



# The modified Dunn procedure provides superior short-term outcomes in the treatment of the unstable slipped capital femoral epiphysis as compared to the inadvertent closed reduction and percutaneous pinning: a comparative clinical study

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## Abstract

**Purpose** The aim of this study was to compare clinical outcomes and radiographic correction after modified Dunn procedure versus inadvertent closed reduction and percutaneous pinning for the treatment of unstable slipped capital femoral epiphysis (SCFE).

**Methods** We evaluated 45 patients with unstable SCFE treated using the modified Dunn procedure ( $n = 27$ ) or percutaneous pinning ( $n = 18$ ) during a minimum follow-up of one year. Clinical outcomes were assessed using the Heyman and Herndon scores. The Southwick angle, alpha angle, and femoral head-neck offset were used to assess radiographic correction. The occurrence of complications and unplanned re-operations were recorded.

**Results** At latest follow-up, 67% (18/27) in the modified Dunn procedure group and 28% (5/18) in the in situ pinning group had good or excellent Heyman and Herndon outcomes ( $p = 0.016$ ). The morphology of the femoral head and neck was improved in the modified Dunn procedure group compared to percutaneous pinning (Southwick angle, alpha angles; femoral head-neck offset;  $p < 0.001$ ). The proportion of osteonecrosis (26 vs. 28%;  $p > 0.999$ ) and unplanned re-operations (26 vs. 33%;  $p = 0.894$ ) was similar in both groups.

**Conclusion** Compared to inadvertent reduction and percutaneous pinning, the modified Dunn procedure provided better clinical and radiographic outcomes with similar proportion of osteonecrosis and unplanned re-operations following an unstable SCFE.

**Keywords** Slipped capital femoral epiphysis · Unstable SCFE · Modified Dunn procedure · In-situ pinning

## Introduction

Most patients with slipped capital femoral epiphysis (SCFE) develop a stable deformity at the level of the growth plate. However, in a subset of patients, a complete dissociation of

the epiphysis from the metaphysis develops in an acute setting. Unstable SCFE has been defined by the presence of severe pain that walking is not possible even with crutches, regardless of the duration of the symptoms [1]. This clinical classification is often used because it has prognostic implications for the occurrence of osteonecrosis of the femoral head [1].

Historically, the mainstay treatment of unstable SCFE has been percutaneous in situ fixation with one or two cannulated screws preceded by inadvertent reduction during patient positioning [2]. In situ pinning is effective to stabilize the epiphysis; however, a high proportion of patients develop osteonecrosis of the femoral head [1]. Recently, a subcapital realignment using the surgical dislocation approach has been described [3]. The initial description of the modified Dunn procedure suggested a very low rate of osteonecrosis; however, recent studies reported an incidence around 25% [4–7].

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There is limited literature of direct comparison of different treatment modalities for unstable SCFE, and the available studies include a small number of patients [6, 8, 9]. In this study, we aimed to compare the preliminary results of the modified Dunn procedure versus an inadvertent closed reduction and percutaneous pinning for the treatment of unstable SCFE in terms of (1) clinical outcomes based on the Heyman and Herndon system; (2) radiographic correction assessed by the Southwick angle, alpha angle, and head-neck offset; (3) the proportion of complications including osteonecrosis of the femoral head; and (4) the number of unplanned re-operations at a minimum one year follow-up.

## Material and methods

This is a single-centre retrospective cohort study approved by the institutional review board. The inclusion criteria were patients diagnosed with unstable SCFE based on the Loder et al. [1] criteria, treated with unintentional reduction and percutaneous pinning or the modified Dunn procedure. The exclusion criterion was a follow-up shorter than one year. Between 1999 and 2014, 56 patients were treated for an unstable SCFE. Twenty-six patients underwent unintentional reduction and percutaneous pinning, but eight (31%) were excluded because of follow-up of less than one year, leaving 18 (69%) patients included. Thirty patients underwent the modified Dunn procedure, but three (10%) were excluded because of follow-up of less than one year, leaving 27 patients included. Electronic medical records were retrospectively reviewed for collection of demographic data, pre-operative and post-operative clinical data, surgical details, and development of complications. The two groups had similar age, gender distribution, average length of pre-operative symptoms, and radiographic pre-operative displacement. Body mass index (BMI) was recorded, and values were normalized for BMI percentile using the growth tables from the United States Centers for Disease Control and Prevention (CDC) pediatric growth charts controlling for age and sex. Seventy-five percent of patients in the modified Dunn procedure group were considered overweight (BMI at or above the 85th percentile and below the 95th percentile) or obese (BMI at or above the 95th percentile for children and teens of the same age and sex). In the modified Dunn procedure group, 68% of the patients were considered overweight or obese. There was no difference ( $p = 0.2888$ ) in the median BMI percentile in the modified Dunn procedure group (median 96.5, interquartile range 87.1 to 98.8) compared to the ISP group (median 93.5, interquartile range 83.8–97.6). Because of the different temporal allocations, the percutaneous pinning group had a longer average follow-up compared to the modified Dunn procedure group ( $p < 0.001$ ; Table 1).

The Heyman and Herndon outcome system for SCFE [10] was recorded at the last clinic visit or immediately before a re-

operation. An excellent result is considered for a hip with no pain, no limp, and normal range of motion. A hip is classified as good if there is no pain, no limp, and slight limitation of internal rotation but internal rotation beyond neutral; fair if there is no pain, no limp, and slight limitation of abduction and internal rotation; or poor if there is slight pain after strenuous exercise, a mild limp, and slight limitation of internal rotation, abduction, and flexion. Pain on activity, limp, and marked limitation of motion requiring reconstructive surgery or progressive radiographic changes classify a hip as failed treatment.

Pre-operative radiographs were reviewed to evaluate the displacement according to Southwick [11]. Although in unstable SCFE measurement of angles may have lower clinical relevance, the Southwick angle was assessed to confirm complete displacement of the femoral epiphysis. The most recent frog-leg lateral view was evaluated for femoral head and neck morphology assessed by the measurement of the Southwick angle [11], the alpha angle, and the femoral head and neck offset [12]. Post-operative radiographs were assessed for the presence of femoral head sclerosis, cysts, collapse, and loss of sphericity consistent with osteonecrosis. The system described by Steinberg et al. [13] was used to classify the extent of femoral head involvement in patients who developed osteonecrosis. Complications and unplanned operations were recorded.

Surgical indication for inadvertent reduction with percutaneous fixation versus modified Dunn procedure was determined with an evolving decision-making algorithm during three distinct study periods. Between 1999 and 2007, all patients underwent percutaneous pinning with or without arthrotomy. The second period (2007–2011) was characterized by the introduction of the modified Dunn procedure at our institution. In this period, the treatment was based on the orthopaedic surgeon on-call as unstable SCFE presents typically as an acute traumatic event. Between 2011 and 2014, all patients underwent the modified Dunn procedure by one of two surgeons. All patients undergoing the modified Dunn procedure had this performed as their index/primary procedure.

Inadvertent reduction and percutaneous pinning were performed with the patient on a radiolucent fracture table (16 patients) or on a flat top radiolucent table (2 patients). Although no specific forced reduction maneuver was applied, all hips had a gentle partial reduction when the lower extremity was positioned to neutral rotation. In 13 cases, one cannulated screw (6.5 or 7.3 mm) was used, and in five cases, two screws were used for fixation. In two cases, an arthrotomy was performed at the time of percutaneous pinning; no arthrotomy was performed in the remaining 16 cases. Post-operative patients were non-weight bearing for four to six weeks followed by protected weight bearing for additional four to six weeks. All percutaneous pinning procedures were performed by one of eight fellowship trained paediatric orthopaedic surgeons.

**Table 1** Demographic and clinical characteristics

Variable	In situ pinning ( <i>n</i> = 18)	Modified Dunn procedure ( <i>n</i> = 27)	<i>p</i> value
Gender, no. (%)			0.67
Female	10 (56)	12 (44)	
Male	8 (44)	15 (56)	
Acute on chronic, no. (%)			0.358
Yes	12 (67)	13 (48)	
No	6 (33)	14 (52)	
Age (years)	12.7 (11.7, 13.7)	12.6 (11.8, 13.5)	0.923
Pre-operative Southwick angle (°)	64.5 (51.2, 81.3)	66.9 (56.6, 79)	0.808
Follow-up (years)	5.8 (4.2, 8)	2.4 (1.8, 3.1)	<0.001

The modified Dunn procedure was performed using the surgical hip dislocation approach careful preparation of the subperiosteal retinacular flap and resection of the posterior metaphyseal callus as previously described [3]. The femoral head was reduced back in the femoral neck and fixed with either two 6.5-mm cannulated screws (14 hips) or three 3.0-mm fully threaded wires (13 hips). Three fellowship trained paediatric orthopaedic surgeons with expertise in hip preservation surgery performed the modified Dunn procedures. Intra-operative assessment of femoral head perfusion was made with a drill hole and observation of active bleeding in five hips and with waveform observation using an intracranial pressure monitor in 22 hips [14]. Post-operatively, patients were placed on a restricted non-weight bearing protocol for six to eight weeks, followed by protected weight bearing with crutches for additional four to eight weeks, depending on radiographic healing status.

Demographic and clinical characteristics were compared using chi-square tests and two-sample *t*-tests. Post-operative radiographic parameters and clinical outcomes were compared using two-sample *t*-tests and Fisher's exact tests. Outcome variables were log transformed if necessary. The level of significance was set as 5%.

## Results

The modified Dunn procedure was associated with superior clinical outcome scores compared to the in situ pinning. At latest follow-up, 67% (18/27) in the modified Dunn procedure group and 28% (5/18) in the in situ pinning group had good or excellent Heyman and Herndon outcomes ( $p = 0.016$ ) (Table 2).

The modified Dunn procedure achieved better radiographic correction assessed by the lateral Southwick angle ( $p < 0.001$ ), the alpha angle ( $p < 0.001$ ), and the femoral head and neck offset ( $p < 0.001$ ), compared to the percutaneous pinning group (Table 3).

With the numbers available, there was no difference in the occurrence of osteonecrosis in both groups. Of the 27 patients treated by a modified Dunn procedure, seven (26%) developed osteonecrosis compared to 28% (5/18) of patients treated by percutaneous pinning ( $p > 0.999$ ). All patients with osteonecrosis were identified during the first six months after surgery, except in one patient after undergoing a modified Dunn procedure who was lost to follow-up after 3 months and returned to clinic after one year of surgery with pain, limp, and radiographic signs of osteonecrosis. Osteonecrosis developed in four patients who underwent modified Dunn procedure prior to 2011 and in three patients who underwent modified Dunn procedure after 2011, with no evident potential correlation with surgeon's learning curve. Results regarding intra-operative assessment of femoral head perfusion have been previously reported for this group of 27 patients undergoing modified Dunn procedure [14], but briefly among the seven patients who developed osteonecrosis, two had a complete tear of the retinaculum and absent perfusion of the femoral head. Of the patients who developed osteonecrosis in the modified Dunn procedure group, 5/8 patients had total femoral head involvement (Steinberg VI classification) and 3/8 patients in this group had incomplete head involvement. One patient was classified as Steinberg III-B with subchondral collapse without flattening involving approximately 20% of the articular surface. The other two patients were classified as Steinberg V-C. Of the patients who developed osteonecrosis in the in situ pinning group, 2/5 had complete head involvement (Steinberg VI classification). Three patients had incomplete head involvement: one patient was classified as Steinberg IV-C, and the other two were classified as Steinberg V-C and V, respectively.

No other major complication was found in the two groups. One patient was found to have a broken screw transfixing the trochanteric osteotomy following a modified Dunn procedure, which healed uneventfully after four weeks of protective weight bearing.

The rate of unplanned re-operations was similar between groups. Twenty-six percent (7/27) of patients in the modified

**Table 2** Post-operative clinical outcomes, complications, and procedures

Variable	In situ pinning ( <i>n</i> = 18)	Modified Dunn procedure ( <i>n</i> = 27)	<i>p</i> value
Heyman and Herndon, no. (%)			0.016
Good/excellent	5 (28)	18 (67)	
Other	13 (72)	9 (33)	
Osteonecrosis, no. (%)			1
Yes	13 (72)	20 (74)	
No	5 (28)	7 (26)	
Additional procedures, no. (%)			0.894
None	12 (67)	20 (74)	
One	3 (17)	3 (11)	
More than one procedure	3 (17)	4 (15)	

Dunn procedure group and 33% (6/18) in the percutaneous pinning group underwent unplanned procedures ( $p = 0.894$ ). Four of the seven patients that developed osteonecrosis in the modified Dunn procedure group had a complete involvement of femoral head and underwent total hip arthroplasty (THA) at an average of 27 months (range 17–48 months). The remaining three patients had incomplete head involvement and retained their native hip. For patients who developed osteonecrosis in the in situ pinning group, two out of five developed a complete head involvement and underwent THA at an average of 19 months. The remaining three patients had partial involvement of the femoral head and retained their native hip.

## Discussion

Treatment of unstable SCFE is controversial due to the increased risk of osteonecrosis. A recent survey showed that the preferred method for the treatment of unstable SCFE among members of the Pediatric Orthopaedic Society of North America is percutaneous fixation after positioning the hip to neutral rotation. However, the modified Dunn procedure has been utilized more frequently among young surgeons and in academic centres [15]. Most studies reporting results of surgical treatment of unstable SCFE lack comparison between different techniques. Moreover, the few studies directly comparing in situ pinning with the modified Dunn procedure for unstable SCFE were limited to a small sample size [6, 8, 9]. In this study, we compared the preliminary clinical and

radiographic outcomes of 27 patients who underwent a modified Dunn procedure for the treatment of an unstable SCFE with 18 patients treated with an in situ percutaneous fixation after inadvertent reduction.

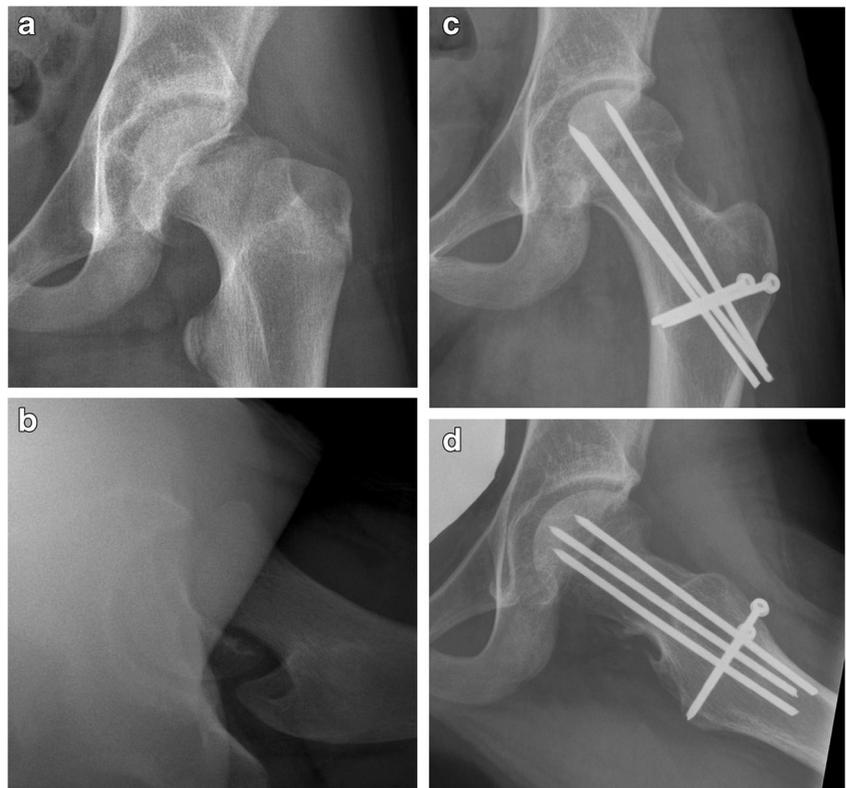
We found superior clinical outcomes for pain, limp, and range of motion at short-term follow-up in patients treated with the modified Dunn procedure compared with those treated with in situ pinning. Good or excellent Heyman and Herndon [10] scores were observed in one third of percutaneous pinning patients, compared to two thirds for the modified Dunn procedure group. Similarly, a high rate of good and excellent clinical outcomes following a modified Dunn procedure for unstable SCFE has been reported in those patients that do not complicate with osteonecrosis [3–5].

A clear advantage of the modified Dunn procedure is the restoration of the anatomical alignment [3–5, 16, 17]. Our data showed that the radiographic correction was better in the modified Dunn procedure group, compared to suboptimal correction of the femoral head and neck anatomy following percutaneous pinning (Figs. 1 and 2). Although remodeling of the residual deformity may be expected, it is unlikely that it would restore the normal anatomy of the proximal femur [18]. Furthermore, the remodeling mechanism has been attributed, at least partially, to impingement of the prominent metaphyseal bump against the acetabular rim [19] which is associated with articular cartilage damage [20]. We did not observe implant failures in the modified Dunn procedure, although two studies reported 8 and 15% of failures using threaded Kirschner wires or solid 4.5-mm screws [5, 21]. Cannulated 6.5-mm screws have been used without failure

**Table 3** Post-operative radiographic parameters

Variable	In situ pinning ( <i>n</i> = 10)	Modified Dunn procedure ( <i>n</i> = 20)	<i>p</i> value
Alpha angle	89.7 (81.7, 97.6)	40.9 (35.3, 46.6)	< 0.001
Femoral head neck offset	−3.4 (−5.2, −1.5)	4.6 (3.3, 5.9)	< 0.001
Southwick angle	41.3 (34.7, 47.9)	4.6 (−0.1, 9.2)	< 0.001

**Fig. 1** Restoration of the proximal femoral anatomy following the modified Dunn procedure for the treatment of unstable SCFE. **a** Preoperative AP radiograph of a 14-year-old female shows complete displacement of the epiphysis secondary to unstable SCFE. **b** Preoperative cross-table lateral radiograph shows complete displacement. **c** Postoperative AP radiograph at 2 years shows normal morphology of the proximal femur. **d** Frog-leg view lateral radiograph at 2 years shows no signs of residual femoroacetabular impingement morphology at the femoral head-neck junction

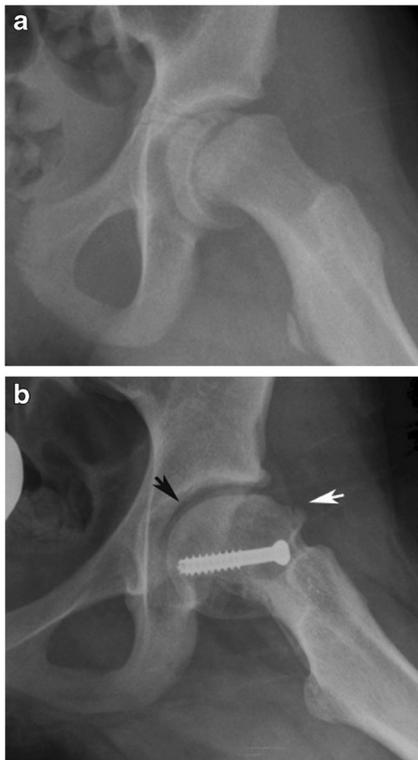


[4] and are our current preference for epiphyseal fixation during a modified Dunn procedure.

With the numbers available, we observed a similar incidence of osteonecrosis among patients treated with the modified Dunn procedure and those treated with in situ pinning following inadvertent reduction. Previous comparative studies with a smaller sample size have found similar results [6, 8, 9]. The proportion of patients who developed osteonecrosis after unintentional reduction and pinning in our study (28%) is in agreement with the current literature reporting 7 to 47% rate of osteonecrosis [1, 22–24]. However, the proportion of osteonecrosis following the modified Dunn procedure (27%) is higher than the initial series describing this procedure [3, 17]. However, in those studies, only a few patients had an unstable SCFE. With popularization of the technique, recent studies from different centers reported rates of osteonecrosis around 25% [4, 5]. Our study as well as the most recent published literature may have been biased by the learning curve associated with this procedure. However, we found no difference in the osteonecrosis incidence between the early and later time periods of this study. The proportion of patients who underwent an unplanned re-operation was similar among the two groups. Likewise, similar rates of unplanned re-operations were reported in a previous study [6]. Advanced femoral head collapse, severe hip deformity, activity-limiting pain, and severe limp were treated with THA in both groups. However, not all patients who developed osteonecrosis progressed to THA. Because most unplanned re-operations were performed in

patients who developed osteonecrosis, future studies will be important to establish interventions to avoid the morbidity associated with the natural progression of the osteonecrosis of the femoral head.

We acknowledge several limitations to our study. First, the length of follow-up was different between the two groups. Patients who developed osteonecrosis required multiple surgical procedures and regularly scheduled follow-up visits. Possibly, patients who developed osteonecrosis after percutaneous pinning had an average follow-up longer because they were operated on the earlier phases of the study. Second, there is potential for transfer bias due to unequal loss to follow-up (10% in the modified Dunn procedure group vs. 31% in the percutaneous pinning group). We believe this may be associated with a longer rehabilitation protocol following the modified Dunn procedure. Third, this is a retrospective study comparing two treatments over a 12-year period with a variation of the surgical technique for percutaneous pinning, performed by eight surgeons. The decision for arthrotomy as well as the use of a second screw were left to the discretion of the treating surgeon. During the early period of treatment in the study, it was not well recognized that arthrotomy could potentially impact the intracapsular pressure and, therefore, it was not routinely performed. This demonstrates the evolution in the treatment of unstable SCFE over the last decade. Notably, the two patients who underwent arthrotomy did not develop osteonecrosis. Future studies should compare the modified Dunn procedure to percutaneous fixation following either a



**Fig. 2** Residual femoroacetabular impingement cam-morphology of the proximal femur after in situ pinning for the treatment of unstable SCFE. **a** Preoperative radiograph of a 12-year-old female with severe unstable SCFE. **b** Postoperative frog-leg view radiograph 2 years after unintentional reduction without forceful manipulation and in situ pinning with one 6.5-mm cannulated screw shows no radiographic signs of osteonecrosis. There is abnormal morphology of the femoral head-neck junction with a residual metaphyseal prominence (white arrow). With hip abduction, there is loss of the sealing effect within the joint with formation of an air arthrogram (black arrow) secondary to the anterior and lateral impingement.

percutaneous or a formal open arthrotomy [25, 26]. Fourth, there was a study period, from 2006 to 2011, when surgeries were performed based on surgeon's preference rather than following specific criteria, which raises a concern for selection bias. Fifth, the retrospective study design, without a blind review of the clinical scores, could have predisposed to observer bias.

In conclusion, the modified Dunn procedure allowed anatomic restoration of the proximal femur and prevention of residual impingement deformity with improved clinical outcomes for pain, limp, and hip motion in comparison to unintentional reduction and percutaneous pinning for unstable SCFE. However, the theoretical advantage of preserving the blood supply to the femoral head with a modified Dunn procedure and reduction of osteonecrosis rate was not observed. We believe that these findings support the use of the modified Dunn procedure for the treatment of unstable SCFE. Future prospective comparative studies should compare the outcomes of the modified Dunn procedure with contemporary

treatment of SCFE including an open arthrotomy or a percutaneous arthrotomy while monitoring the blood supply to the femoral head.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflicts of interest.

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