Does Open Reduction of the Developmental Dislocated Hip Increase the Risk of Osteonecrosis?

Renata Pospischill MD, Julia Weninger MD,
Rudolf Ganger MD, PhD, Johannes Altenhuber MD,
Franz Grill MD

Received: 3 November 2010 / Accepted: 18 May 2011 / Published online: 4 June 2011
© The Association of Bone and Joint Surgeons® 2011

Abstract

Background Osteonecrosis (ON) of the femoral head is one of the main complications associated with treatment of developmental dysplasia of the hips (DDH). The reported rates of ON vary widely between 6% and 48%, suggesting varying factors in these studies influence the rate. Several studies suggest open reduction combined with femoral shortening provides protection against ON. However, it is unclear whether confounders such as failed Pavlik harness treatment, preliminary traction, closed versus open reduction, and redislocation influence the rate of ON.

Questions/purpose We therefore asked whether open reduction with concomitant osteotomies without femoral shortening, redislocation, and secondary surgical procedures for residual acetabular dysplasia influenced the rate of ON.

Methods We retrospectively reviewed 64 children (78 hips) hospitalized with developmental dislocation of the hip between January 1998 and February 2007. Patients younger than 12 months were treated with closed or open reduction. Open reduction combined with concomitant pelvic and femoral osteotomies was performed in patients

past walking age. ON was diagnosed from radiographs obtained at last followup. We used logistic regression analysis to identify predictors for the development of ON. The minimum followup was 3.2 years (mean, 6.8 years; range, 3.2–11.5 years).

Results The overall rate of ON was 40%. Patients who underwent open reduction combined with concomitant osteotomies, experienced redislocation, or required secondary reconstructive procedures after initial reduction were at higher risk for having ON develop.

Conclusions We advocate early reduction of the dislocated hip in the first year of life to avoid the need for concomitant osteotomies combined with open reduction.

Level of Evidence Level III, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

ON of the proximal femoral epiphysis is one of the main complications associated with the treatment of developmental dislocated hips. The overall rates of ON reported in studies have been inconsistent, ranging from 6% to 48% after treatment of the dislocated hip [1, 6, 7, 20, 29, 30]. The complication can lead to acetabular dysplasia and joint incongruity, resulting in early osteoarthritis [4, 5, 8–10, 16, 21]. However, it is widely accepted that early reduction of the developmental dislocated hip and maintained concentric reduction can lead to a satisfactory long-term outcome [17, 20, 23].

The widely varying rates reported in the literature suggest differences in diagnostic criteria, patient demographics, or treatments in the studies influence the rates. For example, the use of extreme positions of immobilization with the hips in

Each author certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article.

Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

R. Pospischill (✉), J. Weninger, R. Ganger,
J. Altenhuber, F. Grill
Pediatric Orthopaedic Department, Orthopaedic Hospital
Vienna-Speising, Speisinger Strasse 109, 1130 Vienna, Austria
e-mail: renata.pospischill@oss.at

90° abduction (frog-leg position) is reportedly a major risk factor for having ON develop [10, 15, 28, 34]. Preliminary traction and femoral shortening facilitate reduction and decrease the incidence of ON [3, 6, 18, 20, 29, 30]. One study suggested the appearance of the ossific nucleus of the femoral head provided protection against ON after reduction [30]. Other reports have documented conflicting data on the importance of the ossific nucleus [20, 25].

A delay in reduction decreases the possibility of spontaneous resolution of dysplastic features because maximal osseous remodeling of the hip occurs during the first year of life [14]. In older children, a pelvic or femoral osteotomy may be necessary in addition to open reduction to address the problem of acetabular dysplasia. Debate continues regarding whether concomitant osteotomies should be performed in children after walking age [19, 26, 27]. Some authors believe pelvic osteotomy may be unnecessary in children who are 5 years or younger [19]. Although Lindstrom et al. [19] suggested there was considerable potential for acetabular remodeling up to age 8, Salter [26, 27] believed the potential for acetabular remodeling rapidly declines after age 18 months and therefore recommended a pelvic osteotomy at the time of open reduction to directly correct residual dysplasia.

Owing to the controversies in risk factors, we therefore asked whether (1) open reduction without preliminary traction or femoral shortening performed in children after walking age, (2) redislocation requiring subsequent open reduction, and (3) numerous other factors (gender, Pavlik harness treatment, age at reduction, appearance of the ossific nucleus at the time of reduction, hip position in the spica cast after reduction, type of reduction [closed, open, or open with concomitant osteotomies], and secondary reconstructive procedures), predicted ON after adjusting for potential confounders.

Patients and Methods

We retrospectively reviewed 233 pediatric patients with 290 abnormal hips who had been treated at our institution between January 1998 and February 2007 with closed or open reduction for developmental dislocation of the hip. We excluded 149 patients with 188 abnormal hips who had teratologic hip dislocation resulting from associated syndromes or other musculoskeletal abnormalities, those who had concomitant neuromuscular diseases, and those who had undergone previous operative reduction at another medical institution. Seventeen patients (21 hips) with less than 3 years of followup and one patient (one hip) who had septic arthritis develop after the reduction were excluded. Eight patients were lost to followup because of emigration of their families, but because six already had shown signs

of ON, we included these six in the analysis and excluded the other two. After these exclusions, 64 children (78 hips) remained (Fig. 1). The minimum followup was 3.2 years (mean, 6.8 years, range, 3.2–11.5 years). Patients were recalled specifically for this study, and all data were obtained from clinical examinations, medical records, and radiographs. Prior institutional review board approval was obtained.

We identified three groups based on patient age and treatment: Group A consisted of patients who underwent closed reduction and were treated before 12 months of age; Group B consisted of patients who underwent open reduction and were treated before 12 months of age; Group C consisted of patients older than 12 months at the time of reduction who previously had not been treated. Patients in Groups A and B had all been treated previously with a Pavlik harness. All except two children in Group B had been hospitalized for preliminary traction before undergoing reduction. The severity of dislocation, as noted on the sonograms, was graded according to the Graf classification [12]. Arthrography of the dislocated hip was performed after traction in both groups with the patients under general anesthesia. In Group A patients, closed reduction was performed if the femoral head was well covered by the labrum, as shown on the arthrogram, and felt stable in the primary acetabulum (Fig. 2). If the hip was unstable after initial closed reduction, or if obstructions to reduction such as an infolded labrum or a constricted capsule were visible on the arthrogram (Fig. 3), open reduction using an anterolateral approach was performed during the same session. These patients were assigned to Group B. Patients in Group C all underwent open reduction through an anterolateral approach performed simultaneously with either a Pemberton [24] (Fig. 4) or varus derotation osteotomy of the proximal part of the femur (Fig. 5). The femoral osteotomies were performed either alone or with a combined procedure. At presentation, the severity of the dislocation was graded on radiographs according to the classification presented by Tönnis [32]. At the time of open reduction, pelvic osteotomy was performed to directly correct residual dysplasia in two scenarios. The first was if the acetabular index was greater than 2 standard deviations from the normal mean (greater than 30°) in children 2 years and older. The second was if the center-edge angle of Wiberg was 2 standard deviations or more greater than normal (less than 20°) in children older than 5 years [31, 32].

Thirty-six patients (46 hips) in Group A and 13 patients (15 hips) in Group B were available for statistical analysis (Table 1). The mean patient age at the time of closed reduction was 4 months (range, 1.2–10.4 months), and was 3.6 months (range, 0.7–7.9 months) at the time of open reduction. Adductor tenotomies were not routinely

Fig. 1 The flowchart shows the sample selection of patients with developmental dislocated hips.

Fig. 2 An arthrogram of the left hip of a 3-month-old patient shows the hip in a flexion-abduction position. The reduction was maintained. The labrum lies flat over the femoral head and has a sharp border.

Fig. 3 An arthrogram is shown of the right hip of a 4-month-old patient before open reduction of a developmental dislocated hip. When the head was docked, the labrum was interposed between the femoral head and the acetabular wall. Because of capsular constriction of the iliopsoas, stable reduction was not possible.

Fig. 4A–B AP view radiographs of the pelvis of a 3-year-old patient show developmental dislocation of the right hip. The radiographs were obtained (A) at the time of presentation and (B) 6 months after

open reduction with capsulorrhaphy and Pemberton osteotomy. Successful reduction is shown.

Fig. 5A–B Preoperative and postoperative AP view radiographs of a patient managed with open reduction, capsulorrhaphy, and femoral varus derotation osteotomy for the treatment of a dislocated right hip

are shown. (A) This radiograph was obtained at first presentation when the patient was 17 months old. (B) Six months after surgery, the radiograph shows successful reduction.

performed before reduction. Group C consisted of 15 patients (17 hips) (Table 1). The mean patient age at the time of reduction was 3.8 years (range, 1.4–14.8 years). Three hips (18%) were treated by open reduction and Pemberton osteotomy and one hip (6%) by open reduction and varus derotation osteotomy only. Twelve hips (71%) were managed with open reduction, Pemberton osteotomy, and concomitant varus derotation osteotomy. Femoral shortening was performed in only one case (6%). In two hips (12%), an additional adductor tenotomy was performed before open reduction.

Patients in Groups A and B were compared regarding age at the time of reduction, gender, Pavlik harness treatment, duration of preliminary traction, severity of dislocation, appearance of the ossific nucleus at the time of reduction, spica cast immobilization after reduction, and duration of followup (Table 2). At baseline, Groups A and B were similar. Except for gender ratio, demographic findings differed between patients of Group C treated past walking age and patients of Groups A and B.

Reductions of dislocated hips were performed at the earliest possible time after patients first presented at our

Table 1. Baseline characteristics

Variable	Group A (46 hips)	Group B (15 hips)	Group C (17 hips)
Type of reduction	Closed	Open*	Open + PO + VDO†
Age at reduction	4.0 months	3.6 months	45.5 months (3.8 years)
Gender ratio (female:male)	30:6	10:3	12:3
Pavlik harness treatment	Yes: 28 (61%)	Yes: 6 (40%)	Yes: 0
Preceding reduction	No: 18 (39%)	No: 9 (60%)	No: 17 (100%)
Duration of preliminary traction	3.7 weeks	3.6 weeks	No
Preceding reduction			
Preoperative severity of dislocation			
Graf III	6 (13%)	1 (7%)	
Graf IV	40 (87%)	14 (93%)	
Tönnis Grade I			0
Tönnis Grade II			1 (6%)
Tönnis Grade III			13 (76%)
Tönnis Grade IV			3 (18%)
Ossific nucleus at time of reduction			
Present	14 (30%)	8 (53%)	17 (100%)
Absent	32 (70%)	7 (47%)	0
Spica cast immobilization after reduction			
Human position	21 (46%)	10 (67%)	
Modified human position	25 (54%)	5 (33%)	
One and one-half spica cast			17 (100%)
Osteonecrosis grade			
I	4 (9%)	2 (13%)	4 (24%)
II	7 (15%)	0	4 (24%)
III	1 (2%)	0	6 (35%)
IV	1 (2%)	1 (7%)	1 (6%)
Total	13 (28%)	3 (20%)	15 (88%)
Osteonecrosis Grades II to IV	9 (20%)	1 (7%)	11 (65%)
Redislocation	8 (17%)	0	1 (6%)
Secondary reconstructive procedures	7 (15%)	2 (13%)	5 (29%)
Postoperative complications			
Skin excoriation requiring cast changes	0	0	2 (12%)
Superficial wound infections	0	0	2 (12%)
Septic arthritis	0	0	0
Followup	6.3 years	7.4 years	6.7 years

PO = Pemberton osteotomy; VDO = varus derotation osteotomy; * open reduction through an anterolateral approach; † open reduction through an anterolateral approach with concomitant Pemberton and/or varus derotation osteotomies.

outpatient clinic. All reductions were performed by two experienced pediatric orthopaedic surgeons (JA, FG) with similar treatment algorithms and techniques. After the primary reduction, redislocations were treated by open reduction. Secondary reconstructive procedures for residual acetabular dysplasia were performed if, in the judgment of the surgeon, the hips showed signs of subluxation or deficient progressive acetabular development. Pelvic osteotomy in patients younger than 4 years was performed only if the persisting dysplasia was deteriorating, as revealed by serial followup radiographs [19]. The indication for varus

derotation osteotomy was failure of concentric reduction after open reduction and pelvic osteotomy. The derotation ranged from 25° (14 hips) to 50° (one hip) and the varus from 10° to 30°.

After closed or open reduction, a spica cast was applied in the human position as described by Salter et al. [28] (100° to 110° flexion, 40° to 60° abduction, and no rotation) or in a modified human position with the hips in 100° to 110° flexion and greater than 60° abduction for the patients in Groups A and B. Casts were retained for 12 weeks. After removal of the spica cast, a full-time

Table 2. Comparison of demographic factors between Groups A and B

Variable	Group A	Group B	p Value
Mean age at reduction (months)	4.0 ± 2.3 (3.3–4.7)	3.6 ± 2.0 (2.5–4.7)	–
Gender (female:male)	30:6	10:3	0.190
Side (unilateral:bilateral)	26:10	11:2	0.215
Pavlik harness treatment preceding reduction (yes: no)	28:18	6:9	0.089
Mean duration of preliminary traction preceding reduction (weeks)	3.7 ± 1.0 (3.5–4.1)	3.6 ± 1.6 (2.8–4.4)	–
Preoperative severity of dislocation (number of hips - Graf III: Graf IV)	6:40	1:14	0.322
Ossific nucleus at time of reduction (present:absent)	14:32	8:7	0.070
Spica cast immobilization after reduction (human position:modified human position)	21:25	10:5	0.090
Mean followup (years)	6.3 ± 2.5 (5.2–7.2)	7.4 ± 2.3 (4.9–7.8)	–

Differences between proportions of gender, side, Pavlik harness treatment, severity of dislocation, presence of the ossific nucleus, and spica cast immobilization tested with Fisher's exact test; values of continuous variables are reported as mean ± standard deviation with the 95% confidence interval in the parenthesis

abduction orthosis maintained the hip at 60° total abduction until acetabular development was normalized, as revealed by radiographs, or until the children started to crawl or sit. For Group C patients, a one and one-half hip spica cast was applied postoperatively for 6 weeks with the hip in 20° flexion, 30° abduction, and 10° internal rotation. During that time, weightbearing was not permitted.

The same radiographic protocol was used for all patients. The radiographs were reviewed independently by two observers (RP and JW). The severity of dislocation as shown on radiographs was classified according to Tönnis [32] and as shown on ultrasound images, according to Graf [12]. Presence of nucleus was determined preoperatively on radiographs and on sonograms of patients younger than 12 months at the time of reduction. The development of ON of the femoral head after reduction, as observed on the final followup radiograph, was classified according to the method presented by Bucholz and Odgen [5]. All grades of ON (Grades I through IV) were considered in the analysis. The intraobserver and interobserver intraclass correlation coefficients were 0.87 (95% confidence interval, 0.77–0.93) and 0.80 (95% confidence interval, 0.61–0.91), respectively.

Normally distributed data are presented as means with 95% confidence intervals. The differences between the groups regarding gender, Pavlik harness treatment, preoperative severity of dislocation, appearance of the ossific nucleus at the time of reduction, spica cast immobilization, incidences of ON, rates of redislocation, and secondary reconstructive procedures resulting from residual acetabular dysplasia were tested with Fisher's exact test for nonparametric data. Continuous numeric variables in the two groups were compared with two-sided unpaired Student's t-test. Treatment effect of redislocation was reported as the relative risk. Multivariate logistic regression was used to develop models predicting ON. Gender, Pavlik harness treatment, age at reduction, appearance of the

ossific nucleus at the time of reduction, hip position in the spica cast after reduction, type of reduction (closed, open, or open with concomitant osteotomies), and secondary reconstructive procedures were entered as risk factors. Post hoc analyses for all outcomes were conducted. Statistical analysis was conducted with the use of the SPSS software (Version 17.0; SPSS Inc, Chicago, IL, USA).

Results

Open reduction without preliminary traction or femoral shortening performed in children after walking age was associated with a greater ($p < 0.001$) incidence of ON of the femoral head compared with patients with early reductions (Groups A and B) (Table 3). The overall rate of ON for the cohort (all patients with developmental dislocation of the hips treated between 1998 and 2007) was 40%.

Compared with patients for whom the initial reduction was maintained, the patients with redislocation had a 67% increased probability of having ON develop (relative risk, 0.33; 95% confidence interval, 0.24–0.46). All hips for which initial reduction failed were treated with an open procedure and subsequent maintenance of reduction. The overall redislocation rate for our series was 12% (nine hips). We found no difference in the rate of redislocation among the groups (Table 3).

We observed no association between ON and gender ($p = 0.69$), failed Pavlik harness treatment before reduction ($p = 0.08$), or the presence of the ossific nucleus at reduction ($p = 0.14$) (Table 4). When controlling for age, preliminary traction, hip position in the spica cast after reduction, type of reduction, and secondary reconstructive procedures, only type of reduction (odds ratio, 11.04; 95% confidence interval, 2.24–54.41; $p = 0.003$) and secondary

Table 3. Comparison of outcome measures among the study groups

Outcome variable*	Group A	Group B	Group C	Total	p Value
Osteonecrosis Grades I to IV	13 (28%)	3 (20%)	15 (88%)	31 (40%)	0.738 [†] < 0.001 [‡] < 0.001 [§]
Osteonecrosis Grades II to IV	9 (20%)	1 (7%)	11 (65%)	21 (27%)	0.716 [†] 0.001 [‡] 0.005 [§]
Redislocation	8 (17%)	0	1 (6%)	9 (12%)	0.182 [†] 0.423 [‡] 0.999 [§]
Secondary reconstructive procedure required to treat residual acetabular dysplasia	7 (15%)	2 (13%)	5 (29%)	14 (18%)	0.999 [†] 0.279 [‡] 0.402 [§]

* Differences tested with Fisher's exact test; [†]difference between Group A and Group B; [‡]difference between Group A and Group C; [§]difference between Group B and Group C.

Table 4. Univariate logistic regression for predictors of osteonecrosis

Independent variable	Odds ratio	p Value	95% Confidence interval
Age at reduction	19.853	< 0.001	4.1–96.134
Age younger than 12 months versus age older than 12 months			
Previous Pavlik harness treatment	0.436	0.084	0.170–1.116
No versus yes			
Preliminary traction	0.093	< 0.001	0.027–0.320
No versus yes			
Spica cast immobilization	2.754	0.003	1.417–5.352
Human position versus modified human position			
Type of reduction	6.936	< 0.001	3.033–15.862
Closed versus open versus open with concomitant osteotomies			
Secondary procedures*	7.683	0.004	1.936–30.488
No versus yes			
Presence of the ossific nucleus	1.973	0.144	0.793–4.912
No versus yes			
Gender	1.233	0.699	0.426–3.568
Female versus male			

* Secondary procedures required to treat residual acetabular dysplasia without signs of osteonecrosis at time of surgery.

reconstructive procedures (odds ratio, 13.97; 95% confidence interval, 2.31–84.58; $p = 0.004$) were associated with increased rates of ON (Table 5). Compared with open reduction with concomitant osteotomies, closed reduction reduced the possibility of ON developing by 99% (odds ratio, 0.01; 95% confidence interval, 0.01–0.01). Open reduction alone led to a decrease of 89% (odds ratio, 0.12; 95% confidence interval, 0.02–0.66). Patients with persisting residual acetabular dysplasia after initial reduction who were treated with pelvic or femoral osteotomies were 14 times more likely to have ON develop than were patients without reconstructive interventions.

Discussion

One of the main complications associated with treatment of developmental dislocated hips is the development of ON of the femoral head [4, 5, 8–10, 16, 21]. Although children undergoing open reduction may have greater risk of ON [1, 6, 7, 20, 30], the importance of the various risk factors is unclear. We therefore asked whether open reduction without femoral shortening performed in children after walking age was associated with a greater incidence of ON of the femoral head, whether redislocation requiring subsequent open reduction increased the risk of ON, and

Table 5. Multivariate logistic regression for adjusted predictors of osteonecrosis

Model	Overall success rate for predicted occurrences (cutoff = 0.3) (%)		
Constant only	40		
Model including all covariates	86		
Sensitivity	94		
Specificity	79		
False-positive rate	26		
False-negative rate	5		

Independent variable	Odds ratio	p Value	95% Confidence interval
Age at reduction	6.162	0.402	0.088–43.051
Age younger than 12 months versus age older than 12 months			
Preliminary traction	0.836	0.907	0.072–27.378
No versus yes			
Spica cast immobilization	0.325	0.167	0.068–1.403
Human position versus modified human position			
Type of reduction	11.035	0.003	2.238–54.411
Closed versus open versus open with concomitant osteotomies			
Secondary procedures*	13.969	0.004	2.307–84.579
No versus yes			

* Secondary procedures required to treat residual acetabular dysplasia without signs of osteonecrosis at time of surgery.

whether any of a number of factors predicted ON after adjusting for potential confounders.

Our study has several limitations. First, as with all retrospective studies, there was a risk of selection bias. However, we included all patients hospitalized at our institution for developmental dislocation of the hip and all were documented in our surgery records program and could be identified for a designated time. Second, we had a relatively small number of patients in the various groups. Post hoc power analysis determined that our sample size was sufficient to achieve a power of 88% to enable detection of a difference of 30% in the incidence of ON. Third, the three groups were heterogeneous regarding the variables previous treatment and type of reduction; the ages of the patients at reduction differed. We addressed this with logistic regression analysis for key variables, although we did not include all potential confounding variables. Fourth, we had a small number of redislocated hips, such that redislocation could not be included as a factor in the logistic regression analysis. Fifth, assessing ON in patients treated after walking age is problematic: 35% (six hips) in Group C had a smaller ossific nucleus on the dislocated hip compared with the unaffected side before reduction. Nearly half the affected hips had an ossific nucleus continuing to grow but remaining dysplastic. It therefore is reasonable to assume that clinically asymptomatic and active patients with mild radiographic changes should not be considered to have ON. However, future studies to follow the children to skeletal maturity and to

determine the clinical relevance and whether such changes should be defined as ON are important.

The overall rate of Grade I ON or worse was 40% in our study compared with reported incidences of 6% to 48% in some studies [1, 6, 7, 20, 30] (Table 6). The use of various classification systems to diagnose or grade ON could have contributed to the variation in the incidences among the studies. Our rates of ON are similar to those in several studies in which a cohort design was used [1, 7]. Segal et al. [30] conducted a case-control study and reported a similar rate of 32%. In the current study, the incidence of ON in patients treated after walking age was 88%. Several authors evaluated results comparable to our findings, with an increase in the rate of ON in dislocated hips treated with open reduction and combined pelvic osteotomy [22, 33]. Carney et al. [6] found an incidence of 48% in older children treated after walking. They concluded that adductor tenotomy reduced the rate of ON. Gulman et al. [13] reported a rate of Grades II through IV ON of 35% in 52 hips after anterior open reduction combined with innominate osteotomy. Most of the patients in the current study who were diagnosed after walking age were treated with open reduction and concomitant osteotomies without femoral shortening. The high rate of ON in this age group may indicate that open reduction combined with pelvic osteotomy should not be performed simultaneously without femoral shortening, as was previously reported [3, 11, 18, 29].

Table 6. Series with incidences of osteonecrosis as reported in the literature

Study	Number of hips	Treatment	FS performed (%)	Adductor tenotomy (%)	Mean age at reduction (years)	Duration of followup (years)	Rate of ON (%)	Redislocation (%)	Secondary reconstructive procedures (%)
Kliscic and Jankovic [18] 1976	60	OR + osteotomies	100	3	8	5	30 (grades not reproducible)	2	10
Mardam-Bey and MacEwen [22] 1982	134	CR OR	0	0	2.6	17.3	24 (Grades I–IV) 46 (Grades I–IV) 14 (Grades I–IV)	4	66 8 6
Schoenecker and Strecker [29] 1984	39	OR + osteotomies	0	100	4.6	11	54 (Grades NR)	31	NR
Barrett et al. [2] 1986	15	OR + osteotomies	100	NR	5.9	4.1	0 (Grades NR)	8	NR
Galpin et al. [11] 1989	33	OR + Salter	0	NR	2.8	10.8	13 (Grades NR)	7	NR
Brougham et al. [4] 1990	210	OR + Salter	100	NR	4.2	3.7	9 (only Grade IV)	12	NR
Tönnis [33] 1990	4357	CR OR OR OR + Salter	0 0 100	34 NR NR	1.2 NR NR	> 2 NR NR	47 (Grades I–IV) 8 (Grades NR) 6 (Grades NR)	NR NR NR	13 NR NR
Gulman et al. [13] 1994	52	OR + FO OR + Salter	0 0	NR NR	Mean, NR; Range, 1.6–4	13	22 (Grades NR) 35 (Grades II–IV)	71	NR
Luhmann et al. [20] 1998	153	CR OR	0	69	0.9	> 3	4 (Grades I–IV) 12 (Grades I–IV)	18 12	28
Segal et al. [30] 1999	57	CR OR	0	47	0.5 0.5	0.5–15.3	32 (Grades I–IV)	NR	NR
Clarke et al. [7] 2005	50	CR OR	0	100	> 1 > 1	> 3 > 3	18 (Grades I–IV) 50 (Grades I–IV)	NR NR	57 41
Current study	78	CR OR OR + osteotomies	0 0 6	0 0 12	0.3 0.3 3.8	6.3 7.4 6.7	28 (Grades I–IV) 20 (Grades I–IV) 88 (Grades I–IV)	17 0 6	15 13 29

OR = open reduction; CR = closed reduction; FO = femoral osteotomy; FS = femoral shortening; NR = not reported; ON = osteonecrosis.

Nine patients (12%) required secondary reduction, which was performed by an open procedure in each case. All except one hip initially had been reduced closed. In each case, the individual surgery report suggested forced reduction considering that obstacles to successful closed reduction, such as the presence of a constricted capsule, were described. All of the hips showed signs of ON at latest followup. Thus, in retrospect, immediate open reduction would have been the appropriate choice. It remains unclear whether this finding is related mostly to the second reduction, which was an open procedure, or to the primary suboptimal closed reduction. Nevertheless, redislocation has been reported with different incidences but with comparable rates of 0% to 20% for the anterior approach [17, 20, 23].

Our observations suggest open reduction with concomitant osteotomies without femoral shortening and secondary reconstructive procedures for acetabular dysplasia predict the development of ON. Patient age at the time of reduction, preliminary traction, history of failed Pavlik harness treatment, and hip immobilization after reduction do not seem to influence the incidence of ON. The need for open reduction with concomitant osteotomies increased the risk of ON by a factor of 11, and patients who underwent secondary reconstructive procedures were 14 times more likely to have ON develop than were patients who did not undergo additional surgery. Although increasing age at reduction was not a risk factor for ON in the final model, it is acknowledged that older patients are more likely to require open reduction with concomitant osteotomies. It seems that early diagnosis with immediate adequate treatment, and thus a greater chance of achieving closed reduction, influences outcome regarding ON.

Our observations suggest shortening of the femur when performing open reduction with concomitant pelvic and/or femoral osteotomies in children after walking age might have reduced the rate of ON. Our results also confirm redislocation resulting from a suboptimal initial primary procedure and the need to consider secondary reconstructive procedures for residual acetabular dysplasia when assessing ON risk. To minimize the risk of the development of ON, we advocate early reduction of the dislocated hip during the first year of life to avoid the need for concomitant osteotomies.

Acknowledgment We thank Dori Kelly MA, for English language editing of the manuscript.

References

1. Ağuş H, Omeroğlu H, Uçar H, Biçimoglu A, Türmer Y. Evaluation of the risk factors of avascular necrosis of the femoral head in developmental dysplasia of the hip in infants younger than 18 months of age. *J Pediatr Orthop B*. 2002;11:41–46
2. Barrett WP, Staheli LT, Chew DE. The effectiveness of the Salter innominate osteotomy in the treatment of congenital dislocation of the hip. *J Bone Joint Surg Am*. 1986;68:79–87
3. Berkeley ME, Dickson JH, Cain TE, Donovan MM. Surgical therapy for congenital dislocation of the hip in patients who are twelve to thirty-six months old. *J Bone Joint Surg Am*. 1984;66:412–420
4. Brougham DI, Broughton NS, Cole WG, Menelaus MB. Avascular necrosis following closed reduction of congenital dislocation of the hip: review of influencing factors and long-term follow-up. *J Bone Joint Surg Br*. 1990;72:557–562
5. Bucholz RW, Ogden J. Patterns of ischemic necrosis of the proximal femur in nonoperatively treated congenital hip disease. *The Hip. Proceedings of the Sixth Open Scientific Meeting of the Hip Society*. St Louis, MO: CV Mosby; 1978:20
6. Carney BT, Clark D, Minter CL. Is the absence of the ossific nucleus prognostic for avascular necrosis after closed reduction of developmental dysplasia of the hip? *J Surg Orthop Adv*. 2004;13:24–29
7. Clarke NM, Jowett AJ, Parker L. The surgical treatment of established congenital dislocation of the hip: results of surgery after planned delayed intervention following the appearance of the capital femoral ossific nucleus. *J Pediatr Orthop*. 2005;25:434–439
8. Cooperman DR, Wallensten R, Stulberg SD. Post-reduction avascular necrosis in congenital dislocation of the hip. *J Bone Joint Surg Am*. 1980;62:247–258
9. Cooperman DR, Wallensten R, Stulberg SD. Acetabular dysplasia in the adult. *Clin Orthop Relat Res*. 1983;175:79–85
10. Gage JR, Winter RB. Avascular necrosis of the capital femoral epiphysis as a complication of closed reduction of congenital dislocation of the hip: a critical review of twenty years' experience at Gillette Children's Hospital. *J Bone Joint Surg Am*. 1972;54:373–388
11. Galpin RD, Roach JW, Wenger DR, Herring JA, Birch JG. One-stage treatment of congenital dislocation of the hip in older children, including femoral shortening. *J Bone Joint Surg Am*. 1989;71:734–741
12. Graf R. Fundamentals of sonographic diagnosis of infant hip dysplasia. *J Pediatr Orthop*. 1984;4:735–740
13. Gulman B, Tuncay IC, Dabak N, Karaismailoglu N. Salter's innominate osteotomy in the treatment of congenital hip dislocation: a long-term review. *J Pediatr Orthop*. 1994;14:662–666
14. Harris NH, Lloyd-Roberts GC, Gallien R. Acetabular development in congenital dislocation of the hip: with special reference to the indications for acetabuloplasty and pelvic or femoral realignment osteotomy. *J Bone Joint Surg Br*. 1975;57:46–52
15. Kahle WK, Anderson MB, Alpert J, Stevens PM, Coleman SS. The value of preliminary traction in the treatment of congenital dislocation of the hip. *J Bone Joint Surg Am*. 1990;72:1043–1047
16. Keret D, MacEwen GD. Growth disturbance of the proximal part of the femur after treatment for congenital dislocation of the hip. *J Bone Joint Surg Am*. 1991;73:410–423
17. Kershaw CJ, Ware HE, Pattinson R, Fixsen JA. Revision of failed open reduction of congenital dislocation of the hip. *J Bone Joint Surg Br*. 1993;75:744–749
18. Klisic P, Jankovic L. Combined procedure of open reduction and shortening of the femur in treatment of congenital dislocation of the hips in older children. *Clin Orthop Relat Res*. 1976;119:60–69
19. Lindstrom JR, Ponseti IV, Wenger DR. Acetabular development after reduction in congenital dislocation of the hip. *J Bone Joint Surg Am*. 1979;61:112–118
20. Luhmann SJ, Schoenecker PL, Anderson AM, Bassett GS. The prognostic importance of the ossific nucleus in the treatment of congenital dysplasia of the hip. *J Bone Joint Surg Am*. 1998;80:1719–1727

21. Malvitz TA, Weinstein SL. Closed reduction for congenital dysplasia of the hip: functional and radiographic results after an average of thirty years. *J Bone Joint Surg Am.* 1994;76:1777–1792
22. Mardam-Bey TH, MacEwen GD. Congenital hip dislocation after walking age. *J Pediatr Orthop.* 1982;2:478–486
23. McCluskey WP, Bassett GS, Mora-Garcia G, MacEwen GD. Treatment of failed open reduction for congenital dislocation of the hip. *J Pediatr Orthop.* 1989;9:633–639
24. Pemberton PA. Pericapsular osteotomy of the ilium for treatment of congenital subluxation and dislocation of the hip. *J Bone Joint Surg Am.* 1965;47:65–86
25. Roposch A, Stöhr KK, Dobson M. The effect of the femoral head ossific nucleus in the treatment of developmental dysplasia of the hip: a meta-analysis. *J Bone Joint Surg Am.* 2009;91:911–918
26. Salter RB. Role of innominate osteotomy in the treatment of congenital dislocation and subluxation of the hip in the older child. *J Bone Joint Surg Am.* 1966;48:1413–1439
27. Salter RB. The classic: innominate osteotomy in the treatment of congenital dislocation and subluxation of the hip by Robert B. Salter, *J Bone Joint Surg (Brit)* 43B:3:518, 1961. *Clin Orthop Relat Res.* 1978;137:2–14
28. Salter RB, Kostuik J, Dallas S. Avascular necrosis of the femoral head as a complication of treatment for congenital dislocation of the hip in young children: a clinical and experimental investigation. *Can J Surg.* 1969;12:44–61
29. Schoenecker PL, Strecker WB. Congenital dislocation of the hip in children: comparison of the effects of femoral shortening and of skeletal traction in treatment. *J Bone Joint Surg Am.* 1984;66: 21–27
30. Segal LS, Boal DK, Borthwick L, Clark MW, Localio AR, Schwentker EP. Avascular necrosis after treatment of DDH: the protective influence of the ossific nucleus. *J Pediatr Orthop.* 1999;19:177–184
31. Tönnis D. Normal values of the hip joint for the evaluation of X-rays in children and adults. *Clin Orthop Relat Res.* 1976;119:39–47
32. Tönnis D. Congenital Dysplasia and Dislocation of the Hip in Children and Adults. Berlin, Germany: Springer-Verlag; 1987
33. Tönnis D. Surgical treatment of congenital dislocation of the hip. *Clin Orthop Relat Res.* 1990;258:33–40
34. Weiner DS, Hoyt WA Jr, O'Dell HW. Congenital dislocation of the hip: the relationship of premanipulation traction and age to avascular necrosis of the femoral head. *J Bone Joint Surg Am.* 1977;59:306–311