Pediatr Radiol (2013) 43 (Suppl 1):S71–S82
DOI 10.1007/s00247-012-2577-x

Imaging SCFE: diagnosis, treatment and complications

Delma Y. Jarrett · Travis Matheney ·
Paul K. Kleinman

Received: 26 August 2012 / Revised: 3 October 2012 / Accepted: 11 November 2012

Abstract Slipped capital femoral epiphysis (SCFE) is a common orthopedic disorder in children. It can lead to avascular necrosis, cartilage loss, femoroacetabular impingent (FAI) and early osteoarthritis. The consequences of SCFE are worsened by delays in diagnosis and proper management. Radiography is the primary imaging modality used to evaluate SCFE; however, MR, CT and bone scintigraphy have important roles. Preoperatively, these modalities assist in surgical planning and predicting prognosis; postoperatively, they provide assessment of hardware failure, ischemic necrosis and morphology predisposing to FAI. Emphasizing a multimodality approach, this review addresses the imaging diagnosis of SCFE, the expected postoperative appearances and the findings of immediate and long-term complications.

Keywords SCFE · Complications · Avascular necrosis · Cartilage

Introduction

Slipped capital femoral epiphysis (SCFE) is a common disorder in children, with displacement of the femoral head epiphysis in relation to the metaphysis. It can lead to limitation of function of the hip, early osteoarthritis and avascular necrosis (AVN). Although it is crucial to recognize the radiologic signs of SCFE on initial presentation, it is also important to be familiar with the postoperative imaging findings and potential complications.

D. Y. Jarrett (✉) · P. K. Kleinman
Department of Radiology, Boston Children's Hospital,
Harvard Medical School, 300 Longwood Ave.,
Boston, MA 02115, USA
e-mail: delma.jarrett@childrens.harvard.edu

T. Matheney
Department of Orthopedic Surgery, Boston Children's Hospital,
Harvard Medical School, 300 Longwood Ave.,
Boston, MA 02115, USA

Diagnosis

Radiography

Radiographs are the primary modality used in the diagnosis of SCFE. AP and frog lateral views of both hips should be obtained. This is important because a significant percentage of SCFE is bilateral, with the exact number unknown, ranging from 18% to 63% in studies [1]. In addition, comparison with an asymptomatic hip can be helpful to diagnose more subtle cases of SCFE.

Klein's line—uses and limitations

In the vast majority of cases of SCFE, the epiphysis is displaced posteriorly in relation to the metaphysis, with variable degrees of medial displacement. On frontal radiographs of the hip, the femoral head normally extends past the lateral margin of the femoral neck. A line drawn along the margin of the superior femoral neck and extended to the level of the epiphysis (Klein's line) transects a portion of the femoral head. If there is medial slip of the femoral head, the line does not intersect it [2]. However, Green et al. [3] noted that in mild cases of SCFE the slipped femoral head still intersects Klein's line. They suggested a modification, where a slip is diagnosed if the maximum width of epiphysis lateral to Klein's line differs by more than 2 mm from that of the control hip, raising sensitivity from 40.3% to 79% (Fig. 1) and demonstrating the importance of an AP radiograph of the pelvis and both hips in the diagnosis of SCFE.

Assessing posterior slip

Often the hip is positioned in external rotation and the posterior displacement then becomes more evident on the frontal projection. However, the extent of posterior slip is

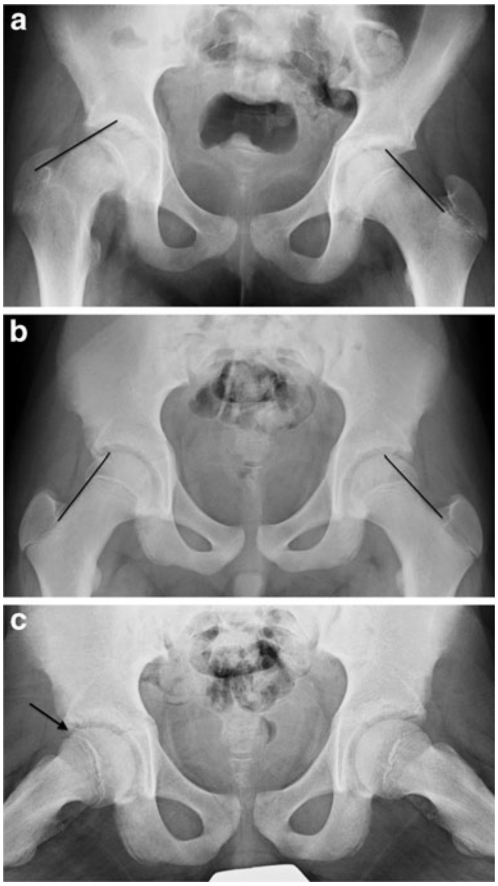


Fig. 1 Klein's line. **a** Frontal pelvic radiograph in a 13-year-old girl with severe right SCFE. Klein's line intersects the femoral head epiphysis on the normal left side but not on the right, consistent with medial slip of the right epiphysis. **b** Frontal pelvic radiograph in a 13-year-old boy with mild right SCFE. Klein's line intersects the femoral head epiphyses bilaterally; however, less of the epiphysis is seen lateral to Klein's line on the right, consistent with medial slip. **c** Frog lateral view of the hips in the same boy confirms the diagnosis, with very mild posterior displacement of the right femoral head relative to the metaphysis (*arrow*). Physeal widening is also more conspicuous on the frog lateral view

usually assessed on the frog lateral view, which is more sensitive in the detection of SCFE. Some advocate the use of a true lateral view, with its increased sensitivity to detect abnormal head shaft angle and potential decreased risk of further displacement of the epiphysis compared to frog positioning [4, 5].

Subtle signs on frontal radiographs

An appreciation of the subtleties of SCFE on the frontal radiograph is crucial because frog lateral views might not be obtained when SCFE is unsuspected clinically. The subtle signs should prompt a request for a frog lateral view. These include widening of the physis compared to the contralateral side, relative loss of height of the epiphysis on the affected sign, and the "metaphyseal blanch sign" described by Steel [6], which results from the posterior margin of the posteriorly slipped femoral head overlapping with the metaphysis (Fig. 2).

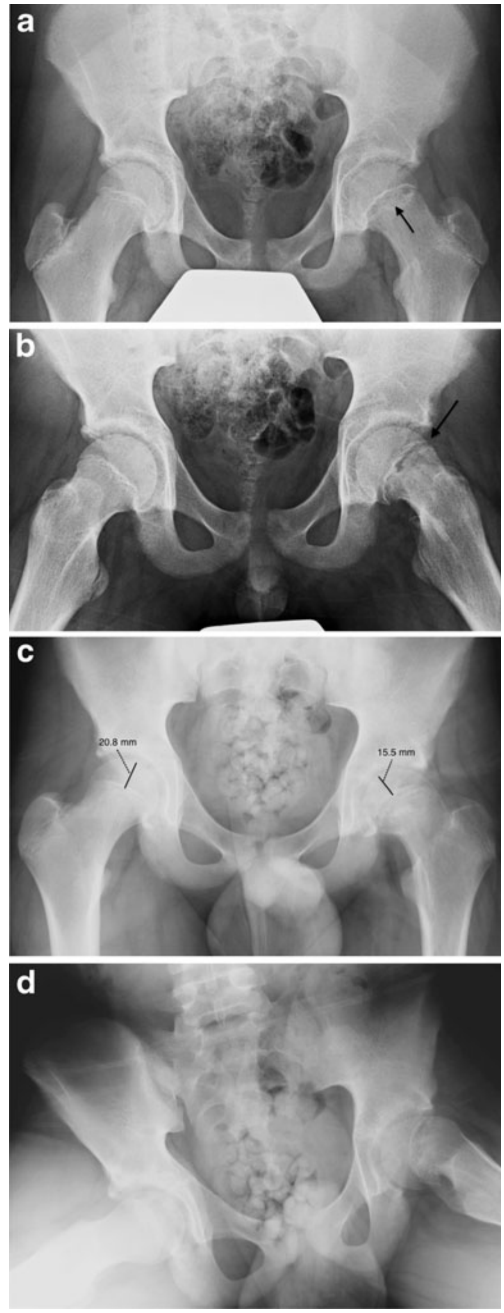


Fig. 2 Additional signs of SCFE on frontal radiographs. **a** Frontal pelvic radiograph in a 14-year-old boy with left SCFE. In addition to mild medial displacement of the epiphysis, there is physeal widening and a crescent-shape density projecting over the metaphysis (*arrow*) caused by superimposition of the displaced posterior portion of the femoral head (metaphyseal blanch sign). **b** Frog lateral view confirms diagnosis, demonstrating mild posterior slip of the femoral head. **c** Frontal pelvic radiograph in another 14-year-old boy with left SCFE shows apparent decrease in the height of the epiphysis on the left compared to the right. **d** Frog lateral view verifies the presence of posterior slip of the left femoral head

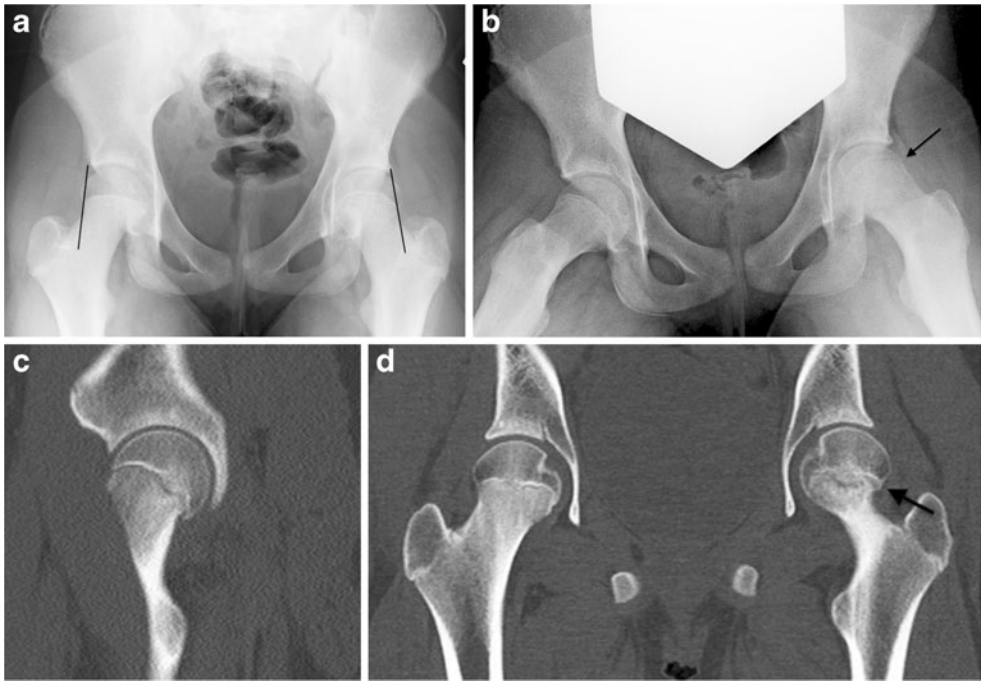


Fig. 3 Valgus slip in a 12-year-old girl with a 2-year history of left hip pain, acutely worse at presentation. **a** Frontal radiograph of the pelvis demonstrates apparent loss of height of the left femoral head epiphysis compared to the right, consistent with posterior slip. However, there is increased lateral extension of the left femoral head epiphysis past Klein's line compared to the right. **b** Frog lateral view of the hips demonstrates posterior slip of the left femoral head epiphysis but also suggests mild lateral displacement of the epiphysis relative to the physis (*arrow*). **c** Sagittal image from CT performed the same day demonstrates the predominantly posterior component to the slip. However, the coronal CT image (**d**) shows that there is mild lateral displacement of the left femoral head epiphysis as well (*arrow*)

Valgus slip

Rarely in SCFE, the femoral head is displaced superolaterally and posteriorly in relation to the metaphysis. This is referred to as valgus SCFE [7]. It is usually seen in children with coxa valga, possibly because the more horizontal orientation of the physis in these children predisposes them to a lateral slip [7, 8]. It is important to be aware of this entity, because in these cases the epiphysis continues to intersect Klein's line. In fact, a larger percentage of the epiphyseal head is lateral to Klein's line than on the normal side; however, the lateral view demonstrates the posterior component of the slip (Fig. 3) [7].

MRI

MRI is useful in early cases of SCFE, before the displacement of the femoral head relative to the metaphysis is evident radiographically, referred to as "pre-slip SCFE." MR findings include widening of the physis with bone marrow edema of the metaphysis, joint effusion and synovitis (Fig. 4) [9–11]. MR is also useful in cases of more

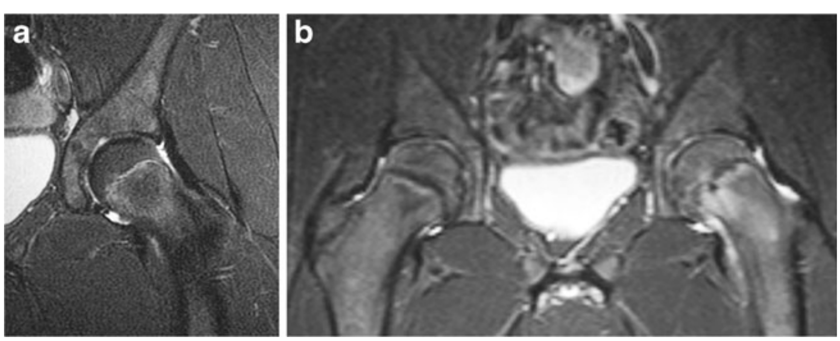


Fig. 4 MR findings of SCFE. **a** Coronal STIR MR image of the left hip in a 13-year-old girl with a history of right SCFE and new left hip pain. The left hip appeared normal on radiographs; however, MR shows increased signal in the juxtaphyseal metaphysis, consistent with edema and suggesting a pre-slip of the capital femoral epiphysis. **b** Coronal T2-W fat-saturated MR image of a 14-year-old boy with left SCFE (same as first child in Fig. 2) shows physeal widening and irregularity, metaphyseal bone marrow edema and joint effusion

severe SCFE, where accurate understanding of the geometry of the slip is necessary to determine patient management because the MR appearance is less dependent on specific patient positioning than radiography [11].

CT

The use of CT in the diagnosis of SCFE is limited, but 3-D models can be a valuable tool in presurgical planning in cases of severe slip [11, 12], as well as in postoperative assessment in complicated cases. For CT as well as MRI, reformats should be generated in appropriate planes to fully characterize the anatomical alterations. An axial/sagittal oblique plane, parallel to the long axis of the femoral neck as seen on coronal images, is most helpful in defining the extent of posterior slip.

US

Sagittal US imaging can demonstrate a step off between the epiphysis and metaphysis, related to the posterior slip of SCFE; however, it has been found to be no better than the frog lateral view assessment. Also, a joint effusion can be seen in acute/unstable cases of SCFE [13, 14].

Categorization of SCFE

The categorization considered most important is whether the SCFE is stable or unstable, and this is determined clinically by the child's ability to bear weight. Unstable SCFE has a much higher risk of developing AVN [15].

Imaging studies help to characterize SCFE, either by the severity of the slip or the chronicity. The severity can be described by the degree of displacement of the femoral head. The Southwick angle measures posterior angulation of the head with respect to the neck and permits comparison between the symptomatic and asymptomatic sides (Fig. 5) [16]. In cases of bilateral SCFE, 12° is used as the normal angle for comparison. Slipped epiphyses can then be divided into three grades based on the slip angle: grade 1/mild (0–30°), grade 2/moderate (30–50°) and grade 3/severe (greater than 50°) [17].

Fig. 5 Southwick angle in a 13-year-old girl with severe stable SCFE on the right (same girl as in Fig. 1). Posterior slip of the femoral head can be quantified on the frog lateral view by connecting the anterior and posterior physeal margins of the epiphysis (*solid line*), drawing a line perpendicular to the epiphyseal line (*dashed line*) and measuring the angle between the perpendicular and the long axis of the femoral shaft (*double line*). The difference in the angle between the side with the SCFE (68°) and the normal side (20°) is the Southwick angle (48°)

SCFE can also be classified as acute, with less than 3 weeks since onset of symptoms, or chronic. When children present with acute symptoms superimposed on a longer history of hip pain, SCFE is classified as acute on chronic. As with stability, this is a clinical assessment; however, radiologic findings seen in chronic SCFE include sclerosis and irregularity at the physis and remodeling of the metaphysis [18]. It is thought that in chronic SCFE, the slow slip of the femoral head gives the vasculature time to adapt and maintain blood supply [19], with a lower risk of AVN compared to acute cases [5].

Surgical management: postoperative appearance and complications

Factors that determine the surgical management of SCFE include the severity and stability of the slip. Some advocate that all mild to moderate cases of SCFE be pinned in situ, with attempts at reduction being limited to unstable severe slips. Others are willing to attempt reduction on unstable SCFEs of all grades, performing gentle reduction in the operating room or closed reduction with 1–2 weeks of continuous traction, before going on to pin or wire fixation (Fig. 6) [20]. Unstable SCFEs might be reduced unintentionally with the induction of anesthesia and positioning the child on the operating table [15].

Gentle manipulation at the physis is not possible with stable SCFE, and these children are either pinned in situ in mild to moderate cases, or in severe slips undergo osteotomy to improve alignment of the femoral head and to try to prevent early osteoarthritis.

Pin fixation

Fixation of the femoral head can be performed with a screw, which is thought to provide superior stability [21], or with a wire, which can lead to less growth restriction of the physis [22]. The contralateral hip can be pinned prophylactically. The indications for this include pain on the contralateral side, SCFE in a child younger than 10, history of endocrinopathy and high risk of inadequate follow-up.

Postoperative radiographs should be assessed for the position of the screw, ideally situated perpendicular to the physis and in the center of the femoral head. One potential complication is encroachment of the screw tip into the joint. Determining the position of the screw tip can be challenging [23]. Radiographs overestimate the distance between the screw tip and the subchondral

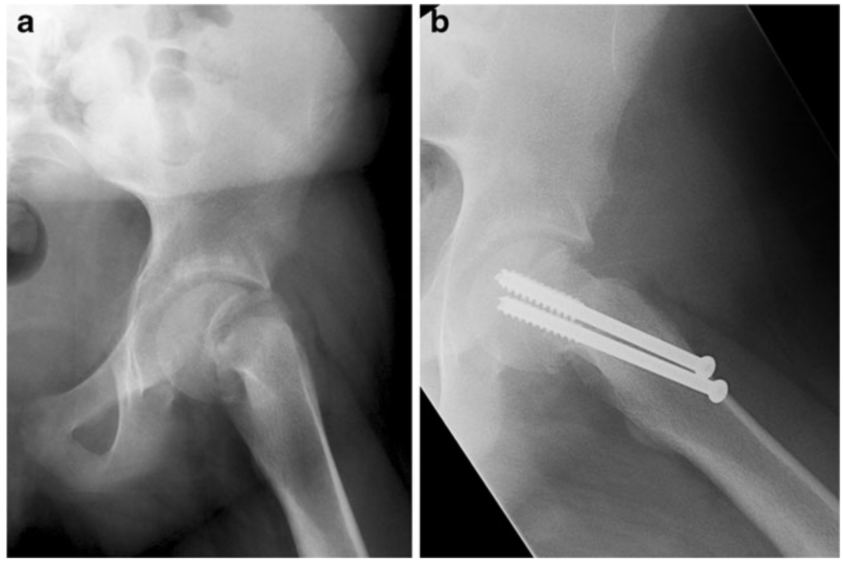


Fig. 6 Reduction of acute SCFE in a 12-year-old girl who slipped and fell the day before, heard a pop and had subsequent inability to bear weight. **a** Externally rotated view of the hip shows moderate to severe left SCFE. After evacuation of a large hematoma in the joint, gentle traction was applied, with flexion, abduction and internal rotation allowing reduction. **b** Frog lateral view following screw fixation shows near-anatomical alignment

bone, though frog lateral views are more accurate than AP views. Using CT as the gold standard, Senthi et al. [24] found that if the screw tip is within 4 mm of subchondral bone on frog lateral or 6 mm on AP view, the screw tip may be penetrating the cortex (Fig. 7).

Another potential complication is screw impingement, when the screw head impacts on the acetabular rim with hip flexion, injuring the acetabulum and labrum. Clinically, this is associated with limitation in flexion. Using cadaveric models, Goodwin et al. [25] found that when the screw head was medial to the intertrochanteric line on AP view, there was high risk of impingement, with little risk when the screw head was lateral (Fig. 8).

After pin fixation, continued growth at the physis can lead to less purchase of the distal screw or pin in the epiphysis, referred to as "growing off" the pin. This decreases stability of the fixation and can cause slip progression (Fig. 9) [26].

Osteotomies

Proximal femoral osteotomies might be performed in SCFE to improve orientation of the femoral head. They can be done at the time of original surgery or subsequent to in situ screw fixation to address ongoing symptoms. Surgical techniques are divided by the level of the osteotomy.

Proximal metaphyseal osteotomy is known as a *cuneiform osteotomy*, with a wedge of bone removed from the metaphysis, allowing realignment of the epiphysis, followed by screw fixation. It has the greatest potential for anatomical realignment of the femoral head because it is

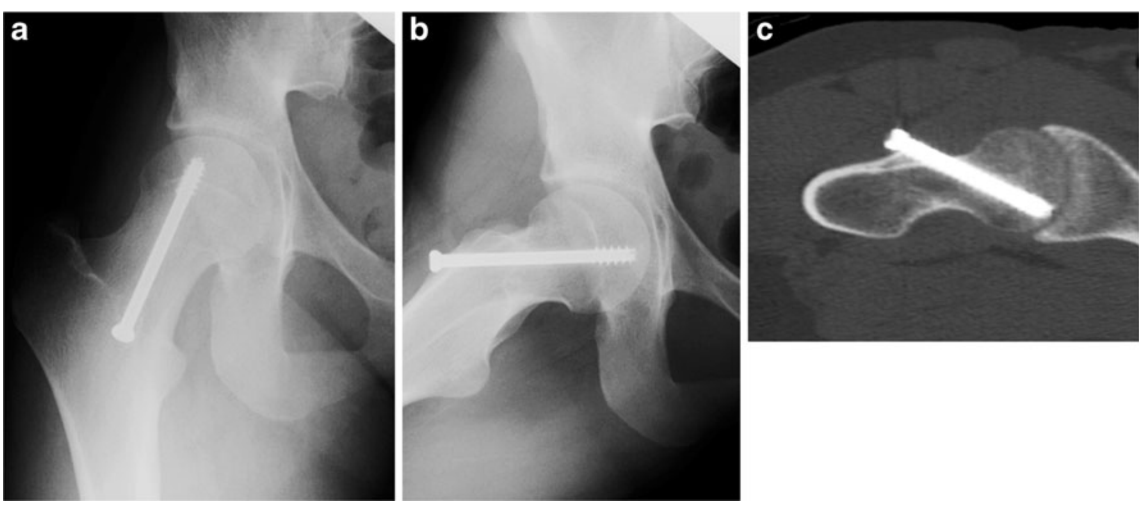


Fig. 7 Assessment of screw position in a 19-year-old woman, status post screw fixation for SCFE. Frontal (**a**) and frog lateral (**b**) radiographs of the hip project the screw tip within the medullary cavity. **c** CT scan performed the same day and reformatted along the long axis of the femoral neck shows that the tip of the screw is intimately below the cortex. Although the screw tip does not enter the joint, the distance from the joint was underestimated by the radiographs

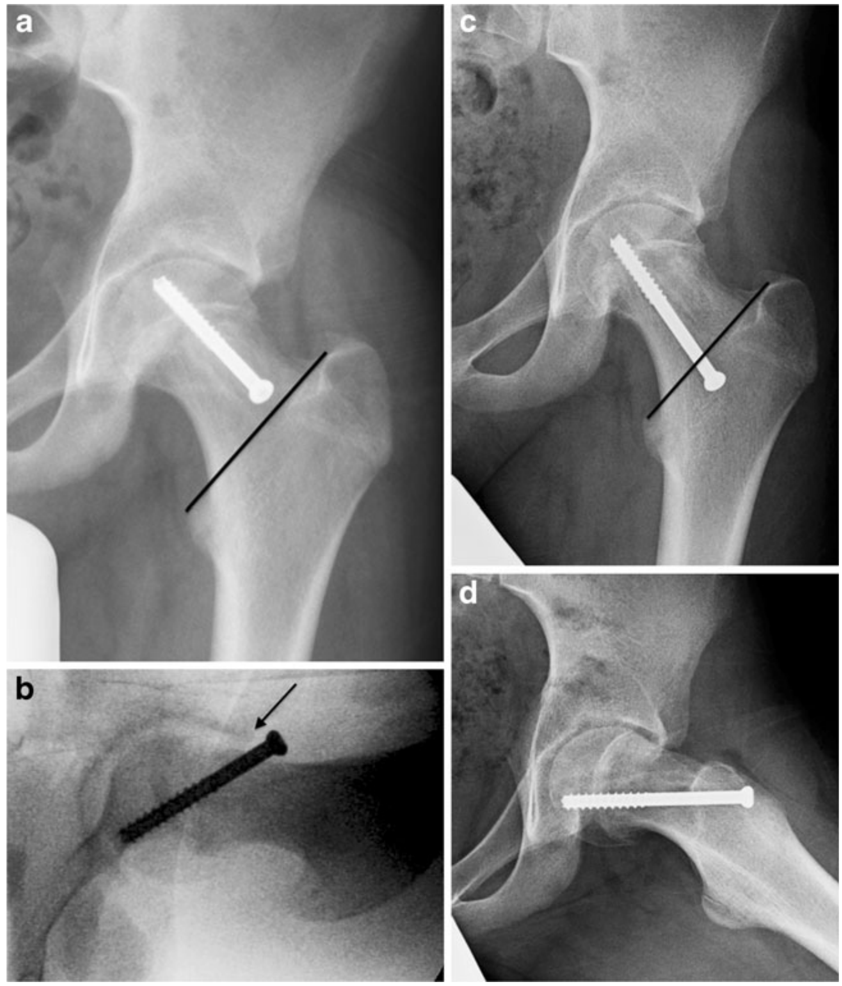


Fig. 8 Screw impingement in a 14-year-old boy with continued hip pain 9 months after pinning of left SCFE. **a** Frontal radiograph of the hip demonstrates the screw head medial to the intertrochanteric line. **b** Intraoperative fluoroscopic image with the hip in flexion shows the proximal screw abutting the lateral acetabular rim (*arrow*). Following screw revision, the screw head is lateral to the intertrochanteric line (**c**) and remains remote from the lateral acetabulum with hip flexion (**d**)

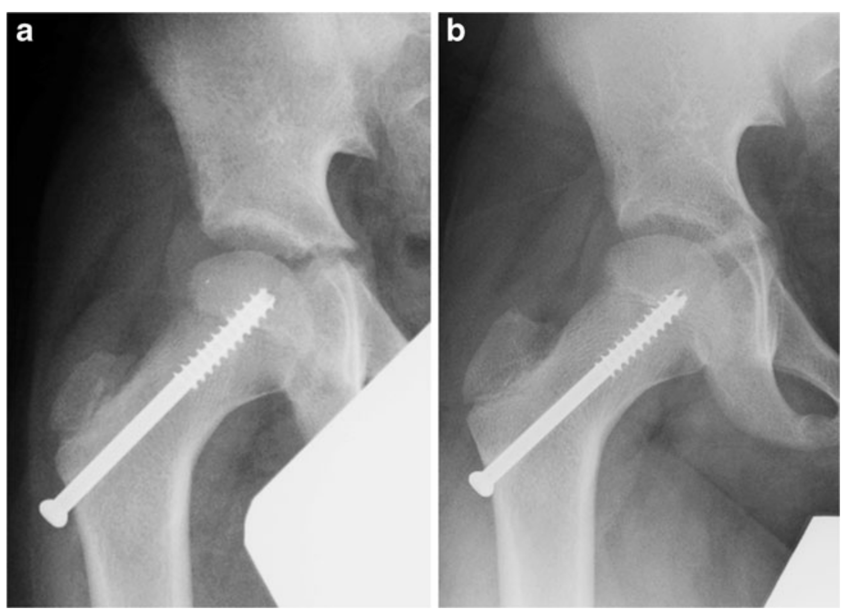


Fig. 9 Growing off screw. Images in a 9-year-old boy, status post screw fixation of SCFE. **a** Frontal radiograph of the right hip reveals that the fourth turn of the screw is at the level of the physis. **b** Two years later, the epiphysis has grown off of the screw with the second turn of the screw at the level of the physis. A new screw was placed to prevent recurrent slip

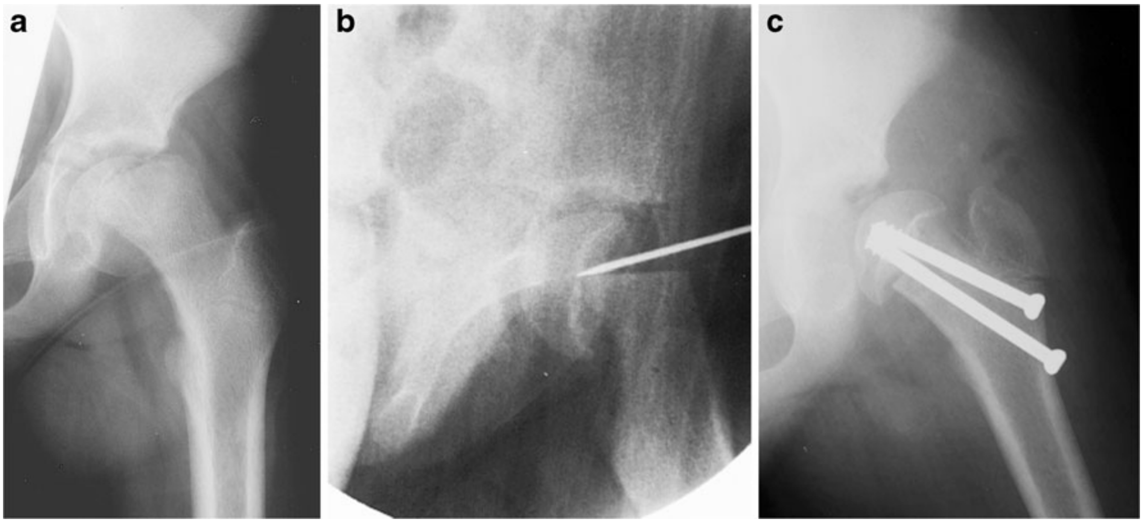


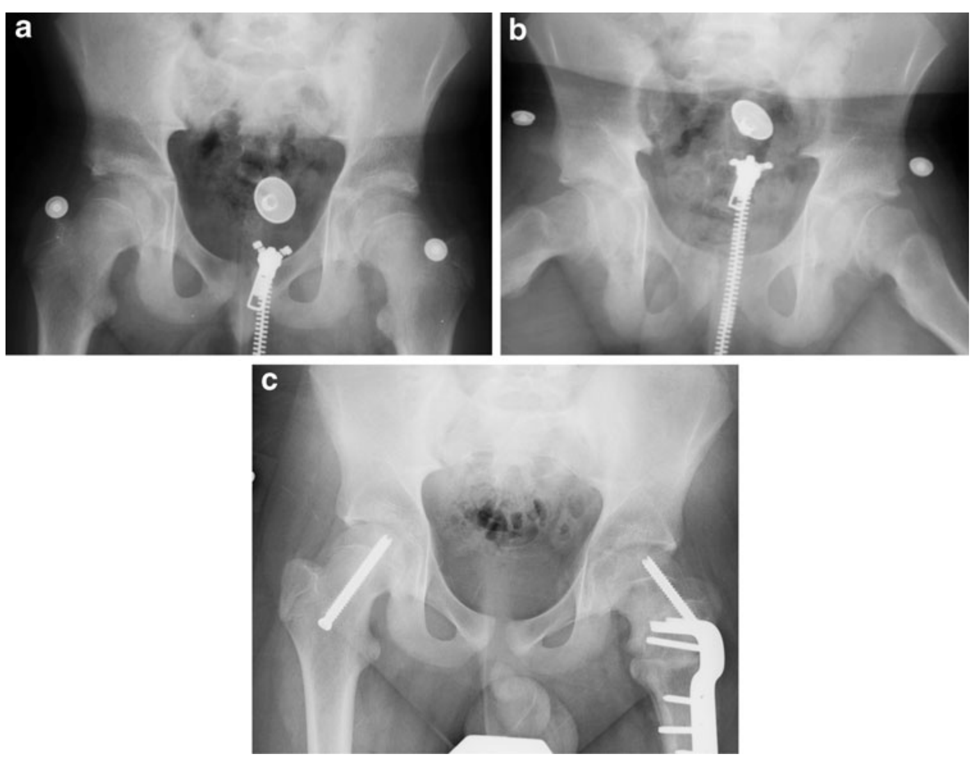
Fig. 10 Cuneiform osteotomy. **a** Frontal hip radiograph of the left hip in a 9-year-old girl with SCFE. **b** Intraoperative fluoroscopic image demonstrates proximal metaphyseal (cuneiform) osteotomy. **c** Postoperative radiograph demonstrates reduction of the femoral head with two-screw fixation

performed at the level of the SCFE deformity; however, it also has the highest risk of avascular necrosis (Fig. 10) [1].

Base of femoral neck osteotomy is a wedge osteotomy performed at the base of the femoral neck; both the osteotomy site and the slipped femoral head epiphysis are then fixed with pins. This has a decreased rate of avascular necrosis (AVN) compared to the cuneiform osteotomy, but only 35–55° of correction is possible. It also shortens the femoral neck, increasing the risks of leg-length discrepancy as well as impingement of the greater trochanter on the lateral acetabulum with hip abduction [1].

Intertrochanteric osteotomy was originally described by Southwick. This osteotomy is performed with removal of an anterolateral wedge of bone and then flexion abduction and internal rotation of the distal fragment followed by fixation of the osteotomy and the SCFE. There is no risk of avascular necrosis. The intertrochanteric osteotomy allows for up to 45° of correction AP and 60° lateral. Like the femoral neck osteotomy, it causes shortening with risk of leg-length discrepancy (Fig. 11) [1].

Fig. 11 Intertrochanteric osteotomy in a 13-year-old boy with bilateral SCFE. **a** Frontal radiograph of the pelvis shows bilateral SCFE. **b** Frog lateral view of both hips better demonstrates the severity of the slips, worse on the left. **c** In situ pin fixation was done on the right. In addition to a transphyseal screw on the left, an intertrochanteric osteotomy was carried out



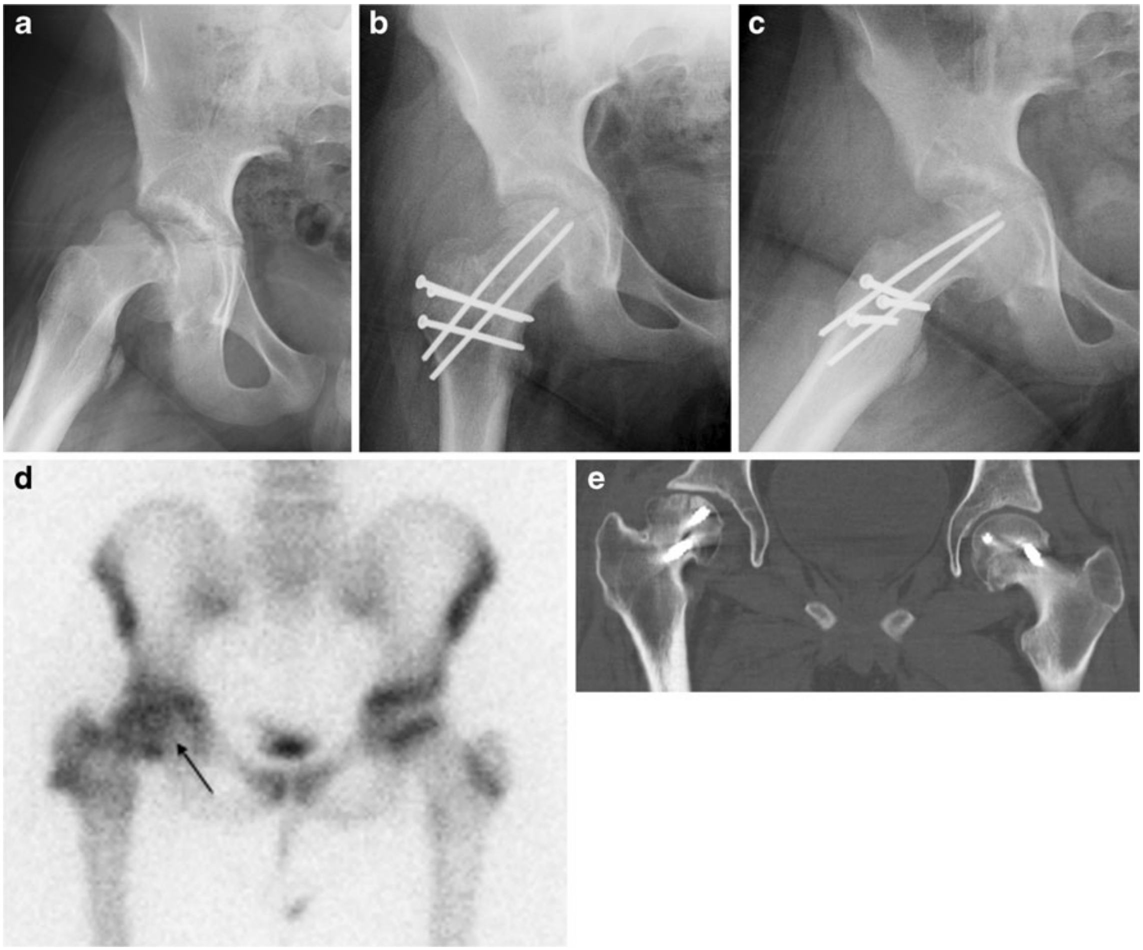


Fig. 12 Modified Dunn osteotomy in an 11-year-old boy with severe slip. **a** Preoperative frog lateral radiograph of the right hip. **b**, **c** Frontal and frog lateral views of the hip after surgical dislocation and modified Dunn osteotomy demonstrate reduction of the slip. **d** Technetium 99 m bone scan performed 5 months after surgery demonstrates decreased tracer uptake in the medial aspect of the femoral head (*arrow*). **e** Coronal CT image shows irregularity and sclerosis of the right femoral head consistent with avascular necrosis. Note mild bend of the more lateral screw in (**b**) and (**c**). This later went on to fracture

Because the deformity of SCFE occurs at the level of the physis, surgical correction targeted to this area has the potential for greater correction but also carries higher rates of complication, specifically AVN and chondrolysis [27, 28]. A relatively new surgery to improve the femoral head-neck relationship in cases of moderate and severe SCFE is the modified *Dunn osteotomy*. In this technique, the hip is surgically dislocated via greater trochanter osteotomy, then the femoral neck is thinned using a subperiosteal dissection. This leaves the important arterial supply to the femoral head intact and decreases the risk of AVN. The femoral head is reduced and fixed with screws, followed by relocation of the hip, and screw fixation of the greater trochanter osteotomy (Fig. 12) [29, 30].

Postoperative radiographs of screw fixation and osteotomy procedures should be assessed for evidence of hardware fracture, loosening and non-union (Figs. 13 and 14).

Complications

AVN

This serious complication of SCFE occurs secondary to injury of the arterial supply of the femoral head. The medial circumflex artery, a branch of the deep femoral artery, gives rise to superior retinacular vessels, which form the lateral epiphyseal arteries (LEAs) [31]. The LEAs enter the femoral head in the posterosuperior quadrant before anastomosing with vessels from the ligamentum teres. Injury in this location can compromise vascularity to the weight-bearing surface of the femoral head [32].

Damage to the arterial supply of the femoral head can occur at the time of the slip. Angiographic studies have shown that in some patients with unstable slip, reduction of the femoral head can improve its perfusion [19]. Other potential risk factors for AVN include

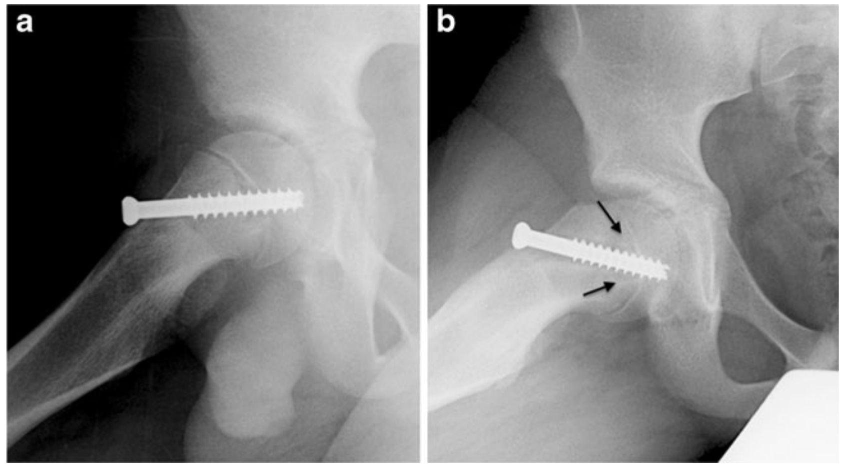


Fig. 13 Screw loosening in a 13-year-old boy who presented with worsening right hip pain after screw fixation of SCFE. **a** Postoperative frog lateral view of the right hip shows satisfactory screw position. **b** Frog lateral view 3 months later shows increased lucency around the screw (*arrows*) and progressive posterior slip of the epiphysis consistent with hardware loosening

severity of the slip, younger age of patient or shorter duration of symptoms (which could reflect increased physeal instability) [33–35].

Potential treatment/iatrogenic risk factors include reduction of the slip, particularly over-reduction of an acute slip or attempted reduction of a chronic slip [1]. Poor screw placement in the important posterior/superior quadrant of the femoral head can lead to AVN. As previously stated, femoral osteotomies, in particular cuneiform osteotomies, also increase the risk of AVN.

Radionuclide bone scans performed within the first 2 weeks after surgery, preferably by the seventh day, are very sensitive for detection of AVN, with a 100% negative predictive value. Changes can be seen well before there is radiographic evidence of AVN [36]. Radiographic and CT changes of avascular necrosis include increased sclerosis of the femoral head, subchondral fracture, fragmentation and collapse of the epiphysis (Figs. 12 and 15). MRI can be used to evaluate femoral head vascularization before and after surgery to assess risk of AVN [37], though postoperative assessment can be challenging because of artifact from screw fixation (Fig. 15). As with femoral head AVN from other causes, surgical management includes femoral osteotomy, with severe cases going on to joint replacement.

Cartilage loss and femoral acetabular impingement

Articular cartilage damage in the hips following SCFE can occur soon after surgery because of chondrolysis, which is defined as joint space loss with cartilage thickness measuring 2 mm less than the contralateral hip or joint space width of 3 mm or less [38]. A major risk factor for chondrolysis is penetration of the screw tip into the joint space; however, other risk factors include severe slip and early osteotomy (Fig. 16) [38, 39].

Cartilage loss following SCFE can result from femoral acetabular impingement (FAI)—abnormal contact between the femoral neck and the acetabulum occurring during hip flexion and more pronounced with internal rotation [40]. FAI is thought to be a major mechanism for joint damage in stable SCFE [41]. Because of the

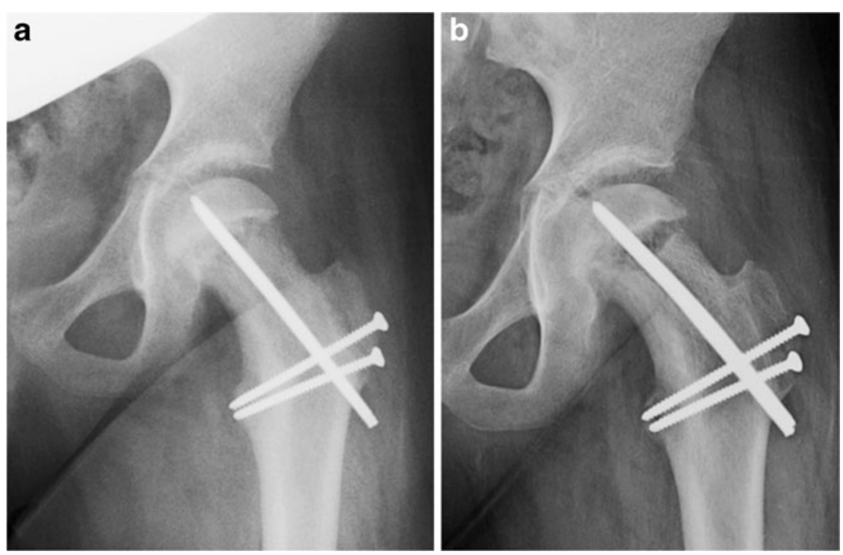


Fig. 14 Non-union following modified Dunn osteotomy. **a** Frontal radiograph of the left hip in a 9-year-old girl after modified Dunn osteotomy for severe SCFE. **b** Two months later, there is increased widening and irregularity at the proximal femoral physis/osteotomy site, consistent with non-union. The girl underwent revision of hardware with subsequent healing

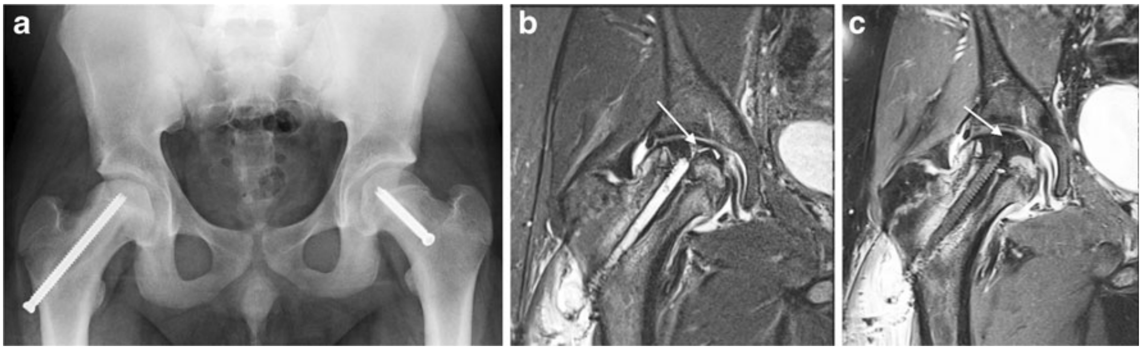


Fig. 15 MRI of avascular necrosis in a 14-year-old boy with left SCFE, status post in situ pin and prophylactic pin on the right. **a** Frontal radiograph of the hips obtained 7 months after surgery demonstrates abnormal sclerosis, irregularity and articular surface collapse of the right femoral head, consistent with AVN. Coronal inversion recovery (**b**) and T1-W fat-saturated postcontrast (**c**) images from MR performed 8 months after surgery, status post screw removal, also show the changes of AVN with a hypointense, non-enhancing region of bone marrow in the femoral head, containing a subchondral line consistent with fracture (*arrow*)

abnormal position of the femoral head with resulting metaphyseal prominence and decreased offset at the femoral head-neck junction, SCFE carries an increased risk of femoral acetabular impingement, even in mild slips. In fact, some believe that subclinical SCFE might be a mechanism for formation of the cam deformity associated with FAI [42].

Direct, intraoperative observation of the hip in patients with SCFE has demonstrated that the metaphysis, which extends to or anterior to the femoral head, impinges on the superior medial acetabular rim, causing injury to the labrum [40]. Labral hypertrophy and degeneration has been seen in patients with chronic symptoms following SCFE [43]. With flexion, the prominent metaphysis enters the acetabulum causing damage to the acetabular cartilage surface, with no damage to the femoral head [40]. The acetabular cartilage loss is most common in the anterior/superior quadrant [43].

Articular cartilage of the hip is well-assessed with MRI for thinning, fissuring and focal defects, using conventional sequences including T2-W and proton-density images. There are also advanced cartilage imaging protocols including T2 mapping and delayed gadolinium-enhanced MRI of cartilage (dGEMRIC). In T2 mapping, T2 relaxation time of cartilage is measured as an indicator of the organization of the collagen fiber network that makes up the cartilage matrix [44, 45]. DGEMRIC imaging is dependent on the decreased glycosaminoglycan (GAG) content of degenerated cartilage. Because GAG and gadopentetate dimeglumine (Gd-DPTA) are negatively charged, an abnormally increased amount of intravenously administered contrast agent accumulates in diseased articular cartilage, resulting in a decrease in T1 relaxation time compared to normal cartilage. T1 maps can then be created, showing areas of cartilage degeneration [44].

In patients with FAI caused by prior SCFE, assessment with dGEMRIC can demonstrate damage to the acetabular cartilage anterosuperiorly, as well as labral tears (Fig. 17), even in cases with modest slips. Zilkens

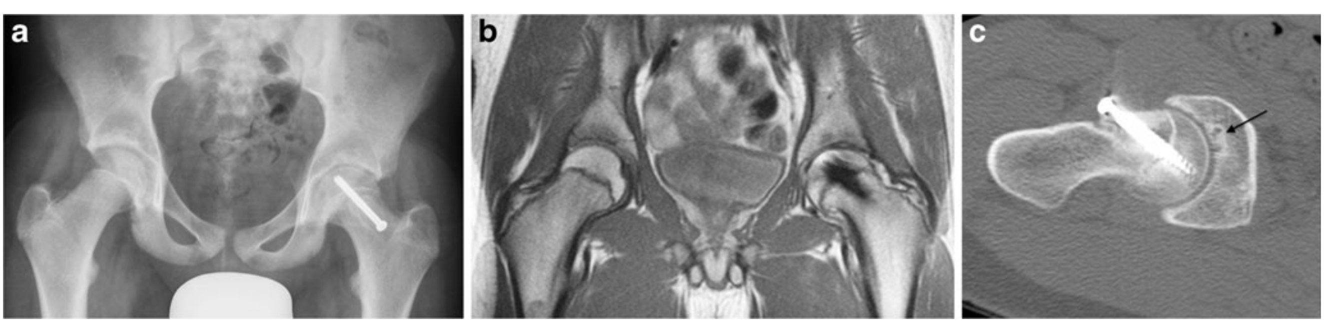


Fig. 16 Chondrolysis in a 14-year-old boy with continued hip pain 9 months after screw fixation of left SCFE (same boy as Fig. 8). **a** Frontal radiograph of the pelvis demonstrates asymmetrical joint space narrowing on the left consistent with chondrolysis. **b** Coronal proton-density MR image confirms joint space narrowing on the left. **c** CT image reformatted along the long axis of the femoral neck demonstrates joint space narrowing, subchondral sclerosis and cystic change of the acetabulum (*arrow*)

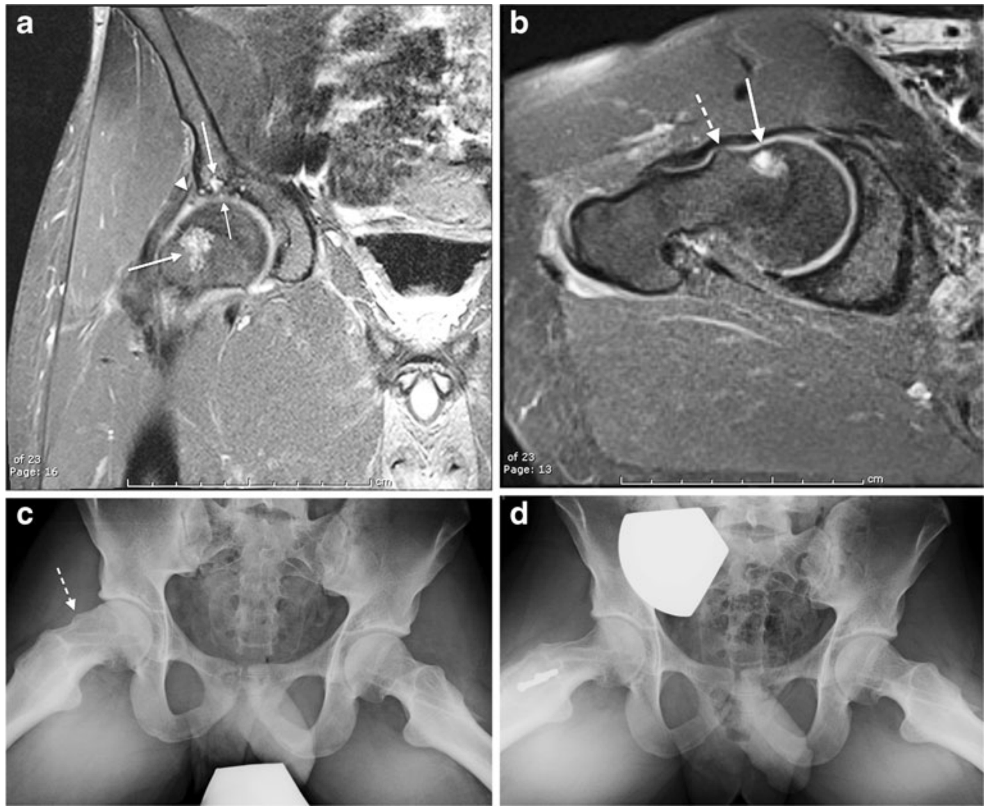


Fig. 17 Femoroacetabular impingement following SCFE in a 17-year-old boy with a history of bilateral SCFE and subsequent FAI. A surgical dislocation with head-neck osteochondroplasty was performed on the right. He presented with worsening symptoms on the left. Coronal (**a**) and axial oblique (**b**) T1-W fat-saturated images from dGEMRIC MR demonstrate cyst formation of the acetabulum and femoral head-neck junction (*thick arrows*), cartilage loss along the acetabular surface (*thin arrow*) and tear of the anterosuperior labrum (*arrowhead*). Bump at the anterolateral head-neck junction (*dashed arrow*) serves as substrate for impingement. **c** Frog lateral radiograph of the hips also shows prominent bump at the anterolateral head-neck junction (*dashed arrow*). **d** Postoperative radiograph after surgical dislocation and head–neck osteochondroplasty shows recontoured femoral neck with absence of bump

et al. [46] studied patients following in situ pinning of mild and moderate slips at a mean of 11 years after surgery. Even when radiographs showed no evidence of osteoarthritis, dGEMRIC showed evidence of cartilage damage at the lateral acetabulum [46]. Similarly using T2 and T2* mapping techniques, cartilage damage was seen in both symptomatic and asymptomatic SCFE patients compared to healthy volunteers [47]. Patients with FAI following SCFE might go on to open or arthroscopic osteochondroplasty for treatment, with trimming of the metaphyseal prominence (Fig. 17) [41].

Conclusion

Radiography remains the primary imaging modality for the diagnosis of SCFE; however, MR, CT and bone scintigraphy can provide earlier recognition of the disorder and its complications and facilitate surgical planning. Our understanding of the natural history as well as the long-term sequelae of treated SCFE has been substantially improved with advances in cross-sectional imaging technologies. A firm grasp of surgical procedures coupled with a multimodality imaging approach optimizes primary diagnosis, management and assessment of potential complications of this important condition.

Disclaimer The authors have no financial interests, investigational or off-label uses to disclose.

References

1. Loder RT, Aronsson DD, Weinstein SL et al (2008) Slipped capital femoral epiphysis. Instr Course Lect 57:473–498
2. Klein A, Joplin RJ, Reidy JA et al (1952) Slipped capital femoral epiphysis: early diagnosis and treatment facilitated by normal roentgenograms. J Bone Joint Surg Am 34:233–239
3. Green DW, Mogekwu N, Scher DM et al (2009) A modification of Klein's line to improve sensitivity of the anterior-posterior radiograph in slipped capital femoral epiphysis. J Pediatr Orthop 29:449–453
4. Billing L, Bogren HG, Wallin J (2002) Reliable X-ray diagnosis of slipped capital femoral epiphysis by combining the conventional and a new simplified geometrical method. Pediatr Radiol 32:423–430
5. Uglow MG, Clarke NM (2004) The management of slipped capital femoral epiphysis. J Bone Joint Surg Br 86:631–635
6. Steel HH (1986) The metaphyseal blanch sign of slipped capital femoral epiphysis. J Bone Joint Surg Am 68:920–922
7. Loder RT, O'Donnell PW, Didelot WP et al (2006) Valgus slipped capital femoral epiphysis. J Pediatr Orthop 26:594–600
8. Shea KG, Apel PJ, Hutt NA et al (2007) Valgus slipped capital femoral epiphysis without posterior displacement: two case reports. J Pediatr Orthop B 16:201–203
9. Lalaji A, Umans H, Schneider R et al (2002) MRI features of confirmed "pre-slip" capital femoral epiphysis: a report of two cases. Skeletal Radiol 31:362–365

10. Umans H, Liebling MS, Moy L et al (1998) Slipped capital femoral epiphysis: a physeal lesion diagnosed by MRI, with radiographic and CT correlation. Skeletal Radiol 27:139–144
11. Tins B, Cassar-Pullicino V, McCall I (2009) The role of pre-treatment MRI in established cases of slipped capital femoral epiphysis. Eur J Radiol 70:570–578
12. Cohen MS, Gelberman RH, Griffin PP et al (1986) Slipped capital femoral epiphysis: assessment of epiphyseal displacement and angulation. J Pediatr Orthop 6:259–264
13. Castriota-Scanderbeg A, Orsi E (1993) Slipped capital femoral epiphysis: ultrasonographic findings. Skeletal Radiol 22:191–193
14. Terjesen T (1992) Ultrasonography for diagnosis of slipped capital femoral epiphysis. Comparison with radiography in 9 cases. Acta Orthop Scand 63:653–657
15. Loder RT, Richards BS, Shapiro PS et al (1993) Acute slipped capital femoral epiphysis: the importance of physeal stability. J Bone Joint Surg Am 75:1134–1140
16. Southwick WO (1967) Osteotomy through the lesser trochanter for slipped capital femoral epiphysis. J Bone Joint Surg Am 49:807–835
17. Loder RT, Aronsson DD, Dobbs MB et al (2001) Slipped capital femoral epiphysis. Instr Course Lect 50:555–570
18. Boles CA, el-Khoury GY (1997) Slipped capital femoral epiphysis. Radiographics 17:809–823
19. Maeda S, Kita A, Funayama K et al (2001) Vascular supply to slipped capital femoral epiphysis. J Pediatr Orthop 21:664–667
20. Parsch K, Weller S, Parsch D (2009) Open reduction and smooth Kirschner wire fixation for unstable slipped capital femoral epiphysis. J Pediatr Orthop 29:1–8
21. de Sanctis N, Di Gennaro G, Pempinello C et al (1996) Is gentle manipulative reduction and percutaneous fixation with a single screw the best management of acute and acute-on-chronic slipped capital femoral epiphysis? A report of 70 patients. J Pediatr Orthop B 5:90–95
22. Seller K, Wild A, Westhoff B et al (2006) Radiological evaluation of unstable (acute) slipped capital femoral epiphysis treated by pinning with Kirschner wires. J Pediatr Orthop B 15:328–334
23. Lehman WB, Menche D, Grant A et al (1984) The problem of evaluating in situ pinning of slipped capital femoral epiphysis: an experimental model and a review of 63 consecutive cases. J Pediatr Orthop 4:297–303
24. Senthi S, Blyth P, Metcalfe R et al (2011) Screw placement after pinning of slipped capital femoral epiphysis: a postoperative CT scan study. J Pediatr Orthop 31:388–392
25. Goodwin RC, Mahar AT, Oswald TS et al (2007) Screw head impingement after in situ fixation in moderate and severe slipped capital femoral epiphysis. J Pediatr Orthop 27:319–325
26. Givon U, Bowen JR (1999) Chronic slipped capital femoral epiphysis: treatment by pinning in situ. J Pediatr Orthop B 8:216–222
27. Biring GS, Hashemi-Nejad A, Catterall A (2006) Outcomes of subcapital cuneiform osteotomy for the treatment of severe slipped capital femoral epiphysis after skeletal maturity. J Bone Joint Surg Br 88:1379–1384
28. Akkari M, Santili C, Braga SR et al (2010) Trapezoidal bony correction of the femoral neck in the treatment of severe acute-on-chronic slipped capital femoral epiphysis. Arthroscopy 26:1489–1495
29. Ziebarth K, Zilkens C, Spencer S et al (2009) Capital realignment for moderate and severe SCFE using a modified Dunn procedure. Clin Orthop Relat Res 467:704–716
30. Huber H, Dora C, Ramseier LE et al (2011) Adolescent slipped capital femoral epiphysis treated by a modified Dunn osteotomy with surgical hip dislocation. J Bone Joint Surg Br 93:833–838
31. Shore BJ, Millis MB, Kim YJ (2012) Vascular safe zones for surgical dislocation in children with healed Legg-Calve-Perthes disease. J Bone Joint Surg Am 94:721–727
32. Brodetti A (1960) The blood supply to the femoral neck and head in relation to the damaging effects of nails and screws. J Bone Joint Surg Br 42:794–801
33. Sankar WN, McPartland TG, Millis MB et al (2010) The unstable slipped capital femoral epiphysis: risk factors for osteonecrosis. J Pediatr Orthop 30:544–548
34. Palocaren T, Holmes L, Rogers K et al (2010) Outcome of in situ pinning in patients with unstable slipped capital femoral epiphysis: assessment of risk factors associated with avascular necrosis. J Pediatr Orthop 30:31–36
35. Tokmakova KP, Stanton RP, Mason DE (2003) Factors influencing the development of osteonecrosis in patients treated for slipped capital femoral epiphysis. J Bone Joint Surg Am 85:798–801
36. Fragniere B, Chotel F, Vargas Barreto B et al (2001) The value of early postoperative bone scan in slipped capital femoral epiphysis. J Pediatr Orthop B 10:51–55
37. Staatz G, Honnef D, Kochs A et al (2007) Evaluation of femoral head vascularization in slipped capital femoral epiphysis before and after cannulated screw fixation with use of contrast-enhanced MRI: initial results. Eur Radiol 17:163–168
38. Jofe MH, Lehman W, Ehrlich MG (2004) Chondrolysis following slipped capital femoral epiphysis. J Pediatr Orthop B 13:29–31
39. Ingram AJ, Clarke MS, Clarke CS Jr et al (1982) Chondrolysis complicating slipped capital femoral epiphysis. Clin Orthop Relat Res 165:99–109
40. Leunig M, Casillas MM, Hamlet M et al (2000) Slipped capital femoral epiphysis: early mechanical damage to the acetabular cartilage by a prominent femoral metaphysis. Acta Orthop Scand 71:370–375
41. Millis MB, Novais EN (2011) In situ fixation for slipped capital femoral epiphysis: perspectives in 2011. J Bone Joint Surg Am 93 (Suppl 2):46–51
42. Fraitzl CR, Kafer W, Nelitz M et al (2007) Radiological evidence of femoroacetabular impingement in mild slipped capital femoral epiphysis: a mean follow-up of 14.4 years after pinning in situ. J Bone Joint Surg Br 89:1592–1596
43. Sink EL, Zaltz I, Heare T et al (2010) Acetabular cartilage and labral damage observed during surgical hip dislocation for stable slipped capital femoral epiphysis. J Pediatr Orthop 30:26–30
44. Blankenbaker DG, Tuite MJ (2011) MR imaging of early hip joint degeneration. Magn Reson Imaging Clin N Am 19:365–378
45. Jazrawi LM, Alaia MJ, Chang G et al (2011) Advances in magnetic resonance imaging of articular cartilage. J Am Acad Orthop Surg 19:420–429
46. Zilkens C, Miese F, Bittersohl B et al (2011) Delayed gadolinium-enhanced magnetic resonance imaging of cartilage (dGEMRIC), after slipped capital femoral epiphysis. Eur J Radiol 79:400–406
47. Miese FR, Zilkens C, Holstein A et al (2011) Assessment of early cartilage degeneration after slipped capital femoral epiphysis using T2 and T2* mapping. Acta Radiol 52:106–110