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ORIGINAL CLINICAL ARTICLE

Correlation between avascular necrosis and the presence of the ossific nucleus when treating developmental dysplasia of the hip

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Abstract
Purpose This study assessed whether avascular necrosis (AVN) is correlated with the presence or absence of the ossific nucleus (ON) at the initiation of conservative treatment for developmental dysplasia of the hip (DDH). To date, the correlation between the presence of the ON and AVN manifestations remains ambiguous.
Methods The medical records of 148 patients with 234 dislocated hips who presented at our institution between January 2006 and December 2007 were reviewed. Based on ultrasound examination, the hips were classified according to Graf IIIa, IIIb, and IV criteria. Patients aged >6 months were simultaneously examined by standardized pelvis radiography.
Results The ON was present in 84 hips (35.9 %) at the beginning of treatment. Treatment was begun at a mean age of 5 months, with overhead traction for 2 weeks followed by arthrography and a spica cast for 4 weeks. Afterwards, we used a Tübingen hip-flexion splint. The mean age at final follow-up was 87 months. Hips were radiographically evaluated at last follow-up according to the Ogden–Bucholz AVN classification scheme. There was no significant difference in AVN prevalence between ON^- versus ON^+ hips in children aged ≤10 months ($P = 0.681$), whereas when all age groups were analyzed together, AVN was significantly increased in ON^+ hips ($P = 0.002$). Clinical examination revealed no differences in limping, leg length inequality, and range of motion of hips in the ON^- versus ON^+ groups.
Conclusion We conclude that DDH treatment should be performed early without regard to the presence or absence of the ON. Reduction should not be delayed beyond >10 months of age because any delay in treatment increases the incidence of AVN.

Keywords Ossific nucleus · Avascular necrosis · Developmental dysplasia of the hip

Introduction

Avascular necrosis (AVN) frequently occurs during the treatment of developmental dysplasia of the hip (DDH) with a reported prevalence of between 6 and 48 % [1]. The correlation between the presence of the ossific nucleus (ON) and AVN manifestations remains ambiguous [1, 2]. Whereas some authors suggest that the presence of the ON before DDH reduction decreases the risk of AVN [3, 4], others have argued for immediate reduction of the dislocated hip regardless of whether the ON is present [5]. The ON is normally definitively observed on radiographs in 80 and 96 % of 6- and 9-month-old infants, respectively [6]. In infants with dislocated hips, the appearance of the ON is delayed until 11 months of age [7]. Ossification within the cartilaginous femoral head can be detected by sonography

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before it is visible by radiographic examination [8]. Unlike most Western countries, in Kosovo, children often present late with DDH; therefore, treatment of this condition remains common. The objective of this study was to determine whether AVN development correlates with the presence or absence of the ON at the initiation of conservative treatment for DDH in children.

Patients and methods

The catchment area of the Orthopedic Department of Kosovo University's Clinical Center includes 1.79 million people. The median age of Kosovo's population is 26.3 years, with 55 % of the population under 29 years of age and 10.3 % aged less than 6 years. Based on the 33,650 live births annually between 2006 and 2007, the incidence of children treated with closed reduction is 0.22 % and the incidence of children treated operatively is 0.09 %. The overall incidence of Kosovoan children with dislocated hips is 0.31 % [9].

Patients are referred to our hospital by pediatricians, orthopedic experts, and directly by parents from all over Kosovo. During the study period, we treated 148 patients (13 boys, 135 girls) with 234 dislocated hips. Treatment was initiated at a mean age of 5.0 (range 0.8–17.9) months. The mean age at last follow-up was 87.1 (range 65.0–103.7) months. Eighty-eight hips (37.6 %) were classified as Graf type IIIa, 54 (23.1 %) as Graf type IIIb, and 92 (39.3 %) as Graf type IV pathology. Sixty-two dislocated hips were unilateral and 86 (58.1 %) were bilateral.

Table 1 Hips with developmental dysplasia and avascular necrosis according to patient age and ossific nucleus status

Age (months)	ON^+ (n = 84; 35.9 %)		ON^- (n =150; 64.1 %)	
	AVN^+	AVN^-	AVN^+	AVN^-
1–10	3 (3.6 %)	66 (78.6 %)	4 (2.7 %)	146 (97.3 %)
10–18	9 (10.7 %)	6 (7.2 %)	0	0

AVN avascular necrosis, *ON* ossific nucleus

Table 2 Ossific nucleus status of hips with developmental dysplasia according to lateral side, disease type, and sex

Parameter	ON^+		ON^-	
	n	% of total hips	n	% of total hips
Left	41	17.5	72	30.8
Right	43	18.4	78	33.3
Graf IIIa	29	12.4	59	25.2
Graf IIIb	29	12.4	25	10.7
Graf IV	26	11.1	66	28.2
Male	6	2.6	15	6.4
Female	78	33.3	135	57.7

Overall, AVN was present in 16 (6.8 %) the 234 hips included in the study (Table 1). Classification of these hips according to the Graf classification were one type IIIa (6.2 %), eight type IIIb (50.0 %), and seven type IV (43.7 %) cases. An overall summary of patient classification is shown in Table 2.

This was a retrospective study with a prospectively planned follow-up examination. Written informed consent was signed by the parents of the children. We also obtained approval from Kosovo University's Ethical Committee, and the study was performed in accordance with the tenets of the Declaration of Helsinki. We reviewed medical records of children with dislocated hips who had been referred to our institution between January 2006 and December 2007. It is a consecutive patient series obtained from the register of medical records on patients treated in our department.

Hips were examined by ultrasonography and classified according to the Graff classification into Graf IIIa, IIIb, and IV grades [10, 11]. Patients aged >6 months were simultaneously examined by standardized pelvis radiography. Sonograms, radiographs, and clinical evaluation were conducted by the first (senior orthopedics) and second author (university professor) together. Patients were divided into two groups according to the presence or absence of the ON as a clear vestige at the first ultrasound examination and/or on the radiograph. The group of hips that were ON^+ was divided into two subgroups based on the mean age of the patient at the time of presentation of ON (younger or older than 10 months of age) [6, 7]. The target patients were healthy newborns up to 18 months of age. Only typical dislocations of healthy infants were included. We excluded all patients with neuromuscular disorders (4 patients), arthrogryposis (1 patient), or operated hips (65 patients). Patients with operated hips were excluded because these were neglected cases and treated with pelvis osteotomies combined or without femoral osteotomies. These patients included 35 bilateral, 13 left, and 17 right hip dislocations. Two patients from the ON^+ hip group failed closed reduction and were excluded for later open reduction.

Conventional treatment involved inpatient overhead traction for 2 weeks, followed by arthrography and spica casting for 4 weeks in the human position (90°–100° flexion, 45°–60° abduction) as an outpatient. Adductor tenotomies were performed in 19 patients. After removing the cast, we applied a Tübingen hip-flexion splint until the hips were assessed to be normal based on ultrasound examination [12]. The brace was taken off only during examinations.

Parents were invited to the final follow-up by phone or post; parents of two patients from the ON^- hip group did not respond to these follow-up invitations and were not included in the study. The final follow-up examination was performed between January and June 2013.

Hips were evaluated at last follow-up clinically and by anteroposterior radiography according to the Ogden–Bucholz classification for AVN [13]. Clinical evaluation included an assessment of limping during walking, leg length inequality, and hip range of motion. Supine abduction and adduction were measured with care taken to stabilize the pelvis. Inward and outward rotation was assessed with both the hip and knee flexed to 90°. Hip range of motion was measured using a goniometer.

Fisher's exact test, unpaired *t* test, relative risk, Pearson correlation coefficient *r*, and mathematical means were used for statistical analyses. Calculations were performed using GraphPad Prism v.5 for Windows software package (GraphPad Software, Inc., San Diego, CA). *P* values of <0.05 were considered to be indicative of statistically significant differences.

Results

In our cohort, the AVN prevalence in ON^- hips was 2.7 %, and the AVN prevalence in hips that were ON^+ until 10 months of age was 4.4 %. There was no significant difference in AVN prevalence between ON^- and ON^+ hips in children aged $\leq$10 months undergoing closed reduction of dislocated hips (Fisher's exact test $P = 0.681$). However, when children in all age groups were analyzed together, AVN was significantly increased in those patients with ON^+ hips ($P = 0.002$) (Table 3). There were no children aged >10 months with ON^- hips. The AVN rate was significantly increased in ON^+ children aged >10 months compared to the ON^+ cohort aged <10 months old. In children aged >10 months, the overall AVN incidence was 60.0 %.

All hips with AVN were type I (5 hips, 31.3 %) or type II (11 hips, 68.8 %) according to the Ogden–Bucholz classification, and there was no significant difference according to the presence of the ON (Fisher's exact test $P = 0.546$). Although the rate of hips with AVN was higher on the right side (10 hips; 8.3 %) than on the left side (6 hips; 5.3 %), this difference was not statistically significant (Fisher's exact test, $P = 0.442$).

The mean age at the time of first diagnosis in the total ON^+ group (6.2 ± 3.2 months) was significantly older than that at diagnosis in the total ON^- group (3.4 ± 1.4 months) (unpaired *t* test 7.1, $P < 0.001$), and the mean age at reduction in the total ON^+ group (6.8 ± 3.3 months) was significantly older than that at reduction in the total ON^- group (3.9 ± 1.4 months) (unpaired *t* test 7.1, $P < 0.001$). Also, the mean splinting duration in the total ON^+ group (5.8 ± 2.3 months) was significantly longer than the mean splinting duration in the total ON^- group (4.2 ± 1.1 months) (unpaired *t* test = 5.7, $P < 0.001$). There was a statistically significant positive association between the age of children at reduction and the splinting duration (Pearson's $r = 0.468$, $P < 0.001$). The follow-up period at final examination was 6.8 ± 0.7 years. At last follow-up there was no child with limping and inequality of lower extremities, and the ranges of hip joint motion in abduction, adduction, and inward and outward rotation were similar in the ON^+ and ON^- groups (Table 4).

Table 3 Effect of a positive ossific nucleus status (ON^+) on avascular necrosis development according to age at treatment initiation

Age at reduction (months)	Relative risk (95 % confidence interval)	*P* value
1–10	1.63 (0.37–7.09)	0.681
1–18	5.35 (1.78–16.09)	0.002

Table 4 Hip range of motion according to the presence of the ossific nucleus during final follow-up

Hip range of motion	ON^+	ON^-	Average ranges of hip motion[a]
Abduction			48
Right	49.3 ± 9.5	54.8 ± 10.4	
Left	48.7 ± 10.0	54.8 ± 10.4	
Adduction			31
Right	34.6 ± 4.6	33.3 ± 5.5	
Left	35.1 ± 5.4	33.7 ± 6.0	
Outward rotation			45
Right	64.1 ± 12.6	62.8 ± 11.4	
Left	63.1 ± 12.0	62.9 ± 11.4	
Inward rotation			45
Right	70.8 ± 14.3	72.8 ± 11.5	
Left	70.9 ± 14.6	72.6 ± 11.5	

Estimated ranges of motion are presented as the average number of degrees ± standard deviation

[a] Averages of estimates from four sources used by The American Academy of Orthopaedic Surgeons

Discussion

In Kosovo, treating DDH remains a challenge. Swaddling is a very popular and traditional way of wrapping infants; however, this is a risk factor for developing DDH [14, 15]. Because of this common practice and the lack of national

postnatal screening programs and counseling centers, treating children with DDH is quite common in our department. However, in Kosovo, pediatric patients often present later than we wish and with more advanced DDH pathology.

Different opinions are expressed in the literature regarding whether or not to wait for the appearance of the ON before performing closed reduction in DDH patients [4]. Some authors recommend deferring DDH treatment until the ON is detected by ultrasonography or radiography or until the child is 12 months old because the presence of the ON prior to performing closed or open reduction for DDH may decrease the risk of AVN [3, 4]. Various studies have suggested that the rate and severity of AVN are higher in children whose initial treatment is begun between birth and age 6 months [16, 17]. To the contrary, other authors have shown that waiting to treat dislocated hips until age >12 months leads to a very poor prognosis, suggesting that the AVN rate increases with age. These experts argue for immediate reduction of dislocated hips regardless of the ON status [5, 18, 19].

The primary cause of AVN seems to be iatrogenic; therefore it is crucial that we continue to seek new concepts and approaches to prevent the development of AVN after treating DDH [3, 13]. The sequelae of AVN can include limb-length discrepancy, greater trochanter overgrowth, acetabular dysplasia, and joint incongruity, all of which affect hip function [20, 21].

Our study confirms the results of Tschauner [11], who reported that older children have a higher risk of developing AVN. Therefore, treatment should be initiated early regardless of the presence or absence of the ON to take advantage of the greater remodeling potential within the first 3 months of life, improve outcome, and shorten treatment time. Additionally, early treatment reduces the risk of the complication of femoral head necrosis [22]. We found a higher AVN rate among hips classified as grade IIIb, although highly dislocated hips are more vulnerable to ischemic changes in other studies [23]. Our opinion is that late-presenting DDH is major risk for developing AVN, regardless of DDH disease classification.

In our study, 58.1 % of patients had bilateral dislocations and 57 % had bilateral acetabular dysplasia, which is similar to previously published data [14]. It is possible that swaddling increases the risk for dislocation in hips with acetabular dysplasia.

The development of the ossification nucleus of the femoral head is delayed in hip joint dysplasia and dislocation, and thus it is less difficult to identify triradiate cartilage [8, 24]. This allows children aged 12–18 months to be assessed by the Graff classification, especially when they are malnourished, as were four of the children in our study with neglected hip dislocation.

During the first 6 months of life, the chondroepiphyseal blood supply is a diffuse canalicular network that is arranged predominantly in a terminal end-arteriole vessel pattern. Each vessel supplies a specific chondroepiphyseal area, without anastomoses to other end arterioles. The largest vascular change occurs between 5 and 7 months of age in the capital femoral epiphysis, when secondary ossification centers become visible on radiographs; during this period, the predominant blood supply shifts to the medial circumflex artery [13, 25, 26]. The results of our study suggest that the most vulnerable age to develop AN in children aged ≤10 months is between 4 and 6 months, corresponding to the initial period of chondroepiphyseal blood supply remodeling. Whether or not this timing is coincidental will require further research with a larger patient population.

We observed a nearly twofold higher AVN rate on the right versus left side, but this difference was not statistically significant. Other studies have reported an opposite trend, but also without significance [20, 27]. We think that there is no influence of the side of DDH on AVN development. Clinical examination has revealed no differences in limping, leg length inequality and hip range of motion in ON^+ versus ON^- hips. Range of hip motion after treatment was comparable with a normal range of motion [28].

Conclusions

Treatment of DDH should be performed as early as possible, without regard to the presence or absence of the ON because ON^+ status is not protective against AVN. Reduction should not be delayed beyond 10 months of age, as this increases the incidence of AVN. Instituting these changes in the Kosovo medical system, where cultural and institutional norms currently result in delayed DDH treatment, is essential to improving patient outcomes.

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