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Morphometric and ultrasonographic study of the human fetal hip joint during intrauterine development

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Abstract

The main method for the early screening of the developmental dysplasia of the hip (DDH) is the ultrasound imaging. There are several studies about the ultrasound imaging of newborns' hips, but only a few studies include the prenatal period of life. Our aim was to examine the prenatal development of the hip joint through the evolution of the α angle seen on the ultrasound, described in the Graf R method, combined with anatomical dissection. *Materials and Methods*: Thirty-one *post-mortem* fetal hips were analyzed trough anatomical dissection, in 25 cases trough ultrasound imaging, in which the α angle was measured. Based on the morphometric examination, we applied the sine rule and we calculated the α1 angle, which also represents the coverage of the femoral head. *Results*: Based on the morphometric examination, not only the diameters of the femoral head and of the acetabulum, but also the joint cavity (X) showed an increase during development. Both of the α angles (measured α, calculated α1) showed a decrease as the fetus developed. *Conclusions*: The decrease of the angles (α, α1) and the increase of the joint cavity during development correspond to the findings of the main research papers: the hip joint is less stable in the perinatal life. The α angle can be accurately determined only after the ossification of the acetabulum had started, in our case after the fetus is older than 18 weeks.

Keywords: morphometry, ultrasonography, hip joint development.

Introduction

The developmental dysplasia of the hip joint (DDH) can be most effectively treated especially if it is detected in the early stages. The rapid development of medical imaging significantly enlarges the palette of methods that facilitate the early diagnosis of DDH after birth. During the clinical examinations of the newborn, there is a high risk of false positive results; therefore, the role of ultrasound examination 2–4 weeks after birth becomes increasingly important. This period is recommended for diagnosis, because the ossification of the joint components has not begun yet, thus, treatment is most effective if started in this stage [1–3]. The most widespread among the ultrasound diagnostic methods is the one developed by Graf R in 1980, which determines the stability of the hip joint through the measure of α angle (the acetabular inclination angle) and β angle (the acetabular cartilage roof angle) [1, 2, 4–6].

DDH is a very common developmental disease. It has been established that the main etiological factors are genetics and the abnormal mechanical forces acting on the joint during the intrauterine life [7–9].

The development of the hip joint starts in the 7th week of the intrauterine life. The process ends in the 11th week, when the joint is completely formed and the main components, the femoral head and the acetabulum, are recognizable [10–14]. In the following weeks, the joint components go through numerous morphological and geometrical changes: the coverage of the femoral head decreases, the shallowness of the acetabulum, the antetorsion of the femoral neck, the collodiaphyseal angle of the femur and the acetabular antetorsion increase [15–17]. The balance between the aforementioned elements of the process ensures the normal development of the hip joint and also the decrease of the stability of the hip joint around time of birth [18, 19].

Although there are numerous studies related to the ultrasound examination of the hip joint of newborns, the prenatal period of the development process presents the focus of a reduced number of studies. The main reason for this relies in the fact that certain anatomical details that are crucial for the measure of α and β angles described by Graf R method are difficult to observe.

Based on the conclusions of Lee J *et al.*, the congenital dislocation of the hip joint is not an early development condition; this explains the absence of any other studies about the hip dislocation in the first half of gestation [20].

Our aim was to examine the prenatal development of the human hip joint through the evolution of the values of the α angle seen on the ultrasound, described in the Graf R method, combined with anatomical dissection.

Materials and Methods

Fetuses

In our study, the hip joints of 31 *post-mortem* fetuses were examined through ultrasound and dissection methods. The fetuses were obtained from the Department of Anatomy and Embryology, University of Medicine and Pharmacy of Tîrgu Mureş, Romania. The age of the fetuses was determined by measuring the crown-to-rump length (CRL). According to this, the smallest fetus had a length of 85 mm, while the longest 220 mm. Gender distribution was as follows: 15 male and 16 female. The fetuses were preserved in 10% formaldehyde solution, their hip joint was in flexion and in a slight external rotation position, but none of them was dislocated.

Ultrasound examination

The 2D ultrasound images of the joints were obtained by a DC-5 Diagnostic, Schenzen Mindray and Philips HD 11XE devices, with a linear transducer. On the ultrasound images, the main anatomical components of the hip joint were clearly visible, but a more detailed image was observable only for the older fetuses (Figures 1 and 2). The angle measured during ultrasound examination will be further denoted as "α".

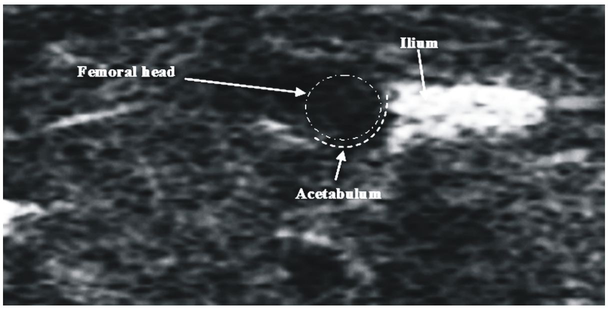

Figure 1 – ***Ultrasound image of a 3-month-old fetus.***

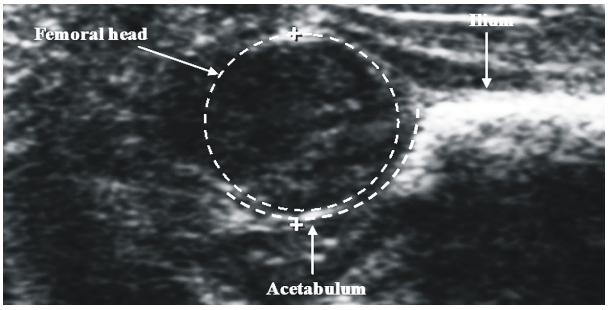

Figure 2 – ***Ultrasound image of a 6-month-old fetus.***

The fetuses were examined in lateral decubitus position. We obtained a lateral coronal view of the acetabulum through the center of the acetabulum. The α angle is formed between the baseline (is drawn parallel to the lateral iliac border) and the bony roof line (is drawn tangential to the bony acetabular roof) and measures the inclination of the acetabular roof (Figure 3). Normal values of the α angle after birth are above 60^0[6].

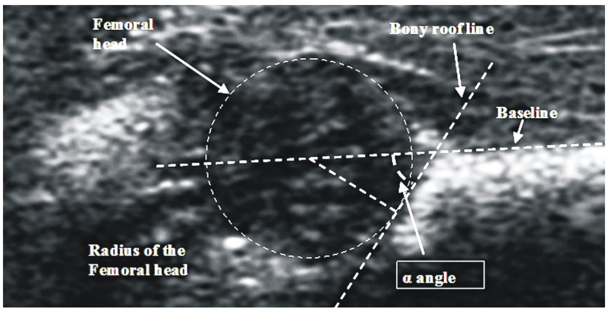

Figure 3 – ***α Angle on the ultrasound image.***

Morphometric analysis

Following the ultrasound examination, an anatomical exploration was performed. After an incision through the greater throchanter of the femur, the periarticular muscles were removed, and then the incision of the joint capsule was performed, followed by the dislocation of the femoral head from the acetabulum. In order to facilitate further measurements, the proximal part of the femur was removed after the dislocation. For the measure of the vertical and transversal diameters of the femoral head and acetabulum, a slide caliper was used with an 0.05 mm accuracy, as shown in Figures 4 and 5 (f1 – vertical diameter and f2 – transversal diameter of the femur; a1 – vertical diameter and a2 – transversal diameter of the acetabulum). Based on these data, the mean diameters were determined (F, respectively A). The size of the joint cavity (denoted by X) was calculated as the difference between the two diameters.

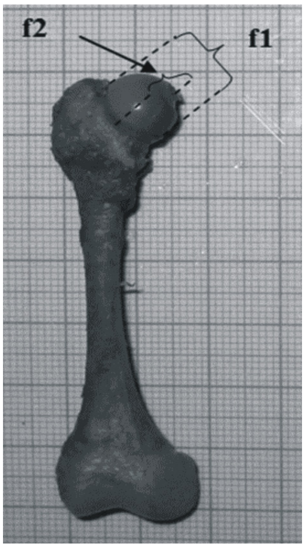

Figure 4 – ***Femoral head measurements.***

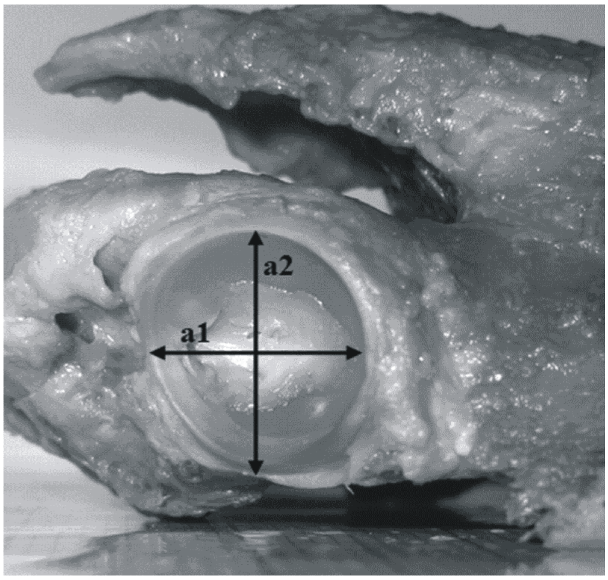

Figure 5 – ***Acetabular measurements.***

Determination of the α1 angle based on the morphometric data. Due to the position of the femoral head and the acetabulum on the ultrasound images, two virtual lines were drawn: one parallel to the ilium that ran through the center point of the femoral head and another crossing the roof of bony acetabulum tangent to the femoral head.

The α1 angle is formed by these two virtual lines. Moreover, the line connecting the center of the femoral head with the tangent will be the radius of the femoral head. The distance parallel to the ilium can be calculated as the sum of the radius of the femoral head (R) and the distance between the femoral head and the superior labrum of the acetabulum (X). Thus, two sides of the right triangle seen on Figure 6 are known and the α1 angle can be determined by applying the sine rule (Figure 6).

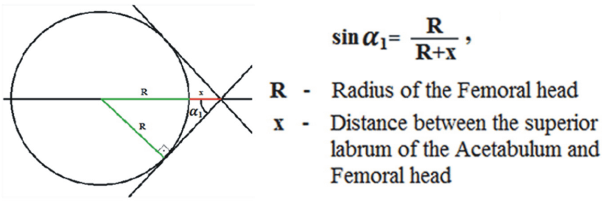

Figure 6 – ***The calculation of the α1 angle.***

Based on the radius of the femoral head and the values calculated for the size of the joint cavity (X), the α1 angle for each fetus was determined. The aim of this method is to be able to calculate the α1 angle for smaller fetuses for which the ultrasound images do not provide a clear view of the points of reference used for the measurement of the α angle.

Statistical analysis was performed using GraphPad InStat 3, version 3.06 statistic calculation software (GraphPad Software Inc., San Diego, USA). The results of the morphometric data and ultrasound examinations were correlated and the difference between the mean values was analyzed using two-tailed Student's *t*-test. The results were considered statistically significant if $p<0.05$, with 95% confidence interval.

Results

The morphometric examination of the hip joint

During dissection, the femoral head was steadily positioned in the acetabulum in all cases; the dislocation was possible only after the removal of the periarticular soft tissue.

There was no statistically significant difference between the transversal and vertical diameters of the femoral head and of the acetabulum, neither on the left, nor on the right side (Student's *t*-test, right femoral head $p=0.93$, right acetabulum $p=0.99$, left femoral head $p=0.92$, left acetabulum $p=0.99$). Based on these results, the acetabulum and the femoral head can be considered a circular geometric shape.

We observed a strong positive correlation between the diameters of the femoral head, of the acetabulum and the CRL during the fetal development (CC=0.907, respectively CC=0.997) (Figure 7).

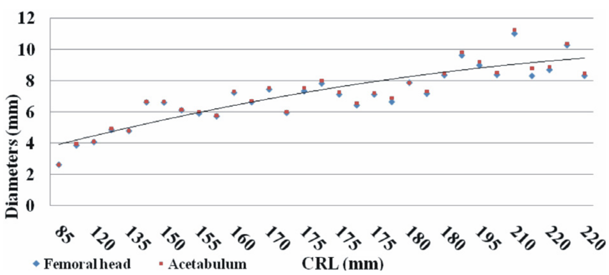

Figure 7 – ***Femoral head and acetabular diameters [mm].***

The size of the joint cavity was determined as the difference between the acetabulum diameter (A) and the femoral head diameter (F). The smallest value (0 mm) was recorded for the 3-month-old fetus (CRL=85 mm), while the largest value (0.55 mm for right hip joint, 0.475 mm for left hip joint) was measured for the 6-month-old fetus (CRL=210 mm). Table 1 illustrates the mean values for the hip joint cavity and for the acetabulum and femoral head diameters.

Table 1 – ***Mean values of the femoral head (F), acetabulum (A) and joint cavity (X)***

Month	Right hip joint			Left hip joint		
	F average [mm]	*A average [mm]*	*X average [mm]*	*F average [mm]*	*A average [mm]*	*X average [mm]*
3	2.62	2.62	0	2.62	2.62	0
4	4.83	4.91	0.08	4.84	4.88	0.04
5	7.06	7.2	0.14	7.04	7.17	0.13
6	9.16	9.42	0.26	9.07	9.32	0.25

Based on our observations, in the early period of hip joint development the joint cavity is very small and gradually increases as the fetus develops (CC=0.669), as shown in Figure 8.

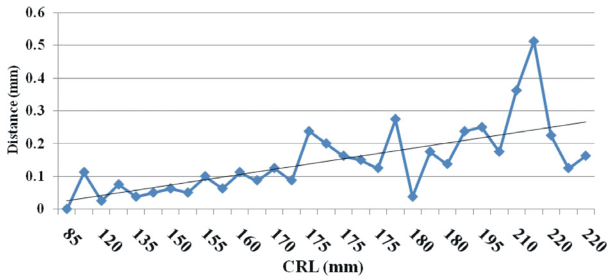

Figure 8 – ***Joint cavity (X) [mm].***

The ultrasound examination of the hip joint

We were able to determine the α angle for 25 out of the 31 fetuses; as described by the Graf R method [1, 2, 4]. The α angle measured during the ultrasound examination decreases as the fetus develops (CC=-0.503) (Figure 9). Based on the values of the α angle, none of the hip joints was dysplastic or dislocated, which was proved by the results of the anatomical dissection.

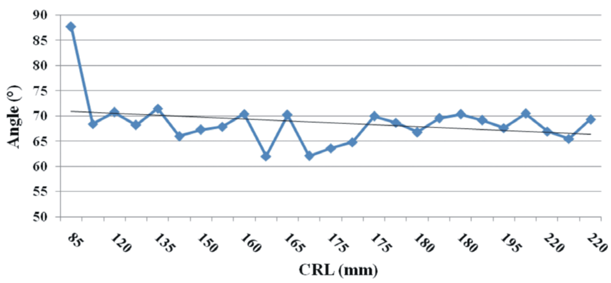

Figure 9 – ***α Angle measurements [^{0}].***

The mathematical determination of the α1 angle

By using the values of the joint cavity (X) determined during anatomical dissection, we applied the sine rule and determined the values for the α1 angle. During the fetal development, this α1 angle gradually decreases (CC=-0.635), as previously determined in the case of α angle during ultrasound examination. The largest α1 angle was measured for the 85 mm CRL fetus (90^0), whereas the smallest α1 angle (62.04^0) was recorded for the 220 mm CRL fetus (Figure 10).

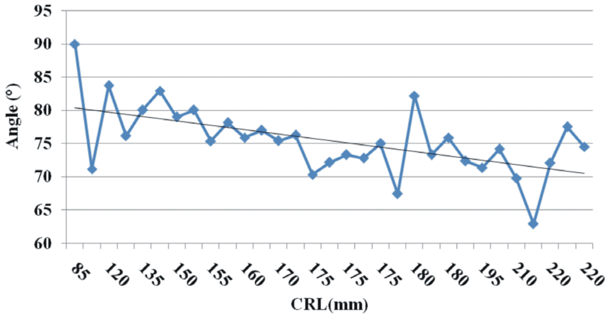

Figure 10 – ***α1 Angle [^{0}].***

There is a statistically significant difference between the measured α angle during ultrasound examination and the calculated α1 angle ($p<0.05$) (Table 2, Figure 11). As Figure 11 shows, this difference gradually decreases for fetuses that have a CRL>175 mm (after five months), whereas for smaller fetuses the difference is significantly larger.

Table 2 – ***Mean values of the α1 and α angles***

Month	Right hip joint		Left hip joint	
	α1 average [^{0}]	*α-angle average [^{0}]*	*α1 average [^{0}]*	*α-angle average [^{0}]*
3	89	90	86.56	90
4	66.36	77.26	69.75	80.38
5	67.27	74.9	67.47	75.44
6	68.86	73.18	67.14	74.71

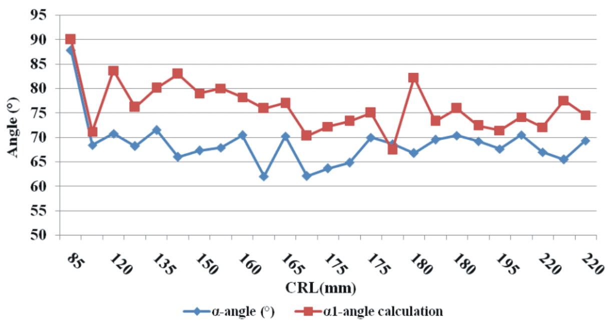

Figure 11 – ***Measured and calculated α angle.***

Discussion

The morphological and ultrasound examinations allowed us to monitor the intrauterine development of the hip joint between the 3rd and 6th month of the pregnancy. Since the vertical and horizontal diameters of the femoral head and the acetabulum did not differ statistically, the geometric shape determined by these was considered a circle. The joint cavity calculated as the difference between the diameters of the acetabulum and femoral head gradually increased with the growth of the fetus.

In our study, the femoral head and the acetabulum showed a progressive increase until six months of gestation. Based on an ultrasonographic study of the prenatal hip joints by Ianakova OM *et al.*, the most intensive growth of the head occurs at 26–38 weeks of gestation [21]. Other authors using magnetic resonance imaging and fetal hip joint ultrasound observed that until the 20th week the diameter of the femoral head and the depth of the acetabulum showed a slight increase, but after 20 weeks they increase exponentially [20, 22]. According to the study of Stiegler H *et al.* the fetal hip joint is sonographically mature at 34 weeks of gestation [23].

Due to the fact that during the early stages of the fetal development the ultrasound image did not allow for a clear measurement of the α angle, we performed the morphological examinations to determine the α1 angle – later, the values measured on the ultrasound images (α) were compared with the values calculated based on the morphologic method (α1). Although the α angle measured for the 12–18-week-old fetuses were higher than the α angle measured for the 18–24-week-old fetuses, the anatomical details on the ultrasound images were less clear for the former than for the latter. In case of the smaller fetuses (12–18 weeks), only the main anatomical components (femoral head and acetabulum) were clearly visible on the ultrasound images, thus, the measured and calculated alpha angles were significantly different. The anatomical details were visible on the ultrasound images only for fetuses older than five months. This is the main reason why the α angle measured by the two distinct methods (ultrasound α and morphologic examination α1) for fetuses older than five months showed no major difference.

Our study affirms the findings of previous research data, that the stability of the hip joint decreases as the fetus develops [15, 16, 18, 19, 24]. According to the study of Wagner UA *et al.* in 1994 related to the ultrasound examination of the hip joint, the α angle can be measured starting from the 21st week of the pregnancy; still, exact measures can be obtained only shortly before birth [23, 25, 26]. The explanation for this is that the acetabulum for small fetuses is composed of hyaline cartilage, which on the ultrasound images shows as a hypoechogene zone [4, 13]. Based on the histological study of Walker JM in 1981, the ossification of the acetabulum starts after 20 weeks, when the fetus is approximately 20 cm long [11]. After 20 weeks, the ossified regions appear as hyperechogene zones on the ultrasound image, which is essential for the correct determination of the α angle.

We aimed to prove the decreasing tendency of the α angle through the sine rule applied during the morphometric examination. The α1 angle was determined for smaller fetuses as well, for which the angles are harder to determine. The formula that we applied describes the ideal state of the hip joint. In the case of normal fetal development, the increase of the joint cavity (X) leads to the decrease of the α1 angle. The difference between the measured (α) and calculated (α1) angles was more accentuated before the ossification of the acetabulum and as the process evolved, these differences gradually decreased. In both methods (ultrasound and morphologic examination), the values of the α angle indicated the decrease of the stability of the hip joint during normal development, which corresponds with the results shown in previous research papers [14–19, 24, 27].

Conclusions

Our research complements the limited pool studies that focus on the intrauterine development of the human hip joint. Our results complete and match the findings of previously published research papers. We concluded that during fetal development the diameters of the femoral head and the acetabulum, as well as the joint cavity, are gradually increasing. The decrease of the coverage of the femoral head leads to the gradual decrease of the measured (α) and calculated (α1) angles as the fetus develops. By ultrasound examination of the fetal hip joint, the α angle can be accurately determined only after the ossification of the acetabulum had started, in our case after the fetus is larger than 175 mm (CRL), respectively older than 18 weeks.

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