Journal of Orthopaedics and Traumatology https://doi.org/10.1186/s10195-026-00906-w

Article in Press

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Received: 01 Sep 2025

Accepted: 26 Dec 2025

Published online: 22 January 2026

Cite this article as: Lu, Y., Xue, C., Canavese, F. *et al.* Iatrogenic femoral neck fractures or separation of the proximal femoral epiphysis during closed reduction of irreducible femoral head fracture–dislocations in children: a review of 12 cases. *J Orthop Traumatol* (2026). https://doi.org/10.1186/s10195-026-00906-w

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Iatrogenic Femoral Neck Fractures or Separation of the Proximal Femoral Epiphysis During Closed Reduction of Irreducible Femoral Head Fracture-Dislocations in Children: A Review of 12 Cases

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Disclosure of interest

Yunan Lu, Chentao Xue, Federico Canavese, Sara De Salvo, Hetu Yao, Dianhua Huang, Ran Lin, Juan Zheng and Shunyou Chen declare that they have no competing interests.

Compliance with ethical standards

All procedures in studies involving human participants were performed in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. This was a retrospective study, and IRB approval was obtained (approval No. 2025239).

Funding

The authors gratefully acknowledge the financial support of Fuzhou Health

Commission Young & Mid-Career Investigator Research Project (2024-S-rc4), Fujian Natural Science Foundation Project (2024J011287, 2022J011311), Fujian Provincial Clinical Medical Research Center for First Aid and Rehabilitation in Orthopaedic Trauma (2020Y2014) and the Key Clinical Specialty of Fujian Province and Fuzhou City (20220104).

Acknowledgments

None.

Author contributions

Yunan Lu and Chentao Xue: design of the study, manuscript preparation, statistical analysis, revision.

Federico Canavese and Sara De Salvo: manuscript preparation, statistical analysis, revision.

Hetu Yao, Dianhua Huang and Ran Lin: drafted the manuscript, statistical analysis and revision of the manuscript.

Juan Zheng and Shunyou Chen: design of the study, revision and general supervision of the research group.

All authors read and approved the final manuscript.

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Abstract

Objectives

This study aimed to analyze the radiologic characteristics of irreducible pediatric femoral head fracture-dislocations to prevent potential iatrogenic femoral neck fractures (FNF) or separation of the proximal femoral epiphysis (SPFE).

Methods

This is a retrospective review of patients who were skeletally immature and diagnosed with traumatic hip dislocations combined with femoral head fractures. The collected data included patient demographics, fracture classification, fragment ratio, combined injuries, urgent reductions, treatment strategies, complications, and final outcomes.

Results

We treated 12 patients with femoral head fractures and dislocations. Eleven out of 12 patients underwent urgent closed reduction (91.7%). Six of the patients failed closed reduction and experienced FNF (n = 2, 33.3%) or SPFE (n = 4, 66.7%). Five patients presented with avascular necrosis of the femoral head after open reduction with internal fixation via a surgical hip dislocation approach, and two patients required further surgical treatment. Analysis of radiographs and computed tomography (CT) scans of irreducible femoral head fracture-dislocations revealed that the fractured femoral head was perched on the sharp angle of the posterior wall of the acetabulum, with a fragment ratio of 18%-27%. After recognizing the irreducibility, one case with a fragment ratio of 26% underwent immediate open reduction without further attempts at closed reduction. This procedure preserved the natural hip joint, preventing FNF and SPFE.

Conclusions

For pediatric patients with irreducible femoral head fracture-dislocation injuries and a

fragment ratio greater than 10%, repeated or forceful closed reduction may result in iatrogenic FNF or SPFE. Examining plain radiographs and CT images carefully before attempting reduction may help determine the safest treatment strategy.

Key words: fracture-dislocations; children; hip; femoral neck fracture; physical separation; iatrogenic injury; avascular necrosis

Introduction

Traumatic hip dislocations (THD) are an uncommon injury in children, accounting for less than 2% of traumatic pediatric conditions [1, 2]. Approximately 5-15% of THDs are associated with femoral head fractures [3, 4]. This combination is referred to as a femoral head fracture-dislocation, and the treatment aims to achieve an early concentric reduction to prevent avascular necrosis of the femoral head (AVN) [5]. Concomitant fractures of the femoral head or acetabular wall resulting from obstructing fragments within the acetabulum may prevent hip reduction in such injuries [6, 7].

THD is occasionally associated with SPFE (separation of the proximal femoral epiphysis), which has been reported in younger patients [8-10]. The adult orthopedic literature reports that THD associated with femoral head fractures can lead to femoral neck fractures (FNF) during closed reduction [11]. However, these case reports did not explore the pathogenetic mechanisms by which SPFE or FNF can occur during the urgent reduction of femoral head fracture-dislocations [8-11].

The risk of iatrogenic SPFE or FNF in patients with femoral head fracture-dislocations when closed reduction is performed suggests the need for different therapeutic strategies to avoid this complication [12-14]. Moreover, the growth plate of the femoral head in children blocks the blood supply, and the lack of communicating branch vessels

makes the incidence of AVN of the femoral head after fractures higher in children than in adults [15, 16]. However, the current published literature lacks data on irreducible femoral head fractures in pediatric patients, including imaging studies, possible mechanisms of irreducibility, and ways to prevent complications [10-13].

The main purpose of this study is to use imaging studies to identify the unique features of irreducible femoral head fracture-dislocations, which carry a high risk of subsequent FNF or SPFE in pediatric patients. The study will then describe an appropriate treatment strategy to prevent iatrogenic fractures and avoid unnecessary morbidity.

Materials and methods

After receiving Institutional Review Board approval (No.2025239), we conducted a retrospective study of pediatric patients who were treated for THD with femoral head fractures at three institutions between 2016 and 2023.

The inclusion criteria were as follows: 1) Age of less than 18 years at the time of injury, 2) diagnosis of acute traumatic hip dislocation (THD) and ipsilateral femoral head fracture via plain radiography or computed tomography (CT), 3) follow-up of more than one year, and 4) complete clinical and radiographic data.

The exclusion criteria were: 1) pathological or open fractures; 2) follow-up of less than one year; and 3) incomplete clinical and radiographic data.

We collected the following demographic and clinical data from the charts: age at injury, gender, laterality, fracture type, femoral head fragment ratio, associated injury, reduction method, type of iatrogenic injury, surgical treatment, and final outcomes. Table 1 presents the demographic details of the patients (Table 1).

Of the 66 cases of THD, 12 patients (six males and six females) had an associated femoral head fracture, accounting for 18.2% of cases. Dislocations due to

developmental hip dysplasia or a neuromuscular etiology were excluded.

The mechanism of injury included traffic accident and falling from a height. The mean age of patients at the time of injury was 13.8 ± 1.5 years (range, 11-16). The mean follow-up period was 48.2 ± 23.4 months (range, 16–77) (Table 1).

Four patients (33.3%) had other associated injuries: one patient had an ipsilateral femoral shaft fracture; one patient had an ipsilateral femoral shaft fracture and an acetabular fracture; and two patients had two ipsilateral acetabular fractures (Table 1). Urgent closed reduction of the dislocations was initially attempted by orthopedic surgeons within less than 6 h after the injuries occurred in the emergency or orthopedic department.

Plain radiography and computed tomography (CT), including three-dimensional (3D) reconstructions, were performed on all patients before and after hip joint reduction to identify and classify the type of injury and to measure the femoral head fragment ratio. The Pipkin classification system categorizes initial femoral head fractures and dislocations based on radiographic and CT images. It identifies: dislocation with a fracture of the femoral head caudad to the fovea capitis (non-load-bearing surface) and the head fragment is small (type I); dislocation with a fracture of the femoral head cephalad to the fovea capitis (load-bearing surface) and the head fragment is large (type II); dislocation with fracture of the femoral head and fracture of the femoral neck (type III); dislocation with fracture of the femoral head and fracture of the acetabular rim (type IV) [17].

The femoral head fragment ratio is the ratio of the width of the displaced femoral head fragment to the diameter of the femoral head (Figure 1).

Iatrogenic fractures of the proximal femur after reduction were classified according to the Delbet-Colonna classification, which identifies four types of fracture:

transepiphyseal (type I), transcervical (type II), basicervical (type III), and intertrochanteric (type IV) [18]. AVN was rated according to the Ratliff classification system, which includes types I (AVN of the head and neck), II (AVN of the head), and III (AVN of the neck) [19].

Two experienced pediatric orthopedic surgeons (LYN and XCT) measured the parameters independently, and we used their mean values for the statistical analysis.

Statistical analysis

The IBM SPSS statistical package, version 22.0 (IBM Corporation, Armonk, NY, USA), was used to analyze the data. First, the Shapiro-Wilk test was used to determine whether the data followed a normal distribution. Since the data on age and follow-up were normally distributed, they are expressed as the mean, range, and standard deviation. Fragment ratio variables were expressed as median (interquartile range) due to the small sample size and non-normal distribution. Three complementary statistical methods were used to evaluate the fragment ratio as a risk factor for iatrogenic fractures: receiver operating characteristic (ROC) curve analysis, boxplot analysis, and regression tree (CART) analysis. The optimal cutoff value, or split point, for potential risk factors was determined using the Youden index and confirmed with a Mann–Whitney U test. Statistical significance was set at $P < 0.05$.

Results

Of the twelve patients initially diagnosed with femoral head fracture-dislocations, nine were Pipkin type I and three were type IV [17]. Eleven out of twelve patients underwent immediate closed reduction (91.7%).

Overall, six out of 11 patients (54.5%) experienced iatrogenic FNF (n=2, 33.3%)

(Figure 2, Case 1) or SPFE (n=4, 66.7%) (Figure 3, Case 6) during urgent closed reduction. All the six patients required open reduction via a surgical hip dislocation approach, as well as fixation of the iatrogenic FNF or SPFE with cannulated screws. In one case with an associated acetabular fracture (Pipkin type IV), the acetabulum was fixed with a plate.

The remaining 5 cases (45.5%) of femoral head fracture-dislocations were successfully reduced. Two cases involving Pipkin type IV acetabular fractures were treated with open reduction and internal fixation. The remaining three cases which involved small fragments (Pipkin type I) were treated conservatively (Table 1).

Plain radiographs and 3D-CT scan images were reviewed to identify features indicative of irreducible femoral head fracture-dislocations at high risk of iatrogenic fractures. In all cases of irreducibility (cases 1-6), we observed close contact between the broken surface of proximal femoral head and the sharp posterior angle of the acetabular region, particularly in the obturator foramen view. This feature of the irreducibility was more clearly visible on the 3D CT scans, showing the fractured proximal femoral head perched on the posterior wall of the acetabulum.

Additionally, we calculated that the femoral head fragment ratio in the iatrogenic fracture groups (cases 1-6) was greater than 18%, whereas in the successfully reduced groups (cases 7-11), it was less than 10%. Furthermore, statistical analysis using three complementary methods revealed that the cutoff value was 10% ($P<0.05$). This suggests that a larger, wider femoral head fragment may result in more difficult reduction and increase the risk of iatrogenic FNF.

Because of the high risk of nonunion and AVN as complications of iatrogenic FNF or SPFE, immediate open reduction and internal fixation were performed without further closed reduction attempts for the most recently treated patient, who had a femoral head

fracture fragment ratio of 26% (Figure 4, Case 12).

All patients were followed up for a mean of 48.2 ± 23.4 months (range, 16–77), and all achieved bony union within six months after the initial procedure.

Five of the six patients with iatrogenic FNF or SPFE developed AVN within 12 months after the initial procedure (83.3%). Among the cases that developed AVN, 2 were Ratliff type I and 3 type II [19]. Two type I patients had obvious symptoms of hip pain and limited mobility and required further treatment: one patient needs triple pelvic osteotomy and the other total hip replacement.

All five patients with successful closed reduction achieved good functional results, with no limitations in daily activities or signs of AVN. The patient (Case 12) who underwent direct open reduction without a repeated closed reduction attempts also had a favorable outcome, with no signs of AVN (Table 1).

Figures 2 to 4 display typical cases presentation (Figures 2-4).

Discussion

Our study revealed that repeated or forceful closed reduction of irreducible femoral head fracture-dislocations in pediatric patients with a fragment ratio greater than 10% can lead to iatrogenic FNF or SPFE and subsequent AVN.

A THD is an emergency, whether or not it is associated with femoral head fracture. Prompt closed reduction is typically required to protect the sciatic nerve, relieve pressure on the articular cartilage of the femoral head, and prevent femoral head AVN [20]. Mehlman et al. reported that hip reduction more than six hours after initial trauma is associated with a twentyfold increase in the risk of AVN of the proximal femoral epiphysis [5]. The primary management method for THD with an associated femoral head fracture is urgent closed reduction followed by definitive treatment to restore the

bony anatomy and joint incongruities [21]. However, the success rate of urgent closed reduction for this injury may be relatively lower than for isolated THD. Lawrence et al. coined the term "irreducible femoral head fracture-dislocation" for this condition, in which the fractured proximal femoral head typically rests on the posterior wall of the acetabulum, preventing closed reduction [11].

Iatrogenic FNF occur in approximately 8.6% of adult patients with THD combined with femoral head fractures during repeated attempts to reduce an irreducible femoral head fracture-dislocation [21]. According to Lawrence et al. and Park et al., subcephalic or transcervical fractures of the femoral neck are predominant [11, 14]. In pediatrics, iatrogenic fractures occur at a lower rate of about 2.3% [13], mainly presenting with SPFE as reported in previous literature [8, 10, 13].

All of our patients with femoral head fracture-dislocations were adolescents between the ages of 11 and 16 as were those previously reported [13, 22, 23]. A greater force is required to dislocate the hip in this age group than in younger children [24, 25]. Fiddian et al. hypothesized that occult fracture or minimal displacement may have been caused by initial injury to the femoral neck or physis [8]. This could result in aggravated instability, amplified displacement, and the development of FNF or SPFE during reduction. When treating pediatric patients with femoral head fracture dislocation, we recommend the following steps: 1) CT should be recommended as the gold standard for detecting femoral head and acetabular fractures, as well as for evaluating the morphology and ratio of the fragments. It can also be used to rule out possible combined femoral epiphyseal instability and latent neck fractures [26]; 2) Attempt emergency closed reduction under general anesthesia with complete muscle relaxation and gentle manipulation; 3) Perform closed reduction under C-arm fluoroscopy. If any instability or displacement is detected during manipulation, stop manipulating; 4) If closed

reduction is unsuccessful after one or two attempts, convert to open reduction with internal fixation.

In our case series of imaging studies of the THD with femoral head fractures, we observed a distinctive phenomenon: the engagement or locking of the femoral head-neck-shaft component against the sharp posterior angle of the acetabulum in obturator foramen views (Figure 2b, Case 1), particularly prevalent in the iatrogenic fracture group (Cases 1-6). Furthermore, coronal and sagittal 3D-CT images obtained prior to reduction invariably demonstrated the cancellous portion of the fractured femoral head-neck-shaft component perched on the cortical bone of the posterior rim of the acetabulum (Figure 3b-d, Case 6).

We calculated the femoral head fragment ratio (Figure 1, Fragment ratio = a/d) and found that the ratio was significantly higher in the iatrogenic fracture group (all greater than 18%) than in the successful reduction group (all less than 10%). The cutoff value was 10%, suggesting that a larger, wider femoral head fragment could lead to a more challenging reduction and increase the risk of iatrogenic injury.

Iatrogenic FNF or SPFE is more likely to occur when the proportion of the femoral head fragment is greater than 10% due to the friction and traction on the bone surface during emergency closed reduction (Figure 1). In Case 12, the bone fragment proportion was as high as 26%, and the femoral head and neck were perched on the posterior rim of the acetabular cortical bone. Due to the relatively high risk of iatrogenic FNF or SPFE, we opted for open reduction and internal fixation. No iatrogenic fracture occurred and the patient did not develop AVN during follow-up (Figure 4, Case 12). Furthermore, a concomitant acetabular fracture can complicate closed reduction and increase the risk of iatrogenic fractures (Case 2). Even if no iatrogenic fracture occurs, open reduction and fixation of the acetabulum may be necessary to stabilize the hip

joint (Cases 7 and 8). Therefore, open reduction is recommended for femoral head fractures with a fragment ratio greater than 10%, especially when combined with acetabular fractures, in order to save time and avoid the high risk of AVN [27, 28].

THD associated with subsequent FNF or SPFE results in serious injury and a high risk of long-term complications. According to most literature, the vast majority of patients develop AVN, resulting in poor outcomes, regardless of the timing or method of treatment [8, 13, 14, 22, 29]. We use the Pikkin classification to more clearly display fracture morphology in children before closed reduction. We use the Delbet-Colonna classification to categorize iatrogenic proximal femoral fractures and the Ratliff classification to evaluate avascular necrosis (AVN). These classifications allow us to better judge the prognosis. In our case series, five out of six patients with iatrogenic fractures developed AVN, and two required further treatment. We used the same surgical approach as Schoenecker et al. to expose the femoral epiphysis with a modified Dunn procedure [10, 30]. Using this technique, we were also able to fix acetabular fractures and perform epiphyseal reduction with direct visualization of the vascular supply (Figure 3, Case 6).

Limitations

Our analysis of the results was limited by the small sample size and short follow-up period in some cases. Despite the small number of cases due to the rarity of such lesions, we identified consistent radiographic patterns and proposed a management strategy for irreducible femoral head fracture-dislocations. Although the patients were treated at three different institutions, they were consecutive and received similar treatment according to established principles. The minimum follow-up period for this study is 16 months, so later complications may not have been detected in some patients yet. Consequently, the incidence of AVN or other issues may be higher than currently

reported. A much larger prospective study with a substantially longer follow-up period is needed to fully evaluate outcomes.

Conclusions

In summary, when managing pediatric patients with irreducible femoral head fracture-dislocations, it is crucial to avoid worsening existing injuries. Due to the high risk of iatrogenic FNF or SPRF when the fragment ratio is greater than 10%, repeated attempts at closed reduction are not recommended for this type of injury. Careful planning based on radiographic and CT findings is essential for prevent iatrogenic injuries and preserving the hip joint.

Figure Legends

Figure 1. Schematic diagram of the potential pathogenetic mechanism of iatrogenic femoral neck fractures (FNF) and separation of the proximal femoral epiphysis (SPFE). The femoral head fragment ratio is represented by the equation a/d, where a is the width of the femoral head fracture fragment and d is the diameter of the femoral head.

Figure 2. Case 1. A 13-year-old girl sustained a left posterior THD associated with a femoral head fracture (Pipkin type I). Initial pelvic radiograph and obturator foramen view revealed the femoral head-neck-shaft component was locked against the sharp posterior edge of the acetabulum (a, b). A 3D-CT scan revealed an iatrogenic FNF (Delbet II) during urgent closed reduction (c, d). Open reduction and internal fixation with cannulated screws was performed (e, f). Three years post-operation, a pelvic radiograph revealed AVN (Ratliff I) of the femoral head, and total hip replacement was required (g).

Figure 3. Case 6. A 12-year-old girl sustained a right posterior THD with a femoral head fracture (Pipkin type I). Initial pelvis radiograph and 3D-CT scan revealed a fractured femoral head-neck-shaft component perched on the posterior acetabulum (a-d). The pelvis radiograph after closed reduction shows an iatrogenic SPFE (Delbet I) (e). Open reduction, and internal fixation with cannulated screws was performed using a modified Dunn procedure (f, g). The hip radiograph and MRI showed fracture healing without AVN 12 months after the initial procedure (h, i).

Figure 4. Case 12. A 16-year-old girl sustained a left irreducible Pipkin type I femoral head fracture-dislocation. Initial radiograph of the pelvis and a 3D-CT scan revealed that the fractured femoral head, neck, and shaft were perched on the posterior acetabulum. The femoral head fragment ratio of the injured side was 26% (a-c). An open reduction and internal fixation with absorbable screws was performed immediately without attempting a closed reduction (d, e). A hip radiograph showed fracture healing without AVN 12 months after the initial procedure (f, g).

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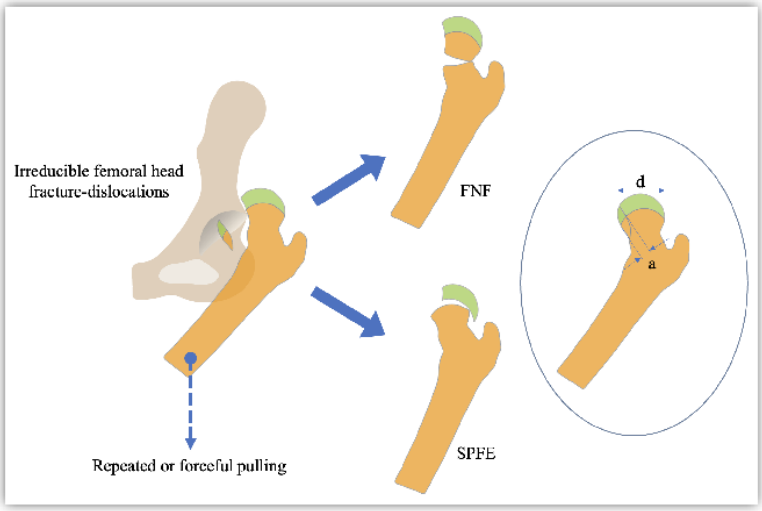

Figure 1. Schematic diagram of the potential pathogenetic mechanism of iatrogenic femoral neck fractures (FNF) and separation of the proximal femoral epiphysis (SPFE). The femoral head fragment ratio is represented by the equation a/d, where a is the width of the femoral head fracture fragment and d is the diameter of the femoral head.

Table 1. Demographics data of femoral head fracture-dislocation and final outcomes

Case	Sex	Age	Side	Pipkin classification	Fragment ratio	Combined injury	Urgent reduction	FNF/ SPFE	Operation	Follow-up	Final outcomes
1	F	13Y	L	I	22%		+	FNF (Delbet II)	SHD, ORIF	77M	AVN (Ratliff I) need THR
2	M	14Y	R	IV	24%	FSF+ ACF	+	FNF (Delbet III)	SHD, ORIF	20M	AVN (Ratliff II)
3	M	15Y	R	I	27%		+	SPFE (Delbet I)	SHD, ORIF	52M	AVN (Ratliff II)
4	M	13Y	L	I	20%	FSF	+	SPFE (Delbet I)	SHD, ORIF	54M	AVN (Ratliff I) need TPO
5	F	11Y	R	I	18%		+	SPFE (Delbet I)	SHD, ORIF	25M	AVN (Ratliff II)
6	F	12Y	R	I	24%		+	SPFE (Delbet I)	SHD, ORIF	18M	-
7	F	14Y	L	IV	8%	ACF	+	-	ORIF	53M	-
8	F	13Y	R	IV	9%	ACF	+	-	ORIF	72M	-
9	F	14Y	L	I	9%		+	-	-	81M	-
10	M	16Y	R	I	7%		+	-	-	48M	-
11	M	15Y	L	I	5%		+	-	-	62M	-
12	F	16Y	L	I	26%		-	-	ORIF	16M	-

M: male; F: female; L: left; R: right; M: month; FNF: femoral neck fractures; SPFE: separation of the proximal femoral epiphysis; FSF: femur shaft fractures; ACF: acetabular fractures; SHD: surgical hip dislocation; ORIF: open reduction with internal fixation; THR: total hip replacement; TPO: triple pelvic osteotomy; AVN: avascular necrosis.