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Ultrasound of femoral head cartilage: a new method of assessing bone age

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Abstract. This paper analyses the relationship between the thickness of the anterior femoral head cartilage (FHC), as measured by ultrasound, and some anthropometric parameters, such as height, weight, skeletal and chronological age. In addition, it provides standard norms for FHC thickness in a paediatric population. Both hips were examined in 213 consecutive subjects (99 boys and 114 girls), aged 1.9–14 years. Seventy-four subjects underwent hand and wrist X-rays for skeletal maturation: 32 of these were dropped from the study because a discrepancy as high as two standard deviations was found between their skeletal and their chronological age. The thickness of FHC correlated strongly with skeletal and chronological age, standing height and body weight. A side difference of 0.2 mm in FHC was considered to be abnormal. The study population was divided into 13 groups according to chronological age and values of FHC for boys and girls are provided for each group. It is suggested that the magnitude of hyaline FHC is a valuable feature in the evaluation of skeletal maturation in children.

Key words: Ultrasound – Hip joint – Femoral head cartilage – Normal standard – Skeletal maturation

Ultrasound (US) has proved valuable in diagnosing many hip disorders of childhood and adolescence. In particular, ultrasonography is extremely sensitive in the detection of hip joint effusion [1–3], and can provide valuable clues to the diagnosis of Legg-Calvé-Perthes disease [2] and slipped capital femoral epiphysis [4].

Although increasing evidence exists that the anterior aspect of the cartilage of the femoral head (FHC) can be accurately imaged by US, little information is available on the amount of FHC and on changes in its thickness under normal and pathological conditions.

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The endochondral ossification of the epiphysis occurring during skeletal maturation is parallelled by progressive thinning of the cartilaginous band surrounding the forming bone. Thus, measurement of the thickness of the articular cartilage could be an alternative way of assessing bone maturation.

This study was designed to examine this hypothesis and provide normal standard values of FHC thickness in children, for use as reference values in pathological conditions involving the articular cartilage.

Materials and methods

US examination of the hips was performed in 213 subjects (99 boys and 114 girls), aged 1.9–14 years (mean 8.1, standard deviation 3.5 year), coming from a northern Italian region. All were free of known hip disorders and chronic systemic diseases. One hundred and thirty-nine had been referred to our department for sonographic evaluation of kidneys and abdomen, or for chest X-ray. Seventy-four were scanned after they had undergone hand and wrist X-ray examination for osseous maturation: 32 of these children were excluded from the normal standard analysis since their skeletal ages were two standard deviations from their chronological ages. Skeletal age was assessed by comparing the hand/wrist radiograph with the standards of Greulich and Pyle [5]. Chronological age, standing height and body weight were recorded for all subjects.

US images were obtained using a real-time scanner (AU 560, Biomedica Esaote, Genoa, Italy), equipped with a 7.5-MHz linear transducer. To avoid interobserver errors, all US examinations were carried out by the same person (A.C.S.). The subjects lay supine, with thighs and legs in neutral position in regard to internal/external rotation. A single scan of each hip in every subject was obtained, using an anterior approach with the probe placed along the axis of the femoral neck. The FHC was defined as the width of the anechoic space between the ossific nucleus and cartilage surface, close to the epiphyseal side of the physeal plate (Fig. 1). Measurements of the FHC were obtained using electronic calipers. Sonographic measurements were made separately for each side, without any comparison between the two sets of photographs.

Correlation of the sonographic measurements with the independent variables chronological and skeletal age, height and body weight were obtained. For statistical analysis the paired t-test and

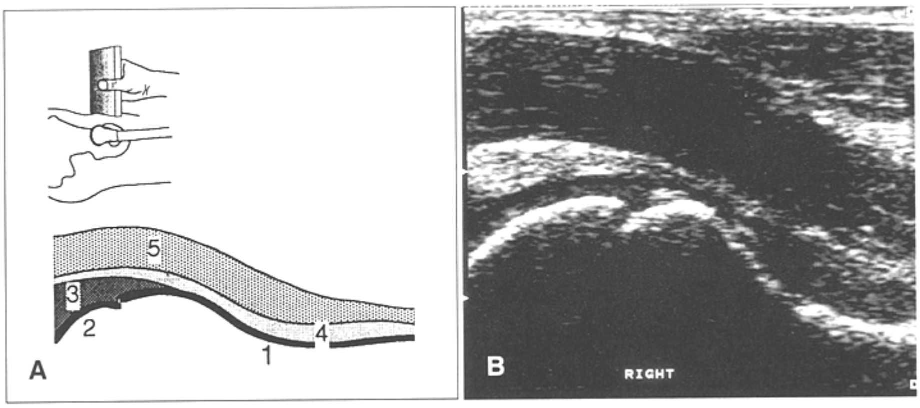

Fig. 1. A Anatomical diagram of hip structures in the plane of the anterior scan, showing the femoral neck (*1*), the ossific nucleus (*2*), the femoral head cartilage (*3*), the joint capsule (*4*) and the psoas bursa (*5*). **B** Sonogram of a normal hip in the same plane as in **A**

Table 1. Range, mean value, standard deviation (SD) and 95th percentile for femoral head cartilage thickness as measured by ultrasound in 181 healthy children (in millimetres)

Femoral head cartilage thickness	Right	Left	Side difference[a]
Range	0.6–4.7	0.5–4.7	0–0.3
Mean	2.13	2.14	0.05
SD	0.92	0.92	0.07
95th percentile	–	–	0.20

[a] Difference between left and right side measurements

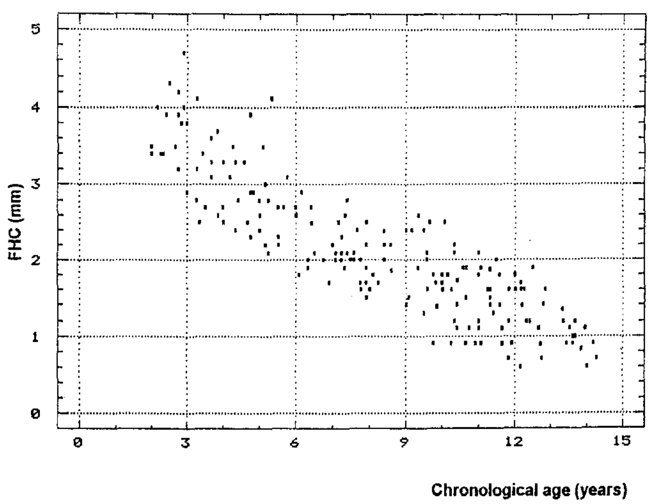

Fig. 2. Scatter plot of the two variables right femoral head cartilage thickness (FHC) and chronological age in 181 normal children. The negative correlation (r =–0.88) is highly significant (p<0.0001)

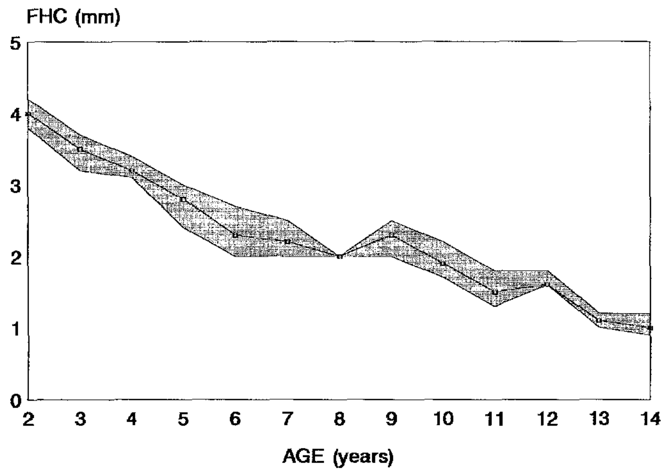

Fig. 3. Mean values and 25th and 75th percentiles of femoral head cartilage thickness (FHC) plotted against chronological age in boys

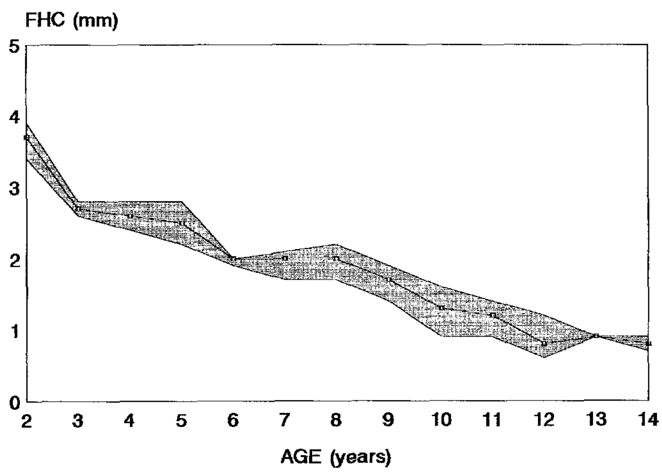

Fig. 4. Mean values and 25th and 75th percentiles of femoral head cartilage thickness (FHC) plotted against chronological age in girls

Pearson's correlation were used. The significance level was set at 95% of confidence limits.

Results

Results are summarized in Table 1. The upper confidence limit (95th percentile) of the side difference indicates that a difference in FHC thickness of more than 0.2 mm for FHC should be regarded as abnormal.

A close correlation was found between FHC and chronological age (r=–0.88; Fig. 2), skeletal age (r=–0.88), standing height (r=–0.89) and body weight

Table 2. Mean values and standard deviation (in millimetres) for right and left femoral head cartilage thickness in boys, divided into 13 age groups

Age group (years)	No. of observations	Right		Left	
		Mean	SD	Mean	SD
1–2	6	4.00	0.43	3.98	0.43
2–3	8	3.50	0.37	3.51	0.41
3–4	8	3.27	0.36	3.26	0.39
4–5	8	2.85	0.60	2.85	0.59
5–6	6	2.35	0.44	2.46	0.48
6–7	10	2.20	0.39	2.23	0.40
7–8	1	2.00	0.00	2.20	0.00
8–9	6	2.30	0.28	2.23	0.25
9–10	7	1.94	0.34	1.92	0.31
10–11	11	1.53	0.35	1.57	0.36
11–12	7	1.61	0.25	1.61	0.26
12–13	5	1.10	0.10	1.10	0.14
13–14	2	1.05	0.21	1.05	0.21

Table 3. Mean values and standard deviation (in millimetres) for right and left femoral head cartilage thickness in girls, divided into 13 age groups

Age group (years)	No. of observations	Right		Left	
		Mean	SD	Mean	SD
1–2	9	3.68	0.36	3.71	0.36
2–3	5	2.74	0.23	2.78	0.31
3–4	6	2.57	0.23	2.65	0.27
4–5	7	2.56	0.48	2.54	0.50
5–6	5	2.06	0.38	2.04	0.34
6–7	15	1.97	0.26	2.00	0.30
7–8	5	1.98	0.30	2.02	0.35
8–9	10	1.66	0.42	1.66	0.42
9–10	11	1.28	0.34	1.31	0.39
10–11	9	1.23	0.41	1.24	0.41
11–12	3	0.83	0.32	0.87	0.38
12–13	3	0.90	0.00	0.90	0.00
13–14	8	0.85	0.24	0.82	0.26

(r=–0.80). The mean values and 25th and 75th percentiles of FHC thickness plotted againsts chronological age are shown for boys and girls in Figs. 3 and 4. In the subgroup of 32 subjects with a skeletal age two standard deviations from their chronological ages (advanced or delayed), statistical analysis showed a similar correlation of FHC with skeletal (r =– 0.88) and chronological age (r =– 0.85).

Based on chronological age, the study population was divided into 13 groups. For each group, the mean value and standard deviation of FHC was registered. Since skeletal development at all ages is more advanced in girls than in boys, separate standards were established (Tables 2, 3).

Discussion

Radiographs of the left hand and wrist are widely used for assessing bone age in children. The most common procedure is a comparison with the standards of Greulich and Pyle [5]. However, this may result in interpretive errors due to interobserver variability and/or to the different emphasis put on the carpal and tubular bones [6]. The precision and accuracy of bone age determination are improved by using the Tanner-Whitehouse method (TW2 method), which provides a maturity score based on the analysis of 20 bones of the left hand and wrist [7]. However, this method is very time-consuming and is therefore little used in daily routine. Other techniques which compare radiographs of the hand/wrist area and the elbow, knee and pelvis to standard atlases have been developed, but all involve either long reading time or a considerable increase in radiation exposure [8, 9].

All the above methods are based on the time of appearance of ossification centres and subsequent changes in size and shape of the newly formed bones. An alternative approach to epiphyseal ossification is the evaluation of the overlying layer of cartilage. Once the ossification centre has appeared at the epiphyseal site, mineralization extends to gradually replace all the epiphyseal cartilage except for that which persists as hyaline articular cartilage. Hence, quantification of depth of cartilage is an index of skeletal maturity.

Using an anterior scanning approach to the hip, it is possible to identify the most anterior aspect of the FHC, which surrounds the corresponding femoral epiphysis. The major goal of the present study was to elucidate the relationship between changes in FHC thickness and some anthropometric parameters, especially the chronological and skeletal ages. As expected, our results indicate that hyaline FHC gradually decreases in thickness during growth, as the deposition of new epiphyseal bone proceeds with age. This phenomenon is substantiated by the very strong correlation between the thickness of FHC and the chronological and skeletal ages. In the subgroup of subjects presenting with a skeletal age two standard deviations away from their chronological ages, the degree of correlation of FHC was similarly high with skeletal compared to chronological age. Although it is not definitely proven whether the FHC can be used as index of biological maturity, it is reasonable to assume that changes in the thickness of the articular cartilage are closely related to skeletal maturation.

An additional aim of our study was to provide normal standards for the thickness of FHC, as assessed by ultrasonography in a paediatric population, representative of different age groups. Although a considerable body of data indicates that articular cartilage may be involved during the course of joint disease in children as well as in adults, few reports have focused attention on sonographic changes in articular cartilage in diseases of childhood. Thickening of FHC may occur in early Perthes disease [2, 10], while thinning is found in juvenile rheumatoid arthritis and chondrolysis complicating slipped capital femoral epiphysis [11]. Differences in FHC thickness between the two hips are easily demonstrable by US. However, this feature is unhelpful in cases of bilateral disease and does not address the level at which a difference between sides becomes significant. Errors in measuring the FHC thickness can be quantified by calculating the precision of the method, on the basis of the closeness of agreement between different measurements. Assuming that in normal subjects the FHC of both hips is equally thick, discrepancies between sides should be attributed to measurement errors. In this regard, the value of 0.2 mm, corresponding to the 95th percentile of the observed side difference in our series, confidently represents the upper limit of error. Thus, asymmetry between the sides by more than 0.2 mm should be considered significant. Moreover, linear regression analysis applied to our series indicates that an error of 0.2 mm reflects under- or overestimation of skeletal age by about 6 months. This would seem an acceptable error in assessment of bone maturation.

A drawback of this study is the relatively small number of subjects in each age group, and the lack of racial heterogeneity of the sample. This makes our results unsuitable for application directly to other racial and ethnic groups. Further investigations are needed to expand the present series, determine racial and ethnic differences and confirm whether the depth of hyaline FHC may provide additional information on skeletal maturation. This would seem to be particularly helpful when a discrepancy in maturity exists between the different bones of the left hand and wrist. Should the reliability of this new method be confirmed by subsequent studies, the investigated children would at least benefit by a considerable reduction in radiation exposure.

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