Slipped Capital Femoral Epiphysis: Current Concepts

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Abstract

Slipped capital femoral epiphysis is a common hip disorder in adolescents, with an incidence of 0.2 (Japan) to 10 (United States) per 100,000. The etiology is unknown, but biomechanical and biochemical factors play an important role. Symptoms at presentation include pain in the groin, thigh, or knee. Ambulatory patients also may present with a limp. Nonambulatory patients present with excruciating pain. The slipped capital femoral epiphysis is classified as stable when the patient can walk and unstable when the patient cannot walk, even with the aid of crutches. Because the epiphysis slips posteriorly, it is best seen on lateral radiographs. The treatment of choice for stable slipped capital femoral epiphysis is single-screw fixation in situ. This method has a high probability of long-term success, with minimal risk of complications. In the patient with unstable slipped capital femoral epiphysis, urgent hip joint aspiration followed by closed reduction and single- or double-screw fixation provides the best environment for a satisfactory result, while minimizing the risk of complications.

Slipped capital femoral epiphysis (SCFE) is a common hip disorder in adolescents. SCFE is characterized by posteroinferior displacement of the capital femoral epiphysis on the metaphysis through the physis. This definition is misleading because in fact it is the metaphysis that moves anterosuperior while the epiphysis remains in the acetabulum. The failure develops through the growth plate, creating a three-dimensional deformity, with the distal fragment in varus in the coronal plane, in extension in the sagittal plane, and in external rotation in the axial plane. Occasionally, the metaphysis moves posteroinferior, creating anterosuperior SCFE, known as valgus SCFE.

The typical patient is an overweight adolescent boy who reports pain in the groin, thigh, or knee as well as limping. Physical examination of the hip demonstrates decreased range of motion, particularly internal rotation. The diagnosis is confirmed on the frog-leg lateral pelvis radiograph. SCFE is usually idiopathic, although it also may be seen in patients with endocrine disorders[1] or renal failure,[2] and in patients who have had radiation therapy.

Epidemiology and Demographics

The incidence of SCFE ranges from 0.2 per 100,000 in eastern Japan to as high as 10 per 100,000 in the northeastern United States.[3] Boys account

for 60% of cases.[3] The mean duration of symptoms in patients with stable SCFE is 5 months. The mean age at diagnosis is 13.5 years in boys and 12.0 years in girls; the age at diagnosis decreases with increasing obesity.[3] At least half of adolescents with SCFE are above the 95th percentile in weight for their age. Although there is variability in chronologic age of adolescents with SCFE, the physiologic age range at which SCFE occurs, measured by skeletal age, is narrower.[4] In latitudes north of 40°, the latitude of New York City, SCFE occurs more frequently in the summer and autumn.[5]

The reported incidence of bilateral SCFE depends on the study, method of radiographic measurement, race, and type of treatment. Most series report an incidence of 18% to 50%, but recent studies with long-term follow-ups indicate bilateral involvement in as many as 63% of patients.[6] Treatment method also may affect the incidence of bilateral involvement. In one study, the prevalence of bilateral involvement was 36% in patients treated with in situ pinning and 7% in those treated in a spica cast.[7] In the adolescent with unilateral SCFE, it is important to examine the contralateral hip, especially when treatment of the symptomatic hip is planned, because bilateral in situ fixation may be indicated.

Between 50% and 60% of patients with bilateral SCFE initially present with bilateral involvement.[8] Of those who present with unilateral involvement and later develop contralateral SCFE, most will develop the second slip within 18 months of the first.[8] The age at presentation is younger in children who initially present with unilateral SCFE and later develop bilateral SCFE than in those who do not develop bilateral SCFE.

There are racial differences in the prevalence of SCFE. Compared with 1.0 for Caucasians, the relative racial frequency of SCFE is 4.5 for Pacific Islanders, 2.2 for those of African ancestry, 1.1 for Native Americans and Hispanics, 0.5 for Indonesian-Malay peoples (eg, Chinese, Japanese, Thai, Vietnamese), and 0.1 for Indo-Mediterranean peoples (eg, Near East, North African, Indian subcontinent).[3] These racial differences may reflect the mean body weight for each group, supporting the theory that obesity is the primary factor in the etiology of SCFE.[3]

Classification

The traditional classification of SCFE includes pre-slip, acute slip, chronic slip, and acute-on-chronic slip. This classification system is based on patient history, duration of symptoms, physical examination, and radiographs. In the pre-slip stage, patients report weakness in the lower extremity, limping, or exertional pain in the groin, thigh, or knee. On physical examination, the most consistent finding is decreased internal rotation and guarding of the involved hip. In patients who have been limping or who have limited their activity, anteroposterior (AP) and frog-leg lateral pelvis radiographs may reveal disuse osteoporosis in the ilium and proximal femur. There also may be widening and irregularity of the proximal femoral physis.

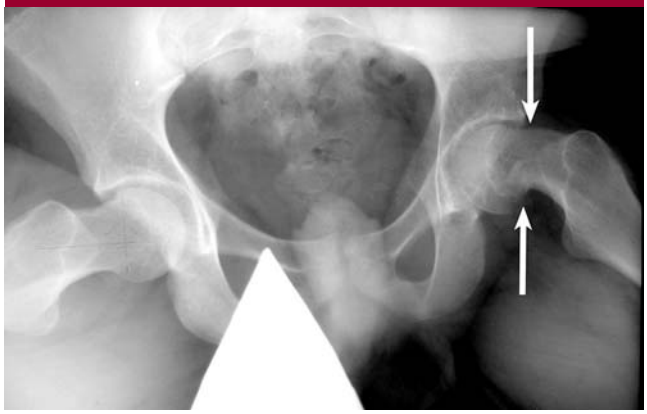
Acute SCFE is an abrupt displacement through the physis, similar to a fracture. Ten percent to 15% of patients with SCFE present with the acute form, which means they have had symptoms for <3 weeks. Physical examination demonstrates external rotational deformity of the lower extremity, with shortening as well as marked limitation of hip motion secondary to pain. A 1- to 3-month history of mild prodromal symptoms, consisting of hip, thigh, or knee pain or a limp, before the acute episode may be elicited in up to 90% of patients with acute SCFE, indicating that a pre-slip or chronic slip may have preceded the acute episode.[9,10] In the patient with acute SCFE, the pain is typically severe enough to prevent weight bearing.

Chronic SCFE is the most common type, accounting for 85% of patients with the condition.[8] The patient with chronic SCFE typically presents with pain in the groin, thigh, or knee and walks with a limp. The duration of symptoms, although variable, lasts >3 weeks. Symptoms often last for several months to years. The patient may have a history of exacerbations and remissions of the pain and limping. Physical examination demonstrates an antalgic gait, with loss of hip internal rotation, abduction, and flexion.[11] In severe cases, limb-length discrepancy with an external rotational deformity of the femur can be detected. With the patient supine, as the hip with the SCFE is flexed, the lower extremity spontaneously externally rotates and abducts. Because knee and/or lower thigh pain is the initial symptom in up to 46% of patients, it is important to perform a hip examination in the adolescent with knee pain.[12]

Acute-on-chronic SCFE occurs when the patient with chronic SCFE develops a sudden acute exacerbation of pain that precludes walking. It is important to distinguish the acute component from the chronic component because attempted reduction of the chronic component may increase the risk of osteonecrosis. We prefer the term osteonecrosis rather than avascular necrosis because, although circulation is compromised, the vessels are still present.

The newer classification is based on physeal stability and the ability of the child to ambulate.[13] With stable SCFE, the child can walk and bear weight, with or without crutches. With unstable SCFE, the child has such severe pain that walking is not possible even with crutches, regardless of the duration of symptoms. The child has excruciating pain and resists any attempt to move the lower extremity. This stability classification is predictive of prognosis. Unstable SCFE may have up to a 50% inci-

Figure 1



Frog-leg lateral pelvis radiograph of a 15-year-old boy who reported left knee pain and a limp of 3 years' duration. Left slipped capital femoral epiphysis (SCFE) with anterosuperior metaphyseal resorption (upper arrow) and posteroinferior subperiosteal new bone formation (lower arrow) are evident, creating a retroversion deformity of the femoral neck.

Figure 2

Anteroposterior pelvis radiograph demonstrating Klein's line intersecting the epiphysis on the right hip. In the left hip, which shows SCFE, Klein's line passes just lateral to the epiphysis.

dence of osteonecrosis compared with nearly 0% in stable SCFE.[13]

Imaging

AP and frog-leg lateral pelvis radiographs demonstrate the posteroinferior displacement of the epiphysis relative to the metaphysis. The early slip, which is typically posterior,[11] is often seen only on the frog-leg lateral pelvis or lateral hip radiograph. In stable SCFE, signs of remodeling are seen, with resorption of the anterosuperior metaphysis and subperiosteal new bone formation developing over the posteroinferior metaphysis, creating a retroversion deformity of the femoral neck (Figure 1). The metaphyseal blanch sign of Steel, seen on the AP pelvis radiograph, is a radiographic double density created by the posteriorly displaced epiphysis overlapping the medial metaphysis. Klein's line, drawn along the anterosuperior aspect of the femoral neck on the AP pelvis radiograph, should intersect the epiphysis. In the patient with SCFE, the epiphysis is flush with or below this line (Figure 2).

The severity of SCFE is measured in two ways. The first method, which measures the displacement of the epiphysis on the metaphysis, is classified based on displacement in relation to the width of the metaphysis: mild (<33%), moderate (33% to 50%), or severe (>50%)[14] (Figure 3). The second classification method measures the epiphyseal-shaft angle on the frog-leg lateral pelvis radiograph. The degree of slip is calculated by subtracting the epiphyseal-shaft angle on the uninvolved side from that on the side with SCFE. In the patient with bilateral SCFE, 12° is the normal value.[15] The degree of slip is classified as mild (<30°), moderate (30° to 50°), or severe (>50°)[16] (Figure 4).

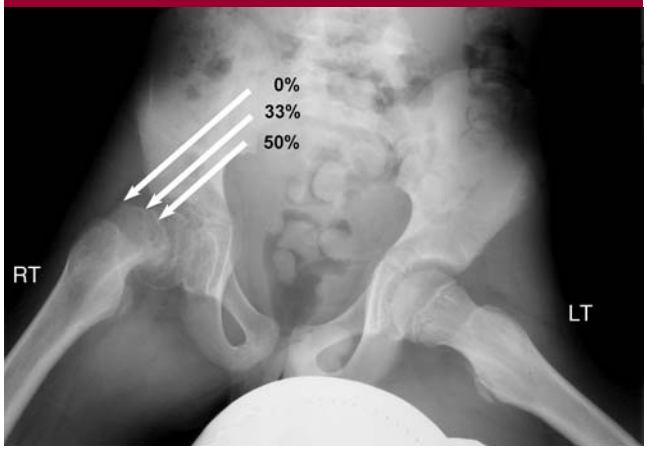
Etiology

The etiology of SCFE includes both biomechanical and biochemical factors that combine to create a weakened physis, with subsequent failure. Mechanical factors, including obesity, femoral retroversion, and increased physeal obliquity, set the stage for developing SCFE.[17] The structural support of the perichondrial fibrocartilaginous complex decreases with age, further increasing the risk of SCFE.

Most children with SCFE are obese, which increases the shear stress across the physis. Obesity is also associated with decreased femoral anteversion. The mean femoral anteversion is 11° in normal-weight adolescents and 0° in obese adolescents. This loss of femoral anteversion (ie, relative femoral retroversion) increases the shear stress across the physis, predisposing these adolescents to SCFE.[17] Patients with SCFE have an 8° to 11° increase in vertical orientation of the physis on the side with SCFE and a 4° to 5° increase on the uninvolved side compared with adolescents without SCFE. The combination of mechanical forces resulting from femoral retroversion and increased physeal slope is enough to cause SCFE.[17]

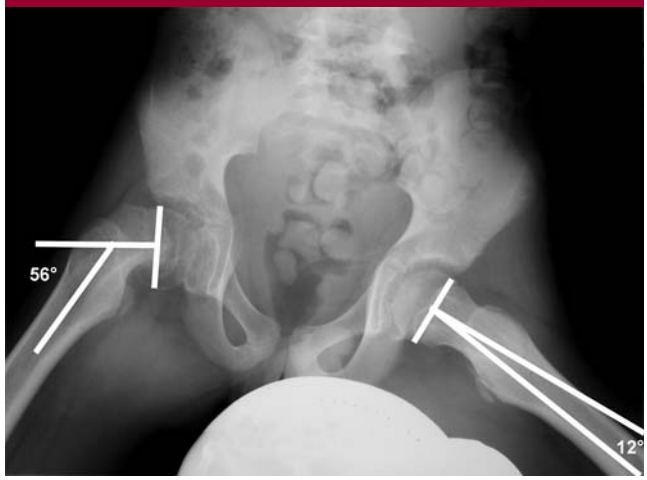
SCFE develops during puberty, a time of many hormonal changes. Rapid longitudinal growth occurs in response to increased levels of growth hormone. This rapid growth is associated with an increased chon-

Figure 3



Frog-leg lateral pelvis radiograph showing moderate SCFE of the right hip and a normal left hip. Classification is based on the percentage of displacement of the epiphysis on the width of the metaphysis (mild, < 33%; moderate, 33% to 50%; severe, >50%).

Figure 4



Frog-leg lateral pelvis radiograph of a patient with a 44° slipped capital femoral epiphysis (moderate), with an epiphyseal-shaft angle of 56° on the right and of 12° on the left (56° – 12° = 44°).

drocyte proliferation rate and increased height of the zone of hypertrophy. This increased height may contribute to the decreased physeal strength seen at puberty.[17] The effects of gonadotropins may explain the male predominance in SCFE; estrogen reduces physeal height and increases physeal strength, whereas testosterone reduces physeal strength. Although most adolescents with SCFE do not have a demonstrable endocrine disorder, a subtle, but yet undiagnosable endocrinopathy may be present. The increased incidence of SCFE in children with hypothyroidism, as well as in children undergoing growth hormone supplementation and in hypogonadal states, suggests an association between SCFE and endocrine dysfunction.

A causal relationship between endocrinopathy and SCFE has been established in cats.[18] Obesity, male sex, castration, and delayed physeal closure have been identified as risk factors for SCFE in cats. Castration decreases both testosterone and estrogen levels, causing delayed physeal closure, which, combined with obesity, predispose these animals to SCFE (Figure 5). Of the 13 cats, age range 4.5 to 24 months, with SCFE evaluated by Craig,[18] 85% were male, 90% were overweight, and 23% were Siamese. The histopathology and demographics were similar to those observed in SCFE in humans.

In patients with SCFE, histology and electron microscopy demonstrate deficiency and abnormality in the supporting collagenous and proteoglycan framework of the physis. There is a decrease in the number of cells relative to the amount of matrix, and the chondrocytes are smaller than in control subjects. There is an increased incidence of chondrocyte degeneration and death in the proliferative and hypertrophic zones. Chondrocyte clustering and disarray of the columns occurs in the zone of hypertrophy. The amount of collagen in the extraterritorial matrix and longitudinal septa is decreased, and most of the collagen consists of haphazardly oriented nonbanded fibrils.[19] Whether these changes represent the cause or effect of SCFE is not known.

Treatment

Most investigators agree that, once SCFE is diagnosed, treatment is indicated to prevent progression of the slip. Because the severity of SCFE is directly related to the duration of symptoms, early treatment is indicated. Long-term follow-up studies after in situ fixation have shown that remodeling occurs and that the loss of internal rotation is not clinically relevant. As a result, most investigators agree that realignment osteotomies are probably not indicated in the initial treatment of mild or moderate SCFE. The goals of initial treatment are to prevent progression while avoiding complications.

Stable Slipped Capital Femoral Epiphysis

Initial Treatment

Initial treatment of the patient with stable SCFE has included single-screw fixation, bone graft epiphysiodesis, in situ fixation with multiple pins, and hip spica cast.

Single-Screw Fixation Single-screw fixation has gradually evolved

Figure 5

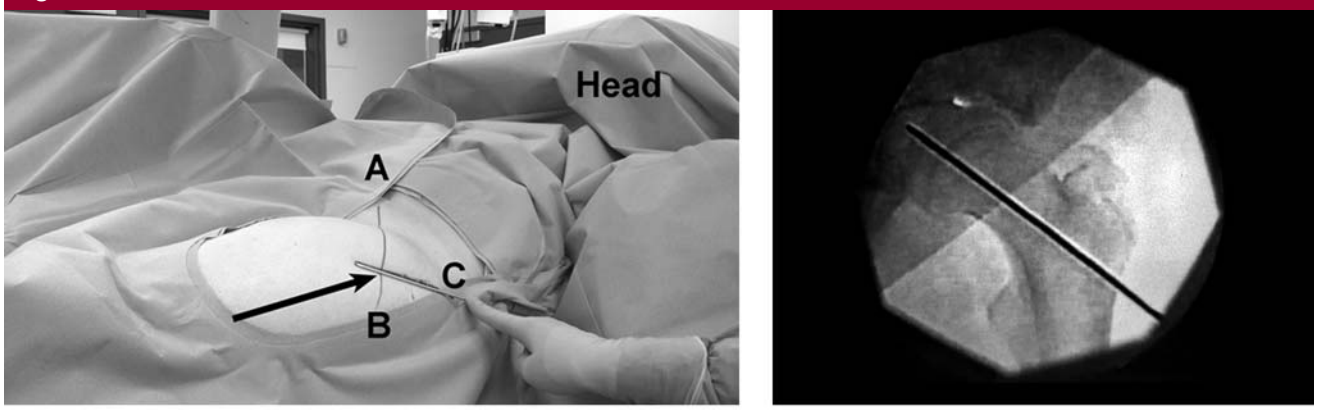
Anteroposterior pelvis radiograph demonstrating slipped capital femoral epiphysis (arrowhead) in an obese cat that had been limping on the left lower extremity.

into the most accepted treatment method for patients with stable SCFE. Advantages of single-screw fixation include percutaneous placement with minimal soft-tissue injury; a high success rate; a high patient satisfaction rate; and a low incidence of slip progression, osteonecrosis, and chondrolysis.[17] In their comparison of single-screw with double-screw fixation in a calf model, Karol et al[20] reported that single-screw fixation was 77% as stable as double-screw fixation. They recommended single-screw fixation because the small gains in stiffness with a second screw did not offset the increased risk of complications.

We prefer using a fracture table for single-screw fixation, but Blasier et al[21] reported less surgical time with similar results by using a radiolucent table instead. The radiolucent table was easier to set up and provided the ability to fully range the hip for screw placement. Mooney et al[22] surveyed the membership of the Pediatric Orthopaedic Society of North America (POSNA); 65.8% of respondents used a fracture table. We prefer to position the patient supine on a fracture table to allow simultaneous biplane AP and lateral fluoroscopic imaging. Because single-screw fixation is image-dependent, excellent visualization of the femoral head and neck is mandatory before beginning the procedure.

Because the procedure is performed through a small incision, it is important to locate the proper starting point. A guide pin is positioned on the skin so it projects over the center of the epiphysis, perpendicular to the physis on the AP image. A line is drawn on the skin along the guide pin. The same procedure is used for the lateral image. A 1-cm incision is made at the intersection of the lines (Figure 6). The guide pin is

Figure 6



A B

A, To locate the starting point for the skin incision in the patient with left-side SCFE, a guide pin is positioned on the skin so that it projects over the center of the epiphysis, perpendicular to the physis, on the anteroposterior image. A line is drawn on the skin along the guide pin with a marking pen (A–B). The same procedure is used for the lateral image (B–C). A 1-cm incision is made at the intersection of the two lines (arrow). **B,** Anteroposterior projection on the image intensifier of the guide pin positioned on the skin over the line connecting A to B in Figure 6, A.

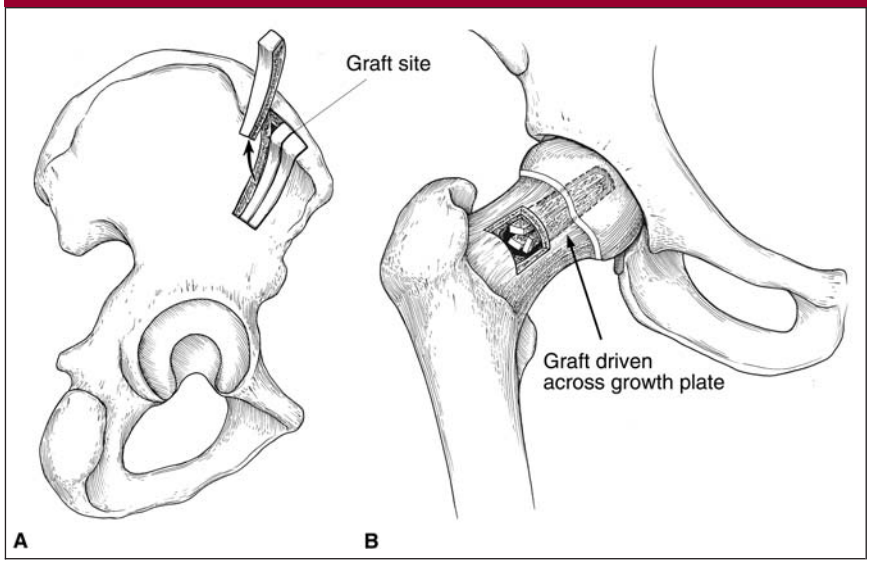
Figure 7

A, Anteroposterior pelvis radiograph of a 13-year-old boy with a stable left SCFE. **B,** Frog-leg lateral pelvis radiograph demonstrating mild SCFE. Postoperative anteroposterior **(C)** and frog-leg lateral pelvis **(D)** radiographs demonstrating satisfactory position of the screw in the center of the femoral head, perpendicular to the growth plate, with 8 to 10 mm of threads (4 to 5 threads) engaging the epiphysis. For ideal screw positioning, the bone is entered on the anterolateral aspect (arrow) of the femoral neck.

advanced freehand to the anterolateral cortex, and the position and angulation are adjusted before drilling into the bone. The ideal position is in the center of the epiphysis, perpendicular to the physis, on the AP and lateral images. If possible, the guide pin should be correctly placed on the first try because multiple drill holes increase the risk of postoperative fracture. The screw length is measured with a depth gauge, and a channel is reamed over the guide pin. A 7.3-mm stainless steel cannulated screw is advanced over the guide pin until 8 to 10 mm of threads (four to five threads) engages the epiphysis (Figure 7). Carney et al[23] reported progression >10° in 9 of 22 hips (41%) when fewer than five threads engaged the epiphysis, and 0% when five or more threads engaged the epiphysis.

The "approach-withdraw phenomenon" indicates the position of the screw tip and helps the surgeon avoid the pitfall of unrecognized screw penetration that is associated with a blind spot that exists with individual views on the image intensifier. As the screw approaches the subchondral bone of the femoral head, the lower extremity is rotated from maximum internal rotation to maximum external rotation while the surgeon observes the image intensifier screen. During the first part of the rotation, the screw tip appears to move closer to the subchondral

Figure 8



The technique for bone graft epiphysiodesis includes **(A)** harvesting bone graft and **(B)** inserting it across the growth plate (epiphysiodesis). (Adapted with permission from Weiner DS, Weiner SD, Melby A: Anterolateral approach to the hip for bone graft epiphysiodesis in the treatment of slipped capital femoral epiphysis. *J Pediatr Orthop* 1988;8:349-352.)

bone (approach), then appears to move away from it (withdraw). The instant of change from approach to withdrawal identifies the view in which the screw tip is shown in its true position.[24] This technique helps avoid unrecognized screw penetration, which causes chondrolysis. The screw should not protrude beyond the lateral cortex, where it can be toggled by the soft tissues, causing pain and screw loosening. In the patient with stable SCFE treated by single-screw fixation, we recommend postoperative partial weight bearing with crutches for 1 to 2 days before advancing to weight bearing as tolerated.

The results of single-screw fixation in SCFE have been gratifying. Aronson and Carlson[25] reported excellent or good results in 36 (95%) of 38 hips with mild SCFE, 10 (91%) of 11 hips with moderate SCFE, and 8 (89%) of 9 hips with severe SCFE. Osteonecrosis developed in one patient with an unstable SCFE; chondrolysis developed in none.

Bone Graft Epiphysiodesis Bone graft epiphysiodesis avoids the complications associated with internal fixation, including unrecognized pin penetration and damage to the lateral epiphyseal vessels. The surgical technique involves an anterolateral approach to the hip; a rectangular window of bone is removed from the anterior femoral neck. A hollow mill creates a cylindrical tunnel across the physis, and multiple corticocancellous strips of iliac crest bone graft are driven across the physis into the epiphysis (Figure 8).

Adamczyk et al[26] retrospectively reviewed data from their 50 years of experience with bone graft epiphysiodesis in 43 patients with 45 cases of unstable SCFE, and in 225 patients with 278 cases of stable SCFE. Slip progression occurred in 6 (13%) of the unstable SCFE cases and in 17 (6%) of the stable SCFE cases. The authors' experience with bone graft epiphysiodesis was positive, with a low rate of osteonecrosis and chondrolysis. However, they noted an unacceptable rate of re-slippage. The authors are considering the use of a fibular allograft for increased stability. Other disadvantages associated with bone graft epiphysiodesis include increased blood loss, a longer duration of anesthesia, and a larger scar.

In Situ Fixation With Multiple Pins The complications associated with in situ fixation with multiple pins have stemmed from a lack of understanding of the three-dimensional anatomy of the SCFE. The pins were often started on the lateral shaft of the femur (similar to the technique for pinning a hip fracture), which caused the pins to enter the epiphysis anterosuperiorly, providing inadequate fixation (Figure 9). Correction was done by angling the pins posteriorly, causing them to exit the neck and enter the posterior epiphysis, thus risking damage to the lateral epiphyseal vessels (Figure 10, A). In situ fixation with multiple pins can also lead to unrecognized pin protrusion, which causes chondrolysis (Figure 10, B).

The lateral epiphyseal vessels provide most of the blood supply to the epiphysis. Brodetti[27] demonstrated that the lateral epiphyseal vessels enter the epiphysis posterosuperiorly and anastomose with the vessels from the round ligament and the posteroinferior epiphyseal vessels at the junction of the medial and central thirds (Figure 11). When multiple pins are placed in the posterosuperior quadrant, the lateral epiphyseal vessels may be damaged. This risk is minimized by placing a single screw in the center of the epiphysis.[25]

The other problem with in situ fixation with multiple pins is that, even with adequate AP and lateral images, there is a blind spot that cannot be visualized. When multiple pins are placed in the periphery of the femoral head, the pins may look well-positioned on the images, yet one pin may have penetrated the femoral head into the joint (Figure 10, A). This unrecognized pin pene-

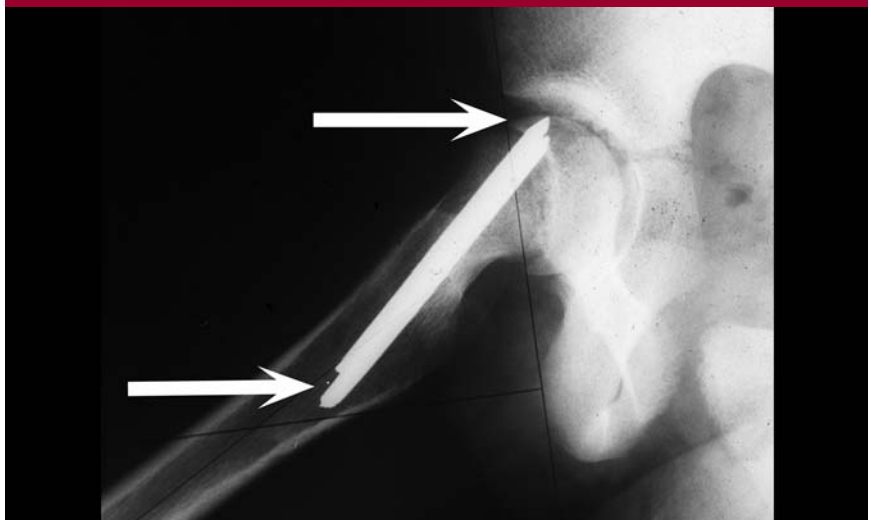
tration may cause chondrolysis (Figure 10, B). We think that the frequency of complications with multiple pins is too high and do not recommend multiple pin fixation for the management of SCFE.

Hip Spica Cast Immobilization in a bilateral hip spica cast avoids the complications associated with a surgical procedure. The prevalence of bilateral SCFE is 20% to 50%; a hip spica cast provides prophylactic treatment of the contralateral hip. Meier et al[28] evaluated 13 patients (17 hips) who were treated in a hip spica cast. SCFE progressed in 3 hips (18%), chondrolysis developed in 9 (53%), and pressure sores developed in 2 (12%). This treatment method is antiquated, and we do not recommend hip spica casting for SCFE.

Late Treatment

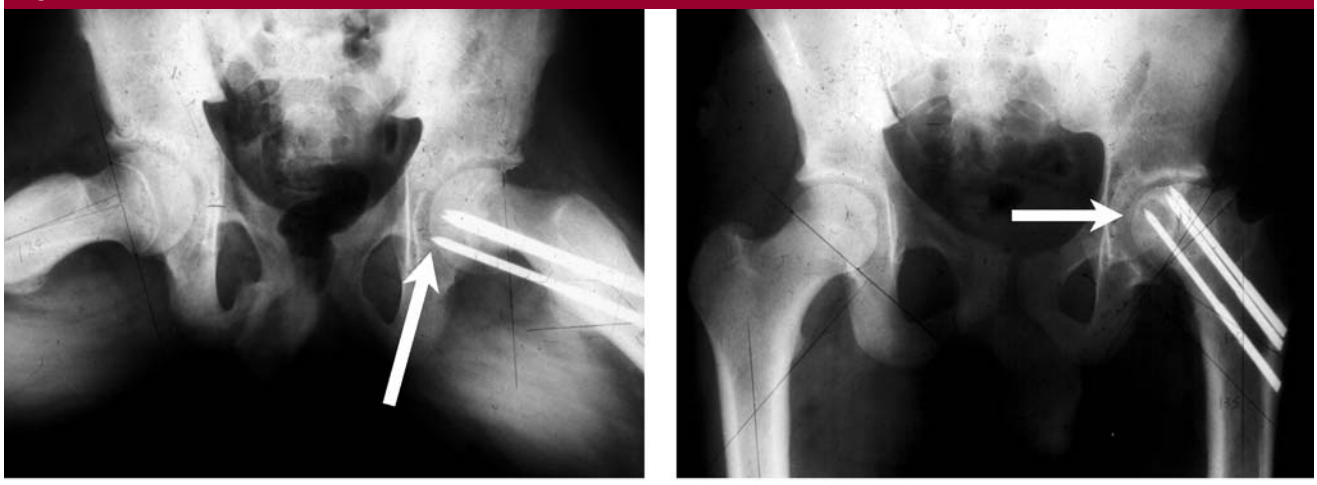
After initial treatment of SCFE, the external rotational deformity of the lower extremity gradually improves as the inflammation resolves and the proximal femoral retroversion deformity remodels. Occasionally, the retroversion deformity may pose problems for the patient and may cause anterior femoroacetabular impingement, which may contribute to the early development of osteoarthritis. The retroversion deformity may be addressed by intertrochanteric osteotomy, cuneiform osteotomy, or open surgical dislocation with femoral neck osteoplasty. Although we do not currently agree, we acknowledge that some orthopaedic surgeons recommend intertrochanteric osteotomy, cuneiform

Figure 9



Lateral radiograph of the right hip demonstrating pins inserted in the lateral shaft (lower arrow), similar to the technique for pinning a hip fracture. The pins entered the anterosuperior epiphysis, providing inadequate fixation (upper arrow). This technique can potentially damage the vascular supply to the epiphysis.

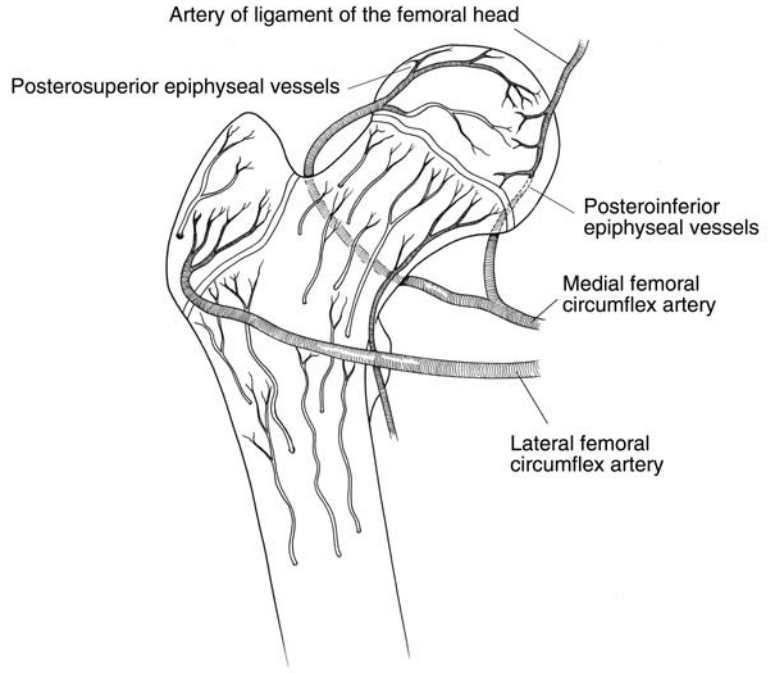
Figure 10



A B

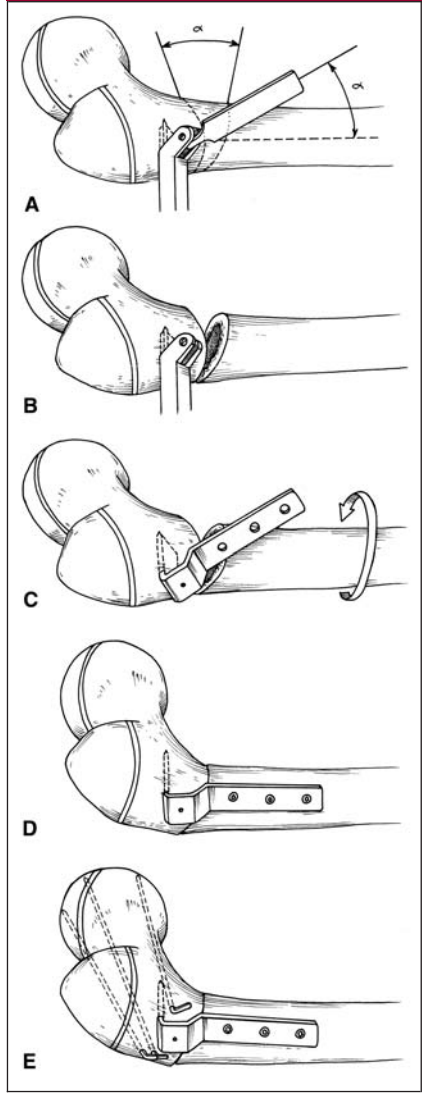
A, Frog-leg lateral pelvis radiograph of a 13-year-old boy who underwent in situ fixation with multiple pins. To prevent anterosuperior placement, the pins were angled posteriorly, exiting the femoral neck and entering the epiphysis, with one pin protruding into the joint (arrow). **B,** Anteroposterior pelvis radiograph 4 years later demonstrating residual chondrolysis with subchondral bone changes.

Figure 11



The most important contribution to the vascular supply of the femoral head is from the posterosuperior lateral epiphyseal vessels that originate from the medial circumflex artery (upper arrow). These lateral epiphyseal vessels anastomose with the vessels from the round ligament and the posteroinferior epiphyseal vessels (lower arrow) at the junction of the medial and central thirds of the femoral head. (Adapted with permission from Loder RT, Aronsson DD, Dobbs MB, Weinstein SL: Slipped capital femoral epiphysis. *Instr Course Lect* 2001;50:555-570.)

Figure 12



Intertrochanteric osteotomy described by Imhäuser, which includes flexion, valgus, and anteversion. **A,** The seating chisel is inserted into the femoral neck at a right angle to the shaft. **B,** The osteotomy removes an anterior-based wedge of bone. **C,** The blade plate is placed, and the distal fragment is internally rotated to correct the femoral retroversion deformity. **D,** The blade plate is fixed to the shaft with screws. **E,** The SCFE is fixed with three smooth Kirschner wires. (Adapted with permission from Müller ME: Intertrochanteric osteotomy: Indication, preoperative planning, technique, in Schatzker J [ed]: *The Intertrochanteric Osteotomy*. Berlin, Germany: Springer, 1984, pp 25-66.)

osteotomy, or open surgical dislocation with repositioning of the epiphysis as the initial treatment of a patient with a severe SCFE or a displaced unstable SCFE.

Intertrochanteric Osteotomy Southwick[16] described an intertrochanteric osteotomy through the lesser trochanter for patients with a 30° to 70° SCFE. The osteotomy was designed to correct the retroversion deformity, improve hip motion and mechanics, and decrease the incidence of degenerative joint disease. Southwick cautioned that correction >60° caused excessive femoral shortening.

Most investigators follow the technique described by Imhäuser, in which the osteotomy creates flexion, abduction, and internal rotation of the distal fragment.[29] The osteotomy is fixed with a blade plate, and the SCFE is fixed with multiple pins (Figure 12). Kartenbender et al[29] evaluated 35 patients (39 hips) at mean follow-up of 23 years after having undergone Imhäuser osteotomy. The average degree of slip was 51°. The authors reported good to excellent results in 77% and fair to poor results in 23% of patients. The radiographs were excellent in 9 hips (23%). They showed early arthritis in 15 hips (38%), moderate arthritis in 10 (26%), and severe arthritis in 5 hips (13%). The authors concluded that the Imhäuser osteotomy is technically demanding and should be considered only in SCFE >40°.

Cuneiform Osteotomy Cuneiform osteotomy is an ideal method for correcting retroversion deformity of the femoral neck. However, the

procedure is recommended only for patients with moderate to severe SCFE (>30°). The surgical technique involves an anterior approach to the hip; an anterior-based wedge of bone is removed from the metaphysis and physis. It is crucial to protect the posterior periosteum in order to protect the lateral epiphyseal vessels. After the wedge of bone is removed, the epiphysis is repositioned and internally fixed with three pins.

Fish[30] performed a cuneiform osteotomy in 61 patients (66 hips); he reported excellent results in 55 hips (83%), good in 6 (9%), fair in 2 (3%), and poor in 3 (5%). Three patients developed osteonecrosis. Velasco et al[31] performed an open reduction in 66 hips and a cuneiform osteotomy in 60 hips. At mean follow-up of 16 years in 66 hips, osteonecrosis had developed in 7 (11%) and chondrolysis in 8 (12%). Degenerative arthritis developed in 19 (40%) of 48 hips that were followed from 10 to 33 years. Because of the high risk of osteonecrosis and relatively poor results, we do not recommend cuneiform osteotomy for the treatment of stable SCFE.

Open Surgical Dislocation With Femoral Neck Osteoplasty The retroversion deformity of the proximal femur created by SCFE is thought to contribute to anterior femoroacetabular impingement by a cam effect that occurs in conjunction with flexion and internal rotation of the hip. The resulting decreased head-neck offset is associated with damage to the cartilage of the femoral head as well as labral tears.[32] Beck et al[33] evaluated 19 patients who had an open surgical dislocation of the hip with removal of any nonspherical portion of the femoral head, thereby improving the femoral neck offset by creating a better waist at the head-neck junction. The osteoplasty recreated the normal concave contour of the femoral neck. At minimum 4-year follow-up, the authors reported substantial improvement in symptoms in 13 hips; 2 remained unchanged and 4 deteriorated. No osteonecrosis of the femoral head was evident. The preliminary results of this procedure are encouraging, but it is technically demanding, and we believe it should be restricted to a few centers until more experience is gained.

Unstable Slipped Capital Femoral Epiphysis

Management of unstable SCFE is similar to that of stable SCFE, but it is more controversial. There is debate concerning emergent or urgent reduction versus elective reduction, incidental reduction (improvement in the SCFE by positioning the patient on the operating table) versus complete reduction, urgent decompression of the hematoma versus no decompression, and single- versus double-screw fixation. What is not controversial is that the risk of complications, particularly osteonecrosis, is much higher in patients with unstable SCFE.

Mooney et al[22] surveyed the membership of POSNA regarding the timing of treatment of unstable SCFE. Fifty-seven percent of respondents favored urgent (<8 hrs), 31% favored emergent, and 12% favored elective treatment. Incidental reduction was favored by 84% of respondents, while 11.8% favored a formal (complete) manipulative reduction. Capsular decompression of the hematoma was not recommended by 64.6% of respondents; 35.4% performed decompression as part of the management of unstable SFCE. Twenty-six percent of those recommending decompression performed it as an open procedure, while 73.4% used a closed aspiration and drainage technique. Single-screw fixation was used by 57.4% of respondents, while 40.3% reported using double-screw fixation.

Peterson et al[34] evaluated 91 patients with unstable SCFE at mean follow-up of 44 months. Of the 42 patients who had closed reduction within 24 hours of presentation, osteonecrosis developed in 3 (7%). Of the 49 patients who had closed reduction more than 24 hours after presentation, osteonecrosis developed in 10 (20%). The authors hypothesized that acute displacement of the epiphysis may kink the posterior femoral neck vessels, thereby compromising the vascular supply. These results support performing urgent formal (complete) manipulative reduction without preoperative traction.

Beck et al[35] evaluated the effects of increased intra-articular pressure on blood flow to the femoral head. In 11 patients undergoing surgical dislocation for the treatment of femoroacetabular impingement, the authors injected saline into the intact intracapsular space while monitoring the blood flow to the femoral head with laser Doppler flowmetry. After an average intracapsular saline injection of 20 mL, there was loss of the pulsatile signal, with an average intra-articular pressure of 58 mm Hg. Aspiration of the joint caused a return of the pulsatile flow. These results support performing urgent decompression of the intracapsular hematoma to optimize blood flow to the femoral head.

Kibiloski et al[36] studied the effects of physiologic shear loading, simulating slow walking and fast walking, in an unstable SCFE bovine model. After creating bilateral unstable SCFE, the authors performed a closed reduction and internal fixation on one side with a single screw; on the other side, they used double-screw fixation. The specimens were subjected to shear loading of 400 N to simulate slow walking and 900 N to simulate fast walking. The rates of creep were larger for the single-screw fixation group, particularly with fast walking, but the results were not statistically significant. The authors concluded that regardless whether one or two screws are used, protected weight bearing is advisable early in the postoperative period.

Figure 13

Frog-leg lateral pelvis radiograph demonstrating collapse of the femoral head (arrow) with osteonecrosis in a 12-year-old girl who was treated with three cannulated screws for unstable SCFE. Two months postoperatively, she developed osteonecrosis, so two screws were removed.

In unstable SCFE, we recommend urgent hip joint aspiration to remove the hematoma, followed by closed reduction and single-screw fixation using the technique described above. One screw may not provide rigid fixation, and two screws may increase the risk of osteonecrosis and chondrolysis. In either case, non–weight bearing on the affected limb with crutches for 6 to 8 weeks is recommended to prevent progression.

Prophylactic Fixation of the Contralateral Hip

The risk of contralateral SCFE developing in a patient with unilateral SCFE is reported to be 2,335 times higher than the risk of initial SCFE.[37] Schultz et al[37] developed a decision analysis model with probabilities for the occurrence of contralateral SCFE. They concluded that prophylactic fixation of the contralateral hip was beneficial to the long-term outcome of that hip. The authors advise using sound clinical judgment with respect to patient age, sex, and endocrine status, as well as considering the preferences of the patient and family, before recommending prophylactic fixation of the contralateral hip.

In their study of 50 children with unilateral SCFE, Stasikelis et al[38] compared a modified Oxford hip score (to assess bone age) with the subsequent development of contralateral SCFE. The prevalence of contralateral SCFE was 85% in hips that were assigned a score of 16 points, and 11% in hips with a score of 21. Contralateral SCFE did not develop with a score ≥22. Despite evidence that prophylactic fixation may be beneficial, only 12.2% of respondents in the POSNA membership survey favored prophylactic fixation of the opposite side.[22]

Complications

Osteonecrosis

Osteonecrosis is a devastating postoperative complication (Figure 13). Factors associated with osteonecrosis include unstable SCFE, overreduction of unstable SCFE, attempted reduction of stable SCFE, placement of pins in the posterosuperior quadrant of the epiphysis, and cuneiform osteotomy. The patient with osteonecrosis typically reports pain in the groin, thigh, and/or knee. On physical examination, there is loss of hip motion, particularly internal rotation, and the hip is irritable. Early radiographs are unremarkable, but collapse of the epiphysis with cyst formation and sclerosis develop after a few months. Tokmakova et al[39] reported that osteonecrosis developed in 21 (58%) of 36 hips in patients with unstable SCFE, and in none of the 204 hips in patients with stable SCFE. They concluded that osteonecrosis was associated with unstable SCFE, severe displacement, and increased number of pins.

If the etiology of osteonecrosis were secondary to acute disruption of the vessels, immediate microvascular repair might be beneficial. If the etiology were secondary to tamponade from an intracapsular hematoma, immediate hip aspiration or decompression should be beneficial. In a goat model, Svalastoga et al[40] reported that an effusion with a tamponade of 75 mm Hg caused the oxygen tension in the femoral head to drop from 48 to 29 mm Hg. If the etiology were secondary to kinking of the vessels, urgent closed reduction might be beneficial. Maeda et al[41] performed angiograms of the medial circumflex femoral artery and reported filling of the lateral epiphyseal vessels in all seven patients with stable SCFE and in two of five patients with unstable SCFE. In one patient with an unstable SCFE with no filling, a repeat angiogram after closed reduction showed filling of the lateral epiphyseal vessels, suggesting that they were kinked or in spasm from the SCFE.

Management of osteonecrosis includes non–weight bearing with crutches, range-of-motion exercises, and anti-inflammatory medication. An internal fixation device that protrudes into the joint should be repositioned in the epiphysis if the physis is open, or removed if the physis is closed. Krahn et al[42] evaluated 22 patients with osteonecrosis after a

mean follow-up of 31 years. Nine patients (41%) had reconstructive surgery—four during adolescence and five during adulthood. The remaining 13 patients were managed nonsurgically, but all had radiographic degenerative changes.

Chondrolysis

Chondrolysis may be present when the patient initially presents for evaluation. However, in most patients with SCFE, the etiology of chondrolysis is secondary to unrecognized pin penetration of the femoral head at the time of surgery (Figure 10). In cases without pin penetration, an autoimmune phenomenon or some factor interfering with cartilage nutrition may contribute to chondrolysis. Factors associated with chondrolysis include unrecognized pin penetration, treatment in a hip spica cast, intertrochanteric osteotomy, and advanced SCFE.

The incidence of chondrolysis in patients with SCFE ranges from 1.8% to 55%, with an overall incidence of 7%, depending on the series.[43] The patient typically reports pain in the groin, thigh, or knee, and on physical examination has decreased hip range of motion, particularly internal rotation. The diagnosis is confirmed by radiographs demonstrating a joint space reduction >50% on the uninvolved side or, with bilateral involvement, a joint space <3 mm. The frequency of chondrolysis can be reduced by using single-screw fixation, which decreases the risk of unrecognized pin penetration.

Patients who develop chondrolysis have a better long-term prognosis than do those who develop osteonecrosis. Tudisco et al[44] evaluated nine patients with chondrolysis at mean follow-up of 14 years. The patients noted gradual regression of hip pain, while radiographs demonstrated restoration of the joint space at a mean of 10 months. At follow-up, five patients had mild pain after prolonged activity, and all nine had partial limitation of abduction and internal rotation.

Natural History Without Treatment

Risk of Progression

The natural history of SCFE is unpredictable, and the risk of progression is difficult to determine. Ordeberg et al[45] evaluated a series of patients 20 to 60 years after diagnosis. Few patients had restrictions in working capacity or social life. There was, however, a risk of progression as long as the physis remained open. Carney et al[46] reported on 36 hips that had symptomatic treatment (bed rest, crutches, or no treatment). Additional displacement developed in six hips (17%) after the initial diagnosis. In five of these six hips, the SCFE became severe. Eleven hips had an acute-on-chronic SCFE; all progressed to severe displacement requiring surgical stabilization.

Risk of Degenerative Joint Disease

The severity of untreated SCFE correlates with the long-term prognosis for degenerative joint disease. Oram[47] reported on 11 patients who were observed for more than 15 years. The hips with moderate SCFE retained good function for years, whereas those with severe SCFE developed degenerative joint disease with poor function. Several studies have shown that patients do well early on, but with time, symptoms increase and function decreases. Carney and Weinstein[48] studied the natural history of untreated stable SCFE in 28 patients (31 hips). Patient mean age was 54 years and mean follow-up, 41 years. The mean Iowa hip rating was 92 for mild (17 hips), 87 for moderate (11 hips), and 75 for severe (3 hips) SCFE. All 17 of the hips with mild SCFE had an Iowa hip rating >80, whereas only 9 (64%) of 14 hips with moderate or severe SCFE had similar ratings. Five (36%) of 14 hips with mild SCFE had no degenerative changes, whereas 13 hips (100%) with moderate or severe SCFE had degenerative joint disease. The authors concluded that the natural history of stable SCFE is favorable provided the displacement is minimal and remains so.

Long-Term Results of Treatment

Wilson et al[49] reviewed 240 patients (300 hips) treated between 1936 and 1960. In situ pinning was performed in 187 hips, with good clinical results in 170 hips (91%) and good radiographic results in 163 hips (87%). Attempted correction of the deformity and fixation was performed in 76 hips, with good clinical results in 47 (62%) and good radiographic results in 42 hips (55%). In reports evaluating the long-term outcome of patients with SCFE,[48,49] the best results were seen after in situ fixation, whereas the worst results were seen after realignment by manipulation or osteotomy.

Carney et al[46] evaluated 124 patients (155 hips) followed for a mean of 41 years. The results were analyzed with the Iowa hip rating system as well as a radiographic classification of degenerative joint disease, ranging from grade 0 (no degenerative changes) to grade 3 (severe degenerative joint disease). Thirty-six (25%) of 142 stable SCFE had symptomatic treatment, 43 (30%) had a spica cast, 34 (24%) had in situ pinning, and 29 hips (20%) had an osteotomy. The frequency of osteonecrosis and chondrolysis increased with increasing severity of the SCFE. In 116 hips, no reduction was performed, and the results demonstrated a mean Iowa hip rating of 85 and a mean radiographic grade of 1.7. Osteonecrosis developed in 7 hips (6%) and chondrolysis, in 14 (12%). In 39 hips, a reduction was performed, and the results demonstrated a mean Iowa hip rating of 72 and a mean ra-

diographic grade of 2.4. Osteonecrosis developed in 12 hips (31%) and chondrolysis, in 11 (28%). Twenty-seven hips with a stable SCFE had in situ pinning. At the most recent follow-up, the mean Iowa hip rating was 90 and the mean radiographic grade was 1.5. Osteonecrosis developed in one hip (4%), and chondrolysis developed in none. The long-term results of this study support in situ fixation as the treatment of choice for SCFE.

In most patients with mild or moderate SCFE in whom osteonecrosis and chondrolysis do not develop, the long-term results of in situ fixation are good to excellent. Patients with severe SCFE and those with osteonecrosis undergo early deterioration with degenerative changes. The osteonecrosis that develops in patients with SCFE differs from other pediatric hip disorders because SCFE occurs at an age when the majority of acetabular development is complete; thus, minimal adaptation to a deformity of the femoral head is possible.

Summary

SCFE is a common hip disorder in adolescents, with an incidence of 0.2 to 10 per 100,000. Bilateral SCFE develops in 20% to 50% of patients. The etiology is unknown, but biomechanical factors that play a significant role include obesity, femoral retroversion, and increased physeal obliquity. It appears that biochemical factors also play a role because SCFE develops during puberty, a period of decreased physeal strength. SCFE is defined as stable when the patient can walk, with or without crutches. Patients with stable SCFE present with pain in the groin, thigh, or knee, as well as with a limp. Unstable SCFE renders the patient unable to walk, with or without crutches, and causes excruciating pain. SCFE is best seen on the frog-leg lateral pelvis radiograph or lateral hip radiograph.

The current treatment of choice for stable SCFE is single-screw fixation in situ. This method has a high probability of success, with minimal risk of osteonecrosis or chondrolysis. When the patient is a girl <11 years of age or a boy <12.5 years of age, or when the patient also presents with an endocrinopathy, prophylactic fixation of the contralateral hip may be beneficial and deserves consideration after discussion of the preferences of the patient and family. After the operation, partial weight bearing with crutches is recommended for several days before advancing to weight bearing as tolerated.

In unstable SCFE, immediate or urgent hip joint aspiration followed by closed reduction and single-screw fixation provides the best chance of a satisfactory result and minimizes the risk of osteonecrosis and chondrolysis. Single-screw fixation does not always provide rigid immobilization. Double-screw fixation, however, increases the risk of osteonecrosis and chondrolysis. Non–weight bearing with crutches for 6 to 8 weeks is recommended to minimize the risk of progression and the loss of reduction in the unstable SCFE.

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Citation numbers printed in **bold type** indicate references published within the past 5 years.

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