The Role of Capital Realignment Versus In Situ Stabilization for the Treatment of Slipped Capital Femoral Epiphysis

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Introduction: Slipped capital femoral epiphysis (SCFE) can be treated by a variety of methods with the traditional method of in situ pin fixation being most commonly used. More recently, the Modified Dunn (Mod. Dunn) procedure consisting of capital realignment has been popularized as a treatment method for SCFE, particularly for more severe cases. Over the last 5 years, our institution has selectively used this method for more complex cases. The purpose of this article is to evaluate the differences between these 2 treatment methods in terms of avascular necrosis (AVN) rate, reoperation rate, and complication rate.

Methods: Eighty-eight hips that were surgically treated for SCFE between July 2004 and June 2012 met our inclusion criteria. The in situ fixation group included 71 hips, whereas 17 hips were anatomically reduced with the Mod. Dunn procedure. Loder classification, severity, acuity, complication rate, and reoperation rate were determined for the 2 cohorts. The χ^2 analysis was performed to evaluate the relationship between the treatment method and outcome.

Results: As expected, stable slips did well with in situ pinning with no cases of AVN, even in more severe slips. Ten stable slips were treated with the Mod. Dunn approach and 2 (20%) developed AVN. Unstable slips were more difficult to treat with 3 of the 7 hips stabilized in situ developing AVN (43%). Two of the 7 unstable slips treated by the Mod. Dunn procedure developed AVN (29%). The other outcomes studied (reoperation rate and complication rate) were not significantly related to the surgical treatment method ($P = 0.732$ and 0.261, respectively).

Conclusions: In situ pinning remains a safe and predictable method for treatment of stable SCFE with no AVN noted, even in severe slips. Attempts to anatomically reduce stable slips led to severe AVN in 20% of cases, thus this treatment approach should be considered with caution. Treatment of unstable slips remains problematic with high AVN rates noted whether treated by in situ fixation or capital realignment (Mod. Dunn).

Level of Evidence: Level III retrospective comparative study.

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Study conducted at Rady Children's Hospital—San Diego, San Diego, CA.

No external funding was received for this study.

The authors declare no conflicts of interest.

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Key Words: SCFE, in situ fixation, open surgical dislocation, modified Dunn procedure

(*J Pediatr Orthop* 2014;34:791–798)

For decades, in situ percutaneous pin fixation has been the accepted standard for treatment of slipped capital femoral epiphysis (SCFE).[1,2] This accomplishes 2 major treatment goals: stabilization of the slip and minimizing the risk for avascular necrosis (AVN). Outcomes associated with this treatment method have been reported as generally favorable with mild deterioration of the hip joint over time. Better long-term results have been reported in patients treated with in situ fixation as compared with those treated with reduction and fixation.[3–5] Consistently, low reoperation rates and only rare occurrences of AVN are reported when evaluating the literature describing in situ fixation.[3,4,6–9]

The overall satisfactory results achieved by in situ stabilization have most commonly been achieved in chronic, stable slips. In 1993, Loder et al[10] in their classic paper, defined the stable versus unstable slip, providing a new language and understanding of slip stability and the associated risk for AVN. Current literature defines slips as being stable versus unstable with less focus on the descriptions of acute, chronic, and acute-on-chronic. All traditional and current reports clarify that the chance for achieving a satisfactory result in an unstable slip is much lower than when treating a stable slip.

Despite the overall good results achieved with in situ stabilization for SCFE, concerns remain. Severe stable SCFE often leaves the patient with residual femoral head-neck deformity, which may lead to premature hip arthrosis due to joint incongruity. The unstable slip has a high rate of AVN, as well as residual head-neck deformity.[10,11] This has left many searching for a better treatment approach for some types of SCFE. The search for an "ideal outcome" (low AVN rate, near-anatomic reduction) in more severe forms of SCFE has steadily evolved over the last 60 years and will be further outlined in the discussion section of this paper.

The most recent expansion of knowledge and development of techniques for SCFE treatment have evolved in conjunction with the development of the concept of femoroacetabular impingement (FAI) and its

evolution to secondary osteoarthritis (OA).[12–14] In 2000, Leunig et al[15] described the damage seen within the acetabulum secondary to a mechanical abutment of the prominent anterior femoral metaphysis associated with displacement of the epiphysis in SCFE.

This interpretation has led some surgeons to reintroduce treatment methods that recreate more normal femoral head-neck anatomy. Recently, anatomic capital realignment by the modified Dunn procedure (Mod. Dunn), performed through an open surgical dislocation, has been proposed as a treatment option to restore the anatomy of the proximal femur[16–18] (Fig. 1). The method was originally focused on more severe, slips, but, in some centers, it has also been applied for moderate slips after studies by Ziebarth et al[18] and Sink et al[19] described premature articular damage due to hip impingement, even in moderate slips.

Unstable slips would also seem a natural candidate for anatomic reduction methods. In addition to the severe deformity commonly associated with unstable slips, they also have a high AVN rate when treated with traditional methods. Select centers with expertise in the technique of anatomic reduction have begun to apply anatomic reduction methods to both stable and unstable slips with the goal of correcting distorted anatomy in anticipation of decreasing the risk of subsequent FAI and eventual secondary OA.[16,18,20–22]

The concept of correcting the anatomic abnormality at the site of the deformity while simultaneously stabilizing the physis, would seem to be theoretically ideal. Variations in providing anatomic reduction of severe SCFE have been commonly advised by certain surgical centers in the past, but never widely adopted by the orthopaedic community. The complexity of the operation, and the risk for potentially creating AVN, all weighed against the generally positive results achieved with in situ fixation.

The recent increase in enthusiasm for anatomic reduction of SCFE has been based on a better understanding of the blood supply to the femoral head,[23] how vessels are distorted and displaced with a slip, and the description of a safer surgical technique based on this anatomic knowledge.[24]

Knowledge of a surgical technique does not assure an excellent outcome. This approach must be weighed against the potential for complications associated with anatomic reduction. AVN is the most feared outcome in the treatment of SCFE with effective treatment options for complete AVN usually limited to hip arthrodesis or early total hip arthroplasty (THA). In the past, anatomic reductions have been associated with AVN in 10% to 16% of cases.[25–27] More recent reports have noted a 26% AVN rate after using the Mod. Dunn technique for the treatment of unstable SCFE.[11,22] In situ fixation has continually shown low rates of AVN with very rare cases seen in stable SCFEs.[6,10,28]

Over the last 5 years our institution gradually introduced the Mod. Dunn procedure for capital realignment in selected cases of SCFE. This paper presents our results when anatomic reduction was used in both stable and unstable slips and compares the results with those achieved by in situ pinning. We will evaluate each surgical



FIGURE 1. A 10-year-old female with an unstable slipped capital femoral epiphysis was treated with surgical capital realignment through the modified Dunn approach with a near-anatomic restoration of proximal femoral anatomy. At 13 months of follow-up she has no symptoms and there is no evidence of avascular necrosis.

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method with regard to AVN rate, reoperation rate, and other complications.

METHODS

After obtaining IRB approval, a query of patients surgically treated for SCFE produced a list of 134 hips. Patients were included if they were treated with either in situ screw fixation or the Mod. Dunn procedure. All surgical and preoperative notes and radiographs were available, and all patients had a minimum of 6 months follow-up. Forty-six hips were excluded. The most common reasons for exclusion were: (a) <6 months of follow-up, and (b) the subject was initially treated at an outside hospital and notes or films were not available. Patients were also excluded if they underwent a concurrent proximal femoral osteotomy at the time of initial treatment of the slip.

Chart Review

A meticulous search of the medical records was performed to identify the weight-bearing capabilities of the patient at presentation, and the timing of the onset of symptoms, in order to appropriately classify each case. We classified each patient with regard to functional classification as described by Loder,[10] and the onset of symptoms.

Specifically, a SCFE was classified as stable if the patient could bear weight with or without crutches. Unstable SCFEs were those that could not bear weight even with assistive devices secondary to pain. With regard to symptom onset, the traditional classification scheme was utilized.[1,29]

FAI and limb-length discrepancy were classified as sequelae of SCFE and not as complications. Correlation between reoperation rate and treatment method was evaluated by looking at reoperations due to complications related to the original treatment method.

Surgical Methods

Percutaneous screw fixation was performed using a radiolucent table or fracture table based on the preference of the operating surgeon. No forceful reduction maneuvers were performed but possible partial reduction occurred due to positioning of the lower extremity. One or two 6.5 or 7.3 mm cannulated screws were then placed by percutaneous methods guided with fluoroscopy. A capsulotomy was performed in 1 unstable hip, which later developed AVN. An osteochondroplasty was performed at the time of percutaneous pinning in 4 cases.

Cases undergoing capital realignment were anatomically reduced using the Mod. Dunn procedure as described by Leunig et al.[17] This included a surgical hip dislocation after trochanteric osteotomy through a lateral surgical approach. The epiphysis was stabilized with a temporary threaded pin to avoid further disruption of the slip during the dislocation maneuver. Next, an extended retinacular flap was created to allow safe mobilization of the epiphysis. The capital realignment portion of the procedure was then performed by excising the callus and physis followed by reduction of the epiphysis onto the femoral neck. Mild to moderate shortening of the femoral neck was performed, as needed, to ensure that no undue tension was applied to the ascending vessels. The epiphysis was stabilized with a cannulated screw plus threaded k-wire or 2 cannulated screws. In many cases, after reduction and stabilization, the femoral head was drilled with a 2.0 mm Kirschner wire to evaluate blood flow to the epiphysis. This was not consistently recorded and will not be evaluated in this paper.

Statistical Analysis

All statistical analyses were conducted using SPSS (version 12; SPSS Inc., Chicago, IL). The χ^2 analysis and the Fisher exact test were performed to evaluate the relationship between treatment method and AVN rate, reoperation rate, and complication rate in both stable and unstable slips.

RESULTS

A total of 88 hips were evaluated. There were 71 hips in the in situ group and 17 hips in the Mod. Dunn group. The majority of our subjects were male (65% males, 35% females). The mean age of our cohort was 12.2 ± 1.6 years (range, 9.3 to 16.7 y). The mean follow-up for the in situ group was 31.4 ± 22.2 months (range, 6 to 90 mo). The mean follow-up for the Mod. Dunn group was 15.6 ± 7 months (range, 8 to 33 mo).

Stable Hips Only

In situ fixation was significantly safer for treating stable slips as compared with the Mod. Dunn procedure ($P = 0.02$). None of the stable hips that were fixed in situ developed AVN. Two of the 10 stable slips treated with capital realignment (Mod. Dunn) went on to develop AVN (Table 1). There was no significant relationship between reoperation rate and treatment method ($P = 0.49$). There was no significant relationship between complication rate and treatment method ($P = 0.07$). A full list of complications for stable hips is shown in Table 2.

Unstable Hips Only

We did not find a significant relationship between treatment method and AVN when evaluating unstable hips ($P = 0.58$). The Mod. Dunn procedure resulted in AVN in 2 of the 7 hips, compared with 3 of the 7 in the in situ group (Table 3). There was no significant relationship between reoperation rate and treatment method ($P = 0.58$). There was no significant relationship between complication rate and treatment method ($P = 0.58$). A full list of complications for unstable hips is shown in Table 4.

TABLE 1. AVN Rate by Treatment Method: Stable SCFE Only

	AVN [N (%)]
In situ (n = 64)*	0 (0.0)
Modified Dunn (n = 10)*	2 (20.0)

*Significant relationship between treatment method and AVN rate.
AVN indicates avascular necrosis; SCFE, slipped capital femoral epiphysis.

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TABLE 2. Complications Stratified by Treatment Method: Stable SCFE Only

	Complication	N (%)
In situ (n = 64)	Painful implant	2 (3.1)
	Infected implant	1 (1.6)
	None	61 (95.3)
Modified Dunn (n = 10)	AVN	1 (10.0)
	AVN, chondrolysis	1 (10.0)
	None	8 (80.0)

AVN indicates avascular necrosis; SCFE, slipped capital femoral epiphysis.

DISCUSSION

The treatment of SCFE over the last quarter century has been guided by the long-term outcomes of patients studied in Iowa by Boyer et al.[3] Their findings determined that most patients treated by in situ fixation had satisfactory long-term results. Patients treated by methods that included manipulative reduction had less favorable outcomes and more complications. The results of the Iowa report have been further supported by Boero et al[5] and Aronson and Carlson.[28] Despite these generally satisfactory results, surgeons have remained concerned about residual anatomic abnormality in SCFE.

The evolution toward achieving anatomic correction of moderate and severe SCFE has an interesting history in the North American and European literature. In the mid 1950s, Heyman et al[30] described a method in which a severe slip was pinned in situ, but at the same time the anterior "bump" was removed from the femoral head-neck junction to decrease impingement with flexion.

In 1964, Dunn[31] (England) proposed a method for anatomic reduction of the femoral head upon the femoral neck. He expanded his report and provided follow-up results in 1978.[32] Szypryt et al[33] (Nottingham) in 1987 provided a comparative report of these 2 methods, noting that the Heyman-Herndon procedure (pinning in situ plus excising the "bump") worked well for moderate cases but did not give satisfactory results in severe deformity. They found better outcomes with Dunn's anatomic reduction for patients with $>50\%$ slip.

In the 1990s, Fish[34] of Hamilton, New York, reported a series of patients treated by anatomic reduction that included a cuneiform osteotomy at the head-neck junction with generally satisfactory results and several North American hospitals adopted the method but with less than ideal results, because of a persistent incidence of AVN.

In 2000, Leunig et al[15] from Bern, Switzerland, reported the often severe joint damage caused by metaphyseal prominence in SCFE. Signs of mechanical wear were consistently present within the acetabulum when the metaphysis was even with, or prominent to, the femoral head. At about the same time, Gautier et al[23] described the anatomy of the medial femoral circumflex artery and its posterior extensions which supply the proximal femoral epiphysis. Ganz et al[24] subsequently described an operative approach which included a trochanteric osteotomy that allows surgical dislocation of the femoral head with careful development of a subperiosteal flap and removal of posterior callous to protect the critical vascular supply to the epiphysis, followed by femoral neck shortening and anatomic reduction of the femoral head. They described this surgical method as the Mod. Dunn procedure.[18,24] The group later reported that with detailed attention to surgical anatomic reduction of SCFE, they could reduce their AVN rate to near zero.[16,17,35] Most reports from Europe suggest a very low AVN rate in patients treated with this technique. The method has been adopted by multiple centers in North America, but with less satisfactory outcomes. The recent report by Sankar et al[22] reported an AVN rate of 26% for unstable slips treated by the Mod. Dunn method.

TABLE 3. AVN Rate by Treatment Method: Unstable SCFE Only

	AVN [N (%)]
In situ (n = 7)*	3 (42.9)
Modified Dunn (n = 7)*	2 (28.6)

*No significant relationship between treatment method and AVN rate.
AVN indicates avascular necrosis; SCFE, slipped capital femoral epiphysis.

TABLE 4. Complications Stratified by Treatment Method: Unstable SCFE Only

	Complications	N (%)
In situ (n = 7)	AVN, nonunion, osteomyelitis	1 (14.3)
	AVN, OA	1 (14.3)
	Implant failure, progression of slip, AVN	1 (14.3)
	None	4 (57.1)
Modified Dunn (n = 7)	AVN	1 (14.3)
	AVN, painful implant	1 (14.3)
	None	5 (71.4)

AVN indicates avascular necrosis; OA, osteoarthritis; SCFE, slipped capital femoral epiphysis.

The issue of joint damage due to residual anatomic deformity in SCFE remains somewhat confusing and may to some degree be related to the population being studied. One cannot be certain that the Iowa and Scandinavian reports are dealing with the same population as the patients in reports by Leunig (Switzerland)[17,18,35] and Sink (New York).[19,36,37] The Iowa and Scandinavian studies reviewed a group of patients whose primary treatment was in the center that then performed the long-term follow-up study. The studies in Switzerland and New York were performed in tertiary centers that may have included more complex cases that had been referred. Thus, selection bias may need to be considered in deciding which data to accept regarding the degree of deformity that can be accepted in SCFE.

Further data supporting the long-term adverse effect of distorted hip anatomy in SCFE was provided by Abraham and colleagues in 2007, who evaluated intraoperative findings during THA surgery. Their study evaluated the proximal femora of 2 groups of patients

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undergoing THA, those with prior SCFEs and those with primary OA. Hips with a post-SCFE deformity required a THA 11 years younger than those with primary OA. The pistol grip deformity seen after SCFE was found to impinge on the acetabulum, creating an abnormal articulation and subsequent wear of the thinner superolateral articular surface of the femoral head. Overall, the abnormal reorientation of the femoral head and lack of head-neck offset seen in an unreduced SCFE was thought to result in a different wear pattern as compared with that seen in primary OA.[38]

As the Mod. Dunn procedure for capital realignment through a surgical hip dislocation became better known, surgeons in our institution gained further training in the technique and then began performing the procedure for selected cases of moderate and severe SCFE based on the preference and skill set of the treating surgeon. We have used the method for both stable and unstable slips.

The issue of training and experience in performing a procedure as technically demanding as the Mod. Dunn procedure must be considered. Each of the surgeons in our institution who performed the procedure are well-trained hip specialists and had training both in Switzerland and at educational seminars that included cadaver-based training. The total volume of 17 hips treated with this method is small but likely reflects the reality of many North American children's hospitals. Clearly focusing the operating experience on 1 (or at most a few) surgeon in an institution offers the best chance for a good outcome.

When adopting new treatment methods, the risk for AVN is a critical consideration. The reported rates of AVN after the Mod. Dunn procedure have ranged widely when including a mixture of stable and unstable slips.[16,18,20,25] Our AVN rate in hips treated with the Mod. Dunn procedure was 24% in all patients treated and 29% when treating unstable slips.

Application of these new treatment methods brings up important issues regarding slip stability and AVN. The Loder classification paper classified this, reporting that 47% of unstable hips developed AVN versus 0% in the stable group.[10] Zaltz et al,[11] in a 2013 systematic review of 15 papers, report an overall AVN incidence of 24% in unstable SCFE.

One must use caution in attempting pure application of stability descriptors in determining the true state of the physis. Likely the terms "stable" and "unstable" are too simple in a new era of SCFE understanding that includes sophisticated imaging (3DCT, MRI) and open surgical inspection that allows correlation with the clinical presentation.[39] We have performed open surgical reduction on patients that we had diagnosed as unstable but intraoperatively found extensive well-formed callus in the head-neck gap. It is not clear whether such patients should be described as being stable or unstable and how they should be treated.

The issue of monitoring blood flow to the femoral head before, during, and after surgical treatment of unstable SCFE remains problematic. Although intraoperative femoral head pressure monitors have been proposed to assess blood flow,[40,41] we have not used the method because the equipment required to perform it was not routinely available. The method of drilling the femoral head to determine

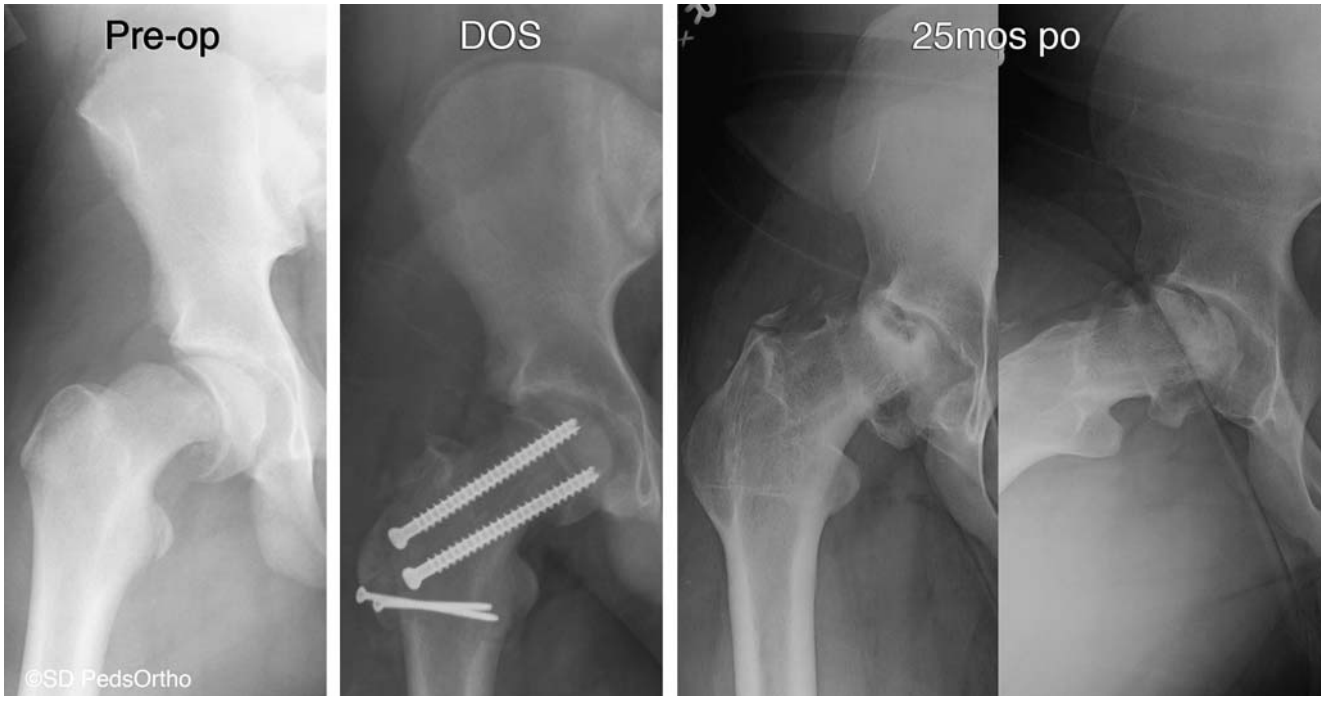


FIGURE 2. A 13-year-old male presented with an unstable slip and was treated with the modified Dunn procedure. He went on to develop avascular necrosis, illustrating the difficulty in treating unstable slips.

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whether active bleeding resulted (which suggests adequate blood flow) was performed but not always clearly recorded and thus not reported in this study. A surgeon must be cognizant of vascular flow issues when treating unstable SCFE.

Because a patient who has a true unstable slip has a very high risk for AVN, we believe that anatomic reduction is an acceptable treatment choice, provided that the treating surgeon is experienced with the method. Although our numbers were small, we found that unstable slips treated with anatomic reduction did as well as similar cases stabilized in situ. The high AVN rate in unstable slips, no matter how they were treated, demonstrates the overall difficulty in managing this condition (Fig. 2).

Other options are available for treatment of unstable SCFE. Parsch et al[42] have published a method that is a compromise between in situ fixation and the Mod. Dunn method. The Parsch method provides a good option for the acute, unstable slip in that it decompresses the hip joint and allows open, "guided" partial reduction. Their report suggests a 5% AVN rate, which is remarkably lower than other publications. Chen et al[43] have published their results using a similar method and report a 16% AVN rate; however, not all of their patients had a formal open capsulotomy as described by Parsch.

The Parsch method decreases the risk for AVN by avoiding overreduction of the displaced epiphysis. All patients are treated urgently and placed on a regular operating table to avoid any fracture table stresses to the vascular structures of the hip. An anterior arthrotomy is performed with a longitudinal capsulotomy. With the head and neck visualized, the degree of acute slip can then be evaluated and any chronic deformation can be determined. The epiphysis is partially reduced, only to the point that it had been located before the acute event. The slip is then stabilized with pins or screws.

In studying stable SCFE, we found that even in severe slips, in situ fixation was a safer choice compared with anatomic reduction, as no patient treated with in situ pinning developed a severe disabling complication (AVN) as compared with AVN developing in 2 of the 10 patients treated with capital realignment (Fig. 3). This experience might lead more traditional centers to continue using in situ fixation for severe stable slips, even though such patients may require a later corrective osteotomy and/or osteochondroplasty.[44,45]

The limitations of our current study consist of those inherently associated with retrospective studies. Although patients within each group underwent a similar procedure, there was no uniform protocol for positioning, screw insertion, or postoperative management. This is likely true for most clinical research reports on this topic. Our unstable group is small and limits the conclusions that can be drawn from the treatment of this fortunately rare entity.

In addition, the mean follow-up of the Mod. Dunn group was significantly shorter than the in situ group at almost 16 versus 31 months, respectively. This was due to the more recent implementation of the Mod. Dunn procedure as a treatment option. Fifteen patients (21%) in the in situ group have <12 months of follow-up, one of those patients was an unstable slip and could potentially develop AVN. Five patients in the Mod. Dunn group have <12 months of follow-up, 2 of them have already developed AVN. This leaves 18% of the patients in the Mod. Dunn group still at

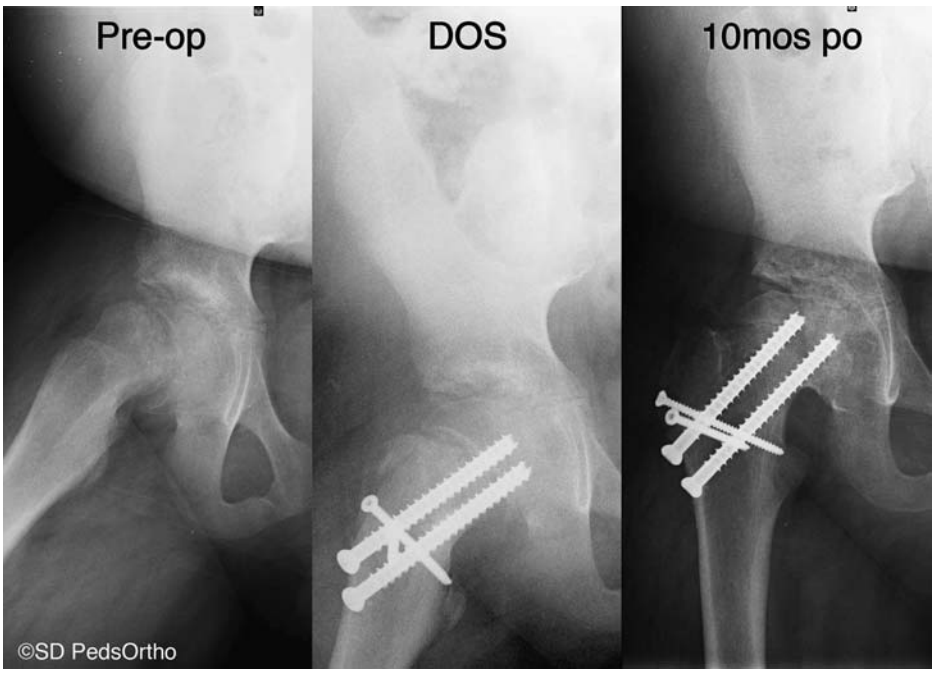


FIGURE 3. A 13-year-old female had a severe but stable slip treated with the modified Dunn procedure. The radiograph taken at 10 months of follow-up shows severe avascular necrosis.

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risk of developing AVN. If any of these patients develop AVN, the Mod. Dunn group, which already has a higher observed rate of AVN, would seem to be a much less favorable treatment option for SCFE.

SUMMARY/CONCLUSIONS

Surgical capital realignment, which allows anatomic reduction of SCFE, holds great promise and is used by some centers to treat severe slips of varying degrees of stability and acuity. This concept is attractive for unstable slips where the prognosis with any treatment method remains guarded. Application of newer treatment methods that have the potential for improving outcome in this group should be vigorously pursued.

The same cannot be said for stable slips, which do not develop AVN when stabilized in situ. Currently, we advise that in most circumstances (typical hospital/surgeon experience) stable slips be treated with in situ fixation to minimize the risk for AVN. If needed, the patient can be treated with a surgical procedure that combines femoral head-neck recontouring with proximal femoral flexion osteotomy. As referral institutions gain more experience, anatomic reduction of severe stable slips may result in AVN rates equal to those achieved by traditional treatment methods, allowing the method to be more broadly applied.

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