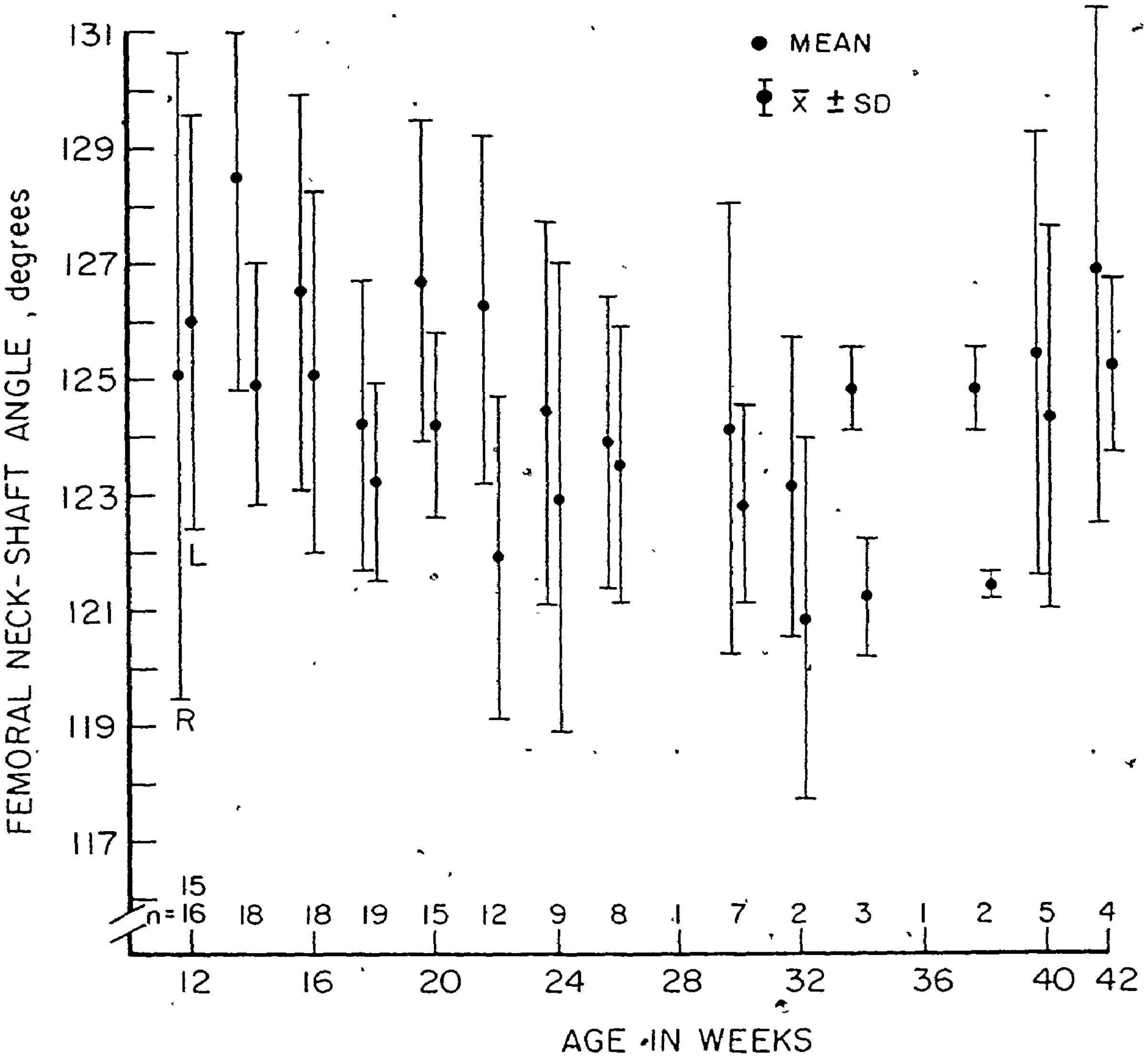


Figure 29 : Neck-shaft angle, mean values and standard deviations, sexes combined, by side, for n = 139 right, 140 left.

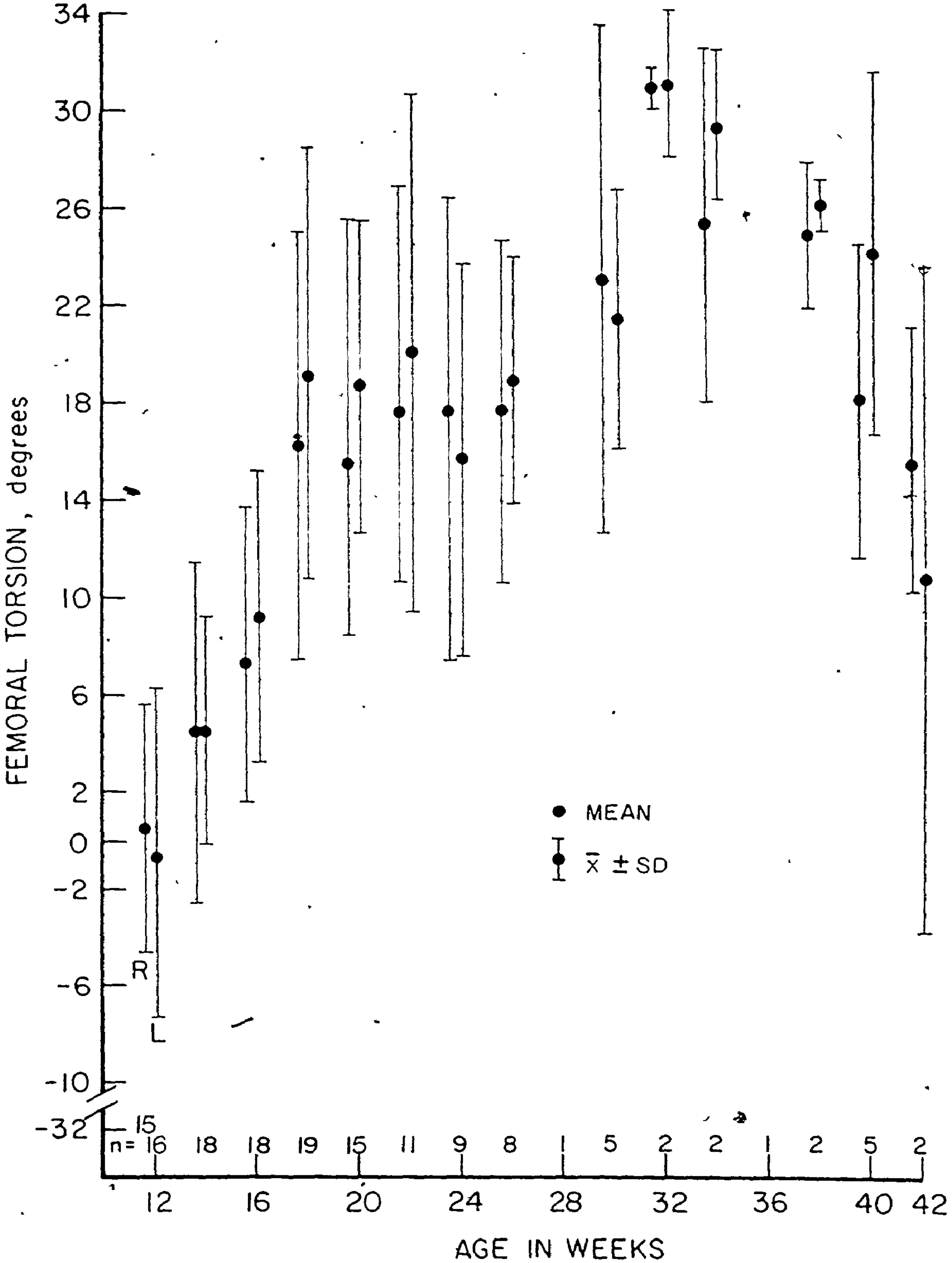


Figure 30 : Femoral torsion, mean values and standard deviations, sexes combined, by side, for n=133 right, 134 left.

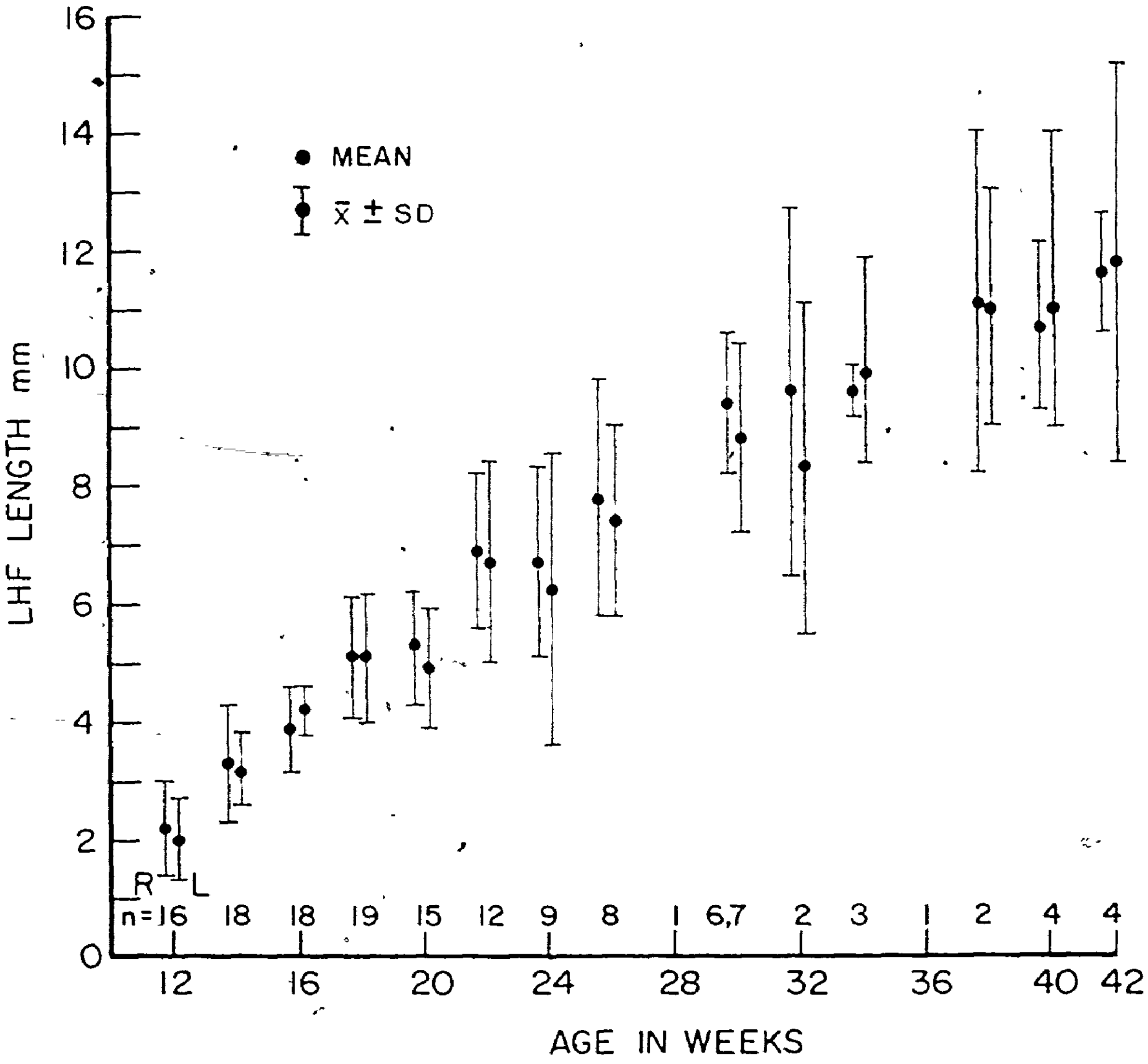


Figure 31 : Ligament of the head of femur (LHF) length, mean values and standard deviations, sexes combined, by side, for n = 138 right, 139 left.

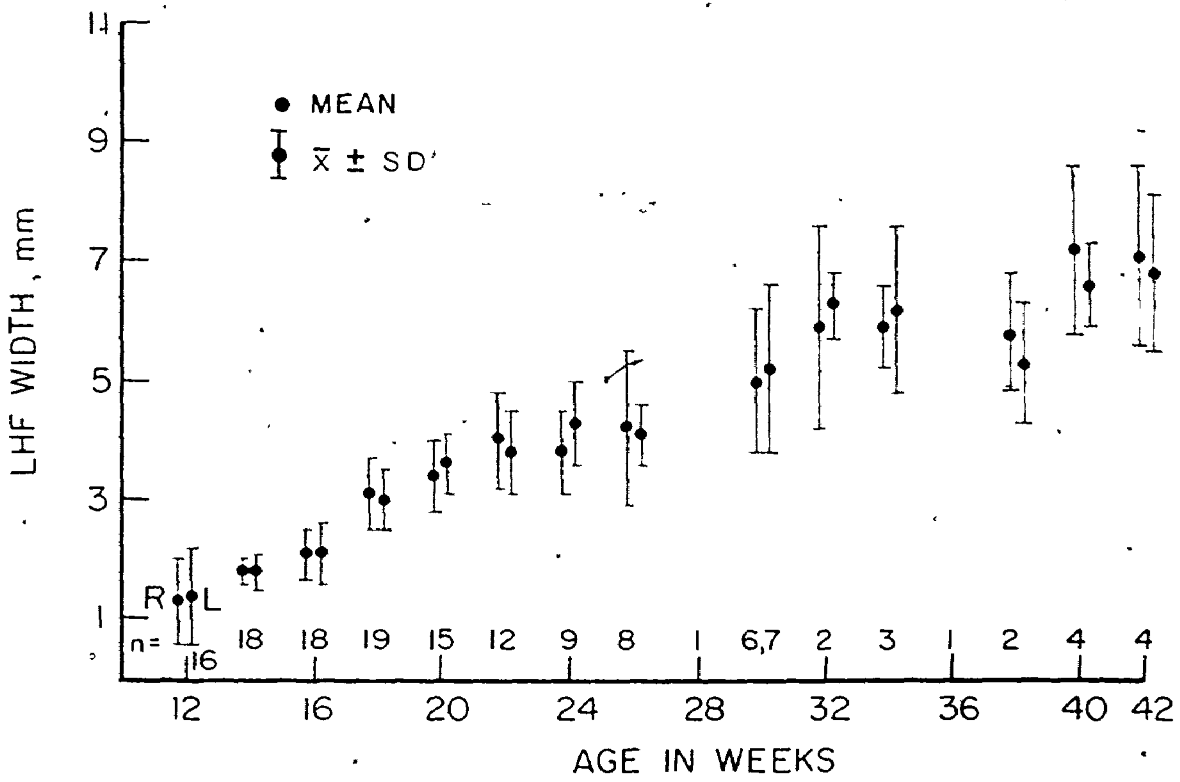


Figure 32 : Ligament of the head of femur (LHF) width, mean values and standard deviations, sexes combined, by side, for n = 138 right, 139 left.

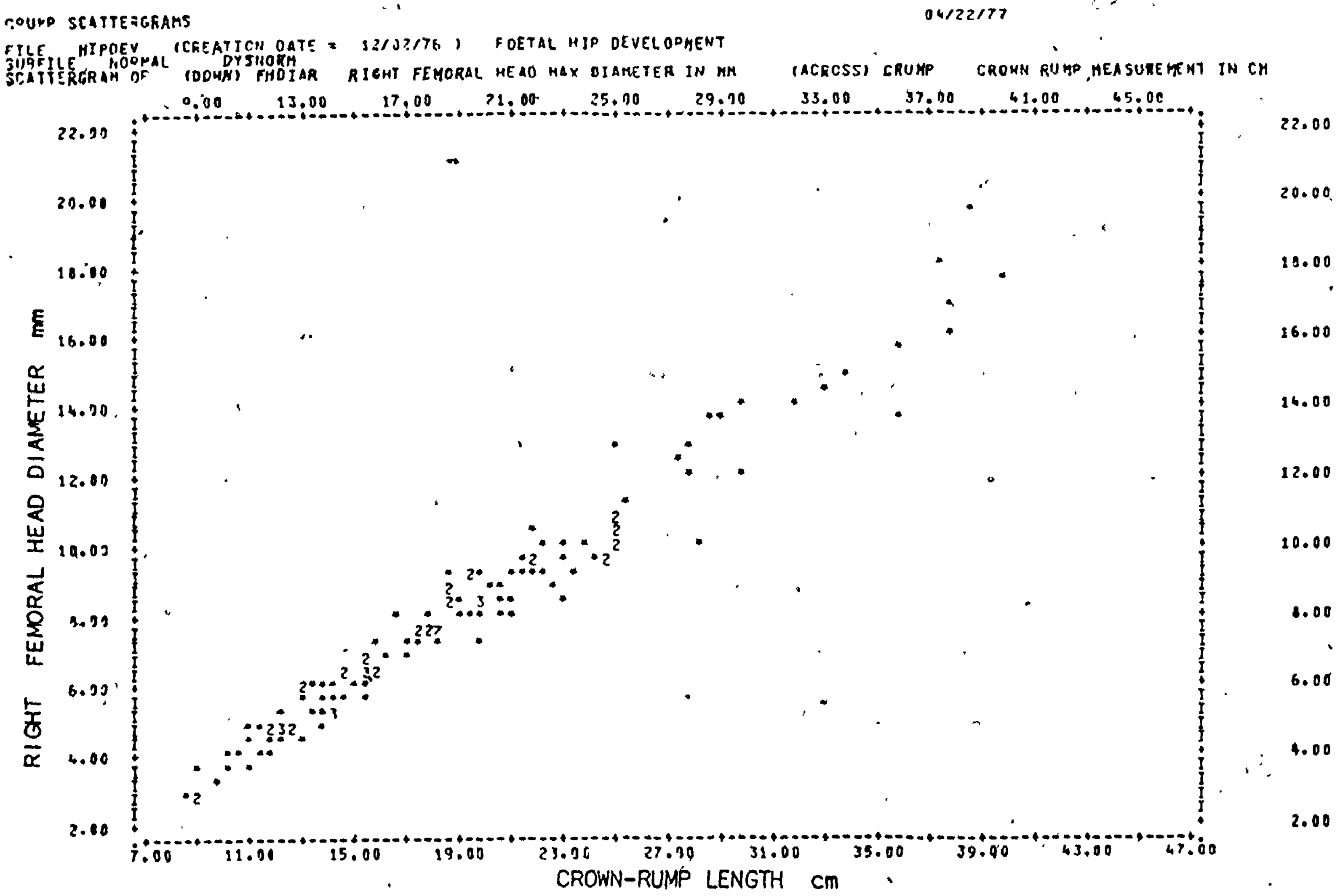


Figure 33 : An example of cases plotted by crown-rump length, right femoral head diameter
* = one observation, numbers = frequency at that point.
(Scatterplots for the remaining variables, right side only, are given in Appendix I.)

With the obvious exception of the neck-shaft angle the means for all variables increase steadily with age. The strongest linear trend in the variables mentioned is seen between age groups 12 and 18 - 20 weeks. The increase in observed means from 12 weeks to term is greatest for LHF length which shows a five-fold increase, and is more than four-fold for LHF width, acediameter and FH diameter. Acetabular depth shows the slowest growth in the period studied, the increase being less than four-fold. Over all age groups a consistent linear growth trend is only apparent in the two diameters, acetabular and femoral head. Standard deviations tend to increase with age and for all variables these overlap between adjacent age groups. Overlapping in standard deviations between age groups is most marked for the LHF variables and the two femoral angles. In the latter two variables standard deviations at term (38 - 42 weeks) overlap with those at 12 weeks demonstrating considerable dispersion in angular values throughout the fetal period.

Lack of obvious change in the neck-shaft angle is seen in a series of femora from 12 weeks to term (Figure 34a). The change in the torsion angle in the same series of femora is shown in Figure 34b. In this sample the maximum values for torsion were observed at 32 weeks (30.0 cm CRL). After 32 weeks torsion angle values decreased but standard deviations are large. One case (normal) at 42 weeks had mean torsion values of 1.7° on the left and 11.7° on the right. Minor side differences are seen in three pairs of femora of different ages (Fig. 34c).

Sample standard errors were the smallest for acetabular depth and largest for torsion (Table 24). These provide a measure of the

Figure 34: Changes in angulation of the femur with age

a) The neck-shaft angle in a series of left femora from 12 weeks (10.2 cm CRL) to term. While the increase in femoral size is obvious, little change takes place in the neck-shaft angle. Note also the shortness of the femoral neck which still has no appreciable length in the 40 week femur.

b) Torsion angle in a series of right femora from 12 weeks (10.2 cm CRL) to term. Note also the variation in the proximal point of contact.

In a) and b) the age of femora are, from the right, 12, 14, 16, 20, 22, 24, 28, 34, 36, and 40 weeks.

c) Side variation and age changes in three pairs of femora.

1 = CRL 8.7 cm
2 = CRL 15.1 cm
3 = CRL 36.0 cm

Note the variation in the proximal point of contact. In #3 the left femur rests on the greater trochanter, while the right rests naturally on the lesser trochanter. Both #1 femora rest on the lesser trochanter. In #2 the right femur rests on the lesser trochanter while the left femur (right side of the pair) rests naturally on the greater trochanter.

a

c

discrepancy between the observed mean and that for the unknown population.

Table 24

Sample standard errors by side for n = 140. Superscript = n of observations.

Variable	Right	Left
Ligament of the head of femur, width	0.147^{138}	0.141^{139}
Ligament of the head of femur, length	0.241^{138}	0.244^{139}
Depth	0.116	0.117
Acetabular diameter	0.309	0.305
Femoral head diameter	0.306	0.306
Neck-shaft angle	0.312^{139}	0.214
Torsion	0.893^{133}	0.936^{134}

Data for the single case (#153) at age group 28 weeks appears consistently high in comparison with adjacent age group means, with the exception of data for LHF width. This may reflect an underestimation of the age of this fetus for which no gestational age or weight data were available. Incorrect age assessment may also be present for the single case (#39) at the age group of 36 weeks. In comparison with adjacent age group values, depth, right acediameter and LHF length are low. However, flattening of the acetabular rim was present and was more marked on the right side. Since the FH diameters are higher than the adjacent group means, this case with a CRL of 34 cm, and an estimated gestational age of 42 weeks, may belong in the 38 week group. Values for the acetabular variables in this case may reflect a localized disturbance of growth.

Similarly, the means for the two term fetuses (#84, #35) in the 38-week group deviate from the general linear trend. Mean values for depth, FH diameter, LHF width are slightly low while values for acetabular diameter are lower. One case (#84) exhibited bilateral acetabular rim dips with variation in labrum thickness.

Growth Curves

To define the pattern of growth for the hip variables, and to obtain predictive values for these variables with a knowledge of age based on crown-rump length, regression models were devised. Multivariate regression programs were used because of the high degree of correlation shown between the variables. Observations made on each hip joint are not independent but are assumed to be a multivariate normal with unknown variance matrix. The hypothesis tested is that the mean vector coefficients are simultaneously zero, that is $\underset{\sim}{B} = \underset{\sim}{0}$. Univariate test results from these programs will be reported.

Examination of residuals showed that the variance was not constant and, with the exception of the neck-shaft angle, the variance increased with age. A correlation was demonstrated when the means and standard deviations, at each age group, for each variable, were plotted against each other. To meet the basic assumption of multivariate analysis that all observations have the same unknown variance matrix and to obtain a straight line relationship, various transformations of the data were attempted. These included a natural logarithmic transformation, the use of a logistic function on some of the dependent variables, and the addition of a second and third power polynomial to the independent variable age. A summary of goodness-of-fit tests for different regression models, with sex as one of the independent variables, is presented in Table 25. Two examples of the analysis of variance (ANOVA) testing for significance of different models, and the determination of model lack of fit are given in Tables 26 and 27. When a simple linear regression model

$$\hat{y} = \hat{\beta}_0 + \hat{\beta}_1 x + \hat{\beta}_2 \text{sex}$$

where y = variable estimated, = a constant for y, a constant for age (x), β_2 = a constant for sex where males = 0, females = 1, was fitted nonsignificant lack of fit was only obtained for both neck-shaft angles, left LHF length and right LHF width. From Table 25 it can be seen that a natural logarithmic transformation of FH, acetabular diameter and depth did not improve the lack of fit when used in conjunction with a second polynomial on age. Furthermore, the modified coefficient of determination, corrected for the mean, Q_m^2, showed a slight decrease when a logarithmic transformation was employed. For FH and acetabular diameters the model with nonsignificant lack of fit included a second and third power polynomial on age, that is:

$$\hat{y} = \hat{\beta}_0 + \hat{\beta}_1 x + \hat{\beta}_2 x^2 + \hat{\beta}_3 x^3 + \hat{\beta}_4 \text{sex}$$

where y = the dependent variable, for example, left depth; β_0 = a constant for the dependent variable y; β_1, β_2 , β_3 = constants for age (x), age^2(x^2), age^3(x^3); $\beta_4$sex = a constant for sex where males = 0, females = 1.

The addition of sex as an independent variable in the models contributed minimally to the total amount of explainable variation. Partial F values for sex were significant at less than 0.05 for torsion

Table 25: Lack of Fit in Different Regression Models
1=mean, 2=age, 3=age^2, 4=age^3, 5=sex, R=right, L=left, FH=femoral head, acediameter=acetabular diameter, LHF=ligament of the head of femur.

VARIABLE		Models: 1,2,5, F*	1,2,5, P(≥F)	1,2,5, Q_m^2%	1,2,3,5 F*	1,2,3,5 P(≥F)	1,2,3,5 Q_m^2%	ln 1,2,3,5 F*	ln 1,2,3,5 P(≥F)	ln 1,2,3,5 Q_m^2%	1,2,3,4,5 F*	1,2,3,4,5 P(≥F)	1,2,3,4,5 Q_m^2%	ln 1,2,3,4,5 F*	ln 1,2,3,4,5 P(≥F)	ln 1,2,3,4,5 Q_m^2%
R	depth	2.05	.0110	94.53	1.66	.0580	95.81	2.35	.0035	94.50	1.03	.4322	97.53	1.02	.4426	97.70
L	depth	2.55	.0008	93.08	1.99	.0160	95.08	2.90	.0003	93.70	1.11	.3534	97.40	1.06	.4016	97.80
R	acediameter	2.85	.0003	97.85	2.54	.0015	98.18	3.50	.0000	96.90	1.71	.0509	98.85	1.27	.2250	99.00
L	acediameter	2.85	.0003	98.01	2.42	.0026	98.39	2.86	.0004	97.30	1.70	.0528	98.93	0.86	.6214	99.20
R	FH diameter	1.91	.0198	98.63	1.51	.0986	98.97	2.05	.0124	97.90	0.60	.8859	99.61	0.00		100.00
L	FH diameter	2.00	.0136	98.59	1.51	.0999	98.99	2.82	.0005	97.30	0.63	.8617	99.60	0.63	.8617	99.40
R	torsion	1.95	.0167	66.41	0.28	.9984	95.40				0.29	.9973	95.50			
L	torsion	3.20	.0000	58.03	1.40	.1464	85.40				1.32	.1932	86.90			
R	neck-shaft	1.04	.4227	7.28	1.48$	.1345	21.32				0.78	.7123	38.16			
L	neck-shaft	1.29	.2041	37.72	0.30$	.9907	89.20				0.19	.9998	88.35			
R	LHF length	2.03#	.0206	95.69	0.81#	.6486	98.53				0.88#	.5757	98.53			
L	LHF length	1.52#	.1134	95.65	1.22#	.2749	97.00				1.27#	.2402	97.15			
R	LHF width	1.31#	.2109	96.77	0.70#	.7478	98.52				0.58#	.8662	98.98			
L	LHF width	2.61#	.0024	94.06	1.74#	.0651	96.60				1.89#	.0375	96.61			
		* df 19,111(R) * 112(L) # df 14,122(R) 123(L)			* df 18,111(R) 112(L) # df 12,122(R) 123(L) $ df 13,122			df 18,111(R) 112(L)			* df 17,111(R)112(L) # df 11,122(R)123(L)			df 17,111(R) 112(L)		

Table 26

Analysis of variance table for right acetabular depth (ℓn)

Source	df	SS	MS	F	P($\geq$F)
Model (mean, age, age^2, age^3, sex)	5	16.00	3.200	161.76	<.0001
mean	1	1.23			
regression (age, age^2, age^3, sex)	4	14.77	3.691	186.66	<.0001
age	1	12.89		651.71	<.0001
sex/age	1	0.00			
age^2/age, sex	1	0.89		45.08	<.0001
age^3/age, age^2, sex	1	0.98		49.70	<.0001
Residual	128	2.53	0.020		
lack of fit	17	0.34	.020	1.02	.4426
pure error	111	2.19	.012		
Total	133	18.53			
mean	1	1.23			
total (cfm)	132	17.30			

$R^2 = 86.3\%$, $R_m^2 = 85.4\%$, $Q^2 = 97.9\%$, $Q_m^2 = 97.7\%$

Table 27

Analysis of variance table for left femoral neck-shaft angle*

Source	df	SS	MS	F	$P(\geq F)$
Model (mean, age, age^2, sex)	4	355.72	88.931	13.37	<.0001
mean	1	123.97			
regression (age, age^2, sex)	3	231.75	77.250	11.62	<.0001
age	1	52.20		7.85	.0006
sex/age	1	54.60		8.21	.0048
age^2/age, sex	1	124.95		18.79	<.0001
Residu[illegible]	135	897.72	6.650		
lack of fit	13	28.05	2.158	0.30	.9907
pure error	122	869.67	7.128		
Total	139	1253.44			
mean	1	123.97			
total (cfm)	138	1129.47			

$R^2 = 2.84\%$, $R_m^2 = 2.05\%$, $Q^2 = 92.69\%$, $Q_m^2 = 89.20\%$

* ANOVA tables for other variables may be obtained from the author.

bilaterally, the left neck-shaft angle and right LHF width. For all other variables the partial F values for the addition of sex were not significant at 0.1. None of the partial F values for sex retained significance at the "4 times" level (Draper and Smith 1966). Predicted sex differences from regression model with age^2 and sex are displayed in Figures 35 and 36. The predicted values for females, for the variables of acetabular and FH diameter, LHF width and length are marginally greater than the predicted values for males at all age groups. This predicted difference is very small (0.1 mm to 0.3 mm). The predicted sex difference for both femoral angles is less than one degree and for the left neck-shaft angle is in the opposite direction to the predicted sex difference for any of the other variables. That is, for the left neck-shaft angle, females have lower predicted values than males. Sex was dropped from the model to be fitted after consideration of these results.

Lack of fit F values from univariate tests, for the three models without sex, and the Q_m^2 are presented in Table 28. With the exception of both acetabular diameters and the left acetabular depth, nonsignificant lack of fit (> 0.05) was obtained by fitting the model with a second power polynomial on age ($\hat{y} = \hat{\beta}_0 + \hat{\beta}_1 + \hat{\beta}_2 x^2$). Nonsignificant lack of fit at the 0.05 level was obtained for all variables by the addition of a cubic term to age (model 3). Since the change in the Q_m^2, the amount of explainable variation apart from the mean that is explained by the model apart from the mean (Goldsmith 1974), is minimal, the model fitted only included a quadratic term. Right

Figure 35: Regression curves for variables in mm, model including sex. X = age, R = right, L = left, ℓn = natural logarithm, ace = acetabular, FH = femoral head, CRL = crown-rump length, ♂ = male, ♀ = female, *n = 1

		$\hat{y}$ =	$\hat{\beta}_0$	+ $\hat{\beta}_1$	+ $\hat{\beta}_2$	+ $\hat{\beta}_3$sex
1	Right depth	ℓny =	-.456	.117	-.002	-.002
2	L depth	ℓny =	-.596	.129	-.002	-.007
3	R acediameter	ℓny =	.181	.129	-.002	-.008
4	L acediameter	ℓny =	.145	.131	-.002	-.011
5	FH diameter	ℓny =	.152	.131	-.002	-.009
6	FH diameter	ℓny =	.085	.135	-.002	-.012
7	LHF length	y =	-4.364	.619	-.006	-.149
8	LHF length	y =	-3.356	.520	-.004	-.105
9	LHF width	y =	-2.019	.304	-.002	-.143
10	LHF width	y =	-2.502	.360	-.003	-.011

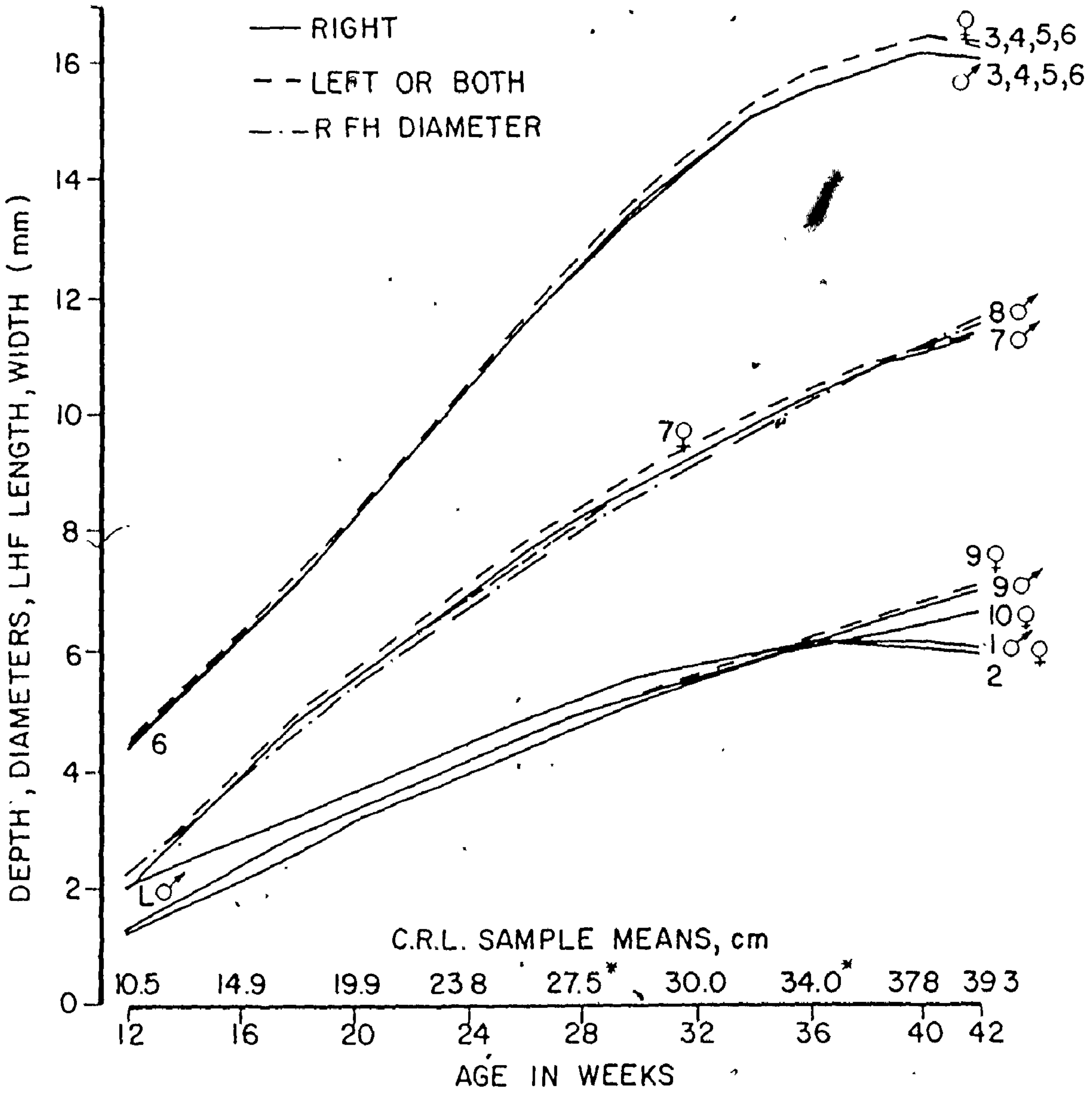

RIGHT
LEFT OR BOTH
R FH DIAMETER
♀3,4,5,6
♂3,4,5,6
8♂
7♂
7♀
9♀
9♂
10♀
1♂♀
2
6
L♂
DEPTH, DIAMETERS, LHF LENGTH, WIDTH (mm)
0
2
4
6
8
10
12
14
16
C.R.L. SAMPLE MEANS, cm
10.5
14.9
19.9
23.8
27.5*
30.0
34.0*
37.8
39.3
12
16
20
24
28
32
36
40
42
AGE IN WEEKS

Figure 36: Regression curves for femoral angles by age for model including sex. x = age, *n = 1, R = right, L = left, ♂ = male, ♀ = female, CRL = crown-rump length .

95% confidence limits (CL) are shown for right torsion, males, the left were similar.

	$\hat{y}$ =	β_0	+ $\beta_1 x$	$\beta_2 x^2$	+ $\beta_3$sex
1	Right torsion	-35.274	3.680	-.058	-1.684
2	L torsion	-39.156	4.095	-.065	-1.425
3	R neck-shaft	131.141	-.433	.007	-0.054
4	L neck-shaft	132.927	-.718	.012	0.669

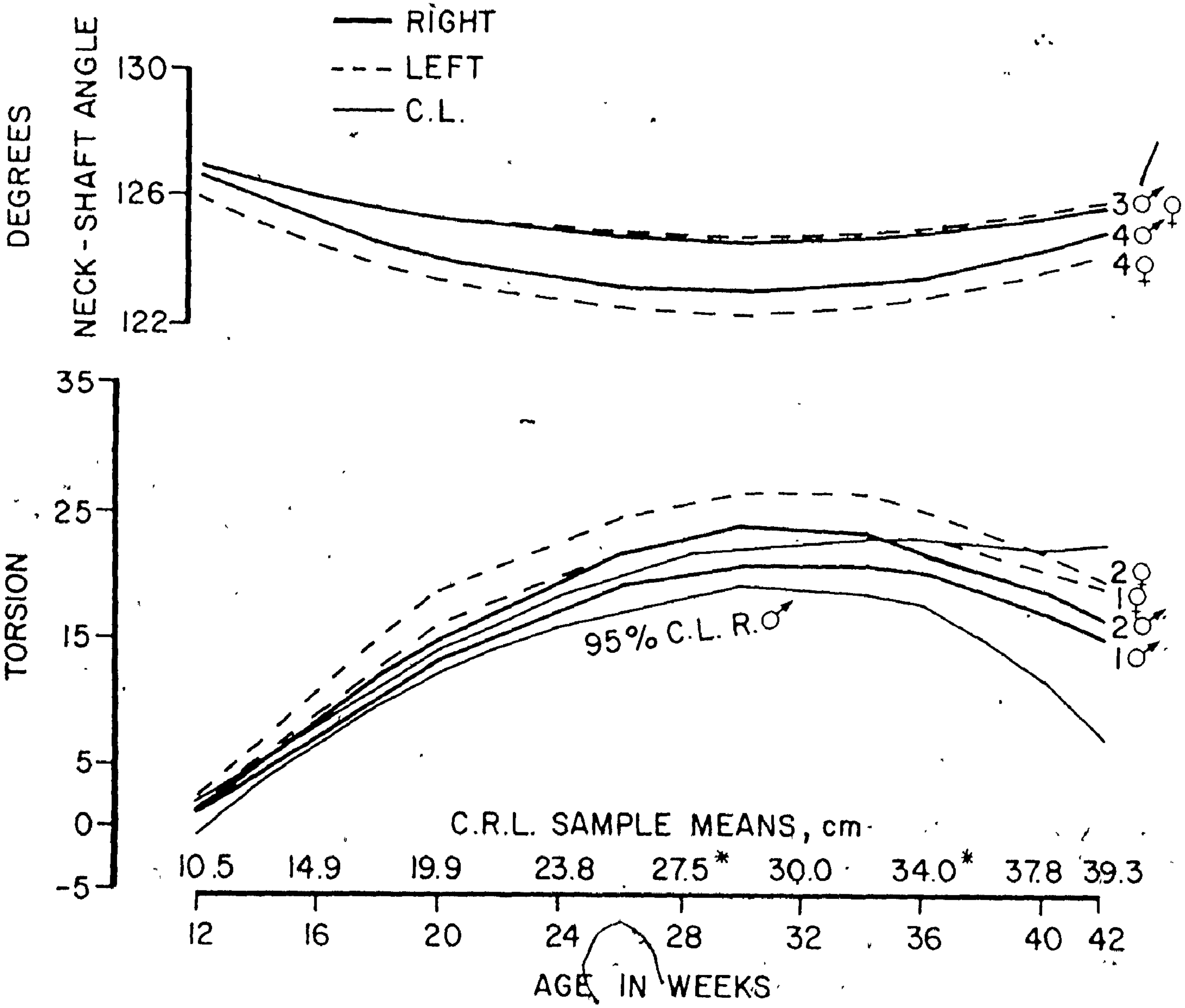

RIGHT
LEFT
C.L.
DEGREES
NECK-SHAFT ANGLE
130
126
122
3♂ ♀
4♂
4♀
35
25
15
5
0
-5
TORSION
2♀
1♀
2♂
1♂
95% C.L. R.♂
C.R.L. SAMPLE MEANS, cm
10.5
14.9
19.9
23.8
27.5*
30.0
34.0*
37.8
39.3
12
16
20
24
28
32
36
40
42
AGE IN WEEKS

Table 28: Lack of fit for regression models without sex or log transformation. 1=mean, 2=age, 3=age^2, 4=age^3, R=right, L=left, FH=femoral head, acediameter=acetabular diameter, LHF=ligament of the head of femur

Models:	1, 2			1, 2, 3			1,2,3,4		
Variable	F*	P(≥F)	Q^2_m%	F*	P(≥F)	Q^2_m%	F*	P(≥F)	Q^2_m%
R depth	1.95	.0155	94.33	1.57	.0760	95.80	0.98	.4874	97.52
L depth	2.52	.0012	93.05	1.89	.0213	95.05	1.07	.3931	97.35
R acediameter	2.71	.0005	97.83	2.41	.0022	98.18	1.62	.0675	98.84
L acediameter	2.72	.0005	98.00	2.31	.0035	98.38	1.63	.0636	98.92
R FH diameter	1.83	.0254	99.16	1.45	.1173	98.95	0.60	.8903	99.59
L FH diameter	1.92	.0173	98.57	1.64	.0592	98.87	0.63	.8707	99.58
R torsion	2.15	.0065	61.19	0.58	.9136	63.00	0.61	.8867	90.10
L torsion	3.87	.0000	55.05	1.59	.0719	82.51	1.54	.0898	83.92
R neck-shaft	1.00	.4722	6.68	0.85	.6455	24.51	0.74	.7589	37.29
L neck-shaft	1.60	.0645	18.45	0.98	.4875	52.52	1.04	.4263	52.52
R LHF length	2.03#	.0232	95.69	0.91#	.5413	98.20	0.99#	.4665	98.21
L LHF length	1.50#	.1252	95.61	1.18#	.3014	96.80	1.23#	.2684	96.92
R LHF width	1.31#	.2144	96.77	1.01#	.4467	97.69	0.97#	.4829	97.95
L LHF width	2.58#	.0034	94.03	1.57#	.1018	96.62	1.70#	.0744	96.63
	* df 20, 111R, 112L # df 14, 122			* df 19, 111R, 112L # df 13, 122			* df 18, 111R, 112L (n=133, 134) # df 12, 122 (n=138)		

torsion was the only variable in which a noticeable change in the Q_m^2, occurred by the addition of a cubic term. For depth, acetabular and FH diameter bilaterally the partial F values are significant at less than 0.05, but none retain significance at the "four times" level. Table 29 presents the partial F values for testing significance of polynomial terms to the model (Zar 1974). With the exception of the neck-shaft angle the Q_m^2 values are close to 100 percent indicating that the fitted model does perform a reasonable function in interpreting the explainable variation.

Table 29

Partial F values for testing the significance of polynomial terms. R = right, L = left, * values which exceed 4 times the critical F point, acediameter = acetabular diameter, FH = femoral head, LHF = ligament of the head of femur.

Variable	Residual df	Quadratic term	P(≥ F)	Residual df	Cubic term	P(≥ F)
R depth	130	8.39	.0044	129	12.24	.0006
L depth	131	12.88	<.0005	130	16.57	<.0001
R acediameter	130	6.93	.0095	129	15.42	<.0001
L acediameter	130	8.80	.0036	130	13.33	.0004
R FH diameter	130	8.46	.0043	129	7.72	<.0001
L FH diameter	131	10.16	.0018	130	17.17	<.0001
R torsion	130	33.97*	<.0001	129	.08	
L torsion	131	43.58*	<.0001	130	2.26	.1352
R neck-shaft angle	130	3.89	.0506	129	2.83	.0948
L neck-shaft angle	131	13.42	.0004	130	.00	
R LHF length	135	16.75	<.0001	134	.05	
L LHF length	135	5.61	.0193	134	.55	
R LHF width	135	5.25	.0235	134	1.51	.2215
L LHF width	135	14.91	.0002	134	.05	

* 4 times $F_{0.05}(1,140) = 20.5$, $F_{0.001}(1,140) = 50.8$

The null hypothesis that the mean vector of coefficients equals zero, ($\underset{\sim}{B} = \underset{\sim}{0}$), was rejected since the largest root criterion, for all models, greatly exceeded the critical values (model with second power polynomial on age, right side variables with $s = 2$, $m = 1$, $n = 62$, LRC = 0.9517 > .05, 0.125; left side variables with $s = 2$, $m = 1$, $n = 62\ 1/2$, LRC = 0.9526 > .05, 0.125). It was concluded that since the coefficients were not all simultaneously equal to zero separate growth curves were required.

The predicted curves for the fitted model with a second power polynomial on age, for all variables by side are shown in Figure 37. The curves for FH and acetabular diameter coincide, as do the curves for right and left acetabular depth except for a marginally lower predicted value for left depth at term (0.1 mm). While predicted values for left LHF length are lower than the right side, this difference is very small and reverses at term. Side differences are predicted for both femoral angles, however, this difference is less than one degree. The only variable in which the left side is consistently predicted as having lower values than the right side is the left neck-shaft angle. Ninety-five percent confidence limits for right neck-shaft angle and right torsion are presented in Figure 38. The left side confidence limits were similar and have not been shown in Figure 38. By side the confidence limits overlap.

In the establishment of the growth curves outlier cases (values $\gtrless \bar{x} \pm 2SD$) were not deleted from the sample since it was considered biological variation may be artificially masked. Examination of outlier cases failed to reveal any particular reason for the difference between

Figure 37: Regression curves from the model fitted for all variables, by side. C.R.L. = crown-rump length, LHF = ligament of the head of femur, FH = femoral head, RD = right depth, LW = left width, *n = 1.

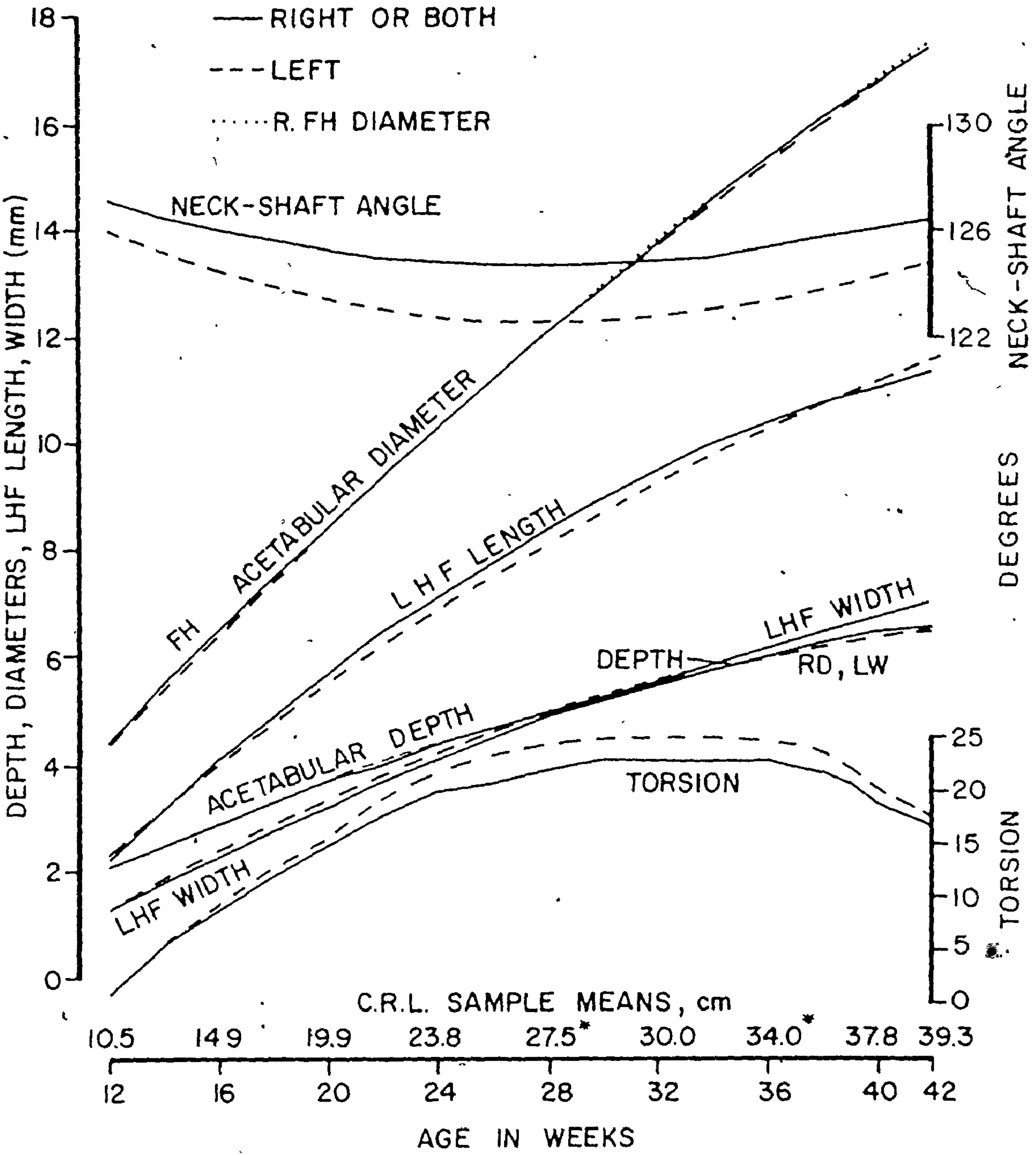
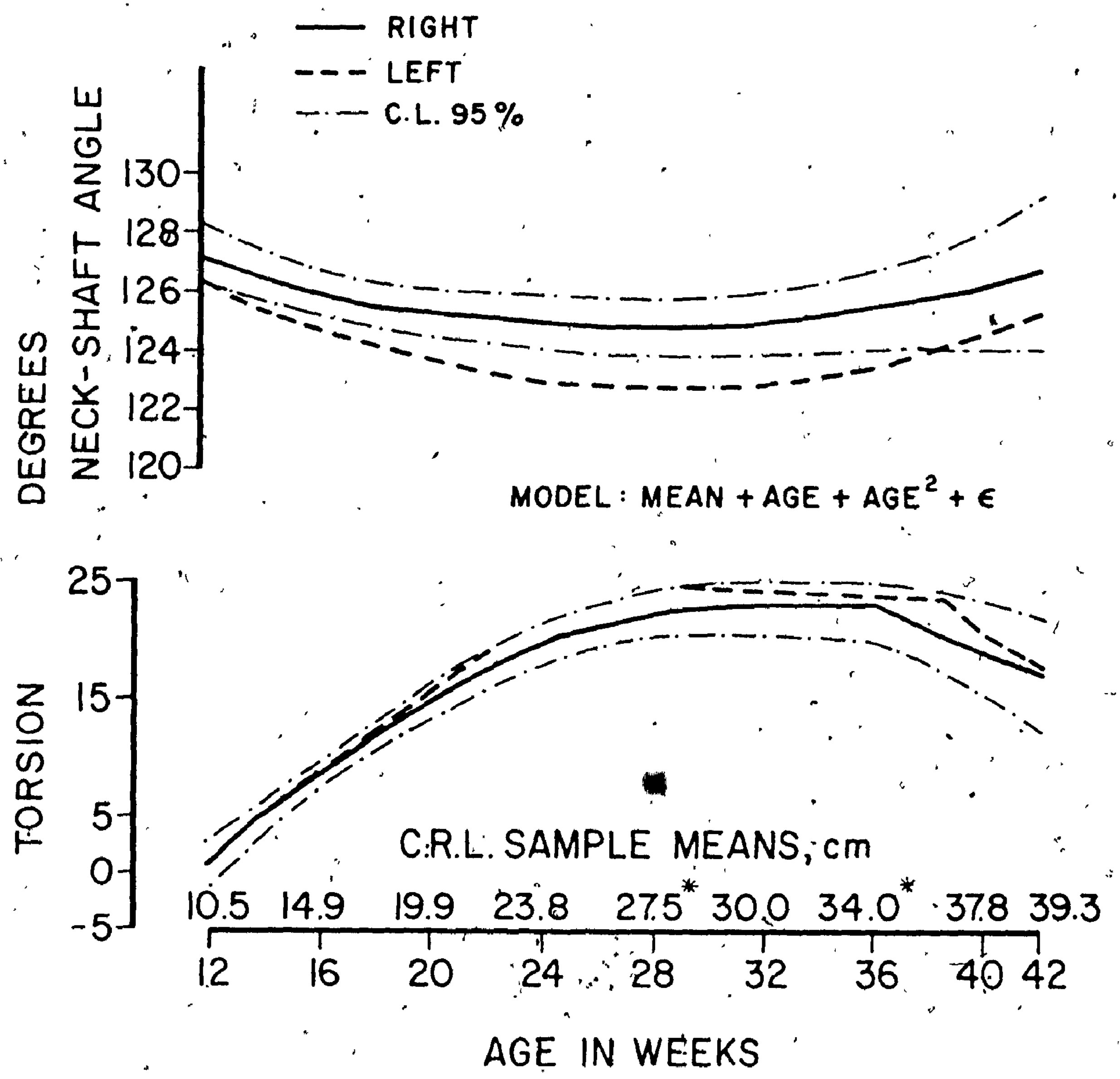

RIGHT OR BOTH
LEFT
R. FH DIAMETER
NECK-SHAFT ANGLE
FH ACETABULAR DIAMETER
L H F LENGTH
LHF WIDTH
DEPTH
RD, LW
ACETABULAR DEPTH
TORSION
LHF WIDTH
DEPTH, DIAMETERS, LHF LENGTH, WIDTH (mm)
18
16
14
12
10
8
6
4
2
0
NECK-SHAFT ANGLE
130
126
122
DEGREES
TORSION
25
20
15
10
5
0
C.R.L. SAMPLE MEANS, cm
10.5
14.9
19.9
23.8
27.5*
30.0
34.0*
37.8
39.3
12
16
20
24
28
32
36
40
42
AGE IN WEEKS

Figure 38: Regression curves from the model fitted for femoral angles, by side with right 95 percent confidence limits. *n = 1


RIGHT
LEFT
C.L. 95 %
DEGREES
NECK-SHAFT ANGLE
130
128
126
124
122
120
MODEL : MEAN + AGE + AGE^2 + ϵ
TORSION
25
15
5
0
-5
C.R.L. SAMPLE MEANS, cm
10.5
14.9
19.9
23.8
27.5*
30.0
34.0*
37.8
39.3
12
16
20
24
28
32
36
40
42
AGE IN WEEKS

the observed and predicted values. In one case underestimation of age by CRL is suspected. In the majority of outlier cases no abnormal morphology was detected on dissection. In outlier cases where the LHF length was $\gtrless \bar{x} \pm 2SD$ from the predicted mean value at a specific point on the curve, the apparent increased or decreased length did not always merit comment at the macroscopic level. Dysnormal cases outnumbered normal cases in the frequency of outlier cases for the variables right depth, right acetabular diameter, and FH diameter bilaterally.

The regression equations for the fitted model with the standard error of the estimate (square root MS residual) used for the curves shown in Figures 37 and 38 are:

$\hat{y}$	$\hat{y} = \beta_0$	$+ \beta_1 x$	$+ \beta_2 x^2$	$\pm$ SE est
R depth	-0.77226	.26366	-.00207	.556
L depth	-1.10807	.29287	-.00263	.574
R acediameter	-2.29841	.59504	-.00292	.861
L acediameter	-2.45417	.60614	-.00314	.828
R FH diameter	-2.37984	.59923	-.00296	.791
L FH diameter	-2.62522	.61492	-.00323	.793
R torsion	-34.69084	3.65390	-.05775	7.703
L torsion	-38.85287	4.08782	-.06506	7.716
R neck-shaft angle.	131.93882	-.51602	.00926	3.650
L neck-shaft angle	132.65402	-.71103	.01254	2.680
R LHF length	- 4.35858	.620199	-.00583	1.177
L LHF length	- 3.36461	.52253	-.00397	1.386
R LHF width	-2.01329	.30592	-.00214	.772
L LHF width	-2.52949	.36261	-.00345	.739

Ninety-five percent limits (CL) were calculated from: $CL = \hat{y} \pm t_{.95}\, \alpha\, (2) \sqrt{\hat{var}\, y}$, and, $\hat{var}\, y = var \hat{\beta}_0 + var \hat{\beta}_1 + var \hat{\beta}_2 + 2\, covar\, \hat{\beta_0 \beta_1} + 2\, covar\, \hat{\beta_0 \beta_2} + 2\, covar\, \hat{\beta_1 \beta_2}$. For n = 134 (less cases missing torsion) the estimated variance of $\hat{y} = .34813387 + x^2(.00276220) + (x^2)^2(.00000112) + 2(-.03018877) + 2(x^2)(.00057213) + 2[(x)x^2](-.00005448)\ \sigma^2$. Sigma^2 for each variable is obtained by squaring the standard error of the estimate given with the regression equations above. Since 95 percent confidence limits for variables other than the femoral angles were very small these limits are not shown on the regression curves displayed in Figure 37.

Rate of growth curves for variables other than the femoral angles are shown in Figure 39. These were derived from the quadratic model, $\hat{y} = \beta_0 + \beta_1 t + \beta_2 t^2$ where [illegible]= time (age). For example, the growth rate equation $\beta_1 + 2\beta_2 t^2$ for right depth at age 20 weeks is: $.26366 + 2[-.00207(20^2)] = -1.39234$ mm/week. From Figure 39 it can be seen that the slowest growing hip variables are depth bilaterally and right LHF width, while the fastest growing variable is LHF length. Between sides, rate of growth curves differ the most for LHF variables where the right length rate of growth exceeds the left but where right width is less than the left. As expected from the regression curves, rate of growth curves for acetabular and FH diameter are very similar with FH diameter growing at a minimally faster rate than acetabular depth (< 1 mm/week).

Indices

The acetabular index (Le Damany 1904, Ralis and McKibbin 1973) provides a measure of the shallowness of the socket. This index, expressed as a percentage, is calculated from acetabular depth x 100 / acetabular diameter and is different from the "acetabular index" calculated on radiographs. In the presence of a shallow socket the

Figure 39: Rate of growth curves by side, for variables measured in mm. Model: mean, age, age^2.

1 = Right depth

2 = Left depth

3 = Right acetabular diameter

4 = Left acetabular diameter

5 = Right femoral head diameter

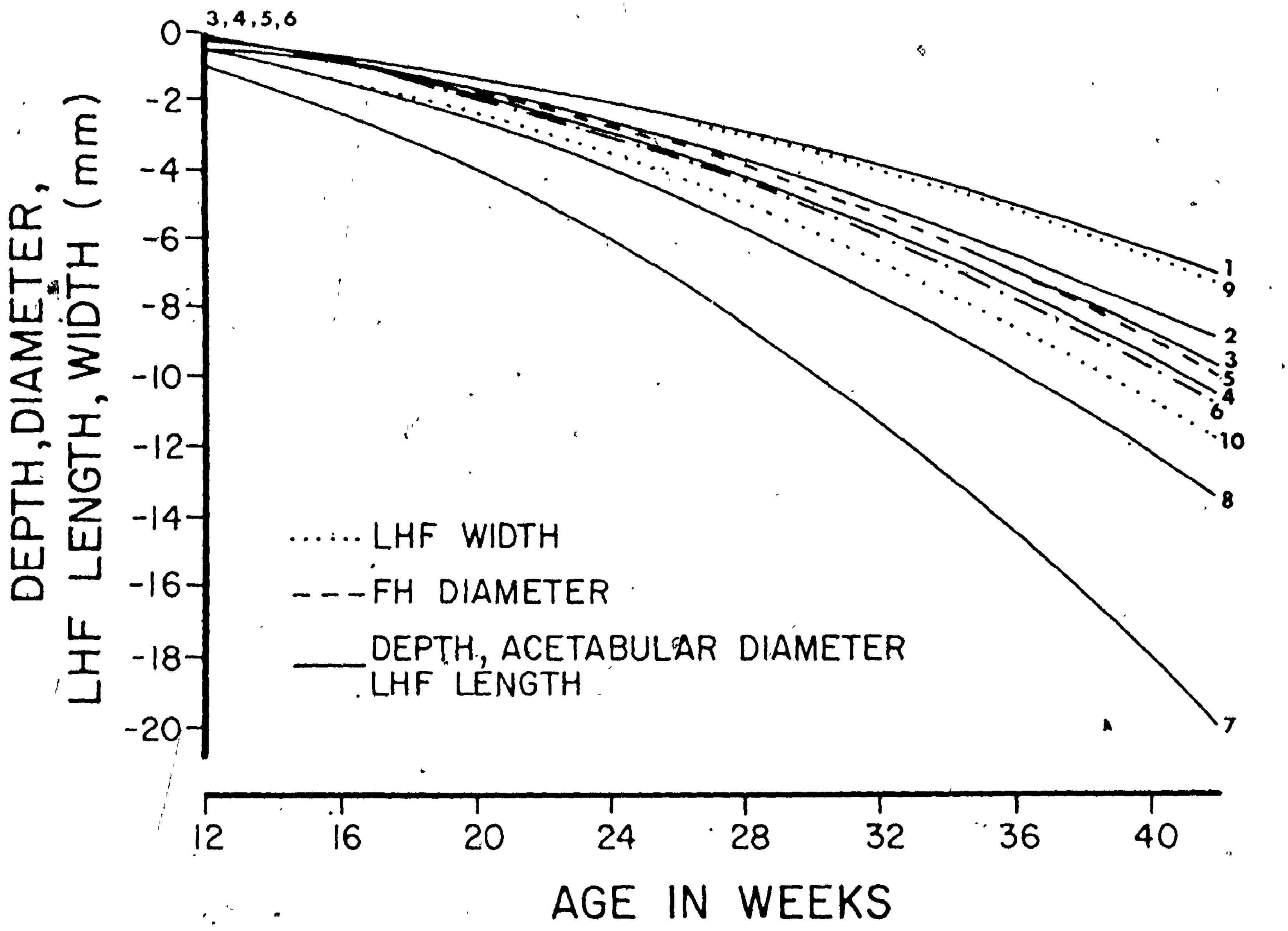
6 = Left femoral head diameter

7 = Right ligament of the head of femur length

8 = Left ligament of the head of femur length

9 = Right ligament of the head of femur width

10 = Left ligament of the head of femur width


3,4,5,6
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
DEPTH, DIAMETER,
LHF LENGTH, WIDTH (mm)
1
9
2
3
5
4
6
10
8
7
12
16
20
24
28
32
36
40
AGE IN WEEKS
······ LHF WIDTH
- - - FH DIAMETER
—— DEPTH, ACETABULAR DIAMETER
LHF LENGTH

diameter will exceed the depth and the index will fall below 50%. Scatterplots of the right and left acetabular index are presented in Figures 40, 41. Means at selected age points are given in Table 30 for each side. While considerable variability in the acetabular index is evident in the scatterplots, there is a distinct trend for this index to be smaller towards term. This trend is expected from consideration of the growth rate curves which showed depth to be increasing at a slower rate than acetabular diameter. As expected, the same trend is seen in the FH index, expressed as a percentage (acetabular depth x 100 / FH diameter) since the femoral head diameter is also growing at a faster rate than is the acetabular depth (Table 30).

Acetabular diameter herein refers to the diameter of the two-dimensional acetabular rim and not the actual diameter of the three-dimensional socket. The FH diameter reported is the maximum transverse diameter of the three-dimensional head. A measure of the extent to which these two diameters are similar can be gained from calculation of a diameter index, expressed as a percentage, FH diameter x 100 / acetabular diameter. Means for these two diameters with the mean diameter index at specific age points are given in Table 30. Equality of diameters would give an index of 100%. Should the FH diameter exceed the acetabular diameter the index would be greater than 100%. With the exception of the left hip at 24 weeks the mean diameter index values are less than 100%. From the range of the mean diameter index values, 95% to 99%, it can be seen that the acetabular diameter only minimally exceeds the FH diameter. Maximum diameter indices exceeded 100% in all age categories except age group 34 (n = 3). This indicates that in a

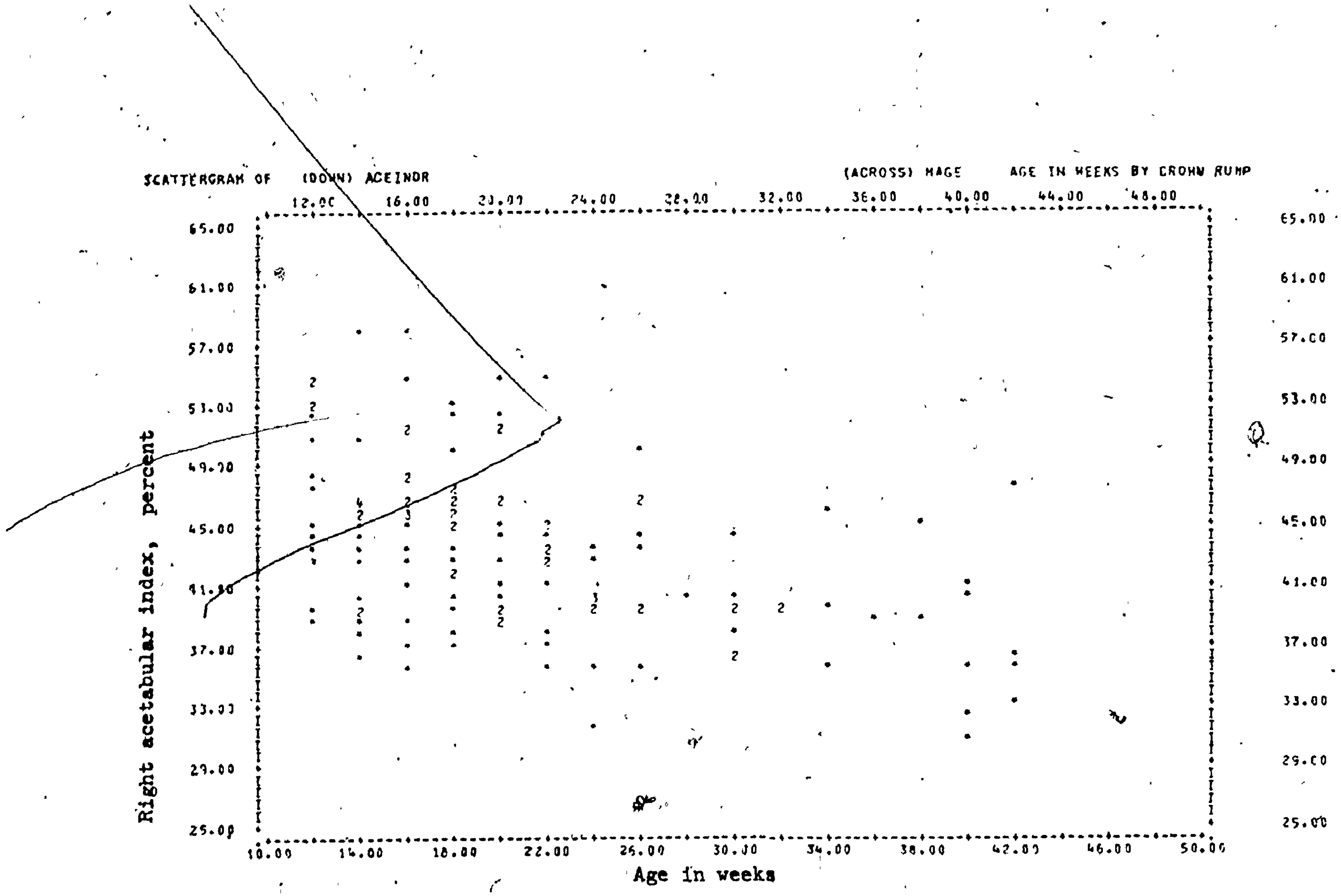


Figure 40 : Scatterplot of the right acetabular index by age, sexes combined. Numbers represent the frequency of observations at each point, * = one observation.

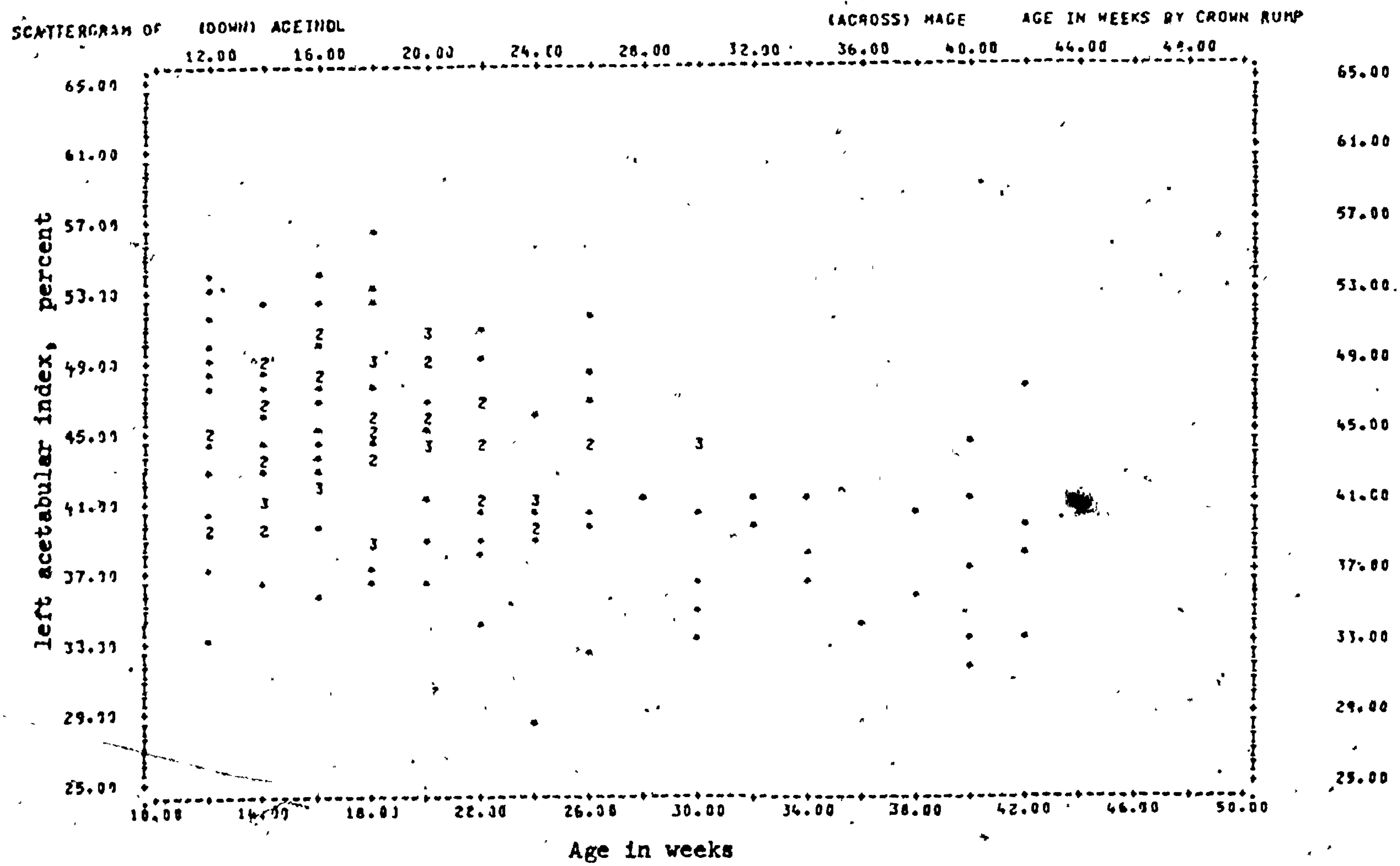


Figure 41 : Scatterplot of the left acetabular index by age, sexes combined. Numbers represent the frequency of observations at each point, * = one observation.

Table 30

Means (mm) and mean indices (%) for selected variables
FH = femoral head, acediameter = acetabular diameter

AGE GROUPS in weeks (frequency)

	12 (16)	16 (18)	20 (15)	24 (9)	30 (7)	34 (3)	40 (5)
RIGHT SIDE							
acetabular depth	1.90	2.92	3.95	3.88	4.95	5.80	6.33
acediameter	4.04	6.32	8.74	9.78	12.25	14.25	17.37
FH diameter	4.02	6.29	8.67	9.75	12.43	13.81	16.98
(depth/acediameter) x 100	46.92	46.22	45.16	40.35	39.35	40.71	36.42
(depth/FH diameter) x 100	47.66	46.57	45.42	39.68	39.90	42.05	37.32
(FH dia/acediameter) x 100	99.49	99.56	99.38	99.94	99.18	96.96	97.90
LEFT SIDE							
acetabular depth	1.84	2.91	4.00	3.87	5.01	5.44	6.49
acediameter	4.10	6.30	8.71	9.72	12.60	14.23	17.15
FH diameter	4.00	6.22	8.60	9.73	12.37	13.62	16.83
(depth/acediameter) x 100	44.77	46.15	45.90	39.76	39.76	38.27	37.86
(depth/FH diameter) x 100	46.54	46.74	46.54	39.68	40.42	40.76	38.79
(FH dia/acediameter) x 100	97.43	98.77	98.80	100.35	98.34	95.63	98.27

number of hips the FH diameter exceeds the acetabular diameter and may not be enclosed by the socket, including the labrum. No distinct trend is seen with age, however there is slightly more variability on the left side.

Ligament of the Head of Femur

Considerable variability is seen in the shape of the ligament of the head of femur (LHF) throughout the fetal period (Fig. 42). However, the predominant shape is that of a linear structure with the length exceeding the width. This has been shown in the rate of growth curves for LHF length and width (Fig. 39). A measure of the shape of the ligament is gained from calculation of a ligament index, LHF width x 100 /LHF length, expressed as a percentage. Means for width and length with the mean ligament index at specific age periods, for each side are given in Table 31. Lack of a pronounced linear shape is evident in that none of the mean indices are less than 50%. Since the mean index values lie between 50% and 70% the LHF does have a greater tendency to be long and narrow than short and wide when the index would be closer to 100%. The upper limit of the mean index range exceeded 100% in age groups 12, 20 and 24 with values of 156.04% for the left side at 12 weeks and 131.93% for the left side at 20 weeks. These values indicate a very nonlinear shape in a few cases. Second to the femoral angles the standard deviations for the LHF variables are the largest for any of the hip variables. This variability is also evident in the mean ligament index values.

The ligament appeared to become a more robust structure with increasing age. In the younger specimens great care was required to

Figure 42: Variability in the shape of the ligament of the head of femur (LHF)

a) A strap-like LHF with length greater than the width in a 20.8 cm CRL fetus. (X 4)

b) A small wide ligament from a 17.9 cm CRL fetus. (X 5)

c) A short wide and thick ligament from a 42 week fetus (R146). (X 5.5)

d) A long wide ligament with greater thickness than the average ligament. This is the left ligament of case #146 (c. shows the right). Both ligaments had a wide area of attachment to the side of the acetabular fossa (arrows). (X 5)


a
b
c
d

Table 31

Ligament of the head of femur (LHF) means (mm) and mean indices (%)
Superscript = n of observations

	AGE GROUPS in weeks (frequency)						
	12(16)	16 (18)	20 (15)	24 (9)	30 (7)	34 (3)	40 (4)
RIGHT SIDE							
LHF length	2.20	3.88	5.27	6.70	9.46^6	9.57	10.74
LHF width	1.34	2.11	3.37	4.33	4.99^6	5.88	7.19
LHF (width/length) x 100	62.72	55.26	66.29	61.58	53.59^6	61.33	68.51
LEFT SIDE							
LHF length	2.07	4.18	4.87	6.22	8.84	9.90	11.05
LHF width	1.44	2.13	3.61	4.33	5.25	6.18	6.59
LHF (width/length) x 100	71.89	52.29	77.04	75.30	58.91	62.01	61.31

avoid detachment of the ligament from either its attachment to the fovea of the head or from its attachment to the acetabular fossa when examining the range of motion permitted to the head of femur by the ligament following capsule division. No cases of congenital absence of the ligament were noted. The majority of ligaments were only attached at their proximal end to the tissue of the acetabular fossa, and through this to the three cartilages comprising the acetabular socket. However, in a number of ligaments the attachment extended along the lateral edge of the ligament to the transverse acetabular ligament, resulting in limited mobility of the head of femur following opening of the capsule. After opening of the capsule but with the ligament intact, motion of the head of femur was tested with flexion, extension, adduction, abduction and rotation. In no instances did the ligament permit the head to be displaced beyond the posterior rim of the socket. Maximum motion occurred in the flexed, adducted and externally rotated position when more than 50% of the head moved out of the socket toward the obturator foramen. With extension, up to 50% of the head could be subluxated anteriorly. Variability in the extent to which the head of femur could be subluxated from the socket with the ligament intact was present from 12 weeks to term. However, the amount of motion seemed greater in older specimens.

Leg Crossing

The leg posture and whether the legs were uncrossed or crossed, in addition to the direction and location of crossing, was noted. In the entire sample this data was missing in 30 cases, and was missing in

22 cases (15.7%) of the 140. In the normal sample of n = 118 with this data, 54 fetuses (45.8%) had the legs uncrossed. In 36 (30.5%) fetuses the right leg was crossed over the left, and in 28 (23.7%) the left was crossed over the right. A chi-square test for randomness of leg crossing in three age groups (12 - 20, 22 - 30, 32 - 42 weeks) was not significant ($\chi^2_4 = 8.92$; $p = .0629$). In age groups 22 - 30 and 32 - 42 weeks twice as many fetuses had the legs in an uncrossed position. In the 12 to 20 week group fewer fetuses had the left leg crossed over the right (24.4%) while the percentage was approximately equal for fetuses with the legs uncrossed or the right leg crossed over the left. Crossing occurred either at the level of the toes, forefoot, or lower leg.

No significant association between leg crossing and torsion angle values (in 3 groups) was noted (right torsion $\chi^2_4 = 2.49$; $p = .6492$, left torsion $\chi^2_4 = 3.61$; $p = .5369$). When torsion exceeded 20° over 50 percent of fetuses had the legs uncrossed, and where torsion was less than 10° a slightly higher number of fetuses had the right leg crossed over the left. This reflects a weak age effect on leg crossing since the torsion angle is shown to increase with age.

Neither was any association seen between leg crossing and hip normality (in four groups: 1 = normal, 2 = rim dysplasia, 3 = socket dysplasia, 4 = other; right $\chi^2_6 = 1.78$; $p = .9380$, left $\chi^2_6 = 11.62$; $p = .0713$). There is a suggestion of some association between hip normality grading and leg crossing on the left side where approximately two-thirds of cases (6.8%, n = 19) with rim dysplasia, that is dysnormal cases, had the legs uncrossed. This may be more related to age and the greater number of dysnormal cases in the post-20 week groups.

Trochanter Position

The greater trochanter in fetal femurs is underdeveloped. Compared with the flexor and adductor muscles, the abductors, gluteus medius and minimus, even in term fetuses, were thin, small and somewhat flimsy. In positioning femora for measurement of torsion, variability in the posterior proximal point of contact was observed. While some femora rested on the lesser trochanter, others rested on the greater trochanter (Fig. 43, and see Fig. 34). Where femora rested on the lesser trochanter the latter appeared to be directed more posteriorly than medially. The null hypothesis of no relationship between trochanter position and age, with age in three groups (12 - 20, 22 - 30, 32 - 42 weeks) was not accepted ($\chi^2_6 = 42.72$; $p < .0001$). While a significant difference between trochanter position and age was demonstrated, no significant difference at the 0.1 level was seen in trochanter position between males and females overall when adjusted for age, or by separate age groups.

In the 12 to 20 week age group, 58 cases (68.2%) bilaterally rested on the lesser trochanter which was directed posteriorly. In the 32 to 42 week age group, 10 cases (71.4%), the greater trochanter was the proximal point of contact. A transitional period in the development of the proximal femur and in the relative positions of the trochanters is seen in the 22 to 30 week group where an equal number of femora rested on either the lesser or the greater trochanter.

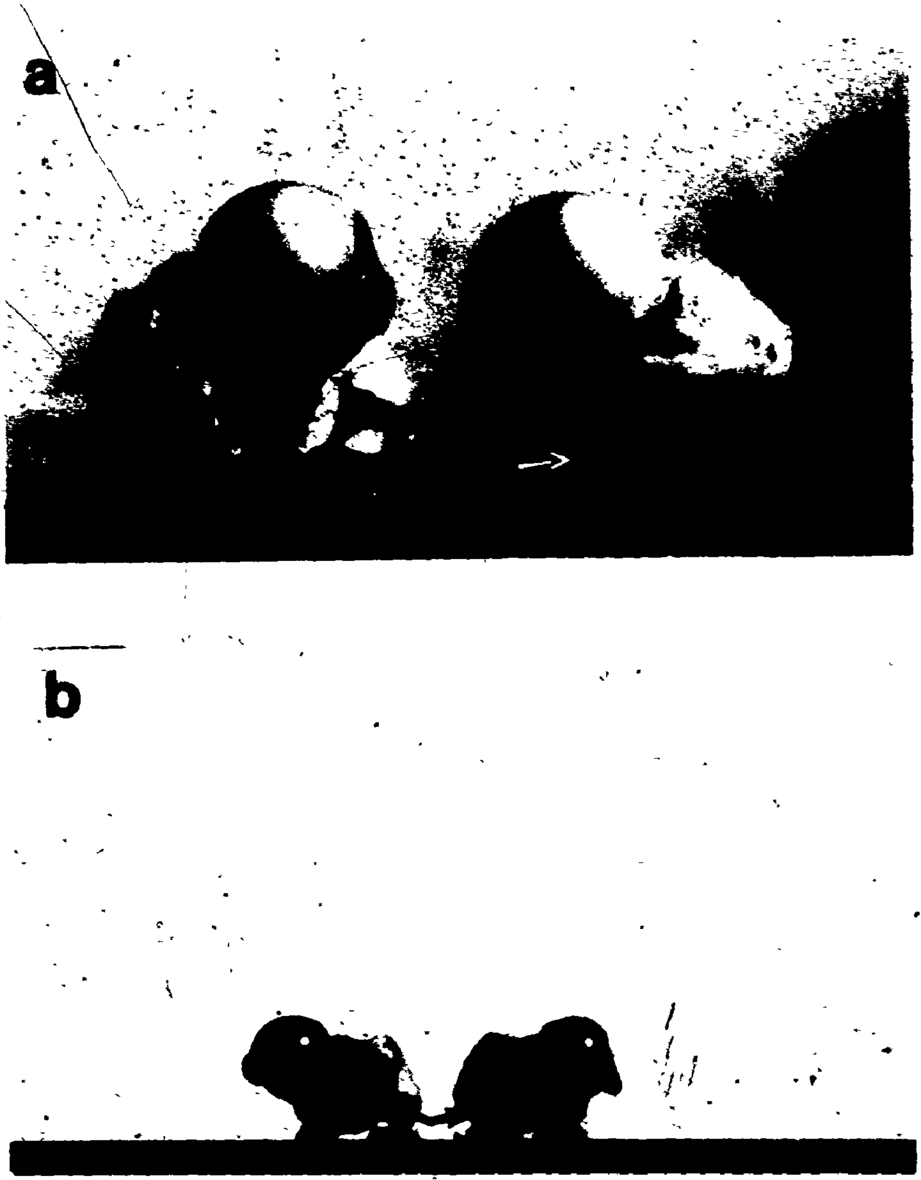


Figure 43

Trochanter position
(see also Fig. 34c)

a) Both femora rest on the greater trochanter. Arrows indicate the location of the lesser trochanter. A term fetus. (X 1.3)

b) Both femora rest on the lesser trochanter. Arrows indicate the position of the greater trochanter. Femora from a fetus with CRL of 29.4 cm. (actual size)

Side asymmetry in trochanter position and thus point of contact when the femur rests on a flat surface was apparent in the 12 to 20 week age group. Fifteen (17.6%) of left femora but only seven (8.2%) of right femora rested on the lesser trochanter.

Analysis was conducted to test for the presence of association between trochanter position and size of the two femoral angles. No association was seen with the neck-shaft angle (in two groups, $< 120°$, $> 120°$) but a significant association with torsion was demonstrated (torsion in three groups: $\leq 0°$, $0° - 20°$, $> 20°$; right $\chi^2_6 = 43.15$. left $\chi^2_6 = 41.90$; $p < .0001$). A greater number of femora with a torsion angle less than 20° rested on the lesser trochanters. Of 19 femora with a negative torsion angle none rested on the greater trochanter. Thirty-nine femora (57.4%) with a torsion angle greater than 20° rested on the greater trochanter but 29 (42.6%) of femora rested on the lesser trochanter indicating that presence and amount of positive torsion is not the only factor involved.

Geometry of the Femoral Head

Considerable variability in the shape of the femoral heads is evident from the polar traces taken in a two-dimensional plane at the maximum diameter of the head (Fig. 44). The modal shape revealed by the traces was that of an ellipse with an oblique orientation and with the narrower diameter in the anteromedial-posterolateral plane (Fig. 44A). The minimal radial zone (MRZ), a measure of roundness, had a range from 0.02 to > 0.6 mm, with a mean of 0.18 mm (0.12), n = 113. The mean MRZ increased with age, as did the range (Table 32).

Figure 44

Traces of femoral head roundness

The traces are orientated with the anterior surface of the head uppermost. The medial surface of the head is marked by an arrow. The lesser trochanter is located below the arrow.

A. A right head trace from a 24 week fetus, CRL 23.0 cm. This ellipse-type trace shows the modal negative orientation, that is the major axis is directed anterolaterally. The minor axis is in the anteromedial-posterolateral plane. This head is circular for 30° on its anterolateral surface. The minimum radial zone (MRZ), the minimum spacing bounded by two concentric circles (*), is shown.

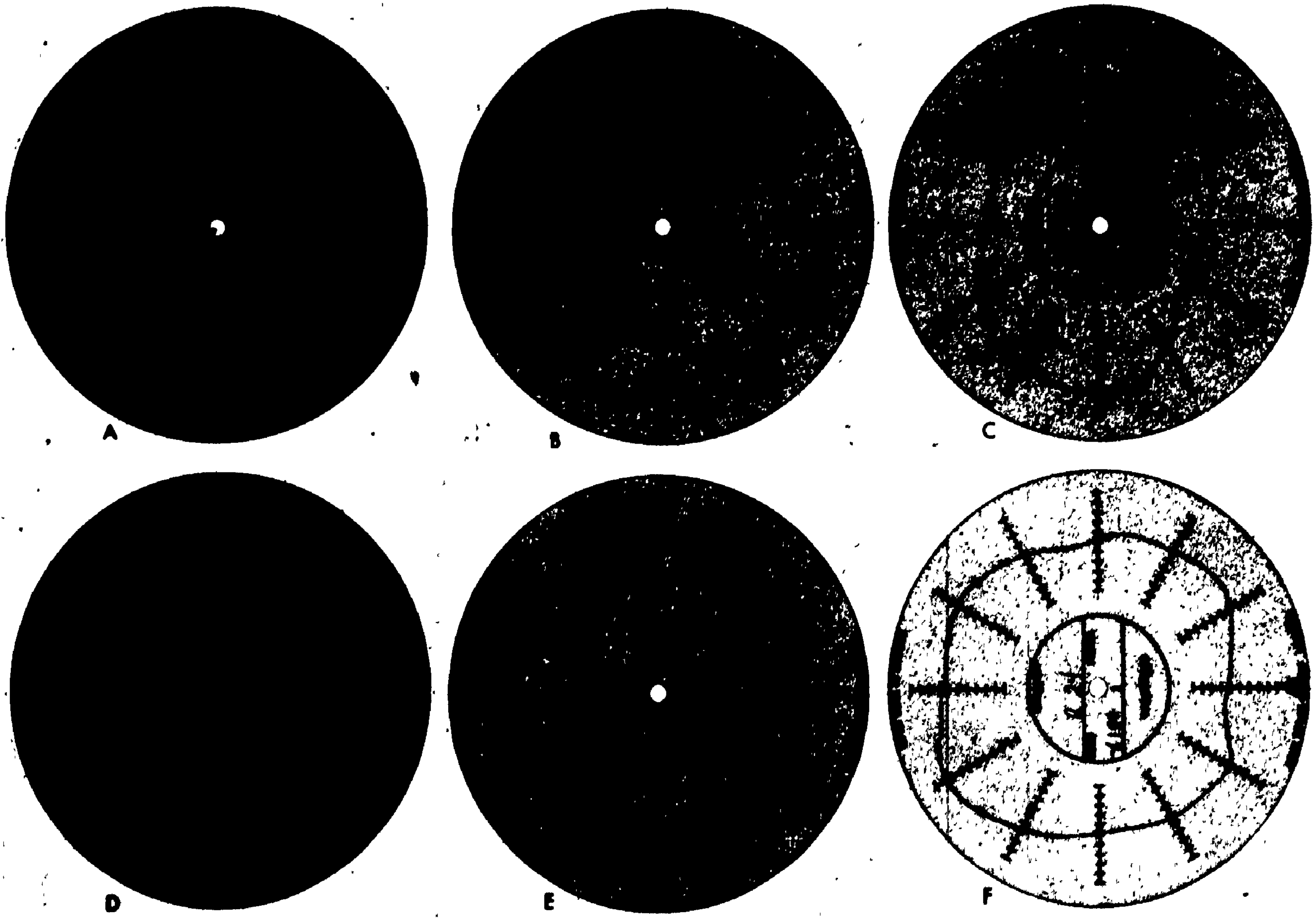
B. A left head trace from a 16 week fetus, CRL 14.2 cm. The ellipse is inclined forwards, negative inclination. The trace is not circular for a minimum of 30°.

C. A right head trace from a 42 week fetus, CRL 38.5 cm. Fine irregularities are seen on the medial and lateral surfaces. This head required a long stylus and 50 times magnification since its lack of roundness approached the limits of the measuring capacity of the machine. The trace has a positive inclination.

D. A right head trace from a term fetus that exceeded the measuring capacity of the machine. The trace shows an irregular surface and is not continuous. The minimum radial zone could not be calculated.

E. A left head trace from a 12 week fetus, CRL 11.7 cm. The trace is circular in the contour tested and coincided with a true circle for 180°. This almost circular trace was atypical.

F. A right head trace from a 16 week fetus, CRL 15.5 cm, which shows no specific inclination.


A
B
C
D
E
F

Since it was necessary to use a longer stylus in the assessment of roundness in older femoral heads and the position of the stylus tended to be slightly oblique, roundness assessment is less reliable in the older specimens (Fig. 44C).

Table 32

Minimal radial zone mean values, standard deviations and range, in mm, by age groups (weeks)

Age Categories	n (femora)	Mean	(SD)	Range
12 - 20	71	0.12	0.05	0.02 - 0.26
22 - 30	30	0.21	0.13	0.10 - 0.56
32 - 42	12	0.43	0.11	0.28 - >.60

A null hypothesis of no difference in means for the right and left sides was not rejected ($|$ two-tailed paired t-test = 0.771 $| < 2.009 = t_{.975,\ 51}$). In the randomly selected sample 32 pairs of femora were female and 26 pairs were male. The mean MRZ for the sexes were identical: female 0.19 (0.15), male 0.19 (0.14).

The degree to which "out-of-roundness" is present in fetal femoral heads in the band measured is very small in the younger specimens. This indicates that early in fetal life the femoral head closely approaches a circular shape in the narrow band measured. This band corresponds to the region of the maximum diameter and, presumably, to the future main weight-bearing region of the head. However, none of the traces from specimens in the age group 32 - 42 weeks approached a circular shape. In this group the radial deviations, in seven heads, exceeded the measuring capacity of the instrument, that is, they were too "out-of-the-round" to be measured on the Talyrond (Fig. 44D).

Many traces were irregular and the irregularity corresponded to an apparent thickening of the cartilage, macroscopically visible, in the region of the fovea on the inferomedial aspect of the head. In this region the articular cartilage frequently was observed to have a different coloring to that on the rest of the head. Fine irregularities of the surface, revealed by small valleys and peaks on the traces (Fig. 44 C) were ignored in calculation of the MRZ. A number of femora had been transported wrapped in gauze, and there was a correlation between the fine irregularities on the traces with gauze impressions on these heads.

The approximate angle of inclination (within 10°) varied from 0° to 90° with the mode angle, without regard for sign, being between 51° and 60°. The angle was positive (upper half of the ellipse directed forwards (Fig. 44B)) in 28 femora and was negative in 64 femora (Fig. 44A). In 21 femora direction (+ or −) could not be determined, the angle being judged 0°, 90° or impossible to determine due to the shape of the trace (Figs. 44E, F). The angle of inclination had the same sign in 25 pairs and was only different in 6 pairs. In 25 pairs this could not be assessed because at least one of the pairs had an angle of 0°, 90°, or an angle which could not be reliably determined. No common characteristics were located for the six pairs in which the sign differed between sides.

The extent to which the head, in the plane examined, is partly a true sphere is revealed by the number of degrees in 360° that the polar trace exactly coincides with the arc of a template circle. This was assessed in 30° arcs. In 42 heads, 30° or more of the trace coincided with a template circle. Only in one head did the trace coincide for 180° (anterior half) (Fig. 44E). Surfaces that are in contact and are exposed to molding effects of motion may be theorized to more closely approach a true round at least in that portion of the total circumference. From Figure 45 it can be seen that while a slightly greater number of left heads were circular for at least an arc of 30° (left n = 25, right n = 17), the left side is more variable. Orientated with respect to the medial surface of the femur, the portions of the total circle in which the heads were round are similar to the modal direction of the ellipse, that is an ellipse with the upper half inclined backwards and with the narrower diameter in the anteromedial-posterolateral axis on both sides.

Ossification of the Acetabulum

Histological sections of the acetabulum, particularly at the proximal quarter-way level of the socket (when orientated in the anatomical position) were examined for presence of bone. In fetuses of 9.1 to 15.3 cm CRL the acetabular socket is composed entirely of hyaline cartilage. Chondrocytes were rounded, evenly spaced within a homogeneous matrix (Fig. 46a). On the inner socket surface the chondrocytes were more closely packed and somewhat flattened. This inner margin stained more intensely than the remainder of the cartilaginous socket. Cartilage canals were mainly present at the outer edges of the acetabulum in specimens less than 12 cm CRL. Vessels appeared to penetrate the acetabular cartilage from the perichondrium. In fetuses from 13 cm CRL the number of cartilage canals within the socket gradually exceeded those

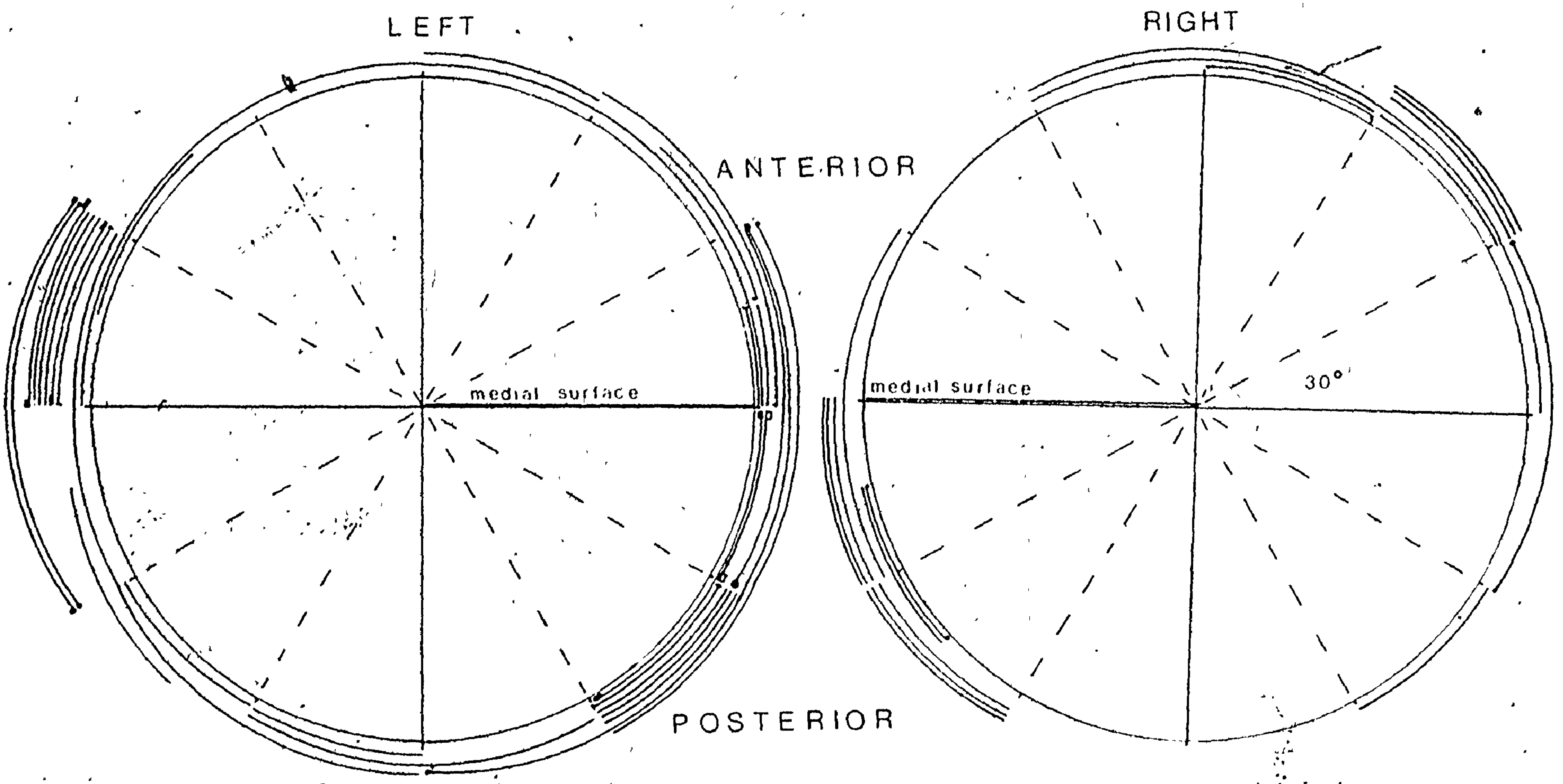


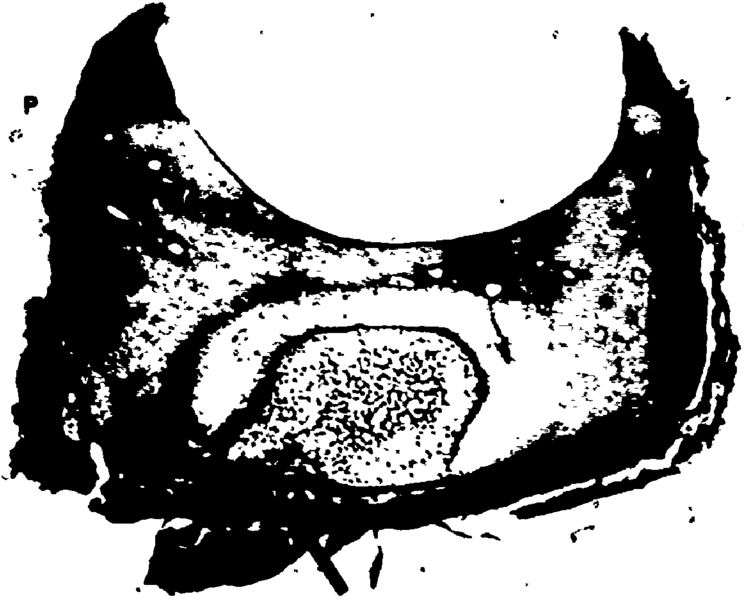
Figure 45: Segments of femoral head traces which were circular. Each line represents one head whose trace exactly coincided with a minimum of 30°. In a number of heads the trace coincided with an exact circle on different parts of the contour; these are indicated by ▫—▫ ●—● The location of the circular portions is approximate due to variation in the position of the lesser trochanter.

Figure 46: Ossification of the acetabulum at the superior quarter-way level (see Fig. 13)

a) A typical section from fetuses with CRL values from 8.7 to 16.0 cm, here from a 15.3 cm CRL fetus. No hypertrophic chondrocytes are seen. A = anterior labrum rim, arrow indicates the acetabular fossa, AB and VG, (X 12).

b) Section from a 21.8 cm CRL fetus. A thin layer of perichondral bone (arrow) is present at the rear of the socket floor, more to the posterior (P) side. There is a central region of endochondral bone surrounded by a zone of hypertrophic chondrocytes. This region does not reach the socket floor. H and E, (X 9).

a



b

Figure 46 cont.

c) Section from a 30 cm CRL fetus. The central region of endochondral bone almost reaches the socket floor and is larger on the posterior (P) side. AB and VG, (X 6).

d) Section from the lower limit of the superior quarter-way level, from a 48 cm CRL postmature "term" fetus. Bone has reached the lateral wall on the posterior (P) or ischial side of the socket but has not extended into the limbs of the socket beyond the level of the acetabular fossa (arrow). AB and VG, (X 4.5).

c

d

present at the outer edge and the canals were randomly distributed throughout the cartilaginous socket. By 20.0 cm CRL, vessels were observed to enter the cartilage from the acetabular fossa depression.

Growth of the iliac primary ossification centre was first observed at the quarter-way level of the acetabulum from a 18.1 cm CRL fetus with the appearance of a zone of clustered hypertrophic chondrocytes. This zone was located at the rear of the acetabular fossa, more to the ischial side, and did not extend to the fossa floor or the posterior margin of the socket. By 21.8 cm CRL (approximately 22 weeks) a thin layer of perichondral bone was present on the posterior border but more to the ischial side. The central region of the socket was composed of endochondral bone surrounded by a zone of hypertrophic chondrocytes. This zone did not reach the floor of the acetabular fossa (Fig. 46b). With growth the amount of osseous tissue present in sections at the quarter-way level point of the acetabulum gradually increased. However, in a 32.0 cm CRL fetus while endochondral bone had reached the floor of the acetabular fossa centrally, this zone had not extended to the lateral borders of the socket, nor did it extend into the limbs (walls) of the socket on either side (Fig. 46c).

In two term acetabula neither endochondral bone nor hypertrophic chondrocytes were visible in the limbs of the socket. However, a layer of perichondral bone was present posteriorly, to the rear of the lateral outer border on the ischial side and in the floor of the acetabular fossa (Fig. 46d). Little change in the extent of osseous tissue at the quarter-way level of the acetabulum was observed in one 48 cm CRL postmature stillbirth infant with an estimated gestational age of 50 weeks.

Growth of the three primary ossification centres of the os innominatum (the iliac, pubic and ischial) and their encroachment into the socket is shown in a series of methyl salicylate cleared specimens (Figure 47). In Figure 47a, a 9.8 cm CRL specimen, the iliac primary centre has spread towards the anterior inferior iliac spine, however the socket is cartilaginous and clear. In specimens of CRL 15.4 cm and 19.5 cm (16 and 20 weeks) the iliac centre has spread to involve the upper part of the superior pole of the acetabulum (Fig. 47b and c) and is located posterocentrally. Side views of the socket rims in a 24.4 cm CRL specimen (Fig. 47d) still reveal no spread of bone into the socket rims. In a 30.0 cm CRL specimen, 32 weeks, all three primary centres have spread into the floor of the acetabulum (Fig. 47e). The iliac and ischial primary centres show greater growth than the pubic centre which is just visible on the socket floor. The acetabular branch of the obturator artery is seen entering the acetabulum via the acetabular notch and ramifying within the acetabular fossa. Minor changes in the extent of ossification are seen in Figure 47f of a 34 cm CRL specimen, 36 weeks of age. The ischial centre has spread to reach the floor of the acetabular fossa. In the acetabulum of a 48 cm CRL postmature term infant the Y-shaped cartilage separating the three primary centres is distinct and the rims of the socket remain cartilaginous. In the superior half of the acetabulum bone has spread into the anterior half but more bone appears present on the posterior or ischial side (Fig. 47g).

Figure 47: Ossification in a series of left acetabula cleared in methyl salicylate

a) The socket in this 12 week fetus (9.8 cm CRL) is cartilaginous with bone only visible on the ischial side of the superior pole. (X 7)

b) Bone is visible in the floor of the superior pole and the ischial centre is present in the socket floor. A = anterior, a 16 week 15.4 cm CRL fetus, (X 3.6).

c) The socket is still cartilaginous in this 20 week fetus, 19.5 cm CRL. A = anterior, (X 1.5).

d) Side view of the anterior rim of the socket from a 24 week, 24.4 cm CRL fetus. The labrum can be distinguished from the hyaline cartilage anterior wall. P = posterior, (X 1.7).

a

b

c

d

Figure 47 cont.

e) The three centres of ossification, iliac, ischial and pubic, are present in the floor of this socket from a 32 week fetus, 30.0 cm CRL. The iliac centre has not reached the anterior inferior iliac spine (arrow). Compare with f). PU = pubis, (X 2.4)

f) In this 36 week fetus, 34 cm CRL, the socket appearance is similar to that shown in e) of a 30.0 cm fetus. The iliac centre covers a smaller area than in e) while the ischial centre has reached the acetabular fossa. The rims remain cartilaginous. (X 2.3)

e

f

g

Figure 47 cont.

g) In this socket from a 48 cm CRL postmature term infant the iliac centre has spread to the anterior side, the non-articular area in the floor of the socket is distinct. The rims remain cartilaginous. A = anterior. (X 3.5)

The Acetabular Labrum

The acetabular labrum of specimens in the 12 week age group (CRL 8.7 - 11.9 cm) has achieved the typical shape of a mature labrum (Fig. 48). The junction between the acetabular hyaline cartilage and the fibrous labrum is distinct. The labrum is triangular in shape with a pointed apex and a gently concave inner surface which is continuous with that of the cartilaginous socket. The inner surface has a lining layer of articular cartilage up to five cells deep. The staining reaction of the labra collagenous fibres is identical with that of the perichondrium or periosteum. There is continuity between fibres within the perichondrium and the labrum. Perichondral fibrous tissue continues along the outer margin of the labrum to the apex which may be covered by a small amount of loose connective tissue. The fibrous joint capsule is attached below the apex of the labrum, which, as Ogden (1974) noted, is an intra-articular structure. A small sulcus between the capsule attachment and the labrum is generally visible at the macroscopic level and can be easily seen in histological sections (Fig. 48).

The most distinctive change in the labrum observed with aging was in the density of the collagenous fibres. In younger specimens labra were typically composed of loosely arranged bundles of collagenous fibres with a certain amount of intervening matrix and fibrocytes. Term labra were composed of intensely staining, densely packed collagenous fibres with no apparent matrix and few cells (see Fig. 19f,g, p.68). Collagenous fibres were visible in labra from the youngest specimen examined (9.1 cm CRL). Chondrocytes were not observed in the substance

Figure 48: The acetabular labrum

a) The typical appearance of the labrum, in a 14 week, 13.7 cm CRL fetus. The collagenous fibres are loosely packed and capillaries are seen entering the labrum from the outer surface. The junction between the labrum and the cartilaginous socket is distinct. Note the capsule sulcus (arrow) and the cartilage canals (arrows). AB and VG, (X 2).

b) Chondrocytes were only observed on the inner articular margin of the labrum (arrow) shown here in a 12 week socket (arrow). CF = collagenous fibres, HA = hyaline cartilage, AB and VG, (X 40).


a
b

of the labra, being only found at the inner margin articular cartilage lining (Fig. 48b).

While variability was observed between the anterior and posterior wall labrum of the same acetabulum, either in height or width of the labrum, and/or in the density of the collagenous fibres, these size differences were minimal (< 0.1 mm).

From the youngest specimens studied, vessels were observed to penetrate the labrum from the outer covering of fibrous tissue which is continuous with the perichondrium. With increase in fetal age, vessels penetrated through to the inner margin of the labrum. Vessels appeared less numerous in the substance of the labrum in third trimester specimens.

In seven acetabula, 13.7% of those studied histologically, from fetuses of CRL from 10.5 to 28.5 cm, loose connective tissue with capillaries was observed on the inner margin, at the junction between the cartilaginous socket and the labrum (Fig. 49). In serial sections vessels at this junction could be traced to the outer margin, penetrating the labrum from the perichondrium and not from the acetabular cartilage canals. In all seven the loose connective tissue at this junction was observed on the anterior labrum in the superior quadrant. In several specimens this junction discontinuity, which had a different staining reaction to both the labrum and the socket cartilage, was observed to be present throughout the length of the anterior rim. In others it had disappeared by the midpoint of the anterior rim length. The loose connective tissue in several of the specimens was replaced in later sections by a distinct groove. In specimen #21 (shown in Figure 49) the

Figure 49: Defects at the cartilage-labrum junction

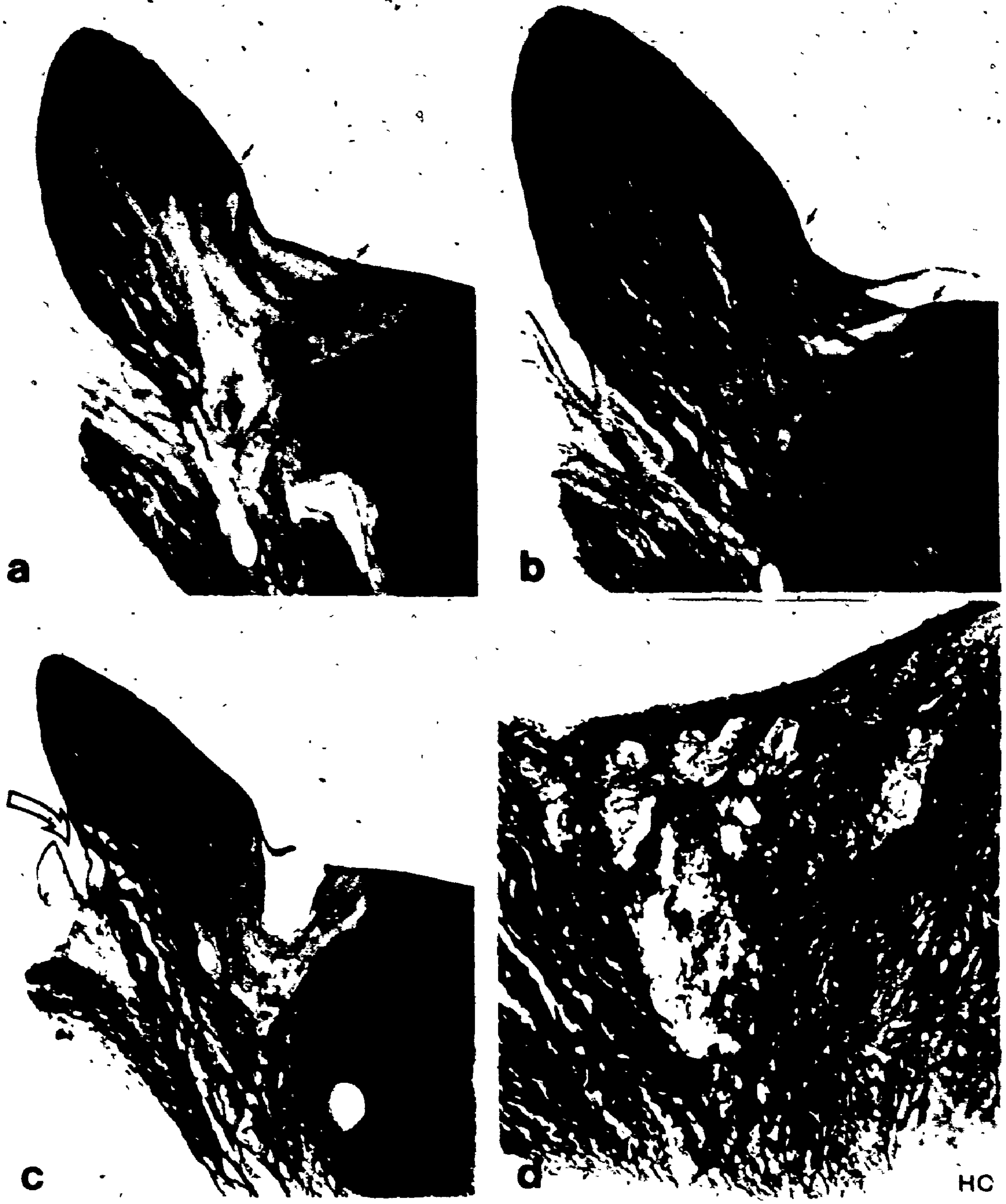
A typical junction is shown in Figure 48a. These defects were only observed on the anterior labrum. a), b) and c) here are froma 14 week, 13.7 cm CRL fetus. All sections are 10μ.

a) The area immediately adjacent to the cartilage of the socket proper (arrows) contains loose collagenous fibres and many capillaries. LA = labrum, HC = hyaline cartilage, AB and VG, (X 12).

b) This section is 600 μ from the section shown in a). Arrows indicate the area of the defect. AB and VG, (X 16).

c) A cleft is present in the region of the defect. This section is 600μ from the section in b). Note that while younger labra have a looser arrangement of collagenous fibres than older labra, the fibre separation seen here and in a) and b) is an artifact. The capsule sulcus is shown (arrow). AB and VG, (X 16).

d) The loose arrangement of tissues at the junctional defect is shown. Hyaline cartilage (HC) is seen on the right, the joint surface is superior and the collagenous labrum is on the left hand side. AB and VG, (X 20).


a
b
c
d
HC

groove was present throughout 26% of the total socket circumference. On macroscopic examination of these acetabula the labra had appeared normal.

The percentage of the socket formed by the labrum was calculated from measurements on sections at approximately the superior one-quarter point of the acetabulum (Fig. 50). The mean percentage of the socket formed by the labrum was 32.45% (10.15%, n = 51). In 38% of specimens the labrum formed between 20% to 29% of the socket. The range was from 14% to 55%. No definite age trend was observed. Only in three acetabula did the labrum form > 50% of the socket. This percentage was found in fetuses less than 14 cm CRL. Percentages greater than 50% and less than 20% were observed in 12 week fetuses and a similar variability was seen in the term fetuses (21% - 40%). The percentage of the socket formed by the labrum from both sides of the same fetuses had a mean difference of 8% and was only identical in two pairs of acetabula.

Abnormal Cases and Cases with Congenital Abnormalities

Abnormal Cases

Data related to sex, crown-rump length, gestational age, study age and the number of abnormal hip joints are presented in Table 33. Autopsies were performed in five of the seven cases. No congenital abnormalities were detected.

For comparative purposes and to reduce repetition of normal values, tables in this section present measurement data for abnormal cases and cases with congenital abnormalities with the means for their appropriate normal age group. Data for each hip joint variable in

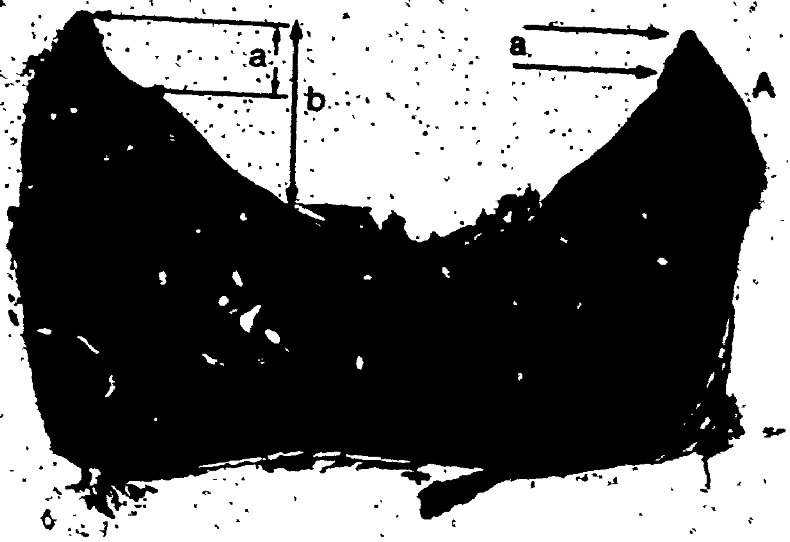


Figure 50: Calculation of the percentage of the socket formed by the labrum

The height of the labrum (a) was measured on both sides and a mean of the two measurements x 100 was divided by the socket depth (b). Depth was taken from the top of the levelled labra to the lowest point of the cartilage, not including the acetabular fossa. A typical side difference in rim labra height is shown. A = anterior, AB and VG, section from approximately the superior one-quarter way level of the acetabulum from a 32 cm CRL fetus. The calculated percentage is approximate, no adjustment was made for the curvature of the socket wall.

Table 33

Abnormal hip cases by sex, age, crown-rump length (CRL) and frequency of abnormal hips. GA = gestational age, F = female, M = male, ND = no data

Case Number	Sex	GA weeks	CRL cm	Age (estimated) weeks	Affected hips
066	ND	term	ND	40	bilateral
154	M	term	38.00	40	bilateral
147	M	37	33.00	34	bilateral
116	F	34	26.00	26	bilateral
115	F	24	18.00	18	bilateral
025	M	ND	16.50	18	left
087	F	ND	9.70	12	right

abnormal cases and cases with congenital abnormalities are shown in Figures 51 - 57 with the means and one SD for the normal group.

Individual Case Characteristics

Case #66

This fetus was a term stillbirth for which no data were located on the sex, CRL, cause of death or family history. Placement in the 40 week group seems justified on data for femoral head and acetabular diameters (Table 34) which may provide a reliable estimate of age. Both hips were fixed in the position of flexion and adduction and no telescoping was evident prior to capsulectomy. Due to poor coverage of the femoral head subluxation occurred once the capsule was opened. Bilaterally, a normal sulcus was present around the entire rim. In the right acetabulum (Fig. 58a) the anterior rim was defective. The labrum was flattened and folded inwards in the anterosuperior half and no cartilage was visible in the midportion of the anterior socket wall due to pulvinar extending over this surface. The left acetabulum (Fig. 58b) had a dip in the anterosuperior quadrant with flattening of the labrum which was narrower than the other quadrants. The anterior horn of the socket was shorter than the posterior horn. The vertical diameter of the socket was 0.8 mm greater than the transverse diameter. Torsion was not measured as only the proximal third of the femora were available. The only measurement falling outside the mean ± one SD for the term group was the right LHF width (< $\bar{x}$ - one SD for age groups 32 to 42 weeks).

Case #154

A male stillbirth, death occurred eight hours prior to delivery by vertex presentation. Maceration appeared minimal. The mother, aged

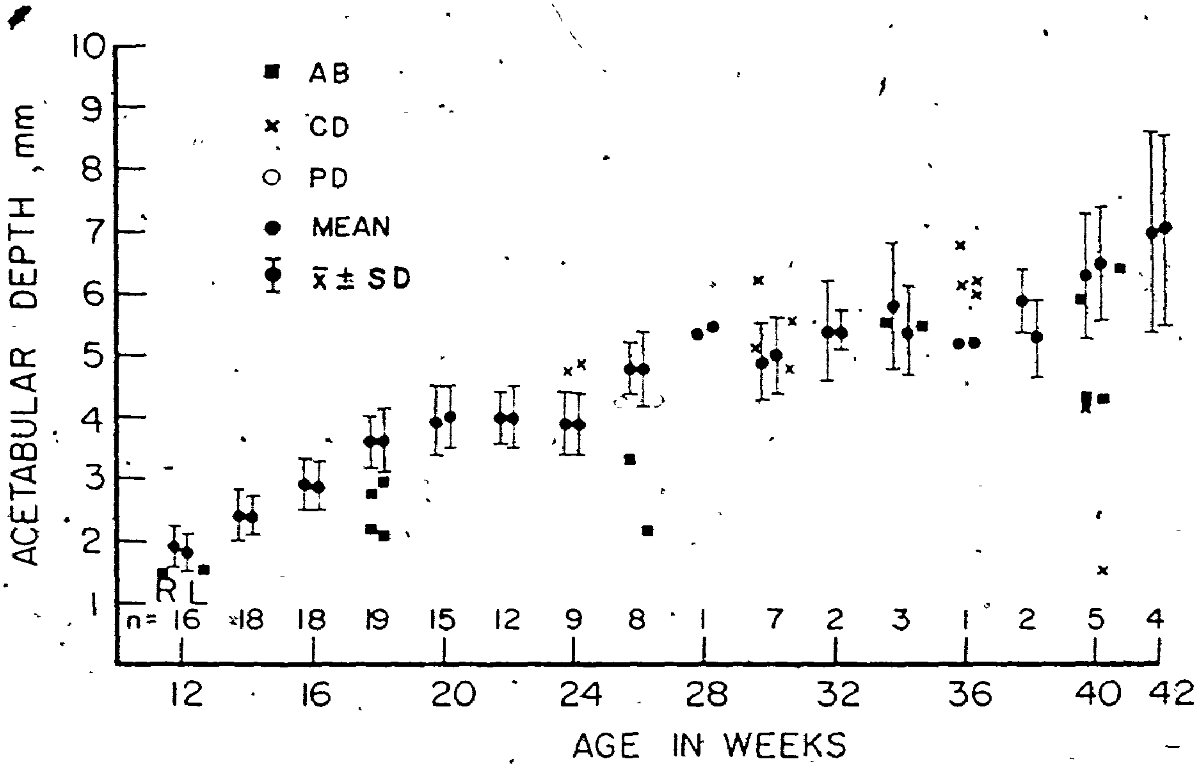


Figure 51 : Acetabular depth, mean values and standard deviations, sexes combined, by side, for normals with the abnormal cases (AB) and cases with congenital abnormalities (CD). PD = postnatal death.

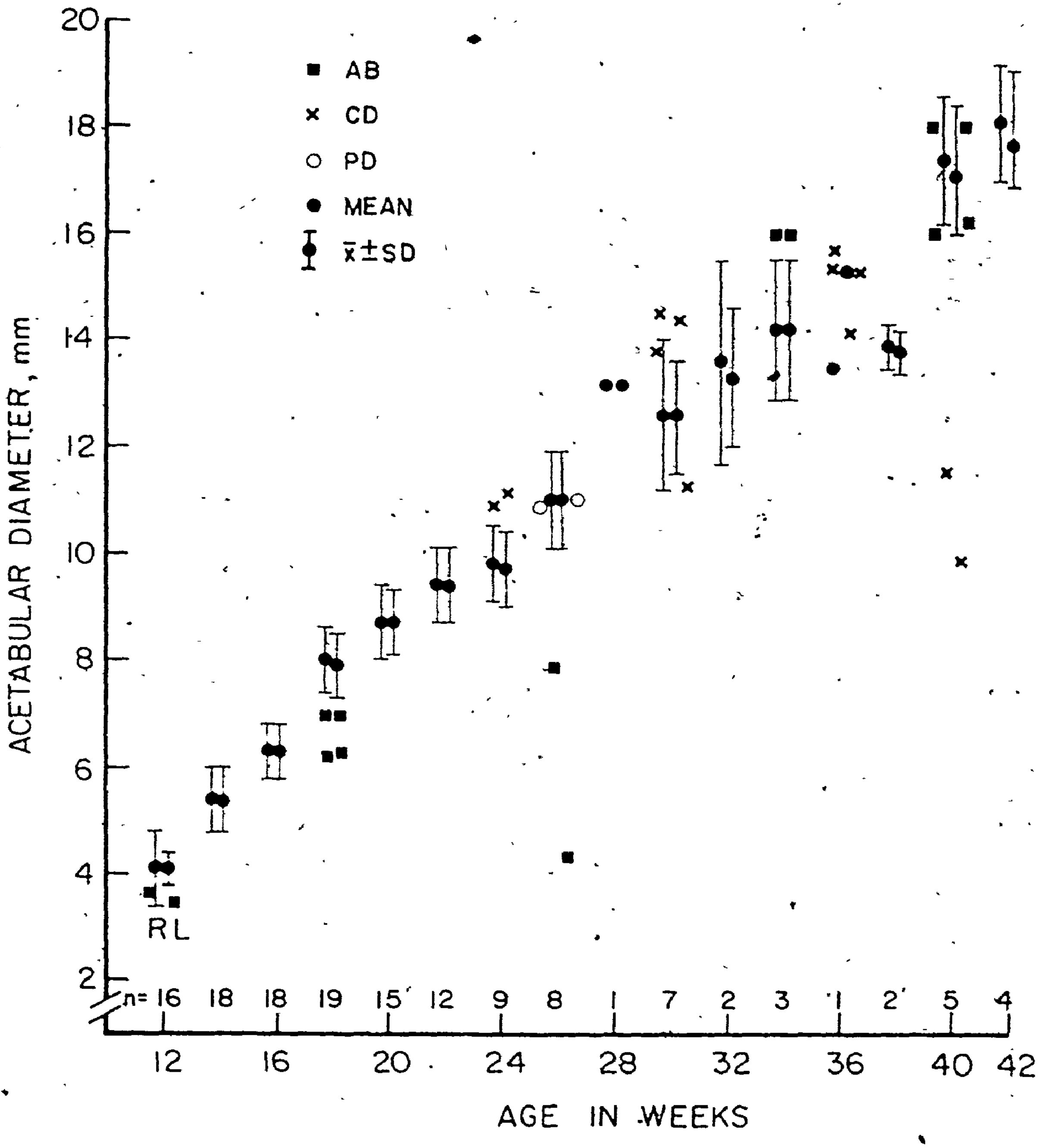


Figure 52 : Acetabular diameter, mean values and standard deviations, sexes combined, by side, for normals with the abnormal cases (AB) and cases with congenital abnormalities (CD). PD = postnatal death.

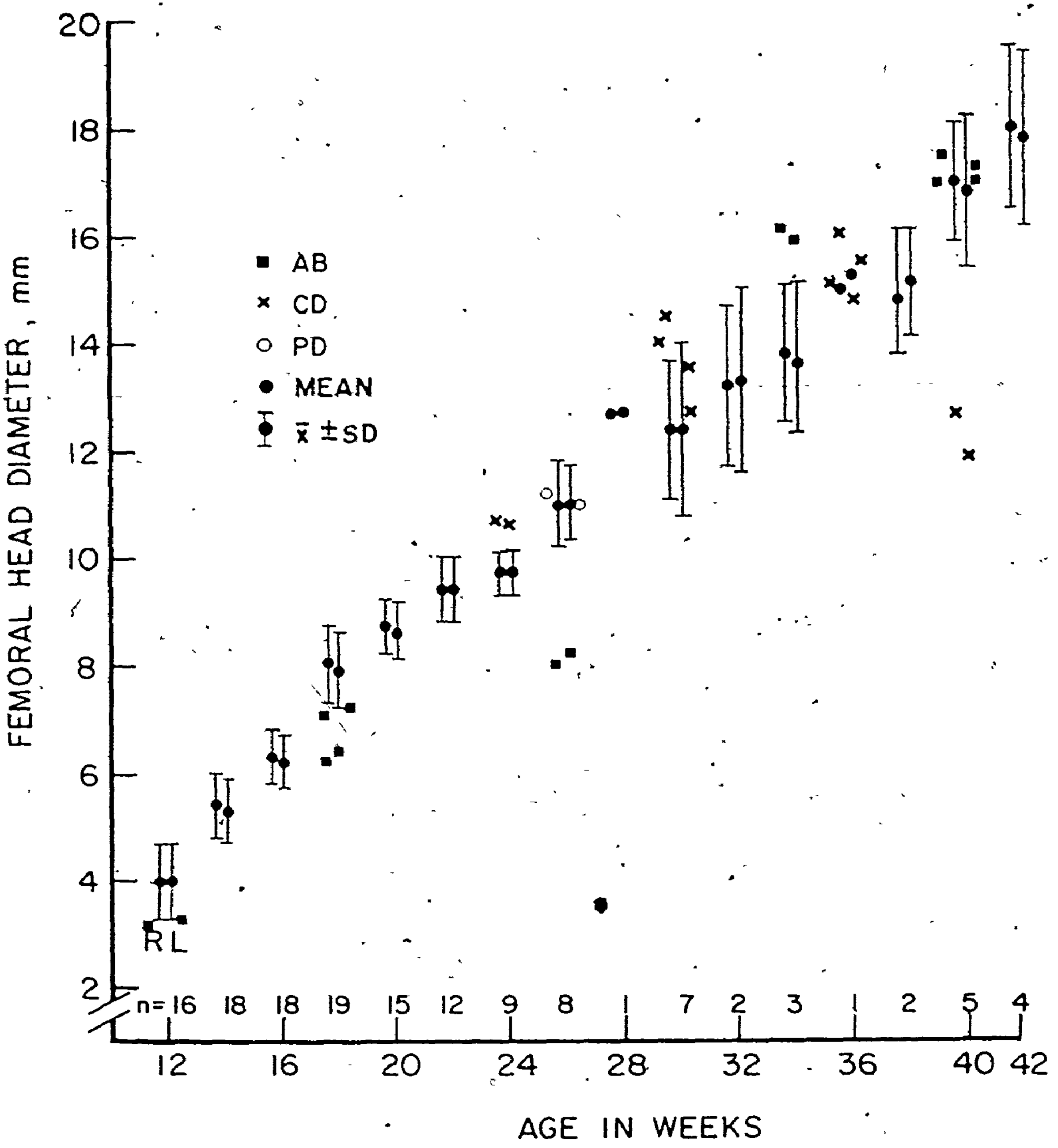


Figure 53 : Femoral head diameter, mean values and standard deviations, sexes combined, by side, for normals with the abnormal cases (AB) and cases with congenital abnormalities (CD). PD = postnatal death.

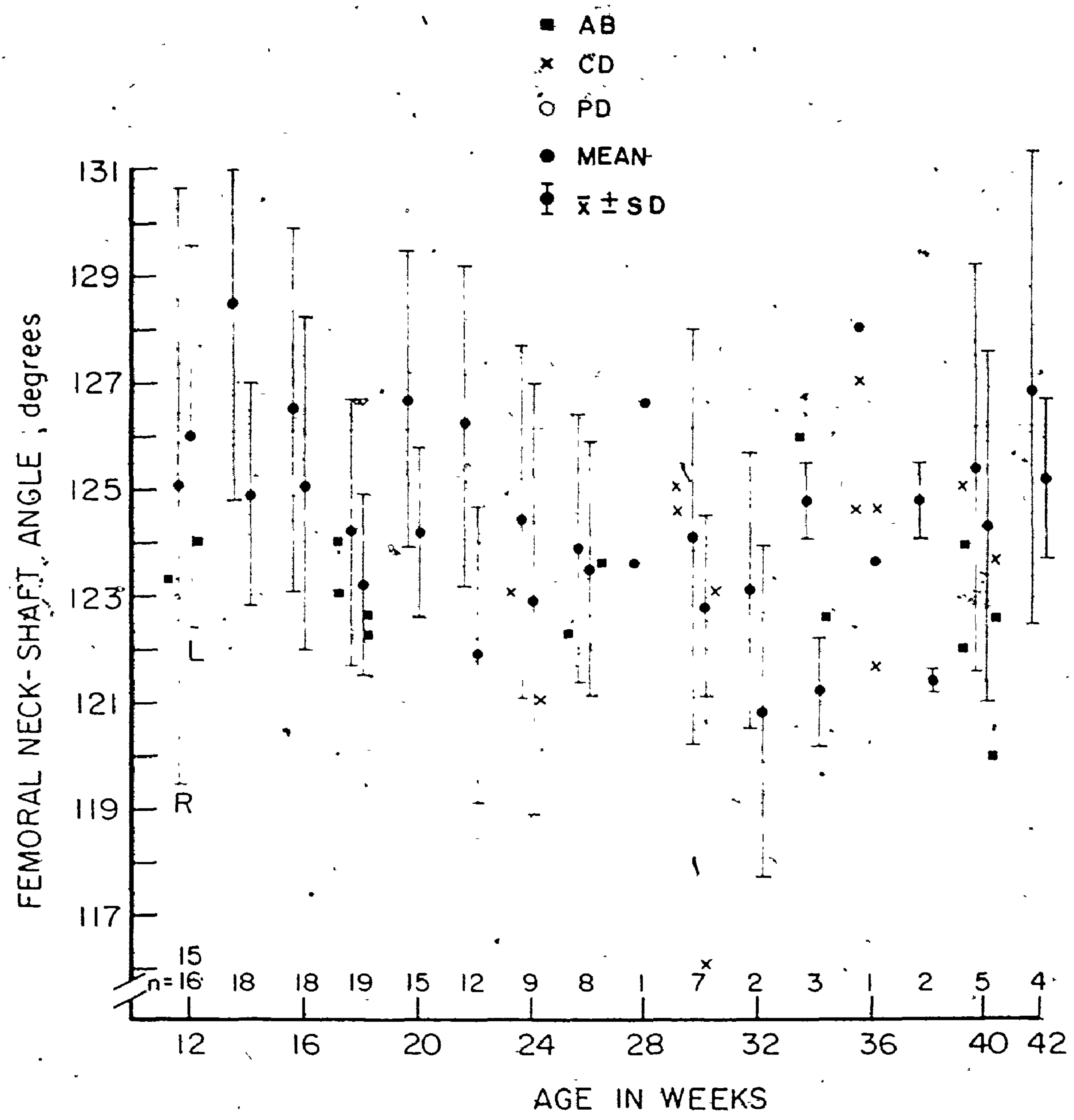


Figure 54 : Neck-shaft angle, mean values and standard deviations, sexes combined, by side, for normals with the abnormal cases (AB) and cases with congenital abnormalities (CD). PD=postnatal death.

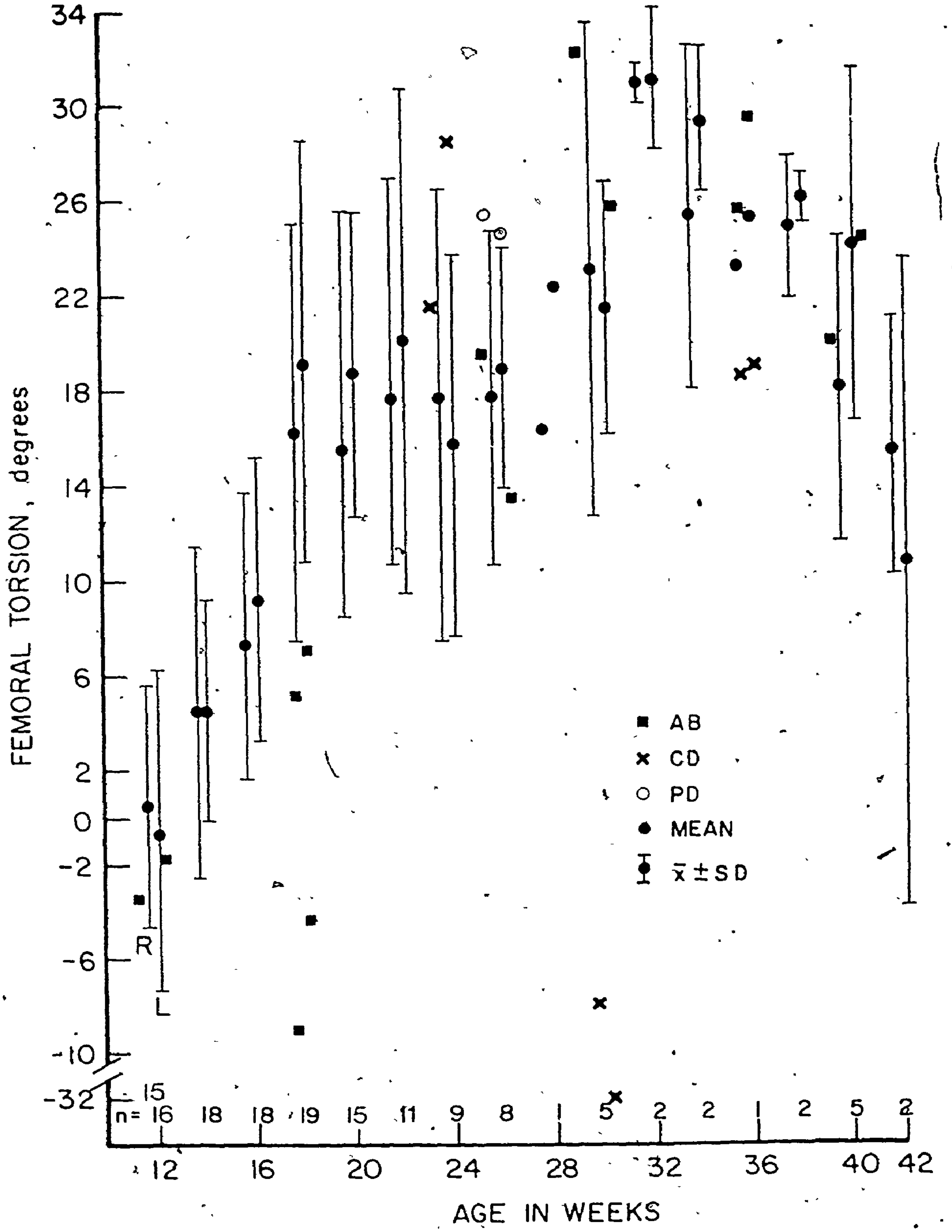


Figure 55 : Torsion, mean values and standard deviations, sexes combined, by side, for normals with the abnormal cases (AB) and cases with congenital abnormalities (CD). PD =

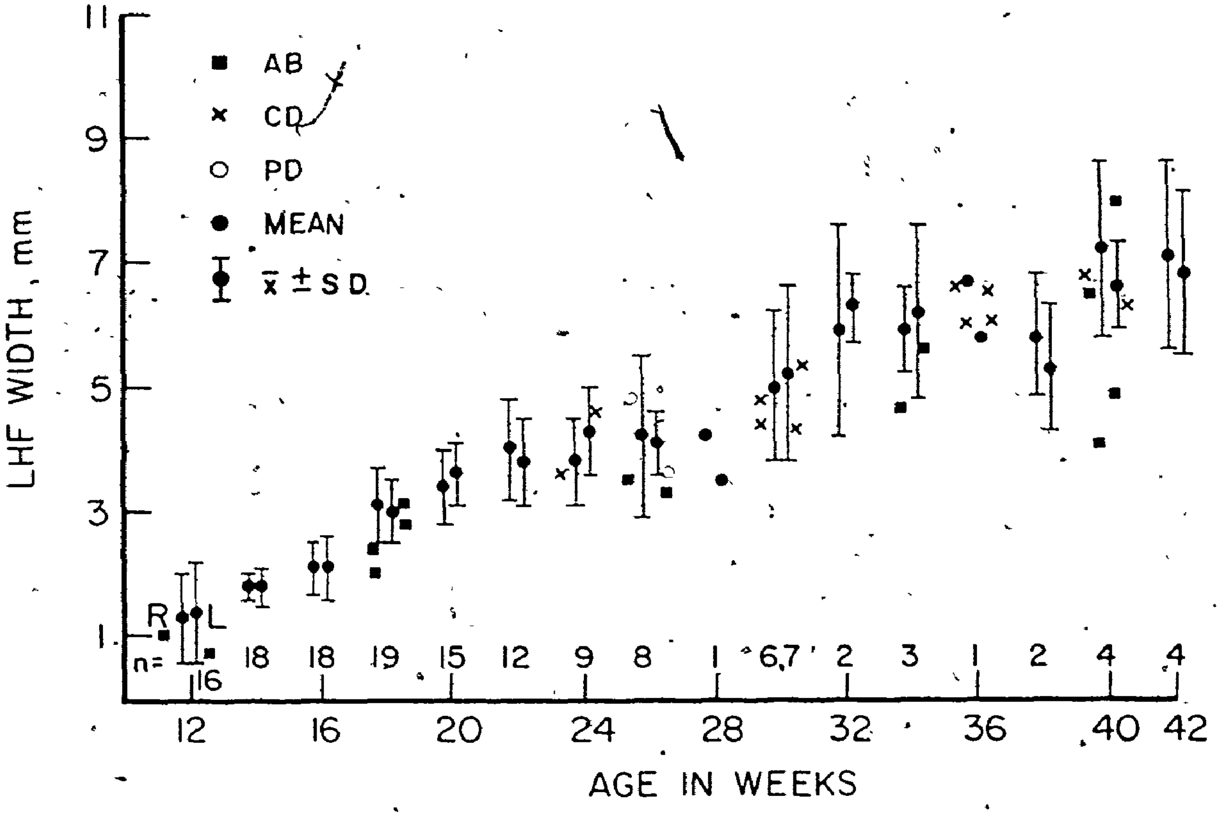


Figure 56: Ligament of the head of femur (LHF) width, mean values and standard deviations, sexes combined, by side, for normals with the abnormal cases (AB) and cases with congenital abnormalities (CD). PD = postnatal death.

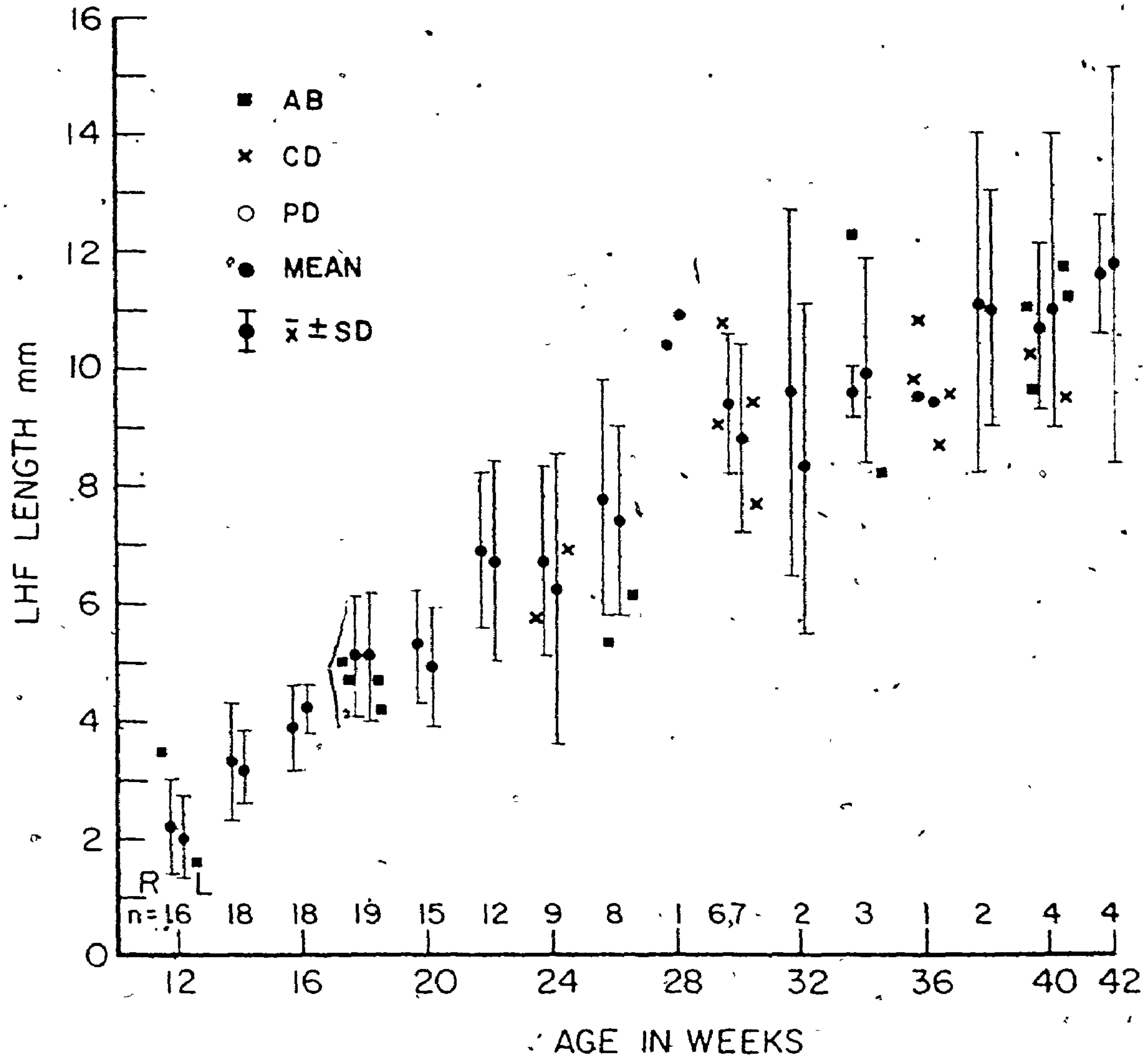


Figure 57 : Ligament of the head of femur (LHF) length, mean values and standard deviations, sexes combined, by side, for normals with the abnormal cases (AB) and cases with congenital abnormalities (CD). PD = postnatal death.

Table 34

Abnormal cases #66 and #154 with the mean values and standard deviations for the 40 week normal group, sexes combined. ND = no data, R = right, L = left, LHF = ligament of head of femur, in mm, angles in degrees.

		Normals		Abnormal Cases	
Variable	Side	Mean	SD	#66	#154
Crown-rump length (cm)		37.83	.29	ND	38.00
LHF width	R	7.19	1.38	4.09*	6.56
	L	6.59	.67	8.05§	4.90*
LHF length	R	10.75	1.38	10.99	9.57
	L	11.05	2.02	11.22	11.75
Femoral head diameter	R	16.98	1.07	17.49	16.99
	L	16.83	1.38	17.33	16.99
Acetabular diameter	R	17.37	1.16	17.98	16.01
	L	17.15	1.27	17.98	16.17
Acetabular depth	R	6.33	.92	6.00	4.43*
	L	6.49	1.10	6.50	4.40*
Neck-shaft angle	R	125.42	3.88	124.00	122.00
	L	124.30	3.34	122.60	120.30*
Torsion angle	R	17.92	6.32	ND	20.00
	L	24.10	7.53	ND	23.30
Acetabular index %	R	36.42	4.71	33.36	27.68*
	L	37.84	5.44	36.14	27.11*

(n = 5)

* < $\bar{x}$ - one SD

§ > $\bar{x}$ + one SD

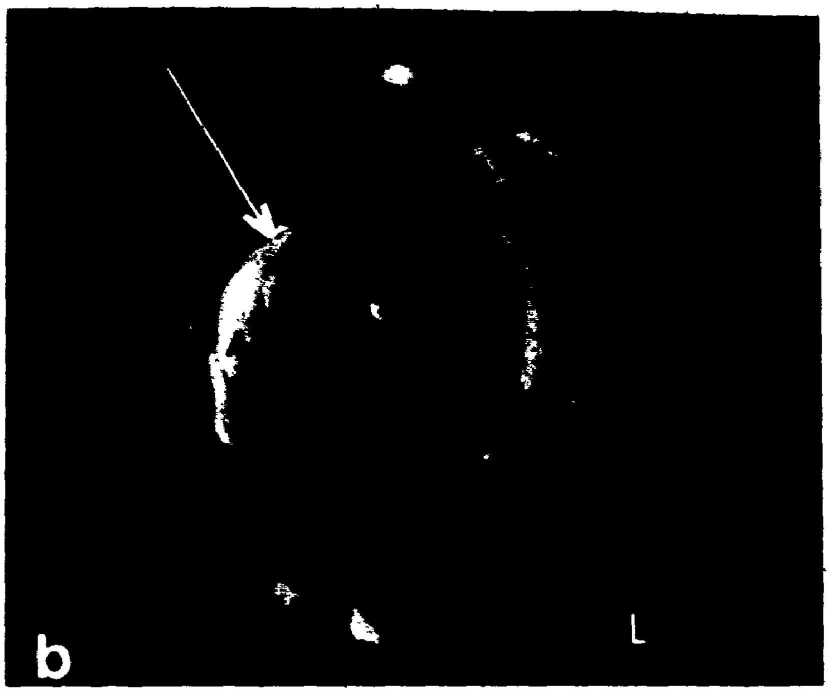
Figure 58: Abnormal acetabula in a normal term fetus, #66

While both heads were seated in the sockets, the socket head coverage was less than 50 percent.

a) Side view of the right (R) socket. The anterior labrum is flattened and overhangs the anterior socket wall which in its midportion was covered with pulvinar. S = superior, A = anterior, (X 2.2).

b) An oblique view of the left (L) socket which has a dip in the anterosuperior quadrant (arrow) and has a short narrow anterior wall. The vertical diameter of the socket exceeded the transverse diameter. (X 2.2)


a
R


b
L

31 years, had a heart murmur. No other family history was located. The CRL was 38 cm and the birth weight 3097.5 g. The lower limbs were flexed with the right crossed over the left at the leg level. No abnormal mobility was detected pre- or postablation of the hip musculature. Capsulectomy revealed bilateral socket abnormality. The right socket is shown in Figure 59. Bilaterally the inner surface of the capsule had a small fold which rested against a defective anterosuperior socket rim and projected into the joint cavity. In this region the labrum was rounded, a slight depression was present with some infolding of the labrum. In contrast, the posterior socket wall was well developed with a sharp rim. A sulcus was present circumferentially on both sockets. The left femur dislocated more completely once the capsule was divided but with the LHF intact. Bilaterally the femoral head diameter exceeded the acetabular diameter (Table 34). Only the depth measurement was less than $\bar{x}$ minus one SD for the term group. Acetabular indices of 27% are low.

Case #147

A male stillborn delivered by caesarean section, the cause of death was fetal atelectasis and abruptio placentio. Grade 2 maceration was evident. The estimated gestational age by the last menstrual period (LMP) was 37 weeks. The CRL was 33 cm and the birth weight 2947.35 g. This infant was aged at 34 weeks by the CRL, but since the bilateral femoral head and acetabular diameters exceeded the mean plus one SD (Table 35) for the 34 week group (n = 3), age may be underestimated using the CRL.

While neither hip could be dislocated prior to ablation of the capsule, some telescoping was present on the left. Removal of the

Figure 59: Abnormal morphology in a normal, 38 cm CRL fetus, #154

Capsulectomy revealed identical bilateral socket abnormality with a fold of the capsule projecting into the socket (arrow) in the region of the anterosuperior quadrant. The right side is shown. In the region of the fold the labrum was rounded and overhung the anterior socket wall. Note the nonspherical head. In both hips the femoral head diameter exceeded the acetabular diameter by 0.8 mm. GT = greater trochanter, P = posterior, S = superior, (X 2).

Figure 60: Abnormal sockets in normal fetus, #147

Note the lack of a well-formed anterior horn bilaterally, more so on the right (R). The tissue of the acetabular fossa extends unusually high on the anterior socket wall. The socket rim shape is aspherical, and bilaterally the femoral heads appeared to be aspherical, slightly conical in shape. S = superior, A = anterior, L = left. This was a male fetus with a CRL of 33 cm. (X 2.8)


S
P
GT

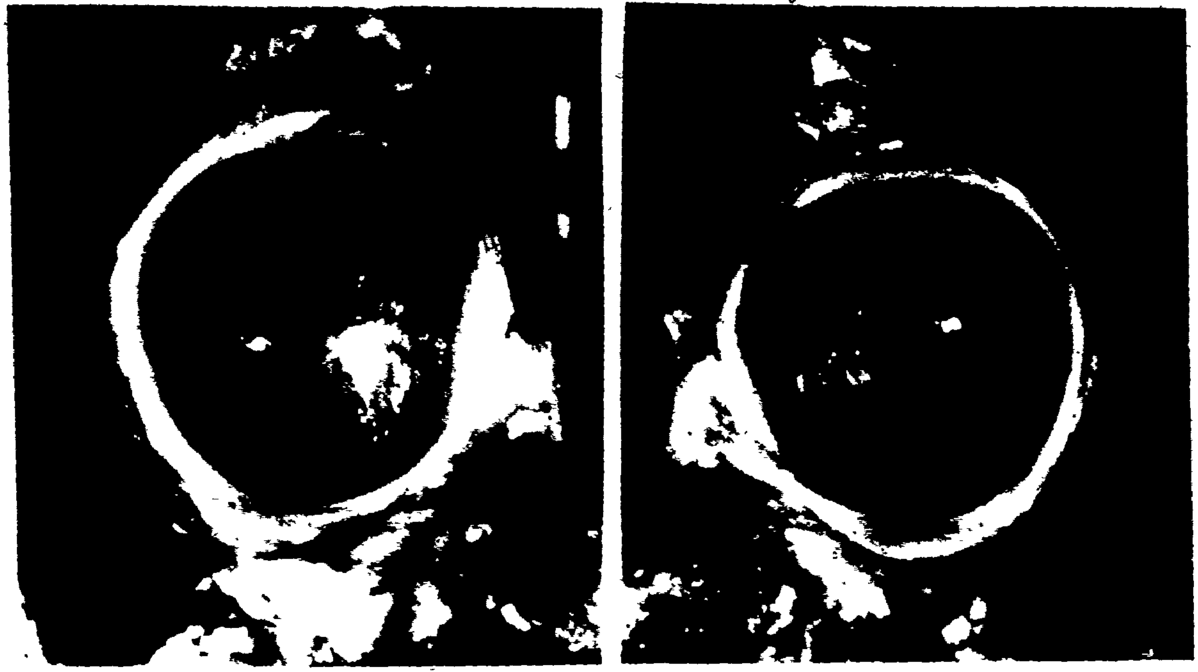


Table 35

Abnormal case #147, congenital abnormalities cases #96 and #145 and the mean values and standard deviations for the normal 34 and 36 week groups. ND = no data, LHF = ligament of the head of femur, R = right, L = left, in mm, angles in degrees.

		Normal	34/52		Normal		
Variable.	Side	Mean	SD	#147	36/52	#96.	#145
Crown-rump length (cm)	R	32.50	.71	33.00	34.00	34.00	34.00
LHF width	R	5.88	.75	4.70	6.75	6.64	5.98
	L	6.18	1.44	5.65	5.78	6.47	5.97
LHF length	R	9.57	.40	12.27§	9.53	10.79	9.85
	L	9.90	1.52	8.22	9.41	8.74	9.46
Femoral head diameter	R	13.81	1.27	16.06§	15.01	15.13	16.01
	L	13.61	1.52	15.95§	15.34	14.85	15.51
Acetabular diameter	R	14.25	1.34	16.01§	13.53	15.67	15.40
	L	14.23	1.32	16.01§	15.34	15.35	4.08
Acetabular depth	R	5.78	1.02	5.70	5.33	6.90	6.20
	L	5.44	.67	5.60	5.26	6.30	6.10
Neck-shaft angle	R	124.77	.68	126.00	128.00	124.60	127.00
	L	121.20	1.06	123.60	123.60	121.60	124.60
Torsion angle	R	25.15	7.28	25.60	23.33	18.66	ND
	L	29.15	3.04	29.60	25.33	19.66	ND
Acetabular index %	R	40.64	5.02	35.61	39.39	40.02	40.26
	L	38.95	2.54	34.99*	34.29	41.06	43.32
		(n = 3♀)			(n = 1♀)		

#147 bilateral abnormal hips,

#96, #145 congenital heart anomaly, both cases bilateral normal hips

* $< \bar{x} - 1$ SD

§ $> \bar{x} + 1$ SD

capsule revealed poor femoral head coverage. With the LHF intact neither femoral head dislocated more than 50%. The separation of the joint surfaces was only slightly greater with hip flexion and adduction. This unusually restricted mobility after division of the capsule was due to an especially thick LHF which, in particular, limited abduction. In both sockets the posterior wall was well formed (Fig. 60). However, anteriorly the tissue of the acetabular fossa and the transverse acetabular ligament appeared to extend high on the pubic side so that a well-formed anterior horn was not present. In this region there was flattening and overhang of the labrum. Bilaterally the femoral heads were aspherical, somewhat bulging on the medial side where no neck constriction was evident.

Case #116

Case #116 was a female stillbirth due to placental insufficiency and Grade 3 maceration was evident. The leg position was unknown. The estimated gestational age based on LMP was 34 weeks. However, with a CRL of 26 cm and a birth weight of 620 g this fetus was placed in the 26 week group. Although the left limb showed marked internal rotation and telescoping was present on this side prior to dissection, the extent of maceration invalidates this finding. On the right side an unusually thick capsule was noted and following capsule ablation there was immediate dislocation of the femoral head anteriorly and inferiorly. Before the capsule was divided the head had been located within the region of the socket. On the right socket a dip with a rounded rim was noted in the anterosuperior half of the rim. No variation in labrum thickness was noted. The acetabular diameter was slightly less than the femoral head diameter. Table 36 presents the data on hip measurements.

The left capsule was deficient posteroinferiorly where it consisted more of fibrous strands than a complete sleeve of fibrous tissue. The head of femur was located outside of the "real" socket, resting on the flattened posterior rim of a distinctly abnormal socket. Appreciable depth was only present in the central portion of the socket (Fig. 61). The socket had a maximum depth of 2.6 mm from the outer edge of the flattened posterior rim and a depth of 2.2 mm from the inner edge of same. The markedly flattened posterior rim had a maximum width of 2.2 mm. In comparison, the anterior rim was folded into the socket and in its midsection was deficient with no visible labrum. Absolute disparity was present between the femoral head diameter (8.19 mm) and the "real" acetabular diameter (4.37 mm). There was a "false" diameter of 6.6 mm from edge to edge of the abnormal socket.

Torsion angle values were not remarkable. The right hip variables were less than the mean minus one SD for the 26 week group while the left variables of depth and acetabular diameter fit the 12 week group. Femoral head diameters fit the 18 week group. For the depth and diameters of the left hip the left LHF length was abnormally long. The left femoral head was aspherical, appeared compressed in the antero-posterior direction and had an indistinct neck. The left acetabular index, calculated on the maximum diameter, indicates a shallow socket.

Case #115

This fetus, a female stillbirth due to placental insufficiency, had an estimated gestational age of 24 weeks (LMP). With a CRL of

Table 36

Abnormal case #116, congenital abnormalities case #158 and case #159 with the mean values and standard deviations for normal 26 week group, sexes combined. ND = no data, R = right, L = left, LHF = ligament of the head of femur, FH = femoral head. In mm, angles in degrees.

		Normals				
Variable	Side	Mean	SD	#116	#158	#159
Crown-rump length (cm)		25.06	.18	ND	23.90 est.	ND
LHF width	R	4.24	1.33	3.51	3.60	4.76
	L	4.06	.92	3.31	4.65	3.62
LHF length	R	7.81	1.97	5.30*	5.75*	6.08
	L	7.45	1.63	6.08	6.93	5.67*
Femoral head diameter	R	10.99	.83	8.05*	10.72	11.22
	L	11.02	.76	8.19*	10.56	11.05
Acetabular diameter	R	10.80	.89	7.91*	10.89	10.89
	L	11.00	.88	4.37*	11.05	11.05
Acetabular depth	R	4.76	.45	3.43*	4.80	4.33
	L	4.81	.58	2.20*	4.90	4.30
Neck-shaft angle	R	123.95	2.26	122.30	123.00	126.30
	L	123.46	2.42	123.60	121.00	122.00
Torsion angle	R	17.69	6.93	19.60	21.60	25.30§
	L	18.79	5.02	13.30*	28.30	24.60§
Acetabular index %	R	43.56	4.70	43.39	44.08	39.76
	L	43.89	5.93	33.13†	44.32	39.90

(n = 8)

#158 anencephalic with normal hips

#159 normal case excluded from growth study as infant lived for 35 days

* $< \bar{x} - 1$ SD

§ $> \bar{x} + 1$ SD

† calculated on maximum diameter

Figure 61: Abnormal left hip in a normal fetus, #116

A female stillbirth with CRL of 26 cm showed Grade 3 maceration. IL = ilium, A = anterior, S = superior, P = posterior, I = inferior. The subluxated position of the left hip was detected prior to removal of the capsule.

a) The intact ligament of the head of femur (arrow) permitted complete dislocation of the head of femur in all directions except posterosuperiorly when the capsule was removed. The head of femur is tilted inferiorly on the neck giving the appearance of an almost 90° neck-shaft angle. Note the head has a somewhat flattened appearance. (X 2.5)

b) Frontal view of the left socket. The head rested on the flattened posterior rim. The "true" socket diameter was 2.23 mm less than that of the "false" socket diameter and the femoral head diameter exceeded the "false" socket diameter. (X 5)


a
IL
L


IL

16.0 cm and a birth weight of 265 g the age of this fetus was estimated at 18 weeks. The mother, a gravida 1, was 26 years old. Grade 3 maceration was present. The left hip was normal except for the vertical diameter of the acetabulum exceeding the transverse diameter (6.64 mm, 6.31 mm) (Fig. 62a). Measurement data are given in Table 37.

The right hip abnormality was apparent after ablation of the musculature. The telescoping test was invalidated by the extent of tissue maceration. The head was located in the region of the socket. With the capsule removed and the LHF intact the head seated well in flexion with abduction and external rotation but dislocated in extension and internal rotation. The rim was deficient anteriorly where both a sulcus and labrum were absent (Fig. 62b). The transverse acetabular ligament lacked a lining of articular cartilage, and a thin film of loose fibrous tissue extended over the anterior socket surface from the acetabular fossa. The acetabular vertical diameter exceeded the transverse diameter by 0.7 mm and the FH diameter was 0.2 mm greater than the acetabular diameter. Despite these findings side differences in acetabular depth were trivial. However, bilaterally the acetabular indices are low indicating shallow acetabula, especially on the left side. Bilateral retroversion of the femoral heads was present and torsion angle values were less than the mean minus two SD's for the 18 week group mean.

Despite the grossly normal left hip appearance, it seems underdeveloped from the measurements obtained. Except for the LHF and the neck-shaft angle, bilaterally all measurements were less than the mean minus one SD for the 18 week group. In comparison with values for

Figure 62: The sockets of a normal fetus, #115

This female stillbirth had a gestational age of 24 weeks by the last menstrual period but a CRL of only 18.0 cm. Neither hip was dislocated but the right hip abnormality was detected after removal of the hip musculature. Tissue autolysis effects are evident.

a) The macroscopically normal left (L) socket. (X 6)

b) On the anterior rim of the right (R) socket a capsule sulcus and the labrum were absent. A thin film of fibroareolar tissue covered the anterior socket articular surface and articular cartilage was not present lining the transverse acetabular ligament. This hip seated well in flexion and abduction but the head dislocated immediately with extension and adduction when the capsule was removed. Except for the dimensions of the ligament of the head of femur and the neck-shaft angle, all measurements were less than the mean minus one SD for the 18 week normal group and were less than the mean minus three SD's for the 24 week normal group. (X 6)

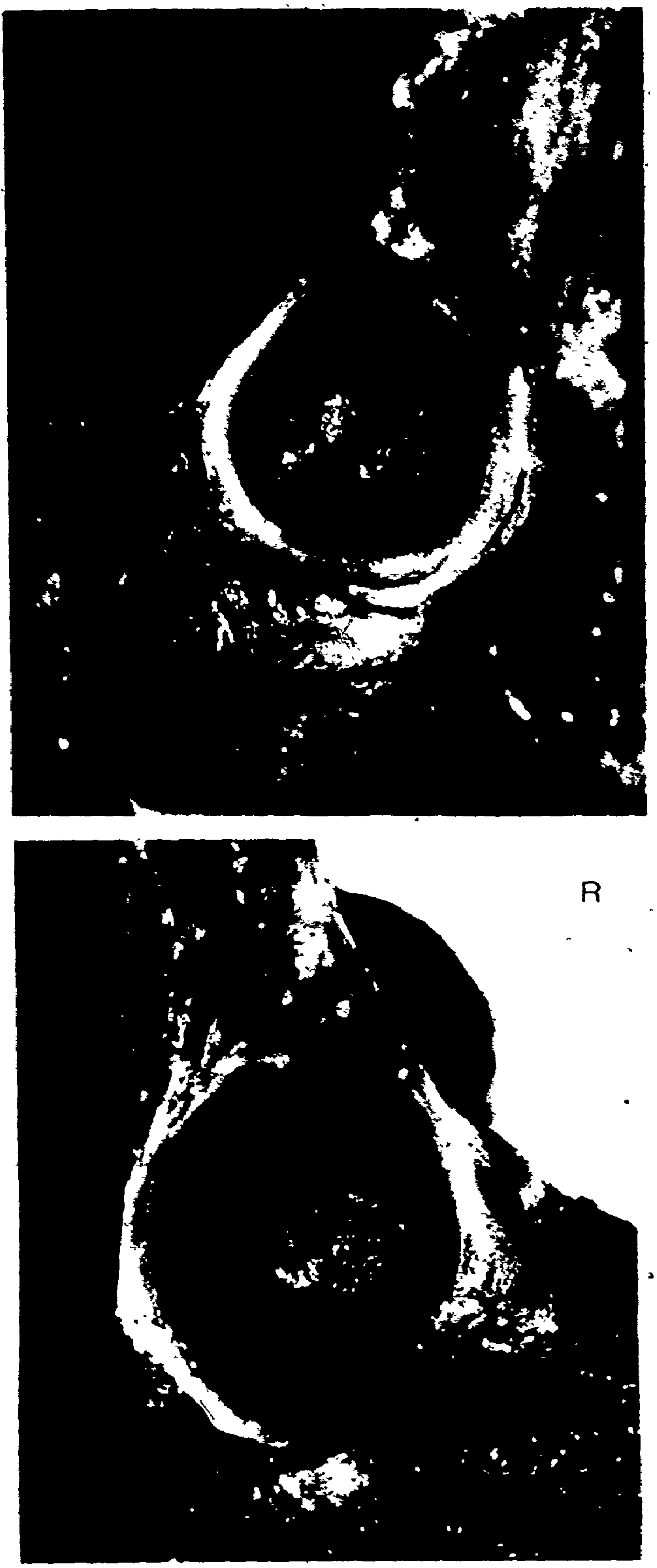

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Table 37

Abnormal cases #115 and #25 with the mean values and standard deviations for the normal 18 week group, sexes combined. R = right, L = left, LHF = ligament of head of femur, in mm, angles in degrees.

		Normals		Abnormal Cases	
Variable	Side	Mean	SD	#115	#25
Crown-rump length (cm)		17.68	.83	18.00	16.50
LHF width	R	3.08	.63	2.43	2.01*
	L	2.99	.52	3.16	2.79
LHF length	R	5.14	1.02	5.00	4.71
	L	5.13	1.12	4.22	4.75
Femoral head diameter	R	8.01	.72	6.23*	7.14*
	L	7.95	.75	6.39*	7.25
Acetabular diameter	R	8.00	.63	6.06*	7.08*
	L	7.93	.60	6.31*	6.61*
Acetabular depth	R	3.60	.37	2.20*	2.83*
	L	3.61	.47	2.13*	3.00*
Neck-shaft angle	R	124.16	2.54	123.00	124.30
	L	123.16	1.75	122.30	122.60
Torsion angle	R	16.25	8.90	-9.00*	5.33*
	L	19.13	9.37	-4.30*	6.66*
Acetabular index %	R	45.06	4.41	36.31*	40.00*
	L	45.54	5.60	33.82*	45.39

(n = 19)

* < $\bar{x}$ - one SD

the 24-week group, depth, diameter and torsion values are less than the mean minus three SD's.

Case #25

Specimen #25 was a male product of a saline induced abortion. The CRL was 16.5 cm, the birth weight 350 g and the age of this fetus was estimated at 18 weeks. The legs were crossed, left over right, and were in full flexion. No laxity was detected prior to division of the capsule. Bilaterally the acetabular rims revealed slight flattening located in the midportion of the posterior rim on the right, and in the middle and superior portion of the left rim (Fig. 63). This flattening only involved the labrum and the length of the flattened regions were greater than the LHF width.

In Table 37 measurement data are compared with that for the 18 week normal group. The left depth is less than the mean minus two SD's, while the acetabular indices reveal a reasonable relationship between depth and diameter.

Case #87

A female product of a saline induced abortion with a CRL of 9.7 cm and a birth weight of 60.58 g, this fetus showed Grade 2 maceration. The legs were uncrossed, in full flexion with bilateral internal rotation of the hips. No hip laxity was detected. Both heads of femur were well seated within the acetabula and neither showed abnormal range of motion after capsule ablation with the LHF intact. Abnormality was observed only in the right socket (Fig. 21b) which was distorted. The posterior half was semicircular but the anterior half was ellipsoid. Compared with the left, the right socket was more laterally directed. In Table 38 the

Figure 63

The left hip of a normal fetus, #25.

A male, obtained from a saline induced abortion, with a CRL of 16.5 cm, 18 weeks. The head was centrally placed in the socket but flattening is evident on the superior and middle portions of the posterior rim. Measurements of the left hip support the observation of a shallow socket. S = superior, PU = pubis, (X 12).

Table 38

Abnormal case #87 with the mean values and standard deviations for the normal 12 week group, sexes combined. R = right; L = left, LHF = ligament of head of femur, in mm, angles in degrees.

Variable	Side	Normals Mean	SD	#87
Crown-rump length (cm)		10.52	1.05	9.70
LHF width	R	1.34	.69	.99
	L	1.44	.77	.77
LHF length	R	2.20	.83	3.56§
	L	2.07	.74	3.29
Femoral head diameter	R	4.02	.73	3.19*
	L	4.00	.74	1.62
Acetabular diameter	R	4.04	.71	3.69
	L	4.10	.29	3.48*
Acetabular depth	R	1.90	.31	1.50
	L	1.84	.29	1.57
Neck-shaft angle	R	125.14	5.64	123.30
	L	126.05	3.64	124.00
Torsion angle	R	.65	4.88	3.33
	L	-.69	6.76	1.66
Acetabular index %	R	47.30	5.40	40.62*
	L	45.33	5.90	45.00
		(n = 16)		

* < x - one SD

§ > x + one SD

measurement data are compared with that for the normal 12 week group. There was disparity between the right FH diameter and the acetabular diameter (3.19, 3.69 mm). Bilaterally the acetabular diameter slightly exceeded the FH diameter. The right LHF length was twice that of the left ligament and more than the mean plus one SD for the 12 week group. The right acetabular index was less than the left (40.62, 45.00). Only the right LHF length exceeded the 12 week group values.

The right head of femur was compressed in the inferomedial half, somewhat similar in shape to the acetabulum.

Cases with Congenital Abnormalities

These cases were not included in the growth study and are distinct from the abnormal cases. As previously stated, measurement data for these cases and that for each case's appropriate normal age group has been presented in tables with the abnormal cases, for convenience only. Table 39 presents the age, CRL, congenital abnormality type and hip status for these six cases. Case #159 is included here. This infant with no congenital abnormality lived for 35 days and was, therefore, excluded from the growth study.

Case #145

Case #145 was a female who died on the fifth postnatal day. The cause of death was a common atrio-ventricular canal. No joint laxity was evident nor was any abnormal morphology detected. For all measurements (see Table 35) the left hip was slightly smaller than the right hip. Bilaterally the FH diameter exceeded the acetabular diameter. The left acetabular vertical diameter exceeded the transverse diameter by 2.48 mm.

Table 39

Congenital abnormalities cases by sex, age, congenital abnormality type and hip status. ND = no data, GA = gestation age (weeks), M = male, F = female, N = normal, AB = abnormal

Case Number	Sex	GA	CRL cm	Age weeks	Congenital Abnormality	Hip Status
145	F	term	34.0	36	heart anomaly	N (2)
096	F	term	34.0	36	heart anomaly	N (2)
141	F	ND	28.8*	30	polycystic kidneys	AB (2)
094	F	term	28.0	30	multiple abnormalities	AB (2)
030	M	37	29.4	30	cyclopia	AB (2)
158	F	ND	20.0	?24	anencephaly	N (2)
159	M	28	25.0	28	none (lived 35 days)	N (2)

* calculated from crown-heel length

Case #96

This case was a liveborn female infant from a normal delivery with a vertex presentation who died on the second postnatal day. The cause of death was hypoplasia of the left side of the heart. The estimated gestational age by the LMP was term, but the CRL was 34 cm and the birth weight 2478 g. This infant was compared with the 34 week group (Table 35). The legs were uncrossed, the hips in 90° of flexion, the knee joints in full flexion and the ankles were at 90°. Both hips were grossly normal, although a sulcus was not present on the right posterior rim and the left labrum showed uneven thickness with a dip in the anterosuperior quadrant (Fig. 64). Some side asymmetry was present, the left measurements being generally smaller than the right.

Figure 64

The left hip in case #96 with a congenital heart anomaly. This female infant had a CRL of 34 cm. A dip is evident in the anterosuperior quadrant of the left socket (side view). Note the roughness of the labrum in the region of the dip (arrow). IS = ischium, IL = ilium, P = posterior, (X 6).

Bilaterally the values for depth were within one SD of term group values but both diameters were one SD less than the mean for the term group.

Case #141

A female stillbirth, this infant with polycystic kidneys lacked family data or data on estimated gestational age. CRL as calculated from crown-heel length (43 cm) was 28.88 cm (Scammon and Calkins 1929), the birth weight was 2,020 g and estimation of age by CRL placed this infant in the 30 week group. Only the hip joints were received. Both hips were fixed in a flexed and adducted position. Little subluxation of either femoral head occurred when the capsule was removed due to a broad band-like LHF which bilaterally had a high attachment to the deficient midportion of the anterior socket rim. While the femoral heads were located within the sockets, bilateral abnormality, more marked on the left, was present. Bilaterally the anterior horn cartilage was missing (Fig. 65) so that, particularly on the left, there was no real anterior socket wall or labrum. Both posterior rims were rounded and the left showed marked flattening indicating that the femoral head had rested on this portion. Sulci were absent anteriorly and deficient posteriorly. The left socket was extremely shallow and removal of the femoral head revealed a socket filled with abundant gelatinous pulvinar material which completely covered the cartilage surface. Bilaterally the femoral heads were a conical shape with an almost nonexistent neck (Fig. 65a). Measurement data are given in Table 40. The FH diameters exceeded the acetabular diameters and the left acetabular index was the lowest observed in the entire sample.

Figure 65: Abnormal hips in a female stillbirth with polycystic kidneys, #141. [CRL 28.8 cm]

a) Sockets and proximal ends of femora shown in actual size. Note the ledge on the inferior aspect of the heads (arrows), more prominent on the left (L), R = right.

b) The posterior rim and wall of the right socket has a normal appearance but on the anterior side the tissue of the actabular fossa extended high on the anterior wall and no anterior cartilage horn is evident. A dip is present in the anterosuperior quadrant. (X 2)

c) The left head of femur rested on the flattened posterior rim and was subluxated posteroinferiorly. The "true" socket is visible with no anterior cartilage horn and a grossly abnormal anterior wall with no labrum. S = superior. (X 2.5)

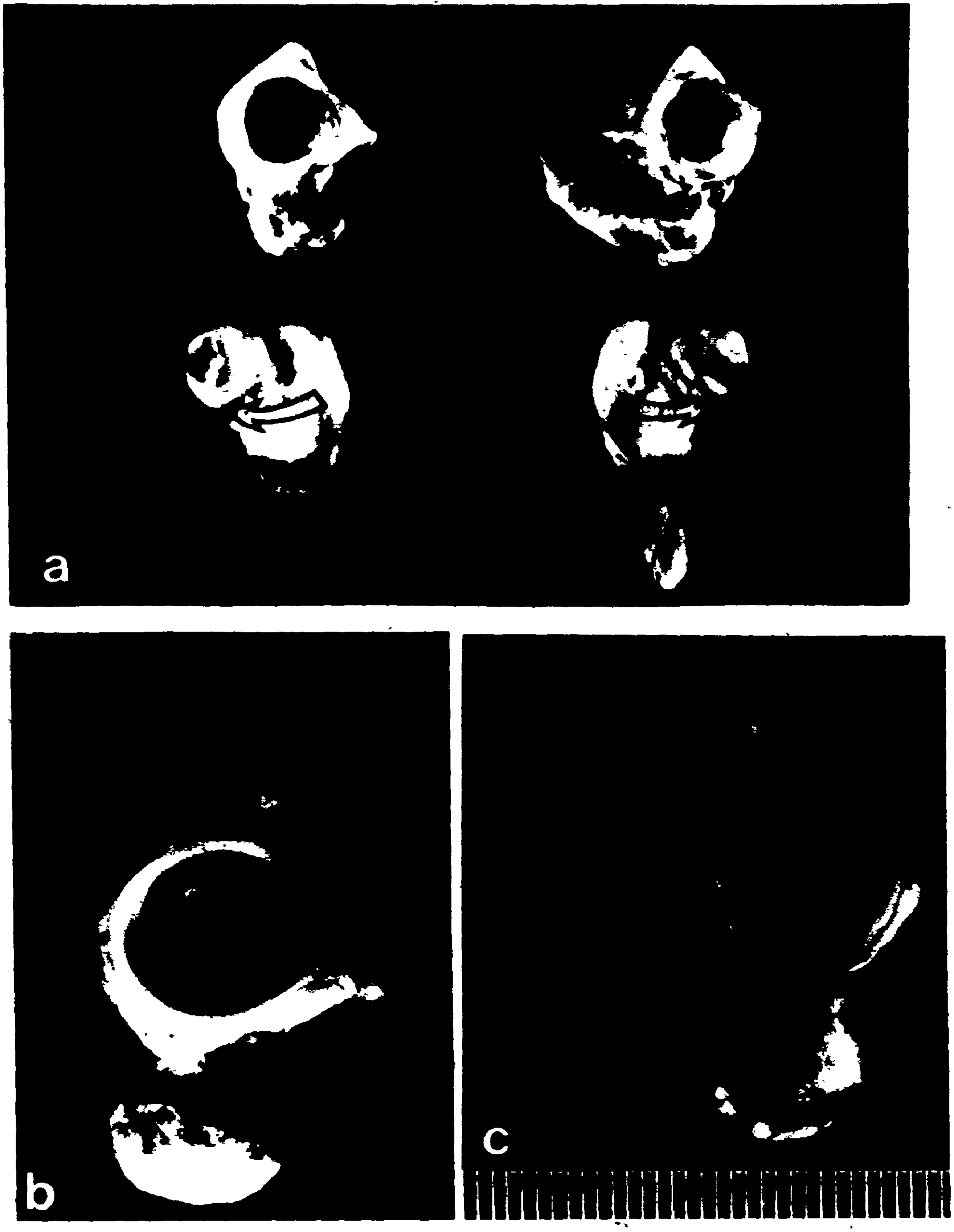

a
b
c

Table 40

Congenital abnormalities cases #141, #94, and #30 with the mean values and standard deviations for the normal 30 week group, sexes combined. ND = no data, R = right, L =left, LHF = ligament of the head of femur, in mm, angles in degrees.

		Normals				
Variable	Side	Mean	SD	#141	#94	#30
Crown-rump length (cm)		28.32	.38	28.80	28.00	29.40
LHF width	R	4.99	1.22	6.83	4.81	4.37
	L	5.25	1.40	6.31	5.34	4.28
LHF length	R	9.46	1.22	10.19	9.02	10.82§
	L	8.84	1.59	9.54	7.69	9.43
Femoral head diameter	R	12.43	1.27	12.71	14.02§	14.52
	L	12.37	1.59	11.88	12.71	14.41§
Acetabular diameter	R	12.59	1.40	11.55	14.46	13.80
	L	12.59	1.10	9.90	11.27*	14.41§
Acetabular depth	R	4.95	.65	4.30	6.30§	5.20
	L	5.01	.63	1.60*	4.80	5.60
Neck-shaft angle	R	124.16	3.90	125.00	125.00	124.60
	L	122.77	1.73	123.60	116.00*	123.00
Torsion angle	R	23.04†	10.40	ND	-8.00*	32.66
	L	21.00†	5.28	ND	-32.00*	25.66
Acetabular index %	R	39.35	2.84	37.23	43.55§	37.67
	L	39.86	4.75	16.16*	42.57	38.86

n = 7

†n = 5

#30 cyclopia, #94 multiple abnormalities, #141 polycystic kidneys, all three cases with bilateral abnormal hip joints

* < x̄ - 1 SD

§ > x̄ + 1 SD

Case #94

This female infant of Italian parents and a twin birth died on the fifth postnatal day. This infant had multiple congenital abnormalities (bilateral equinovarus, meningocele, omphalocele, scoliosis, imperforate anus, six digits on the left hand and externally rotated femora). The CRL was 28 cm and the birth weight 2857.05 g. This infant was placed in the 30 week group though, by birth weight, 34 to 36 weeks may be more appropriate.

No abnormal laxity was noted prior to or following ablation of the musculature, and despite a grossly abnormal left hip the left femoral head was extremely difficult to dislocate. Tissues of this fetus were matted and individual structures were difficult to identify or separate cleanly. Both hips remained fixed in flexion until the tight capsule was removed.

The right femoral head dislocated immediately with division of the capsule due to poor socket head coverage. The LHF permitted dislocation of the head in all directions except posteriorly. The neck of femur rested on the anteroinferior portion of the labrum producing compression and slight overhang of the labrum at this site (Fig. 66a,d). The FH diameter was 0.3 mm smaller than the acetabular diameter (Table 40).

The left socket was distorted and aspherical with virtual absence of the anterior socket wall (Fig. 66a and c). A capsular sulcus was completely absent and the transverse acetabular ligament lacked an articular cartilage lining. The acetabular notch was directed anteromedially instead of the normal inferoanteromedial direction. The left

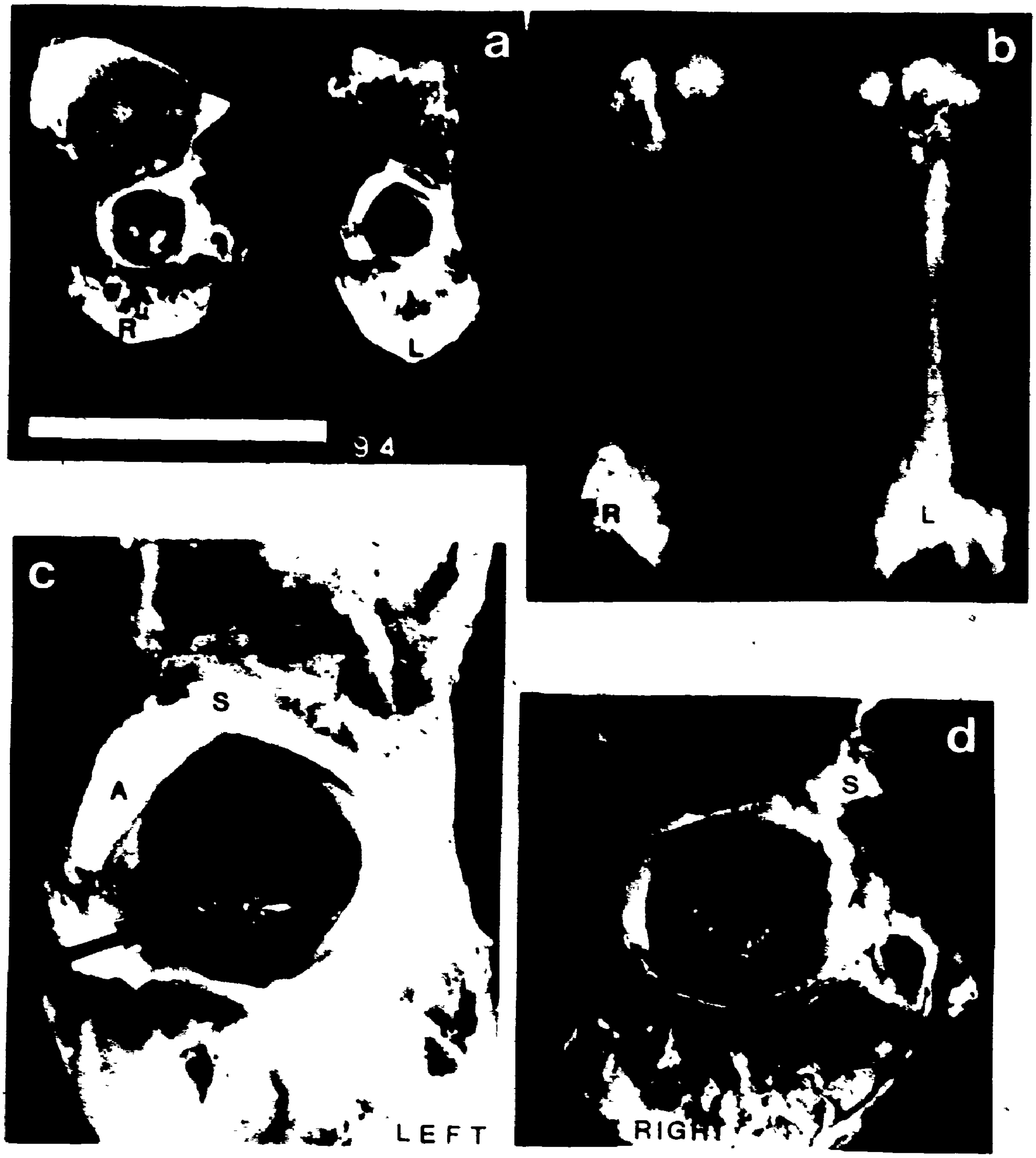
Figure 66: Abnormal hip morphology in case #94 with multiple abnormalities. Female, CRL 28 cm, A = anterior, S = superior, R = right, L= left.

a) The greater abnormality of the left socket is evident (actual size).

b) Both femora showed retroversion, or negative torsion angles. The right torsion angle was -8°, the left -32°. Note the lack of a true neck and the encroachment of retinacula on the inferomedial aspect of the articular cartilage of the heads.

c) There is almost no anterior wall in this left socket, the anterior rim is deficient, the posterosuperior rim is flattened (arrow) and the posterior socket wall is poorly developed. No capsule sulcus was present on this socket.

d) Flattening of the labrum is present anteroinferiorly on the right socket and the anterior socket wall is steeper and narrower than normal.


a
R
L
94
b
R
L
c
S
A
LEFT
d
S
RIGHT

femoral head was congruent in shape with the acetabulum (Fig. 66b) and both femora were retroverted, the left with a value of -32°. The left LHF was 1.3 mm shorter than the right. In addition the left neck-shaft angle was low, and despite the variability of this angle in the entire sample (see Fig. 34a), this value was the smallest observed, less than the mean minus one SD for any age group.

Case #30

Case #30 was a male stillborn cyclops with otherwise normal external morphology. Radiographs of the lower limbs revealed no evidence of fractures or bone disease. Stanisavljevic (1964) reported one case with associated osteogenesis imperfecta and multiple fractures. The lower limbs were in the normal fetal position, but the left tibia was medially rotated and the pelvis appeared slightly twisted. Dissection revealed an asymmetrical pelvis which was compressed on the right side (Fig. 67). The hip musculature was grossly normal and no laxity was detected prior to ablation of the capsule. With the capsule divided but the LHF intact, both femoral heads appeared to be only 25% within the sockets and dislocation was possible in all directions except posteriorly. Both LHFs were long and narrow and the right hip range was greater than the left due to a longer LHF on the right (Table 40). The labra had bilateral rounded rims and on the right side the pulvinar extended in all directions from the acetabular fossa to cover the articular cartilage surface (Fig. 67). This fetus was given a Grade 2 for maceration on the external appearance but on dissection the cartilage was a purplish-blue color. Both acetabula collapsed and became ellipsoid

Figure 67

Abnormal pelvic morphology in a female cyclops, #30. [CRL 29.4 cm]

a) Superior view of the asymmetrical pelvis, R = right, L = left.

b) Frontal view of the pelvis showing variation in the orientation of the acetabula, the right faces more laterally.

c) Frontal view of the right socket in which pulvinar extended outwards from the acetabular fossa to cover a small area of the articular cartilage. Usually this is not seen. P = posterior, S = superior, (X 3.3).


a
030
R
L
b
030
c
S
P
R030

during stage three of paraffin wax infiltration. The sections could not be used.

The LHF width was the only variable less than the mean for the 30 week group, the remainder exceeded the mean, some more than one SD.

Case #158

A female anencephalic stillbirth for whom no data were located; the CRL was 20 cm and the birth weight 732 g. This CRL would place this fetus in the 20 week group but this is obviously a misclassification in the case of anencephaly and in comparison of the values for the hip joint variables (Table 36). Scammon and Calkins (1929, p.48) gave a conversion of CRL to crown-heel length and stated that the height of the cranial part of the head (external auditory meatus to vertex) forms approximately 1/5 of the total body length. These calculations place this fetus in the 24 week group but values for diameters and depth still exceed the mean plus one SD for this group. No abnormalities were detected in dissection of the hip joints.

Chapter 4

DISCUSSION

No previous studies were located which gave quantitative data for the hip joint, in a sample of aborted, stillborn fetuses or perinatal deaths in infants, at regular intervals of age or crown-rump length (CRL) throughout the fetal period. Definition of abnormal development, as seen in congenital hip disease (CHD) or congenital dislocation of the hip (CDH), (congenital hip pathology), is dependent on a knowledge of the limits of normal growth and development of the hip joint. Normal joint function is dependent on normal growth and development in all of its parts. Studies limited to one or two dimensions of the joint (for example, Felts 1954, Ralis and McKibbin 1973) can suggest trends of development but cannot fully describe the manner of growth within the total complex of the hip joint. Dunn (1969) considers a rational definition of CDH to be "an anomaly of the hip joint, present at birth, in which the head of femur is, or may be partially or completely dislocated from the acetabulum". While the abnormality of the joint surfaces may be minimal at birth (Salter 1968), in the established case of CHD the following characteristics are frequently observed: a small, often aspherical head of femur with abnormal angles, a shallow, often aspherical socket, flattened areas of the socket rim, the labrum, and an excessively long ligament of the head of femur (LHF). These are measurable characteristics, at least on dead fetuses and infants. A knowledge of the pattern of growth over time, for a number of dimensions in the human fetal hip joint from the same unit, will contribute to our understanding of joint development and assist in the definition of abnormal development. A contribution to our understanding of congenital hip disease may also be expected.

None of the reported studies on hip dimensions of human fetuses have separated the data by sex and/or side. However, sex differences in the morphology of the acetabulum have been published (Le Damany 1914, Pearson and Bell 1919, Getz 1955, Caffey _et al_. 1956, Dega 1961, Mellbin 1962, McKibbin 1970). MacKenzie (1972) stated that the hip joint developed more slowly in males than females. In measurements of the angle of the acetabular roof on radiographs of infants and children, higher angles on the left side have been observed. This was more common in females (Caffey _et al_. 1956, Ryder and Mellbin 1966, Tonnis 1976). Differences in the commencement of ossification of long bones between the sexes are reported (Gardner and Gray 1950).

In congenital hip disease, a male to female ratio of 0.15 is reported (Carter 1969); that is, there are 6.5 females affected to every one male. The female preponderance in 29 studies ranged between 2.5 females to 20 females to every male affected (Walker 1973). On the average the left hip is involved four times that of the right (Lowrie 1970). A marked association between females and the left side is reported (MacKenzie 1972).

The data presented here provide no evidence that a significant difference exists in the growth and development, or in the growth rates, of the hip dimensions studied, either between males and females, or between the right and left sides. In multivariate analysis, of sex and side, differences were not significant. Depth, in univariate tests, with the effect of age removed, was shown to have the least nonsignificant values for the effect of sex, and for the effect of side. There is a suggestion of a difference between the sexes in the femoral angles. In univariate tests for the effect of sex with the effect of age removed, torsion was significant at $p = 0.01$, and in testing for the effect of side, only the angles approached significance. Additionally, there is a suggestion of an effect of sex for LHF width and length. In the pooled sample means a general trend for males to be larger than females was noted, regardless of side. This nonsignificant difference is small (0.5 mm or 2°). Partial F probabilities for the inclusion of sex in regression models were greater than 0.1 except for torsion bilaterally, the left neck-shaft angle and the right LHF width ($p < .05$). Minor differences only were predicted between the sexes, with the values for females larger than those for males, for both diameters, LHF width and length (see Figs. 35, 36). Only for the left neck-shaft angle were males predicted to have values consistently larger than females.

Sex was initially included in the regression models, despite the lack of significance shown in multivariate tests, because it is an easily determined characteristic of neonates. It may be considered desirable to detect even minor differences in size. Since the predicted differences between males and females were minimal and none of the partial F probabilities for entry of sex into the model exceeded the "four times" level (Draper and Smith 1966), sex was eliminated from the final model. It is possible that the sample size was too small to detect significant differences between males and females in growth of the different hip dimensions. There are several instances in these data where, at each two-weekly age group, only one of the sexes is represented (see Table 11). Of interest are the lack of fit terms and modified coefficients of determination (Q_m^2) for the different regression models when sex was included in the model. A difference between the sides is indicated by lack of fit terms which were more significant on the left for depth, femoral head (FH) diameter, torsion, neck-shaft angle and LHF width (see Table 25). Noticeable differences are present in the ability of the model to explain the explainable variation for femoral angles. The Q_m^2 values are low for the right neck-shaft angle and left torsion, regardless of the model fitted, indicating that the models fitted are not adequate. Change in these variables with time is affected by factors not included in the models fitted.

When sex was deleted from the regression model fitted, minor differences between the sides remain (see Figs. 37, 38) and are most noticeable for the femoral angles and LHF width. Examination of rate of growth curves for the fitted regression model with a quadratic on age (see Fig. 39) shows that right acetabular depth, LHF width and acetabular diameter are predicted to change at a marginally slower rate than these same variables on the left side. The right LHF length and femoral head diameter are predicted to be increasing at a marginally faster rate than the left LHF length and femoral head diameter.

Only for the LHF indices are side differences apparent. The right shows a trend towards a more linear type of ligament than on the left side (see Table 31).

No differences between the sexes or between the sides were noted in a random sample (n = 58 pairs) of femoral heads tested for roundness. Again there is the suggestion that the left side may be more variable.

To detect the presence or absence of differences between males and females, both sexes should be present in adequate numbers, at each two-weekly age interval, throughout the period examined. The sample size at each two-weekly period is small after 26 weeks, and unequal representation of the sexes is present in these data. It is possible that failure to detect real differences between the sexes is due to inadequacy of the sample studied. There is a suggestion of possible side differences, particularly for the femoral angles and the ligament of the head of femur.

There is a significant effect between sides for each variable, with the exception of the neck-shaft angle (see Table 15). Therefore, in a growth study, each side should not be regarded as a single isolated unit, for instance, 140 fetuses giving 280 femora.

The results of analysis for possible differences between the sexes or between the sides, reported for the first time for the human fetal hip joint, may give support to Dunn's (1969, 1976c) explanation for the greater female and left side preponderance in CDH. This author has observed that the high female preponderance in CDH exists when CDH is the only deformity present and the birth presentation is normal. He considers that the higher incidence in females is due to a greater influence of maternal sex hormones in females producing hormonal pelvic laxity. Dunn has shown the greater left hip involvement to be significantly related to the tendency for fetuses to lie with their backs toward the mother's left side ($p < .001$). He observed the leg most posteriorly positioned, the left, to be more frequently dislocated regardless of the birth presentation ($p < .01$).

Le Damany (1914), from measurements on plaster of paris casts of acetabula, claimed that the acetabulum became shallower with increase in fetal age. This alteration in shape was first described by Sainton (1892-3) and was recently substantiated by Ralis and McKibbin (1973) from direct measurements of acetabula. It means a reduction in femoral head coverage and a less stable joint at birth than at any other period of fetal life. However, the opinion, based on naked eye impressions (Gardner and Gray 1950, Dunn 1969) or the indirect evidence of arthrography (Laurenson 1965), that there is little change in the relative acetabular depth or general morphology of the joint in the fetal period has received acceptance in orthopaedic literature (Hughes 1974). These previous studies have based their opinions on small samples, with often only one fetus at different age points. To date no one has calculated growth rates for depth, acetabular diameter and femoral head diameter from the same unit with other dimensions of the hip joint. The findings of this study give strong support to the theory that the socket is shallower at term than at any other stage of fetal life. While femoral head and acetabular diameter increase 4.4 fold between 12 and 42 weeks (mean ($\bar{x}$) CRL 10.5 to 39.3 cm), depth increases in size only 3.8 fold over the same period. Depth showed the smallest increase of any of the hip variables measured, the femoral angles excluded. The observed velocity of growth for these three dimensions was not constant through time and a significant lack of fit ($p < .01$) was obtained when a simple linear regression model was fitted to these data (see Tables 25, 28). All three dimensions increase approximately 2.1 fold from 12 to 20 weeks ($\bar{x}$ CRL 10.5 to 19.9 cm). The rate between 20 and 30 weeks ($\bar{x}$ CRL 19.9 to 28.3 cm) decreased to approximately 1.4 fold for both diameters but was slower for depth (~1.2 fold). In the final fetal period 30 to 42 weeks ($\bar{x}$ CRL 28.3 to 39.3 cm) the velocity of growth for both diameters remained almost constant at 1.4 fold with acetabular diameter being minimally slower than femoral head diameter, while depth showed an increase to 1.4 fold. The observed greater reduction in velocity of growth for depth between 20 and 30 weeks may be an artifact of the data, primarily due to incorrect estimation in age of the fetuses. It is reasonable to expect that this, if present, would affect dimensions of the same complex equally. Furthermore, high coefficients of determination are demonstrated between depth and the diameters ($R^2 \geq .88$, see Table 14). The correlations between these variables are only slightly reduced when the effect of age is eliminated (see Table 16). Figure 39 shows predicted rate of growth curves from the regression model which included a polynomial on age. While there are similarities in the predicted growth rates for depth and the diameters by side, differences in the rate of change between sides are only distinctive for depth. In depth, the two sides are shown to have different velocities of growth from an early age.

Nonsignificant lack of fit terms ($p > .05$) were obtained by fitting a model with two polynomials on age (see Tables 25, 28). The improvement in the lack of fit and in the amount of explainable variation expressed by the Q_m^2 may be interpreted as adjustment for expressing growth of the femoral head and the acetabulum, three-dimensional structures with length, breadth and mass or surface, solely by one linear dimension. It can be expected that growth will proceed in all dimensions over time, and that when present, differences in growth rates between, say, length and breadth will produce alteration in the overall shape of the socket over time.

A measure of change in shape is gained from calculation of the acetabular index (depth x 100/diameter). Mean indices in this study, with a large sample at regular intervals throughout the fetal period, never exceeded 50% (see Table 30). The results confirm the findings of Le Damany (1904) and Ralis and McKibbin (1973) on much smaller samples. The trend for a decrease in the mean indices or the spread of individual points between 12 and 22 weeks is not as distinct (see Figs. 40, 41) as in the plots of individual values shown by Ralis and McKibbin. The latter authors observed a maximum index value of 70% whereas the maximum in these data was less than 60%. The difference lies in the size of fetuses since Ralis and McKibbin report, for 11 1/2 weeks, a CRL of 5.5 cm, whereas the mean CRL for the 12-week group in this study is 10.5 cm with the minimum CRL in the study being 8.7 cm. However, their observation of higher acetabular indices in younger fetuses may indicate that a substantial reduction occurs very early in fetal life, soon after opening of the joint cavity. High indices indicate a deep cavity which, it is presumed, would almost totally enclose the head. The socket would then be greater than a hemisphere than when the ratio falls below 50%. Indices at term around 35% indicate the socket more closely resembles one-third of a sphere. The femoral head index (acetabular depth x 100/FH diameter) simply reflects that the femoral head diameter is marginally less than the acetabular diameter since mean values for this index are slightly higher than those for the acetabular index, but all are again less than 50% (see Table 30).

The diameter index considers the relationship between the acetabular and femoral head diameters. It is reiterated that acetabular diameter herein refers to the transverse diameter of the two-dimensional acetabular rim or mouth when orientated in the anatomical position, and not to the three-dimensional spherical surface of the socket. Should the femoral head diameter exceed the acetabular diameter it is reasonable to assume, given the acetabular indices, that soft tissue structures around the joint must play an important part in joint stability, especially at term. That mean diameter indices are less than 100%, except for the left hip at 24 weeks (see Table 30), indicates that the maximum diameter could be contained within the socket margins. When the diameter indices are less than 100% the acetabular diameter is greater than the femoral head diameter.

Joint surfaces are considered to achieve a high degree of fit. The surfaces are theorized to be separated by a film of fluid with a thickness in the order of hundredths of microns, perhaps one-tenth of the diameter of a free hyaluronic acid molecule (Tanner 1966, Fein 1967, Maroudas 1969, Swanson 1973). Differences reported herein between the acetabular and femoral head diameters as measured are of a higher order (< 0.1 mm) and imply a larger gap between the joint surfaces than these theories suggest exist from <u>in vitro</u> experiments. No previous study was located that gave both acetabular and femoral head diameters. A possible explanation for the acetabular diameter being larger than the femoral head diameter may be that the concave socket and the solid femoral head are affected differently by tissue shrinkage which accompanies fixation. The less rigid limbs of the socket may retract away from the head such that the mouth of the socket is slightly wider than in vivo, while the head, affected evenly over its circumference, becomes marginally smaller. While this hypothesis, if true, would also imply a tendency to exaggerate shallowness of the socket, as expressed by the acetabular index, it does not remove the trend revealed for the socket to become shallower with increasing age.

Naked eye impressions during dissection of these joints amply demonstrated that the maximum diameter of the head was not contained within the limits of the socket. In third trimester fetuses division of the capsule produced immediate subluxation or dislocation of the head. In younger fetuses after division of the capsule a certain force may be required to distract the head seated within the socket. Statistical analysis permits quantitative statements of these observations. Minimum-maximum values of the diameter index were 88% to 118% where 100% indicates the two diameters are equal. Values greater than 100%, which indicate that the femoral head diameter exceeds the acetabular diameter, were observed in all age groups except age group 34 (n = 3). A higher percentage of diameter indices exceeded 100% bilaterally in fetuses aged 30 weeks and over.

These data give justification to the claim that soft tissue structures must play a role in the stability of the fetal hip joint. In fetuses, this joint does not appear to be the secure ball and socket joint seen in the adult. Capsular laxity at term would therefore predispose to joint instability, the "dislocatable hip" of neonates. This is thought to be due to the effects of maternal hormones which have a greater influence in female fetuses (Andren and Borglin 1961a, b, Dunn 1976c).

The acetabular index is the preferred measure of socket shallowness which enables inferences about the coverage of the head by the socket. The diameter index does not distinguish between "good" and "poor" head coverage (Fig. 68). In both instances, the acetabular diameter, measured at the rim, is less than the femoral head diameter. At the end of the first trimester the head is well enclosed by the limbs of the socket. The acetabulum may be more than a hemisphere and while the diameter of the head is contained within the socket the acetabular diameter measured at the rim is less than the femoral head diameter. In third trimester fetuses the socket is less than a hemisphere. While the femoral head diameter is not contained within the limbs of the socket, the acetabular diameter measured at the rim is less than the femoral head diameter and the diameter index is greater than 100 %. In this case the head coverage is "poor."

Of interest are the predicted growth rates for femoral head and acetabular diameter from the regression model with a quadratic on age. At term, femoral head diameter is predicted to be growing at a marginally higher rate than acetabular diameter. In the left hip this difference in growth rates is predicted to commence earlier than on the right side,

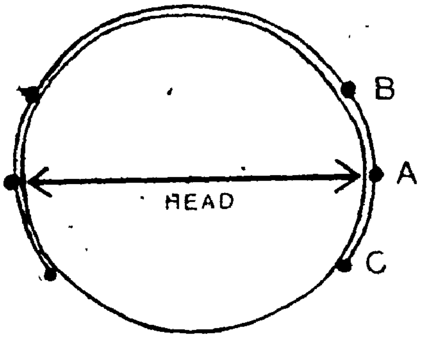


Figure 68: Theoretical head coverage by the socket

Dots indicate the extent to which the socket covers the head. At A the socket is hemispherical in shape, the acetabular diameter is approximately equal to the femoral head diameter (FH).

At B, which is seen in third trimester fetuses, there is poor head coverage, the acetabular diameter is less than the FH diameter.

At C, which is seen in first trimester fetuses, there is "good" head coverage, the acetabular diameter is less than the FH diameter.

If at C and B the acetabular diameter = 8.4 mm, and the FH diameter = 8.6 mm. then FH x 100/acetabular diameter = 102.4% and fails to distinguish between differences in socket shape.

at 28 weeks. Differences in predicted growth rates, while small, appear bilaterally between the diameters as early as 20 weeks. However, they are more obvious and consistent on the left side. When crown-rump lengths are compared, values for acetabular depth reported herein are similar to those reported by Le Damany (1904) and Watanabe (1974). Unfortunately, Ralis and McKibbin did not report specific depth measurements. Watanabe's maximum depth of 4.1 mm, for a stated maximum age of

24 weeks and maximum study CRL of 30 cm, is equivalent to that found in this study for 24 week fetuses but with a mean CRL of 23.8 cm. The value of 4.1 mm is less than the mean minus one standard deviation for the study mean CRL of 30.0 cm. Laurenson (1965), while recognizing that his measurements from arthrograms were only approximate, considered his data (n = 14) provided evidence that the acetabulum continued to cover the femoral head from 14 weeks to term. When Laurenson's values were compared with the present data his measurements showed a distinct tendency to be from one to two mm greater, at any age. This may reflect inaccuracies of measurements made from arthrograms, and the possible inclusion in the depth measurement of the acetabular fossa with which the head does not make contact. His conclusions reflect the disadvantages of interpreting isolated segments of data. As previously explained, measurement of femoral head height and acetabular depth alone do not provide an accurate indication of socket coverage. It is the relationship between depth and acetabular diameter which will largely determine the extent to which the head is covered by the socket, not depth alone. If the femoral head diameter exceeds the maximum acetabular diameter and not just the diameter of the rim measured herein, then, regardless of the available depth, the head cannot be contained securely within the boundaries of the socket. As the sample standard errors for depth are the smallest for the variables reported, depth measurements reported herein may provide a reliable indicator of the population mean.

In attempts to fit a regression model, both depth and femoral head diameter had slightly smaller lack of fit terms, and higher coefficients of determination on the right side. Perhaps this is indicative of less variability in development of the right hip joint. It is of interest that the dimension with the most significant lack of fit terms, and with the lack of fit whose significance is still equal to 0.06 with the addition of a cubic term, was acetabular diameter bilaterally (see Tables 25, 28). Examination of residual plots for these dimensions showed that the variance was not constant over time. Plots of means against the standard deviations for each age group showed, for all three dimensions bilaterally, a tendency to cluster in two groups. Age groups 26 weeks and less had standard deviations less than one and the term group (38 - 42 weeks) consistently exceeded one standard deviation. The greater variability demonstrated for term fetuses may reflect uncertainty in age estimates and possible under- or over-estimation of age based on the CRL. A possible four week error in term estimates of age is known (Böving 1965). It is recognized that length measurements of fetuses, as crown-rump or crown-heel, due to the flexed posture of the fetus, are less reliable than is assessment of weight (Gruenwald 1970). It may simply be, as Thompson (1942) stated, that the spread around a mean increases with time because older fetuses have had a longer period in which to vary.

The largely cartilaginous connective tissue hip anlage is extremely sensitive to outside influences (Kummer 1963). Measurement of roundness, a measure of sphericity in one band of the femoral head contour which corresponded to the maximum diameter of the head, indicated increased "out-of-the-round" in older specimens. In fact, most term femoral heads proved too irregular to be assessed by the Talyrond roundness machine (see Fig. 44D). However, it must be noted that only a random sample of 58 pairs of femoral heads was assessed. It is suspected that due to increased fetal size, and with the uterine wall stretched to its full potential, at term there is decreased fetal mobility. This results in reduced hip joint range with the joint surfaces no longer exposed to uniform molding forces. The common fetal posture is one with the hips flexed and abducted (Crelin 1976). This is associated with varying degrees of internal or external rotation dependent on the total fetal posture, which limb is uppermost, or whether the lower limbs are crossed. The latter factor is considered to severely limit motion (Dunn 1976b). Motion is hypothesized to be restricted to one plane, an oblique plane, with only a small range of flexion-extension movement possible. This may produce a tangential flattening of the femoral head. The maximum diameter of the head would lie at right angles to the dominant axis of motion. Only the portions of the head and socket in contact during this motion would be exposed to continuous molding influence. The acetabulum and the head may become less circular, concomitant with the increasing shallowness of the socket. Examination of Figure 45, which shows the frequency of femoral heads which were circular for at least 30° of the contour examined, may provide support for this hypothesis. The circular portion of the heads lies on an oblique axis which corresponds with the modal direction of the polar trace ellipses (see Fig. 44A). There is a suggestion of reduced roundness on the anteromedial- posterolateral axis on both sides. The left head appears more variable. Younger femoral heads (CRL 8.7 to 12.9 cm) showed the least amount of "out-of-the-round", or alternatively, most closely approached a true circle. The modal angle of inclination of the ellipse form traces was negative (n = 64); that is, the ellipse was inclined backwards.

Blowers, Elson and Korley (1972) are the only other investigators who have reported assessment of femoral head sphericity in fetuses. Their study included seven term fetuses. However, comparison cannot be made with their results as these authors utilized a Talyrond with a reference computer and based their evaluation on the mean least-squares ellipse and the mean least-squares circle. A similar Talyrond was not available for this study. There appear to be no guidelines to indicate the extent to which a head must depart from roundness before it may be stated that true asphericity exists. Due to the magnification, the deviations reported herein are in fact very small (Emmett 1977). The mean values of the minimal radial zone (MRZ) suggest an age trend, varying from 0.02 to > .60 mm (see Table 32). These mean MRZs represent from 0.5 to 3.6% of the smallest and largest femoral head diameters recorded.

Since the Talyrond measurements were not taken on femoral heads immediately after separation of the joint surfaces, it is possible that storage and handling may explain the small number of heads which were circular for at least 30° of the contour examined. Hammond and Charnley (1967) and Blowers <u>et al.</u> (1972) investigated whether or not the effects of formalin preservation may alter the shape of the cartilage. The conclusions were that shape was not significantly altered by formalin preservation. Given the pliability of fetal cartilage these observations may be, in part, artifacts of tissue autolysis associated with the effects of saline infusion for elective abortion, or death <u>in utero</u> at a period prior to delivery. The latter may have a greater effect.

While there are no other reports of measurement of femoral head sphericity, subjectively, many investigators have stated that the fetal head is spherical and does not change in shape through the fetal period (Gardner and Gray 1950, Stansavljevic 1964, Dunn 1969, Watanabe 1974). It must be emphasized that the sphericity assessment reported herein only measures roundness in one contour and no statement can be made concerning the small area of the head distal to this contour. Problems exist in assessment of femoral head sphericity. It seems likely that a photographic method, in at least three planes, as used by Hammond and Charnley (1967) would be preferable. The method must be suitable to permit measurement of all heads, regardless of any irregularity that may be present. Further study is required to identify a more suitable method for fetal femoral heads of all ages; to verify the suggestion of this limited study that with an increase in fetal age the femoral head becomes less round, and to determine if the axis of symmetry is constant in one direction.

Hammond and Charnley suggested that restriction of movement largely to the sagittal plane leads to arthritic changes in the adult femoral head and a slow change towards a "roller shape" of head. This author suggests that limitation of space restricts hip motion in the third trimester of fetal life and this is reflected in ellipsoid-shaped traces and a degree of "out-of-the-round." Since Blowers et al. and Hammond and Charnley found postnatal femoral heads to possess a remarkable degree of sphericity, it is further suggested that in early postnatal life the femoral head returns to a more completely spherical shape under the molding influence of multi-directional motion in distinctly larger range.

With the demonstrated high correlation between femoral head and acetabular diameter it seems reasonable to expect a strong correlation between head shape and socket shape. It may be expected that this would be greatly influenced by the degree to which the head is accurately centred in the socket. However, while no specific measurements were made of the acetabular shape, minimum-maximum differences of 0.1 to 1.32 mm between the transverse, vertical and oblique diameters of the socket were observed (see Fig. 21). Differences in the various diameters of the acetabular rim were measured only when, subjectively, the socket appeared to be nonspherical. It was observed that many joints demonstrated a position of "best fit" or maximum congruency between the head and the socket. This corresponded with the presumed in utero posture, assessed post delivery. It is well established that neonates can be folded up more easily into one position which, it is assumed, is the in utero postural position (Browne 1936, 1955, Chapple and Davidson 1941, Wilkinson 1963, 1966, Dunn 1969, 1976c). In this position there was maximum head coverage and the least amount of intra-joint motion. Given that a position of best fit appears to exist, it may be suggested that a change in the relative positions of the two joint surfaces would cause some separation of the joint surfaces. The increased joint space so produced may then render the joint less stable and more dependent on the efficiency of surrounding soft tissues. That many joints dislocate in early postnatal life is well established. This may be one of the mechanisms involved.

Since Cheynel and Huet's (1952) data suggested differences for hip dimensions between newborn Whites and Blacks, and Trotter and Peterson (1969) showed significant differences in the growth of American

Negroes and Whites, an attempt was made to restrict the growth sample to Whites. While no known Negroid fetuses or infants were included, a racial mixture is suspected since 39 percent of the sample was derived from American sources where a high proportion of the population is Negroid. Cheynel and Huet showed a 3.5 mm difference for depth and 30° for torsion between ten Black fetuses (Senegal) and an unstated number of White term fetuses. However, mean values in this study for males at 42 weeks are similar to Cheynel and Huet's acetabular depth value for Blacks of 7.1 mm. Furthermore, in the present study the acetabular depth value of 3.5 mm reported for term Whites is exceeded by both sexes after 26 weeks ($\bar{x}$ CRL 25.1 cm). The mean value for depth in White newborns given by Cheynel and Huet is low, both by the present study and other published reports (Le Damany 1904, Watanabe 1974). Presence of racial admixture may exist in this study and may have contributed to higher values for depth and lower values for torsion at term. There is a need for a similar study to be conducted on a racially pure Negroid sample to determine whether Cheynel and Huet's findings are real. Distinct anatomical differences present at birth, particularly in the existence of a deeper socket, may be genetically determined. This may explain the marked lower incidence of congenital hip disease in African populations (Hass 1951, Edelstein 1966, Robinson and de Buse 1970, Wynne-Davies 1970). ~~Of~~ related interest is the reported higher incidence of primary protusio acetabuli in African populations, a condition in which the head protrudes inwards through a deep socket (Wynne-Davies 1973).

In analyzing the rate of growth at different time periods it was observed for depth and both diameters, but more so for depth, that a deceleration in rate occurred after 20 weeks ($\bar{x}$ CRL 19.9 cm). Examination of scatterplots for all of the hip variables, with the exception of the femoral angles (see Figs. 26 - 28, 31, 32, and Appendix I), and analysis of the rate of growth curves (see Fig. 39) for the same variables reveals this retardation of growth after 18 to 20 weeks ($\bar{x}$ CRL 17.7 to 19.9 cm). This retardation is earlier than the observed slowing of growth in length seen in the third trimester when the fetus shows an acceleration in overall mass, or weight (Gruenwald 1966, 1970). A possible explanation may lie in the sample composition which is not homogeneous. Fetuses from 12 weeks to between 20 and 24 weeks (the latter interval spans age differences for declaration of a stillbirth in Canada and the USA) are the products of elective and therapeutic abortion. The sample from 20 to 24 weeks onwards is comprised of fetuses which spontaneously aborted, were stillbirths or perinatal deaths within 24 hours of delivery. The cause of death is not always established in the latter group. It may be reasonable to infer that the sample younger than 20 to 24 weeks would then be more representative of normal growth and development than the post 20 to 24 week group. A higher incidence of growth problems, such as those producing small-for-dates or large-for-dates infants, the presence of placental insufficiency, undetected maternal latent diabetes, in addition to congenital malformations and postural deformities are known to occur in stillbirths. It cannot be assumed, therefore, that this group is necessarily representative of normal growth patterns either in terms of total length measurements, birth weight, or in the growth of isolated segments such as the hip joint. To the uncertainty attached to the normalcy of growth in fetuses with gestational age of 20 to 24 weeks and older must be added the known error in age estimates of between three to four weeks, and the error in measurement of crown-rump length. However, growth and development of the human fetal hip joint, as with any fetal growth study, can only be performed on the products of elective or spontaneous abortion, stillbirths and perinatal deaths. It must be recognized that such samples are, therefore, a biased sample of the unknown population and estimated age based on the CRL is a rough approximation (Gardner and Gray 1970). Inclusion criteria are required to limit the degree of error. With recognition of these limitations, the present study can provide a measure of growth trends and range of variability and improve our ability to detect deviation from "normal" patterns of growth and development.

Morville (1936) contended that the acetabulum is flat in all newborns. The author was referring to the osseous roof of the acetabulum at term, and there is general agreement that the osseous portion is flat at birth. Some misinterpretation has arisen due to insufficient attention, this author believes, between the osseous and cartilaginous portions of the socket at term. There is agreement with Badgley's (1949) observation that at birth the limbs (sides) of the socket are cartilaginous. He considered that a greater increase in growth occurred in the posterior portion of the pelvis in proportion to the extent of growth in the pubic portion. It was suggested that this resulted in the forward and downward inclination of the acetabulum. Laurenson (1965), from arthrogram studies, concurred with Morville's observations that the roof was flat, but noted on histological sections that the medial outer perichondral border was more prominent than the lateral (anterior) spur.

This gives support to Badgley's observations of increased rate of growth posteriorly. To investigate the extent of ossification in the socket as a whole, and the possibility that the rate of ossification was different between the anterior and posterior limbs of the socket (lateral and medial), sections from the superior one-quarter way level of the acetabulum were studied (see Fig. 13). Sections from this level were selected since this area corresponds to the region of the socket which forms the roof, providing a limit to upward or supero-oblique motion of the head. This region will receive and transmit forces in the upright position. Sections from 9.1 cm CRL fetuses confirm the previous reports that the cartilaginous anlage is fully formed, resembles in form the adult socket, and appears to be a deep concavity, almost an 180° arc (de Santo and Colonna 1939, Strayer 1943, Gardner and Gray 1950, Andersen 1962, Gardner and O'Rahilly 1972, Watanabe 1974). Laurenson's observations that the posterior side appeared more prominent than the medial in development were confirmed. Ossification in the floor of the socket was first observed in sections from a 21.8 cm CRL fetus. The central zone of endochondral bone had reached the floor of the acetabular fossa, or inner articular margin of the acetabular floor, in a 32.0 cm CRL fetus but had not extended into the limbs of the acetabulum or reached the lateral walls of the socket base (see Fig. 46c). From the first instance in which signs of ossification were detected (hypertrophic cartilage cells) the area of ossification was placed more to the medial or ischial side. The zone of ossification increased in a horizontal manner across the floor of the acetabulum to reach the outer margins of the base of the socket in sections from two term fetuses. Little change was observed in a 48 cm CRL postmature stillborn infant aged 50 weeks. Bone had not extended into the limbs of the socket beyond the lowest level of the socket floor (see Fig. 46d).

The series of methyl salicylate cleared specimens, at intervals from 12 weeks to term, corroborates the detailed observations made by Gardner and Gray (1950) on the relative development of the three primary centres. The iliac primary centre appears first close to the lesser sciatic notch and spreads outwards in a triangular fashion. It seems, therefore, not surprising that ossification in sections from the superior one-quarter way level of the acetabulum was detected initially more posteriorly in the socket.

It is well known that pressure is an important stimulus to bone development (Vaughan 1970). The Hüter-Volkmann law states that pressure just below physiological limits may promote stronger growth in that area whereas excessive pressure or insufficient pressure may produce retardation of growth. There is a gradual restriction of mobility due to increased fetal size and decreased stretch potential of the uterine wall towards term. If, in the common posture of flexion and abduction, forces are directed along the long axis of the femur to the hip joint, this pressure may provide a stimulus for greater development of the socket floor in relation to the socket walls. Alternatively, muscle forces acting on the joint may, by a traction effect, reduce the pressure stimulus for growth. Differential rates of growth within the acetabulum must be responsible for the observation that, with age, the socket becomes shallower. The acetabulum may become shallow because of a higher rate of bone formation, due to a greater pressure stimulus, in dimension "a" of Figure 69. If this hypothesis was true, dimension "a" should be seen to increase over time, in relation to other dimensions, of the socket. This was not observed. It is possible that a greater range of motion is required to stimulate growth of the socket limbs. Ralis and McKibbin (1973) demonstrated that after birth, when the range of hip motion is greatly increased, the acetabular indices increase from the values observed at term; that is, the acetabulum becomes less shallow and again more of a hemispherical shape.

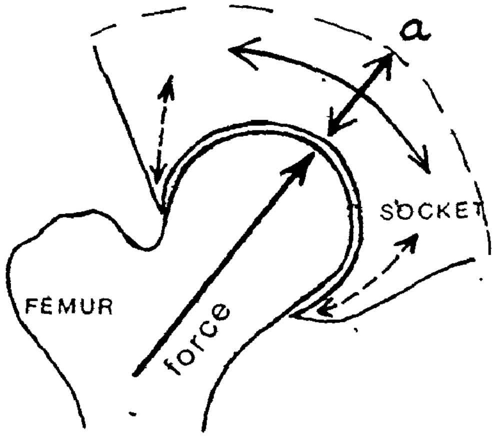


Figure 69: Theoretical development of the socket. When pressure is directed through the femur (arrow) to the socket, growth is stimulated in the floor of the socket (arrows) more than in the socket walls (dashed arrows). No increase in dimension "a" was observed over time.

Kobayashi and Mizuno (1965) made measurements of angular values of the cartilaginous acetabulum and the angular values of the labrum. They observed that, whereas the angular values of the cartilaginous socket reached a maximum value at 15 weeks (9.1 cm CRL) and decreased rapidly thereafter, the labrum angular values remained fairly constant after 18 weeks. These authors concluded from their measurements on radiographs that the socket does become more shallow and that the labrum plays a role in joint stability. Many authors have commented on the role of the labrum in greatly increasing the depth of the socket and providing support to the head of femur (Severin 1941, Strayer 1943, Badgely 1949, Gardner and Gray 1950, Dunn 1969). Since no study was located that reported the percentage of the socket formed by the labrum at different ages, an attempt was made to measure this. Calculations made on sections at the superior quarter-way level of the acetabulum showed that, on the average, the labrum formed 32.45% (10.15% SD) of the socket with a percentage greater than 50% only observed in fetuses less than 14 cm CRL. There was, however, a similar but lower range of variability observed in sections from term fetuses (21% to 40%). These data confirm the impressions made by other workers that the labrum does contribute significantly, from one-fifth to one-half, to the overall socket depth and femoral head coverage. It is noted that no mathematical adjustment was made for the visually apparent concavity of the inner surface of the labrum in measurement of its height. Further, measurements made on histological sections are only approximate because of tissue shrinkage in preparation of the sections.

Sawada (1968), in the only study published on the normal labrum at all ages, maintained that this structure is composed of fibrous tissue, with cartilaginous cells only observed at the articular margin. However, most authors, including some authors of anatomical texts, refer to the fibrocartilaginous labrum (Badgley 1949, Grant 1958, Matles 1967, Crouch 1972, Ralis and McKibbin 1973, Warwick and Williams 1973, Gardner, Gray and O'Rahilly 1975 and others). Dunn (1976b) commented on the "perfectly circular cartilaginous limbus," and Ogden (1974) considered the bulk of the labrum to be hyaline cartilage. Sawada's findings are supported by Gardner (1972). Milgram and Tachdjian (1976) describe "a fibrous limbus projects over the hyaline cartilaginous acetabular labrum." It appears that these authors consider the true labrum to be cartilaginous. The term limbus, normally used as a synonym for the labrum, especially in radiographic studies, is used by these authors to refer to a new lip of fibrous tissue. A similar point of confusion is made by Gardner and Gray (1950) who refer to the "cartilaginous labrum" and the "fibrous acetabular lip."

Since the composition of the labrum appeared to be in contention, observations were made on the labrum structure. The findings support Sawada's thesis. Cartilaginous cells were only found at the inner articular margin of the labrum. At all ages, the junction between the hyaline cartilage of the socket proper and the labrum was distinct. A different staining reaction in the cartilage and in the labrum was seen (Fig. 48). The staining reactions of the labrum were similar to those of the perichondrium or periosteum, both predominantly composed of collagenous fibres. The most distinctive change in labrum structure with age was an increased density of the collagenous fibres concomitant with a decrease in the amount of matrix between the fibres (see Figs. 46d, 19). All of the specimens in this study and in Sawada's study were fixed in formalin. Matles (1967) found that frozen sections, nonformalin-fixed, from refrigerated specimens, more closely resembled adult fibrocartilage. Differences in histologic findings may therefore be due to the technique of preparation. Further studies may enable a definitive statement to be made on the structure of the labrum, at all ages. There is, however, no evidence to support the observations that the bulk of the labrum is hyaline cartilage.

Of unknown significance to the strength of the labrum at the socket rim are the observations of discontinuity and variability in labra structure at the junction between the labrum and the cartilaginous socket (see Fig. 49). The loose connective tissue and capillaries which filled this area, or surrounded a microscopically detected cleft or groove were only observed on the anterior labrum of the socket superior quadrant. Sawada (1977) made similar observations but did not consider them significant to the development of congenital hip disease. Should these apparent defects be artifacts of tissue handling or preparation it seems reasonable to presume that they would be seen on either rim, in any of the four quadrants, and perhaps be seen in a greater number of specimens. A more extensive study with serial sectioning of fresh labra could validate the presence of these apparent defects. These defects seen in seven acetabula, 13.7 percent of those sectioned, were noted in fetuses with CRL values from 10.5 to 28.5 cm. Only two term acetabula were sectioned. Is it feasible that this type of structure may weaken the labrum? With alteration of fetal leg posture the head may subluxate to a minor degree, in the direction in which the defect was found on the socket rim. This morphology may be evidence of maldevelopment due to insufficient pressure stimulus.

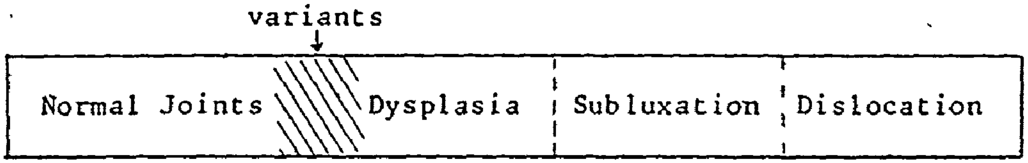
It seems doubtful that it is just a coincidence that 62.3 percent of localized variants from the normal description of the hip joint were located in the anterosuperior quadrant of the acetabulum (see Fig. 14). These 33 hips were classified as dysnormal cases. Only 13.2 percent of the localized variants (7 hips) were in the remaining three quadrants. One or more of the variants observed in dysnormal hips, such as flattened areas or dips in the labrum, capsular folds, and fibrous pannus over the articular cartilage surface of the socket, have been frequently described as part of a more complex abnormality in dysplastic, subluxated and, in particular, dislocated hip joints (Badgley 1949, Stanisavljevic and Mitchell 1963, Laurenson 1964, Stanisavljevic 1964, Dunn 1969). However, no reports of these variations in the morphology of normal hip joints were located. Perhaps other investigators observed similar variations in acetabular morphology but did not consider them worthy of comment in publications. Some, or all, of these variants may have been considered, or can now be considered, as part of the normal range of morphological variability. At other sites this is seen, for example, as variation in ear lobes, nose length and shape, and linearity of digits. A range of variation in size, form and shape may be expected to occur in the degree to which the apex of the labrum is sharp, in the shape of the ligament of the head of femur (LHF), and in the socket shape. Support for the latter hypothesis may be gained from the results of statistical analysis for the presence of significant difference in the mean values of the hip variables, between "normal" cases (which conformed with the published descriptions of normal hip morphology) and "dysnormal" cases. Multiple classification analysis, with the possible confounding effect of age removed, revealed only small differences in the mean values for each variable. These results suggest there is no significant difference between normal and dysnormal cases. Furthermore, examination of scatterplots of normal and dysnormal cases, by side for each variable, revealed no tendency for clustering of data from either normal or dysnormal cases (see Fig. 24 and Appendix G). After adjustment of age the largest differences between the mean values, for normal and dysnormal cases, were present in torsion bilaterally and the right acetabular diameter (see Table 7). The significance of the interaction for left torsion was equal to 0.029. Since the significance of the interaction for all other variables was greater than or equal to 0.1, the "dysnormal" and "normal" cases were pooled to give 144 cases in the growth study (four cases were then deleted since the age exceeded 42 weeks).

Alternatively, these variants can be considered as microforms of congenital hip pathology which have contributed to the variability seen in the growth statistics for the presumed normal group, especially for the femoral angles, acetabular diameter and LHF length. None of the variants described would be detected on an ordinary radiograph, or, it is suspected, on an arthrogram. Spontaneous remission of dislocatable hips in neonates is known to occur. Should these variants, particularly flattened areas of the labrum, labrum overhang and capsule folds, be microforms of the same process producing dysplasia, subluxation or dislocation, their presence in aborted and stillborn fetuses may be interpreted a variety of ways. Firstly, their presence could be the result of a temporary joint incongruity, the partially decentralized head of femur pressing on the socket rim for an unknown period of time, but spontaneously returning to a centralized position within the socket. It may then be suggested that, had the fetus in this case been liveborn, no abnormality would have been detected at birth. However, dissection of the stillborn fetus would reveal a nonsubluxated or dislocated joint with a flattened labrum. It is reasonable to hypothesize a temporary subluxation *in utero* which traps part of the capsule when the head spontaneously reduces, still *in utero*. This sequence of events could explain the capsular folds observed, which, while small, were distinct macroscopically (see Fig. 19). The presence of a fibrous pannus has been observed covering articular cartilage surfaces in immobilized joints (Enneking and Horowitz 1972, Salter *et al*. 1975). It may be suspected for the capsular folds, and particularly for the flimsy pulvinar covering the socket observed in a number of hips, that, if these fetuses had been liveborn, these structures would very quickly be worn away by the greater range of joint motion present postnatally. Alternatively, the presence of capsular folds between part of the joint surfaces, and fibrous pannus, may simply be examples of a process similar to that seen in immobilized joints, of fibrous tissue filling empty spaces. It is presumed that these spaces are empty, or lack appreciable contact, due to lack of congruity between the joint surfaces.

A third alternative process is that these variants, as microforms, represent the early stages of maldevelopment which may have progressed to a clinical and radiological form of congenital hip disease, at a later stage of fetal development, at birth, or postnatally.

Even if it is considered that these variants, some, or all, are simply an expression of the normal range of morphological variability, the possibility exists that hip joints with these features may be predisposed to arthritic changes in later years. This hypothesis would assume that these variants are not restricted to the acetabula of aborted, stillborn fetuses and infants who die in the perinatal period.

Barlow (1966) suggested that abnormal hips reported in fetuses may simply be the result of tissue autolysis. This point has been raised previously with regard to the labrum structure and roundness of the femoral head. It can also be applied to the variants described in dysnormal cases, and to the abnormal hip joints to be discussed later in terms of growth patterns. It is contended, for variants seen in dysnormal cases, that these features are not simply the result of tissue autolysis. Firstly, the distribution of these variants by socket quadrant or socket rim is not random ($p < .001$). While the frequency of dysnormal cases was not significantly related to age ($p = 0.517$), a chi-square test of linear trend with five age categories demonstrated a non-random distribution with regard to age ($p = .007$). Since saline infusion is known to have a severe effect on tissues it seems reasonable to expect at least an approximately equal distribution of dysnormal cases in the therapeutic or elective abortion group, pre-20 weeks, and later stillbirths. Dysnormal cases formed 55 percent of all cases greater than 28 weeks and only 23 percent of all cases less than 28 weeks. The distribution of the dysnormal cases appears to fit the observations of Nishimura (1970) that congenital postural deformities, such as CDH, are extremely rare among fetuses aborted before 20 weeks. Further, Dunn (1976a) has contended that congenital postural deformities are late fetopathies, and that at least two percent of infants exhibit postural deformities at birth. Dunn suggested that most of these congenital postural deformities will either resolve spontaneously or respond to early postural correction. Dunn, reiterating the earlier work of Dennis Browne (1936, 1955), considers these postural deformities are caused by mechanical factors, arise after the embryonic period and are essentially non-structural. It is likely that the joints in which these variants were observed would be classified as normal hips by current radiological and clinical criteria. A possible hypothesis seems to be that these variants are at the point of a continuum between normal morphology and dysplasia (clinically unstable or dislocatable joints, often with abnormal acetabular angles on radiographs).



It is considered that the flattened areas and the dips of the labrum may be the result of pressure and are probably not due to the effects of post-delivery fixation and handling. Care was taken to ensure the use of adequately-sized containers. However, for specimens received from outside the local area, post-fixation effects cannot be eliminated as a possible cause. Admittedly it is entirely speculative to hypothesize how these joints may have developed. The significance of these variants is, at this time, unknown. Tentatively however, this author suggests that rounding of the labrum rim (see Fig. 15) is more likely to be an expression of normal variation than the result of an autolytic process. The rounded area appeared firm and of similar consistency to the remaining sharp portion of the rim. Rounding of the labrum may be a precursor of flattening of the labrum. Pressure, from a decentralized head, the greater trochanter, the undeveloped neck region or the ligament of the head of femur, may produce flattened areas or dips in the labrum. Cases were noted where the greater trochanter, in the position of "best fit", rested against the labrum rim. No cases were observed where the area of flattening was similar to that of the ligament width. It seems plausible that a labrum fold with overhang, with or without a capsule fold, may be a progression of a flattened area. Alternatively, dips in the labrum may be due to underdevelopment, the result of insufficient growth stimulus.

Why were 62.3 percent of the localized variants, such as dips, in the anterosuperior quadrant, along with all of the observed deviations in microscopic labra structure? Dislocation or even subluxation in an anterosuperior direction in congenital hip disease is rarely reported although Stanisavljevic (1977) recently stated that he considered this direction to be modal in cases of subluxation. While it seems plausible to consider fetal posture, specifically the limb posture, and perhaps fluctuation in the amount of amniotic fluid may play a role, there is little evidence to support this suggestion.

One of the variants for which reports were not located was a kinked and/or twisted ligament of the head of femur (LHF) (see Fig. 22). While the orthopaedic literature abounds with statements based on naked eye impressions, concerning the shape and apparent dimensions of the LHF, no study was located which reported actual measurements of the LHF. Neither were studies located which examined the pattern of growth, growth rates or the extent to which this structure is correlated with other hip joint dimensions. An abnormally long LHF or hypertrophied LHF has frequently been reported in cases of congenital hip disease. It seems difficult to state that a structure is abnormal, say in length, when no knowledge exists on the normal amount of variation seen in this structure.

Length measurements reported herein are of the entire length, from the attachment to the femoral head fovea to the cut acetabular end. Length was measured in this manner because of poor reproducibility of measurements in attempts to record the free length. Considerable variability in both length and width is evident over time in the standard deviations which are the largest for all of the linear dimensions studied (see Tables 22, 23, Figs. 31, 32). Length of the LHF was the fastest growing variable of the hip joint dimensions, increasing five-fold from 12 weeks ($\bar{x}$ CRL 10.5 cm) to term ($\bar{x}$ CRL 39.9 cm). The ligament is presumed to be responsive to environmental factors such as forces acting through the joint and to joint mobility. The variation in the rate of growth of length and width is reflected in the variety of shapes observed at all periods of fetal life (see Fig. 42). These observations give some support to Crelin's (1976) contention that the older term, round ligament, is "descriptively erroneous" but do not support the view that the LHF is always a flat linear band of connective tissue.

A measure of ligament shape is gained from calculation of the LHF index (width x 100 / length). Since mean values for the LHF index are less than 100% (see Table 31) the shape tends to a linear type of structure. Since none of the mean values of the index were less than 50%, the ligament does not appear to be, on the average, a distinctly linear structure (with the length greater than twice the width). The minimum-maximum observed index values were from 12.84% to 109.85%. Ligaments in which the width greatly exceeded the length (indices > 100%) were not observed in fetuses over 24 weeks (CRL > 24.7 cm). However, small sample sizes in the third trimester may artificially restrict the variability observed. A tendency for this ligament to be squatter in shape in younger fetuses may exist. Crelin (1976) observed a flat band-like structure in all of his 26 term fetuses similar to that seen in the hip joints of adult cadavers. No measurements were reported. However, mean LHF indices in this study show no distinct age trend, especially on the right side.

Growth rates over the periods 12 to 20 weeks ($\bar{x}$ CRL 10.5 cm to 19.9 cm), 20 to 30 weeks ($\bar{x}$ CRL 19.9 to 28.3 cm) and 30 to 42 weeks ($\bar{x}$ CRL 28.3 to 39.3 cm) are similar for width and length. In both dimensions, the rate of growth decreases with time, being approximately 1.3-fold between 30 and 42 weeks. Rate of growth curves from the regression model which includes a quadratic on age predict a difference at term between the right and left sides. The right length is predicted to grow at a higher velocity than the left length (see Fig. 39). Similarly, a noticeable difference is predicted between the sides for width, but for this measurement, the velocity of growth on the left is predicted to exceed the right. No explanation is offered for these predicted differences which suggest, if this pattern of growth was to continue, the right ligament would become a slightly more linear structure than the left. It is noted that mean LHF indices suggest the left ligament is a more linear structure than the right at birth.

Ligament data was best fitted by a regression model which included a polynomial on age taking into account that a third dimension, thickness, is involved in the growth of this structure and which contributes to the overall form. This model appears to do a reasonable job in accounting for the explainable variation in ligament length and width. Perhaps a further indication that the LHF becomes more linear with age is evident in the partial F values for the addition of a cubic term which were not significant (see Table 29). This may indicate that volume, or mass, does not increase with time to a noticeable degree. Both left length and right width had nonsignificant lack of fit when a rectilinear model was fitted, and the change in the coefficient of determination by fitting higher models was minimal. Only for these two dimensions does the increase in size appear to be a simple interest type. The greater discrepancy between the observed and predicted means for right length and left width demonstrated by lack of fit for the linear model, is not, at this time, explained.

While the coefficients of determination between sides for both dimensions of the ligament are high ($R^2 > .845$, see Table 15), only low correlation is evident, when the effect of age is eliminated, between the LHF variables and the other hip variables (see Table 16). The correlation with depth, acetabular diameter and femoral head diameter is similar to that for torsion with only that for the neck-shaft angle being less. Adjusted for age, LHF length shows a slightly higher correlation with femoral head diameter than does width (r = .407). With the exception of the neck-shaft angle, length shows the lowest correlation with acetabular depth. This suggests that ligament shape and socket shape are not closely related.

The exact function of this ligament is not clearly established. While no specific tests were conducted to assess the strength of the LHF the range of femoral head motion with the LHF intact but with the capsule removed was examined. This assessment of mobility, performed on fixed specimens, while not as accurate as tests of LHF function performed on fresh specimens (Stanisavljevic 1964, Crelin 1976), supports Crelin's finding that, in fetuses, the LHF principally restricts posterosuperior motion of the head of femur. In none of the joints did the LHF permit the head to move more than one-quarter of its diameter over the posterior socket rim. The greatest motion was permitted inferiorly in the direction of the obturator foramen, especially when the hip was flexed and adducted. Up to 50 percent of the head could be moved over the anterior socket rim. During the fetal period, especially in the third trimester, in many of the joints, the femoral head diameter has been shown to exceed that of the socket rim. Under these conditions stabilization of the head must be gained from soft tissue structures about the joint. It seems, therefore, highly probable, as Crelin has proposed, that the LHF, a more robust collagenous structure than the capsule, must play a role in fetal hip joint stability. This is particularly evident at term when the socket is shallower and maternal hormones are believed to affect soft tissue structures. A mechanical function seems unlikely in normal joints, but the LHF may function to prevent the progression of a subluxation to a dislocation.

No cases of congenital absence of the LHF or ruptured LHF were found. Scaglietti and Calandriello (1962) reported a 20 percent incidence of absence of this ligament in operative cases of congenital dislocaton of the hip (CDH). The incidence of this anomaly in non-CDH cases is unknown. However, if the LHF has a stabilizing role, it seems reasonable to expect a higher incidence of ligament absence in CDH cases.

With abnormal length of the LHF, abnormal femoral angular values are reported in cases of CDH. A number of investigators have published values for the femoral angles. However, only Felts (1954) and Watanabe (1974) have published values from a reasonable sample size at different stages of fetal life. Felts' study was restricted to the femur without regard for sex or side, and Watanabe's study extended only to 24 weeks of fetal life. This then is the first report in which femoral angles are examined, together with other hip joint dimensions, over the fetal period from 12 weeks to term ($\bar{x}$ CRL 10.5 to 39.3 cm). A high degree of variability is evident in published reports for both femoral angles, and, because of this, Felts considered the angles are characteristics which may readily be classified as functional adaptations. Torsion and the neck-shaft angle are measurements of the same anatomical complex in different planes. The manner in which the angles change over time is influenced by environmental conditions such as fetal posture, capacity of the uterine cavity, the potential for stretch of the uterine wall, and the amount of amniotic fluid. Felts questioned whether the femoral angular dimensions could be measured as accurately as, say, bicondylar width. Both angles are usually associated with large standard deviations (see Tables 2 and 3). Radiographic studies reported for torsion have an average error of 5°. In this study, torsion has the highest pooled standard error (0.936°), and at any age group the standard deviations were largest for torsion. While the pooled standard errors for the neck-shaft angles were similar to that for acetabular and femoral diameters (0.312°), the standard deviations for this angle were large.

This investigator considers that in fetal femora, with a virtual absence of a neck (see Fig. 34), determination of the femoral angles is less precise than determination of linear dimensions, such as acetabular depth. The main source of error lies in the observer's alignment of the neck axis. Variation in values reported at specific age periods may be largely due to differences in measurement technique. However, this does not account for the spread of values seen at any age point.

It is generally accepted that the neck-shaft angle, commonly termed the angle of inclination (when measured on radiographs) in the orthopaedic literature, decreases during prenatal life. Values at term, as cited by Stanisavljevic (1964), of 140° to 145° are accepted as the average. Infant values calculated from radiographs, such as 137° at birth (Harris 1976) and 150° at four to six months postnatal (Hadziselimovic and Secerov 1968) are higher than values reported for any age period in this study. Pooled sample mean values for the neck-shaft angles were, for the right 125.75° (3.68°) and for the left 123.97° (2.86°). Not only are the pooled mean values lower than that reported by Stanisavljevic and by a number of investigators in infants and children, but also no apparent change in this angle was observed with age (see Fig. 29 and Table 21). This is confirmed by the absence of correlation with age. The scatter of points is similar over all age groups. The accepted adult value is around 125°. With the sexes combined (11 groups, by side = 22) this value was exceeded in five age groups and values were less than 125° in 13 age groups, with four groups being at 125° (see Table 21). However, differences from the adult value in mean values for any age group are very minor in nature. Both Watanabe and Felts demonstrated a similar lack of change in this angle over the period studied. Felts noted a decrease of 5°. The lack of variation in mean values at different age points through the fetal period is considered to give support to the theory that the greatest decrease in this angle occurs in early prenatal life. Badgley (1949) suggested this angle was produced by the gradual adduction and rotation of the limb bud. In histological sections the observation has been made that the long axis of the neck is nearly in line with that of the shaft in embryos (Friedlander 1901, Strayer 1943, Badgley 1949).

Variability in reported mean values, for example, Stanisavljevic's 140° to 145°, may be due to use of the head in alignment of the neck axis. Since the head may be off-centre with regard to the "neck" this can produce larger angle values (see Fig. 9). Higher values observed in infants and children, when the angle is evaluated from radiographs may partially be accounted for by differences in the attitude of the limb. Hamacher (1974) observed on radiographs that internal rotation reduces the value of this angle whereas external rotation of the limb increases its value. The limb has a natural tendency to fall into external rotation. It is obviously easier to ensure that the proximal end of the femur and the shaft are in the same plane, that is, torsion is neutralized, when measurements are made directly on the femur.

Observations made on a number of hip dimensions permitted examination of the extent to which the neck-shaft angle is correlated with other dimensions, an analysis not previously reported. When the effect of age was eliminated, the correlation coefficients for this angle with the other variables did not exceed 0.1 indicating an unexpected absence of any appreciable correlation (see Table 16). While it may be easier to determine this angle from arthrograms than it is to determine acetabular depth, the lack of correlation means this variable is of no use in prediction of the approximate value of any of the other hip dimensions.

Felts (1954) fitted a rectilinear regression curve for change in the neck-shaft angle in relation to the total length of the femoral shaft. In this study fitting of a rectilinear curve, a simple interest model, was associated with nonsignificant lack of fit terms (see Tables 25, 28). However, the amount of variability explained by this model, especially on the right side, was poor (right Q_m^2 = 7.28%, left 37.72%). Fitting of models with first and second order polynomials increased the Q_m^2 on the right side to only 38.16%. This indicates that these models do not perform a reasonable job at all, in interpreting the explainable variation in neck-shaft angle values. This result may be expected given the demonstrated lack of correlation with age. Rate of growth curves, calculated from the model with a quadratic term, predict a steady increase in values over time. The rate of increase is predicted to have a higher velocity at the end of the fetal period. This predicted velocity of change bears no relationship to the observed lack of change in the neck-shaft angle which more closely resembles the horizontal zero velocity rate of change with time curve. The latter is the derivative of the equation for a simple linear model. Therefore, prediction or estimation of the neck-shaft angle at any fetal age, may best be performed by taking the pooled sample mean values and standard deviations (right 125.75° (3.68°), left 123.97° (2.86°)) or the pooled mean values and standard deviations for sex and side (Table 10).

The accepted average value for torsion at birth is around 35° (Whitman 1923, Stanisavljevic 1964, Harris 1976). However, values of 64° (Kingsley and Olmsted 1948) and -2° (Rogers 1934) have been cited. It is accepted that torsion reaches a maximum value around term and decreases thereafter to an adult value from 8° to 12° (Harris 1976, Kingsley and Olmsted 1948). From radiographic studies Harris (1976) reported a maximum range of 10° at any postnatal period. A wide range of values is generally reported in most studies (see Table 3 for range in adult studies). As with the neck-shaft angle, variation in mean values may be partially explained by variability in the measurement technique. However, Pelts considered that there was insufficient variation in techniques to account for the wide dispersion of values. Studies, shown in Table 3, where the range of observed values is 59°, were based on anatomical collections. The possible inclusion of an unknown amount of pathology may partially explain the range seen in these studies.

Watanabe (1974), for fetal age groups 10 – 15, 15 – 20 and 20 – 24 weeks, gives mean values of -4°, 5° and 11° with the range at any one group not less than 40°. Since he observed neutral values up to 24 weeks (maximum CRL 30.0 cm) he, with Kingsley and Olmsted (1948) supported Le Damany's (1904) theory that positive torsion develops in the second half of pregnancy. In the first half of pregnancy Le Damany considered that the axis of the neck and that of the shaft were in parallel planes, thus torsion is zero. In the present study torsion showed the strongest linear trend early in fetal life, between age groups 12 and 18 weeks ($\bar{x}$ CRL 10.5 to 17.7 cm) (see Fig. 30). Zero or negative values were rarely observed in fetuses older than the 18-week group. The present data are more similar to that reported by Felts. From his studies on the prenatal femur, and investigation of torsion at different levels of the femoral shaft in a small sample, Felts concluded that torsion was a total characteristic, present through most of the shaft. The increase was considered characteristic of the whole prenatal period. The observation herein of the strongest linear trend between age groups 12 and 18 weeks, with a cluster of negative values round 12 weeks, appears to give support to Felts' argument. Discrepancy between this study and Watanabe's may be due to the latter including dysplastic cases in his total sample, but perhaps it is due to variation in positioning the femora for measurement.

Kingsley and Olmsted (1948), then Dunlap et al, (1953) emphasized the importance of ensuring when measuring torsion, that the proximal point of contact was the posterior surface of the greater trochanter, principally to enable a retroverted femoral head to be free of support. This is important. However, in this study it was noted that a larger proportion of young femora (68.2%) with negative or low positive torsion angles naturally rested on the lesser trochanter (see Fig. 43). Failure to ensure greater trochanter proximal support by the use of blocks gives a low reading to the torsion angle. This may account for the greater number of negative and neutral angles observed by Watanabe up to 24 weeks, and in part for the range reported in a number of studies.

A significant relationship between trochanter support (equivalent to trochanter position) and age was demonstrated ($p = .0001$). A transitional period is evident between the 22 and 30 week groups ($\bar{x}$ CRL 21.7 and 28.3 cm), and beyond this age 71.4 percent of femora rested on the greater trochanter. Trochanter support was correlated with torsion since, of the 19 femora with negative torsion values, none rested on the greater trochanter, and 57.4 percent of the femora with torsion greater than 20° did rest on the greater trochanter. Thus it appears that concomitant with an increase in the amount of positive torsion with age, there is a change in the morphology of the proximal femur. This change brings the lesser trochanter from a more posteriorly directed position to a medially directed position. This supports Le Damany's and others' opinions that torsion takes place in the femoral shaft, as indeed Felts demonstrated in a limited study, and not between the head and the neck. Since 42.6 percent of femora with torsion greater than 20° did not naturally rest on the greater trochanter, there is evidence that torsion is not the only factor influencing the direction or position of the lesser trochanter in relation to a sagittal plane. Further explanation may lie in development of the greater trochanter compared with that of the lesser trochanter. The pull of the abductor muscles influences the greater trochanter development. Development of the abductor muscles may be retarded due to the limited mobility within the uterine cavity, and the flexed and abducted posture of the fetal hip joints. Then, despite the presence of positive torsion, the lesser trochanter may have a greater mass posteriorly than the greater trochanter. In this situation a femur would naturally rest on the lesser trochanter.

The present data suggest a trend for mean values to decrease prior to birth (see Fig. 30). This has not been previously reported. The highest mean values are observed at the 32 week group ($\bar{x}$ CRL 30.0 cm, right 30.8°, left 33.15°) with means of 17.92° and 24.10° reported for the 40 week group ($\bar{x}$ CRL 37.8 cm). This suggested decrease may be an artifact of the small sample size at each two-weekly period after 30 weeks which was still further reduced by femora in which this angle could not be measured since only the proximal portions were received. The range of observed values remains wide with standard deviations overlapping between the 42 week and 12 week groups. Even with deletion of one "normal" case at 42 weeks which had values of 11.7° and 1.7°, the standard deviations still overlap between age groups 42 and 14 weeks.

The term values are definitely lower than those reported from infant radiographs (Stanisavljevic 1964). Postnatal decline is generally attributed to forces acting through the hip due to weightbearing and the tension of the joint capsule in the extended position.

Felts found that 80 percent of his fetal femora exceeded Elftman's (1945) average adult value of 11.2°. In the present study 61.7 percent of femora exceeded this value while a higher percentage (38.3) were less than this value. Where the maximum CRL of fetuses which did not exceed the adult value was 16.3 cm in Felts' study, in the present study the maximum CRL was 25 cm. This may merely be another expression of the individual variability exhibited for torsion.

Examination of Watanabe's data up to 24 weeks (maximum CRL reported 30.0 cm) demonstrates a very low or an absence of correlation with age (not specifically reported). Felts fitted a rectilinear model against the total femoral shaft length. When a rectilinear model was fitted to the present data against age, based on CRL, significant lack of fit was obtained (right $p = .02$, left $p < .0001$). Given the lack of a linear trend throughout the entire period studied, it is not surprising that this model should explain less than 70 percent of the explainable variation in the data (see Tables 25, 28). Nonsignificant lack of fit was gained by fitting a quadratic term to age and the amount of variation explained by the model increased to greater than 85 percent. The addition of a cubic term made little difference to either the lack of fit terms or the modified coefficients of determination. This may suggest that torsion is not particularly influenced by change in the mass or volume of the femur. However, area, length and breadth increasing at unequal rates in the prenatal femur (Felts 1954) may influence the angle and explain the better fit of the model which included a quadratic function on age. Felts did not report lack of fit terms. Torsion is recognized as a fluent characteristic, influenced by environmental factors which play a greater role in the last trimester of pregnancy (Dunn 1976a). It is not, therefore, surprising that a linear model which predicts change at the same rate throughout, would show lack of fit, particularly towards term. Based on the modified coefficients of determination, the quadratic model appears to perform a reasonable job of interpreting the explainable variation, apart from the mean. However, obvious discrepancy, especially near term, is revealed when the differential rate of growth curve is plotted. The predicted velocity of change curve is linear and negative. Unlike the observed data, a steady rate of increase in torsion is predicted for the entire fetal period, with the rate of change between 30 and 42 weeks predicted to be three times that between 12 and 20 weeks. This prediction is more in line with studies such as Felts' which show a steady increase in torsion values to term, and with Le Damany's (1904) theory, supported by Milch (1943), Kingsley and Olmsted (1948) and Watanabe (1974). The predicted curve is a mathematical function of the quadratic equation and it may merely be a coincidence that the prediction for rate of change in torsion fits previous reports for observed change in torsion values. With the exception of Felts, none of these authors have studied changes in torsion, with a reasonable sample through the entire fetal period. In the present data the highest rate of change was observed between 12 and 18 weeks, not in the third trimester.

The present data give support to Le Damany's claim, with which Felts agrees, that since torsion appears correlated with other hip joint dimensions, it should not be studied in isolation. A highly significant effect for side was present as expressed by the coefficient of determination ($R^2 = .769$, see Table 15). The side effect for torsion was less than that found for all the other hip variables, with the exception of the neck-shaft angle, and was low after adjustment for age. From Table 16 it can be seen that torsion is moderately correlated with depth, acetabular and femoral head diameters (highest $r = .431$) and only minimally correlated with LHF dimensions. If the suggestion of declining values near term is an artifact, it may be expected that torsion would demonstrate a higher correlation with depth and the two diameters. There are no data with which to compare the demonstrated correlations. If, because of its width and lack of length, the femoral neck impinges against the acetabular margin and thus limits joint motion, torsion may be influenced by a dimension not reported herein, that is, inclination of the socket itself. Torsion may be influenced by the growth of the different components of the joint, in addition to the fetal posture and the suggested dominant influence of forces acting through the femur from the uterine wall. Change in torsion is the resultant, then, of several processes and their interaction. This angle appears more variable than the neck-shaft angle. Given that both angles exhibit considerable dispersion of individual values, it seems difficult to determine when these angles can be considered abnormal or pathologic at term.

It was considered that a comparison of data for normal fetuses in which abnormal hip joints were detected may be informative, and so these cases were retained separately in the study. For the same reason six fetuses with congenital abnormalities, received despite the study exclusion criteria, were also retained but in a separate group. The degree to which hip joint data for these cases are similar to, or deviant from, the mean values and one standard deviation of their appropriate age group may contribute to our understanding of congenital hip disease (CHD), and assist in definition of abnormality. While the morphological features of abnormal hip joints have been reported, with the exception of the femoral angles, no quantitative data have been given, or if made, have been compared with the scanty normal data then available (Stanisavljevic and Mitchell 1963, Stanisavljevic 1964, Laurenson 1964, 1965, Dunn 1969, Watanabe 1974, Milgram and Tachdjian 1976).

This author agrees with Dunn (1969, 1972, 1976c) and Stanisavljevic (1964) that the hip joint abnormality seen in abnormal joint~~s~~ is not simply the result of tissue autolysis as suggested by Barlow (1966). The features observed in these abnormal joints closely resemble operative findings on live infants or children with CHD. The possibility that tissue autolytic effects may render abnormal morphology more distinct cannot be eliminated.

Cases of congenital hip pathology are characterized by the presence of a small and often nonspherical femoral head, a small, shallow and often noncircular socket, an elongated ligament of the head of femur (LHF) and abnormal femoral angle values. These are measurable characteristics. It seems plausible to expect that abnormal hips when compared with their appropriate age group's mean ($\bar{x}$) and standard deviation (SD) would show values that would be smaller by greater than one SD for depth, acetabular and femoral head diameter, and would have values for LHF length and torsion greater than the $\bar{x}$ plus one SD. It may also be expected that an elongated LHF would be narrow and the values for LHF width may be smaller than the $\bar{x}$ minus one SD. That it is reasonable to compare the data for each case with the mean values and standard deviations for the case's appropriate age group depends on the validity of the estimated age of the fetuses. As the assumption of accurate assessment of age may not be valid these cases were also compared with data for adjacent age groups. These comments will also apply to comparisons made for fetuses with congenital abnormalities and one or both abnormal hip joints.

Tables 34 - 38 and Figures 51 - 57 permit comparison of data from the cases with abnormal hips. For convenience, the main features of this comparison are summarized below (Table 41). Five cases (#66, #154, #147, #116, #115) showed bilateral joint abnormality and two cases showed unilateral hip involvement (left (L) #25, right (R) #87). It can be seen that the expectation that values for these cases would be less than the $\bar{x}$ minus one SD is generally met for depth, acetabular and femoral head diameter, and for LHF width. Dimensions from the two cases with the most severely abnormal joints, L#116 and R#115, were also less than the $\bar{x}$ minus one SD for adjacent age groups. Neither of these two joints were dislocated. Both joints, most notably L#116, showed an absence of a normal anterior socket wall with the femoral heads resting on a false socket formed by the flattened labrum rim (see Figs. 61, 62).

Table 41: Summary of the comparison between measurements in abnormal hips of normal fetuses and growth study mean values and standard deviations*

	Depth	Acetabular diameter	FH Diameter	Torsion	Neck-shaft angle	LHF Width	LHF Length
$<\bar{x}$ - 1SD	(116),(115) (154), 25 87	25,115 (116),154	87,L25 R25,115 (116)	(115),25 L116	(154)	R115,R25 R147,R26 L154,L116	R116 L147
$>\bar{x}$ + 1SD		147	147			(L66)	R87 R147

* where one side only fits, R (right) or L (left) precedes the case identity number. Cases circled were less than the $\bar{x}$ minus one SD for both the adjacent age groups; i.e., if a case is compared with age group 32 weeks, it is circled only if the values were $<\bar{x}$ - one SD or $>\bar{x}$ + one SD for age group 30 and age group 34.

Cases #87 and #147 were the only two fetuses which had a ligament whose length was greater than the $\bar{x}$ plus one SD. The age in case #147 may be underestimated. It was surprising that the LHF length dimensions did not generally exceed the mean plus one SD considering the frequent observations of a "lengthened", "hypertrophied," or "excessively long" LHF reported in the orthopaedic CDH literature. These data indicate the difficulties associated with definition of abnormality when no standards for normalcy exist. Since only hips that have been diagnosed as abnormal will come to surgery, observations on the length, and of the shape of this ligament may be considered to have been made on a non-random and biased sample of hip joints. Alternatively, and more reasonably, while not specifically stated, ligaments may have been described as excessively long because the length permitted the head to move completely out of contact with the "true" socket. Since none of the joints in this study were completely dislocatable except in an inferior direction, it is not surprising that the values for LHF length were generally within one SD.

Case #25 showed two areas of labrum flattening (see Fig. 63) in the left hip with no malposition of the head relative to the socket. This case was the first presumed abnormal joint detected. In retrospect, on the morphological features, the more appropriate classification would seem to be dysnormal. However, five of the seven dimensions from this specimen were less than $\bar{x}$ minus one SD and the assessed "normal" right hip was also less than $\bar{x}$ minus one SD for five of the dimensions measured, including depth. Values for case #25 were within one SD for the adjacent age groups. On quantitative data, the original classification is considered correct. A possible reason for the presence of flattened areas of the labrum has previously been given.

The dominant abnormality observed in case #87 was a distinctly nonspherical shaped right socket (see Fig. 21b) with a similar shaped femoral head. Other distinctive features were the internally rotated limb posture and a right socket which faced more laterally than the left socket. Post delivery compression may be ruled out as a possible cause, and with a crown-rump length (CRL) of 9.7 cm ample room <u>in utero</u> may be expected. No reason can be offered here for the socket shape and, as with all of these cases, it would be speculative to consider the course of development in this hip had this fetus not been aborted. It is interesting that bilaterally depth was less than the x minus one SD for the 12 week group.

Case #66, a term stillbirth of unknown sex and CRL, was classified as an abnormal case because of the number of variants observed bilaterally (see Fig. 58) and because of poor head coverage which seemed less than that normally observed in term hips. All but one of the dimensions were within one SD. Only the left LHF width exceeded the mean plus one SD. It must be considered that this case should have been placed with the dysnormal cases.

Bilateral capsular folds were observed in case #154 (see Fig. 59), similar to that reported as a variant in dysnormal cases. This case was classified as an abnormal because of the visual impression of poor head coverage, especially on the left side, which resulted in immediate dislocation after capsule ablation. Shallow sockets were also noted. The latter impression was confirmed by depth measurements that are less than the x minus one SD for the 40 week group and by the presence of low acetabular indices (27%). While no proof can be offered, it is suspected that the presence of a capsular fold will limit the amount of contact the head has with the socket and may predispose to a subluxated hip postnatally. It is interesting that in case #154 the legs were crossed, a posture which Dunn (1976b) has suggested is a position of great mechanical disadvantage from the point of view of fetal kicking. If the legs are "trapped" and motion is limited, reduced functional molding of the joint surfaces may occur. A reduced potential for motion to wear away excessive fibrous tissue, such as a small capsular fold between the joint surfaces, may exist.

None of these joints were dislocated. The degree of abnormality seen, particularly in the left hip of fetus #116, appears to suggest that the malposition of the head of femur had been present for some time. It is possible that the features were intensified by tissue autolysis as this fetus was rated as Grade 3 for maceration. Had fetuses #115 and #116 been liveborn it is highly probable, given the malposition of the joint surfaces and the distorted sockets, that complete dislocation in a posterosuperior direction would have occurred. Salter (1968) considers that a distinctive feature of congenital hip disease (CHD) when compared with other congenital abnormalities, is the minimal abnormality of the joint surfaces at birth. The abnormality progresses rapidly if accurate reduction is not achieved. This observation applies to typical cases of CHD and not to those termed atypical or teratological in which it is considered that the abnormality develops early _in utero_. Cases #115 and #116 would appear to be examples of atypical CHD because of the extent of the abnormal joint features and the considered duration of the subluxation.

Dunn (1969, 1976c) has proposed a three-point grading system for CDH (congenital dislocation of the hip). In this system CDH Grade 1 hips were termed "dislocatable" on clinical assessment. CDH Grade 2 hips showed marked instability and the hip dimensions were "smaller than normal." Joints that were dislocated and exhibited the greatest alteration in structure were given CDH Grade 3. By this system it is considered that L#116 and R#115 would be CDH Grade 3. Cases #154 and

#147 would be CDH Grade 2 and cases R#116, L#115, L#25 and R#87 would be CDH Grade 1. Even though the dysnormal hips in this study were shown not to be significantly different from the normal hips it is likely that a proportion of the dysnormal hips would have been CDH Grade 1 or 2 by Dunn's classification. It is suggested that hips with dips in or flattened areas of the labrum, and hips with capsular folds may be, on clinical assessment, dislocatable. As the majority of specimens were in formalin when received, this test could not be performed. Dunn gave CDH Grade 2 to joints in which, among other features, the acetabula were shallower than normal. Yet, previous to this report depth data only consisted of mean values for fetuses up to 24 weeks with no limits (SD) given, or were isolated case values. This study provides limits which will enable a more precise classification of abnormal joints in dead fetuses.

A high incidence of CDH in children with multiple congenital abnormalities has been noted (Muller and Seddon 1953, Ingram and Farrar 1955, Record and Edwards 1958, Ruszkowski and Kovacic 1967, Phillips 1968, Czeizel, et al. 1975). In CDH studies investigators have usually excluded teratological cases. Warkany (1971) noted that in many of these, CDH represents a minor anomaly that is not emphasized. The congenital abnormalities, not involving the hip joints, seen in the six cases reported here are of the type termed teratologic, the abnormality developing in utero and arising during the period of organogenesis. Bilaterally normal hip joints were observed in two fetuses with congenital heart disease and in one anencephalic infant. In these three cases, there was only one measurement outside normal limits (> $\overline{x}$ + I SD) for its appropriate age group (case #158, see Table 36). However, as age group 36 weeks consists of only one case, values for the two infants with congenital heart disease could only be evaluated by relating their data to that one case and the adjacent age groups 34 and 38 weeks (see Figs. 51 to 57). Data from the fetuses with congenital heart disease appeared to be within normal limits.

Case #30, a cyclops, had hip morphology similar to that seen in dysnormal cases. Since three dimensions exceeded the mean plus one SD, in particular, femoral head and acetabular diameter which show a steady linear trend in the normals, the age of this fetus may be underestimated. Evidence was present, in the form of tibial torsion and an asymmetrical pelvis, to suggest a more complex defect in development than is accepted for typical CDH hips.

Markedly low femoral angle values were a feature of the hips in case #94 which had multiple congenital abnormalities. Depth and the diameters for the grossly abnormal left hip (see Fig. 66) were within one SD. However, the right hip values for the same variables exceeded the mean plus one SD. No explanation can be given here for the remarkably low bilateral torsion angle values and the left neck-shaft angle value observed in this infant. Except for this case, and #115 in the abnormal hip group, femoral angles in fetuses with abnormal hips did not deviate markedly from normal limits. It is reiterated that a wide range of variability was evident, in normal cases, for both angles. In abnormal hips, a range of positive torsion values from 32° to 90° has been reported. By this study a number of these reported abnormal values would not have exceeded the mean plus one SD (for example, see Laurenson 1964).

Dunn (1971a, 1976b) observed an almost invariable association between congenital postural deformities and the presence of anomalies of the urinary tract that prevent urination. An association with kidney abnormality is seen in case #141 which had polycystic kidneys and bilateral abnormal hips (see Fig. 65). Neither hip was dislocated but both were subluxated. Dimensions for depth and both diameters were smaller than the mean minus one SD for the 30 week group. Dunn (1971b, 1976a) and others have presented evidence that oligohydramnios, present in case #141, favours deformation, and that oligohydramnios itself may contribute to growth retardation. Decreased volume of amniotic fluid with primigravidity in which the uterine wall and abdominal muscles are less stretched, are hypothesized to be among the factors producing deforming pressure on the developing fetus. The extent of deformation will depend on the amount and duration of pressure, in addition to the ability of fetal tissues to resist deformation. Pressure applied over a considerable period of time may contribute to the deformity seen in fetus #141. A lesser amount of pressure applied over a shorter time period may give rise to deformations such as flattened areas of the labrum, due to contact perhaps, with the short and comparatively wide neck of the fetal femur.

The abnormal joint morphology seen in cases with congenital abnormalities did not appear to be distinctly different from that seen in the abnormal joints of normal fetuses, stillborn infants or perinatal death infants. Case #94 is a possible exception. However, the angular values observed in the latter case have been reported frequently in the CDH literature.

The range of morphological abnormality observed in this study, in either normal fetuses or fetuses with congenital abnormalities, is the same as previously reported in the literature. Growth data compiled in this study, however, have permitted the abnormal joints reported here to be evaluated, not simply in terms of the abnormal appearance of the joint and visual impressions of underdevelopment, but in relation to normal growth limits. It is more meaningful to compare abnormal joints, and to classify these joints in terms of abnormality, when general joint dysplasia, or, say, a shallower socket than normal, can be stated in terms of the number of standard deviations from the mean an observed dimension was. The extent to which abnormal hip dimensions vary from the limits given herein for normal hips is dependent on the degree to which the growth sample is representative of normal growth and development in the abortion/stillbirth/perinatal death population. This study provides quantitative data at different age points (CRL). Abnormal joints in dead fetuses and infants can now be evaluated more precisely. The evaluation would include clinical assessment of instability and the visually observed abnormality of structure. It is considered that evaluation of angular dimensions on radiographs may be less precise than when the angles are measured directly on the bones. Furthermore, because of the variability seen in the femoral angles, exactly which angle values should be considered abnormal is in doubt. Since the femoral angles, especially the neck-shaft angle, exhibited low correlations with the other hip dimensions, abnormality of the angles alone may be a poor indicator of hip dysplasia.

In this study the hip joints were initially classified as normal or abnormal on the morphological features. Comparison with the normal growth data gave support to the designation "abnormal". In a few cases these comparisons suggested a greater degree of underdevelopment in the joint than had been suspected from naked eye inspection. While with experience it is feasible to detect by inspection abnormal femoral angles, similar detection is difficult for the other dimensions reported here because of the small SD's at each age group. These data for depth, acetabular and femoral head diameter, and the LHF dimensions had low standard errors for the pooled means, and can be regarded as reliable estimators of the unknown population means.

A point of contention is the significance of the so-called dysnormal cases. The common term for minor grades of CDH, dysplasia, may be applied to this group by some investigators. Statistically these hips were shown not to be significantly different from the normal joints. Classification of abnormal hip joints by quantitative data for a number of dimensions has previously only been attempted in living infants and children, and is based on evaluation of angular measurements made on radiographs (Tonnis 1976). Obviously, direct measurements must be taken to permit comparison with these data. The extent to which this can be done is severely limited in living children. It may be feasible during surgery to gain at least approximate measurements of the ligament and femoral head diameter, directly or via photography. It can, therefore, be asked: What is the purpose of fitting regression curves to the data and calculating predictive equations for the different hip variables? Fitting regression curves to data is one way of summarizing the main features of the data and is valuable when there are a large amount of individual data over time. Quantitative definition of visually apparent trends is made possible. It is considered that these data provide limits for growth changes in the main hip dimensions. Determination of regression equations permits the identification of which growth curve is most appropriate for a set of data. Comparison with growth of other parts or areas of the body can be made. While previous investigators have largely fitted a simple linear regression line, that is, a simple interest model, to hip region dimensions (Scammon and Calkins 1929, Felts 1954), this model was not appropriate to the data presented here. Van't Hof <u>et al</u>. (1976) commented that while the fitting of polynomials has several convenient mathematical properties, the biological interpretation of the results is difficult.

It is desirable to fit a curve which firstly provides a close fit to the data; secondly, has relatively few parameters, with meanings which are clear and have biological significance; and thirdly, has a reasonably simple functional expression (Van't Hof <u>et al</u>. 1976). To meet the above, sex, for which no significant differences were detected, was eliminated from the model. Only a first order polynomial was fitted despite the least significant lack of fit terms being obtained for depth and the two diameters when a cubic term was added. This was deemed reasonable as none of the F values for lack of fit exceeded a "four times" limit (Draper and Smith 1966). That lack of fit terms were generally not significant at the 0.05 level, when a quadratic term was fitted to age, may be explained biologically in that the measurements which were made all belong to structures that possess area or surface. Growth is occurring within these structures in dimensions not measured. The result of growth in different dimensions of a structure, perhaps at varying rates within the structure, is seen in a change of form or shape as detected in the hip socket. Regression equations are additionally useful to predict the value of a variable (y) for a specific value of an independent variable (x), when the value of y cannot be directly assessed. There is at present no clinical method available to obtain precise measurement of most of the variables measured in this study until ossification is completed. However, these data can provide an estimate of these variables given crown-rump length or age information. A method is required to measure femoral head diameter precisely without exposure of infants to unnecessary radiation hazards. In view of recent developments in the general field of radiology this may eventually be feasible. Since a high correlation was shown between depth, acetabular diameter and femoral head diameter, these type of data could then be useful to gain a quantitative measure of depth and acetabular diameter at a specific age or CRL. This would provide an assessment of how well-formed the cartilaginous joint is, in an infant with an unstable or dislocatable hip. There is general agreement that radiographs are of limited value up to three postnatal months owing to the lack of ossification in the femoral head.

Since the regression equations are by age, based on CRL, there is an implicit degree of error. Age estimates for fetuses less than 17 weeks are recognized as being in error by one week, and at term the error is up to four weeks (Böving 1965). In different studies, variability is seen in CRL at different ages (Moore 1973). There is a real need to evolve a more accurate measure of fetal age. While these data are presented in two-weekly age groups from 12 weeks, the actual mean age for each group from the 12 week group to the 24 week group, based on Moore's (1973) average CRL, is one week greater. That is, the mean age for the 12 week group is 13 weeks, and so forth. If Streeter's (1920) or Mall's (1910) standards for the length of dead fetuses are used, the minimum mean age for the 12 week group would be equivalent to their 15 weeks. Ranges given for CRL should be utilized to determine which series of values a specimen should be compared with. The age in weeks which is given to a specific crown-rump length is dependent on the fetal aging standards an investigator personally considers the most reliable. Zeigler et al. (1976), for example, considered Mall's 1910 data to be the best set of length measurements of dead fetuses. At least two studies have shown a significant increase in infant length in the periods 1860 - 1920 (Abolin 1962) and 1910 - 1972 (Olivier 1977). The secular increase in stature seen in the 20th century is well known. It seems reasonable that studies from early in the 20th century and when elective abortions were not practised, may err on the low side for length measurements. Underestimation of length is considered possible since fetuses may have been shorter. Furthermore, at that time, a greater amount of abnormality was present in the samples since these were comprised of the products of spontaneous abortion. Perhaps a more precise measure of fetal maturity, at all ages, may be gained by assessment of skeletal maturity from radiographs (Cruikshank, Miller and Browne 1924, Acheson 1954). Gruenwald (1970) stated that it is impractical to evaluate human growth prior to the third trimester owing to the lack of empirical standards.

CONCLUSIONS

1. These data provide no morphological evidence for significant differences in fetal hip joints between males and females, or between the right and the left sides. There is a suggestion that the left side may be more variable. The results indicate that explanation of the greater female preponderance and left side involvement in congenital hip disease must lie in factors other than growth changes of cartilage or bone.
2. The ligament data provide no evidence to support previous observations that this structure is unusually long in abnormal hip joints. The ligament is shown to be variable in length, width and shape. It is not a distinctly linear structure though linearity may increase with age.
3. There is a trend for the femoral head to become less round with age and more oval or ellipsoidal in shape. A position of "best fit" exists, particularly in the third trimester. It is suggested that altered position of the joint surfaces occurring at birth may decrease

congruency and increase joint instability. A possible factor producing dislocatable joints in neonates is identified.

4. While the femoral head diameter is shown on the average to be marginally smaller than the acetabular diameter, in many hips the femoral head diameter exceeded the acetabular diameter. This indicates that soft tissue structures around the joint, such as the ligament of the head of femur, must play an important role in joint stabilization. Any factor which would tend to increase flexibility of soft tissues, such as maternal sex hormones, may then predispose to a dislocatable joint.

5. Growth of the hip variables was shown not to be a simple interest function with age or CRL. The velocity of growth was higher in the period 12 to 20 weeks. Acetabular depth was shown to be the slowest growing hip variable with a deceleration noted between 20 and 30 weeks. These data support previous findings that the socket becomes shallower towards term but indicate the greatest amount of change in shape may occur very early in fetal life.

6. A change in the orientation of the lesser trochanter which is correlated with the development of positive torsion is reported. With low torsion angles femora will naturally rest on the lesser trochanter but with torsion of 20° and more, femora tend to rest on the greater trochanter. The lesser trochanter appears to change gradually from a posteriorly directed prominence to a more medially directed structure. Evolution of positive torsion does not appear to be the sole factor producing the change in the lesser trochanter orientation. This observation may be pertinent to reading of radiographs where the

trochanters are used as landmarks. Support is given to the theory that torsion takes place in the femoral shaft.

7. Torsion is shown to be highly variable. The sharpest linear increase was observed between 12 and 18 weeks giving support to the hypothesis that torsion is a characteristic of the entire fetal period. There is a suggestion in these data that torsion may commence to decrease prior to birth. Values reported for the third trimester are lower than those currently accepted by clinicians for newborns.

8. The neck-shaft angle was also shown to be variable with values throughout the fetal period in the accepted adult range and lower than those generally accepted for term infants. There was no significant correlation with age.

9. Because of the variability shown in both femoral angles, exactly when angular values should be considered abnormal at term is in doubt. Since the neck-shaft angle showed poor correlation with the other hip variables and torsion demonstrated only moderate correlation with the same variables neither angle alone appears to be a useful indicator of normal hip joint development.

10. These data demonstrate that there is a significant degree of interaction between variables by side, and high correlation exists between the femoral head diameter, the acetabular diameter and acetabular depth. Should a method be devised to precisely measure the cartilaginous femoral head at birth, a reasonable prediction of socket depth could then be obtained.

11. This study provides limits for the growth and development of the fetal hip joint from 12 weeks (8.7 cm CRL) to term. Abnormal joints can

now be evaluated in terms of clinically detected instability, radiographic appearance and morphology, and in relation to these normal limits. In this study comparison with normal growth data more clearly defined the designation "abnormal" and in a few cases indicated a greater degree of dysplasia than was detected by naked eye examination. Abnormal joints, at least in dead fetuses and infants, can now be evaluated more precisely.

12. A number of morphological variants were observed in hip joints that were neither subluxated nor dislocated, nor were shown to be statistically different from joints with a normal morphological appearance. It is suggested that while a few of these variants may be part of the normal range of biological variability, some are microforms of congenital hip disease.

13. There was a significant localization of variants and abnormal socket features to the anterosuperior quadrant of the socket and the anterior socket wall. As subluxation and dislocation occurs most commonly in a posterosuperior direction the greater involvement of the anterosuperior quadrant was surprising. This may reflect abnormal development of the socket due to insufficient pressure stimulus from a closely applied femoral head.

14. A normally developing hip joint should have depth, acetabular and femoral head diameter values which are within one standard deviation for the case's appropriate age group.

LIST OF APPENDICES

APPENDIX A

Source of Specimens

<u>Source Code</u>

1 = McMaster University, Anatomy
2 = McMaster University Medical Centre, Pathology
3 = Yale University, Anatomy, New Haven
4 = Buffalo Children's Hospital, Pathology
5 = St. Joseph's Hospital, Hamilton
6 = Other: University of Western Ontario, London, Anatomy
Hospital for Sick Children, Toronto, Pathology
St. Michael's Hospital, Toronto, Pathology
Henderson Hospital, Hamilton, Pathology
New York State University, Buffalo, Anatomy

Table 42

Specimens by source, age or cause of death

	1	2	3	4	5	6	Total %
Abortion							
Spontaneous	3	3	15	4	7	5	37 (23.4)
Induced							
saline	18	42	1				61 (38.6)
prostaglandin			36	1			37 (23.4)
Age at death							
neonate			7	8		3	18 (11.4)
infant			3			2	5 (3.2)
Total (Percent)	21 (13.3)	45 (28.5)	62 (39.2)	13 (8.2)	7 (4.4)	10 (6.3)	158 (100)

Table 43

Normal specimens by source, age or cause of death

	1	2	3	4	5	6	Total %
Abortion							
Spontaneous	2	3	13	2	6	3	29 (20.7)
Induced							
saline	17	40	1				58 (41.4)
prostaglandin			36				36 (25.7)
Age at death							
neonate			6	8		1	15 (10.7)
infant						2	2 (1.4)
Total	19	43	56	10	6	6	140
(Percent)	(13.6)	(30.7)	(40.0)	(7.1)	(4.3)	(4.3)	(100)

APPENDIX B

Specimen Age

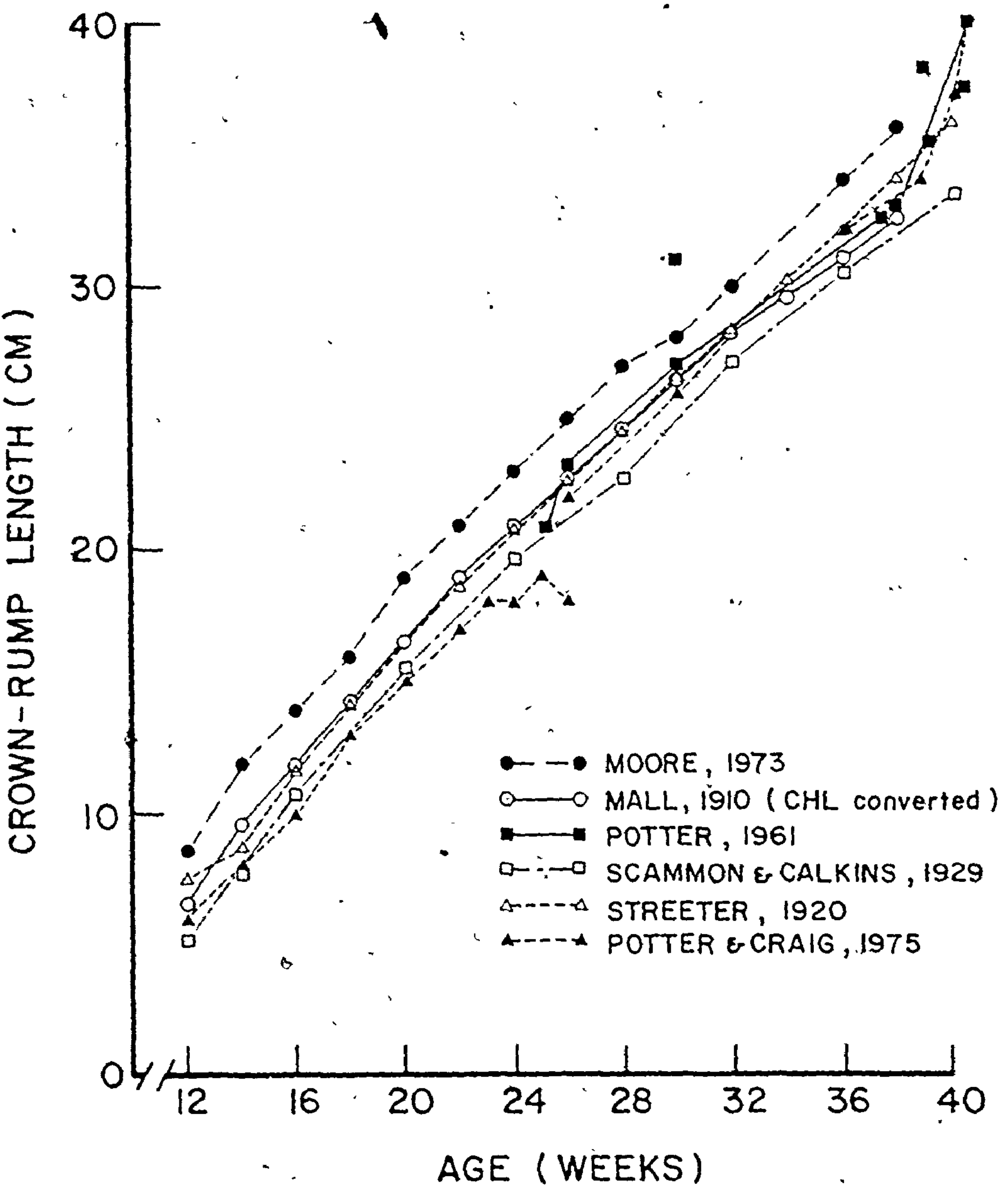


Figure 70 : Age by crown-rump length.
CHL = crown-heel length.

Table 44

Comparison of data from Moore (1973) and Potter and Adair (1949) for specimens of different ages. CRL = crown-rump length (mm), BW = birth weight (g)

Moore (1973)			Potter & Adair (1949)		
Weeks	CRL	BW	BW range	$\bar{X}$ BW	$\bar{X}$ CRL
16	14.0	200			
18	16.0	320			
			250 - 750	550	21.0
20	19.0	420			
22	21.0	630			
24	23.0	820			
			750 - 1250	990	24.7
26	25.0	1000			
28	27.0	1300			
			1250 - 1750	1477	27.9
30	28.0	1700			
32	30.0	2100	1750 - 2250	2006	30.9
34			2250 - 2750	2508	32.9
36	34.0	2900	2750 - 3250	3005	34.8
38	36.0	3400	3250 - 3750	3439	36.3
			3750 - 4250	3945	37.3
40			>4250	4662	39.0*

* only n < 70

APPENDIX C

Record Forms

HIP STUDY RECORD FORM 1

Specimen Number	Source	Hospital Records Checked	Sex	CPL cm	BW gm	Gest.Age weeks	Est. Age Weeks	Photos	Embed	Slides	Stain	Slide Anaylsis

HIP STUDY RECORD FORM 11

Specimen Number	LHF		RL	FHdia.	Acetabular		Aceindex	LHF		RL	FHdia	Acetabular		
	width	length			depth	diameter		width	length			depth	diam.	index

HIP STUDY RECORD FORM 111 : Femoral Angles

Specimen Number	Side	Head-Neck-Shaft	Mean	Torsion	Mean
	Right				
	Left				
	Right				
	Left				

APPENDIX D

Data Frequencies

Table 45: Data frequencies by age groups for normals

Age Groups (weeks)	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	Grand Total
Mean CRL (cm)	10.5	12.9	14.9	17.7	19.9	21.7	23.8	25.1	27.5	28.3	30.0	32.5	34.0	36.0	37.8	39.3	
VARIABLES																	
LHF length	16	18	18	19	15	12	9	8	1	6R 7L	2	3	1	2	4	4	138R 139L
LHF width	16	18	18	19	15	12	9	8	1	6R 7L	2	3	1	2	4	4	138R 139L
Acetabular depth	16	18	18	19	15	12	9	8	1	7	2	3	1	2	5	4	140
Acetabular diameter	16	18	18	19	15	12	9	8	1	7	2	3	1	2	5	4	140
Femoral head diameter	16	18	18	19	15	12	9	8	1	7	2	3	1	2	5	4	140
Femoral torsion	15R 16L	18	18	19	15	11	9	8	1	5	2	3	1	2	5	2	133R 134L
Femoral neck-shaft angle	15R 16L	18	18	19	15	12	9	8	1	7	2	3	1	2	5	4	139R 140L
Birth weight	10	10	18	12	9	4	4	6	0	4	2	2	0	1	2	3	87
Total in each group	16	18	18	19	15	12	9	8	1	7	2	3	1	2	5	4	140

APPENDIX E

ANOVA Tables, Repeated Measurements in Femoral Angles

Table 46: ANOVA, right torsion repeated measurements

Source of Variation	df	SS	MS	F	P(≥ F)
Measurements	5	12.73	2.547	0.63	.6770
set 1 X set 2	1	8.07	8.067	2.00	.1641
other	4	4.67	4.667	0.29	.8836
Femora	9	1968.60	218.733	54.20	.0001
Residual	45	181.66	4.036		
Total (cfm)	59	2162.93			

Table 47: ANOVA, left torsion repeated measurements

Source of Variation	d	SS	MS	F	P(≥ F)
Measurements	5	23.33	4.667	1.24	.3060
set 1 X set 2	1	19.27	19.267	5.12	.0284
other	4	4.07	1.017	.27	.8958
1_1 X 2_1	1	7.20	7.200	1.91	.1733
1_2 X 2_2	1	14.45	14.450	3.84	.0561
1_3 X 2_3	1	1.25	1.250	0.33	.5671
other	2	0.43	0.217	0.06	.8114
Femora	9	1874.07	208.230	55.34	.0001
Residual	45	169.33	3.763		
Total (cfm)	59	2066.73			

Table 48

ANOVA, right neck-shaft angle repeated measurements

Source of Variation	df	SS	MS	F	P(≥F)
Measurements	5	147.53	29.507	3.15	.0158
set I X set 2	1	129.06	129.060	13.78	.0006
other	4	18.47	4.618	0.49	.7409
1_1 X 2_1	1	54.45	54.450	5.81	.0200
1_2 X 2_2	1	26.45	26.450	2.82	.0997
1_3 X 2_3	1	51.20	51.200	5.47	.0238
other	2	15.43	7.717	0.82	.3688
1_1 X 1_3	1	3.20	3.200	0.34	.5618
1_1 X 1_2 X 1_3	1	2.02	2.016	0.22	.6449
2_1 X 2_3	1	2.45	2.450	0.26	.6115
2_1 X 2_2 X 2_3	1	6.02	6.016	0.64	.4270
other	1	133.85	133.851	14.29	.0004
Femora	9	671.33	74.593	7.96	<.0001
Residual	45	421.47	9.367		
Total (cfm)	59	1240.33			

Table 49

ANOVA, left femoral neck-shaft angle repeated measurements

Source of Variation	df	SS	MS	F	P($\geq$F)
Measurements	5	63.13	12.627	5.35	.0006
set 1 X set 2	1	22.14	22.144	9.38	.0037
other	4	40.99	10.247	4.34	.0047
1_1 X 2_1	1	9.80	9.800	4.15	.0473
1_2 X 2_2	1	36.45	36.450	15.44	.0003
1_3 X 2_3	1	11.25	11.250	4.77	.0341
other	2	5.63	2.817	1.19	.3127
1_1 X 2_1	1	8.45	8.450	3.58	.0648
1_1 X 1_2 x 1_3	1	0.02	0.016	0.01	.9346
2_1 X 2_2	1	0.00			
2_1 X 2_2 X 2_3	1	2.40	2.400	1.02	.3185
other	1	52.27	52.267	22.15	<.0001
Femora	9	507.40	56.378	23.89	<.0001
Residual	45	106.20	2.360		
Total (cfm)	59	676.73			

APPENDIX F

Computer Raw Data

Column

1 Case identity number
2 Side, 1 = right, 2 = left
3 Sex, 1 = male, 2 = female
4 Crown-rump length (cm)
5 Birth weight (g)
6 Abortion type, 1 = saline, 2 = prostaglandin, 3 = spontaneous, 4 = neonatal death, 5 = infant death
7 Age in two-weekly groups on crown-rump length (Moore 1973) or gestational age
8 Ligament of the head of femur width (mm)
9 Ligament of the head of femur length (mm)
10 Femoral head diameter (mm)
11 Acetabular depth (mm)
12 Acetabular diameter (mm)
13 Torsion angle (degrees)
14 Neck-shaft angle (degrees)
15 Hip normality grade, 1 = normal bilaterally, 2 = labrum anomaly, 3 = socket anomaly, 4 = dislocatable hip, 5 = dislocated hip, 6 = other (kinked LHF, capsule fold, variant socket shape, excessive pulvinar, hemarthrosis)

Cases are listed in subfile sequence so that identity numbers do not follow in sequence.

	Case Number		
Subfile	First No.	Last No.	Page
"normals"	1	157	267 - 274
"dysnormals"	22	155	274 - 277
abnormal hips	25	154	277
congenital deformity cases	30	158	277 - 278

```
                         COMPUTER RAW DATA
                         -----============

 1  2  3   4      5     6   7     8     9    10    11    12      13     14   15
--------------------------------------------------------------------------------

 1  1  1  25.0 1170.8  3   26    1.23  4.58 10.29 4.10 11.38    7.00 119.60 1
    2                            2.54  5.82 10.67 3.70 11.22   10.00 119.00 1
 2  1  1  11.1  143.0  1   12    1.45  2.18  4.73 2.50  4.70    1.70 125.60 1
    2                            3.90  2.50  4.68 2.30  4.72    1.00 128.30 1
 3  1  2  15.3  330.0  1   16    2.26  3.31  7.09 3.40  7.39    9.30 126.00 1
    2                            1.83  3.23  7.09 3.60  7.22    9.30 126.00 1
 5  1  2  10.2   87.0  1   12    1.00  1.85  4.06 2.20  4.01  -11.30 133.30 1
    2                            1.07  1.85  4.00 2.00  4.04  -11.00 129.60 1
 6  1  1   8.7         1   12     .45   .44  2.93 1.30  2.69                1
    2                             .40   .43  2.89 1.50  2.89   -7.30 125.00 1
 7  1  1   9.1         1   12     .57  1.19  2.98 1.70  3.11  -10.00 126.30 1
    2                             .97  1.02  2.95 1.40  3.13   -4.30 126.00 1
 8  1  2  12.2         1   14    1.39  2.37  4.57 2.10  4.68   -3.70 123.60 1
    2                            1.40  2.76  4.56 2.00  4.65   -6.70 126.00 1
 9  1  1  11.3         1   12    1.30  1.81  4.20 2.10  4.43   -1.00 129.00 1
    2                            1.91  2.03  4.12 1.90  4.39   -1.70 126.60 1
10  1  2  11.1         1   12    1.96  3.06  5.12 2.30  5.06     .70 123.60 1
    2                            1.69  2.85  5.23 2.20  5.48    5.00 117.00 1
11  1  2  12.3         1   14    1.83  2.51  4.81 1.90  4.81    2.30 126.30 1
    2                            1.59  2.31  4.79 2.00  4.81    1.70 121.60 1
12  1  1  12.2         1   14    1.34  2.29  5.12 2.00  4.98    2.30 130.30 1
    2                            1.11  2.47  4.87 2.00  4.98    4.70 127.00 1
13  1  1  13.0         1   14    1.99  1.95  6.09 2.90  6.14    3.00 132.30 1
    2                            2.33  3.33  5.84 2.50  6.06    4.70 127.30 1
14  1  2  11.5         1   12    3.16  3.25  4.95 2.00  5.15    1.70 113.00 1
    2                            1.91  2.69  4.95 1.70  5.03    2.30 125.30 1
15  1  2  12.8         1   14    1.64  2.89  5.17 2.30  5.31    2.30 130.60 1
    2                            1.73  2.59  5.09 2.40  5.09    4.70 123.00 1
```

(CONTINUED)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
16	1	2	12.2		1	14	1.72	4.04	5.40	2.00	5.48	.30	136.00	1
	2						1.81	3.64	5.15	1.90	5.20	2.30	120.60	1
17	1	2	13.2		1	14	1.88	4.06	6.17	2.40	6.17	2.70	135.60	1
	2						2.06	3.88	6.17	2.70	6.17	3.30	127.00	1
18	1	2	10.9		1	12	1.37	1.99	3.65	1.90	3.60	-2.70	134.30	1
	2						1.35	2.23	3.69	1.40	3.76	.30	130.60	1
19	1	2	12.5		1	14	1.81	3.03	4.98	1.90	5.01	3.00	128.00	1
	2						1.82	2.98	5.06	2.53	5.15	5.30	124.00	1
20	1	1	15.3	273.0	1	16	2.37	3.38	6.03	2.10	5.81	5.00	127.60	1
	2						2.03	4.20	5.89	2.06	5.75	4.30	126.60	1
21	1	2	13.7	189.0	1	14	1.84	2.92	5.59	2.77	5.87	11.30	121.30	1
	2						1.93	3.42	5.62	2.20	5.56	7.30	122.30	1
23	1	2	15.4	368.0	1	16	2.60	4.52	6.69	3.33	6.83	5.30	127.60	1
	2						2.05	5.60	6.12	3.66	6.72	9.00	123.30	1
24	1	2	15.5	319.0	1	16	2.03	3.21	7.16	3.23	6.97	17.70	124.60	1
	2						2.07	5.33	7.06	3.10	6.89	13.70	122.30	1
26	1	2	24.7	414.6	3	24	4.00	7.28	9.68	4.10	9.38	24.00	121.30	1
	2						4.18	6.23	9.74	3.73	9.46	23.70	119.00	1
27	1	1	16.1	331.9	1	18	1.69	4.30	6.92	2.53	6.81	8.70	128.00	1
	2						1.78	3.15	6.67	2.63	6.72	14.30	125.30	1
28	1	2	15.1	238.0	1	16	2.08	3.40	6.39	3.67	6.31	10.70	129.30	1
	2						2.28	3.57	6.22	3.13	6.42	9.30	120.60	1
31	1	1	40.0	4321.8	3	42	6.14	10.82	17.99	6.06	18.21	11.70	126.30	1
	2						5.17	8.79	17.87	6.17	18.42	1.70	125.60	1
33	1	1	14.2	162.6	1	16	1.49	3.43	5.42	2.63	5.56	4.70	131.30	1
	2						2.28	3.61	5.42	2.60	5.51	12.70	130.60	1
34	1	2	15.7	34.1	1	16	2.23	4.55	6.42	3.03	6.56	5.00	125.00	1
	2						2.48	4.58	6.39	2.80	6.45	5.00	131.00	1

(CONTINUED)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
35	1	1	36.0	3357.7	3	38	5.15	13.18	15.84	6.23	13.69	27.00	124.30	1
	2						4.56	12.47	15.84	4.83	13.53	26.70	121.60	1
36	1	1	22.2		4	22	4.73	8.77	10.17	4.73	10.39	38.30	123.60	1
	2						4.87	6.94	10.39	4.90	10.34	41.00	125.00	1
38	1	1	24.7	2351.6	3	24	2.98	4.53	9.74	4.16	10.23	15.70	126.00	1
	2						4.15	4.04	10.12	4.36	9.41	13.30	129.30	1
41	1	2	19.6	475.0	2	20	3.26	6.18	8.08	3.53	8.24	12.70	127.00	1
	2						2.95	4.15	8.05	4.20	8.22	15.00	124.30	1
42	1	2	20.6	635.0	2	20	3.12	3.34	8.47	4.50	8.19	24.30	121.60	1
	2						3.24	3.62	8.58	3.53	8.47	26.70	122.30	1
43	1	2	20.8	555.0	2	20	3.09	5.65	8.33	3.37	8.55	13.30	128.30	1
	2						3.28	4.95	8.47	3.76	8.47	21.30	127.00	1
44	1	1	21.8	696.4	2	22	3.03	6.91	9.68	3.60	10.06	10.00	128.60	1
	2						2.68	7.51	9.90	3.87	9.90	4.70	116.60	1
45	1	2	18.1	352.0	2	18	2.85	4.14	7.22	3.83	7.33	20.00	126.00	1
	2						3.66	4.20	7.14	3.97	7.41	31.70	125.00	1
46	1	2	20.3	567.0	2	20	4.04	5.30	9.13	4.03	8.91	11.30	122.30	1
	2						3.92	4.60	8.88	4.13	8.91	17.70	125.60	1
47	1	2	28.5		3	30			13.69	4.73	11.55	23.30	125.30	1
	2						4.81	8.65	12.15	4.96	12.15	17.30	122.60	1
48	1	1	24.0		3	24	4.31	5.75	10.23	4.17	10.18	1.30	126.60	1
	2						3.89	4.71	10.23	4.03	10.39	4.00	121.30	1
49	1	1	23.0		2	24	3.83	8.14	9.90	4.46	10.39	6.30	125.30	1
	2						4.18	5.56	9.68	4.07	10.06	4.70	123.00	1
51	1	2	22.[illegible]		2	24	4.49	2.84	8.71	3.13	8.71	17.30	127.60	1
	2						4.62	3.93	8.69	3.40	8.13	14.00	117.60	1
53	1	1	22.0		2	22	2.88	5.42	9.35	4.20	9.79	18.70	129.30	1
	2						4.04	5.19	9.38	4.17	9.40	24.30	125.60	1

(CONTINUED)
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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
54	1	2	20.0		2	20	3.21	3.77	8.77	4.63	8.96	18.30	127.30	1
	2						3.16	4.60	8.69	4.57	8.94	18.30	124.60	1
56	1	1	21.0		2	22	3.48	4.97	8.52	4.63	8.41		132.60	1
	2						4.28	4.72	8.47	4.06	8.58		123.60	1
57	1	2	20.6		2	20	3.99	5.00	9.13	3.66	9.13	23.30	128.60	1
	2						3.92	4.76	9.21	3.40	9.24	16.00	123.30	1
58	1	1	20.0		2	20	2.77	4.94	7.58	3.50	7.44	4.00	131.00	1
	2						4.08	4.41	7.38	3.50	7.39	14.00	124.60	1
59	1	1			4	40			15.62	7.03	17.16	12.00	126.60	1
	2								14.85	7.00	16.88	21.30	125.30	1
60	1	1	19.2	423.0	2	20	3.48	4.83	8.24	3.30	8.25	11.00	129.30	1
	2						3.48	5.56	8.30	3.73	8.30	17.70	126.00	1
61	1	9			5	52	6.56	7.75	16.55	7.26	16.66			1
	2						6.34	9.56	18.26	7.06	17.16			1
62	1	1			5	50	7.03	9.22	16.00	8.30	16.77			1
	2						6.78	10.54	16.34	6.26	16.50			1
65	1	2	20.0		2	20	4.13	5.16	8.44	3.60	8.88	12.30	129.60	1
	2						4.61	6.32	8.49	4.03	8.71	15.70	124.30	1
67	1	2	20.0	441.0	3	20	2.20	6.94	8.36	3.33	8.08	4.70	128.30	1
	2						2.56	5.35	8.30	3.17	8.16	8.70	123.30	1
68	1	2	22.0	984.9	3	22	5.89	8.83	10.58	3.90	10.23	18.70	124.60	1
	2						4.73	10.48	10.06	4.30	10.45	13.70	119.00	1
69	1	2	22.5	807.5	3	22	3.82	8.45	8.96	4.10	8.99	16.00	129.00	1
	2						3.84	8.23	9.19	3.80	9.10	13.30	125.60	1
70	1	1	14.5	302.0	1	16	2.43	5.06	6.75	2.50	6.67	11.70	131.00	1
	2						2.55	4.92	6.56	3.37	6.45	9.00	127.00	1
71	1	2	13.5	210.0	1	14	1.84	4.04	5.53	2.53	5.51	3.70	131.00	1
	2						1.85	4.37	5.64	2.60	5.37	7.00	127.30	1

(CONTINUED)
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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
76	1	1	15.9	266.2	1	16	2.21	4.94	6.53	3.17	6.53	1.30	124.00	1
	2						2.15	5.01	6.56	2.80	6.69	3.30	125.60	1
77	1	2	14.2	183.2	1	16	1.50	4.47	5.73	2.60	5.73	9.30	126.60	1
	2						2.13	4.08	5.64	2.80	5.48	16.70	122.60	1
79	1	2	25.5	1279.9	3	26	5.09	10.64	11.27	5.10	11.50	28.30	123.30	1
	2						2.03	10.42	11.17	5.13	11.50	28.30	126.60	1
80	1	2	13.6	247.0	1	14	1.95	6.09	6.36	3.00	6.64	19.00	128.60	1
	2						2.01	3.91	6.59	3.00	6.47	17.00	127.30	1
83	1	2	17.0	431.5	1	18	2.79	7.05	7.50	3.55	7.58	20.30	125.00	1
	2						2.91	6.01	7.39	3.43	7.50	31.00	126.30	1
85	1	1	16.0	350.0	3	18	3.11	3.61	7.47	3.77	7.55	11.00	125.30	1
	2						2.72	4.27	7.47	3.40	7.58	7.70	126.00	1
86	1	2	9.8	60.0	1	12	1.39	1.66	3.47	1.40	3.55	.70	122.30	1
	2						1.29	1.52	3.37	1.60	3.52	2.00	123.30	1
88	1	2	13.7	248.9	1	14	2.28	4.61	6.34	3.00	6.34	8.00	126.30	1
	2						2.56	3.75	6.28	3.03	6.50	4.30	123.30	1
90	1	2	13.0	132.0	1	14	1.68	2.72	4.79	2.30	4.87	-2.30	125.30	1
	2						1.37	2.19	4.65	2.40	4.87	1.30	124.00	1
91	1	2	13.8	178.5	1	14	1.81	3.84	5.15	2.17	5.37	24.00	126.60	1
	2						1.60	3.06	5.15	2.40	5.40	9.30	125.00	1
92	1	2	15.5	255.2	3	16	1.24	2.72	5.95	2.33	5.98	-1.70	127.60	1
	2						1.65	3.44	5.95	2.43	6.06	4.00	123.00	1
102	1	1	14.7	204.1	1	16	2.72	3.63	5.81	3.10	5.95	2.70	129.00	1
	2						2.80	3.22	5.81	3.00	5.89	17.30	124.00	1
103	1	2	9.2	55.3	1	12	.59	1.98	3.63	1.90	3.72	1.00	127.60	1
	2						.87	1.89	3.60	1.97	3.64	-10.00	126.60	1
104	1	1	14.2	204.8	1	16	2.00	3.99	6.14	2.60	6.03	5.30	126.30	1
	2						.87	3.49	6.00	2.53	6.03	9.70	128.60	1

(CONTINUED)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
105	1	1	17.2	352.8	1	18	3.56	5.58	7.80	3.80	7.88	18.30	126.60	1
	2						3.40	5.60	7.72	3.80	7.72	21.70	123.00	1
106	1	2	17.8	330.0	1	18	3.56	5.58	7.80	3.80	7.88	14.70	119.00	1
	2						3.40	5.60	7.72	3.80	7.72	21.30	121.30	1
107	1	1	9.1	49.2		12	.77	1.66	2.93	1.70	3.20	1.60	117.30	1
	2						.82	1.35	3.04	1.60	3.20	-5.30	128.00	1
108	2	1	15.4	216.1	1	16	2.29	4.36	6.61	3.17	6.69	8.60	121.00	1
	2						2.00	4.46	6.69	3.26	6.75	7.60	123.60	1
109	1	2	10.7	93.3	1	12	1.63	2.28	4.20	1.90	4.40	2.00	123.60	1
	2						1.14	2.23	4.16	1.80	4.41	-2.60	119.30	1
110	1	2	16.7	538.2	1	18	2.85	6.31	8.38	3.87	8.33	30.30	120.30	1
	2						3.36	6.65	8.22	4.10	8.25	24.30	120.60	1
111	1	1	11.7	104.4	1	12	1.77	2.32	4.32	1.90	4.32	3.00	122.00	1
	2						1.20	2.48	4.28	2.00	4.19	-8.60	127.00	1
114	1	2	25.0	960.0	4	26	4.65	9.22	10.23	4.67	9.90	23.30	123.60	1
	2						4.56	5.42	10.39	4.67	9.90	19.30	121.60	1
117	1	1	17.1	352.2	1	18	2.32	5.19	7.06	3.03	7.19	20.00	125.30	1
	2						2.35	5.13	6.97	3.20	7.06	25.30	124.60	1
118	1	1	18.7		2	18	4.20	6.49	9.52	3.90	9.10	24.00	121.60	1
	2						3.27	6.90	9.30	3.40	8.77	24.30	123.60	1
119	1	2	19.4		2	20	3.49	5.41	9.40	4.63	9.85	9.30	122.60	1
	2						3.35	4.77	9.57	4.90	9.90	19.60	123.30	1
121	1	2	19.5		2	20	3.67	5.24	9.55	5.00	9.68	18.30	126.00	1
	2						3.76	5.54	9.46	4.37	9.74	20.00	123.30	1
125	1	2	17.6		2	18	3.57	4.56	8.00	4.10	7.72	13.00	123.60	1
	2						2.61	3.41	8.05	4.47	7.86	8.60	121.30	1

(CONTINUED)
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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
126	1	1	24.4		2	24	4.29	7.84	9.95	4.26	10.73	28.00	120.00	1
	2						5.78	11.37	10.06	4.40	10.67	26.30	125.30	1
132	1	1	21.6		2	22	4.60	6.52	9.63	3.93	9.21	7.00	124.60	1
	2						4.61	5.23	9.71	4.80	9.77	10.30	122.30	1
133	1	1	28.9		3	30	4.73	8.76	13.86	5.53	14.63	15.60	126.30	1
	2						6.64	10.38	13.86	5.33	14.69	19.60	123.60	1
135	1	1	25.0		3	26	5.42	7.72	10.89	4.30	10.73	10.30	123.30	1
	2						4.87	6.26	10.83	4.50	11.32	20.00	122.60	1
136	1	1	17.9	460.0	2	18	1.92	5.35	7.94	3.60	7.97	-2.60	125.00	1
	2						2.23	4.29	7.88	3.50	8.05	-3.00	121.60	1
137	1	1	18.3	446.0	2	18	3.43	3.46	7.83	3.20	7.94	4.00	126.00	1
	2						2.75	4.77	7.80	3.60	7.86	10.60	124.00	1
138	1	1	18.1	418.0	2	18	2.79	4.82	7.66	3.70	7.83	13.30	121.30	1
	2						2.85	4.10	7.47	3.90	7.47	17.30	123.00	1
140	1	2		1785.0	4	30	5.45	9.06	11.55	4.40	12.05		123.60	1
	2						6.78	10.12	11.88	4.37	12.98		119.60	1
143	1	2		1512.0	3	34	6.28	9.40	12.37	5.10	12.70		125.00	1
	2						6.56	9.54	11.88	4.90	12.70		120.00	1
144	1	1			4	42	6.22	10.69	17.16	6.00	16.66		124.00	1
	2						7.22	8.96	16.34	6.10	15.95		123.30	1
146	1	1		3334.0	4	42	9.32	12.69	16.66	6.70	18.21		124.00	1
	2						8.13	15.43	17.11	6.93	17.54		125.00	1
150	1	1	25.0	1163.4	4	26	4.15	8.12	10.89	4.80	11.06	21.60	125.30	1
	2						3.73	8.14	11.22	4.90	10.89	19.00	124.00	1
152	1	2	11.6	114.4	1	12	1.36	3.44	4.62	2.00	4.65	-3.00	128.00	1
	2						1.56	2.96	4.56	1.80	4.56	6.00	126.60	1
156	1	2	28.0			30	4.29	8.86	13.04	5.10	12.70	34.30	130.60	1
	2						4.59	7.95	13.04	5.57	12.54	30.00	125.00	1

(CONTINUED)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
157	1	2	38.0	2131.5	3	40	5.95	10.63	17.16	6.20	17.33	18.00	124.60	1
	2						5.84	10.50	16.66	5.90	15.79	20.60	122.60	1
22	1	2	17.3	135.0	1	18	2.59	6.11	7.47	3.50	7.55	16.70	124.60	1
	2						2.76	6.20	7.30	2.93	7.91	18.30	123.30	2
29	1	2	15.3	294.2	1	16	2.37	4.09	6.72	2.73	6.56	20.30	127.30	2
	2						3.05	4.33	6.75	3.07	6.75	22.00	124.60	1
32	1	1	14.1	165.4	1	16	1.68	2.66	5.59	3.10	5.67	11.70	125.30	1
	2						1.83	4.62	5.64	2.40	5.67	4.30	125.60	2
37	1	1	28.0	1634.1	3	30	3.84	11.86	12.15	4.80	13.25	10.00	118.00	2
	2						5.06	10.44	12.21	5.13	11.60	17.30	124.00	2
39	1	2	34.0		3	36	6.75	9.53	15.01	5.33	13.53	23.30	128.00	2
	2						5.78	9.41	15.35	5.26	15.35	25.30	123.60	2
40	1	2	19.8	616.0	1	20	2.16	5.53	8.47	3.56	9.16	29.00	125.60	1
	2						3.60	6.77	7.94	4.13	8.38	27.00	123.60	6
50	1	1	22.0		2	22	3.49	6.09	9.74	4.40	10.06	21.30	123.30	1
	2						3.77	5.82	9.74	3.47	10.18	22.30	122.30	6
52	1	1			3	40	8.38	11.29	17.93	5.90	18.87	26.30	120.30	1
	2						7.36	11.81	18.48	6.00	18.75	37.30	124.60	6
55	1	2		880.0	3	24	4.25	8.74	9.74	3.07	9.57	27.00	127.00	2
	2						4.48	7.00	9.57	2.90	10.06	24.00	127.30	2
63	1	2	21.3	519.0	2	22	3.99	6.70	9.32	4.20	9.60	29.00	127.00	1
	2						3.91	7.14	9.24	4.26	8.38	24.70	122.30	2
64	1	1	25.0		2	26	3.71	5.46	10.73	4.63	9.79	15.70	127.60	6
	2						4.15	7.43	10.29	4.77	9.74	17.00	125.30	6
72	1	2	30.0	1800.7	3	32	7.08	11.88	14.30	6.00	14.96	30.30	121.30	1
	2						6.67	10.31	14.52	5.63	14.19	35.30	118.60	6

(CONTINUED)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
101	1	1	14.1	204.9	1	16	1.99	3.75	5.40	2.87	5.56	.30	130.00	1
	2						2.25	3.42	5.45	2.76	5.81	-4.00	127.30	2
112	1	1	10.4	54.3	1	12	.72	2.69	3.65	1.60	3.73	1.30	121.60	2
	2						1.29	1.88	3.56	2.00	3.76	3.60	130.00	1
113	1	1	20.0	794.0	4	20	4.17	6.80	9.40	4.17	9.40	31.60	125.30	6
	2						4.49	4.80	9.24	4.27	9.40	32,60	121.00	1
120	1	2	18.5		2	18	3.53	3.86	9.05	3.90	9.21	5.60	122.60	2
	2						3.60	4.56	9.05	4.13	8.96	11.60	121.30	1
122	1	1	18.5		2	18	3.60	4.47	8.80	3.43	8.60	26.00	122.00	2
	2						3.48	5.50	8.80	4.20	8.80	29.30	121.30	2
123	1	2	17.9		2	18	3.27	5.28	8.22	3.33	8.71	20.30	123.30	2
	2						2.79	4.70	8.25	3.67	8.30	29.60	122.00	1
124	1	2	18.7		2	18	3.44	5.40	8.71	3.70	8.38	24.60	125.00	2
	2						3.44	7.01	8.88	3.00	8.13	26.00	122.30	2
127	1	1	23.6		2	24	2.49	6.89	9.57	3.60	8.91	29.60	119.30	2
	2						3.28	5.46	9.73	3.90	9.71	15.00	119.30	1
128	1	1	18.5		2	18	3.43	6.15	8.88	3.80	8.35	10.60	128.60	2
	2						3.41	5.32	8.88	3.40	8.63	13.60	124.30	2
129	1	2	21.0		2	22	3.90	7.48	8.38	3.73	8.38	11.00	123.30	2
	2						2.68	6.32	8.52	3.87	8.66	19.60	119.30	2
130	1	2	22.3		2	22	4.44	6.25	9.55	3.20	8.63	19.30	123.30	6
	2						2.99	7.82	9.52	3.40	8.44	23.00	120.60	6
131	1	2	21.0		2	22	3.55	6.11	9.21	3.60	8.71	4.60	126.30	2
	2						3.36	5.67	9.31	3.50	9.21	13.60	121.30	1
134	1	2	28.2	1134.0	3	30	4.40	8.66	10.23	4.10	10.39	32.00	122.00	2
	2						2.77	6.12	10.56	4.00	11.38	22.30	122.60	1
139	1	2		1926.8	3	30	7.22	9.53	12.49	6.00	13.53		123.30	2
	2						6.11	8.24	12.87	5.70	12.81		122.00	1

(CONTINUED)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
73	1	1	11.9	119.5	1	12	2.01	3.46	4.87	1.93	4.34	14.00	129.60	2
	2						1.63	3.21	4.93	2.23	4.93	14.30	127.60	1
74	1	1	12.2	130.0	1	14	1.51	2.83	4.95	2.80	4.81	.30	128.60	2
	2						1.71	3.13	4.90	2.60	4.93	2.30	126.00	1
75	1	1	13.2	191.2	1	14	2.17	3.40	5.73	2.80	5.53	.30	128.30	2
	2						2.03	3.81	5.75	2.40	5.75	3.00	126.30	1
78	1	2	13.9	186.4	1	14	1.55	4.15	5.67	2.50	5.73	4.30	126.30	1
	2						1.77	3.95	5.59	2.43	5.59	5.70	126.30	2
81	1	1	14.5	312.7	3	16	2.56	4.37	6.72	3.00	6.89	8.30	117.30	2
	2						2.12	4.06	6.64	2.93	6.81	12.30	119.30	2
82	1	2	32.0		3	34	6.34	10.02	14.25	6.97	15.18	30.30	125.30	6
	2						7.39	11.56	14.30	6.23	14.96	31.30	121.60	1
84	1	1	36.0		4	38	6.45	9.01	13.86	5.55	14.19	22.70	125.30	2
	2						5.98	9.57	14.41	5.72	14.02	25.30	121.30	2
89	1	1	12.0	129.0	1	14	1.73	2.66	4.90	2.17	4.70	-1.00	128.30	6
	2						1.42	2.80	4.76	2.30	4.84	2.30	124.00	1
93	1	1	19.0	546.0	3	20	3.79	4.90	8.69	4.37	8.30	9.00	128.00	2
	2						3.76	2.85	8.47	4.30	8.47	11.70	126.30	1
95	1	1	48.0	4441.5	3	50	5.84	12.53	18.64	6.60	18.75	18.00	128.30	2
	2						6.31	12.86	18.26	6.60	18.81	22.70	124.60	1
97	1	2	25.0	1131.5	4	26	4.95	7.89	10.73	5.50	10.94	16.30	124.60	1
	2						4.63	8.50	10.89	5.70	11.00	17.00	123.30	2
98	1	1	25.0	1407.0	4	26	4.73	8.88	12.87	5.00	12.54	19.00	124.30	2
	2						5.09	7.61	12.70	5.10	12.49	19.70	125.30	2
99	1	1	38.5	5491.5	5	42	6.64	12.39	20.00	9.30	19.47	19.30	133.30	2
	2						6.39	14.13	20.00	9.10	19.03	19.70	127.00	2
100	1	2	37.5	4725.0	5	40	6.06	12.18	18.04	7.40	17.82	21.70	131.00	2
	2						6.25	13.32	17.71	8.17	18.15	22.70	129.00	1

(CONTINUED)

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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
142	1	1			5	58	5.81	11.77	19.30	8.40	18.37		130.30	1
	2						8.71	12.36	18.98	8.40	17.60		129.30	6
148	1	1	23.0	840.0	4	24	4.01	7.28	10.23	3.93	9.90	8.00	127.00	1
	2						4.44	7.70	9.74	4.00	9.57	15.60	124.30	6
149	1	1	30.0	4669.5	4	32	4.65	7.42	12.21	4.90	12.21	31.30	125.00	6
	2						5.95	6.35	12.05	5.17	12.37	31.00	123.00	1
151	1	2	33.0	2814.0	4	34	5.01	9.28	14.80	5.33	14.85	20.00	124.00	2
	2						4.59	8.59	14.69	5.50	15.01	27.00	122.00	2
153	1	1	27.5		3	28	4.16	10.39	12.70	5.40	13.20	16.30	123.60	2
	2						3.52	10.93	12.70	5.50	13.20	22.30	126.60	2
155	1	2	38.0		3	40	8.38	8.91	16.17	5.10	15.68	11.60	124.60	2
	2						6.80	8.57	16.45	5.40	16.17	18.60	120.00	2
25	1	1	16.5	350.0	1	18	2.01	4.71	7.14	2.83	7.08	5.30	124.30	3
	2						2.79	4.75	7.25	3.00	6.61	6.70	122.60	2
66	1	9			3	40	4.09	10.99	17.49	6.00	17.99		124.00	3
	2						8.05	11.22	17.33	6.50	17.99		122.60	2
87	1	2	9.7	60.6	1	12	.99	3.56	3.19	1.50	3.69	-3.30	123.30	3
	2						.77	1.63	3.29	1.57	3.48	-1.70	124.00	1
115	1	2	18.0	278.3	3	18	2.43	5.00	6.22	2.20	6.06	-9.00	123.00	3
	2						3.16	4.22	6.39	2.13	6.31	-4.30	122.30	1
116	1	2	26.0	651.0	3	26	3.51	5.30	8.05	3.43	7.91	19.60	122.30	2
	2						3.31	6.08	8.19	2.20	4.37	13.30	123.60	5
147	1	1	33.0	2947.4	3	34	4.70	12.27	16.06	5.70	16.00	25.60	126.00	3
	2						5.56	8.22	15.95	5.60	16.00	29.60	123.60	3
154	1	2	38.0	3097.5	3	40	6.56	9.57	17.00	4.43	16.00	20.00	122.00	3
	2						4.90	11.75	17.00	4.40	16.17	23.30	120.30	3
30	1	1	29.4	1964.6	3	30	4.37	10.82	14.52	5.20	13.80	32.70	124.60	6
	2						4.28	9.43	13.53	5.60	14.41	25.70	123.00	6

(CONTINUED)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
94	1	1	28.0	2857.1	4	30	4.81	9.02	14.02	6.60	14.46	-8.00	125.00	2
	2						5.34	7.70	12.70	4.80	11.27	-32.00	116.00	2
96	1	2	24.0	2478.0	4	36	6.64	10.79	15.13	6.90	15.68	18.70	124.60	1
	2						6.47	8.74	14.85	6.30	15.35	19.70	121.60	2
141	1	2		2121.0	3	40	6.84	10.19	12.70	4.30	11.55		125.00	3
	2						6.31	9.54	11.88	1.60	9.90		123.60	3
145	1	2	24.0	3202.5	4	36	5.98	9.85	16.00	6.20	15.40		127.00	2
	2						5.98	9.46	15.51	6.10	14.08		124.60	1
158	1	2	20.0	768.6	2	20	3.60	5.75	10.73	4.80	10.89	21.60	123.00	1
	2						4.65	6.93	10.56	4.90	11.06	28.30	121.00	1
159	1		25.5	1025.9		26	4.76	6.08	111222	4.33	10.89	25.30	112.63	1
	2						4.62	5.67	11.05	4.30	11.05	24.60	122.00	1

APPENDIX G

Scatterplots of Values for "Normal" and "Dysnormal" Cases by Side, Sexes Combined

The frequency of values at each specific coordinate is not given. LHF = ligament of the head of femur. Ligament of the head of femur width is presented in Figure 24.

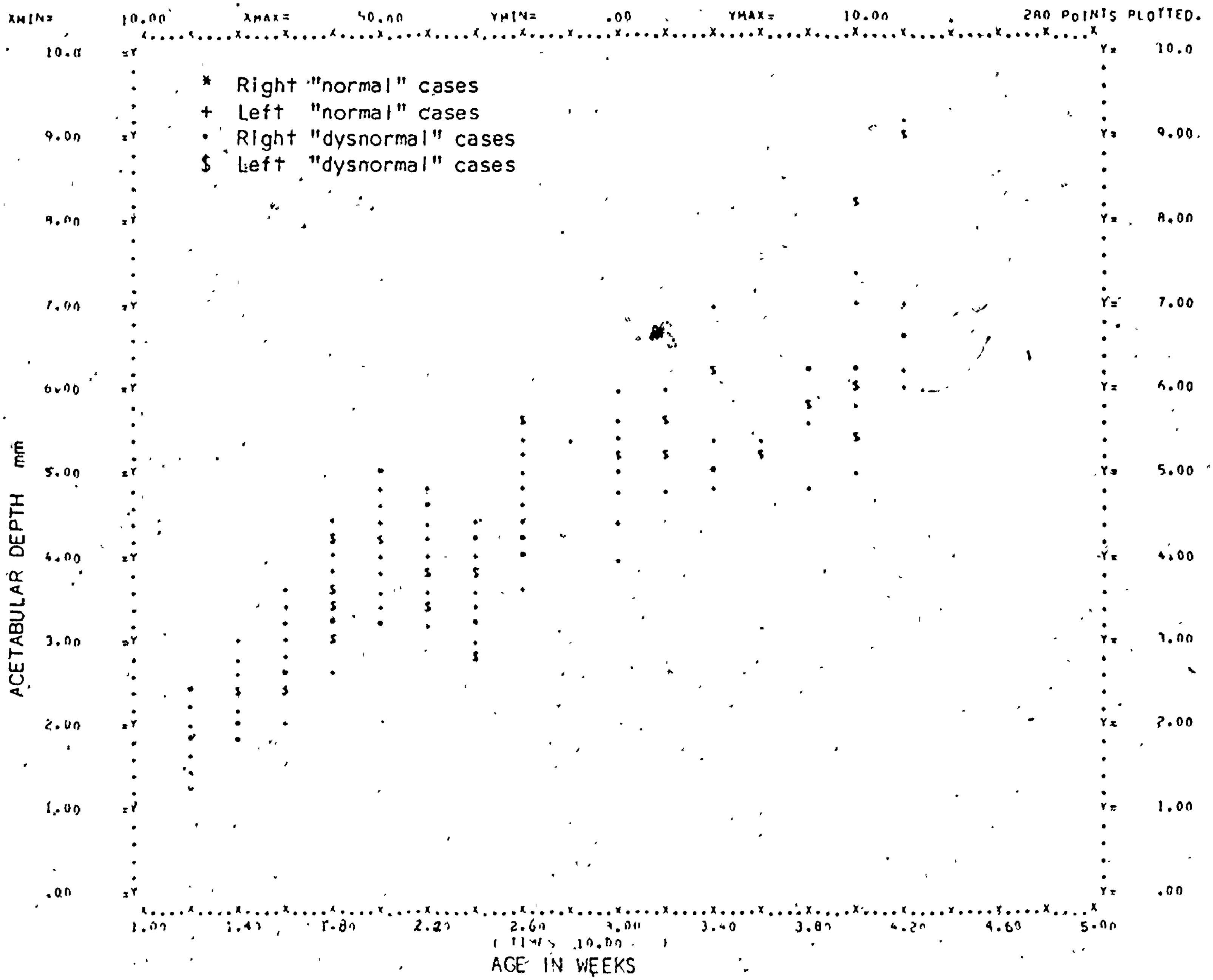

Figure 71 : Acetabular depth in "normal" and "dysnormal" cases by side

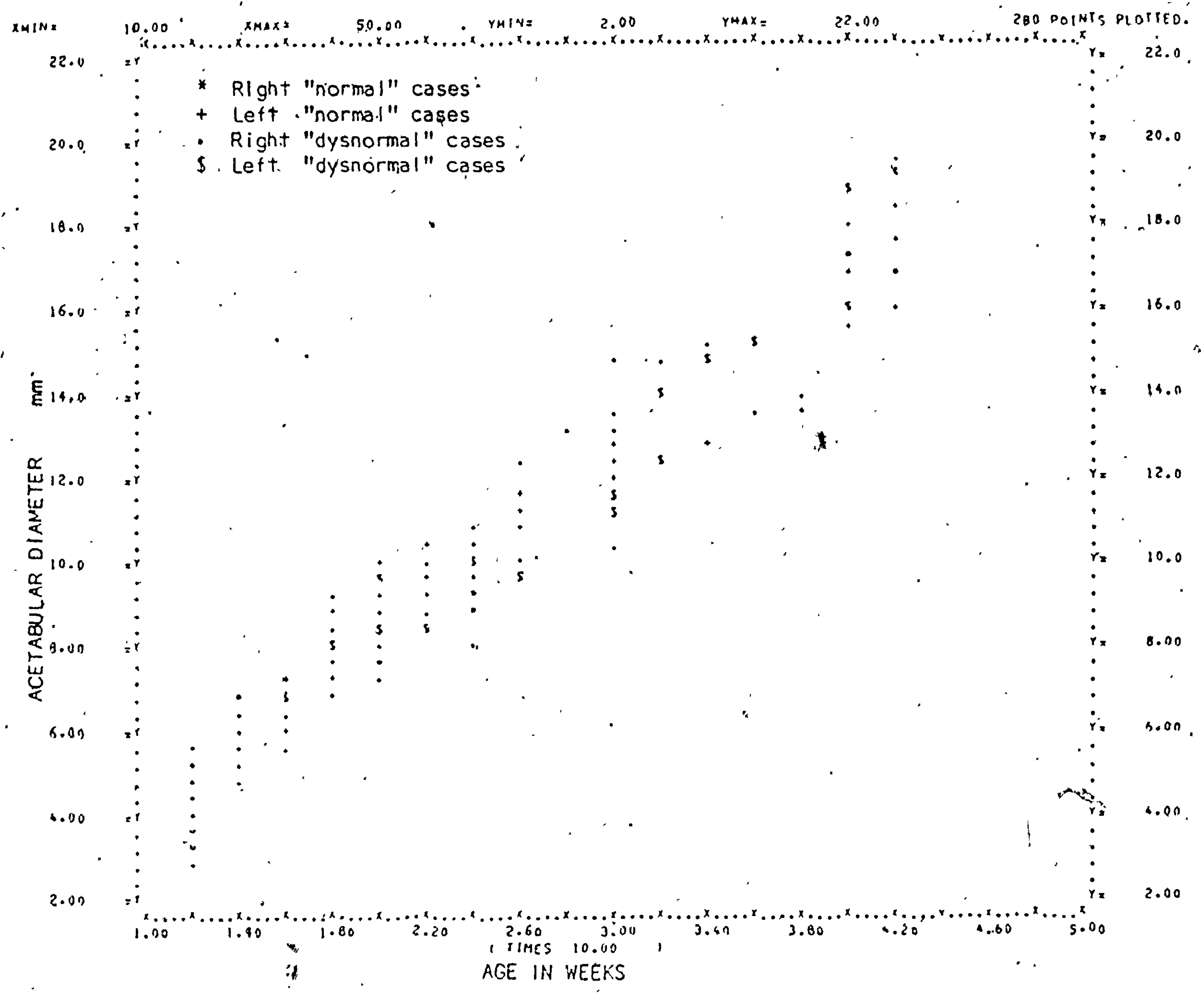

Figure 72 : Acetabular diameter in "normal" and "dysnormal" cases by side

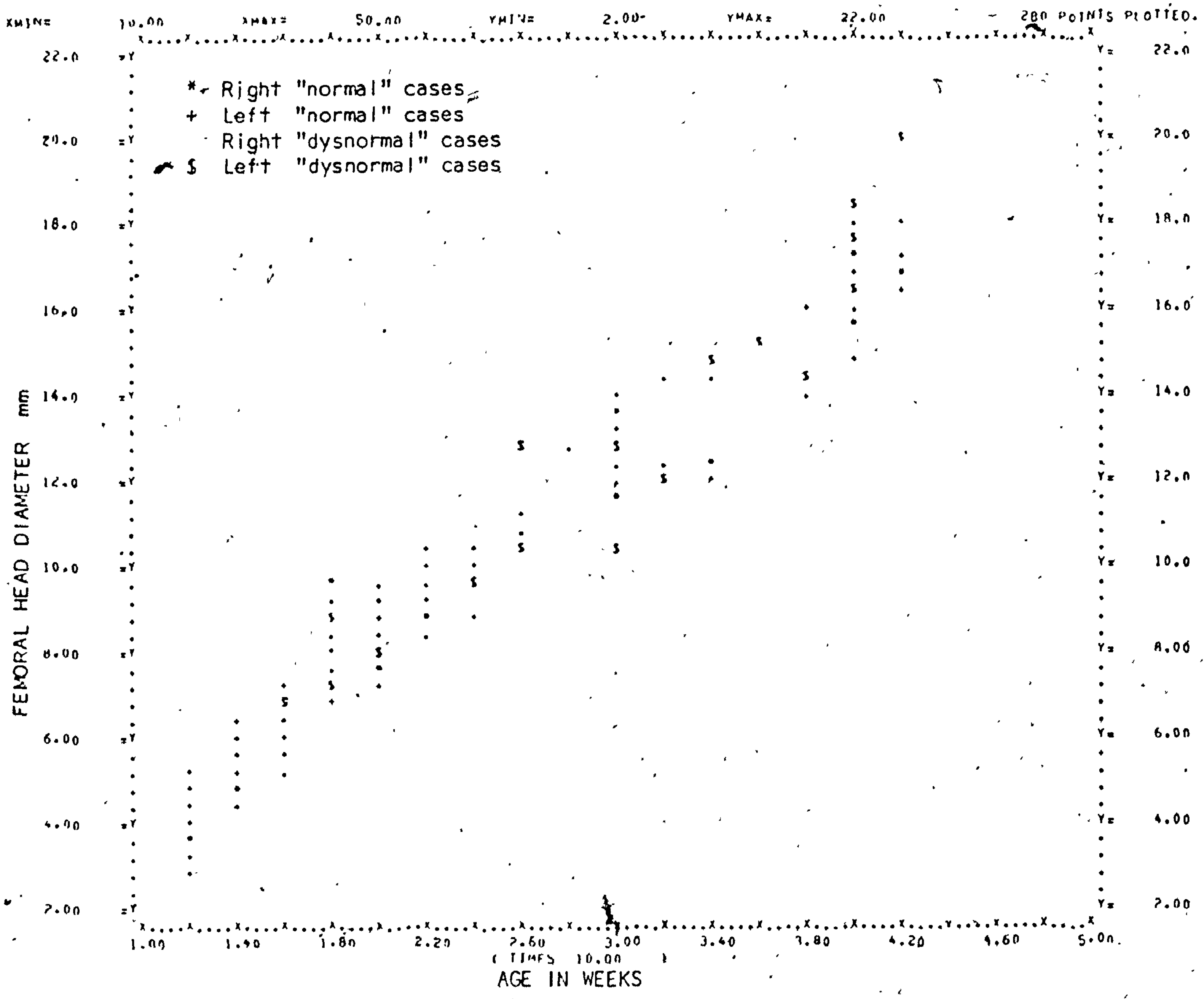

Figure 73 : Femoral head diameter in "normal" and "dysnormal" cases by side

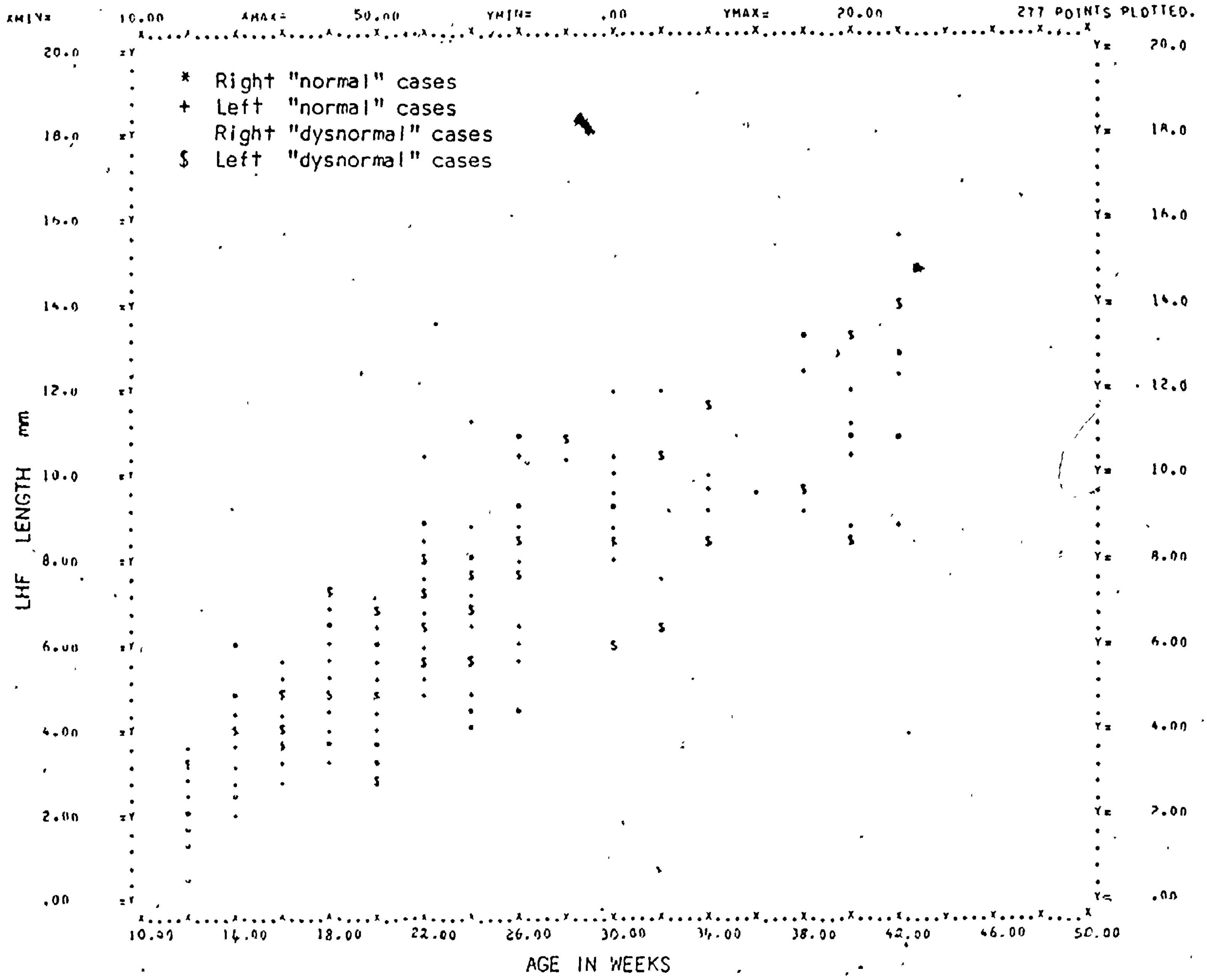

Figure 74 : LHF length in "normal" and "dysnormal" cases by side

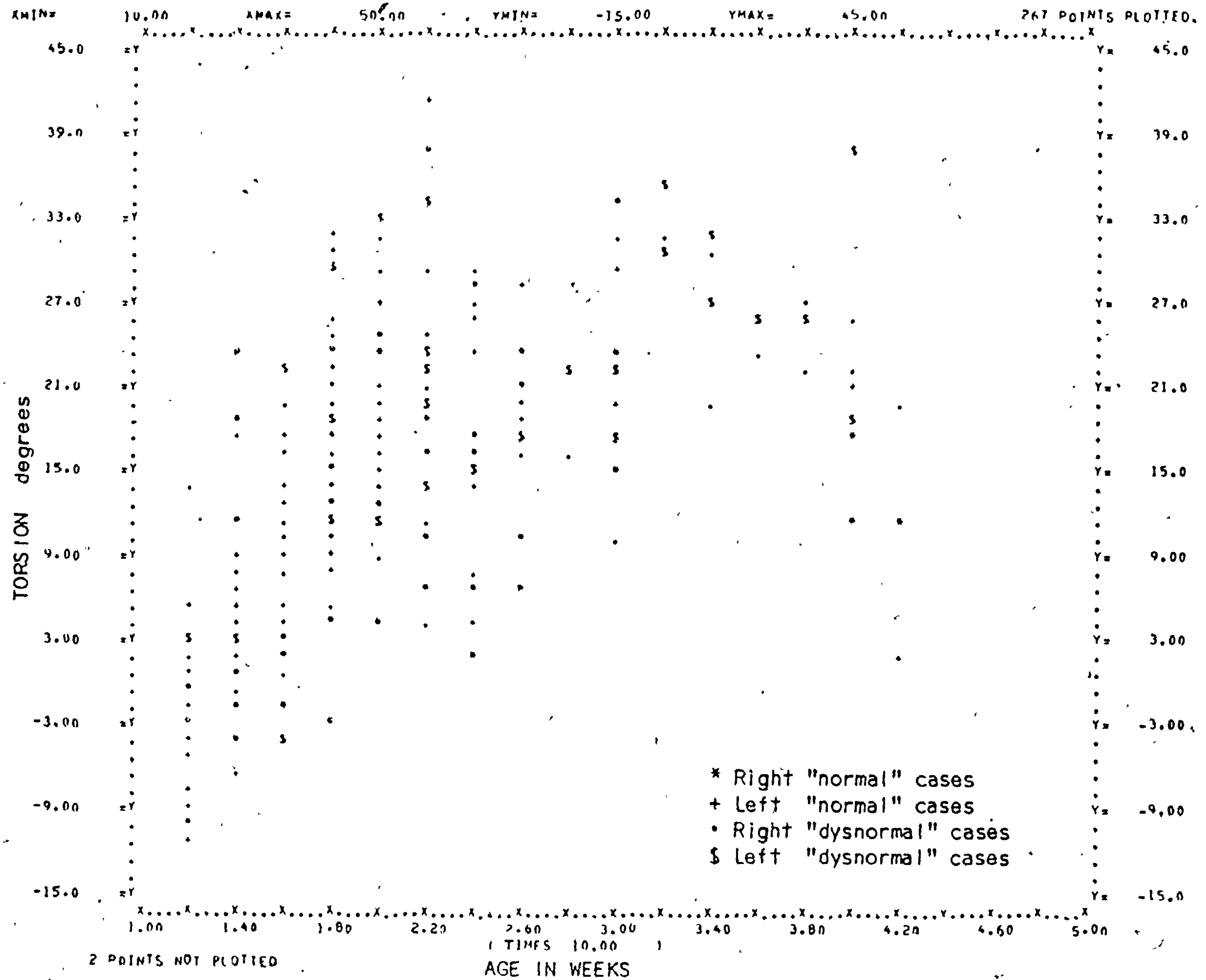

Figure 75 : Torsion in "normal" and "dysnormal" cases by side

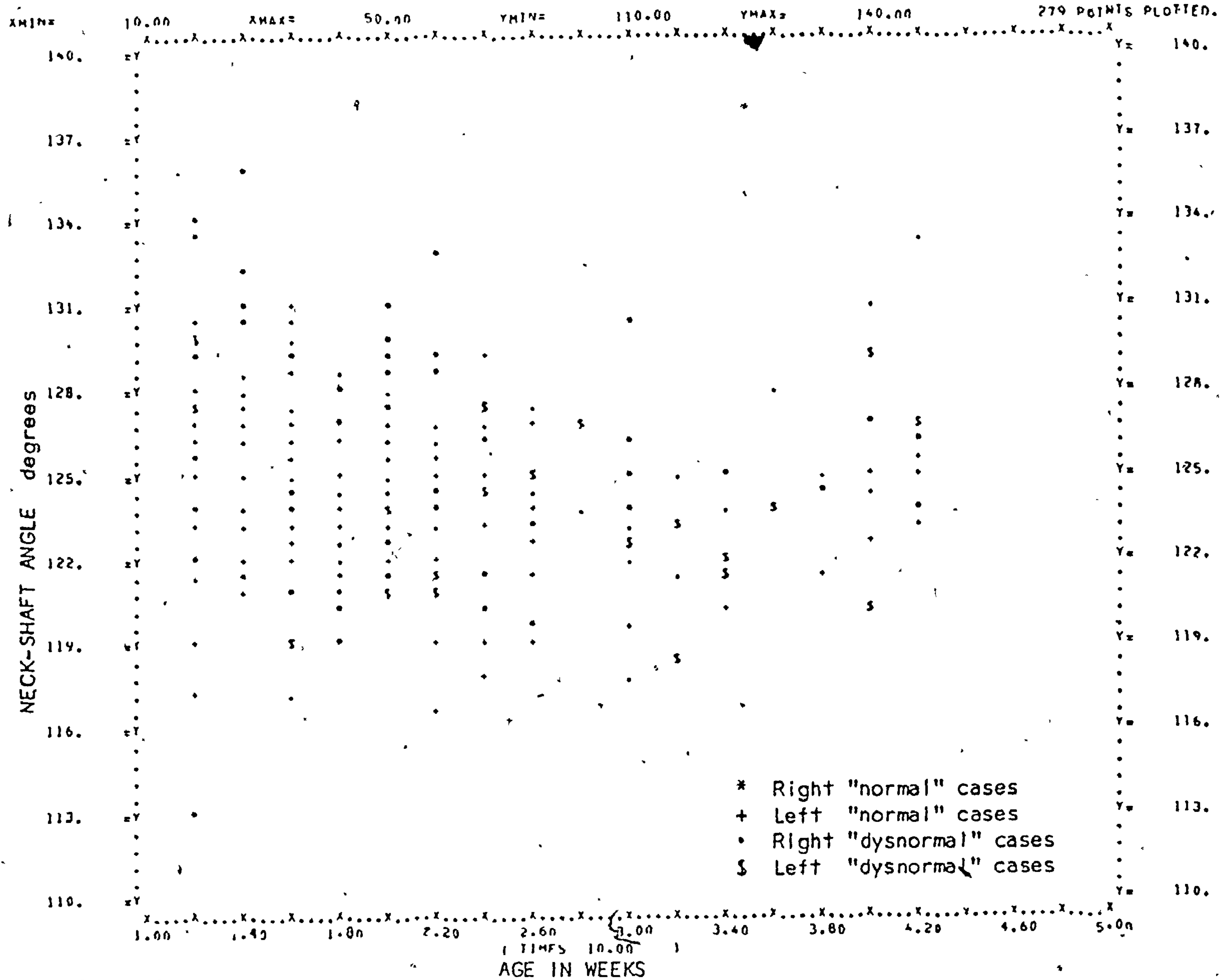

Figure 76 : Neck-shaft angle in "normal" and "dysnormal" cases by side

APPENDIX H

Age Groups by Sex and Side

Mean values and standard deviations, in mm, angles in degrees, LHF = ligament of the head of femur, R = right, L = left, suprascript = n of observations.

<u>Table</u>

50: Age group 12 weeks

51: Age group 14 weeks

52: Age group 16 weeks

53: Age group 18 weeks

54: Age group 20 weeks

55: Age group 22 weeks

56: Age group 24 weeks

57: Age group 26 weeks

58: Age groups 28 and 36 weeks

59: Age group 30 weeks

60: Age group 32 weeks

61: Age groups 34, 38 and 42 weeks

62: Age group 40 weeks

APPENDIX H

Table 50: Age group 12 weeks. Superscript = n of observations

VARIABLE	SIDE	SEXES COMBINED $\overline{X}$	SEXES COMBINED SD	MALES $\overline{X}$	MALES SD	FEMALES $\overline{X}$	FEMALES SD
Crown-rump length		10.52	1.05	10.40	1.28	10.61	0.84
LHF length	R	2.20	0.83	1.97	0.92	2.44	0.70
	L	2.07	0.74	1.86	0.90	2.28	0.52
LHF width	R	1.34	0.69	1.13	0.59	1.56	0.76
	L	1.44	0.77	1.51	1.07	1.36	0.34
Femoral head diameter	R	4.02	0.73	3.83	0.81	4.21	0.63
	L	4.00	0.74	3.81	0.81	4.20	0.67
Acetabular diameter	R	4.04	0.71	3.82	0.74	4.27	0.64
	L	4.10	0.29	3.90	0.77	4.31	0.70
Acetabular depth	R	1.90	0.31	1.84	0.36	1.95	0.27
	L	1.84	0.29	1.87	0.33	1.81	0.25
Femoral neck-shaft angle	R	125.14	5.64^{15}	124.49	4.42^{7}	125.71	6.79
	L	126.05	3.64	127.31	1.53	124.79	4.73
Torsion angle	R	0.65	4.88^{15}	1.51	7.04^{7}	0.11	1.96
	L	0.69	6.76	-1.04	7.43	0.35	6.52
TOTAL		n = 16		n = 8		n = 8	

APPENDIX H cont.

Table 51: Age group 14 weeks

VARIABLE	SIDE	SEXES COMBINED $\overline{X}$	SEXES COMBINED SD	MALES $\overline{X}$	MALES SD	FEMALES $\overline{X}$	FEMALES SD
Crown-rump length (cm)		12.94	0.66	12.52	0.54	13.11	0.65
LHF length	R	3.36	1.02	2.63	0.55	3.64	1.04
	L	3.24	0.64	3.11	0.51	3.29	0.69
LHF width	R	1.78	0.24	1.75	0.34	1.79	0.21
	L	1.78	0.35	1.72	0.48	1.81	0.31
Femoral head diameter	R	5.41	0.56	5.36	0.53	5.43	0.52
	L	5.36	0.60	5.22	0.53	5.41	0.64
Acetabular diameter	R	5.44	0.60	5.23	0.60	5.52	0.61
	L	5.41	0.58	5.31	0.56	5.45	0.60
Acetabular depth	R	2.42	0.38	2.53	0.42	2.37	0.38
	L	2.41	0.32	2.36	0.23	2.43	0.35
Femoral neck-shaft angle	R	128.52	3.75	129.56	1.74	128.12	4.28
	L	124.91	2.13	126.12	1.30	124.44	2.24
Torsion angle	R	4.43	7.15	0.98	1.63	5.76	8.04
	L	4.42	4.58	3.40	1.22	4.81	5.36
TOTAL		n = 18		n = 5		n = 13	

APPENDIX H cont.

Table 52: Age group 16 weeks

VARIABLE	SIDE	SEXES COMBINED		MALES		FEMALES	
		$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Crown-rump length (cm)		14.94	0.62	14.69	0.63	15.25	0.46
LHF length	R	3.88	0.71	3.96	0.74	3.78	0.71
	L	4.18	0.74	4.10	0.65	4.27	0.87
LHF width	R	2.11	0.41	2.17	0.39	2.04	0.71
	L	2.13	0.47	2.09	0.51	2.19	0.43
Femoral head diameter	R	6.29	0.55	6.10	0.53	6.52	0.51
	L	6.22	0.53	6.07	0.50	6.40	0.52
Acetabular diameter	R	6.32	0.55	6.14	0.51	6.54	0.54
	L	6.30	0.53	6.14	0.49	6.50	0.54
Acetabular depth	R	2.92	0.40	2.82	0.36	3.04	0.45
	L	2.91	0.42	2.77	0.40	3.07	0.41
Femoral neck-shaft angle	R	126.49	3.45	126.28	4.54	126.75	1.54
	L	125.09	3.15	125.82	3.08	124.18	3.19
Torsion angle	R	7.53	5.69	5.96	4.02	9.49	7.06
	L	9.19	6.10	7.65	5.99	11.13	6.04
TOTAL		n = 18		n = 10		n = 8	

APPENDIX H cont.

Table 53: Age group 18 weeks

VARIABLE	SIDE	SEXES COMBINED $\overline{X}$	SEXES COMBINED SD	MALES $\overline{X}$	MALES SD	FEMALES $\overline{X}$	FEMALES SD
Crown-rump length (cm)		17.68	0.83	17.64	0.99	17.73	0.66
LHF length	R	5.14	1.02	4.94	1.01	5.37	1.05
	L	5.13	1.12	4.90	1.03	5.37	1.21
LHF width	R	3.07	0.63	3.00	0.81	3.16	0.39
	L	2.99	0.52	2.82	0.58	3.17	0.40
Femoral head diameter	R	8.01	0.72	7.99	0.83	8.04	0.61
	L	7.95	0.75	7.90	0.85	8.00	0.68
Acetabular diameter	R	8.00	0.63	7.92	0.66	8.08	0.62
	L	7.93	0.60	7.87	0.71	8.01	0.47
Acetabular depth	R	3.60	0.37	3.48	0.44	3.73	0.24
	L	3.61	0.47	3.50	0.42	3.72	0.52
Femoral neck-shaft angle	R	124.16	2.54	124.97	2.58	123.27	2.31
	L	123.16	1.75	123.67	1.50	122.60	1.92
Torsion angle	R	16.25	8.90	13.33	8.94	19.50	8.11
	L	19.13	9.37	16.11	9.63	22.49	8.32
TOTAL		n = 19		n = 10		n = 9	

APPENDIX H cont.

Table 54: Age group 20 weeks

VARIABLE	SIDE	SEXES $\overline{X}$	COMBINED SD	MALES $\overline{X}$	MALES SD	FEMALES $\overline{X}$	FEMALES SD
Crown-rump length (cm)		19.92	0.52	19.55	0.53	20.06	0.47
LHF length	R	5.27	0.95	5.37	0.96	5.23	1.00
	L	4.87	0.98	4.41	1.14	5.04	0.91
LHF width	R	3.37	0.64	3.55	0.59	3.31	0.67
	L	3.61	0.56	3.95	0.44	3.49	0.56
Femoral head diameter	R	8.67	0.56	8.48	0.77	8.74	0.49
	L	8.60	0.60	8.35	0.76	8.70	0.54
Acetabular diameter	R	8.74	0.66	8.35	0.81	8.88	0.58
	L	8.71	0.66	8.39	0.83	8.83	0.59
Acetabular depth	R	3.95	0.56	3.83	0.51	3.99	0.60
	L	4.00	0.48	3.95	0.40	4.02	0.52
Femoral neck-shaft angle	R	126.72	2.81	128.40	2.40	126.11	2.79
	L	124.19	1.59	124.48	2.43	124.08	1.31
Torsion angle	R	15.49	8.39	13.90	12.16	16.07	7.27
	L	18.80	6.20	19.00	9.40	18.73	5.23
TOTAL		n = 15		n = 4		n = 11	

APPENDIX H cont.

Table 55: Age group 22 weeks. Superscript = n of observations

VARIABLE	SIDE	SEXES COMBINED		MALES		FEMALES	
		$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Crown-rump length (cm)		21.73	0.54	21.77	0.43	21.68	0.67
LHF length	R	6.88	1.27	6.45	1.34	7.30	1.15
	L	6.76	1.63	5.90	1.10	7.61	1.69
LHF width	R	3.98	0.83	3.70	0.79	4.26	0.85
	L	3.81	0.76	4.04	0.77	3.58	0.74
Femoral head diameter	R	9.43	0.62	9.52	0.55	9.34	0.73
	L	9.45	0.57	9.60	0.65	9.31	0.50
Acetabular diameter	R	9.37	0.74	9.66	0.73	9.09	0.70
	L	9.37	0.75	9.69	0.64	9.04	0.77
Acetabular depth	R	4.02	0.45	4.25	0.43	3.79	0.36
	L	4.03	0.49	4.21	0.55	3.85	0.37
Femoral neck-shaft angle	R	126.29	3.04	127.00	3.75	125.58	2.26
	L	121.96	2.79	122.57	3.22	121.35	2.42
Torsion angle	R	17.63	9.81^{11}	19.06	12.28^{5}	16.43	8.26
	L	20.05	10.70^{11}	20.52	14.07^{5}	19.65	8.37
TOTAL		n = 12		n = 6		n = 6	

APPENDIX H cont.

Table 56: Age group 24 weeks. Superscript = n of observations

VARIABLE	SIDE	SEXES COMBINED		MALES		FEMALES*	
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Crown-rump length (cm)		23.83	0.73	23.78	0.71	23.95	1.06
LHF length	R	6.70	1.66	6.74	1.37	6.62	2.52
	L	6.22	2.31	6.47	2.70	5.72	1.60
LHF width	R	3.85	0.67	3.65	0.75	4.25	0.25
	L	4.33	0.67	4.29	0.83	4.43	0.23
Femoral head diameter	R	9.75	0.45	9.94	0.26	9.38	0.51
	L	9.73	0.45	9.93	0.24	9.33	0.56
Acetabular diameter	R	9.78	0.69	10.06	0.62	9.22	0.45
	L	9.72	0.73	9.97	0.49	9.22	0.99
Acetabular depth	R	3.88	0.50	4.10	0.30	3.43	0.58
	L	3.87	0.47	4.13	0.21	3.34	0.42
Femoral neck-shaft angle	R	124.46	3.30	124.03	3.45	125.30	3.48
	L	122.93	3.98	123.75	3.46	121.30	5.24
Torsion angle	R	17.47	10.43	14.82	11.79	22.77	4.97
	L	15.62	8.00	13.15	8.22	20.57	5.69
TOTAL		n = 9		n = 6		n = 3	

* #55 age group placement by gestational age

APPENDIX H cont.

Table 57: Age group 26 weeks

VARIABLE	SIDE	SEXES COMBINED $\bar{X}$	SEXES COMBINED SD	MALES $\bar{X}$	MALES SD	FEMALES $\bar{X}$	FEMALES SD
Crown-rump length (cm)		25.06	0.18	25.00	0.00	25.17	0.29
LHF length	R	7.81	1.97	6.95	1.84	9.25	1.38
	L	7.45	1.63	7.05	0.97	8.11	2.52
LHF width	R	4.24	1.33	3.85	1.60	4.90	0.23
	L	4.06	0.92	4.08	1.02	4.04	0.96
Femoral head diameter	R	10.99	0.83	11.13	1.00	10.74	0.52
	L	11.02	0.76	11.14	0.94	10.82	0.39
Acetabular diameter	R	10.98	0.89	11.10	1.00	10.78	0.81
	L	11.01	0.88	11.13	0.99	10.80	0.82
Acetabular depth	R	4.76	0.45	4.57	0.37	5.09	0.42
	L	4.81	0.58	4.59	0.55	5.17	0.52
Femoral neck-shaft angle	R	123.95	2.26	124.02	2.94	123.83	0.68
	L	123.46	2.42	123.24	2.62	123.83	2.54
Torsion angle	R	17.69	6.93	14.72	6.04	22.63	6.03
	L	18.79	5.02	17.14	4.16	21.53	5.97
TOTAL		n = 8		n = 5		n = 3	

APPENDIX H cont.

Table 58: Age groups 28 and 36 weeks

VARIABLE	SIDE	AGE GROUP 28 WEEKS	AGE GROUP 36 WEEKS
Crown-rump length (cm)		27.50	34.00
LHF length	R	10.39	9.53
	L	10.93	9.41
LHF width	R	4.16	6.75
	L	3.52	5.78
Femoral head diameter	R	12.71	15.02
	L	12.71	15.35
Acetabular diameter	R	13.20	13.53
	L	13.20	15.35
Acetabular depth	R	5.40	5.33
	L	5.50	5.26
Femoral neck-shaft angle	R	123.60	128.00
	L	126.60	123.60
Torsion angle	R	16.30	23.33
	L	22.30	25.33
TOTAL		n = 1 male	n = 1 female

APPENDIX H cont.

Table 59: Age group 30 weeks. Superscript = n of observations

VARIABLE	SIDE	SEXES	COMBINED	MALES		FEMALES	
		$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Crown-rump length (cm)		28.32	0.38^{5}	28.45	0.64	28.23	0.25^{3*}
LHF length	R	9.46	1.22^{6}	10.31	2.19	9.03	0.37^{4}
	L	8.84	1.59	10.41	0.04	8.22	1.44
LHF width	R	4.99	1.22^{6}	4.29	0.63	5.34	1.36^{4}
	L	5.25	1.40	5.85	1.12	5.01	1.55
Femoral head diameter	R	12.43	1.27	13.01	1.21	12.20	1.19
	L	12.37	1.59	13.04	1.17	12.10	0.99
Acetabular diameter	R	12.59	1.40	13.94	0.98	12.04	1.19
	L	12.59	1.10	13.14	2.18	12.37	0.64
Acetabular depth	R	4.95	0.65	5.17	0.52	4.87	0.74
	L	5.01	0.63	5.23	0.14	4.92	0.74
Femoral neck-shaft angle	R	124.16	3.90	122.15	5.87	124.96	3.37
	L	122.77	1.73	123.80	0.28	122.36	1.93
Torsion angle	R	23.04	10.40^{5}	12.80	3.96	29.87	5.80^{3}
	L	21.30	5.28^{5}	18.45	1.63	23.20	6.40^{3}
TOTAL		n = 7		n = 2		n = 5	

* #140 and #139 age group placement by gestational age

APPENDIX H cont.

Table 60: Age group 32 weeks

VARIABLE	SIDE	SEXES COMBINED $\overline{X}$	SEXES COMBINED SD	MALE	FEMALE
Crown-rump length (cm)		30.00	0.00	30.00	30.00
LHF length	R	9.65	3.15	7.42	11.88
	L	8.33	2.80	6.35	10.31
LHF width	R	5.87	1.72	4.65	7.08
	L	6.31	0.51	5.95	6.67
Femoral head diameter	R	13.26	1.48	12.21	14.30
	L	13.28	1.75	12.05	14.52
Acetabular diameter	R	13.58	1.94	12.21	14.96
	L	13.28	1.28	12.37	14.19
Acetabular depth	R	5.45	0.78	4.90	6.00
	L	5.40	0.33	5.17	5.63
Femoral neck-shaft angle	R	123.15	2.62	125.00	121.30
	L	120.80	3.11	123.00	118.60
Torsion angle	R	30.80	0.71	31.30	30.33
	L	33.15	3.04	31.00	35.33
TOTAL		n = 2		n = 1	n = 1

APPENDIX H cont.

Table 61: Age groups 34, 38 and 42 weeks. Superscript = n of observations

VARIABLE	SIDE	FEMALES 34 WKS*		MALES 38 WKS		MALES 42 WKS**	
		$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Crown-rump length (cm)		32.50	0.71	36.00	0.00	39.25	1.06^{2}
LHF length	R	9.57	0.40	11.10	2.95	11.65	1.04
	L	9.90	1.52	11.02	2.05	11.83	3.45
LHF width	R	5.88	0.75	5.80	0.92	7.08	1.51
	L	6.18	1.44	5.27	1.00	6.73	1.26
Femoral head diameter	R	13.81	1.27	14.85	1.40	17.95	1.47
	L	13.62	1.52	15.13	1.01	17.83	1.58
Acetabular diameter	R	14.25	1.34	13.94	0.35	18.14	1.15
	L	14.23	1.32	13.78	0.35	17.74	1.34
Acetabular depth	R	5.80	1.02	5.89	0.48	7.02	1.56
	L	5.54	0.67	5.27	0.63	7.07	1.40
Femoral neck-shaft angle	R	124.77	0.68	124.80	0.71	126.90	4.40
	L	121.20	1.06	121.45	0.21	125.23	1.53
Torsion angle	R	25.15	7.28^{2}	24.85	3.04	15.50	5.37^{2}
	L	29.15	3.04^{2}	26.00	0.99	10.70	12.73^{2}
TOTAL		n = 3		n = 2		n = 4	

* #143, ** #144, #146 age group placement by gestational age

APPENDIX H cont.

Table 62: Age group 40 weeks. Superscript = n of observations

VARIABLE	SIDE	SEXES COMBINED		MALES		FEMALES	
		$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Crown-rump length (cm)		37.83	0.29	no data*		37.83	0.29
LHF length	R	10.75	1.38	11.29^1	0.00	10.57	1.64
	L	11.05	2.02	11.81	0.00	10.80	2.39
LHF width	R	7.19	1.38	8.38^1	0.00	6.80	1.38
	L	6.59	0.67	7.36	0.00	6.33	0.53
Femoral head diameter	R	16.98	1.07	16.77	1.63	17.12	0.94
	L	16.83	1.38	16.67	2.57	16.94	0.68
Acetabular diameter	R	17.37	1.16	18.01	1.21	16.94	1.12
	L	17.15	1.27	17.82	1.32	16.70	1.27
Acetabular depth	R	6.33	0.92	6.47	0.80	6.23	1.15
	L	6.49	1.10	6.50	0.71	6.48	1.48
Femoral neck-shaft angle	R	125.42	3.88	123.45	4.46	126.73	3.70
	L	124.30	3.34	124.95	0.50	123.87	4.63
Torsion angle	R	17.92	6.32	19.15	10.11	17.10	5.11
	L	24.10	7.53	29.30	11.31	20.63	2.05
TOTAL		n = 5		n = 2		n = 3	

* #59 and #52 age group placement by gestational age

APPENDIX I

Variables by Crown-rump Length

Sexes combined, numbers represent the frequency of observation at each point, * = one observation. (The right femoral head diameter is presented in Figure 33. The left side plots were similar and may be obtained from the author).

Figure

77: Right acetabular depth by crown-rump length

78: Right acetabular diameter by crown-rump length

79: Right torsion by crown-rump length

80: Right neck-shaft angle by crown-rump length

81: Right ligament of the head of femur (LHF) length by crown-rump length

82: Right ligament of the head of femur (LHF) width by crown-rump length

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CRUMP SCATTERGRAMS                                                          04/22/77

FILE    HIPDEV    (CREATION DATE =  12/02/76 )    FOETAL HIP DEVELOPMENT
SUBFILE   NORMAL      DYSNORM
SCATTERGRAM OF    (DOWN) ACEDEPR   RIGHT ACETABULAR DEPTH IN MM              (ACROSS) CRUMP    CROWN RUMP MEASUREMENT IN CM
```

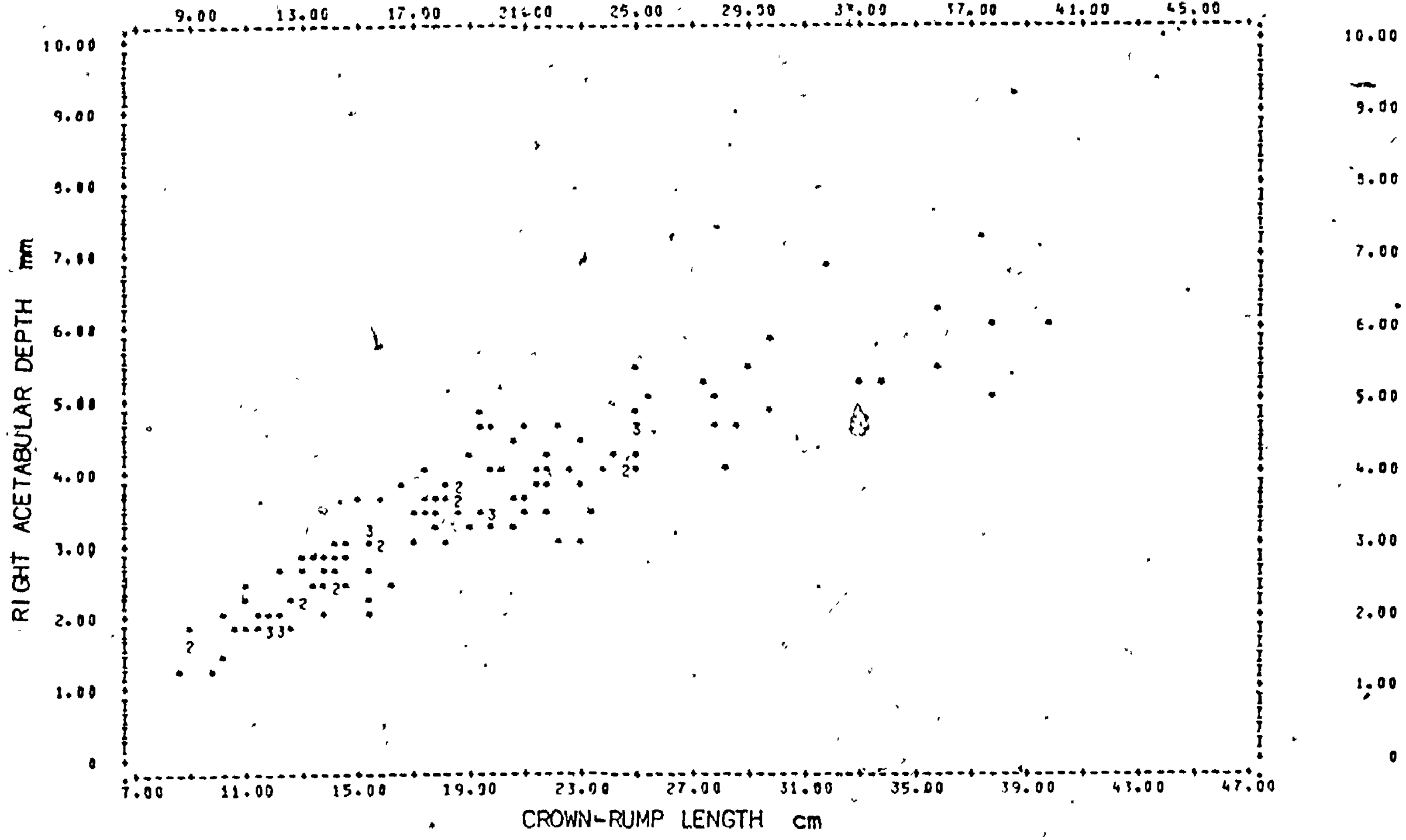


Figure 77 : Right acetabular depth by crown-rump length

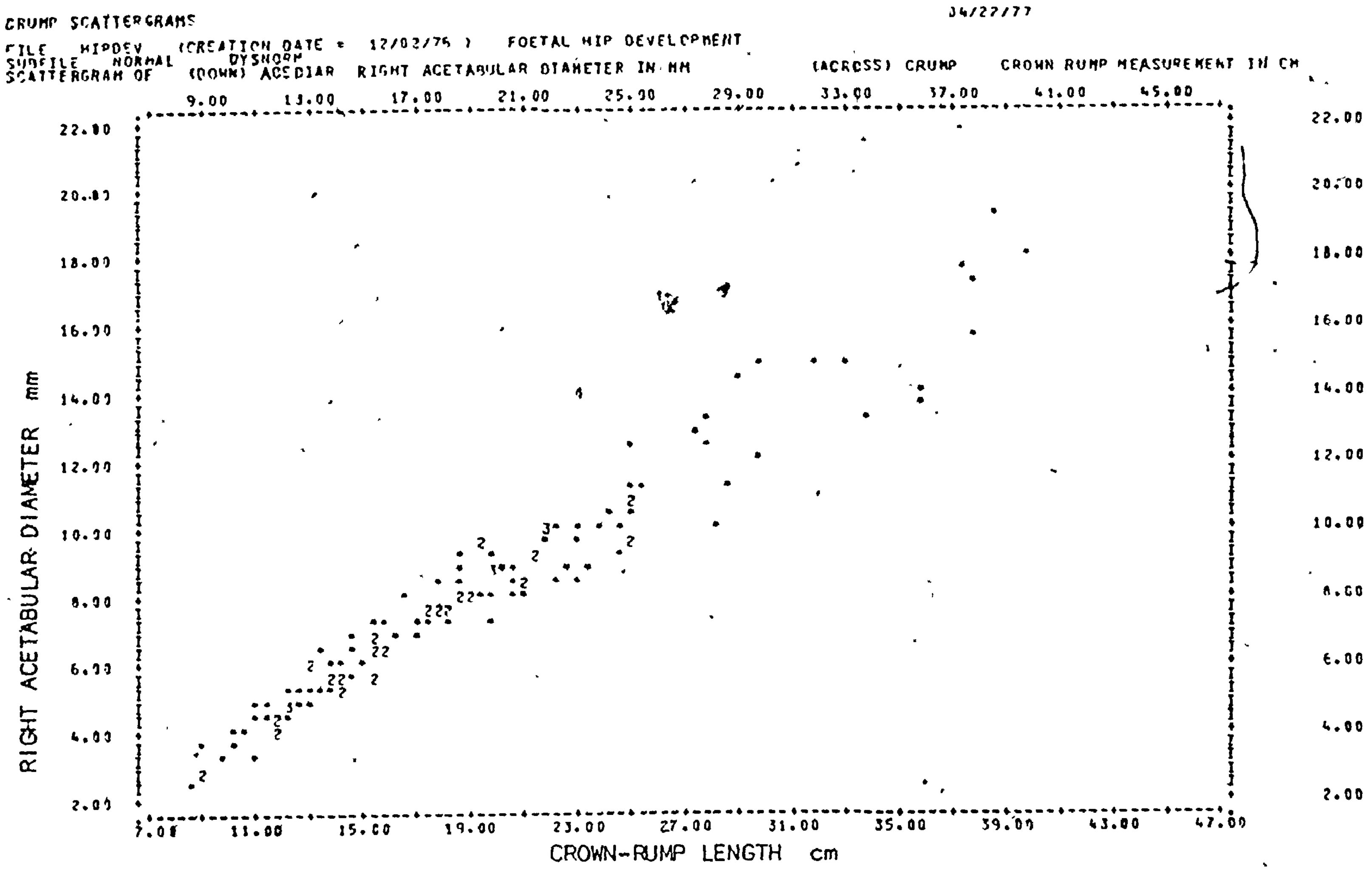


Figure 78 : Right acetabular diameter by crown-rump length

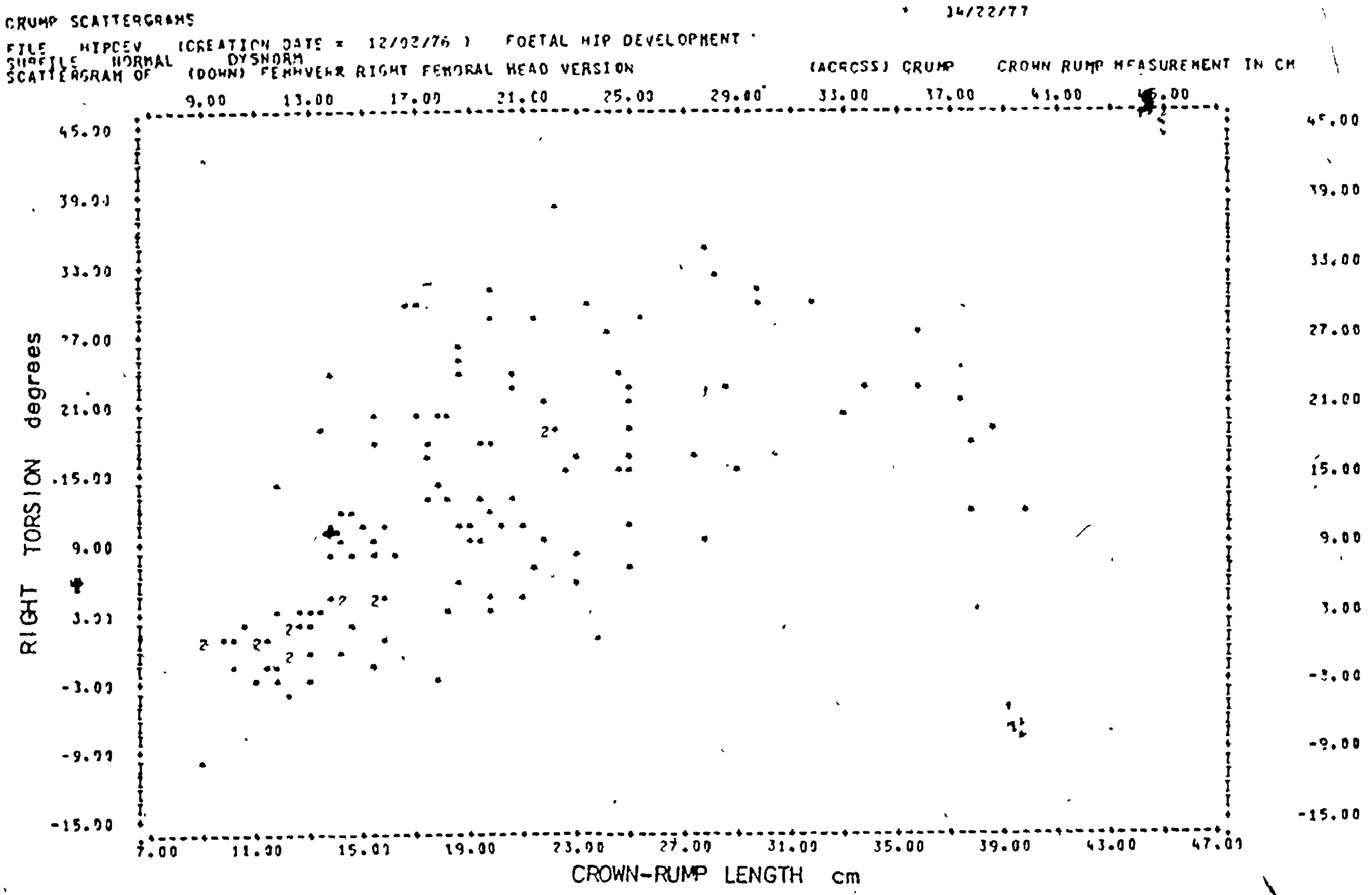


Figure 79 : Right torsion by crown-rump length

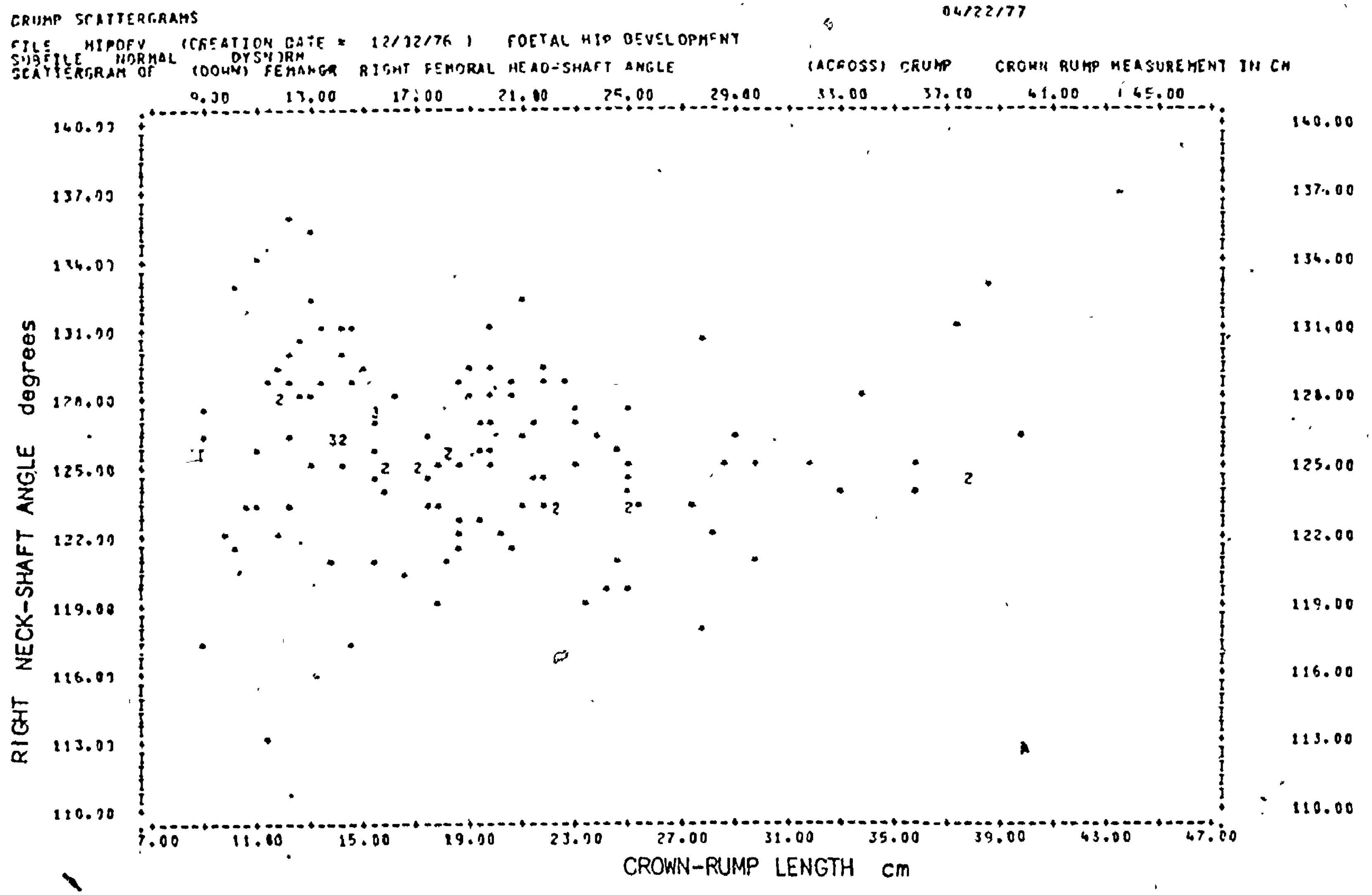


Figure 80 : Right neck-shaft angle by crown-rump length

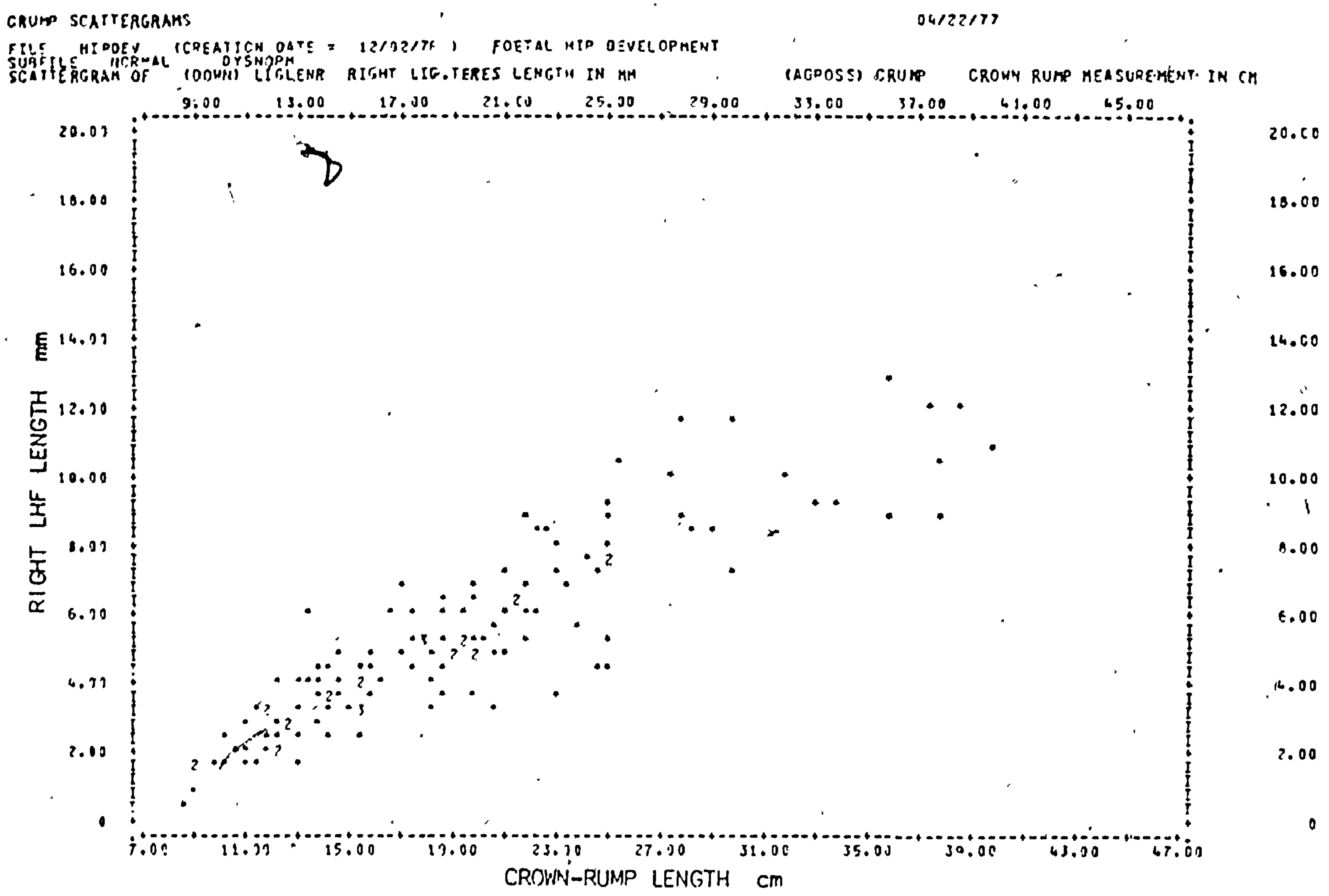
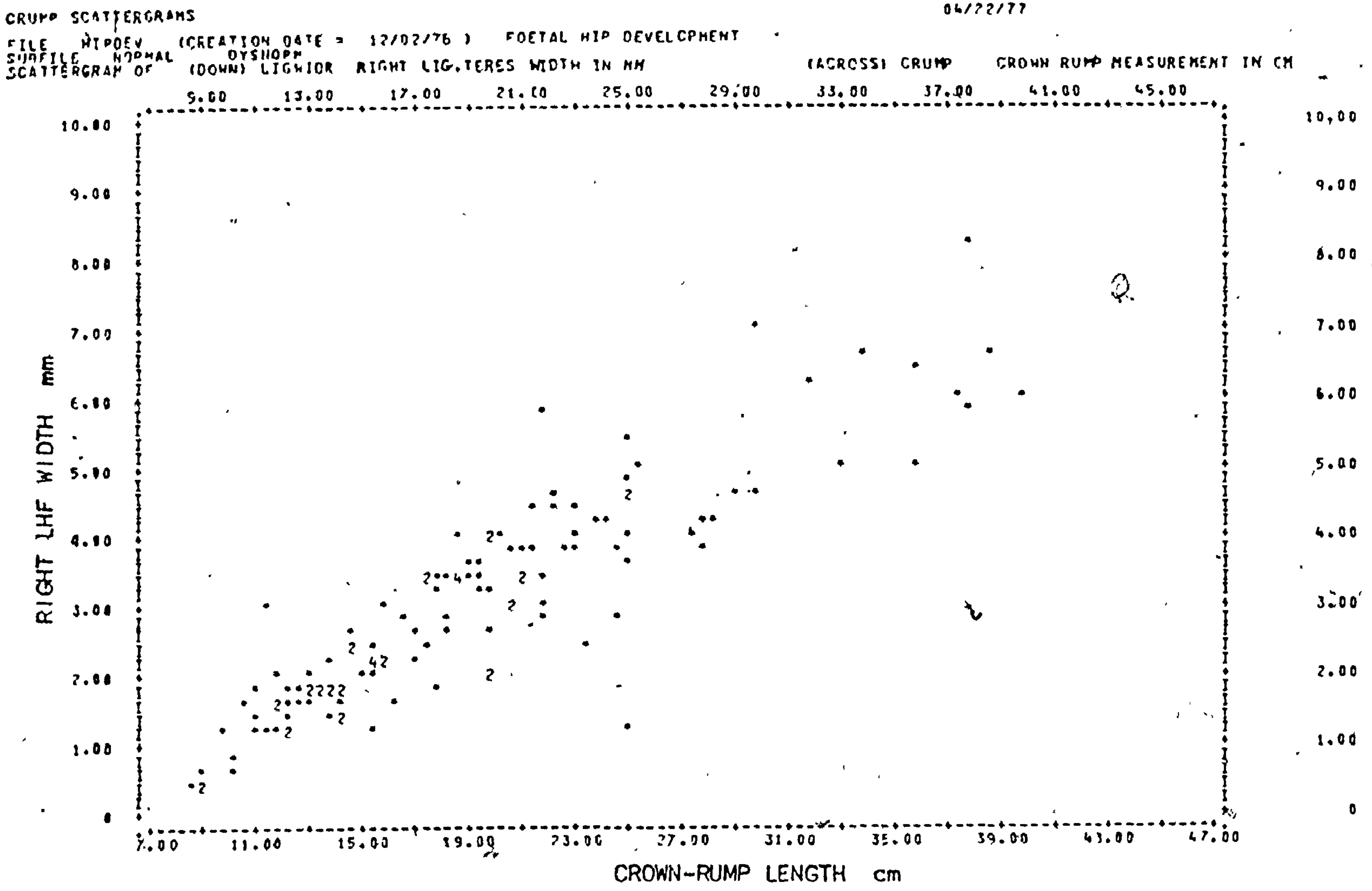


Figure 81 : Right ligament of the head of femur (LHF) length by crown-rump length



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CRUMP SCATTERGRAMS                                                                   04/22/77
FILE    HIPDEV    (CREATION DATE =  12/02/76 )    FOETAL HIP DEVELOPMENT
SUBFILE    NORMAL      DYSHOPM
SCATTERGRAM OF    (DOWN) LIGWIDR  RIGHT LIG.TERES WIDTH IN MM          (ACROSS) CRUMP     CROWN RUMP MEASUREMENT IN CM
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Figure 82 : Right ligament of the head of femur (LHF) width by crown-rump length

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