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ORIGINAL ARTICLE

Does cranial bone ossification differ in children with developmental dysplasia of the hip?

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ABSTRACT

Objectives: This study aims to compare cranial bone ossification between patients with developmental dysplasia of the hip (DDH) and healthy individuals.

Patients and methods: Between September 2021 and April 2022, a total of 60 healthy female individuals (median age: 24.5 months; range, 18 to 36 months) and 56 female DDH patients (median age: 23 months; range, 18 to 35 months) were included. Age, head circumference, weight, height, and patency of the anterior fontanel were measured in groups. Percentiles were classified as very low, low, normal, high and very high. All patients were female and those with abnormal thyroid function test, vitamin D, calcium, phosphate and alkaline phosphatase values were not included in the study. For those diagnosed with DDH, they were included in the group regardless of the type of treatment.

Results: No statistically significant difference was found between the groups in terms of age and weight ($p>0.05$). The very low and very high head circumferences were more frequent, and the normal head circumferences were less frequent in the DDH group ($p<0.05$). There was no significant difference between groups in terms of fontanel closure ($p>0.05$). In open fontanels, no significant difference was found in both groups in terms of age ($p>0.05$).

Conclusion: Our study results showed no significant difference between the fontanel ossifications of children with and without DDH; however, we found that the ossification of the skull bones of children with DDH was different compared to healthy children.

Keywords: Dysplasia, fontanel, hip, ossification, skull.

Developmental dysplasia of the hip (DDH) is characterized by the deterioration of the relationship between the acetabulum and the femoral head and represents a wide spectrum ranging from a mildly dysplastic, concentrically located and stable hip to a severely dysplastic and dislocated hip.[1] In the past, it was a significant cause of disability and, recently thanks to the advanced early diagnostic modalities, particularly hip ultrasonography, that is implemented routinely, DDH can be diagnosed and treated immediately before degenerative arthritis develops.[2,3]

Although the exact etiology of DDH has still not been fully elucidated, it is a multifactorial disease in which mechanical, environmental, familial, and sex factors affect its etiology.[4] The anterior fontanel closes at approximately 16 to 18 months, which is the last fontanel to be closed. Closure of the anterior fontanel before six months of age is considered early; however,

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closure after 18 months is considered delayed. If the anterior fontanel remains open, congenital diseases, such as congenital hypothyroidism, osteogenesis imperfecta, rickets, achondroplasia, Down syndrome, and hypophosphatemia, should be excluded.[5] The association between hip and fontanel development can be considered a part of bone growth and maturation. However, to date, no such mechanisms or attributes have been defined or investigated between them.

In the literature, the effects of systemic mechanisms that may adversely affect acetabular ossification of fontanel closure and heap development have been examined. The ossification of the skull bones and fontanels is intramembranous.[6] Intramembranous ossification plays an important role in acetabular development.[7,8] Considering the problematic acetabular ossification in DDH.[9-11] In the present study, we hypothesized that cartilage acetabular ossification and fontanel and cranial bone ossification may occur via the same mechanisms. We, therefore, aimed to compare the fontanel and skull bone development of patients with DDH considered to have delayed cartilage acetabular calcification with those of healthy children.

PATIENTS AND METHODS

This single-center, cross-sectional study was conducted at Gazi University, Faculty of Medicine, Departments of Orthopedics and Traumatology and Pediatrics between September 2021 and April 2022. A total of 60 healthy individuals and 60 patients with DDH who were diagnosed and treated before were included. To evaluate the relationship between fontanel patency and DDH, 18 months, which is the age limit for persistent fontanel, was considered as the minimum age limit and 36 months were selected.[12] Healthy individuals were selected from patients who did not have any congenital or chronic diseases and who were admitted to the hospital with acute symptoms such as upper respiratory tract infection etc. that would not affect our research subject. To increase homogeneity, all the individuals were selected as female. Individuals having any congenital diseases or endocrinologic disorders were excluded from the study. Both groups had similar features apart from possessing DDH. Healthy individuals were selected from the third author's clinical center and patients with DDH were selected from the first author's located in the same region. Thyroid function test, vitamin D, calcium, phosphate, and alkaline phosphatase (ALP) levels of patients in both groups with fontanel patency were examined. Patients with pathological findings were excluded. During the study, four patients with DDH were lost to follow-up. Finally, the study was completed with 60 healthy female individuals (median age: 24.5 months; range, 18 to 36 months) and 56 female DDH patients (median age: 23 months; range, 18 to 35 months).

Children with genetic and neuromuscular diseases, such as achondroplasia, osteogenesis imperfecta, spondyloepiphyseal dysplasia, and maternal diabetes, were excluded from this study. Patients diagnosed with DDH were included in the study group, regardless of treatment method.

Age, head circumference, weight, height, and patency of the anterior fontanel were measured in both groups. To evaluate fontanel persistency, physical examination was performed. As the parameters differed with age, they were calculated in percentiles to avoid confusion.[9] The percentiles were classified as very low, low, normal, high, and very high as described by Neyzi et al.[13] Measurements were performed by two authors.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 25.0 software (IBM Corp., Armonk, NY, USA). Continuous data were expressed in median (min-max), while categorical data were expressed in number and frequency. Normality analysis was performed using the Kolmogorov-Smirnov test. Due to the abnormal distribution, the Mann-Whitney U test was performed to compare age variables between the groups. The chi-squared test and Bonferroni method were used to compare categorical variables between the groups. A p value of <0.05 was considered statistically significant.

Power analysis was not performed through a separate reference study, but through the Power A&X application on input data.[14] Power level was found 91% with significance level of 0,01 to identify a difference between two groups.

RESULTS

Age, height, weight, head circumference, and status of fontanel closure in the participants are shown in Table I. No statistically significant differences were observed between the groups in terms of age ($p=0.075$). However, there was a significant difference of head circumference between groups ($p=0.002$).

Owing to the small number of participants in some height groups to satisfy the chi squared test conditions, the height variable was modified as very low-low, normal, and high-very high. There was no significant difference between the groups (Table II).

TABLE I
Age, height, weight, head circumference, and fontanel closure in the groups

	Normal hip (n=51.7)				DDH (n=48.3)				
	n	%	Median	Min-Max	n	%	Median	Min-Max	*p*
Age (month)			24.5	18-36			23.0	18-35	0.75*
Height									0.252
Very low	3	5.0			6	10.7			
Low	5	8.3			4	7.1			
Normal	26	43.3			30	53.6			
High	9	15.0			7	12.5			
Very high	17	28.3			9	16.1			
Weight									0.491
Very low	7	11.7			8	14.3			
Low	11	18.3			8	14.3			
Normal	20	33.3			26	46.4			
High	12	20.0			6	10.7			
Very high	10	16.7			8	14.3			
Head circumference									0.002
Very low	2	3.3			8	14.3			
Low	12	20.0			5	8.9			
Normal	31	51.7			16	28.6			
High	9	15.0			10	17.9			
Very high	6	10.0			17	30.4			
Fontanel									0.909
Closed	55	91.7			51	91.1			
Open	5	8.3			5	8.9			

DDH: Dysplasia of the hip; * Mann-Whitney U test.

TABLE II
Comparison of the groups of height in terms of groups

	Normal hip	DDH	Total
Very low and low			
Count	8*	10*	18
Expected count	9.3	8.7	18.0
% within the type of hip	13.3	17.9	15.5
Residual	–1.3	1.3	
Adjusted residual	–0.7	0.7	
Normal			
Count	26*	30*	56
Expected count	29.0	27.0	56.0
% within the type of hip	43.3	53.6	48.3
Residual	–3.0	3.0	
Adjusted residual	–1.1	1.1	
High and very high			
Count	26*	16*	42
Expected count	21.7	20.3	42.0
% within the type of hip	43.3	28.6	36.2
Residual	4.3	–4.3	
Adjusted residual	1.7	–1.7	
Total			
Count	60	56	116
Expected count	60.0	56.0	116.0
% within the type of hip	100.0	100.0	100.0

DDH: Dysplasia of the hip; p=0.252 (Chi-square test). Each subscript letter denotes a subset of type categories whose column proportions do not differ significantly from each other at the 0.05 level.

TABLE III
Comparison of the groups of weight in terms of the groups

	Normal	DDH	Total
Very low			
Count	7[a]	8[a]	15
Expected count	7.8	7.2	15.0
% within the type of hip	11.7	14.3	12.9
Residual	–0.8	0.8	
Adjusted residual	–0.4	0.4	
Low			
Count	11[a]	8[a]	19
Expected count	9.8	9.2	19.0
% within the type of hip	18.3	14.3	16.4
Residual	1.2	–1.2	
Adjusted residual	0.6	–0.6	
Normal			
Count	20[a]	26[a]	46
Expected count	23.8	22.2	46.0
% within the type of hip	33.3	46.4	39.7
Residual	–3.8	3.8	
Adjusted residual	–1.4	1.4	
High			
Count	12[a]	6[a]	18
Expected count	9.3	8.7	18.0
% within the type of hip	20.0	10.7	15.5
Residual	2.7	–2.7	
Adjusted residual	1.4	–1.4	
Very high			
Count	10[a]	8[a]	18
Expected count	9.3	8.7	18.0
% within the type of hip	16.7	14.3	15.5
Residual	–.7	–0.7	
Adjusted residual	–.4	–0.4	
Total			
Count	60	56	116
Expected count	60.0	56.0	116.0
% within type	100.0	100.0	100.0

DDH: Dysplasia of the hip; p=0.491 (Chi-square test). Each subscript letter denotes a subset of type categories whose column proportions do not differ significantly from each other at the 0.05 level.

TABLE IV
Comparison of the groups of head circumference in terms of the groups

	Normal	DDH	Total
Very low			
Count	2[a]	8[b]	10
Expected count	5.2	4.8	10.0
% within the type of hip	3.3	14.3	8.6
Residual	–3.2	3.2	
Adjusted residual	–2.1	2.1	
Low			
Count	12[a]	5[a]	17
Expected count	8.8	8.2	17.0
% within the type of hip	20.0	8.9	14.7
Residual	3.2	–3.2	
Adjusted residual	1.7	-1.7	
Normal			
Count	31[a]	16[b]	47
Expected count	24.3	22.7	47.0
% within the type of hip	51.7	28.6	40.5
Residual	6.7	–6.7	
Adjusted residual	2.5	–2.5	
High			
Count	9[a]	10[a]	19
Expected count	9.8	9.2	19.0
% within the type of hip	15.0	17.9	16.4
Residual	–0.8	0.8	
Adjusted residual	–0.4	0.4	
Very high			
Count	6[a]	17[b]	23
Expected count	11.9	11.1	23.0
% within the type of hip	10.0	30.4	19.8
Residual	–5.9	5.9	
Adjusted residual	–2.7	2.7	
Total			
Count	60	56	116
Expected count	60.0	56.0	116.0
% within type	100.0	100.0	100.0

DDH: Dysplasia of the hip; p=0.491 (Chi-square test). Each subscript letter denotes a subset of type categories whose column proportions do not differ significantly from each other at the 0.05 level.

There were no significant differences between the normal hip and DDH groups in the weight subgroups (p=0.491) (Table III).

The very low and very high head circumference frequencies were higher and the normal head circumference frequency was lower in the DDH group than in the normal hip group (p=0.002) (Table IV).

Majority of the patients had closed fontanels in either group and there was no significant difference (p=0.909) (Table V). In addition, when patients with open fontanels were compared, there was no significant difference in the median age between the groups (p=0.810).

DISCUSSION

It is well known that packaging problems have a significant impact on the etiology of DDH.[15-17] Due to the similar ossification mechanism of the acetabulum and skull bones, we compared the development of skull bones in DDH and healthy individuals. Thus, we attempted a different

TABLE V
Comparison of the fontanel closure in terms of the groups

	Normal	DDH	Total
Closed			
Count	55[a]	51[a]	106
Expected count	54.8	51.2	106.0
% within the type of hip	91.7	91.1	91.4
Residual	0.2	−0.2	
Adjusted residual	0.1	−0.1	
Open			
Count	5[a]	5[a]	10
Expected count	5.2	4.8	10.0
% within the type of hip	8.3	8.9	8.6
Residual	−0.2	0.2	
Adjusted residual	−0.1	0.1	

DDH: Dysplasia of the hip; p=0.491 (Chi-square test). Each subscript letter denotes a subset of type categories whose column proportions do not differ significantly from each other at the 0.05 level.

approach to elucidate the etiology of DDH. Therefore, we determined the percentile rate of head circumference and the presence of a persistent anterior fontanel. Although we found no significant differences in fontanel status, head circumference measurements in DDH patients were different (lower and higher) than in healthy controls. This finding indicates that DDH may not only consist of hip dysplasia, but may also be a symptom of a pathology underlying generalized ossification problems. To the best of our knowledge, this is the first study to examine the association between head and hip development. Although we can make no concrete statements based on these limited data, we believe this may be due to a potential abnormality in bone metabolism by genetic or biochemical means.

Bone formation in the human body can be divided into intramembranous and endochondral ossifications. In endochondral ossification, mesenchymal stem cells first differentiate into chondrocytes, and cartilage structure and ossification occur over time in chondrocytes. The bones that constitute the skeleton usually develop this way.[18] However, during intramembranous ossification, there is no intermediate form of cartilage formation, and mesenchymal stem cells differentiate directly into osteoblasts to form bone tissue.[4]

In acetabular development, in addition to endochondral ossification of the triradiate cartilage, intramembranous ossification of the pelvic bones that make up the acetabulum also plays a role.[7,8] Similarly, fontanel development also occurs through intramembranous ossification and haploinsufficiency of the Msx gene may have a role in persistent open fontanel.[19] Although the effect of the Msx gene on acetabular ossification has not been elucidated, it can be speculated that these two conditions may be related.

Malnutrition can also delay fontanel ossification. Philip[20] examined 24 neonates and reported that intrauterine growth retardation could be associated with delayed endochondral and membranous ossification. However, in our study, none of the participants were known to experience or have a history of malnutrition.

In their 10-year study, Fujioka et al.[21] compared the development of DDH and healthy hips and found that some healthy hips turned into dysplastic hips in the follow-up. They reported that this may have occurred as a result of disruption of normal hip growth and development by an intrinsic factor. While we agree with the same opinion, we believe that this situation is not limited to the hip, but also affects the development of the head and other bone tissues.

The most common reasons for delayed anterior fontanel ossification are Down syndrome, achondroplasia, rickets, hypothyroidism, and intracranial pressure-elevating conditions, such as hydrocephalus. To evaluate the association between rickets and DDH, Topak et al.[22] compared 40 patients with DDH and 40 healthy participants by measuring the blood levels of calcium, phosphorus, ALP, vitamin D, and vitamin D receptor (VDR). They found no significant differences in the levels, except for the levels of VDR, which were significantly lower in the DDH group than in the healthy control group. Thus, low levels of VDR may play a role in the etiology of DDH.

In a study conducted by Ishikawa[23] to examine the association between hyperthyroidism and DDH, birth cases between 1996 and 2003 were examined. The mothers of 21 babies, 18 of whom were female, were diagnosed with DDH, whereas 13 were healthy, three were associated with Graves' disease, and five had gestational transient hyperthyroidism. A diagnosis of hyperemesis gravidarum was established, and DDH was associated with first trimester maternal hyperthyroidism.[23]

An important factor in the etiology of DDH is an increase in soft tissue laxity around the joint. One of the main reasons for this is the increase in the levels of intracellular estrogen receptors. Estrogen changes the structure of collagen in soft tissues

and reduces its amount. Kapoor et al.[24] examined the association between vitamin D and estrogen receptor gene polymorphisms and DDH. The authors found that wild-type estrogen receptors were more common in patients with DDH, although there were no significant differences. In addition, in patients with DDH, mutant Taq 1 VDRs were associated with a higher acetabular index.

Several studies have also shown that estrogen receptors increase compared to normal in DDH patients, particularly in the joint capsule and ligamentum capitis femoris.[25] Considering that estrogen plays a vital role in skeletal maturation, the delay in fontanel closure or deviation in head circumference may also be due to a functional disorder in estrogen receptors.

Nonetheless, there are some limitations to this study. First, the number of patients in both groups is limited. However, as this is the first study to compare cranial bone ossification between patients with DDH and healthy individuals, including only female infants, who have a higher risk of developing DDH, we believe the numbers can be considered sufficient to make an initial comparison. Not being designed as a prospective and blinded manner can be named as other limitations to our approach.

In conclusion, our study results do not suggest a deterioration of fontanel ossification in developmental hip dysplasia. However, this is the first study to demonstrate that there may be a relationship between hip and head development. Considering the results of this study, we can recommend DDH to be investigated in children whose head diameters are outside the normal percentile during routine pediatric control. We believe that intrinsic factors may be more effective than previously thought in the etiology of DDH and this should be investigated further by biochemical and genetic evaluations of bone metabolism.

Ethics Committee Approval: The study protocol was approved by the Ankara City Hospital Ethics Committee (date: 30.06.2021, no: E2-21-641). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea/concept: T.T., H.A.; Design: C.Y., H.A.; Control/supervision: Ş.M.A., H.A., T.T., C,Y.; Data collection and/or processing: H.E.T., A.Ş.H.; Analysis and/or interpretation: H.E.T.; Literature review: H.E.T., Ş.M.A.; Writing the article: H.E.T.; Critical review: T.T., Ş.M.A., H.A.; References and fundings: H.E.T, S.S.; Materials: H.E.T, H.A., A.Ş.H.; Other: S.S.

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