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Evolving Understanding of and Treatment Approaches to Slipped Capital Femoral Epiphysis

James D. Wylie[1] · Eduardo N. Novais[2]

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Abstract

Purpose of Review To review slipped capital femoral epiphysis (SCFE), with a focus on new insights into its etiology and evolving methods of operative fixation.

Recent Findings The epiphyseal tubercle and its size during adolescence are paramount to understanding the mechanism of SCFE. In chronic stable SCFE, the epiphysis rotates about the tubercle protecting the lateral epiphyseal vessels from disruption. In an acute unstable SCFE, the tubercle displaces, increasing the risk of osteonecrosis, also known as avascular necrosis (AVN). Intraoperative stability suggests that stable and unstable SCFE based on ambulation may be inaccurate. For stable SCFE, in situ pinning remains the most accepted treatment for mild slips with delayed symptomatic femoroacetabular impingement (FAI) management. Treatment of moderate to severe stable slips with realignment osteotomy leads to less femoral deformity and potentially better outcomes. However, it has a higher risk of complications, including AVN and chondrolysis.

Summary Our knowledge of the etiology for SCFE is evolving. The optimal technique for operative treatment of moderate to severe SCFE is controversial and varies by center. Well-controlled studies of these patients are needed to understand the best treatment for this difficult problem. Furthermore, increasing the awareness about SCFE is paramount to allow for early recognition and treatment of deformity at its early stages and avoiding severe SCFE deformity which has been associated with worse long-term outcomes.

Keywords Slipped capital femoral epiphysis · SCFE · Femoroacetabular impingement · Modified Dunn · Imhauser osteotomy · In situ pinning · Femoral osteoplasty

Introduction

Slipped capital femoral epiphysis (SCFE) is the most common hip problem in adolescents. It most commonly affects overweight or obese patients and those with endocrine disorders [1, 2]. This is commonly due to excess mechanical stress on the physis from obesity or normal shear stresses on an abnormal physis, due to with metabolic bone disorders which can arise despite a normal or low patient weight [3]. Traumatic fracture through the physis can be a third, but more rare, mechanism of acute unstable SCFE. Independent of the mechanism, SCFE has a potential to be a devastating injury in this young population, given the risk of complications including AVN, hip instability, and chondrolysis.

Classic treatment of SCFE is operative and may include in situ screw fixation, often referred to as 'pinning', of the epiphysis in its existing, displaced position, closed reduction with pinning, and internal fixation [4–6]. Attempts were made historically to treat severe SCFE with closed or open reduction techniques, but many of these techniques were fraught with high rates of AVN and chondrolysis of the epiphysis [7, 8]. The standard of care therefore became in situ pinning of the epiphysis with or without a gentle attempt at partial closed reduction in cases of acute displacement [5]. This reduced the occurrence of catastrophic complications, but often left the patients with femoral deformity leading to femoroacetabular impingement (FAI) [5, 9]. FAI associated with SCFE has been described as 'impaction', when the metaphysis abuts against the acetabular rim, or as 'inclusion',

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✉ James D. Wylie
james.wylie@imail.org

[1] Intermountain Health Care, The Orthopedic Specialty Hospital, Salt Lake City, Murray, UT 84107, USA

[2] Boston Children's Hospital, Boston, MA, USA

when the remodeled metaphysis enters the joint and conflicts with the articular cartilage [10]. Multiple reconstructive procedures have been described for a healed SCFE deformity, from femoral-sided osteoplasty to osteotomies at various sites, from the sub-trochanteric to the sub-capital regions of the femur [11–13]. Outcomes for these reconstructive options have been mixed, and this may be explained by the wide spectrum of joint damage that may be seen at the time of reconstructive surgery [14, 15].

Recent insights in the etiology and pathomechanics of SCFE have highlighted the importance of the epiphyseal tubercle and epiphyseal cupping in capital physeal stability [16, 17]. There has also been an increasing interest in preventing SCFE deformity-induced FAI due to the mixed results with reconstruction and the natural history of osteoarthritis development in patients with SCFE deformity [18, 19]. This paper aims to review current concepts on the presentation and treatment of SCFE. It will emphasize the evolving understanding of etiology of SCFE and the evolving treatment of both SCFE and the resulting deformity from in situ fixation.

Epidemiology

SCFE is the most prevalent hip disorder afflicting adolescents. It affects between approximately 1 and 10 per 100,000 children depending upon racial, seasonal, geographic, and gender variation in populations [2]. Racial differences include higher prevalence rates in blacks, Native Americans, and Hispanics, compared to whites [20]. Seasonal variations include increased incidence in the summer months in areas with seasonal variation [21]. In the USA, there is a higher incidence in the Northeast and West regions of the country as defined by the United States census bureau [20]. There is almost a two-to-one ratio of males affected compared to females. However, there is no gender difference in the incidence of unstable SCFE [2, 20]. Males are commonly affected around age 13 years, while females are commonly affected at a mean age of 11 years [20, 22]. Obesity is a key factor in the development of SCFE, due to its increase in the mechanical stress on the physis. The incidence of SCFE has been increasing in recent decades and this likely is due at least in part to the increasing obesity epidemic that is afflicting our society [23].

Patient Presentation

The importance of recognizing a patient with SCFE in its early stages cannot be over-emphasized. Although patients commonly present with a traumatic groin or thigh pain and limp, patients may have knee pain as the first presentation of SCFE [1]. Others report acute inability to bear weight after a traumatic event, which are commonly acute unstable SCFE cases [24]. Multiple authors have reported a significant delay in diagnosis from the time patients first report symptoms to the time of treatment [25, 26•, 27]. The time from first symptoms to diagnosis has ranged from a mean of 10 weeks for mild SCFE to 20 weeks for severe SCFE [25], which has not changed significantly over time, despite interest in enhancing awareness of the condition [26•]. The hallmark sign on physical examination is lack of internal rotation or obligate external rotation with hip flexion [1]. Given that the severity of the SCFE and the duration of symptoms before treatment have the greatest effect on patient outcome, provider education designed to increase early diagnosis and treatment may be among the most effective measures in improving patient outcomes [27].

Etiology and Classifications

The etiology of SCFE has long been thought to be either a mechanical overload of the normal capital physis or normal loads on a pathologic physis due to an underlying metabolic/endocrine disorder. It commonly affects adolescents due to the rapid skeletal growth, weight gain, and activity levels that stress the physis during this period of development. Obesity is the most common risk factor identified [28]. Patients younger than 10 years of age and older than 16 years of age are more likely to have secondary SCFE from an underlying disorder. In addition, if a patient is between 10 and 16 years of age and has a body mass index below the 50th percentile, then they are likely to have an underlying disorder as an etiologic factor.

Recent studies on the anatomy of the proximal femur and the capital epiphysis have elucidated significant findings related to the pathogenesis of SCFE. Tayton proposed a mechanism for SCFE in which the epiphysis rotates around the epiphyseal tubercle, leading to the deformity seen in SCFE [29]. Since the lateral epiphyseal vessels enter near the tubercle, this rotational mechanism explains why chronic stable SCFE has a low rate of avascular necrosis (AVN) because the rotational motion around the tubercle limits stress on the vasculature. However, when the epiphysis displaces in acute or acute-on-chronic unstable SCFE, so does the tubercle, and this leads to greater risk to the vessels and higher AVN rates. Liu et al. furthered this concept with detailed study of the anatomy of the epiphyseal tubercle [16]. It is located in the posterior superior aspect of the capital epiphysis and is most prominent in younger patients and decreases in size throughout adolescence [16]. They also showed that, throughout this same age range, the proximal femur undergoes epiphyseal cupping [30•]. The combined concept is that as the tubercle decreases in size, the epiphyseal cupping increases the stability of the physis to compensate. A porcine study has validated the tubercle as a key stabilizer of the capital femoral epiphysis

in a large animal model [31]. Patients with robust epiphyseal cupping secondary to physeal stress likely prevent a SCFE from occurring, but instead may end up with a femoral cam deformity [30•]. The timing of the progressive decrease in the size of the tubercle likely explains the age range in which SCFE occurs. To further validate this concept, lucency around the epiphyseal tubercle is an early radiographic sign that may be predictive of subsequent SCFE [32••]. This likely represents increased stress and micro-motion occurring at the tubercle before the epiphysis begins to slip [32••]. Secondary stabilizers of the epiphysis include the physeal cartilage and the perichondral ring around the physis [31]. In the setting of a metabolic or endocrine disorder, these tissues are often weakened, leading to less force needed for a SCFE to occur. Therefore, these clinical syndromes have been associated with SCFE in non-obese patients.

Severity

The Southwick slip angle is the most commonly used measure of SCFE severity. This is defined as the angle between the shaft and a line perpendicular to the epiphysis on the frog lateral hip view. This angle is then subtracted from the contralateral normal hip or, in the setting of bilateral SCFE 10 degrees is subtracted. Slips are characterized as mild (0–30°), moderate (30–60°), or severe (> 60°) [1]. The slip angle has been a strong predictor of patient outcome after SCFE, with more severe SCFE doing worse over time [33].

Stability

The stability of a SCFE can range from an unstable/displaced epiphysis to a completely stable/healed chronic SCFE. Clinically, this has classically been judged by the patient's ability to bear weight, with inability to ambulate without crutches being indicative of an unstable SCFE [34]. With the development of the surgical dislocation approach, this concept has been questioned. Ziebarth et al. investigated physeal stability during surgical dislocation and found that 54% of patients with unstable slips had a stable physis on direct investigation [35]. More importantly, 29% of patients with stables slips clinically had physeal instability on direct examination of the physis [35]. This suggests that many patients with stable SCFE are at risk of acute worsening or an acute-on-chronic SCFE. This makes prompt diagnosis of SCFE paramount to avoiding devastating complications that can be associated with an acute-on-chronic displacement.

History of Treatments of SCFE

Historical treatment of SCFE included spica cast immobilization. This was replaced by in situ pinning to stabilize the physis with either multiple pins or, more recently, one or two cannulated screws, which reduced the rate of complications in comparison to multiple pins, though the procedure continued to be referred to as 'in situ pinning'. While patients have done well with in situ fixation in the short term, long-term studies of in situ fixation show high rates of osteoarthritis development at 10 to 20-year follow-up, affecting patients in their twenties and thirties, especially in cases of severe deformity [18]. Recognition of the SCFE deformity as far back as Whitman in 1909 inspired some surgeons to attempt reduction of the deformity through closed or open means [36]. Closed reduction and internal fixation, similar to an adult femoral neck fracture, were attempted but lost favor, due to an increased risk of AVN. Whitman first proposed a cuneiform osteotomy to correct the deformity acutely with removal of the anterior metaphysis without violation of the posterior cortex [36]. This allowed the epiphysis to be reduced to a more anatomic position on the metaphysis with theoretically a lower risk of AVN. Fish et al. reported excellent results in 40 of 42 patients with a modified cuneiform osteotomy emphasizing the interval removal of bone until the epiphysis could be reduced without tension on the posterior periosteum [37]. However, after adoption of the cuneiform osteotomy, it later fell out of widespread use, also due to high complication and AVN rates [38••]. The Dunn osteotomy was originally described in the 1970s and has since been modified to its current form [38••, 39]. After description of the surgical dislocation approach, the modified Dunn osteotomy was described to reduce the epiphysis in SCFE using the trochanteric flip osteotomy. This technique is technically demanding and only used in selected centers by select individuals to address SCFE due to high complication rates when widely adopted [51].

Natural History of SCFE Hips

There has been relative controversy over the natural history of the SCFE hip. Historical long-term studies have reported good outcomes if complications such as chondrolysis or AVN can be avoided. The classic paper by Carney et al. reported on 155 hips at a mean of 41-year follow-up [7]. They found that 12% developed AVN, 12% developed chondrolysis, and reduction or realignment was detrimental to the natural history of the hip [7]. They also found that more severe SCFE was associated with more degenerative change over-time. Given the worse natural history with intervention, they recommended in situ pinning for the best long-term health of the hip [7]. More recent studies have challenged the favorable natural history of the in situ pinned reported in the study by Carney et al. While in situ pinning does provide early symptom relief and return to function, even in mild cases, a deformity of the proximal femur SCFE leads to mechanical impingement in most patients, which may remain silent (asymptomatic) for several

years, despite causing cartilage deterioration. There have been multiple reports of significant intra-articular damage including labral damage and acetabular cartilage defects in young patients with a healed SCFE deformity even in mild SCFE [14, 15]. Zilkens et al. used delayed gadolinium-enhanced MRI of cartilage to show significant acetabular and femoral cartilage injury in patients in their twenties with a healed SCFE deformity [40]. Castaneda et al. reported a minimum of 20-year follow-up of 121 patients and found that osteoarthritis was found in all hips with moderate osteoarthritis (Tönnis grade 2) in 26% and severe osteoarthritis (Tönnis grade 3) in 62% [18]. Patients with radiographic signs of FAI had lower modified Harris hip scores (mHHS) than those who did not and the degree of deformity was directly related to the degree of osteoarthritis in the patients 30s and 40s [18]. Similarly, Larson reported on 176 SCFE patients with a mean of 16-year follow-up and found that 12% had undergone reconstructive procedures and another 33% had persistently painful hips [41]. Patient-reported outcomes, including the modified Harris hip scores, in patients surveyed approximately 20 years after SCFE have also been found to be considerably lower than in the general population [42•]. Given the fact that SCFE leads to abnormal hip mechanics, cartilage damage associated with impingement, and symptoms of pain and disability in many patients, some surgeons have advocated for reconstructive surgeries early in the disease process that might alter that natural history. There are no current studies showing that intervention changes the process of degenerative change in the post-SCFE deformity. However, a recent study on the 10-year follow-up of the contemporary modified Dunn suggests that deformity correction may have long-term effects of normalizing joint function, pain, and possibly preventing degenerative change [38••].

Healed SCFE Deformity

The deformity from a healed SCFE that was either neglected or pinned in situ generally consists of varying degrees of epiphyseal retroversion, extension, and varus. There is commonly some remodeling of the abnormally oriented proximal femoral metaphysis that happens after in situ fixation of SCFE. Even after remodeling, there is a femoral metaphyseal prominence and a cam deformity that can be severe throughout the anterior (3 o'clock) to lateral (12 o'clock) regions of the femoral head neck junction. FAI from these combined deformities can be exacerbated by the retroverted acetabulum commonly encountered in SCFE patients. The femoral cam deformity leads to 'inclusion' of the deformity into the acetabulum with flexion and internal rotation. In very severe deformity, the metaphyseal prominence is unable to include into the acetabulum and joint injury is more analogous to pincer-FAI mechanics. Patients commonly walk with an external foot progression angle and have a lack of internal rotation or obligate external rotation with hip flexion that is worse with more severe SCFE. At the time of deformity correction surgery, most patients have significant labral and articular cartilage injuries in the acetabulum [14, 15]. In fact, even at the time of in situ pinning of symptomatic SCFE patients, there are reports of acetabular labral and cartilage injuries [43, 44]. This suggests that even early in the process, there are intra-articular injuries that may be predisposing the joint to a degenerative cascade.

Biomechanics

Rab studied the biomechanics of the SCFE deformity [10]. He found that significant alterations in patient motion were needed to compensate for the SCFE deformity. While mild slips are generally well tolerated by patients, his models calculated the need for at least 10° of excess external rotation to avoid metaphyseal impingement in a mild slip [10]. This increased substantially with moderate and severe slips to 30° and 40°, respectively [10]. Sitting was noted to have more anterior metaphyseal impaction on the acetabulum than walking at all degrees of hip severity. He similarly noted that remodeling of the femoral metaphysis would lead to inclusion of the femoral metaphyseal bone into the acetabulum even with mild SCFE, which increased proportionally with increasing slip severity [10]. He proposed the mechanism of acetabular cartilage shearing as a main etiologic factor of joint injury in the SCFE deformity, where the remodeling metaphysis causes the mainly acetabular cartilage injury. Mamisch et al. used computed tomography data on 31 SCFE patients to simulate motion in patients with history of mild to severe SCFE [45]. They confirmed that mild SCFEs underwent inclusion impingement, but as the severity increased, the mechanism of injury switched to that of impaction on the acetabular rim. They also found that the degree of range of motion restriction was proportional to the severity of the SCFE [45].

Treatments

While the treatment of SCFE at the time of presentation will be further discussed below, the current subsection discusses non-acute elective treatment specifically of the resulting SCFE deformity, which follows two principles: (1) addressing the resulting FAI with femoral head/neck osteoplasty and (2) addressing the altered mechanics of the hip by addressing femoral retroversion deformity if it is deemed severe enough to warrant osteotomy [19, 46••]. Before the description of the surgical dislocation approach and the evolution of hip arthroscopy, addressing both of these principles was not regularly performed.

Prior studies consisted of mostly subtrochanteric and intertrochanteric osteotomies. The most commonly performed

of these were those described by Southwick and Imhauser [47, 48]. Reported long-term outcomes of these procedures are favorable, with more than half of patients have good and excellent outcomes at long-term follow-up. The Imhauser osteotomy, consisting of derotation and flexion, has become the osteotomy of choice for the treatment of the deformity over the last few decades. With the increased understanding of the SCFE deformity and FAI, the surgical dislocation approach has been used to address both the metaphyseal prominence through femoral osteoplasty and, when needed, the more complex proximal and rotational femoral deformity via osteotomy [19]. When FAI is encountered from mild slips, hip arthroscopy can effectively address the cam deformity or metaphyseal prominence [49]. However, given the recent evolution of arthroscopic techniques, long-term studies are not available to determine the outcomes of these procedures.

Evolving Treatments for the Moderate to Severe SCFE

While most centers agree that in situ pinning of the epiphysis is the treatment of choice in mild cases, the treatment of moderate to severe cases is much more controversial. Some centers have adopted more aggressive initial treatment protocols that have employed the modified Dunn procedure for acute realignment, while others advocate for gentle partial closed reduction and pinning of the epiphysis.

Those centers advocating for continued partial reduction and in situ pinning of the SCFE point to the AVN rates seen in early reports of the modified Dunn in American centers that ranged close to 30% in initial series [50]. One center illustrated that AVN after modified Dunn for moderate to severe SCFE was surgeon-dependent and therefore should only be attempted if appropriate expertise was available [51]. However, it is important to note that in the acute moderate to severe unstable SCFE, there is a baseline 20 to 50% risk of AVN with closed reduction followed by pinning [34, 52]. A recent study comparing in situ pinning to modified Dunn in these patients showed a comparable AVN rate, but less femoral-sided deformity and better short-term hip function in the patients undergoing modified Dunn [53]. Parsh also recently described an anterior open-reduction technique for the moderate to severe unstable SCFE that had excellent short-term clinical outcomes with low proportion of avascular necrosis and appropriate restoration of femoral anatomy [54]. Schrader described a closed reduction technique assisted by monitor of the blood flow to the femoral head and capsular decompression with promising low proportion of avascular necrosis in a relatively small series [55]. Monitoring blood flow of the femoral head has also been described during unstable SCFE treatment with the modified Dunn procedure with good sensitivity and specificity for predicting AVN [56].

While early studies on the outcome of the modified Dunn mostly came from Switzerland with excellent results [38••, 57], there have been multiple reports over the last few years on outcomes from other centers [53, 58, 59], They have mostly reported favorable outcomes and restoration of more appropriate femoral anatomy [58]. Because of these results from multiple centers, acute realignment of the moderate to severe acute SCFE with contemporary open-reduction techniques is becoming a viable treatment option to restore femoral anatomy where proper expertise is available. However, controversy still surrounds about the indication for surgical treatment of stable SCFE with the modified Dunn procedure. Although a short-term studies have reported better outcomes compared to in situ pinning [53, 58], and the swiss have reported excellent long-term results [38••], multiple studies have reported significant complications of the modified Dunn for SCFE [51, 60, 61]. With the Parsh technique and modified Dunn technique both demonstrating promising outcomes, multi-center prospective comparative outcomes studies are needed to elucidate the optimal approach to moderate to severe SCFE.

Conclusions

Our understanding of SCFE has increased over the last decade. The understanding of the epiphyseal tubercle, epiphyseal cupping, and the rotational mechanism of SCFE displacement has furthered out understanding of SCFE etiology. Advances in our understanding of the pathophysiology of the post-SCFE deformity support the role for realignment for moderate to severe SCFE and in situ fixation for mild SCFE with osteoplasty of the metaphyseal prominence to avoid post-operative impingement. However, further studies are needed to determine the efficacy and safety of the procedure in stable SCFE and to determine whether realignment can effectively reduce the articular cartilage damage and impact the positive long-term survival of hips with severe deformity. Monitoring of the blood flow to the femoral head appears as a key diagnostic tool to minimize AVN rates during treatment of unstable SCFE by open or percutaneous techniques. Beyond the discussion surrounding optimal strategies for management of moderate and severe SCFE deformity is the urgent necessity to increase awareness about SCFE to pediatric caregivers and its potential long-term damage to the hip. Treatment of SCFE is more effective, safe, and successful at its early stages, and early recognition and treatment should be a central focus of future efforts towards decreasing the healthcare burden of SCFE.

Compliance with Ethical Standards

Conflict of Interest James D. Wylie reports research funding from Arthrex, Inc., is an editorial board member for Arthroscopy and a board committee member for AOSSM.

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Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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tubercle was an early sign of subsequent SCFE. Further studies are needed to confirm whether this is an early radiographic sign that is predictive of SCFE.

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