# 8 Slipped Capital Femoral Epiphysis

Balakumar Balasubramanian, Sattar Alshryda, and Sanjeev Madan

## Introduction

Slipped Capital Femoral Epiphysis (SCFE) is an important hip disorder in the adolescent age group. It can be associated with devastating complications with long lasting sequelae if not addressed appropriately. In SCFE, the femoral head stays in the acetabulum while the femoral neck and the metaphysis moves antero-superiorly. This is the typical varus slip which is by far the commonest form of SCFE (Fig. 8.1). The so-called 'valgus slip' is rare (Fig. 8.2). The first description of this entity was by Müller in 1926. They may represent a true femoral capital slip where the femoral head tilts superolaterally relative to the femoral neck, but remains within the acetabulum [1].

The purpose of this chapter is to describe and evaluate the current practice regarding the diagnosis and treatment of SCFE, the evidence that underpins this practice, and to provide an overview of future clinical and research directions in this area.

**Fig. 8.1** Varus slipped capital femoral epiphysis. This young boy of 12 presented with right sided knee pain for the last 6 months

B. Balasubramanian
Royal Orthopedic Hospital, Birmingham, UK

S. Madan
Sheffield Children's Hospital, Sheffield, UK

S. Alshryda (✉)
Clinical Director of Paediatric Trauma and Orthopaedic Surgery, Royal Manchester Children Hospital, Manchester University NHS Foundation Trust, Manchester, UK
e-mail: Sattar26@doctors.org.uk


S. Alshryda et al. (eds.), *The Pediatric and Adolescent Hip*,
https://doi.org/10.1007/978-3-030-12003-0_8

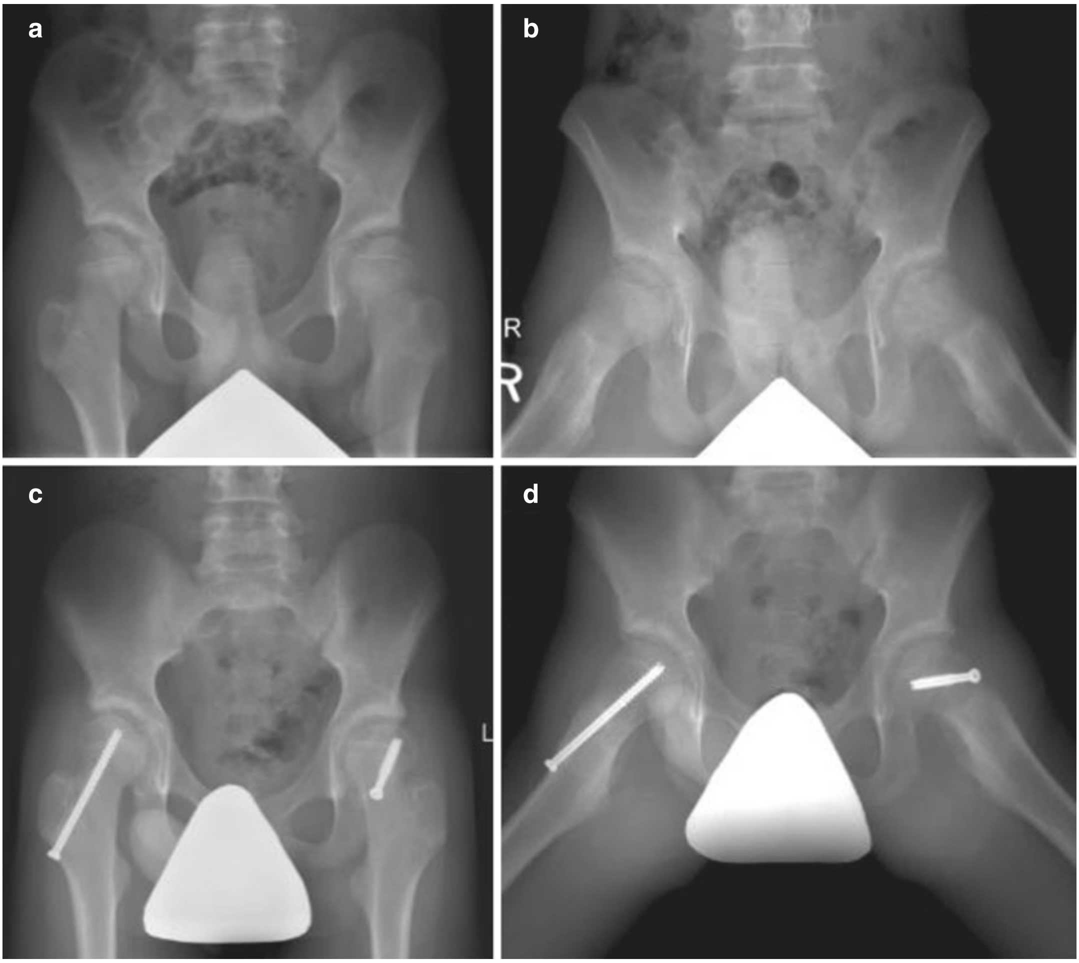


**Fig. 8.2** 13-Year-old boy with symptomatic left valgus SCFE. (**a**, **b**) Anteroposterior (AP) and frog-leg lateral pelvic X-rays demonstrating relative anteromedial displacement of the femoral epiphysis on the left and lateral physeal tilt on the right (asymptomatic) side. (**c**, **d**) Postoperative AP and frog-leg lateral pelvic X-rays showing *in situ* screw placement of the left valgus SCFE and prophylactic screw placement on the right side. Note the trajectory of the left *in situ* screw, the valgus alignment necessitating a more medial (and anterior) starting point than a typical SCFE, putting the femoral neurovascular bundle at risk. As such, a mini-open—rather than percutaneous—approach was used in this case to protect these structures. (Courtesy Jason J. Howard)

## Pathophysiology

Slipped capital femoral epiphysis is associated with unique pathophysiological processes involving the growth plate (the physis). Anatomical, histological, and mechanical factors have roles in the disease process. 'Slippage' occurs when the shear forces imparted exceed the strength of the growth plate. This mechanically unfavourable situation can occur secondary to excessive shear forces, a weak growth plate, or both [2].

> ***"SCFE occurs when the shear forces exceed the strength of the growth plate. This mechanically unfavourable situation can be secondary to excessive shear forces, a weak growth plate, or both"***

In patients with SCFE, the growth plate is unusually widened, primarily due to expansion of the zone of hypertrophy [3, 4]. This is usually apparent on plain X-ray (often called a 'pre-slip' for cases where no displacement has yet occurred) (Fig. 8.3). The hypertrophic zone

**Fig. 8.3** Plain radiograph showing a widened growth plate on the right side; the so-called 'pre-slip'

typically constitutes 15–30% of the normal width of the growth plate. In SCFE, this can increase by up to 80% of the width of the growth plate. Histologically, abnormal cartilage maturation, endochondral ossification, and perichondral ring instability occur. This leads to less organization of the normal cartilaginous columnar architecture which weakens the growth plate. Slippage occurs through this weakened area [5].

The shear forces imparted to the physis are proportional to body weight. Children with obesity (greater than 80th percentile) are predisposed to SCFE [6]. SCFE is typically seen during the adolescent growth spurt (between 10 to 16 years of age). Moreover, anatomical changes such as retroversion of greater than 10° and an abnormal inclination of the proximal femoral growth plate, serve to increase the net effect of shear forces across the growth plate, predisposing to slippage. Trauma is often implicated, tipping the delicate balance which results in the slippage.

## Natural History

Slipped capital femoral epiphysis is not a single entity but instead is a disease spectrum, ranging from a very mild, primarily asymptomatic, condition that only comes to medical attention later in life (Fig. 8.4) to a sudden, severe presentation that requires urgent surgical intervention. In their long term review of 100 patients treated for SCFE, Jerre et al. [7] found that 71% of patients

**Fig. 8.4** Subclinical slip. This 45 year-old electrician presented with bilateral hip pain over the previous 2 years. He recalled that he had right hip pain when he was a teenager but he never seeked medical advice. Note the right-sided cam and pincer lesions—with joint space narrowing—that have, most likely, resulted from this undiagnosed SCFE when he was a teenager

had developed an asymptomatic slip on the contralateral side. We do not know the number of patients with SCFE that never seek medical advice.

There is worldwide consensus that SCFE should be treated. The types and timing of surgical treatment, as well as postoperative protocols, can vary between (and even within) centres and by region worldwide. These differences in management are based on considerations relating to clinical presentations, resources, personal surgical expertise, and preferences. Therefore, it is impossible to establish the true natural history as almost all published series have reported on treated SCFE and the volume of subclinical cases is unknown.

***"It is impossible to establish the natural history of SCFE as almost all published series have reported on treated SCFE and the volume of subclinical cases is unknown"***

Carney and Weinstein [8] published a series of 31 untreated chronic SCFE with a long term follow-up, ranging from 26 to 54 years. The authors stated that the reasons for no treatments were not always clear from the medical records but included family refusal, delayed presentation or treating the more severe side in cases of bilateral SCFE. In their series, there were 17 mild, 11 moderate, and 3 severe SCFEs. The mean Iowa Hip Score (IHS) was 89 points (92 points in mild slips, 87 points in moderate slips and 75 points in severe slips). All severe and moderate slips showed radiographic features of osteoarthritis (OA) in contrast to 13% of those with mild slips. Complications occurred in four slips (one AVN and two further displacements developed in three severe slips and one chondrolysis in one mild slip).

In another series, Carney et al. [9] reported on 155 SUFEs in 124 patients after 41 year follow up. Forty-two percent of the slips were mild; 32% were moderate; and 26% were severe. Various treatments methods were used which were categorized into pinning *in situ* or re-alignment procedures. They found that the natural history of the slip is mild deterioration related to the severity of the slip and complications. The Iowa hip score deteriorated significantly over time ($p = 0.0025$), with the number of poorer results (a rating of ≤80 points) increasing with each 10-year increment of follow-up (Fig. 8.5). Realignment procedures were associated with an increased risk of complications which adversely affected the natural history. In the hips that had been realigned, the mean Iowa hip score was ≤89 at (40–49 years of follow-up) when the slip had been mild, at (30–39 years) when the slip had been moderate, and at (20–29 years) when the slip had been severe which are lower than the ones that were not aligned (Fig. 8.6).

Surgical techniques for the treatment of SCFE—including the addition of re-alignment procedures—have evolved significantly over the last 40 years and it would be interesting to see whether the above findings and trends would remain the same with modern surgical techniques.

Patients with SCFE represent a small percentage of those requiring total hip replacement. The Nordic joint registry (1995–2006) indicated that pediatric orthopaedic diagnoses collectively accounted for 3.1% of 69,242 THRs in Denmark, 1.8% of 140,082 THRs in Sweden, and 8.6% of 70,138 THRs in Norway [10]. Larson et al. [11] reviewed 33,000 hip replacement performed in their centre between 1954 and 2007 and found that SCFE was the indication for replacement in only 38 hips in 33 patients (0.1%). The main reasons for hip replacement in this subset were AVN or chondrolysis in 25 hips and degenerative changes and/or impingement in 13 hips. All slips in their series underwent either pin fixation (27) or primary osteotomy (9). They found that the

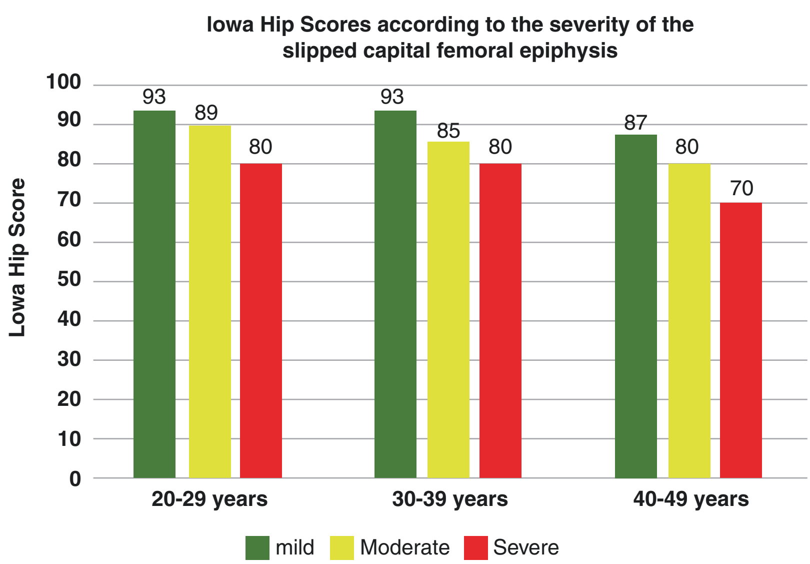


**Fig. 8.5** Long term follows up of treated slipped upper femoral epiphysis by disease severity. Iowa hip scores were least affected in the 'mild' group and most affected in the severe group. With each decade of follow-up, the scores further deteriorated

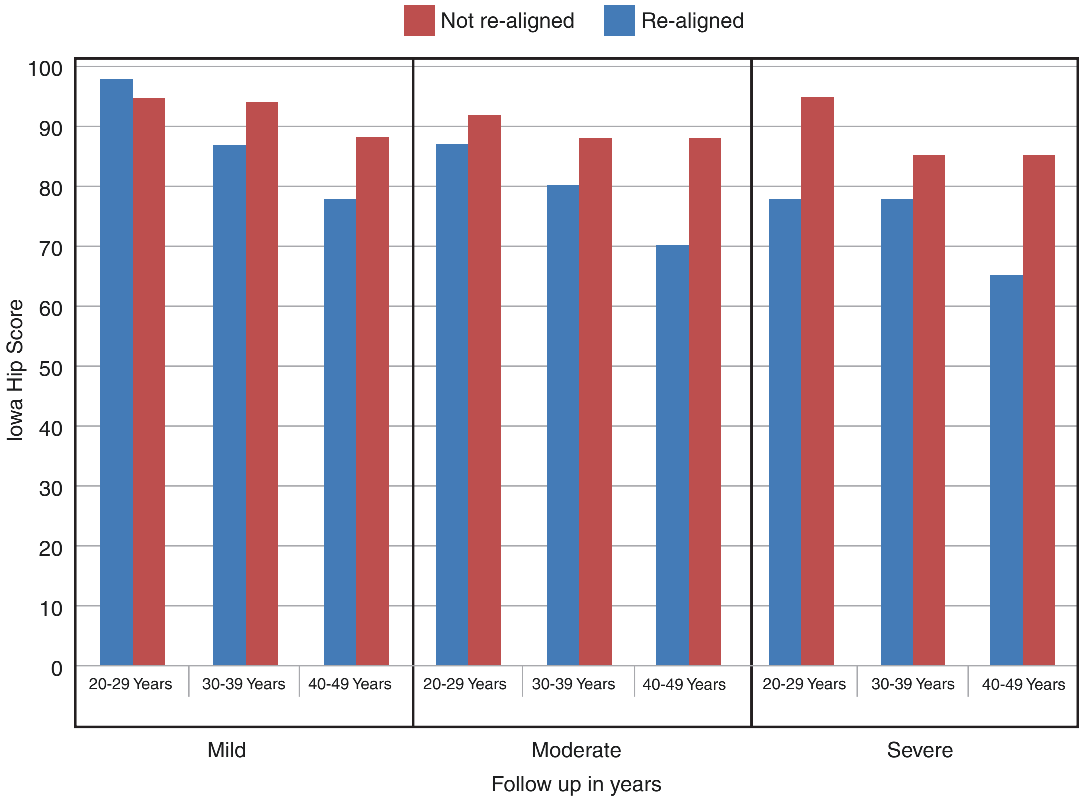


**Fig. 8.6** Long term follow-up of treated slipped upper femoral epiphysis. Adapted from Carney et al. [9]. The re-aligned slipped capital epiphysis fair worse than the those who were not re-aligned

mean time from slip to hip replacement was 7.4 years in patients with AVN or chondrolysis and 23.6 years in patients with degenerative change ($p < 0.0002$).

> ***"SCFE is a rare indication for total hip replacement"***

## Epidemiology

SCFE is not common. The incidence of known cases varies from 1 to 10 per 100,000. It is more common in boys with the peak disease onset occurring at 12–15 years for boys and at 10–13 years for girls. It is rarely reported after the age of 20 years [12]. A higher incidence was reported in blacks and Polynesians [13]. There is a definite regional variation. The prevalence has been reported as 0.2 per 100,000 in eastern Japan [14], as 2.13 per 100,000 in the southwestern United States, and as high as 10.08 per 100,000 in the northeastern United States [15]. It is difficult to know how much of this variation is true and how much is secondary to better detection of mild cases.

Like DDH, SCFE affects the left side more than the right. The cause of this is unknown. One theory proposed suggests a role for a certain sitting posture of right handed children which is more common than in left handed children. This theory is worth studying in a large retrospective cohort.

SCFE is bilateral in about 20%; 50% of these cases present with both hips involved initially while the other 50% develop SCFE in the contralateral side at a later time. The majority of sequential bilateral slips develop within 18 months of the first side presentation. Some studies showed a much higher incidence of bilateral hips involvement. Jerre et al. [7] reported on a series of 100 patients with SCFE after an average follow up of 32 years. They found that 59 patients in this series had bilateral SCFE. More interestingly, slipping of the contralateral hip was asymptomatic in 42 of these 59 patients (71%). Furthermore, regarding the timing of diagnosis, bilateral slipping was identified at primary admission (23 patients), during adolescence (18 patients), and during adulthood (18 patients).

In their series, Carney et al. [9] reported that 25% of patients presented with bilateral SCFE. Almost half (45%) were symptomatic at presentation. The rest developed it in the other side within 1 year and only one developed symptoms in the other side after a year.

Younger patients with open triradiate cartilages and those with endocrine or metabolic abnormalities are at much higher risk for bilateral involvement [2]. There is a debatable seasonal variation as some studies showed it is more common in June and July [2, 15].

## Clinical Presentation

Typically, the child with SCFE presents with complaints of knee, groin, medial thigh or hip pain associated with a limp. Parents and friends may have noticed that the child's foot points outward. The knee pain—which is a referred pain from the obturator nerve—often confuses the treating primary clinician and can delay the diagnosis. Acute slips have a more dramatic presentation, with sudden severe pain and inability to walk.

Limping and out-toeing gait will be noted on careful clinical examination (Fig. 8.7). The affected leg appears short and externally rotated when patient is lying on their back (Fig. 8.8). In chronic, stable SCFE, obligatory external rotation (positive Drehmann's sign) is typically present on flexion of the hip (Fig. 8.9).

In case of chronic SCFE, hyperextension of hip can be identified on clinical examination. Also, Craig's test (also known as the prone trochanteric test) would show a retroverted femur. Trendelenburg sign will be positive in chronic

**Fig. 8.7** A clinical photograph of a child with left SCFE. Notice the short and externally rotated left leg. The patient was investigated and treated for knee pain before finally being diagnosed with SCFE

**Fig. 8.8** A child with right SCFE. A young boy presented with right leg pain. The right lower limb is short and externally rotated

**Fig. 8.9** Drehmann's sign. Obligatory passive external rotation of the right hip occurs when performing hip flexion. Internal rotation of the hip joint is not possible in comparison to the left normal side

slips. When an unstable slip is present, the patient will be unable to bear weight, precluding this test. In equivocal cases, the patient should be advised to be non-weight bearing until the diagnosis of SCFE is ruled out as a subsequent acute event could cause an unstable slip with its associated poorer prognosis.

Although rare, endocrine disorders must be considered in any child outside the age range of 10–16 years typical for SCFE and for those less than 50th centile of weight (Fig. 8.10). Loder and Greenfield [16] identified two types of SCFE: (1) idiopathic and (2) atypical (where there is an underlying cause such as endocrine or metabolic disorders). They studied the demographics of 433 patients with 612 SCFEs (285 idiopathic, 148 atypical) and found that weight and age were predictors for atypical SCFE. As such, they recommended applying an *age-weight test*, where a negative test corresponds to an age between 10 and 16 years old and more than 50th centile of weight and a positive test being outside of these values. For cases with a negative test, 93% were found to have an idiopathic SCFE. For cases with a positive test, 52% were found to have an atypical SCFE.


**Fig. 8.10** Atypical slipped capital epiphysis in a child with renal failure. Notice the substantially widened physis, the thin cortices and clear trabecular pattern of the bone. The patient underwent pinning of both sides

**Essential Clinical Tests**

1. General
   (a) Overweight
   (b) Observe for limping and out-toeing gait (foot and knee point outward)
2. Specific
   (a) A positive Trendelenburg sign
   (b) Short and externally rotated limb
   (c) Obligatory external rotation (Drehmann's sign) on flexion of the hip
   (d) Patients prefer to sit in a chair with the affected leg crossed over the other
   (e) Thigh and gluteal atrophy

## Classifications

Several classifications of SCFE has been evolved over the last 3 decades. Loder's classification is probably the most useful [17]. According to Loder, SCFE can be classified as being *stable* or *unstable*. He considered a slip as stable if walking and weight bearing was still possible with or without crutches, otherwise it was classified as unstable. There has been some confusion about this definition when a patient can stand or even walk but cannot weight bear on the affected leg. Such patient has a stable slip according to Loder's classification.

Loder reported on 55 SCFEs, 30 of which were unstable and 25 being stable. He showed that avascular necrosis (AVN) developed in 47% of unstable slips but in none of the stable hips. In a patient level meta-analyses, we found a similar trend with a pooled AVN rate of 1.5% for stable SCFE and 33% for unstable SCFE [18, 19].

Loder's classification prompted several authors to study the concept of slip instability further to better understand its relationship to the development of AVN. Kallio et al. [20, 21] suggested that a stable slip corresponds to an adherent physis during weight-bearing, active leg movements, and gentle joint manipulation. Physeal instability implied that the displaced epiphysis can move in relation to the metaphysis. In their study of 55 SCFEs, they found that physeal instability was better indicated by joint effusion and an inability to bear weight. A slip was very unlikely to be unstable in a child who was able to bear weight and has no joint effusion on ultrasound scan.

Ziebarth et al. [22] studied the anatomical relationship between the femoral head and neck. They coined the term "intra-operative stability", referring to when the physis was not disrupted and had no abnormal movement. This "intra-operative stability" was then compared to the "clinical stability" criteria of Loder in 82 patients with SCFE treated by open surgery. They found complete physeal disruption at open surgery in 28 of the 82 hips (34%). They calculated the sensitivity and specificity of Loder classification (stable and unstable) to predict physeal disruption (i.e. intra-operative instability) as 39% and 76%, respectively.

SCFE stability is a very interesting concept and the link to the development of AVN is beyond doubt. Mobility and weight bearing status, however, are only surrogates of slip stability. Although they are easy to identify, a search for a better predictor of future AVN is warranted.

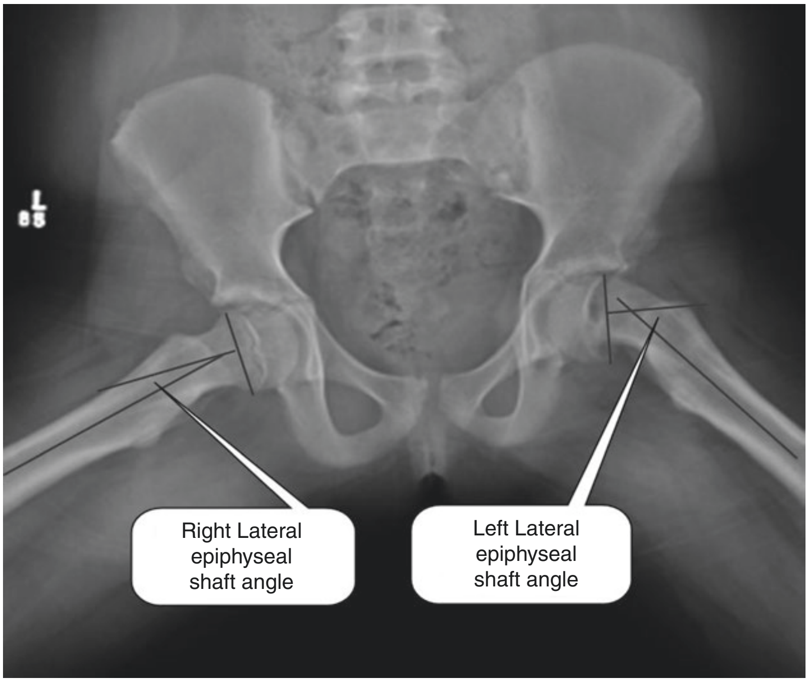


**Fig. 8.11** SCFE radiological grading using the Southwick angle. The Southwick angle is the difference between the lateral epiphyseal shaft angle of the slipped and the non-slipped sides. Mild slip (grade I) has an angle difference of less than 30°, moderate slip (grade II) has an angle difference of between 30° and 50°, and severe slip has a difference of over 50°

***"SCFE stability is a good predictor for future outcome. Stable slips have better outcome whereas unstable slips have poor outcome. Currently, weight bearing and ambulation are the most popular surrogates for stability but they may be not the best factors to consider".***

SCFE has also been classified according to symptom onset, including:

1. *Pre-slip*: The patient has symptoms with no obvious anatomical displacement of the femoral head on the metaphysis.
2. *Acute*: There is an abrupt displacement with symptoms and signs developing over a short period of time (less than 3 weeks).
3. *Chronic*: Symptoms and signs develop gradually over longer period (more than 3 weeks), associated with displacement.
4. *Acute on chronic*: initially, patient has chronic symptoms but subsequently develops acute symptoms accompanied by a sudden increase in the degree of slip.

The severity of the slip is another important factor in assessing and treating patients with SCFE. Two grading systems are currently in use, both of which are based on radiographic findings. Wilson measured the displacement of the femoral head relative to the neck on the anteroposterior (AP) view while Southwick measured the degree of angulation on the lateral views (Fig. 8.11) [2].

In practice, most clinicians tend to use a combination of the Loder classification and one of the radiographic classifications. There is some crossover between the classifications but severe slips are more likely to be unstable [23].

***"Most clinicians tend to use a combination of the Loder classification and one of the radiographic classifications when describing SCFE severity".***

## Imaging

### Plain Radiographs (AP and True Lateral Views)

The frog lateral view is not recommended in unstable slip as it may displace the slip further; however, it may be useful to evaluate a stable

**Fig. 8.12** A positive Trethowan's sign when the Klein's line intersect less epiphysis on the affected side

slip. The accuracy of the frog lateral view in assessing the severity of slip has been contested due to variations in positioning but the other suggested views are not flawless either. Several radiological signs have been reported to aid diagnosis such as:

1. Trethowan's sign is positive; a line (often referred to as Klein's line) drawn on the superior border of the femoral neck on the AP view should pass through the lateral aspect of the femoral head. In SCFE, the line passes over the head rather than through the head (Fig. 8.12).
2. Decreased epiphyseal height as the head is slipped posteriorly behind the neck (Fig. 8.13).
3. Remodeling changes of the neck with sclerotic, smooth superior part of the neck and callus formation on the inferior border. This may not be seen in acute slip.
4. Increased distance between the tear drop and the femoral neck metaphysis (Fig. 8.13).
5. Capener's sign: Normally, on the AP view, the posterior acetabular margin cuts across the medial corner of the upper femoral metaphysis. In SCFE, the entire metaphysis is lateral to the posterior acetabular margin (Fig. 8.14).
6. Widening and irregularity of the physeal line (early sign during pre-slip phase).
7. Steel's blanch sign: A crescent shaped hyperdense area in the metaphysis due to superimposition of the femoral neck and the head (Fig. 8.14).

**Fig. 8.13** Slipped capital femoral epiphysis: loss of epiphyseal height, increased the distance between the tear drop and the femoral neck metaphysis (red arrow) and the steel blanch sign (blue arrows)

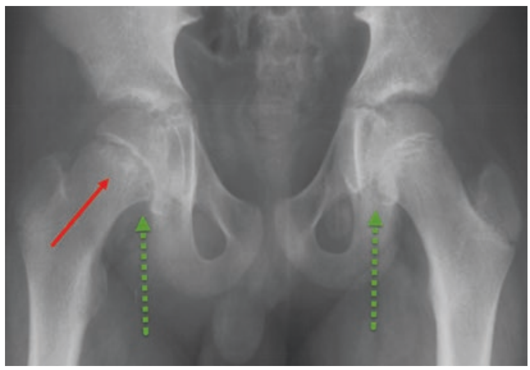

**Fig. 8.14** Radiological signs of slipped capital epiphysis: widening of the physis over the right side; Steel's blanch sign (red arrow) and Capener's sign (green arrow)

## Computed Tomography (CT)

It is not essential to use CT to diagnose and treat SCFE. However, it can be valuable in:

1. Assessing the anatomical features accurately (such as degree of the slip, head–neck angle, retroversion, the severity of residual deformity, presence of callus etc.).

2. Ruling out penetration of the hip joint by metalware after surgery.
3. Confirming closure of the proximal femoral physis.

### Ultrasound

Ultrasound can be helpful to assess the stability of slip. The presence of a joint effusion is suggestive of an acute/unstable slip. 'Step off' at the level of the slip could be noted as well, signifying displacement. Absolute displacement of greater than or equal to 6 mm, or relative displacement of greater than 2 mm when compared with the unaffected side, were considered diagnostic of a slipped epiphysis on ultrasound.

### Magnetic Resonance Imaging (MRI) and Bone Scanning

MRI can be useful to assess equivocal cases of SCFE in the preslip stage, where it may not be easily identifiable on plain radiographs (Fig. 8.15). MRI has been used in the assessment of the avascular necrosis of the femoral head post SCFE. Furthermore, perfusion MRI scan has been found to be useful to assess the vascularity of the femoral head [24]. dGEMRIC scans have been used to assess the cartilage wear in the femoroacetabular impingement cases. In case of metal artefact disturbances, bone scan can help to decide the vascularity of the femoral head. Bone scan has 100% negative predictive value for AVN [25] of the hip.

**Essential Imaging Tests and Measurements**

1. Plain radiography
   (a) Make the diagnosis
   (b) Assess the severity (Southwick angle)
2. CT scan
   (a) Is there callus and how much remodeling is present?
   (b) Preoperative planning for screws placement
   (c) Postoperative to rule out screw penetration into joint
3. MRI scan
   (a) Establish the diagnosis in equivocal cases (pre-slip)
   (b) Is there AVN?

## Non Operative Management

There is a universal consensus that SCFE should be treated operatively to prevent progression of the slip. Severe and, to a lesser extent, moderate slips could be reduced to an anatomical or near anatomical position but the risk of surgery—including AVN and chondrolysis (CL)—are major concerns.

Non operative treatment in the form of bed rest and traction are usually used as temporary measures until investigations are completed or definite surgery is performed. Although hip spica casting was used as a definitive treatment in the past, it is obsolete now days due to poor outcomes (AVN rate of 8% and chondrolysis of 20%) [9, 18, 19, 26, 27]. Hip spica may be used, however, to protect SCFE stabilization for cases where the fixation is not adequate, the bones are osteopenic, or the patients are deemed to be unreliable.

> ***"Slipped capital femoral epiphysis should be treated operatively to prevent progression of the slip"***

## Operative Management

As previously discussed, Loder and colleagues identified two types of SCFE and showed that AVN developed in 47% of unstable slips but in none of the stable slips. These findings have been replicated by others [28–32]. It has since become apparent that these two types of SCFE behave differently in term of presentation, progression and complications. Their respective treatments are no exception.

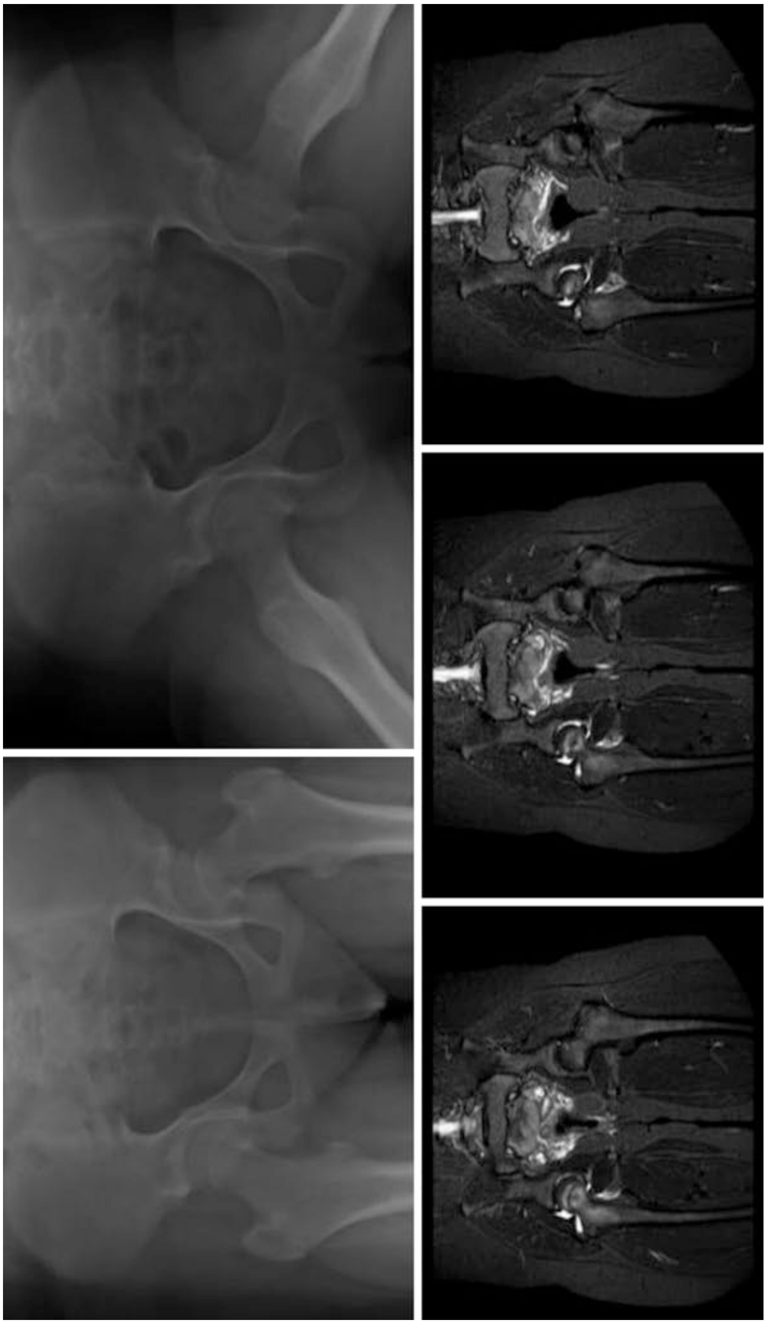

**Fig. 8.15** Subtle SCFE. MRI scan confirmed the diagnosis showing high signal in the peri-physeal area of the right hip

## Treatment of Stable SCFE

The current golden standard treatment of choice for mild and most moderate stable slip is pinning-in-situ (PIS) using a single cannulated screw (SS) [19, 33]. If the slip is severe, pinning in situ can be technically difficult, if not impossible. Closed reduction is often unsuccessful and not advisable in a stable SCFE because of the risk of AVN. For these cases, the options are either performing a primary corrective osteotomy or PIS (if possible) with a secondary re-alignment osteotomy at a later date depending on the extent of post-operative remodeling.

Several primary corrective osteotomies have been recommended for the treatment of SCFE. In stable slip, the surgical hip dislocation approach described by Ganz has shown superior results to all other re-alignment procedures in term of AVN rates and patient satisfaction (Table 8.1) (Fig. 8.16). Table 8.1 was reproduced from a recent systematic review and patient level analysis of 2227 stable SCFEs drawn from 41 studies (none were randomised controlled trials) that met the authors' inclusion criteria [19]. The review compared several techniques to treat stable SCFE and showed that the type of surgical intervention is an important risk factor for AVN. Pinning in

**Table 8.1** Pooled summary of studies of stable slips treatments [19]

| Intervention | Hips | AVN (%) | CL (%) | Satisfactory patients result[a] |
|---|---|---|---|---|
| Hip spica | 101 | 9 (9%) | 21 (20.8%) | NR |
| Epiphysiodesis | 464 | 14 (3%) | 8 (1.7%) | 67 (67%) excellent<br>6 (6%) good<br>10 (10%) fair<br>7 (7%) poor<br>7 (7%) failure |
| Pinning using single screw | 722 | 11(1.5%) | 15 (2.1%) | 113 (47%) excellent<br>86 (36%) good<br>19 (8%) fair<br>10 (4%) poor<br>11 (5%) failure |
| Pinning using multiple pins | 273 | 6 (2.2%) | 11 (4%) | 76 (67%) excellent<br>19 (17%) good<br>0 (0%) fair<br>16 (14%) poor<br>3 (3%) failure |
| Physeal osteotomy | 615 | 68 (11.1%) | 60 (9.8%) | 131 (28%) excellent<br>210 (45%) good<br>46 (10%) fair<br>72 (16%) poor<br>3 (6%) failure |
| Ganz surgical dislocation | 95 | 3 (3.1%) | 2 (2.1%) | 52 (87%) excellent<br>2 (3%) good<br>0 (0%) fair<br>5 (8%) poor<br>1 (2%) failure |
| Base of neck osteotomy | 92 | 2 (2.1%) | 6 (6.5%) | 22 (60%) excellent<br>11 (30%) good<br>2 (5%) fair<br>2 (5%) poor |
| Inter-trochanteric osteotomy | 336 | 5 (1.5) | 16 (4.8%) | 121 (44%) excellent<br>105 (38%) good<br>35 (13%) fair<br>15 (5%) poor |

[a]Satisfactory patients result based on closely related rating such as Heyman and Herndon classification, Harris hip score or Iowa hip scores


**Fig. 8.16** Ganz surgical hip dislocation. This child presented with severe stable left SCFE. He had a previous hip surgery for right hip congenital dislocation with type II growth disturbance. Pinning in situ is a safe option when the expertise to surgical dislocation is not available; however, patient satisfaction is low. The Ganz surgical hip dislocation can potentially restore the anatomy to almost normal (*see Surgical Technique description in the Operative Management section*)

situ was associated with the lowest AVN rate (1.5%). Moreover, the CL, FAI and OA rates were relatively low in patients who underwent pinning in situ. However, these low complication rates were not translated into high patient satisfaction rates among these patients with 47% only reporting an "Excellent" outcome. In contrast, although the Ganz surgical dislocation was associated with an AVN rate of 3.3%, 87% of patients reported an "Excellent" outcome. Furthermore, five of the seven studies which investigated the Ganz surgical hip dislocation reported AVN rates of 0%.

Secondary realignment procedures be performed at one of three levels: subcapital (Ganz, Dunn, or Fish osteotomies) [34–36], base of the femoral neck (Kramer and Barmada) [37, 38] intertrochanteric (Imhauser osteotomy) [39] or subtrochanteric (Southwick osteotomy) [40] levels (Fig. 8.17).

Anatomical correction can be best achieved by an osteotomy at the subcapital level (at the Center of Rotation of Angulation (CORA)) and least achieved with intertrochanteric or subtrochanteric osteotomies. However, the risk of AVN is the highest with a subcapital level osteotomy (reported to be 3–11%), less with base of neck osteotomy (2.1%) and the lowest with intertrochanteric osteotomy (1.5%) (Table 8.1). It is not surprising to see patient satisfaction correlates directly to techniques that better correct the anatomical deformity. If older subcapital osteotomy techniques (i.e. those reported by Dunn and Fish) are excluded, 87%, 60%, and 44% patients reported excellent outcomes according to site of osteotomy, respectively.

**Fig. 8.17** Imhaser osteotomy. This 16-year-old girl presented with substantive hip impingement symptoms following pinning in situ of stable SCFE. The screw was removed in hope to improve her symptoms. Her X-rays showed features of osteoarthritis (subchondral bone sclerosis, narrowing of joint space and subchondral bone cysts). Surgical options included Ganz surgical hip dislocation, open or arthroscopic femoral osteochondroplasty, subcapital osteotomy, intertrochanteric osteotomy, or a combination of these. She opted to have an intertrochanteric osteotomy (Imhauser) and future arthroscopic osteochondroplasty if her symptoms continued. The bottom picture is 1 year after her initial surgery. At that point, she was completely asymptomatic and her radiological features of osteoarthritis have improved dramatically. The authors believe further arthroscopic surgery is warranted to prevent subclinical impingement damage

> ***"Mild and most moderate stable slips can be treated with pinning-in-situ. If the slip is severe, pinning in situ can be technically difficult if it is not impossible. For these cases, the options are either performing a primary corrective osteotomy using the Ganz surgical hip dislocation or pinning in situ (if possible) with a secondary re-alignment procedure at a later date".***

Residual deformity that has not improved naturally by remodeling, or by any of the above procedures, can be treated with femoral head/neck osteochondroplasty (Fig. 8.18). This can be performed arthroscopically, through a limited anterior arthrotomy, or by surgical hip dislocation.

## Treatment of Unstable SCFE

The principle of treating the unstable slip is essentially the same as for stable slips: stabilize the slip to prevent further progression without increasing the risk of complications. However; there are two important considerations:

1. There is a high risk of AVN associated with the unstable slip.
2. Unstable slips usually undergo spontaneous reduction intra-operatively and the severity of the slip can improve substantially with gentle (unintentional!) positioning of the patient.

Several interventions to treat unstable SCFE have been reported. These have been the subject of a recent systematic review and patient level analysis [18]. This review included 25 studies, providing data on 679 unstable SCFEs. The

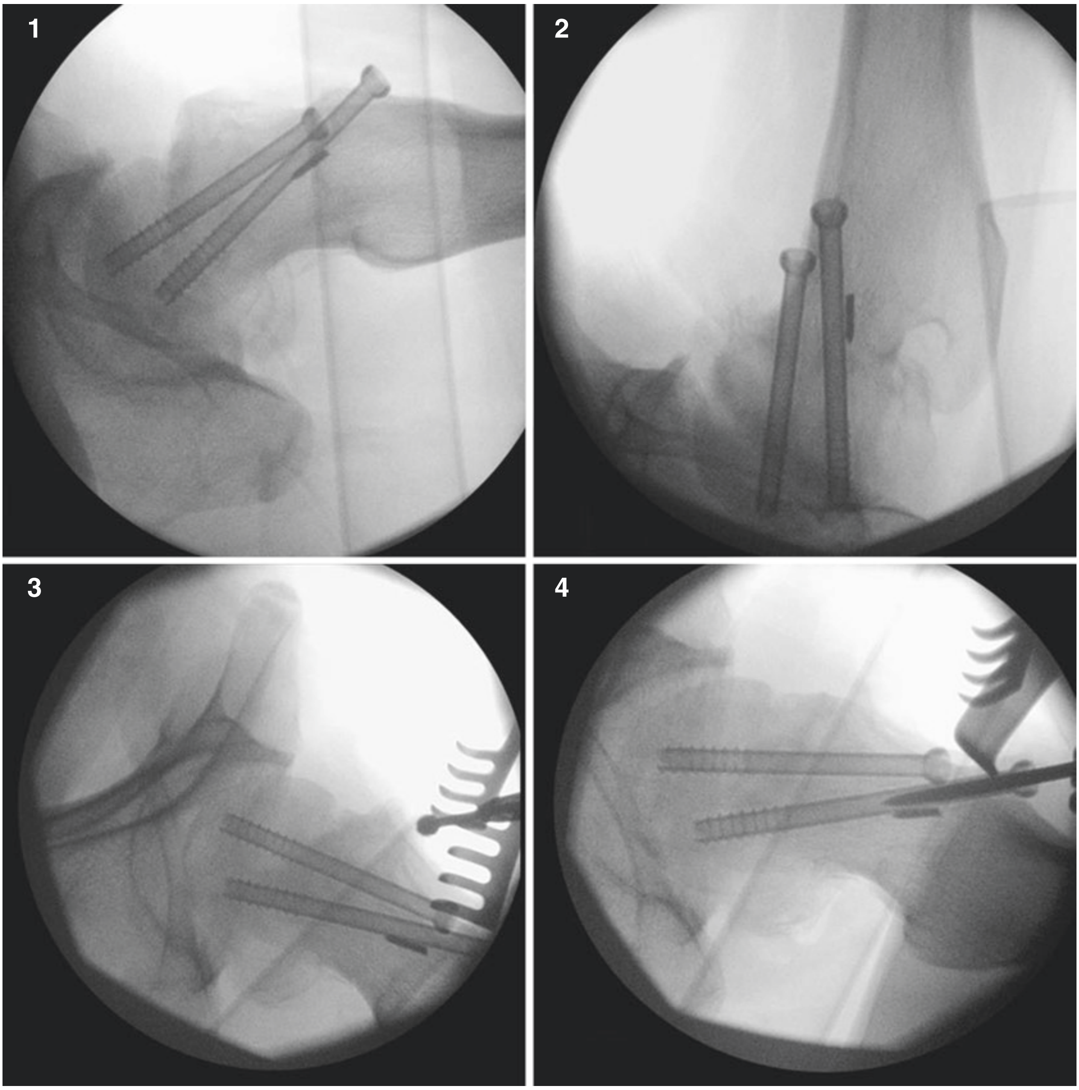


**Fig. 8.18** Femoral head osteochondroplasty. Osteochondroplasty can improve the range of motion and symptoms dramatically. The below patient was not able to flex her hip more than 60° without pain. The femoral neck deformity (image 1) was flattened using a burr (images 2 and 3). She achieved an almost full flexion (image 4) with minimal discomfort. Although osteochondroplasty can improve some of the out toeing gait, it is not as effective as femoral osteotomy. This is important when consulting patients

interventions that were assessed included: epiphysiodesis [41, 42], pinning in situ [29, 32, 43–50], closed reduction and pinning (CRIF) [17, 30, 41, 43, 46, 47, 51–56], open reduction and physeal osteotomy (PO) [29, 32, 47, 57], open reduction and internal fixation (ORIF) [54–56, 58], and surgical hip dislocation (SD) [47, 49, 59–61]. Four cases that were treated with hip spica were excluded from the analysis, three of which went on to develop AVN (75%) [41].

The findings of the review are summarized in Table 8.2. The AVN rates among these interventions ranged from 5% to 33%. Open reduction and internal fixation using the Parsch technique [58] had the lowest AVN rate at 5%. This was a statistically significant finding ($p < 0.05$).

**Table 8.2** Pooled summary of studies of unstable slips treatments [18]

| Interventions | Hips | AVN (%) |
|---|---|---|
| Epiphysiodesis | 64 | 7 (11%) |
| Pinning in situ | 115 | 38 (33%) |
| Closed reduction and pinning | 269 | 71 (26%) |
| Open reduction and internal fixation (Parsch technique) | 84 | 4 (5%) |
| Physeal osteotomies (Dunn or Fish) | 59 | 10 (17%) |
| Ganz surgical dislocation | 70 | 13 (18%) |
| Total | 661 | 143 (22%) |

Excluding the Parsch study, the differences among various interventions were not statistically significant. Several centres have since started using the Parsch technique and it will be interesting to see whether Parsch's findings will be replicated in other centres. Ganz reported a 0% AVN rate in unstable SCFE from Inselspital in Bern, Switzerland [61] but this rate was not replicated by other centres with pooled AVN rates for the surgical hip dislocation approach being 18%. Interestingly, Parsch's centre is moving more towards using Ganz's surgical dislocation technique rather than the ORIF technique they reported (personal communication).

## Timing of Surgery

Timing of surgery is an important consideration in unstable slips because there is increasing evidence that early surgery (within 24 h) is likely to result in a lower AVN rate. Given the frequency of the unstable SCFE, most studies that have investigated the timing of surgery and the respective outcomes are small. As such, a pragmatic approach is recommended. In a recent systematic review and exploratory patient level analysis [18], we reported on 358 unstable SCFE with an AVN rate of 13.3% (28/210) for those hips that were treated within 24 h. Of the hips treated between 24 and 72 h, an AVN rate of 40% (38/95) was found. For hips treated after 72 h, an AVN rate of 14.8% (5/53) was found.

Other smaller studies showed similar findings [32, 41, 62]. Hence, the aim is to stabilize unstable SCFE within 24 h of the event. However, if this is not possible for any reasons, the current evidence supports delaying surgery for at least a week to allow the inflammation to subside as high rates of AVN had been noted when unstable SCFE is stabilized between 48 to 72 h after the presentation. A similar but not identical phenomenon has been noted in distal tibial pilon and ankle fractures when early operation before swelling starts or delaying the surgery until swelling subsides reveal better results. Further research is required to identify the optimal timing of surgery and the reasons to support it.

> ***"Timing of surgery is important in unstable slips. The type of surgery remains controversial"***

## Prophylactic Pinning of the Contralateral Non-slipped, Asymptomatic Side

It is always wise to image both hips as some studies showed that 20% of slips are bilateral at presentation. The rest might develop a contralateral slip within 12–18 months from the date of index slip (see *Epidemiology* section). The reported risk of contralateral slip varies from 18% to 60% [63, 64]. Most were mild slips and they rarely went on to develop AVN. Prophylactic pinning is not free of risks, however, these should be weighed against the benefits. The complication rates associated with prophylactic pinning have been reported to be approximately 5%, including AVN and peri-prosthetic fracture [63, 65, 66]. Bearing these in mind and the fact that most patients with SCFE will not have a contralateral slip, routine prophylactic pinning of contralateral side should be avoided.

Several authors proposed clinical and radiological criteria to aid decision making on whether to prophylactically stabilize the other side or not. Stasikelis et al. [67] proposed using the modified Oxford bone age score to help in decision making. The score is based on the appearance and fusion status of the iliac apophysis, femoral capital physis, greater and lesser trochanters. It ranged from 16–26. They found that the score strongly correlated with the risk of development of a contralateral slip. Contralateral slip did not develop in any patients with a score above 22 whereas it developed in 100%, 97%, 85%, 44% and 5% when scores were 16, 17, 18, 19, and 20 respectively. The original study was performed on a retrospective series of 50 children with SCFE. It was re-validated on a bigger series of 260 patients with consistent findings [68].

The modified Oxford bone age is not widely used because of the complexity of the scoring system, difficulty in viewing all five radiographic features on a single X-ray, and phenotypic variation. Nicholson et al. [69] proposed a calcaneal apophyseal ossification sequence for predicting modified Oxford hip scores and risk of contralateral slip. They studied 279 pelvises and matching foot X-rays that—taken at the same session—from 94 healthy children aged 3–18 years. The modified Oxford hip scores were compared with calcaneal scores for each set of matched hip and calcaneal X-rays and the weighted risk of contralateral slip was subsequently calculated. They estimated that the weighted risk of contralateral SCFE was 94% for calcaneal stage 0, 86.5% for calcaneal stage 1, 90.3% for calcaneal stage 2, 55.8% for calcaneal stage 3, 6.1% for calcaneal stage 4, and 0 for calcaneal stage 5. They concluded that calcaneal stages 0–3 reliably correspond to modified Oxford scores associated with an elevated risk of contralateral SCFE. The main drawback of this score is the extra X-ray that is required to establish the calcaneal stage compared to the modified oxford hip score which can be calculated from an X-ray that is already available.

Phillips et al. [70] examined the posterior sloping angle (PSA) in 132 patients as a predictor for contralateral slip (Fig. 8.19). They found that the mean PSA was 17.2° ± 5.6° in 42 patients who had subsequently developed a contralateral slip, compared to 10.8° ± 4.2° for the 90 patients who did not develop contralateral slip ($p = 0.001$). They concluded that if a PSA of 14° or greater was used as an indication for prophylactic fixation, 83% of contralateral slips would have been prevented but 21% would have been pinned unnecessarily.

All the above methods are not perfect and clinical judgment is the key. The authors recommend a pragmatic approach for contralateral pinning, considering the following factors to help in decision making:

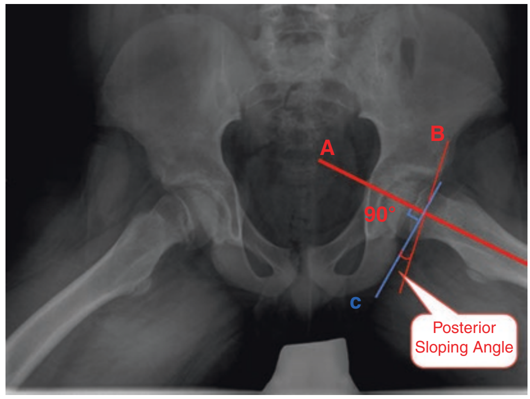


**Fig. 8.19** 8.45 angle (PSA) is measured by a line (A) through the center of the femoral shaft and metaphysis. A second line (B) is drawn from one edge of the physis to the other, which represents the angle of the physis. Where lines A and B intersect, a line (C) is drawn perpendicular to line A. The PSA is the angle formed by lines B and C posteriorly, as illustrated

1. Age of the child; less than 10 years old is associated with a higher risk of contralateral slip.
2. Slips associated with renal osteodystrophy and endocrine disorders have a higher risk of contralateral slip.
3. Anticipated poor compliance of the child and family.
4. The nature of the current slip; rapid progression and severity of the index slip may justify pinning the contralateral side.
5. PSA greater than 14° and/or a modified Oxford score of 16 or to 18.

## Surgical Technique: Pinning In Situ for SCFE

1. Supine position on fracture table or radiolucent table (surgeon's discretion) (Fig. 8.20).
2. For an unstable slip, the fracture table is preferred to avoid risk of further displacement and damage to femoral head vascularity. Do not forcefully internally rotate the hip to avoid AVN in unstable SCFE.

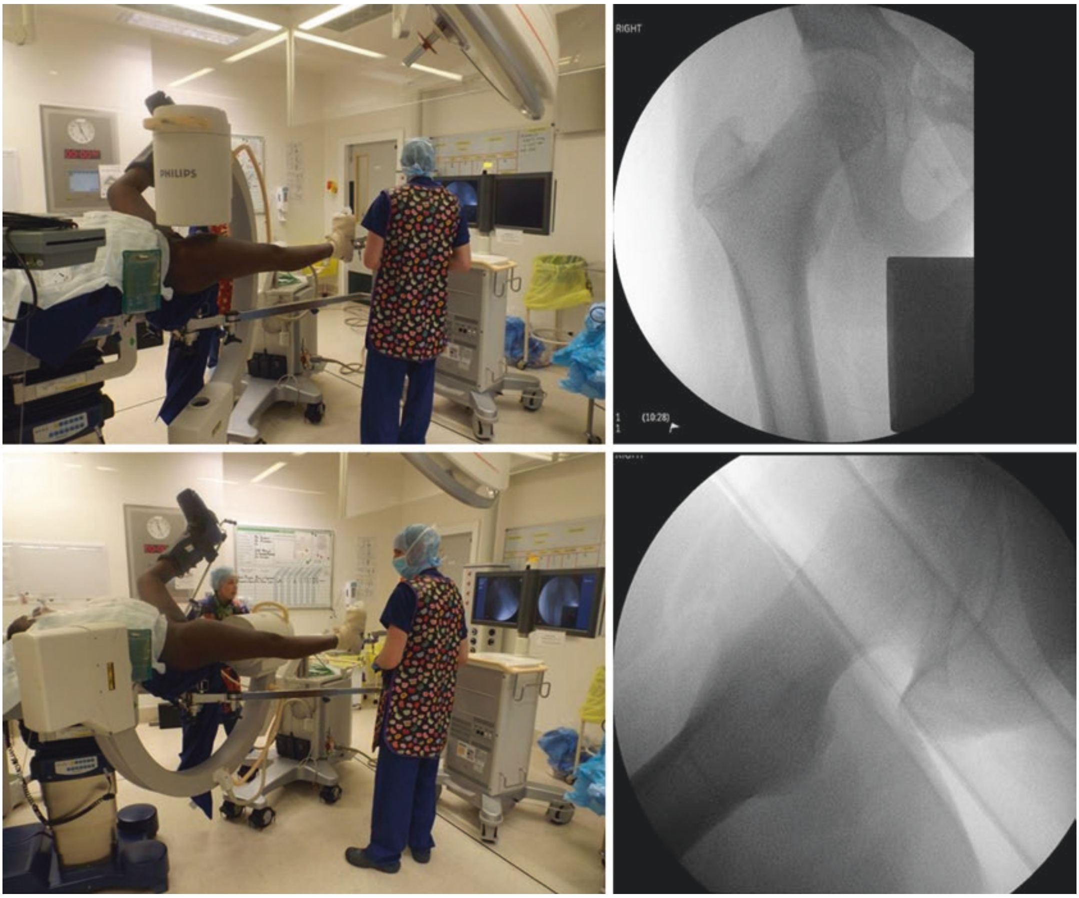


**Fig. 8.20** Patient positioning using the fracture table

3. Obtain AP and lateral images before prepping to ensure adequate femoral head visualization.
4. Mark the guide wire trajectory on AP and lateral views with the wire at the centre of the femoral head and perpendicular to the physis. The entry is at or proximal to the intersection of these two lines (Fig. 8.21).
5. Due to posterior slip displacement, the screw entry point is usually near the base of the femoral neck anteriorly.
6. Try to stay at or distal to the intertrochanteric line to avoid screw head impingement with hip flexion. Avoid a subtrochanteric entry point as it increases the risk of postoperative fracture.
7. Under AP and lateral image guidance, advance the terminally threaded guidewire perpendicular to the physis and into the centre of the femoral head. Advance the guidewire as far as possible into the subchondral bone without penetrating the hip joint.
8. When necessary, the entry point for the guide wire can be made deeper by rotating at the perched point, facilitating a change in guidewire trajectory angle without slipping off the bone (Fig. 8.22).
9. Measure the length of the screw off the guide wire, keeping in mind the distance of the wire tip from the subchondral bone. Aim to get at least 4–5 screw threads into the epiphysis with a minimum of at least three.
10. Drill over the guidewire, stopping 5–10 mm short of the wire tip to avoid wire loosening and back out.

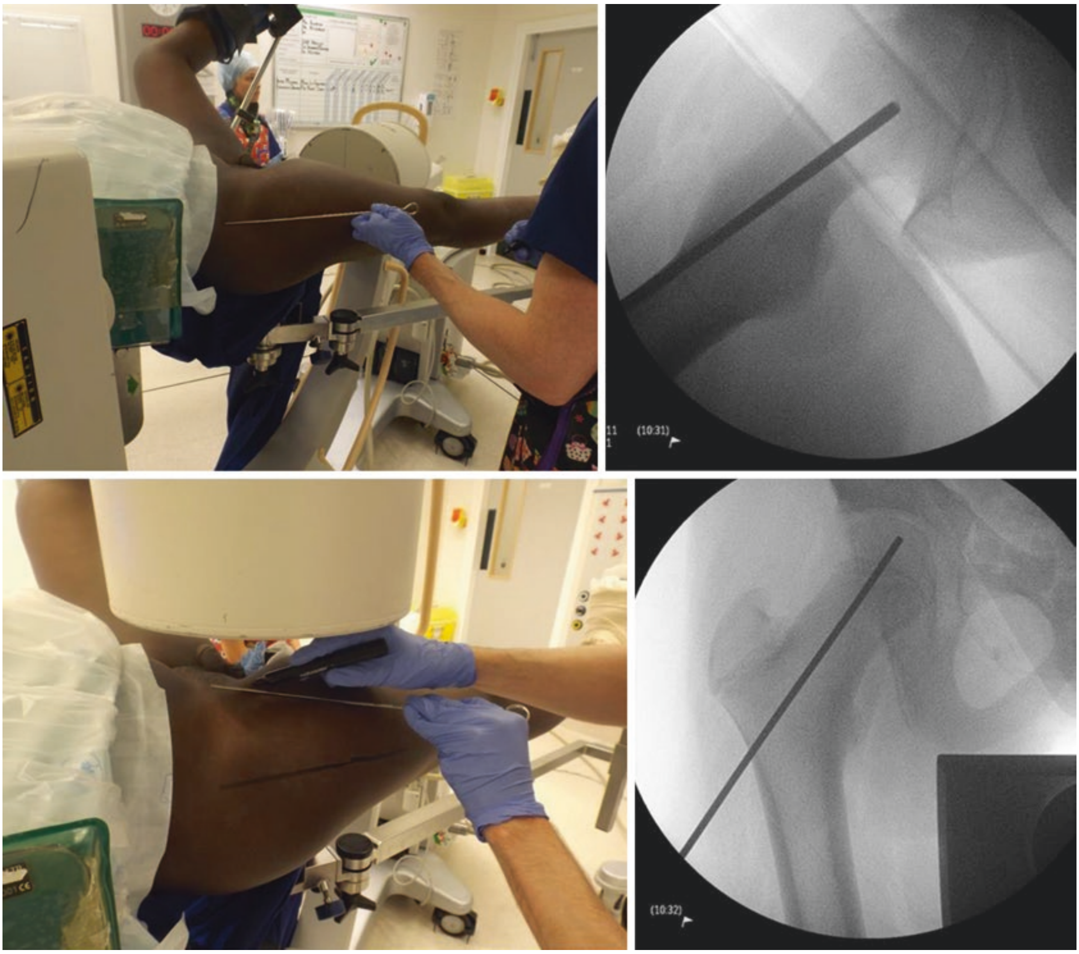

**Fig. 8.21** Marking the lines of trajectory for screw placement

11. Insert either a 6.5 mm or 7.3 mm fully threaded cannulated cancellous screw over the guidewire, taking care not to penetrate the joint (Fig. 8.23). For unstable slips, a second screw might be placed to enhance the stability of fixation. The second screw needs to be placed in an inferior position to avoid the vulnerable superior part of the head which allows the lateral epiphyseal vessels entry. A derotation wire might also be placed to avoid torque on the femoral epiphysis during drilling and screw insertion.
12. If a radiolucent table is used, the fascia needs to be incised to avoid bending of the guide wire when taking frog lateral views by flexing and abducting the hip.
13. Finally the screw tip position should be checked using the approach-withdraw (i.e. 'near-far') method to ensure there is no screw penetration into the joint. In this technique, the hip is moved from internal to external rotation in various degrees of flexion under live fluoroscopy, during which the screw tip would approach near the subchondral bone and move away from it as the hip is rotated from internal rotation to external rotation. The point at which the approaching screw tip withdraws from the subchondral bone determines the shortest distance from the screw tip to the subchondral bone. If at any point if the screw tip projects beyond the subchondral bone, then we know that the

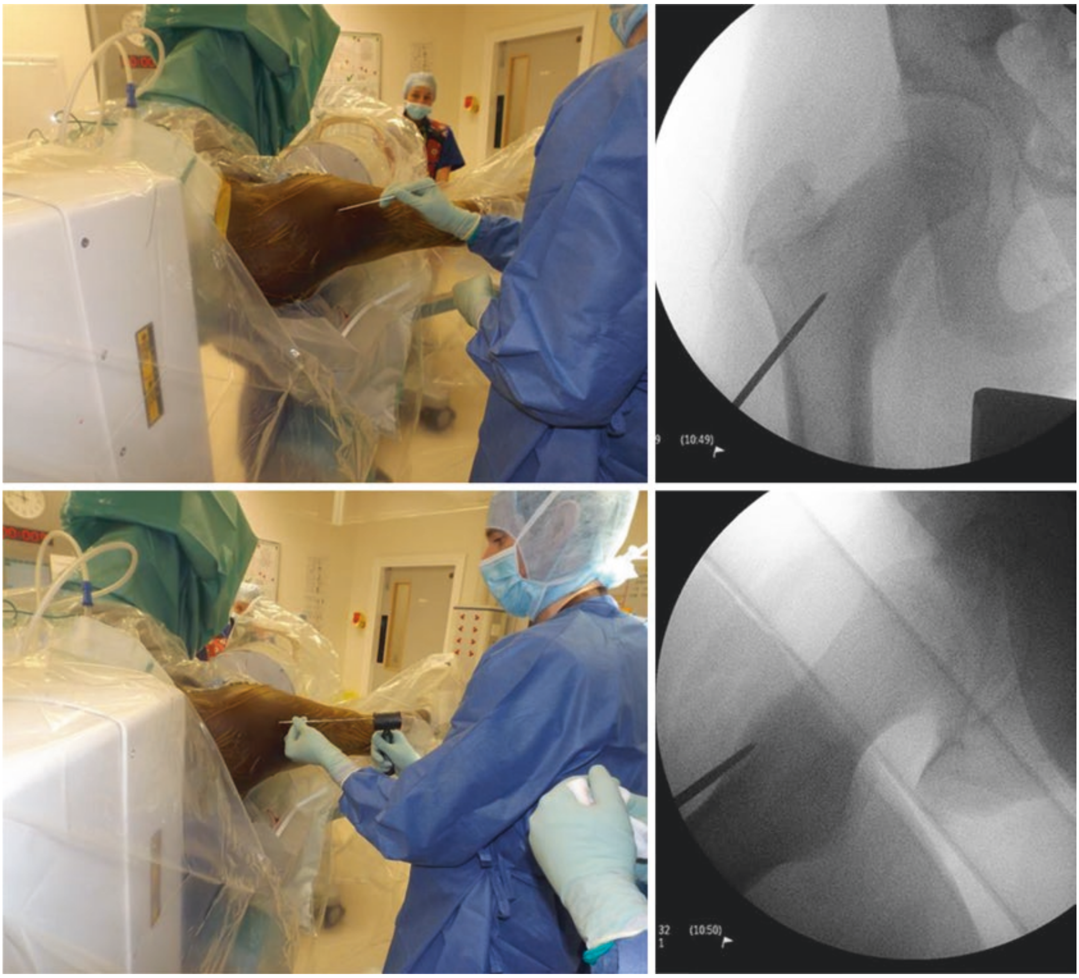


**Fig. 8.22** Anchoring the guide wire at the entry point

tip is intra-articular. If using a fracture table, it is easier to ask an unscrubbed assistant to take the boot off the traction and rotate the leg as above to check the blind spot (Fig. 8.24).

## Surgical Technique: Parsch Method of Pinning an Acute, Unstable SCFE

1. The patient is positioned supine on a radiolucent table with a sand bag elevating the hip. A Watson Jones (anterolateral) approach is performed with exposure down to the hip joint capsule.
2. An anterior longitudinal capsulotomy is performed, followed by evacuation of hematoma and intra-articular clots.
3. A K wire is placed in the centre of the metaphysis under X ray control, stopping just short of the proximal femoral physis (Fig. 8.25).
4. The surgeon's fingertip feels for the gap between the epiphysis and metaphysis.
5. The scrubbed assistant is then instructed to gently flex, abduct, and internally rotate the hip. Care is taken to avoid any jerky, abrupt or rash movements. The gentleness of reduction is entirely controlled by the surgeon's finger at the level of the slip.

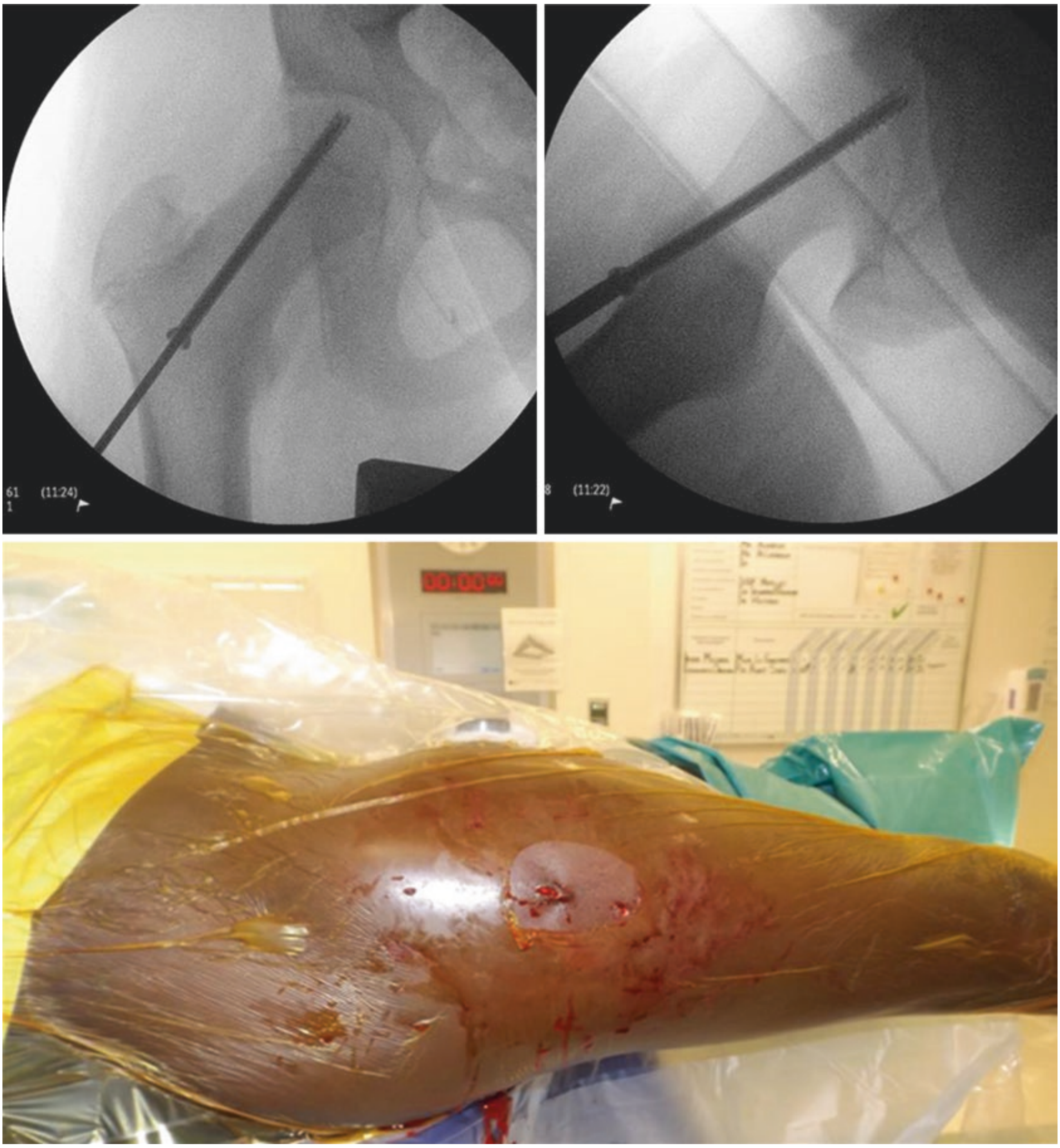


**Fig. 8.23** Top images: Advancing the screw with 3–5 threads in the epiphysis. Bottom image: Making a larger hole in the Ioban to prevent it from wrapping around the guide wire. The other leg should be lowered down as soon as the c-arm machine is not required any more

6. The SCFE is not reduced beyond the unstable part of the slip. Any stable part of the slip—with residual deformity—is accepted.
7. Care should be taken not to crush the finger of the surgeon while manoeuvring the hip during the gentle reduction.
8. The K wire is then advanced into the epiphysis, stopping short of the joint surface.
9. The wire position is confirmed using fluoroscopy for both AP and lateral views.
10. Two additional K wires are inserted under X ray control to enhance the stability of fixation.
11. The wires are bent to 90° to avoid proximal migration in to the joint and also to prevent catching the soft tissues (especially the tensor fascia lata).

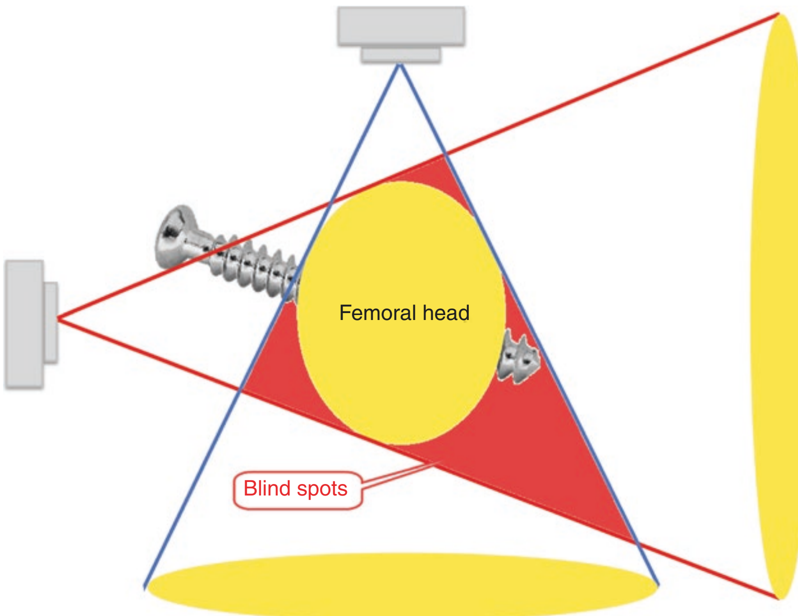


**Fig. 8.24** The Blind spot. The blind spots (red) of orthogonal imaging demonstrate the need for live fluoroscopy using the withdraw method to avoid missing intra-articular screw placement

12. The wires are changed at follow-up if the physis has grown off of the wires.
13. The authors have modified the technique, substituting the K wires for cannulated screws.

## Surgical Technique: Ganz Surgical Hip Dislocation Approach

1. The patient is placed in a lateral decubitus position, held with hip positioners and a large pillow below the affected side to relax the abductors. Bony prominences are well padded (Fig. 8.26). X-ray screening is performed before draping to ensure adequate visualisation of all important landmarks.
2. A plastic hip drape is used to allow placement of the leg into a sterile bag during the anterior dislocation manoeuvre.
3. Gibson's approach is utilized, with an incision over the anterior third of greater trochanter, extending proximally to just below the iliac crest and distally 6–8 cm below the vastus ridge.
4. The anterior border of gluteus maximus is identified with the help of the perforators from the inferior gluteal artery (Fig. 8.27).
5. The gluteus maximus is dissected off the tensor fascia lata and the fascia lata is split distally.
6. The vastus lateralis and intermedius are raised off the periosteum distally.
7. The posterior border of the gluteus medius is identified (Fig. 8.28, green arrow) and the anterior border of piriformis is delineated (Fig. 8.28, yellow arrow).
8. The posterior border of gluteus medius is identified and the plane between this muscle and the hip joint capsule (Fig. 8.29, red arrow) is exposed using a Hohmann retractor.
9. With the hip internally rotated, the line of trochanteric osteotomy is marked from the posterior border of the gluteus medius to the vastus ridge. A 15 mm thick trochanteric flip osteotomy is then made with a power saw (Fig. 8.30, image 1). The trochanteric flip osteotomy is completed with a flat osteotome anteriorly (Fig. 8.30, image 2).
10. The remnant of gluteus medius (Fig. 8.31, green arrow) attached to the stable trochanter is released. The trochanteric flip is mobilized anteriorly and held with a Hohmann

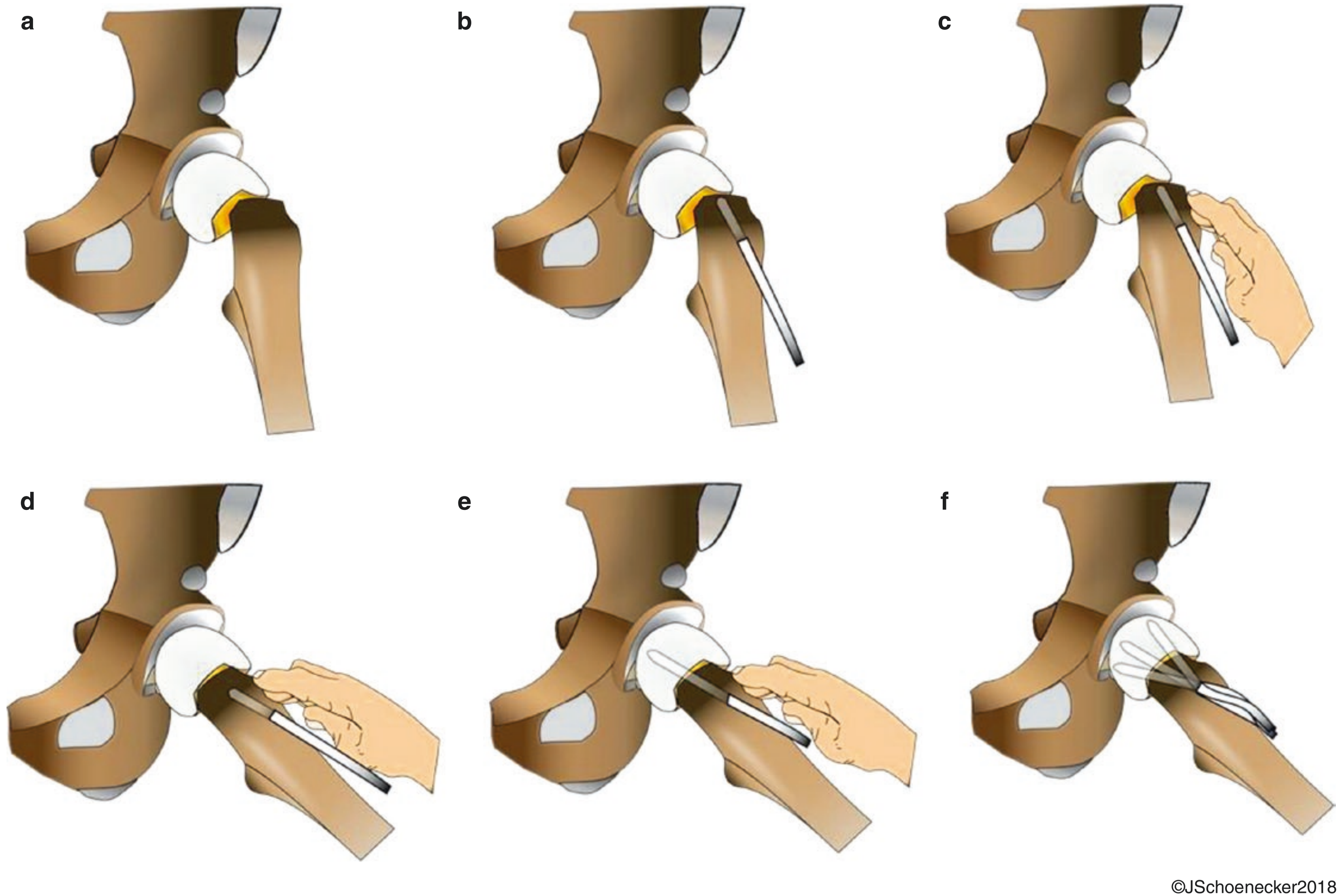


**Fig. 8.25** Parsch technique for treatment of unstable slip. (**a**) Patient positioned supine on a radiolucent table. (**b**) A K wire is introduced just short of the metaphyseal border. (**c**, **d**) Joggling manoeuvre to reduce the unstable part of the slip, controlled by the surgeon's fingertip. (**e**) The K wire is advanced after achieving the reduction of the unstable slip component. (**f**) Additional K Wires are added to enhance the stability of fixation

**Fig. 8.26** Positioning and padding bony prominences

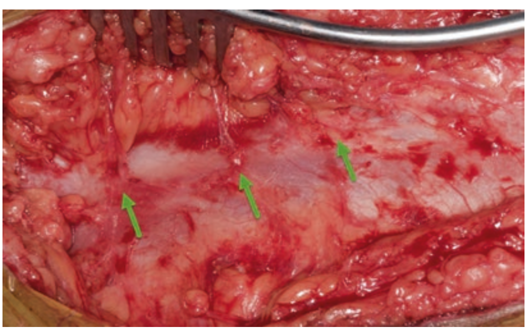

**Fig. 8.27** Gibson approach (the anterior border of gluteus maximus is identified with the help of the perforators from the inferior gluteal artery)

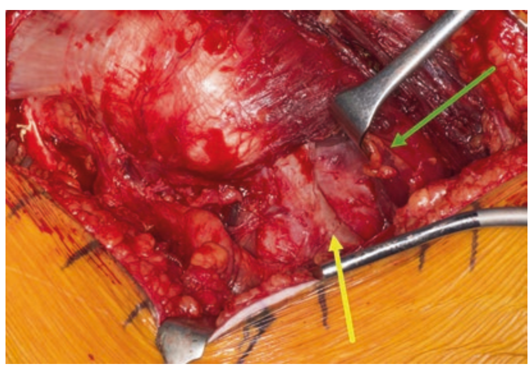

**Fig. 8.28** Identifying the plane between piriformis (yellow arrow) and gluteus medius (the green arrow)

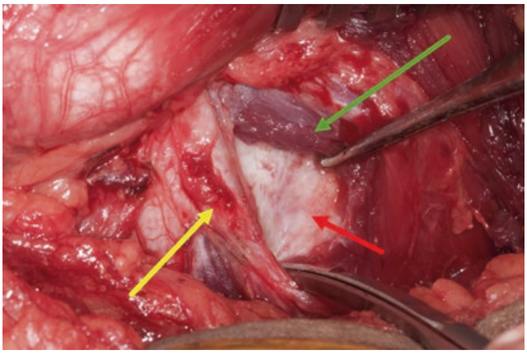

**Fig. 8.29** Exposing the hip joint capsule (red arrow) underneath the glutei muscles (green arrow) and above the piriformis (yellow arrow)

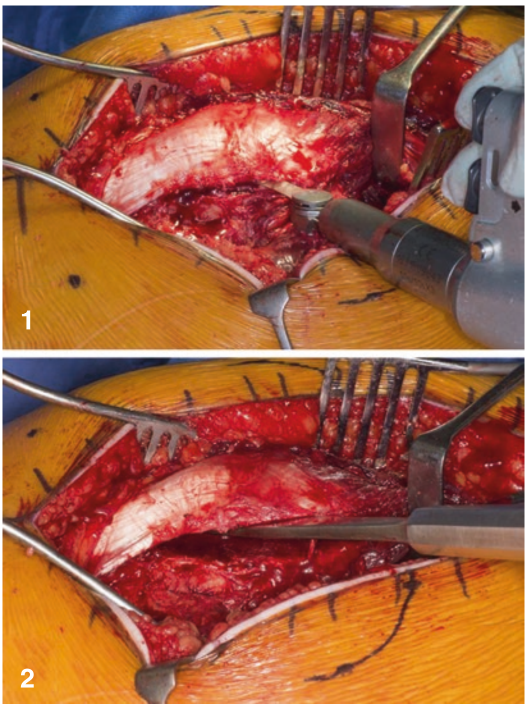


**Fig. 8.30** Flip trochanteric osteotomy. 15 mm thick trochanteric flip osteotomy is made with a power saw (image 1). The anterior border of the trochanter is completed using a flat osteotome (image 2)

retractor impacted in to the anterior acetabulum. Gluteus minimus is dissected from the capsule (Fig. 8.31, red arrow) anteriorly.

**Fig. 8.31** Full exposure of the capsule. The trochanter is lifted anteriorly and the capsule carefully exposed to allow a full view of the capsule from the acetabular edge until the greater trochanter

11. Staying proximal to piriformis tendon is critical to avoid injury to the medial femoral circumflex artery and the trochanteric anastomosis.
12. A 'Z' shaped capsulotomy is then performed, dividing the capsule along the femoral neck while protecting the femoral head and the labrum. This is carried distally along the intertrochanteric line to the lesser trochanter and proximally along the acetabular margin to the piriformis (dashed green line in Fig. 8.32).
13. Under direct vision, the femoral epiphysis is secured provisionally with two K-wires to avoid any further slippage during the dislocation maneuver. A single k-wire is not optimum to safely dislocate the femoral head. At this point, it is important to drill a hole in the femoral head to check its vascularity (Fig. 8.33).

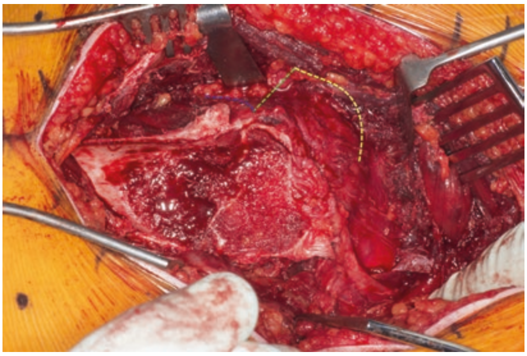

**Fig. 8.32** Z-capuslotomy: the capsule is first divided along the femoral neck (dashed green line) while protecting the femoral head and the labrum. This is carried distally along the intertrochanteric line to the lesser trochanter (dashed blue line) and proximally along the acetabular margin to the piriformis (dashed yellow line)

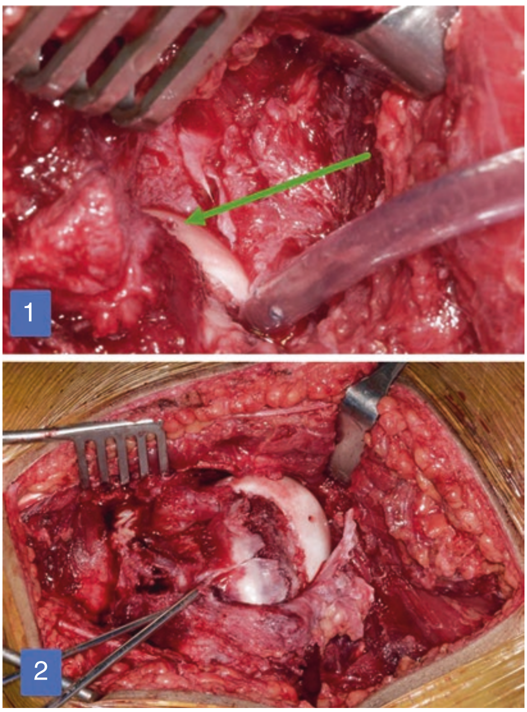


**Fig. 8.33** It is important to establish head vascularity before dislocating the femoral head. A 2 mm drilled hole of the femoral head (green arrow) is made in the epiphysis (image 1). The direction of the drilling should be away from the physis to avoid a false positive. In this case, there was no bleeding from the femoral head, an expected finding based on results from the preoperative MRI scan (image 2)

14. Several methods have been proposed to monitor femoral head vascularity (Figs. 8.33 and 8.34). The best method has not yet been established. It is the authors personal experience that intraoperative vascularity of the femoral head does not always correlate with the postoperative course.
15. The ligament teres is divided using the long curved scissor. With the slip secured with K wires, the hip is dislocated and the femoral head and acetabulum can now be inspected fully. At this point, any cartilaginous or labral lesions are identified and addressed as necessary.
16. The hip is then relocated to develop the extended retinacular flap which is subperiosteally dissected off the femoral neck. The K wires are removed prior to starting the extended retinacular flap.
17. The extended retinacular flap dissection starts with the trochanteric osteotomy 'overhang' at the stable (i.e. non-mobile) trochanter.
18. The stable trochanter is cut in such a way that the posterior cortex is greensticked, with the bony fragment subsequently sharply dissected off the periosteum with a knife. The physeal scar (Fig. 8.35, green arrow) acts as a guide to start the stable trochanteric cut for the extended retinacular flap. The level of this physis corresponds to the superior cortex of the femoral neck.
19. The periosteum is elevated along the neck and proximally as far as the femoral epiphysis. Care is taken not to button-hole the periosteum at any point.
20. The extended retinacular flap contains the periosteum, piriformis, posterior capsule, medial femoral circumflex artery, and short external rotators (yellow arrow, Fig. 8.35).
21. Distally the retinacular flap is dissected to the level of the lesser trochanter to reduce tension on the retinacular vessels.
22. The femoral head is then gradually mobilized off the metaphysis. The epiphysis, with


**Fig. 8.34** Methods used to monitor femoral head blood supply: top images showed the use of intracranial pressure monitoring indicating a pressure of 9 mmHg. The bottom images show the use of normal cannula connected to arterial line monitoring indicating a pressure of 12 mmHg

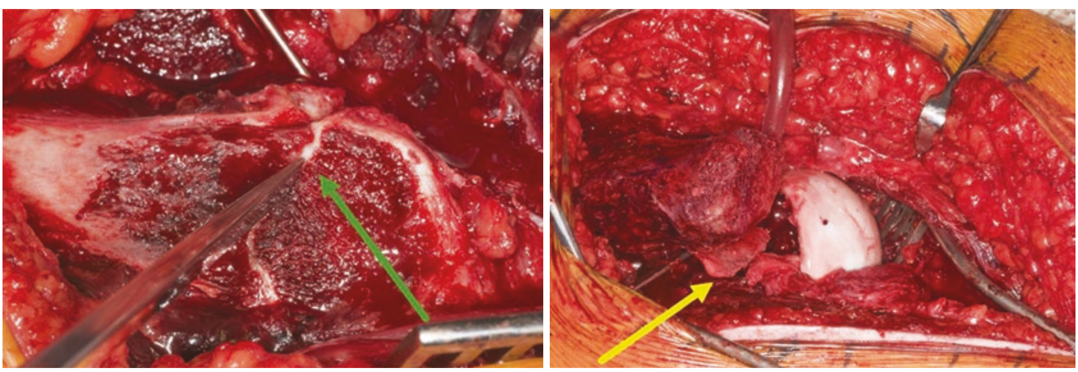

**Fig. 8.35** Creating the retinacular flap. Using the physeal scar as a guide to access the shoulder of the neck/femur junction with less risk to damage the superior retinacular arteries

its attached posterior retinaculum, can then be gently relocated into the acetabulum.

23. In SCFE, the metaphysis typically has callus or bony remodelling changes that make it difficult to reduce the slip without substantial tension on the soft tissues and retinacular vessels. Therefore, resection of the callus (Fig. 8.36, yellow arrow) and essential shortening of the neck (Fig. 8.36, blue arrow) is performed to achieve a tension-free reduction of the slip. Care must be taken not to shorten the neck too much which can lead to post-operative hip instability.

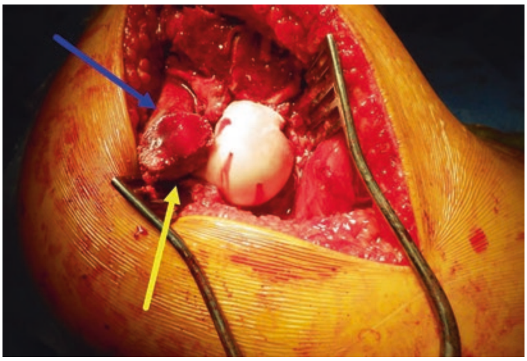

**Fig. 8.36** Shortening the femoral neck. Resection of the callus that is commonly present behind the neck (yellow arrow) and careful shortening of the neck (blue arrow) to allow tension-free reduction of the slip

24. The remaining physis is curetted from the epiphysis which is then reduced onto the metaphysis. The slip is then stabilized with K wires, advanced from the femoral head into the metaphysis and out through the lateral cortex of the proximal femur and two cannulated 6.5mm cancellous screws are used to fix the epiphysis on to the metaphysis (Fig. 8.37).
25. The head checked for vascularity with the drill hole or with a pressure transducer.
26. The retinaculum and the joint capsule are closed loosely to avoid any constrictive effect on the retinacular vessels.
27. The trochanteric flip is reduced back to its bed and two drill bits are inserted from a superolateral to inferomedial direction to provisionally stabilize the osteotomy.
28. One drill bit is removed and the screw depth is measured while the other drill bit holds the fragment in place. Fixation is achieved with two 4.5 mm cortical or cancellous screws which are placed sequentially (Fig. 8.38).

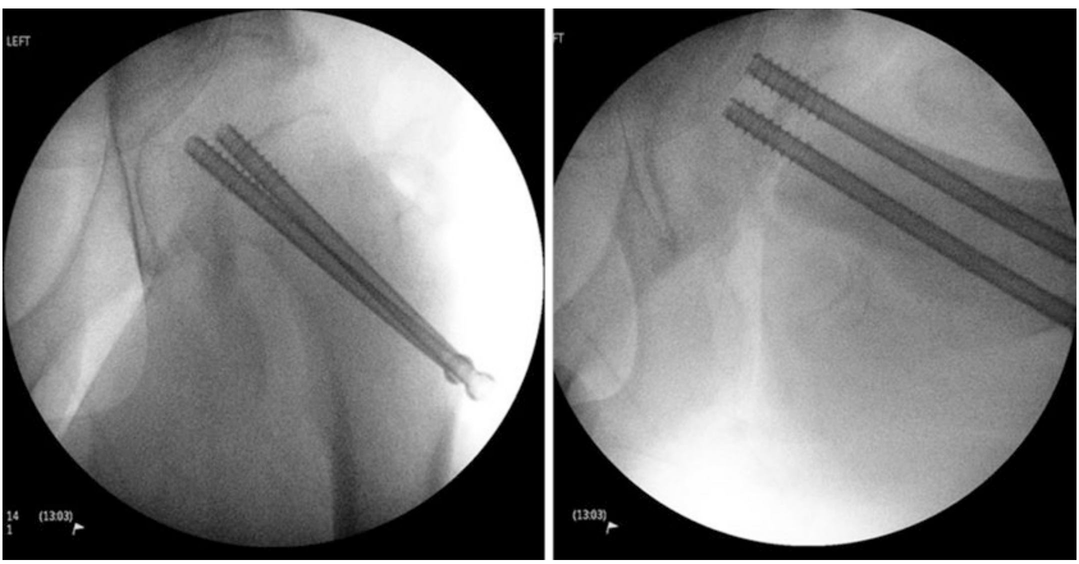


**Fig. 8.37** Femoral head fixation with cannulated screws. The authors have moved away from using threaded wires to stabilize the femoral head for several reasons. Screws are less symptomatic when patients lie on their side, and are easier to remove if AVN develops or if symptomatic

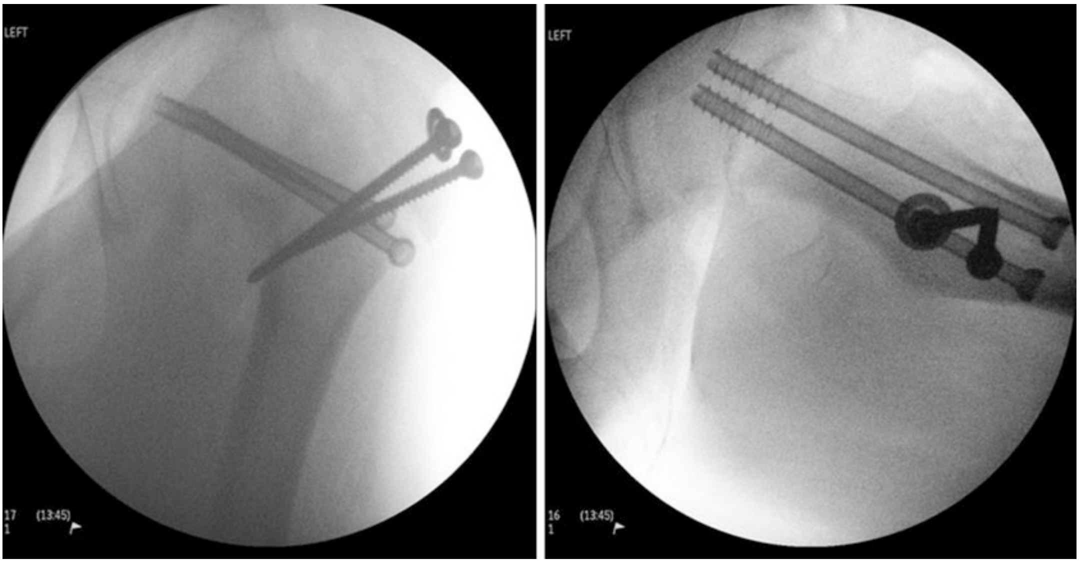


**Fig. 8.38** Trochanteric osteotomy fixation

29. A layered closure is performed. A drain is placed as necessary.

## Surgical Technique: Southwick Osteotomy

The objectives of the Southwick osteotomy are to create a compensatory deformity (valgus, flexion, and rotation) at the subtrochanteric level to secondarily realign the residual deformity caused by the slip. This osteotomy is most often used to correct deformities associated with moderate or severe SCFE, usually after an in-situ pinning acutely or, most commonly, as a secondary procedure. The maximum valgus correction possible is 45°. Beyond this, there would be too much medial translation of the femoral shaft, leading to a restriction in hip adduction. The maximum flexion correction possible is 60°. More than this would lead to excessive femoral neck shortening.

Several techniques have been described to achieve the objectives of the procedure. They are based on excising a pre-calculated wedge from the anterolateral aspect of the femur, then re-aligned the bone and stabilise it. With the modern locking devices, this type of bone carving is not necessary. We described below our preferred technique.

1. Preoperative planning is performed to calculate the desired correction (flexion, valgus and internal rotation). This should be measured radiologically and clinically.
2. The operation can be done on a radiolucent table or on a fracture table. Supine position is used and biplanar imaging is checked prior to draping.
3. A lateral subvastus approach to the proximal femur—from greater trochanter distally—is used. Caution is need when cauterizing the perforators at the posterior border of the vastus lateralis. Proximal extension of the approach may be performed if an anterior capsular release is needed.
4. Circumferential subperiosteal dissection in the subtrochanteric area at the level of the osteotomy is performed (see Fig. 8.39, images 1–6).
5. The authors prefer to use the pediatric hip proximal locking plate (Synthes, Solothurn, Switzerland) instead of a blade plate. The

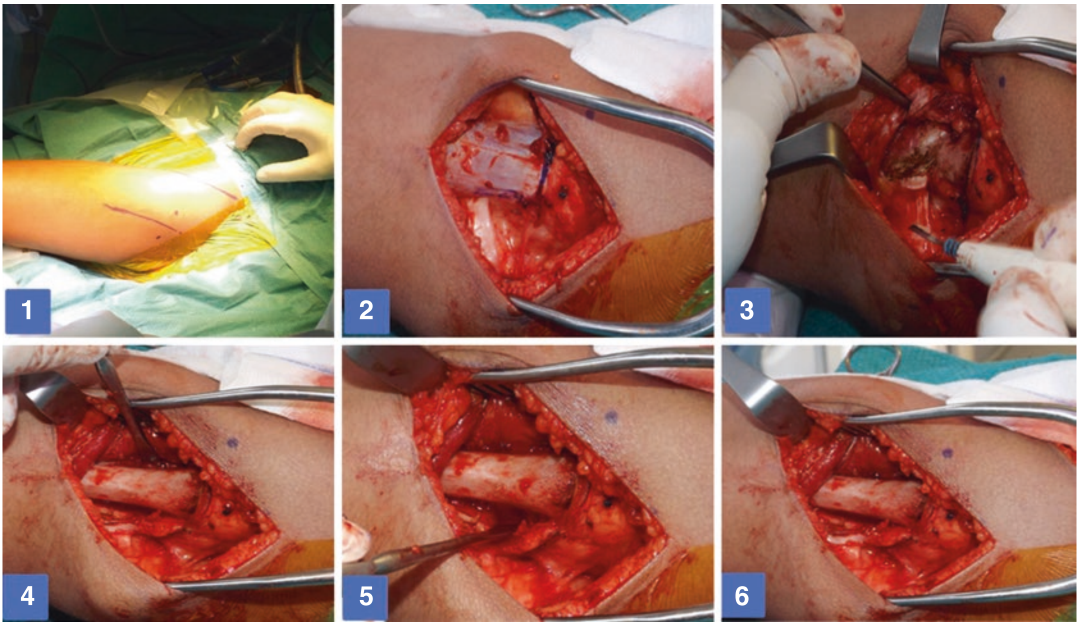


**Fig. 8.39** Lateral subvastus approach. Image 1 shows marking the incision. The three dots mark the anterior, superior and posterior borders of the greater trochanter. Image 2 shows the L-type cut of the vastus lateralis whereas image 3 demonstrates subperiosteal dissection of the vastus lateralis while cauterising the perforators before cutting them. Images 4 and 5 demonstrate the circumferential dissection of the femur at the osteotomy site and image 6 shows the full exposure which be long enough to fit the length of the locking plate without a struggle

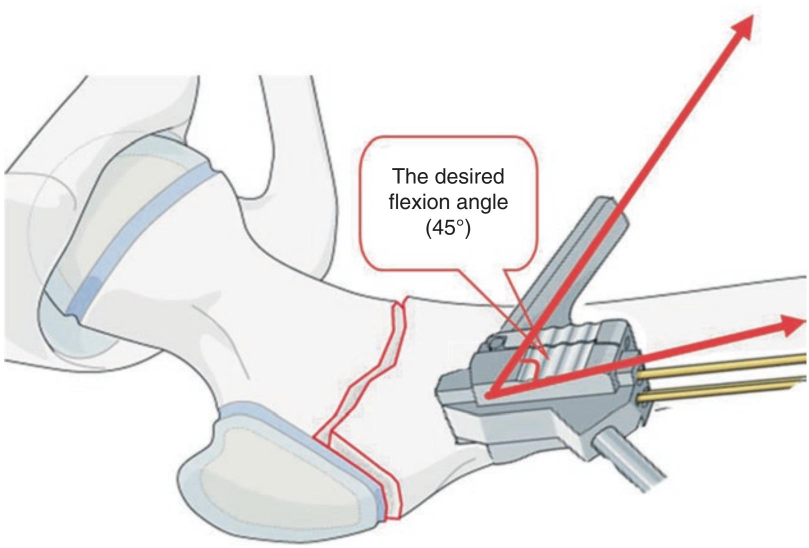


**Fig. 8.40** Planning the desired flexion of the proximal femur. The locking jig flexed by the desired amount of flexion

5 mm, 120° (or 150°) pediatric proximal locking plate is a good option. The jig is set to achieve the pre-planned valgus. The positioner for aiming block is angled forward (flexed) by the desired flexion correction angle. Three k-wires then advanced through the neck using the aiming block and checked using X-ray screening (Figs. 8.40 and 8.41).

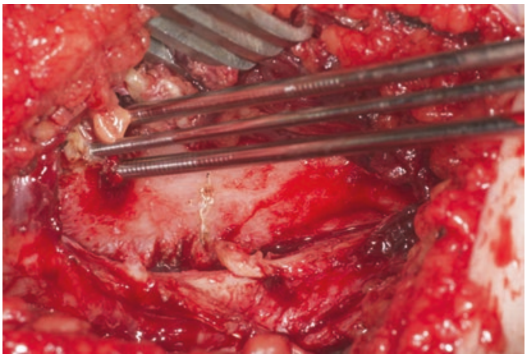

**Fig. 8.41** Three wires into the proximal femur using the jig in flexion and valgus (relative to the proximal fragment)

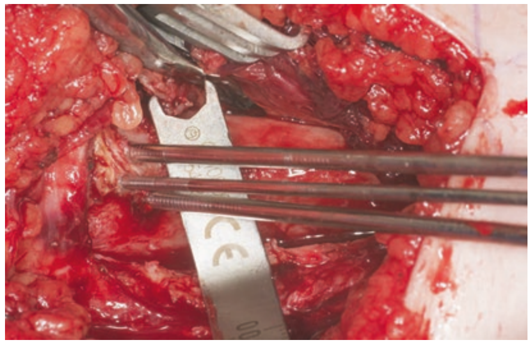

**Fig. 8.42** Marking the osteotomy site using the hockey stick

6. The rotation is controlled using proximal and distal k-wires. The aim is to rotate the distal fragment internally to normalize femoral neck anteversion.
7. The level and direction of the osteotomy is determined by placing the hockey stick (a small spanner to tighten the locking guide that looks like a hockey stick) (see Fig. 8.42) parallel to the lower two wires. The osteotomy is made using an oscillating saw with the soft tissue protected using bone levers.
8. The plate is fixed proximally using locking screws then the distal fragment is reduced to the plate using bone holding forceps. This will create the planned valgus and flexion correction. The bone holders are then loosened and an assistant internally rotates the limb to the desired derotation angle. Fix the distal fragment using screws (Fig. 8.43).
9. After adequate fixation, the hip range of motion checked and AP and lateral views saved. Bone gaps can be filled with bone graft to speed up healing. The wound is irrigated and a layered closure is performed.

## Removal of Metal Ware

There is increasing evidence that the risk of removing screws after SCFE is higher than leaving them in. There was a trend to remove the screws when the SCFE was healed. The proposed benefit was to make future hip replacement (if necessary) easier and less complicated. However, this has been contested for two reasons: the high complication rate associated with removing these screws and the fact that it is much easier to remove them at the time of hip replacement. Several studies have shown that removing SCFE screws can be challenging and not without risk. In one study [71], screw removal was attempted in 27 patients (with 43 screws). The average surgical time for removal was double the average time of insertion at 51 min (range, 26–107 min). Eleven patients needed extensive chiseling. Two children sustained femoral fractures at 5 and 7 weeks after screw removal. Seven screws could not be totally removed. Several other studies reported similar results and they advised against routine removal of such screws [72, 73]. Screws should be removed when prominent screws anteriorly result in symptomatic femoroacetabular impingement, or if found to be penetrating the hip joint. Infection would be another potential reason for removal.

We do, however, recommend plate removal, particularly for cases where the future need for hip replacement is thought to be high. A plate that is fully covered with bone can pose serious challenges for future hip replacement and could potentially comprise the outcome (Fig. 8.44).

## Complications: Avascular Necrosis

Avascular necrosis is one of the most serious complications of SCFE and is widely regarded as a sur-

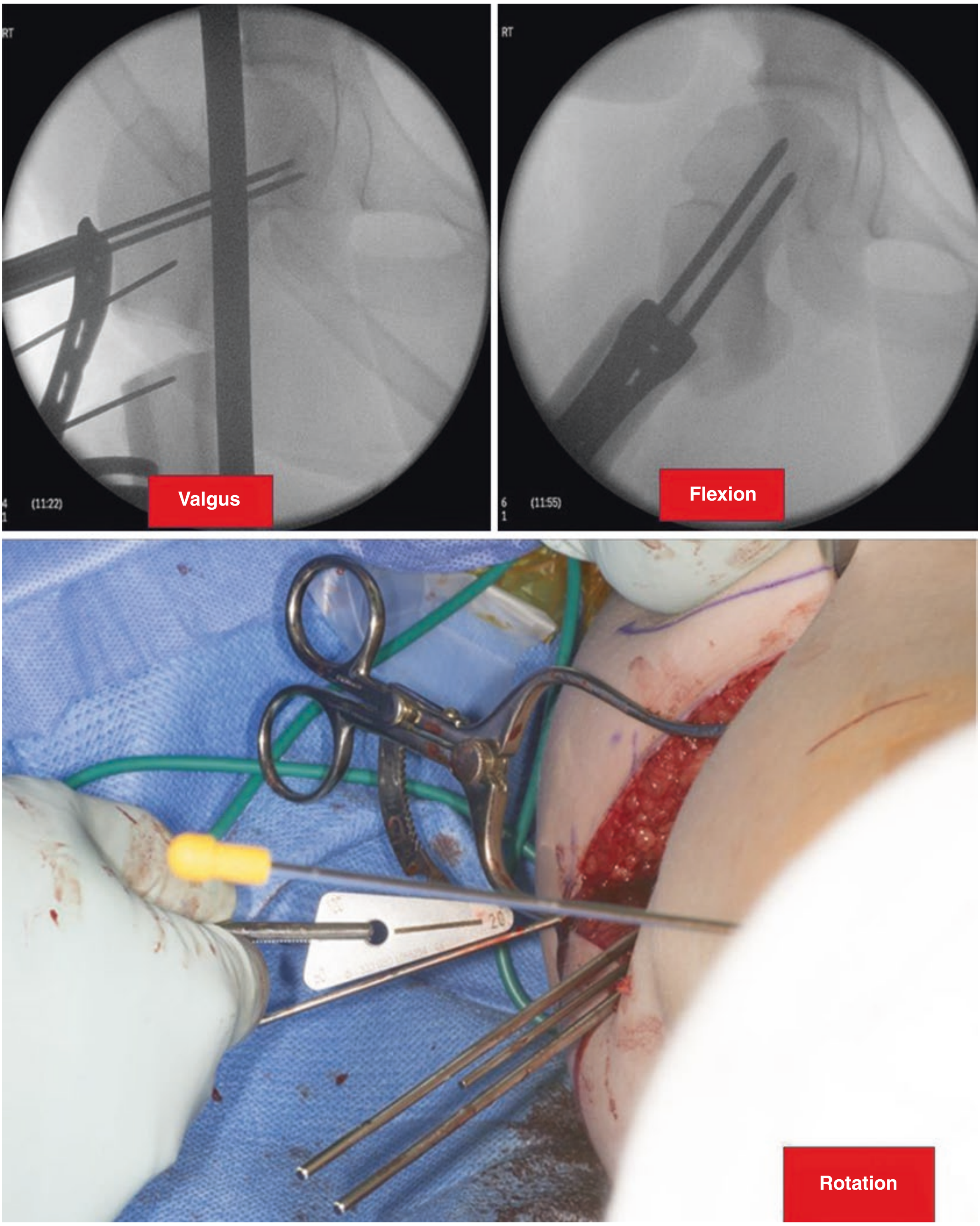


**Fig. 8.43** Creating valgus, flexion and internal rotation at the subtrochanteric level

rogate for bad outcome. The death of bone cells of the femoral head as a result of the interruption of its blood supply (particularly in the unstable type) leads to a gradual and painful collapse of the femoral head and the covering articular cartilage. Although femoral head eventually heals; it does not retain its optimum congruity and smoothness, often leading to gradual joint destruction.

Avascular necrosis can be total or partial depending on the percentage of the head involvement (Fig. 8.45). Most AVN becomes apparent within a year or two. MRI is the most sensitive and specific test to diagnose and assess the extent of AVN. Involvement of greater than 30–50% of the femoral head indicates an increased risk of articular collapse [74].

One of the earliest sign of AVN is the increasing stiffness and pain following a period of improvement after stabilization. Infection and loss of fixation should be excluded but they are much rarer than AVN.

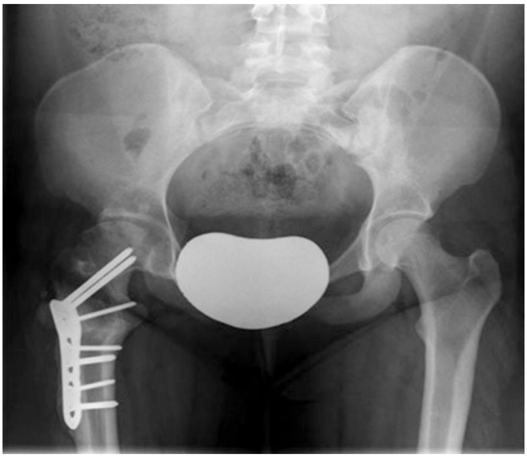

**Fig. 8.44** Metal ware challenges following slipped capital femoral epiphysis. This young patient had Southwick osteotomy which has healed however the metal ware is fully covered with bone which may pose serious challenges during future hip replacement, a high possibility for this patient. It is strongly advisable such metal ware to be removed before it has reached this stage

The best treatment for AVN is to prevent it in the first place by careful planning, appropriate surgical timing, choice of surgical intervention, and monitoring of the femoral head circulation during surgery. Early diagnosis and treatment are important to achieve the best outcomes. In our centre, all patients whose femoral head does not bleed intraoperatively are offered bisphosphonate treatment and an articulated hip distractor. The appearance of postoperative subchondral osteoporosis (Eid Crescent Sign) is a good sign that head vascularity is being restored (Fig. 8.46). It is usually visible around the 6 weeks' mark; however, it is not always visible.

There are four principles of treatment of pediatric AVN that are drawn from the adult experience: (1) prevent or slow collapse, (2) speed up healing, (3) prevent or reduce damage to the joint by an abnormally shaped head, and (4) replace the joint when the advanced degeneration is present. Several medical and surgical interventions have been proposed to address these principles. None of these have shown to be consistent or superior in their effects. Moreover, the few published reports (see below) were not specific to AVN secondary to SCFE which makes it difficult


**Fig. 8.45** Femoral head AVN: left image shows a total head AVN (right hip) and the right image shows a partial head AVN (left hip)

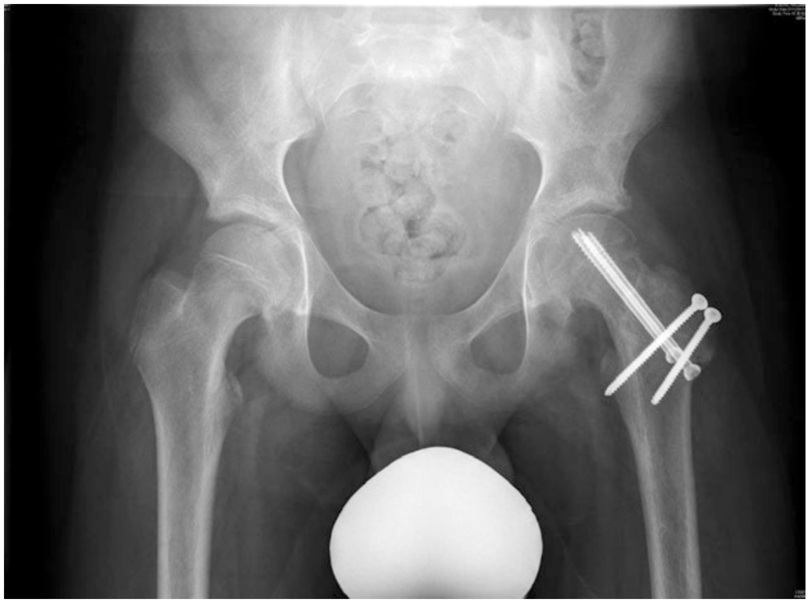

**Fig. 8.46** Eid Crescent sign. Postoperative femoral head subchondral bone osteoporosis is a good sign of restoring femoral head vascularity (© Dr S. Alshryda)

to make firm conclusions as to how to treat. Despite this, the following is a brief summary of current treatments:

### Non-operative Treatments for Femoral Head AVN

1. Bisphosphonates have been recommended to prevent femoral head collapse after AVN [45, 75, 76]. This may be combined with articulated hip distraction using an external fixator although the evidence for this is controversial [77, 78]. Patients with AVN secondary to SCFE do not seem to benefit from articulated hip distraction as much as other patients do [78].
2. Bone morphogenic proteins (BMPs) are a group of growth factors that have the ability to induce the formation of bone and cartilage. One study suggested that core decompression may be more effective if combined with BMP [79]. However, the numbers in this study were small and larger studies will be required to determine if this approach has merit.
3. Anticoagulants, statins and vasodilators have been used in treating early AVN but results are still not conclusive and further works are required before either of these therapies can be recommended [80–83].
4. Pulsed electromagnetic field (PEMF), Extracorporeal shockwave therapy (ECSWT) and Hyperbaric Oxygen Therapy (HBOT) have been used to treat AVN individually or as an adjunct with other forms of treatments. Most studies that reported on these are small with short follow up. PEMF stimulation has been proposed to reduce local inflammation and enhance the repair activity by stimulating new blood vessel formation. Extracorporeal shockwave therapy (ECSWT) has been shown to improve symptoms in a small number of patients when combined with other treatments but it has not been shown to change the progression of the disease. Hyperbaric oxygen (HBOT) therapy (100% oxygen at a high—2–2.4 atm—pressure) for a 1–2 h is thought to improve oxygenation, reduce bone oedema, induce new blood vessel formation, and improve microcirculation [84, 85]. Reis investigated 16 hips (in 12 patients) with early AVN (Steinberg Stage-I—[86]) treated with HBOT in a case-control study. The necrotic areas were 4 mm or more thick and/or 12.5 mm or more long on MRI. Overall, 81% of patients who received HBOT showed a return to normal on MRI as compared to 17% in the untreated group.

### Operative Treatments for Femoral Head AVN

1. Core decompression to relieve intraosseous hypertension (a common pathophysiological finding in AVN) has been advocated [87]. This reduces symptoms and stimulates a healing response via angiogenesis. Core decompression is often combined with local injection of bone marrow concentrate, BMPs, mesenchymal cell and bone graft. Several types of bone graft have been used including autogenous bone graft, allograft, osteochondral, muscle-pedicle bone graft, free cortical grafts and vascularized bone grafts with iliac or fibular bone. A review of 24 studies, with a total of 1206 hips treated by core decompression (with or without bone grafting), revealed an overall clinical success rate of 63.5% (range 33–95%). Less than 33% of the hips required a replacement or salvage procedure during the minimum 2 year follow-up period [88].
2. Rotational osteotomy to move a small necrotic area away from a weight bearing surface has also been suggested. Osteotomy is thought to reduce intraosseous pressure and improve vascularity. In carefully selected patients, 70–90% success rates have been reported. Successful outcome (and patient selection) was dependent on the ratio of transposed intact posterior articular surface to the acetabular weight-bearing area after osteotomy. This relationship suggested that the transposed intact area should occupy more than 36% of the acetabular weight-bearing area by adequate rotation and intentional varus position in addition to rotation, especially for extensive lesions [89–92].
3. Curettage and bone grafting through the trapdoor technique [93] or lightbulb technique [94] for focal AVN (in pre-collapse stage) has been reported. These techniques involve creating a window in the femoral head (Trapdoor technique) or the junction of the femoral head and the neck (lightbulb technique) to remove all necrotic tissues and replace with cancellous bone graft (with or without osteogenic materials). Reported success rates are 80% at 5–10-year follow-up.

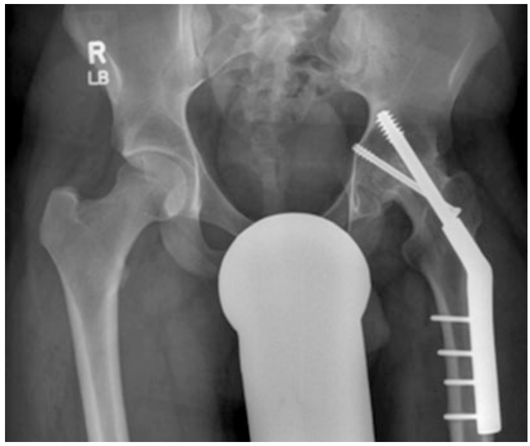


**Fig. 8.47** Hip fusion. (Used with permission, Alshryda, Jones and Banaszkiewicz, Postgraduate Pediatric Orthopaedics, 1st Edn, 2013, courtesy of Cambridge University Press)

4. Hip arthrodesis is usually indicated when the hip joint is severely degenerated post AVN (Fig. 8.47). It is a very effective operation to alleviate pain but it sacrifices movement. Arthrodesis transfers stress to the joints above (lumbar spine) and the joint below (the knee). Painful degenerative changes in the opposite hip, the lumbar spine, and the knee are well known after hip arthrodesis [95, 96].
5. Pelvic support osteotomy (PSO) works by increasing the contact surface area between the femur and the pelvis to support the body in standing (Fig. 8.48). In contrast to hip fusion, it allows movement between the pelvis and the femur resulting in less impact on neighbouring joints [97].
6. Total hip replacement in children has become a common practice and moved from being a last resort to a first choice in several centres (Fig. 8.49). This has been fueled by the high success of THR in older people, the availability of custom made implants and the lack of expertise in performing hip joint fusion or PSO among surgeons. Although short term results are encouraging, there is uncertainty about longevity of the prosthesis. The reported revision surgery rate of THR in children varies from 11% to 42% at 10 years [10, 11, 98, 99]. The reason for such variation is

**Fig. 8.48** Pelvic support osteotomy. Bottom left image shows the femur was cut twice to create three fragments. The upper two fragments were aligned to support the pelvis while the bottom fragments were used to lengthen and align the leg so it is parallel, and of equal length, to the other side. (Images are courtesy of Mr. James Fernandes, Sheffield Children's Hospital)

unclear. Of interest, THR has been successfully performed in patients who had a previous hip fusion or PSO when they were children [100, 101].

## Complications: Chondrolysis

Chondrolysis refers to acute cartilage necrosis of the capital femoral epiphysis, a compli-

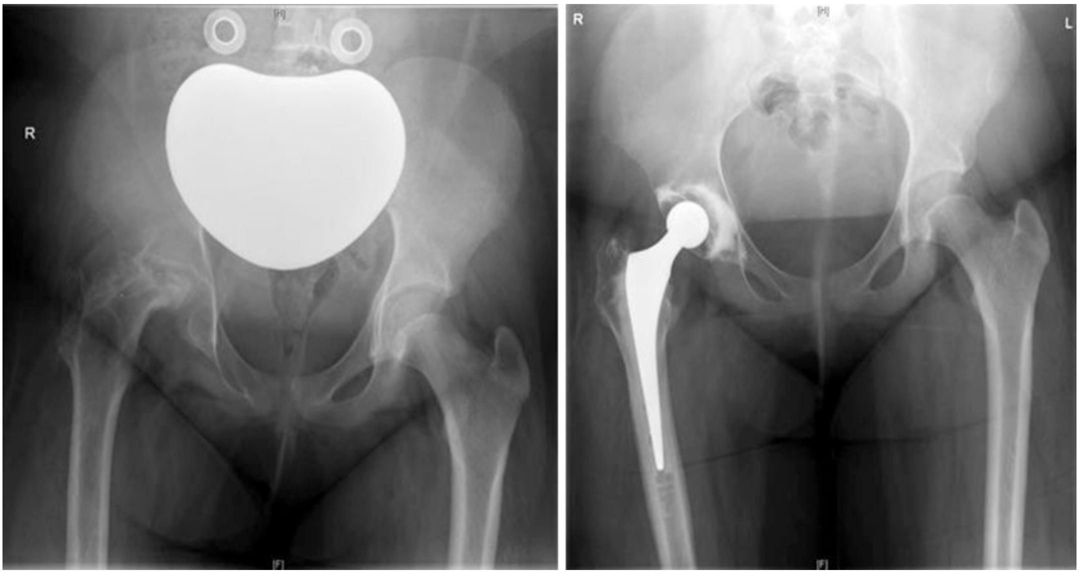

**Fig. 8.49** Total hip replacement in a child of 13 year who developed total AVN following an unstable SCFE

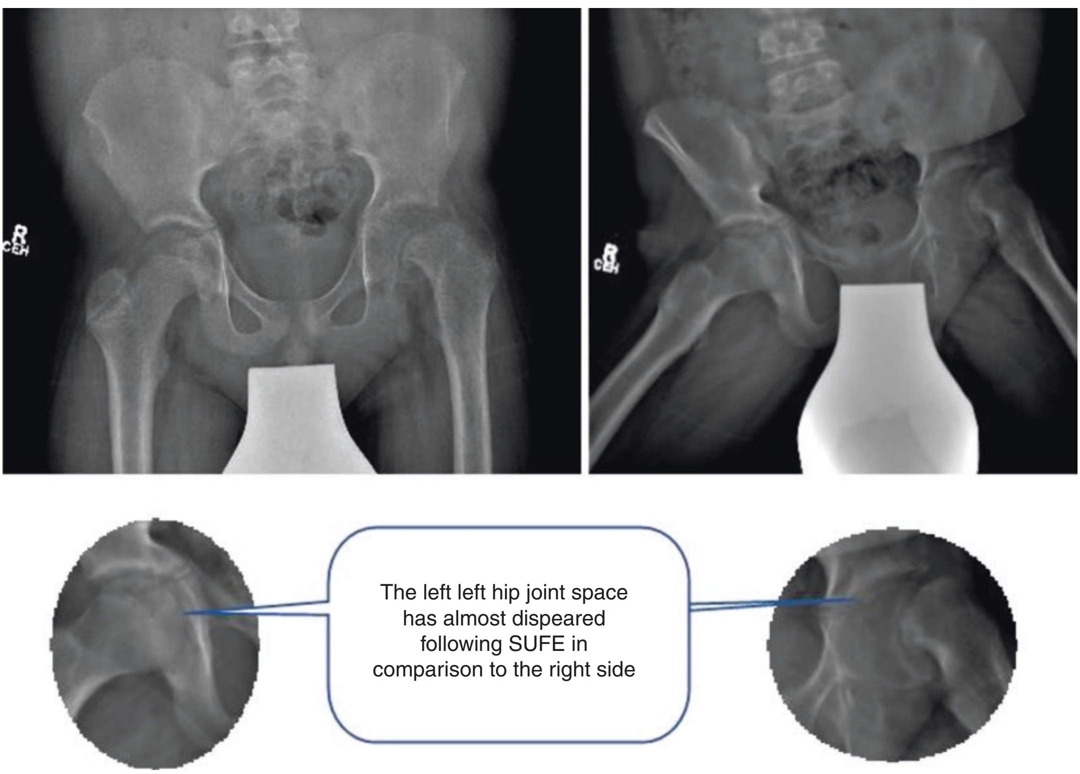


**Fig. 8.50** Chondrolysis of the left hip joint following SCFE. This child presented with acute on chronic slip; treated with Ganz surgical dislocation

cation that can occur following both treated and untreated SCFE [102]. Chondrolysis can be identified as narrowing of the joint space on plain X-ray (Fig. 8.50). Its exact aetiology remains largely unknown, no treatment has been completely successful, and the general prognosis and natural history are not clear [103]. Several authors attributed the development of chondrolysis to hardware penetration into the joint [104]. However, based on the facts that chondrolysis is far more frequent following hip spica treatment without fixation and can occur in both treated and untreated hips, an immune mechanism has been postulated. Local inflammation, mechanical factors, disuse effect, and vascular causes have also been implicated. Chondrolysis is not unique to SCFE but can occur without any obvious cause (idiopathic chondrolysis) [104–107].

Treatment of chondrolysis is largely symptomatic, including analgesia, physiotherapy and anti-inflammatory medications. More than half of patients can regain cartilage space and functional range of motion in the hip as long as 3 years after the diagnosis [108].

## Femoro-acetabular Impingement Secondary to SCFE

Femoro-acetabular impingement (FAI) is covered in more details in Chap. 9, however, a brief summary of the condition as is relevant to SCFE is discussed here. SCFE inevitably causes a cam-type FAI due to the abnormal shape of the femoral head (Fig. 8.51). Although children can often undergo substantial bony remodeling and natural deformity correction, this depends on the age of the child and the location of the deformity. The younger the child the better remodeling is. Remodeling after SCFE, however, is rarely good enough to completely prevent FAI. Although most children adapt their function accordingly, several studies have showed that FAI can lead to premature joint arthritis [109, 110].

Several types of surgery have been described to correct residual deformity of SCFE. These can be performed at the subcapital, base of the neck, intertrochanteric or subtrochanteric levels. This can be combined with open or arthroscopic shaving of impinging lesion that is caused by deformity (see stable slip treatment above).

## Osteoarthritis Following SCFE

Osteoarthritis (OA) often occurs as a final outcome following one or more of the adverse sequel described above—AVN, chondrolysis and FAI. Once OA is established, treatment options will be limited. The three options are total hip replacement, hip fusion or pelvic support osteotomy (see AVN treatment above).

In summary, although slipped capital femoral epiphysis is a well-known condition, there are still gaps in our understanding of the condition. Classifying SCFE into a stable and unstable was a significant milestone in our understanding of the condition. The two types behave differently and require different treatments. Currently, open reduction and internal fixation on an urgent basis (within 24 h) is shown to be associated with the best outcome for children with unstable slip. Contrary to stable SUFE where pinning in situ is recommended for mild and to a lesser extent moderate slips. For severe stable slip, Ganz surgical dislocation provides higher satisfaction rate than pinning in situ but higher AVN rate (provided AVN does not occur). Provided patients and parents agree to take the higher AVN risk for better satisfaction and the surgical expertise is available.

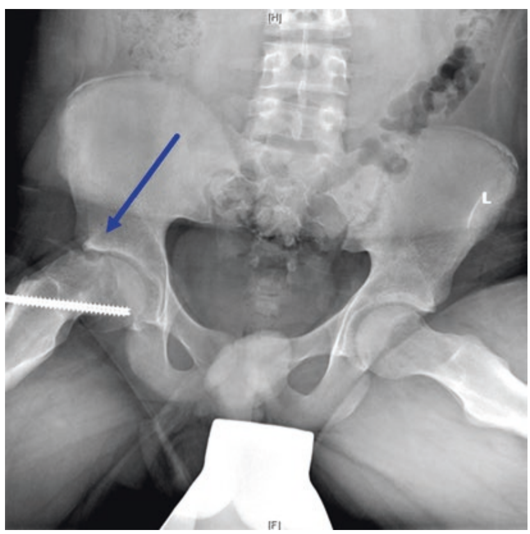


**Fig. 8.51** Pelvis X-ray shows impingement of femoral neck over the acetabular socket. This is a 16-year-old boy who had SCFE pinned in situ 2 years ago. He is symptomatic. Maximum flexion is 70°, no internal rotation and 30° abduction

## Classic Papers

**Loder RT, et al., Acute slipped capital femoral epiphysis: the importance of physeal stability. J Bone Joint Surg Am, 1993. 75(8): p. 1134–40**. Loder and colleagues introduced the concept of slip stability and its implications, changing our understanding and approach to SCFE treatment.

**Southwick, W.O., Osteotomy through the lesser trochanter for slipped capital femoral epiphysis. J Bone Joint Surg Am, 1967. 49(5): p. 807–35**. Southwick highlighted the importance of correcting SCFE deformity in a safe way. His technique of creating a compensatory deformity in the subtrochanteric area has been shown to be successful in relieving pain. However, after the total hip replacement era started, a deformed femoral canal caused by his osteotomy became a great a disadvantage. Imhauser [39] has partly overcome the problem by performing the osteotomy at the intertrochanteric level.

**Fish, J.B., Cuneiform osteotomy of the femoral neck in the treatment of slipped capital femoral epiphysis. A follow-up note. J Bone Joint Surg Am, 1994. 76(1): p. 46–59**. Fish published two papers about his osteotomy [35, 111] in which he corrected the deformity at the physis (at the CORA). It is a true anatomical correction of the deformity. However, compared with the modern techniques, the AVN rate of 4.5% for stable SCFE is relatively high although it would have been impressive when it was first introduced.

**Dunn, D.M. and J.C. Angel, Replacement of the femoral head by open operation in severe adolescent slipping of the upper femoral epiphysis. J Bone Joint Surg Br, 1978. 60-B(3): p. 394–403** [34]. Dunn introduced the trochanteric osteotomy technique to SCFE deformity correction which laid the foundation for Ganz's surgical hip dislocation technique. Not having fully appreciated the anatomy of the vascular supply of the femoral head, his AVN rate was high (12%) which was a one of the main reasons that many surgeons preferred the Fish osteotomy.

**Ganz, R., et al., Surgical dislocation of the adult hip – A technique with full access to the femoral head and acetabulum without the risk of avascular necrosis. Journal of Bone and Joint Surgery-British Volume, 2001. 83B(8): p. 1119–1124**. Ganz was a scientist as well as an innovative surgeon. He knew that the key for finding a successful surgical technique to correct the SCFE deformity (and several intra-acetabular hip pathology) was to understand the blood supply to the femoral head. In this paper, he described his techniques of surgical hip dislocation which was the dawn of the young adult hip preservation subspecialty.

**Carney, BT and SL Weinstein, Natural history of untreated chronic slipped capital femoral epiphysis. Clinical Orthopaedics and Related Research, 1996(322): p. 43–47** [112]. Carney and Weinstein published probably the longest follow up of SCFE in their case series [8, 9]. Their findings have stood the test of time and—even with the current advancement of surgical techniques—we have not been able to reliably obtain better results.

## Key Evidence

**Loder RT, O'Donnell PW, Didelot WP, Kayes KJ. Valgus slipped capital femoral epiphysis. J Pediatr Orthop. 2006 Sep–Oct;26(5):594–600**. Valgus slips are extremely rare. In this paper, Loder and colleagues reviewed the literature on valgus SCFE and presented new four cases.

**Loder RT, Greenfield ML. Clinical characteristics of children with atypical and idiopathic slipped capital femoral epiphysis: description of the age-weight test and implications for further diagnostic investigation. J Pediatr Orthop. 2001 July–Aug;21(4):481–7**. Another excellent paper from Loder's team in which he highlighted the importance of atypical SCFE, the difference from typical ones and how to predict them by introducing the age weight/age height test.

**Halverson SJ, Warhoover T, Mencio GA, Lovejoy SA, Martus JE, Schoenecker JG. Leptin Elevation as a Risk Factor for Slipped Capital Femoral Epiphysis Independent of Obesity Status. J Bone Joint Surg Am. 2017 May 17;99(10):865–872**. There has been huge amount of research about SCFE and, unfortunately, we still do not fully understand why it happens so that we can prevent it. When we read this paper, it inspires that we should not just focus on treatment and ignore preventative measures. The search for the causes of SCFE may eventually allow for this prevention.

**Ziebarth K, Domayer S, Slongo T, Kim YJ, Ganz R. Clinical stability of slipped capital femoral epiphysis does not correlate with intraoperative stability. J Pediatr Orthop. 2009 Mar;29(2):163–9**. In this paper, Ziebarth and colleagues questioned whether ability to weight bear is the best surrogate for the concept of stability; introduced by Loder in 1993. It is perhaps too simplistic to explain the large differences between stable and unstable SCFE. They found that clinical stability of SCFE did not correlate with intraoperative stability and proposed that clinical classification systems are not adequate in this regard.

**Alshryda S, Tsang K, Chytas A, Chaudhry M, Sacchi K, Ahmad M, Mason JM. Evidence based treatment for unstable slipped upper femoral epiphysis: Systematic review and exploratory patient level analysis. Surgeon. 2018 Feb;16(1):46–54**.

**&**

**Naseem H, Chatterji S, Tsang K, Hakimi M, Chytas A, Alshryda S. Treatment of stable slipped capital femoral epiphysis: systematic review and exploratory patient level analysis. J Orthop Traumatol. 2017 Dec;18(4):379–394**. Trying to understand the published evidence on best treatment for SCFE, these two systematic reviews and patients level exploratory analyses confirmed by large numbers what had been felt as the best current treatments for SCFE. The findings from both reviews underpin the recommendations of this chapter. They covered the best treatments, timing of surgery, patients' satisfactions and complications.

**Phillips PM1, Phadnis J, Willoughby R, Hunt L. Posterior sloping angle as a predictor of contralateral slip in slipped capital femoral epiphysis. J Bone Joint Surg Am. 2013 Jan 16;95(2):146–50**. Prevention is better than treatment; however, in SCFE this has proven difficult to apply. Several researchers published methods to predict bilaterality. Phillips and colleagues developed further the posterior sloping angle, first described by Barrios et al. [113]. The biggest advantages of this angle are that it is a simple, single measure that does not require further tests or X-ray exposure. He examined its value in 132 patients as a predictive factor for developing a contralateral slip. He found that if a posterior sloping angle of 14° were used as an indication for prophylactic fixation, 35 (of 42 = 83.3%) would have been prevented, and 19 (of 90 = 21.1%) would have been pinned unnecessarily. Their findings have been validated by others [114, 115].

**Take Home Messages**

- SCFE is not common but a very distinctive pediatric and adolescent hip problem that is still commonly missed. There is a need for a wider awareness and critical review of radiographs and clinical history to avoid missing SCFE, especially during the pre-slip stage or those that are mild in severity.
- Once SCFE is diagnosed, surgical stabilization is indicated. The AVN rate is very low in stable slips so the timing of surgery is not paramount. Mild and moderate SCFE can be treated by pinning in situ with good outcomes expected. However, severe stable SCFE poses challenges for the treating team. Accepting severe deformity will often cause impingement which lowers patients' satisfaction, function and may cause premature osteoarthritis. Correcting the deformity risks having iatrogenic AVN. Ganz's surgical hip dis-

location technique (i.e. the Modified Dunn procedure) is the best current method to correct severe stable SCFE. The risk of AVN in experienced hands should be in the region of 3%.
- In unstable SCFE, the AVN rate is high; therefore, several measures have been advocated to try to mitigate this complication. The evidence to support early surgery (within 24 h) is convincing, however, it can be difficult to transfer patients to a centre where the expertise and equipment are available to operate on them within 24 h. For these cases, there is evidence to support delaying surgery for over a week but this is based on small numbers. The types of surgical interventions are still controversial and being evaluated, but the trend supports open surgery rather than closed reduction or pinning in situ even. Surgical hip dislocation has been shown unequivocally superior to other methods.

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