Clin Orthop Relat Res (2016) 474:1180–1188
DOI 10.1007/s11999-015-4501-9

Clinical Orthopaedics and Related Research®
A Publication of The Association of Bone and Joint Surgeons®

CrossMark

SYMPOSIUM: THE HIP FROM CHILDHOOD TO ADOLESCENCE

Acetabuloplasties at Open Reduction Prevent Acetabular Dysplasia in Intentionally Delayed Developmental Dysplasia of the Hip: A Case-control Study

M. Belen Carsi MD, PhD, BSc, FRCS, Nicholas M. P. Clarke ChM, DM, FRCS

Published online: 14 August 2015

Abstract

Background Avascular necrosis (AVN) and residual acetabular dysplasia are the two main complications of developmental dysplasia of the hip (DDH) treatment. Although early reduction of the hip may decrease the incidence of residual dysplasia, it may increase the incidence of AVN and vice versa. However, we do not know if changes in surgical technique may lead to a modification in these outcomes.

Questions/purposes Does an incomplete periacetabular acetabuloplasty, as an added step to delayed open reduction, (1) diminish the risk of developing acetabular dysplasia; or (2) increase the rate of AVN compared with patients treated with open reduction alone?

Methods We conducted a retrospective matched case-control study comparing 22 patients (27 hips) with early isolated DDH who underwent intentionally delayed open reduction and acetabuloplasty from 2004 to 2010 and followed up > 4 years (88% of the cohort) with early historic controls treated with delayed open reduction alone. Of 53 patients available for matching, 45 (85%) had enough followup (> 10 years) to be considered. They were matched one to one for age at presentation and bilaterality (fuzz 45, 0). This generated a control group of 25 patients (27 hips). The mean followup was different between the groups ($p < 0.001$). Residual dysplasia considered when center-edge angle < 15° (6–13 years old) or < 20° (≥ 14 years old) or as a nonevolving acetabular index > 30° and pelvic osteotomies were used as our primary outcomes. The proportion of patients with AVN was also compared.

Results Patients treated with open reduction and an incomplete periacetabular acetabuloplasty were less likely to develop acetabular dysplasia and undergo pelvic osteotomies than were patients in the control group (0% [zero of 27] versus 37% [10 of 27]; odds ratio [OR], 11; 95% confidence interval [CI], 2–80; p = 0.02 and 0% [zero of 27] versus 26% [seven of 27]; OR, 8; 95% CI, 1–60; p = 0.025, respectively). With the available numbers, there was no difference in terms of the proportion of patients who developed AVN (11 of 27 [41%] both groups; OR, 1; 95% CI, 1–2; p = 1).

Conclusions The addition of an incomplete periacetabular acetabuloplasty to all hips undergoing open reduction eliminated residual acetabular dysplasia, whereas it did not appear to have deleterious effects as evidenced by the similar AVN proportion.

Each author certifies that he or she, or a member of his or her immediate family, has no funding or 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.
All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research®* editors and board members are on file with the publication and can be viewed on request.

Each author certifies that his or her institution approved or waived approval for the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.
This work was performed at the University Hospital Southampton, Southampton, UK.

M. B. Carsi
University Hospitals North Midlands, Stoke-on-Trent, UK

N. M. P. Clarke (✉)
University of Southampton and University Hospital Southampton Foundation Trust, University Hospital Southampton, Tremona Road, Southampton SO16 6YD, UK
e-mail: ortho@soton.ac.uk

Level of Evidence Level III, therapeutic study.

Introduction

Avascular necrosis (AVN) of the femoral head is the most devastating complication after treatment for developmental dysplasia of the hip (DDH). Although AVN has been reported in as many as 73% of patients [9], a more typical range after open reduction in isolated DDH is 20% to 40% [6, 8, 39]. It is widely accepted that the disruption of the blood supply is iatrogenic, because untreated dislocated hips do not develop this complication [11], whereas nondislocated hips in treated children are still vulnerable to it [13, 34]. The consequences of AVN for the growing hip can be severe, resulting in an incongruent hip prone to premature degenerative changes. It has been suggested that the ossific nucleus formation is associated with the development of an anastomotic vascular supply to the chondoepiphysis that makes it less susceptible to compression injury [8]. Hence, speculatively, to avoid AVN, some practitioners elect to intentionally delay the surgical treatment of DDH until the appearance of the ossific nucleus [6, 8, 36].

However, this advantage conferred by delayed treatment has to be balanced with the potential disadvantage of the loss of remodeling potential that can result in residual acetabular dysplasia. The prevalence of residual acetabular dysplasia after surgical treatment of DDH varies between 20% [16] to over 80% [1, 12, 23, 29]. The debate about the timing of a pelvic procedure to address this common problem is still controversial. For some [7, 15, 30–32], this can be added primarily at the time of DDH treatment. Others prefer to reserve pelvic procedures for those who develop this complication as a secondary procedure [16, 22]. Because AVN and residual acetabular dysplasia are the two main complications of DDH treatment, the ideal treatment would minimize one without increasing the incidence of the other. Early in 2014 [7], we published the early results of an incomplete periacetabular acetabuloplasty as an adjunct to delayed open reductions. This added step incurred little morbidity or extra surgical time. We theorized that this would allow the surgeon to delay surgical intervention and potentially reduce the incidence of AVN while being confident about the development of a mature acetabulum; however, this has not been proven, and we wished to provide followup on this group of patients to evaluate this set of issues. We therefore compared a cohort of patients who underwent open reduction and acetabuloplasty with historically matched control subjects who were treated with open reduction alone.

Specifically, we asked: Does an incomplete periacetabular acetabuloplasty, as an added step to delayed open reduction, (1) diminish the risk of developing acetabular dysplasia; or (2) increase the rate of AVN compared with patients treated with open reduction alone?

Materials and Methods

This is a retrospective matched case-control study comparing two groups of patients with isolated DDH who presented early, before 3 months of age, and for whom the surgery for their hip dislocations was intentionally delayed. The use of an incomplete periacetabular acetabuloplasty as an adjunct to some open reductions was started in our unit in 2003 and was added to every open reduction from 2004 to the present.

Between 1987 and 2010, 375 children were treated for isolated DDH at our institution by the senior author (NMPC). Of those, 242 underwent open reductions of their dislocated hips. However, 152 patients presented late, after 3 months of age, and were excluded because their delay to surgery was partly caused by their late presentation. Ninety patients presented early and were considered eligible (Fig. 1). However, 12 were operated on during 2003 and were excluded to avoid selection bias. Between 1987 and 2002, we performed open reduction on 53 children with isolated DDH. Forty-five (85%) had followup at a minimum of 10 years (mean, 15 years; range, 12–27 years) and so were potentially available for inclusion in the control group. Of those, two of them had persistent dislocations and were considered unsuitable for this study that focuses on acetabular development. Thirty-three of those 43 available for matching had been discharged from the pediatric orthopaedic clinic at skeletal maturity.

Between 2004 and 2010, we added an incomplete periacetabular acetabuloplasty to all of our open reductions. During that time, we treated 27 patients who presented early with this approach. Of those, 25 (88%) had followup at a minimum of 4 years (mean, 7 years; range, 4–11 years) and so were potentially available for inclusion in the study group. The mean duration of followup was significantly different between the groups ($p < 0.001$), whereas the proportion of patients with complete followup of the underlying cohorts was no different between the groups ($p = 0.5$).

In those with bilateral disease who were treated by simultaneous closed and open reductions, only the hip undergoing open reduction was taken into account (Fig. 2 A–F). However, in those patients with bilateral disease treated with sequential open reductions, data for each hip were considered independently (Fig. 3A–E). This is a common practice condoned in orthopaedics although it may violate the principle of statistical independence. However, it avoids selection bias because bilateral disease

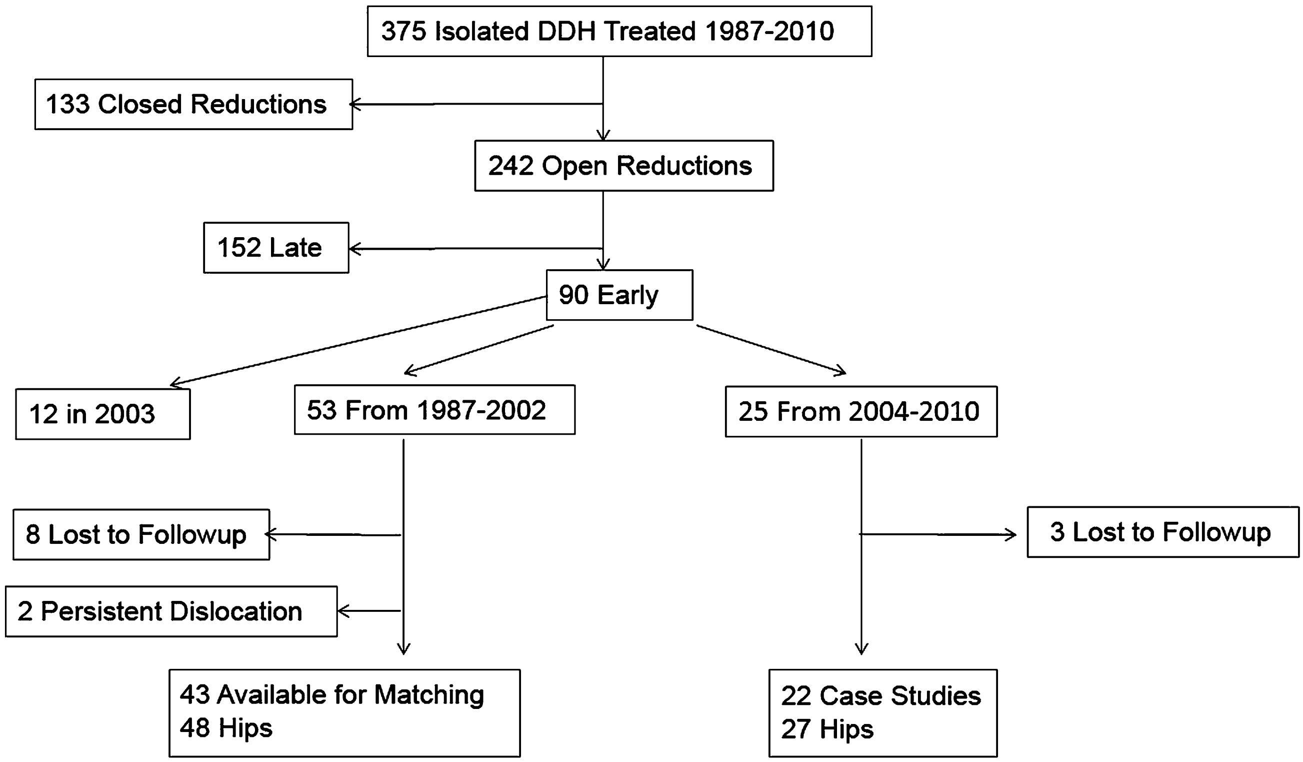

Fig. 1 Flowchart shows the patients who met the inclusion/exclusion criteria for the study and control groups.

often has asymmetrical outcomes and worse prognosis [25, 41]. This is why we matched patients according to bilaterality. Disregarding repeated measurements, however, does not necessarily always lead to erroneous results [28, 35]. On the other hand, there is a general consensus that early detection improves outcome [10, 19] and hence the age at presentation determines how prompt conservative treatment is started. All the patients in both groups had undergone failed conservative treatment before surgery was indicated. Consequently, matching between case and control patients was then performed with a ratio of one to one using the parameters bilaterality and age at diagnosis with a fuzz factor of 0 and 45 days, respectively.

The matching generated a control group consisting of 25 patients (27 hips) to match the study group of 22 patients (27 hips). The control group had two patients who underwent sequential open reductions and eight patients who were treated simultaneously with open and closed reductions, whereas the study group had five patients treated with sequential open reductions and two patients treated with simultaneous open and closed reductions. Sequential open reductions were staged 6 weeks to 8 months apart (mean, 4 months; range, 2–8 months; Fig. 3A–C). All patients had their surgery delayed until the ossific nucleus appearance or 13 months of age, whichever came first. The ossific nucleus appearance was monitored with serial ultrasounds. The average age at surgery was 13 months (range, 7–19 months) for the control group and 12 months (range, 7–18 months) for the study group ($p = 0.14$). Hence, the mean delay to surgery from the time of diagnosis was 12 months (range, 4–18 months) for the control group and 11 months (range, 5–16 months) for the study group ($p = 0.51$) (Table 1).

The operative protocol for all patients included an arthrogram (Figs. 2B, 3B), adductor tenotomy, and open reduction using an anterior approach to the hip through a bikini-line incision. The case group had an incomplete periacetabular acetabuloplasty as an added step. The full technique has been described elsewhere [7]. Briefly, after capsulorrhaphy, the outer table of the ilium is osteotomized following the contour of the acetabulum (Fig. 4A) and displaced downward minimally (Fig. 4B). A synthetic graft such as Osteoset (Wright Medical Technology, Arlington, TX, USA) can be used to maintain the tipped acetabular roof without additional fixation (Fig. 4C).

All patients underwent similar aftercare. Postoperative reduction of the hip is confirmed with a limited CT study. Patients are immobilized in a spica cast 6 weeks followed by similar periods in broomstick plasters and night splints.

Patients are reviewed initially at 4-monthly intervals for the first year, 6-monthly intervals for the next year, and annually thereafter until growth is finished. At each

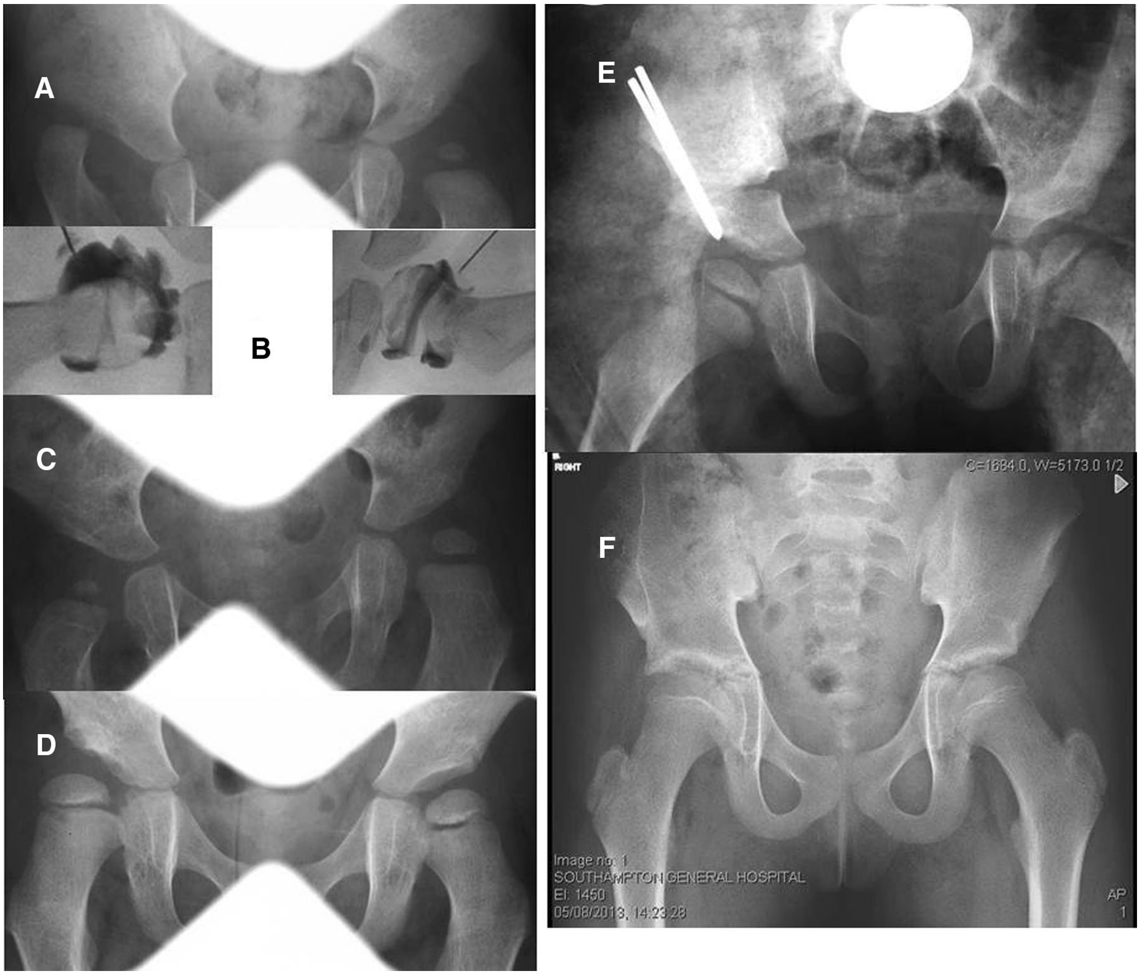

Fig. 2A–F A female patient presented with bilateral disease (**A**). Her intraoperative arthrograms showed a concentric reduction on the left hip and eccentric on the right (**B**). Consequently, she underwent simultaneous open and closed reductions of her right and left hips, respectively, at 1 year of age. Her right acetabulum was not developing as expected at 2 years of age (**C**) and 3 years of age (**D**) and she underwent a pelvic osteotomy to address residual acetabular dysplasia at age 3 years 9 months (**E**). At 8 years of age, she has adequate acetabular development bilaterally (**F**).

followup appointment, the senior author (NMPC) or one of his assistants reviewed the patients clinically and radiologically. Standard supine radiographs were taken with a film focus distance of 110 cm. Those radiographs obtained after December 2006 were digitalized in a Picture Archiving and Communications System.

The International Hip Dysplasia Institute classification [26] was used to identify the height of dislocation in preoperative films. These were also analysed by three independent reviewers (SA-H, KW, MBC, the first two blinded to the final outcomes) to record the absence or presence of ossific nucleus and preoperative acetabular indices. Postoperative radiographs were reviewed (SA-H, KW, MBC) to calculate the acetabular index [17] and assess residual acetabular dysplasia and epiphyseal development. Center-edge and Sharpe's angles were recorded on the last followup radiograph available.

Residual acetabular dysplasia and pelvic osteotomies were used as our primary outcome. Residual dysplasia was considered when center-edge angle was $< 15°$ (6−13 years old) or $< 20°$ ($\geq$ 14 years old). In younger children, acetabular indices over 30° in two repeated radiographs 1 year apart were considered indicative of dysplasia [1] (Fig. 2C−D). If dysplasia was diagnosed before the closure of the trirradiate cartilage, it was treated with a Salter-type pelvic osteotomy (Fig. 2E). After closure and if patients were asymptomatic, acetabular dysplasia was left untreated. All the parents of patients to whom a pelvic osteotomy was indicated accepted the procedure.

Other outcome measure was AVN Grade II to IV graded according to Kalamchi and MacEwen [20]. The existence of AVN and its grade was rated independently by the two authors on plain films (MBC, NMPC, not involved and involved in the direct care of these children) and no

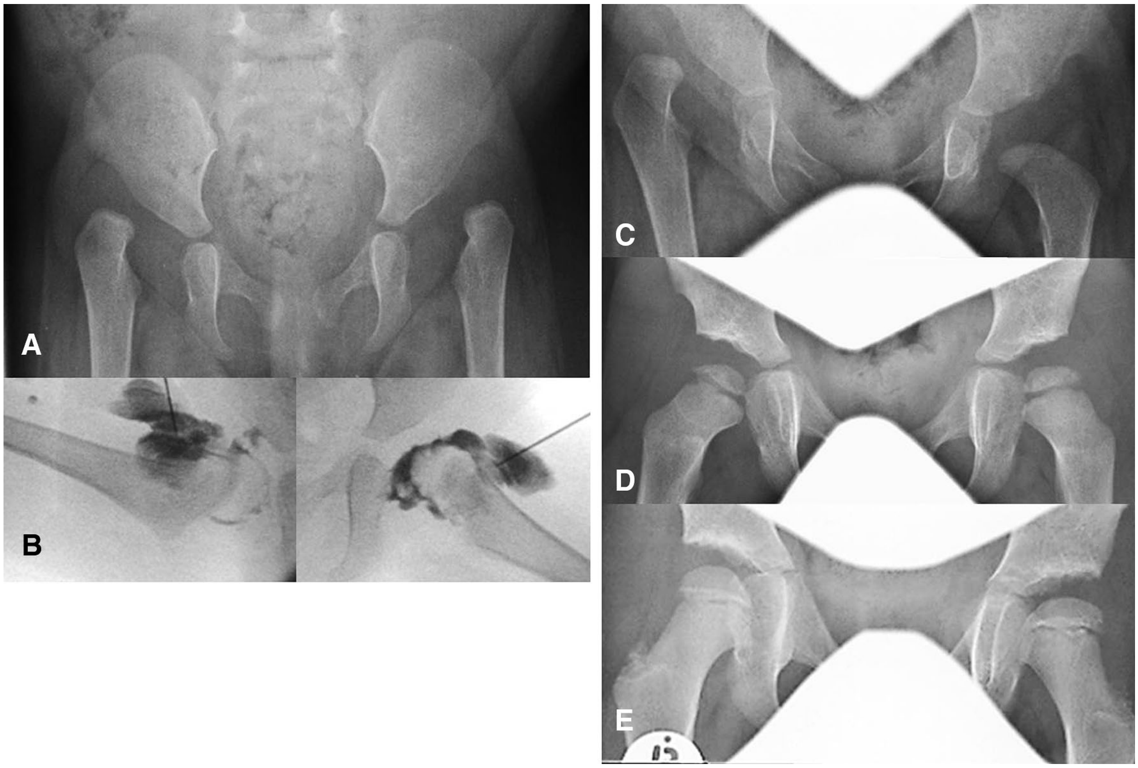

Fig. 3A–E A female patient presented with bilateral disease (**A**). Arthrograms demonstrated eccentric reductions (**B**). She was treated with sequential open reductions and acetabuloplasties at 1 year (**C**) and 1 year 3 months of age (**D**), respectively. Followup radiographs showed good acetabular development albeit the left hip shows early lateral growth arrest (**E**).

Table 1. Patient demographics (number of hips) in case and control groups

Parameter	Patient group	Control group	Mean difference	95% CI	p value
Male:female	3:27	6:21			0.467
Right:left	13:14	13:14			1.000
Bilateral (no:yes)	15:12	15:12			1.000
Severity of dislocation (IHDI) 3:4	2:25	1:26			1.000
Ossific nucleus at surgery (yes:no)	17:10	3:24			0.540
Age at diagnosis (days)	30 (23)	28 (23)	2	−10 to 14	0.748
Delay to surgery (months)	11 (2)	13 (4)	−1.4	0.8 to −3	0.117
Preoperative AI	40 (3)	39 (5)	0.3	−2 to 3	0.762

Quantitative variables are followed by mean (SD); CI = confidence interval; IHDI = International Hip Dysplasia Institute; AI = acetabular index.

disagreements occurred. Allowing for a 90% power to detect a 10% clinically meaningful difference between the groups in a 5% two-sided test indicates that 286 patients per group would have been required. Considering a 10% dropout during the followup period, the total number of patients required would be 636. Hence, this study is underpowered.

Clinical data collected from records included age at diagnosis, use of a Pavlik harness, delay to surgery, and the need for reintervention as well as pain, limping, leg length discrepancy, and the ROM of both hips.

Further surgery was required in 15 hips in the control group and in one belonging to the group treated with open reduction and acetabuloplasty. These included one revision of the open reduction, four varus derotation osteotomies, seven pelvic ostetomies, and seven apo- or epiphysiodeses. Two hips required first pelvic osteotomies and then varus derotation osteotomies performed on separate occasions,

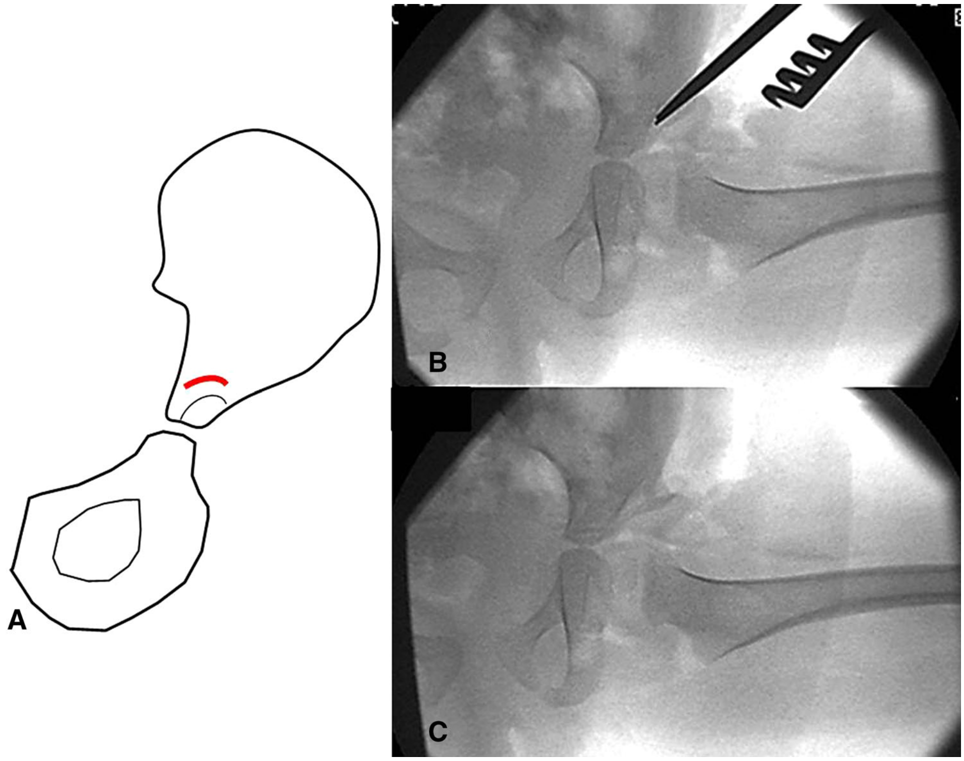

Fig. 4A–C Incomplete periacetabular acetabuloplasty technique is shown. The outer table of the ilium is osteotomized following the contour of the acetabulum (**A**) and displaced downward minimally with the help of one or two osteotomes (**B**). A synthetic graft can be used to maintain the tipped acetabular roof without additional fixation (**C**).

Table 2. AVN and need for further surgery in case and control groups

Parameter	Cohort	Control group	p value
AVN (yes:no)	11:16	11:16	1
Grade AVN (2:3:4)	4:6:1	8:2:0	0.117
Further surgery (yes:no)	1:27	15:12	< 0.001
Severin grade (Ia:Ib:IIa:IIb:III:IV)	14:1:11:1:0	13:2:7:5:2	0.283
Mackay class (I:II:III)	21:4:2	13:8:4	0.149

AVN = avascular necrosis.

whereas one hip required a pelvic osteotomy and later a medial screw epiphyisodesis. The seven hips in the control group (26%) that required pelvic osteotomies were operated on an average of 50 months from the index open reduction (SD 23; range, 20–85 months). The preoperative acetabular indices in these hips were not significantly different from the hips that did not require a pelvic osteotomy. One patient underwent a THA in 2015. In the case group, one hip required a medial screw epiphysiodesis for late lateral growth arrest.

Modified Mackay [24] and Severin [37] classifications were used to measure clinical and radiologic outcomes at last followup, respectively (Table 2). Although many more patients required further surgery after the index open reduction in the control group, there were no detectable differences between the groups regarding radiological or functional scores.

SPSS Version 22 (IBM, Armonk, NY, USA) was used for analysis. Univariate t-tests, odds ratios, multivariate logistic regression, and Fisher's exact tests were used to compare the statistical data. Statistical significance was taken as $p < 0.05$.

Results

Patients treated with open reduction and an incomplete periacetabular acetabuloplasty were less likely to develop acetabular dysplasia than were patients in the control group (0% [0 of 27] versus 37% [10 of 27]; odds ratio [OR], 11; 95% confidence interval [CI], 1.5–80 after zero cell correction; $p = 0.02$).

Similarly, patients in the study group undergoing open reduction and incomplete periacetabular acetabuloplasty were less likely to require pelvic osteotomies (0% [0 of 27] versus 26% [seven of 27]; OR, 8; 95% CI, 1–60 after zero cell correction; $p = 0.025$).

With the numbers available, there was no difference in terms of the proportion of patients who developed osteonecrosis between the groups treated with or without incomplete periacetabular acetabuloplasty (11 of 27 [41%] in either group; OR, 1; 95% CI, 0.6–2; p = 1).

Discussion

The surgical treatment of DDH is challenging as evidenced by the many protocols available. The best management for patients, parents, practitioners, and administrators alike would be such that offers the best results with the minimum amount of interventions. The purpose of this case-control study was to determine whether an incomplete periacetabular acetabuloplasty as an added step to delayed open reductions would diminish the risk of developing acetabular dysplasia or increase the risk of AVN. This added step has proven to add minimal morbidity or surgical time [7].

The main difficulty in this study was to elicit statistically meaningful comparisons when no events of our main outcomes (residual acetabular dysplasia and pelvic osteotomy) occurred in the case group. Although the fixed zero cell correction meets the objective of avoiding computational errors, it usually has the undesirable effect of biasing study estimates toward no difference and overestimating variances of study estimates [38]. Additionally, this study was severely underpowered to calculate meaningful AVN comparisons. Another important limitation arises from the fact that we are comparing a current patient group, still undergoing regular followups, with historic controls, the majority of which had been discharged at skeletal maturity. This limitation may be causing us to overstate the benefits of adding an incomplete periacetabular acetabuloplasty at the time of open reduction. Finally, this is a single-surgeon series and this fact brings its own set of limitations. The learning curve of the operating surgeon may influence comparisons between new and historic groups. Jain et al [18] demonstrated how AVN in open reductions improves after the first 28 cases, reaching a plateau after that. The choice of pelvic osteotomy and its timing are also strongly influenced by personal choice.

Residual acetabular dysplasia, described according to Severin's class or as an increased and nonevolving acetabular index, was much more likely in the group treated with open reduction alone and found in 37% of children. This is not only not surprising, but rather average if we remember that their mean age at open reduction was 13 months. According to Albinana et al [1], acetabular dysplasia is directly related to the age at open reduction, increasing from 20% at 6 months to 60% at 32 months or older. Hence, for these authors, children treated at 18 months of age have a probability of 36% to develop acetabular dysplasia. The unusual fact is that no cases of residual acetabular dysplasia were found in the case group, although their mean age at operation was similar. Hence, an incomplete periacetabular acetabuloplasty appears to be a powerful tool to counteract the deleterious effect of intentionally delaying surgery.

The current matched case-control series used the need for an early pelvic osteotomy as an objective endpoint to assess residual acetabular dysplasia. There were no pelvic osteotomies indicated in the case group, whereas in the control group, treated with open reduction alone, a pelvic osteotomy was required in 26% of the cases. The need for acetabular or femoral osteotomies after open reduction is less frequent than after closed reduction when treating isolated DDH but still rather common [4], even in those children treated early [23]. Some authors advocate the use of an intraoperative stability test [42] to selectively add femoral or pelvic osteotomies to their open reductions; however, this is not a fail-proof method either. The universal addition of a pelvic procedure at the time of open reduction has been advocated by Salter [31–33] and others [14, 15] when treating children older than 18 months of age, whereas other authors suggest that the addition of a pelvic osteotomy is unnecessary in children who are younger than 5 years of age [2, 21, 22]. It has been suggested that the initial preoperative acetabular index may be used as a criterion to add an acetabular procedure to the primary treatment [16]. In the present study, the preoperative acetabular index was not different in those hips that required a pelvic osteotomy from those that did not, making this measure a poor initial discriminator. Bolland et al [4] and Albinana et al [1] found the acetabular index becomes a reliable predictor for the need for a pelvic osteotomy at an average of 1.5 years or 2 years after the hip reduction, respectively. The addition of an incomplete periacetabular periacetabuloplasty to all hips undergoing open reduction eliminates the uncertainty, whereas it does not appear to have deleterious effects, as evidenced by the similar Severin and Mackay scores. These scores were obtained at the final followup and, in the control group, many further surgeries were required. However, if practitioners prefer, this technique can be added to selected cases that present late or are particularly unstable intraoperatively.

Some authors have described an increased risk of AVN using a combination of open reduction and Salter pelvic osteotomy [3, 27]. In the current series and with the numbers available, there were no differences between patients undergoing acetabuloplasties and control patients in terms of the likelihood of developing AVN. In view of the differences in followup, it is possible that the proportion of patients with AVN in the study group is underestimated. The proportion of patients developing

AVN in both of our groups was in range with other studies (41%), and our groups were likely too small to resolve differences that might have been clinically important. Future, larger studies are needed. In the United Kingdom, a randomized controlled trial was launched in 2014 to compare the AVN rate in children with dislocated hips treated early with those treated with intentionally delayed surgery. Nevertheless, these represent higher proportions of patients with avascular necrosis than previous series by the same surgeon [4, 7, 8]. However, our rate of AVN is similar to other case-control studies; Segal et al [36] reported a 32% rate and Sankar et al [33] 41%. The high proportion of AVN in this series may be explained by several factors; all of our patients had failed conservative treatment with a Pavlik harness, a known risk for AVN [40]; bilateral disease was overrepresented [5]; the majority were high dislocations (International Hip Dysplasia Institute 4); and over half of these hips, despite the delay, did not have an ossific nucleus present at surgery, another indirect indicator of severe disease.

The addition of an incomplete periacetabular acetabuloplasty to all hips undergoing intentionally delayed open reduction eliminated residual acetabular dysplasia in this cohort, in the followup available, whereas it did not appear to have deleterious effects, as evidenced by an equal AVN proportion and similar Severin and Mackay scores.

Acknowledgments We thank Sariyam Al-Hallao and Karim Wahed for reviewing the control radiographs. We also thank the reviewers and editors who have improved the quality and clarity of this article.

References

1. Albinana J, Dolan LA, Spratt KF, Morcuende J, Meyer MD, Weinstein SL. Acetabular dysplasia after treatment for developmental dysplasia of the hip. Implications for secondary procedures. *J Bone Joint Surg Br.* 2004;86:876−886.
2. Arslan H, Sucu E, Ozkul E, Gem M, Kişin B. Should routine pelvic osteotomy be added to the treatment of DDH after 18 months? *Acta Orthop Belg.* 2014;80:205−210.
3. 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.
4. Bolland BJ, Wahed A, Al-Hallao S, Culliford DJ, Clarke NM. Late reduction in congenital dislocation of the hip and the need for secondary surgery: radiologic predictors and confounding variables. *J Pediatr Orthop.* 2010;30:676–682.
5. Cady RB. Developmental dysplasia of the hip: definition, recognition, and prevention of late sequelae. *Pediatr Ann.* 2006;35:92–101.
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. Carsi B, Al-Hallao S, Wahed K, Page J, Clarke NM. Incomplete periacetabular acetabuloplasty: a one-stop procedure for DDH. *Acta Orthop Scand.* 2014;85:66–70.
8. Clarke NMP, 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.
9. Crego C Jr, Schwartzmann JR. Follow-up study of the early treatment of congenital dislocation of the hip. *J Bone Joint Surg Am.* 1948;30:428–442.
10. Eastwood DM. Neonatal hip screening. *Lancet.* 2003;361:595–597.
11. Ferguson AB Jr. Primary open reduction of congenital dislocation of the hip using a median adductor approach. *J Bone Joint Surg Am.* 1973;55:671–689.
12. Fernandez CA, Dolan LA, Weinstein SL, Morcuende JA. Natural history of type III growth disturbance after treatment of developmental dislocation of the hip. *Iowa Orthop J.* 2008;28:27–35.
13. 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.
14. Grudziak JS, Ward WT. Dega osteotomy for the treatment of congenital dysplasia of the hip. *J Bone Joint Surg Am.* 2001;83:845–854.
15. Haidar RK, Jones RS, Vergroesen DA, Evans GA. Simultaneous open reduction and Salter innominate osteotomy for developmental dysplasia of the hip. *J Bone Joint Surg Br.* 1996;78:471–476.
16. 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.
17. Hilgenreiner H. Classic. Translation: Hilgenreiner on congenital hip dislocation. *J Pediatr Orthop.* 1986;6:202–214.
18. Jain NP, Jowett AJ, Clarke NM. Learning curves in orthopaedic surgery: a case for super-specialisation? *Ann R Coll Surg Engl.* 2007;89:143–146.
19. Jones D. Neonatal detection of developmental dysplasia of the hip (DDH). *J Bone Joint Surg Br.* 1998;80:943–945.
20. Kalamchi A, MacEwen GD. Avascular necrosis following treatment of congenital dislocation of the hip. *J Bone Joint Surg Am.* 1980;62:878–888.
21. Kim HT, Kim JI, Yoo CI. Acetabular development after closed reduction of developmental dislocation of the hip. *J Pediatr Orthop.* 2000;20:701–708.
22. 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.
23. Luhman SJ, Bassett GS, Gordon JE, Schootman M, Schoenecker PL. Reduction of a dislocation of the hip due to developmental dysplasia. Implications for the need for further surgery. *J Bone Joint Surg Am.* 2003;85:239–243.
24. Mackay DW. A comparison of the innominate and the pericapsular osteotomy in the treatment of congenital dislocation of the hip. *Clin Orthop Relat Res.* 1974;98:124–132.
25. Morbi AH, Carsi B, Gorianov V, Clarke NM. Adverse outcomes in infantile bilateral developmental dysplasia of the hip. *J Pediatr Orthop.* 2015;35(5):490–495.
26. Narayanan U, Mulpuri K, Sankar WN, Clarke NM, Hosalkar H, Price CT. Reliability of a new radiographic classification for developmental dysplasia of the hip. *J Pediatr Orthop.* 2015;35(5):478–484.
27. Pospischill R, Weninger J, Ganger R, Altenhuber J, Grill F. Does open reduction of the developmental dislocated hip increase the risk of osteonecrosis? *Clin Orthop Relat Res.* 2012;470:250–260.

28. Ripatti S, Palmgren J. Estimation of multivariate frailty models using penalized partial likelihood. *Biometrics.* 2000;56:1016–1022.
29. Roose PE, Chingren GL, Klaaren HE, Broock G. Open reduction for congenital dislocation of the hip using the Ferguson procedure. A review of twenty-six cases. *J Bone Joint Surg Am.* 1979;61:915–921.
30. 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.
31. Salter RB. The classic. Innominate osteotomy in the treatment of congenital dislocation and subluxation of the hip. *Clin Orthop Relat Res.* 1978;137:2–14.
32. Salter RB, Dubos JP. The first fifteen year's personal experience with innominate osteotomy in the treatment of congenital dislocation and subluxation of the hip. *Clin Orthop Relat Res.* 1974;98:72–103.
33. Sankar WN, Young CR, Lin AG, Crow SA, Baldwin KD, Moseley CF. Risk factors for failure after open reduction for DDH: a matched cohort analysis. *J Pediatr Orthop.* 2011;31:232–239.
34. Schoenecker PL, Bitz M, Whiteside LA. The acute effect of position of immobilization on capital femoral epiphyseal blood flow. A quantitative study using the hydrogen washout technique. *J Bone Joint Surg Am.* 1978;60:899–904.
35. Schwarzer G, Schumacher M, Maurer TB, Ochsner PE. Statistical analysis of failure times in total joint replacement. *J Clin Epidemiol.* 2001;54:997–1003.
36. 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.
37. Severin E. Congenital dislocation of the hip: development of the joint after closed reduction. *J Bone Joint Surg Am.* 1950;32:507–518.
38. Sweeting MJ, Sutton AJ, Lambert PC. What to add to nothing? Use and avoidance of continuity corrections in meta-analysis of sparse data. *Stat Med.* 2004;23:1351–1375.
39. Thomas IH, Dunin AJ, Cole WG, Menelaus MB. Avascular necrosis after open reduction for congenital dislocation of the hip: analysis of causative factors and natural history. *J Pediatr Orthop.* 1989;9:525–531.
40. Tiruveedhula M, Reading IC, Clarke NM. Failed Pavlik harness treatment for DDH as a risk factor for avascular necrosis. *J Pediatr Orthop.* 2014;35(2):140–143.
41. Wang TM, Wu KW, Shih SF, Huang SC, Kuo KN. Outcomes of open reduction for developmental dysplasia of the hip: does bilateral dysplasia have a poorer outcome? *J Bone Joint Surg Am.* 2013;95:1081–1086.
42. Zadeh HG, Catterall A, Hashemi-Nejad A, Perry RE. Test of stability as an aid to decide the need for osteotomy in association with open reduction in developmental dysplasia of the hip. *J Bone Joint Surg Br.* 2000;82:17–27.