THE YALE JOURNAL OF BIOLOGY AND MEDICINE 53 (1980), 307-316

Growth Characteristics of the Fetal Ligament of the Head of Femur: Significance in congenital hip disease*

J.M. WALKER, Ph.D.

Assistant Professor, The Departments of Physical Therapy and Anatomy, University of Southern California, Downey

Received March 10, 1980

Measurement of the length and width of the ligament of the head of femur (ligamentum teres) in 140 normal human fetuses between 12 weeks and term provides limits for growth changes in this structure. These observations provide no morphological evidence of a significant difference between males and females, or between the right and left sides, to explain the female and left hip preponderance reported in congenital hip disease. The ligament is shown to be variable in length, width, and shape, and it is not a distinctly linear structure though linearity may increase with age. Tests of femoral head mobility support the opinion that this ligament must play a role in fetal and neonatal hip joint stability. Weak correlation only was demonstrated between the ligament variables and acetabular depth, which suggests that ligament shape and socket shape are not closely related. Comparison of measurements from normal and 12 dysplastic or subluxated joints provides no evidence to support previous observations that this structure is unusually long in abnormal hip joints which are not frankly dislocated.

An abnormally long ligament of the head of femur (LHF) [1] with a shallow socket and capsular laxity are features of joints with congenital hip disease [2-5]. However, the ligament was absent in 20 percent of dislocation of the hip cases studied by Scaglietti and Calandriello [6]. No observations are yet available on the normal variation of ligament length at different ages. It is not established whether the "elongated" ligament observed in abnormal hips [3-5] reflects a ligament that was originally longer than "normal," or whether the excessive length occurred in response to the stress of the abnormal position of the head of femur relative to the socket. Crelin [7] noted in 26 stillborn infants that the ligament was a flat band of connective tissue as in the adult. He commented that the terms ligamentum teres or round ligament are "descriptively erroneous." The shape of the ligament has only received comment when some pathology was present.

There is agreement that the LHF develops *in situ* [8-14]. No support exists for 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 [15-19]. The function of this ligament is still not clearly established. Sandifort [2] in 1834 discounted a joint stabilization role for this ligament. The consistent function attributed to the LHF is to convey blood vessels to the head of femur. While Haines [12] considered his observations gave support to this hypothesis, Andersen [14] and Gardner and Gray [13] found that few vessels actually entered the fetal head of femur. Crelin [7] from a

*This work formed part of a doctoral dissertation in Medical Sciences (Growth and Development Program) submitted to the McMaster University, Hamilton, Ontario, Canada.

Address reprint requests to: J.M. Walker, Ph.D., Depts. of Physical Therapy and Anatomy, University of Southern California, 12933 Erickson Avenue, Downey, CA 90242

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.

A review of the world literature revealed no quantitative growth study of the ligament. Measurements of the length and width and growth rates for the ligament are reported here. These were taken as part of a study on the growth and development of the human fetal hip joint [20] which will be reported separately.

METHODS

One hundred and forty fetuses were obtained after elective abortion (62.3 percent), stillbirth (23.7 percent) and death in the perinatal period (14.1 percent). The cause of death, and in stillbirths the length of the period of death *in utero* prior to delivery, was not always clearly established. Inclusion criteria were used to limit sample variability. No specimens were included where a known growth retarding factor was present. It may be reasonable, however, to infer that the sample younger than 20 to 24 weeks (age for declaration of a stillbirth) would be more representative of normal growth and development than the post 20- to 24-week group. Criteria for inclusion in the study of normal development were: absence of external malformations, minimal maceration [22], duration of postnatal viability not more than 24 hours, Caucasian race, gestational age between 12 and 42 weeks or a crown-rump length from 8.7 cm to 40 cm [23], and normal hip joint morphology as determined by examination with the naked eye and at ten times magnification.

Approximately 90 percent of fetuses were received prefixed in neutral 10 percent formaldehyde and were transferred to neutral formalin buffered to pH 7.0 [24]. Since many specimens were received already fixed in formaldehyde it was necessary, therefore, to accept the formalin state as a basis for the group as a whole. Fetuses were generally measured after two weeks in fixative as there is a small increase in crown-rump length immediately after simple preservation in formalin [22,25]. Schultz [25] noted that fixative changes affect external circumferences and soft tissue dimensions more than length and hard tissue dimensions and that these changes are most rapid in the initial period of fixation. After a period of time the specimen tends to return to its original size and weight [22,25,26]. No reports of the effect of formaldehyde specific to structures such as the ligament of the head were located. The effect should be constant in all specimens, however differences in the period of time in formaldehyde may contribute to variability demonstrated in ligament dimensions.

To improve fixation in larger fetuses, the hip joints were immediately dissected down to the level of the capsule. Since the majority of joints were received prefixed, mobility of the hip was not used as a criterion of joint normality. However, the range of motion permitted by the intact ligament of the head of femur was assessed at room temperature (20° C) before and after cutting of the joint capsule. The push-pull test [27] was used to assess the tendency of the femoral head to dislocate. The ligament was then carefully detached from the acetabulum.

Measurement

A stereoscope, fitted with a ten-power wide-field measuring eyepiece and graticule having a scale with 120 divisions (0.1 mm apart) was used to measure the maximum length of the LHF and the maximum width of the free portion of the LHF. All measurements were repeated three times with the specimen moved and repositioned each time. The means of these measurements were recorded. Three joints were received already dislocated and in these joints the ligament was not measured. To limit any effects of tissue contraction, the ligament was measured immediately following its detachment from the acetabular fossa, but still attached to the fovea of the femoral head.

Length

Maximum length was recorded from the junction of the ligament with the cartilage of the femoral head to the free acetabular end. Attempts to record the maximum length of the free portion of the ligament proved unreliable 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 (mm) $= (2x°/360°) \times d$, where $s < l$, s = microscope measurement of LHF length, l = corrected length, d = microscope measurement of the maximum transverse diameter of the femoral head. The shape of the femoral head was assumed to be spherical.

Width

The maximum width of the free portion of the ligament was measured. Measurements had high reproducibility, with the maximum range in sets of three measurements equal to 0.4 mm.

Data Analysis

The statistical analysis was done on a CDC 6400 computer at McMaster University. The SPSS (Statistical Package of Social Sciences) system of computer programs was utilized [28,29]. The level of significance used was 0.05.

RESULTS

Of 140 fetuses, 66 were male and 74 were female. Table 1 shows the frequency of males and females by two-weekly age groups from 12 to 42 weeks, and gives the mean and range of the crown-rump length for each age group.

TABLE 1
The number of fetuses by age groups with mean values, range of crown-rump lengths (CRL), and sex

Age Group (weeks)	CRL (mean) cm	CRL Range min.	CRL Range max.	Sex Male	Sex Female	Total
12	10.5	8.7	11.9	8	8	16
14	12.9	12.0	13.9	5	13	18
16	14.9	14.1	15.9	10	8	18
18	17.7	16.0	18.7	10	9	19
20	19.9	19.0	20.8	4	11	15
22	21.7	21.0	22.5	6	6	12
24	23.8	23.0	24.7	6	3	9
26	25.1	25.0	25.5	5	3	8
28		27.5		1	0	1
30	28.3	28.0	28.9	2	5	7
32	30.0	30.0		1	1	2
34	32.5	32.0	33.0	0	3	3
36		34.0		0	1	1
38	36.0	36.0		2	0	2
40	37.8	37.5	38.0	2	3	5
42	39.3	38.5	40.0	4	0	4
				66	74	140

While considerable variability is seen in the shape of the LHF throughout the fetal period (Fig. 1), the predominant shape is that of a linear structure with length exceeding width. A faster rate of growth for the length of the ligament through the fetal period is shown in Fig. 2. A measure of ligament shape is gained from calculation of a ligament index (width × 100/length, expressed as a percentage). Lack of a pronounced linear shape was evident in that none of the mean indices were less

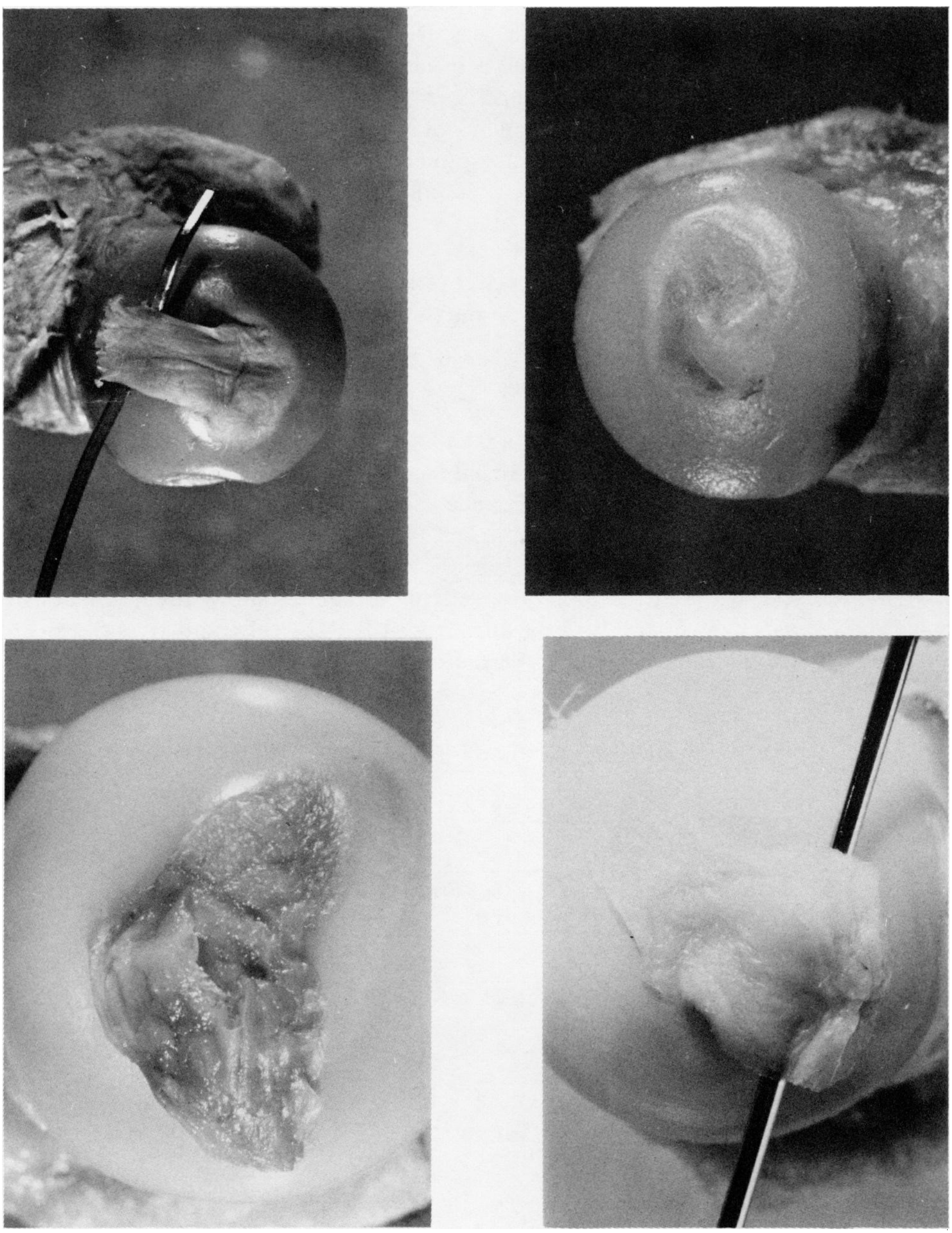

FIG. 1. Variability in the shape of the ligament of the head of femur. *a.* strap-like LHF with length greater than width. *b.* small wide LHF. *c.* short, wide, and thick LHF. *d.* long, wide LHF which had a wide area of attachment to the side of the acetabular fossa.

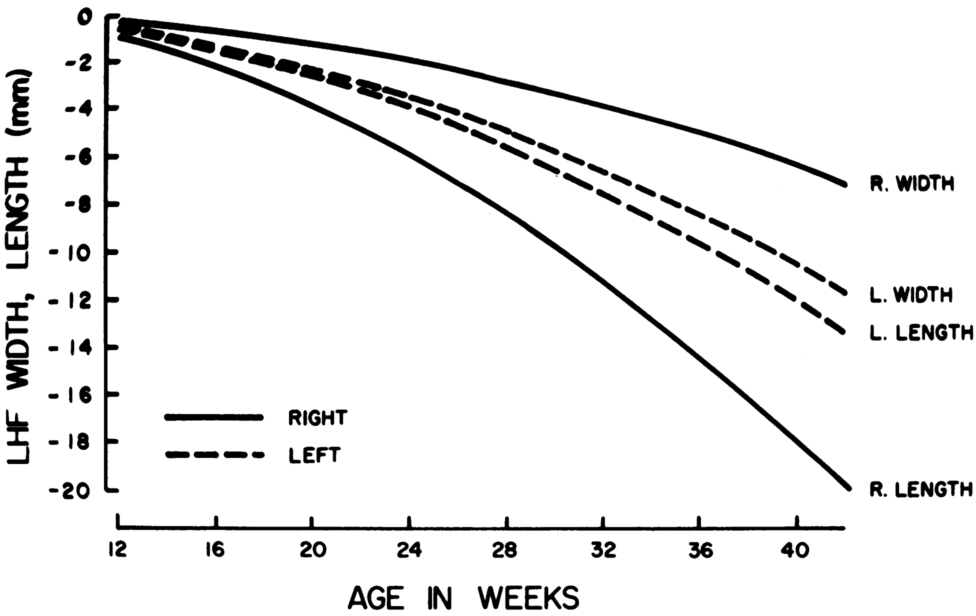

FIG. 2. Rate of growth curves, by side for LHF length and width. Model: mean, age, age^2.

than 50 percent (Table 2). Since the mean index values lie between 50 and 70 percent, the LHF does have a tendency to be long and narrow rather than short and wide when the index would be closer to 100 percent. A very nonlinear shape was shown in a few cases. The upper limit of the index range exceeded 100 percent in age groups 12, 20, and 24 weeks, with individual case values of 156 percent for the left side at 12 weeks, and 132 percent for the left side at 20 weeks.

With increasing age the ligament appeared to become a more robust structure. In younger specimens great care was required to avoid detachment of the ligament from either the attachment to the femoral head fovea or from the attachment to the acetabular fossa when examining the range of motion at the joint following capsule division.

TABLE 2
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) × 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) × 100	71.89	52.29	77.04	75.30	58.91	62.01	61.31

No cases of congenital absence of the ligament were noted. The majority of ligaments were only attached to the acetabular fossa; however, in a few the attachment extended along the lateral edge of the ligament to the transverse acetabular ligament. These hips showed limited mobility of the head of femur following opening of the capsule. In no instance did the length of the ligament permit the femoral head to be displaced beyond the posterior rim of the socket. Maximum motion occurred in the flexed, adducted, and externally rotated position of the joint when more than 50 percent of the head moved out of the socket toward the obturator foramen. With extension of the hip approximately 50 percent 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.

Since no significant difference was shown in the means between the sexes or between the right and left sides ($F > .1$), the sexes were pooled. Raw coefficients of determination for between the right (R) and left (L) sides were high ($p < .001$; 138 fetuses, R length, L length $R^2 = .862$; R width, L width $R^2 = .845$). The analysis was therefore conducted on 140 cases instead of regarding each hip joint as a separate unit making 280 cases. Correlations of ligament length and width, between sides, adjusted for age, was strongest with femoral head diameter (.407, .343) and acetabular diameter (.347, .319), and weak with acetabular depth (.242, .222). No correlation was shown between the ligament variables and the two proximal femoral angles, torsion, and neck-shaft. Mean values and standard deviations,* sexes combined, by side, are presented in Figs. 3 and 4. The strongest linear trend is seen between age groups 12 and 18 to 20 weeks. Ligament length shows a fivefold increase in observed

*by two-weekly age groups for sexes combined and separate, from the author.

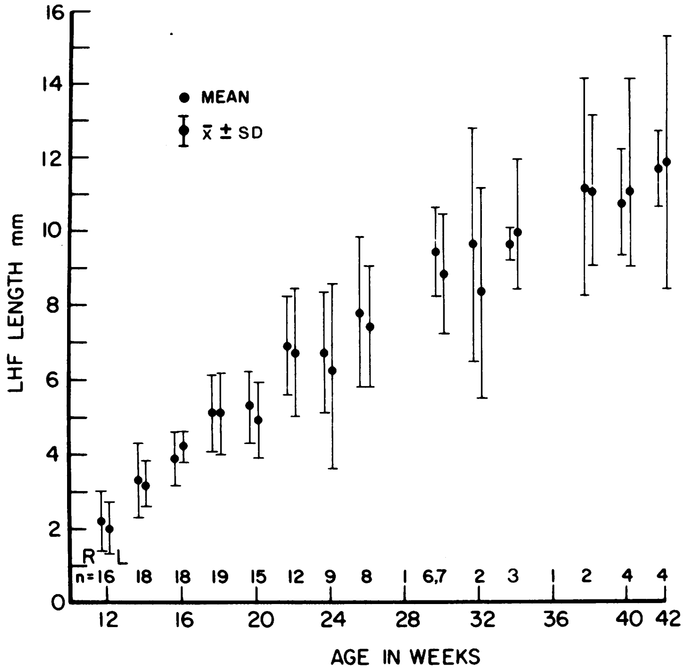

FIG. 3. LHF length, mean values plus and minus one standard deviation, sexes combined, by side, for n = 138 right, 139 left.

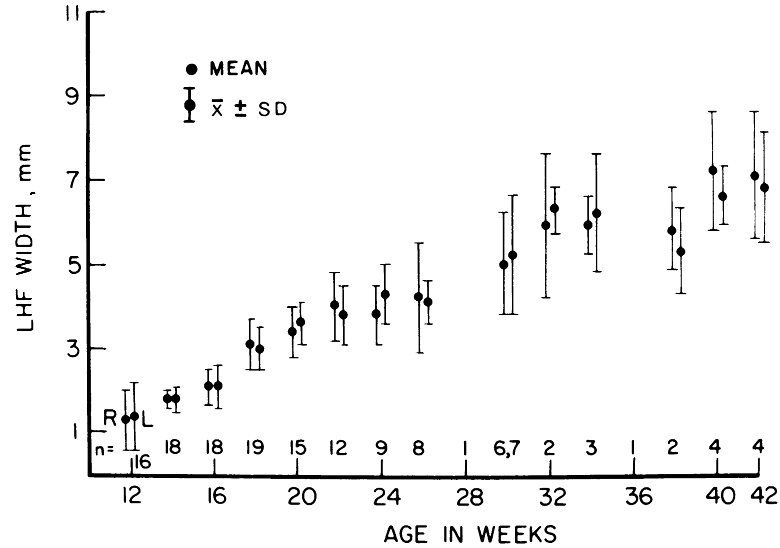

FIG. 4. LHF width, mean values, plus and minus one standard deviation, sexes combined, by side, for n = 138 right, 139 left.

means between 12 weeks and term. Overlapping of standard deviations between age groups is apparent for both width and length.

Regression models were devised to define the pattern of growth for all hip variables, and to obtain predictive values for these variables based on crown-rump length. These included a natural logarithmic transformation, the use of a logistic function, and the addition of a second and third power polynomial to the independent variable age. When a simple linear regression model was fitted, nonsignificant lack of fit was only obtained for left LHF length and right LHF width. The addition

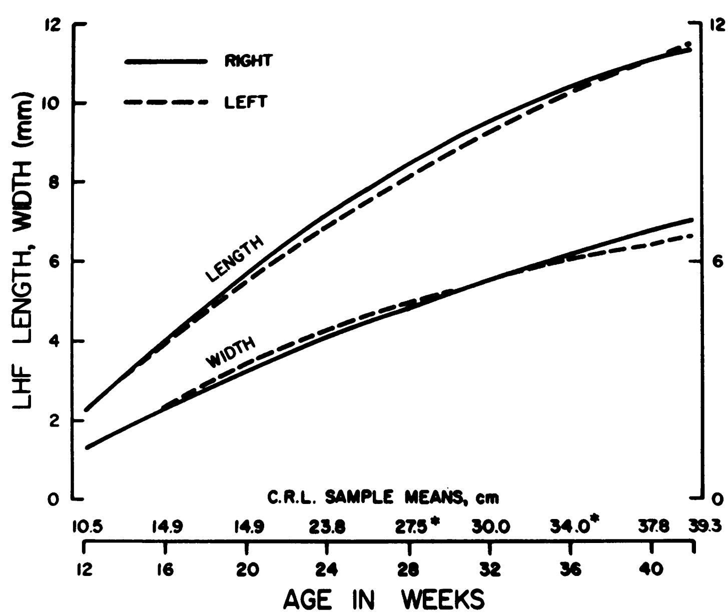

FIG. 5. Regression curves from a quadratic model for LHF length and width, by side. *n = 1.

of sex as an independent variable in the model contributed minimally to the total amount of explainable variation, with partial F values for the addition of sex only significant for right width ($p < .05$). Since the partial F value for sex was not significant at the "four times" level [30], sex was eliminated from the model to be fitted.

Nonsignificant lack of fit was obtained by fitting the model with a second power polynomial on age. Since modified coefficients of determination (corrected for the mean [31]) were greater than 96.6 percent, this indicates that the fitted model did perform a reasonable job in explaining the variation. Regression equations for the fitted model with the standard error of estimate (square root MS residual) are:

	$y = \beta_0$	$+\beta_1 x$	$+\beta_2 x^2$	$\pm$ = SE est
right length	−4.35858	.62019	−.00583	1.177
left length	−3.36461	.52253	−.00397	1.386
right width	−2.01329	.30592	−.00214	.772
left width	−2.52949	.36261	−.00345	.739

Rate of growth curves were derived from the quadratic model ($y = \beta_0 + \beta it + \beta_2 t^2$; t = age). Right LHF width was the slowest growing hip variable with acetabular depth bilaterally [21] while LHF length was the faster growing variable studied. A difference in the rate of growth for length and width was shown between sides (Fig. 2). The rate of growth was greater for length on the right side, but for width on the left side.

DISCUSSION

There are numerous statements in the orthopedic literature, based on naked eye impressions, concerning the shape and apparent dimensions of the ligament of the head of femur. Since no study was located on the normal amount of variation in this ligament at different ages, no limits are available to determine when, in a hip with congenital dislocation, the ligament is excessively long or hypertrophied [3,4,5].

These observations of LHF length and width do not support the hypothesis that a difference exists in the growth either between males and females, or between the left and right sides. There is a suggestion for an effect of sex which requires further investigation with a larger sample, and even numbers of each sex, at each age period, but particularly in the third trimester. Dunn [5,32] has shown the side involvement in congenital hip disease (CHD) to be significantly related to the tendency for fetuses to lie with the back toward the mother's left side. The leg most posteriorly positioned, the left, was more frequently dislocated, regardless of the birth presentation. *In utero* positioning rather than side morphological differences may better explain the greater left side involvement in CHD [31].

Considerable variability in both length and width of the ligament is evident over time in the standard deviations which were the largest for all of the linear dimensions studied. This variability is reflected in the variety of shapes observed at all periods of fetal life. Length of the LHF was the fastest growing variable of the hip joint dimensions, increasing fivefold from 12 weeks to term. These observations support Crelin's [7] contention that the older term, round ligament, is misleading, but do not demonstrate that the fetal ligament is always a flat linear band as observed by Crelin in 26 term fetuses and in adult cadavers. No measurements were reported.

A tendency for the ligament to be squatter in shape in younger fetuses may exist. Ligament indices greater than 100 percent indicate a short, wide ligament. Indices of this value were not observed in fetuses over 24 weeks of age. The mean LHF indices suggest that at birth the left ligament is a more linear structure than the right. However, rate of growth curves, from the regression model fitted, predict a side difference at term with the right length predicted to grow at a higher velocity than the left length. The velocity of growth for left width was predicted to exceed that for the right. No explanation is offered for the discrepancy between observed and predicted values, or for the predicted differences which suggest, if this pattern of growth was to continue, that the right ligament would become a more linear structure than the left. This ligament is presumed to be responsive to environmental factors such as *in utero* position, forces acting through the joint and joint mobility.

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. That partial F values for the addition of a cubic term to the model were not significant may indicate that volume, or mass, does not increase with time to a noticeable degree.

While Scaglietti and Calandriello [6] reported that the ligament was absent in 20 percent of operative cases of congenital dislocation of the hip, no cases of absence of the ligament were found in the 294 normal and abnormal joints dissected. Mean values for normal joints and observations made on twelve subluxated or dysplastic joints, not included in the growth study, were compared. Contrary to observations reported in the CHD literature, only in two abnormal joints did the ligament length exceed the mean plus one standard deviation (SD). This worker was not able to detect, prior to comparison of the measurements, those ligaments that did exceed the normal group's mean plus one SD. Since only abnormal hip joints are operated on, observations at surgery on the length or shape of this ligament are made on a non-random and biased sample of joints. It is possible that ligaments may be described as excessively long because the length permitted the head to move completely out of contact with the primary socket. When the effect of age was removed, only weak correlation was shown between LHF length and width with other hip variables. This suggests that ligament shape and socket shape are not closely related.

The assessment of mobility, while performed on fixed specimens, supports Crelin's [7] finding that, in fetuses, the ligament 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, particularly when the hip was flexed and adducted. Up to 50 percent of the head could be moved over the anterior socket rim. It seems therefore probable, as Crelin proposed, that the LHF, a more robust collagenous structure than the capsule in fetuses, may play a role in fetal hip joint stability. The LHF may function to prevent or retard the progression of an unstable hip to a dislocated hip, particularly at term when the greatest discrepancy between femoral head size and socket depth is present [34,35,21].

ACKNOWLEDGEMENTS

The assistance of the Department of Anatomy and Section of Orthopaedics at Yale University, the Children's Hospital, Buffalo, and the Hospital for Sick Children, Toronto, in procuring third trimester specimens is gratefully acknowledged. I thank Drs. J. Ogden, E. Crelin, C. Mosley, D. Carr, and C. Goldsmith for constructive assistance. Funding was from the Dean's Fund, Faculty of Health Sciences, and the Department of Anatomy at McMaster University, and the Crippled Children's Aid Society, New Haven.

REFERENCES

1. International Anatomical Nomenclature Committee: Nomina Anatomica. 3rd ed. Princeton, Excerpta Medica, 1966, p 36
2. Salter RB: Etiology, pathogenesis and possible prevention of congenital dislocation of the hip. Can Med Assn J 98:933–945, 1968
3. Watanabe RS: Embryology of the human hip. Clin Orthop 98:8–26, 1974
4. Stanisavljevic S: Congenital Hip Pathology in the Newborn. Baltimore, Williams & Wilkins, 1964
5. Dunn P: Congenital dislocation of the hip (CDH): Necropsy studies at birth. Proc R Soc Med 62:1035–1037, 1969
6. Scaglietti O, Calandriello B: Open reduction of congenital dislocation of the hip. J Bone Joint Surg (Br) 44(2):257–283, 1962
7. Crelin ES: An experimental study of hip stability in human newborn cadavers. Yale J Biol Med 49:109–121, 1976
8. Schuster H: Zur entwicklungsgeschichte des Huft—und kniegelenkes. Mitt Embryol Inst, Wien 199–211, 1878. Cited by: Anderson H, 1962, p 258
9. Bardeen C: Studies on the development of the human skeleton. Part C. The development of the skeleton of the posterior limb. Am J Anat 4:279–302, 1905
10. Walmsley T: A note on the retinacula of Weitbrecht. J Anat 51:61–64, 1917
11. Strayer L: Embryology of the human hip joint. Yale J Biol Med 16:13–26, 1943
12. Haines RW: The development of joints. J Anat 81:33–55, 1947
13. Gardner E, Gray DJ: Prenatal development of the human hip joint. Amer J Anat 87:163–191, 1950
14. Andersen H: Histochemical studies of the development of the human hip joint. Acta Anat (Basal) 48:258–292, 1962
15. Sutton JB: The ligamentum teres. J Anat 17:191–193, 1883
16. Moser E: Ueber das ligamentum teres des Huftgelenkes. Anat Anz, Jena 7:82–87, 1892
17. Parsons FG: The joints of mammals compared with those of man. Part II: The joints of the hind limbs. J Anat Physiol 34:301–306, 1900
18. Keith A: Human Embryology and Morphology. 5th ed. Baltimore, William Wood & Co, 1933, p 456
19. Frazer JE: Anatomy of the skeleton. London: Churchill, 1940, pp 127–128
20. Sandifort ECA: Animadversiones de Vitiis Congenitis et de fracturis Articulatonis Coxae. Ludguni-Vatvorum, Apud S and J Luchtmans, 1834, pp 12–43
21. Walker JM: A study of the growth and development of the human fetal hip joint. Unpublished doctoral dissertation, McMaster University, 1977
22. Streeter GL: Weight, sitting height, head size, foot length, and menstrual age of the human embryo. Contrib Embryol 11:143–170, 1920
23. Moore KL: The Developing Human. Toronto, WB Saunders Co, 1973, p 78
24. Lillie RD: Histopathologic Technic and Practical Histochemistry. 2nd ed. New York, Blakiston, 1954
25. Schultz AH: Changes in fetuses due to formalin presentation. Amer J Phys Anthropol 2:35–41, 1919
26. Scammon RE, Calkins LA: The development and growth of the external dimensions of the human body in the fetal period. Minneapolis, The University of Minnesota Press, 1929
27. Babb F, Sundberg B: Congenital dislocation of the hip. Min Med 53:150–200, 1970
28. Nie NH, Hull CH, Jenkins JG, et al: SPSS Statistical Package for the Social Sciences. New York, McGraw-Hill, 1975
29. Cohen E, Burns P: SPSS—Manova multivariate analysis of variance and covariance. Northwestern University, Document 413, 1976
30. Draper NR, Smith H: Applied Regression Analysis. New York, John Wiley & Sons, 1966
31. Goldsmith CH: Some useful concepts in regression analysis motivated by medical data. Handout prepared for presentation at the Statistical Science Assoc of Canada Annual meeting, University of Toronto, May 30, 1974
32. Dunn PM: The anatomy and pathology of congenital dislocation of the hip. Clin Orthop 119:23–27, 1976
33. Lowrie MF: Congenital dislocation of the hip. Nurs Times, 66(3):72–74, 1970
34. Ralis Z, McKibbin B: Changes in shape of the human hip joint during its development and their relation to its stability. J Bone Joint Surg (Br) 55:780–785, 1973
35. Le Damany P: Congenital luxation of the hip. Am J Orthop Surg 11:541–567, 1914