CHILDREN

Slipped upper femoral epiphysis

Samuel J. Parsons*, Cefin Barton, Robin Banerjee, Nigel T. Kiely

Robert Jones and Agnes Hunt Hospital, Gobowen, Oswestry, Shropshire SY10 7AG, UK

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Summary
Slipped upper femoral epiphysis is a common adolescent hip disorder. The classic image of the obese hypogonadal male child presenting with a limp is widely known; despite appearances few of these children demonstrate an endocrine disorder. Most are idiopathic, but some are associated with obesity, younger bone age, race and biomechanical factors. Historical treatments, such as spica casts, have been abandoned and in situ pinning is widely held to be the optimum treatment. The more severe slips frequently require osteotomy and may go on to require salvage surgery. This article presents a review of the aetiology, features and treatment options available.

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Introduction
Slipped upper femoral epiphysis (SUFE) is a well recognised disorder of adolescent hips. It is characterised by displacement of the capital femoral epiphysis from the metaphysis through the physis.

Although the disorder is called SUFE, this term is technically incorrect. The femoral epiphysis maintains its normal relationship within the acetabulum stabilised by the ligamentum teres femoralis and surface tension. It is the femoral neck and shaft that displace relative to the physis and acetabulum. The deformity is one of superior migration, adduction and external rotation of the femoral neck.

The epiphysis displaces primarily posterior relative to the femoral neck.1 Most of the children affected by SUFE will not have any demonstrable endocrine abnormality, even when their body habitus suggests otherwise, but some will have an important associated endocrinopathy.

Early diagnosis with appropriate management should reduce the morbidity and complications of SUFE that can lead to loss of range of movement, pain, premature arthritis and leg length discrepancy.

Historical perspective
Descriptions of SUFE predate X-ray studies for originally SUFE would have just been another cause of a limp. Ambroise Pare—renowned French barber surgeon, is credited with the first description of SUFE in 1564: 'when the epiphyses and heads of the bones are plucked from the bone whereon they were placed or fastened; which unproperly called kind of luxation, hath place chiefly in the bones of young people. And it is known by the importance of the part

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the noise and grating together of the crackling bones when they are handled.

Jean-Louis Petit, in 1723, gave a more sober description and described it thus: ‘decollement — separation of the head from the neck — in the sense that one says a criminal has been beheaded; or else one may understand this word, the separation of the epiphysis from the neck, looking upon the cartilage that is found between them as cement that joins both parts.’

Ernst Muller, in 1888, describes ‘an affection in young individuals from 14 to 18 years; there occurs without special cause or preceding trauma a weariness and gradual shortening of the affected limb. The symptoms develop quite gradually. The patients are in other respects, except for fortuitous affections, healthy specifically without evidence of other joint or bone disease.’ He goes on to comment, from looking at autopsy specimens ‘the femoral neck gives the impression of being molded by pressure from above downward.’ From this he coined the term ‘Schenkelhalsverbiegungen im Jungesalter’ meaning bending of the femoral neck in adolescence.

Demographics and epidemiology

The Incidence of SUFE varies by sex, race and geography. The incidence is estimated to be around 2 per 100,000 of the population. There is a male predominance, with the left hip affected more than the right. Early in the 20th century 90% of those with the disorder were boys but now this figure is 60%. Loder found a male/female ratio of 3:2, and a left/right ratio of 3:2. Of those with unilateral involvement, 60% are left hips. Whether this reduction in male prevalence is due to increased participation of girls in sporting activities is not known. The left/right ratio may be due to the sitting posture of right handed subjects whilst writing. Average age at diagnosis is 13.5 years for boys and 12.0 years for girls. At presentation 80% of the boys were between 12 and 15 years, and 80% of the girls were between 10 and 13 years. Onset before 10 years is unusual for both sexes and after 14 years for girls and 16 years for boys. The range of skeletal ages of these children is much narrower than their chronological age. Most children with SUFE have an open triradiate cartilage and are Risser 0. The youngest reported patient without an identifiable endocrinopathy has been a girl aged 5 years and 9 months.

Between 51% and 77%, of children with SUFE are obese. With at least 50% being over the 95th percentile for weight according to age. Age at onset is reduced with increasing weight. If a child is over the 95th percentile for weight for age, the mean age at presentation is 12.4 years, and if under the tenth percentile mean age is 14.3 years. Although the chronological age at which slips can occur varies, the physiological age range seems smaller, with a narrow window during which it can occur. Obese children with slow maturation appear to be at especially high risk.

The relative racial frequency of SUFE is 1.0 for whites, 4.5 for Pacific Islanders, 2.2 for blacks, 1.05 for American Indians (Hispanic, native Americans), 0.5 for Oriental races (Chinese, Japanese, Thai, Vietnamese) and 0.1 for Indo-Mediterranean. There are two possible explanations for this observation: (1) the mean body weight for the racial group, supporting the idea of obesity being an important factor; (2) a racial variability in acetabular depth and femoral head coverage. We know that the acetabula in adolescent black children are deeper than those in white children. However, recently Loder et al. felt that these observed racial differences in acetabular size did not correspond with the racial frequencies observed historically in SUFE.

The incidence of bilateral involvement is affected by race, method of radiographic measurement and possibly treatment. In most series the prevalence of bilaterality is 18–50%. Most studies identify bilateral involvement either on initial presentation or subsequently in around 20–25% of patients while long-term studies have shown radiological evidence of bilateral involvement in the range of 60–80% of patients. The percentage of bilateral involvement is higher in black children (34%) with White and Hispanic children at 17% and Asian children at 18%. Treatment may also affect the incidence of bilaterality since one study has shown a prevalence of 36% in 169 patients treated with in situ pinning and 7% in 30 treated with a spica cast.

Most children (82%) who go on to develop second hip involvement, having only presented with a unilateral slip, will do so within 18 months. These patients are younger at presentation than children in whom the disorder is unilateral. This difference is seen in both chronological age and pelvic bone age. There may also be seasonal variation, with increased symptoms in summer and autumn months, but only in races living above 40° north latitude. In the same study Hansson also noted an increased tendency for SUFE in rural children compared to urban children.

Aetiology

The cause of SUFE is unknown in the majority of patients. Regardless of the aetiology, the final common pathway appears to be a mechanical insufficiency of the proximal femoral growth plate occurring because of physiological loads across an abnormally weak physis or abnormally high loads across a normal physis.

Biomechanical factors

Shear forces across the epiphyseal plate are least when the plate is perpendicular to the resultant force across the hip joint and the femoral neck is anteverted.

Shear strength of the proximal physis varies with age and is dependant on the surrounding perichondrial ring complex, especially in infancy and early childhood. The perichondrial fibrocartilaginous ring complex, is a fibrous band that encircles the physis at the cartilage–bone junction. The perichondrial ring acts as a limiting membrane giving mechanical support to the physis. It contributes significantly to the ability of the epiphysis to resist shear forces. Its shear strength is provided by collagen fibres that run obliquely, vertically and circumferentially. These collagen fibres span the physis, attaching to the ossification groove on the epiphyseal side and powerfully bound to the subperiosteal
metaphyseal bone. It is strongest in infancy, but decreases in volume and strength especially in adolescence. As children age the mammillary processes (interdigitating reciprocal protrusions of bone and cartilage at the epiphyseal–meta-
physeal interface) become more important in providing resistance to shear.

Obesity is associated with increased femoral retroversion, anteverision averaging 10.6° in normal weight adolescents, but only 0.4° in obese adolescents. This relative femoral neck retroversion increases the shear stress across the physis. Children with SUFE also have a more vertical proximal femoral physis. Patients with a slip had a slope averaging 11° more on the affected side and nearly 5° more on the unaffected side than the controls. In laboratory studies shear strength has been shown to vary with physeal inclination. A decrease in the neck shaft angle has been reported in SUFE children when compared to normal non-slip controls; such a decrease results in a more vertical physis, which may increase the shear force across the physis (Figs. 1–8).

The combination of mechanical forces resulting from relative retroversion and increased physeal slope may be enough to cause a slip, under physiological conditions. Whereas the mean shear load to failure of the capital physis in normal weight children is four times body weight; the mean shear load to failure in adolescents who are running, who are obese, or who have neutral version (or 10° of retroversion) is five times body weight.

Children with greater acetabular depth were felt to be at greater risk for SUFE as this greater coverage yields more stress across the physis. It was also felt that a deeper acetabulum could cause increased shear stress across the femoral epiphysis. However, this difference alone seems not to account for the increased incidence of SUFE in these racial groups.

Kordelle et al. have not found any differences in the acetabular morphology in the affected and unaffected hips of patients with SUFE. Little potential exists for acetabular remodelling and this may explain the high incidence of bilateral SUFE. Equally, bilateral acetabular symmetry in those with unilateral SUFE suggests that even if increased acetabular depth is a risk factor there must be other aetiological factors involved. SUFE has also been associated with other lower limb conditions, such as infantile and adolescent Blount’s disease, peroneal spastic flat foot and Perthes disease.

Figure 1 Plain radiograph of a unilateral SUFE.

Figure 2 Prepared histological slide of a femoral epiphysis with the Ring of Lacroix circled.
Endocrine factors

Endocrine abnormalities may account for 5–8% of SUFE cases. SUFE has been estimated to be six times more common in conditions such as hypothyroidism, panhypopituitarism, growth hormone abnormality, hypogonadism, craniopharyngioma, hyperparathyroidism, MEN II-B, Turner’s syndrome and optic glioma. The increased prevalence of hypothyroidism in Down’s children is a likely explanation for the increased risk of SUFE in these children, although hyperlaxity may be contributory. The initial diagnosis of hypothyroidism is often made after the diagnosis of SUFE, whereas in children with SUFE and growth hormone deficiency the endocrine abnormality is usually known prior to diagnosis.

The relative risk of SUFE is increased in children with growth hormone deficiency both prior to and during growth hormone treatment. Blethen and Rundle19 concluded that the risk for development of SUFE in patients receiving growth hormone for idiopathic short stature was the same as that reported in the general population, but was
some families there is an autosomal dominant inheritance (10%).

Previous radiation therapy to the hip and pelvis increase the risk of SUFE, in a dose-related manner, possibly as high as 1%. Other factors (such as obesity) remains unclear. Rennie showed that the risk of a SUFE in a second family member was 7.1% and that 14.5% of SUFE patients had a close family member who also had the disorder. There may be an association with HLA markers, such as DL4 or B12 but again this is unclear.

There have been mixed results implicating an immunological basis for SUFE. Some studies have shown increased C3 complement and immunoglobulins and possibly higher serum IgA levels. In patients with chondrolysis IgM levels are also elevated. More recent studies have not shown this serum level increase but have shown synovial fluid abnormalities, with immune complexes more likely to be found in the synovial fluid of SUFE joints than non-SUFE joints. The role of these immune complexes or whether they reflect exposed proteoglycan serving as antigenic stimulus is not clear. Hence there is uncertainty if these observed changes are the cause or the effect of SUFE.

Clinical features

History

The most common findings at presentation of SUFE include pain, limp and decreased range of motion of the hip. Hip or groin pain in an obese, peripubertal child is highly suggestive of SUFE. However hip pain is absent in as many as 50% of the children with SUFE, including up to 8% with a painless limp. Pain is localised to the knee and/or distal thigh in 23–46% of cases. SUFE often presents with only knee pain and not hip pain.

Previous studies have noted that this can cause significant delay in diagnosis, misdiagnosis, unnecessary radiographs, increased slip severity and sometimes unnecessary knee arthroscopy. These findings indicate the importance of examining the hips in all patients presenting with distal thigh and/or knee pain.

Age at diagnosis and symptom duration are very important since older children with longer symptoms do present with more severe slips.

Examination

On examination range of motion and rotational profile of the hips should measured and compared. With SUFE the hip will automatically fall into external rotation (so-called obligate external rotation) as it is progressively flexed. Obligate external rotation is highly suggestive for SUFE. There is also a corresponding loss of internal rotation. Hip rotation is abnormal because of both the abnormal anatomy and synovitis that accompanies the SUFE. In unilateral SUFE comparison with rotation of the other hip clearly demonstrates this change in the arc of motion (it may also be noted that the other normal hip is slightly retroverted). In bilateral SUFE both hips will demonstrate this shift toward external rotation.

The ability to flex the hip to 90° is uncommon, and flexion contractures are often seen. Abduction is also limited compared to the contralateral, normal hip. There may be shortening of the affected limb of around 1–2 cm.
If the child can walk there will be a trunk lean to the affected side during stance phase (Trendelenberg gait). If there is marked pain an antalgic gait (decreased stance phase on the affected limb) will be present as well.

Chondrolysis produces continuous pain and a greater interference with daily activities due to loss of range of motion. Pain occurs throughout the arc of motion, not just at extremes.

**Classification**

SUFE can be classified by speed of onset of the disorder, by the magnitude of the slip, and by the stability at presentation.

**Acute**

Symptoms are present for less than 3 weeks and X-rays will show no remodelling. AVN frequent complicates acute SUFE with a reported incidence of 17–47% in treated cases.

**Chronic**

Chronic SUFE is more common. Patients present with symptoms over more than 3 weeks. Loder reported that 85% of 1630 children with 1993 slips had chronic symptoms and 15% had acute symptoms, as defined by the 3 week’s symptoms. Radiographs of patients with chronic SUFE show a variable amount of posterior migration of the femoral epiphysis and remodelling in the same direction causing bending of the neck.

**Acute on chronic**

Acute on chronic presentation is one in which both ends of the spectrum are present. Prodromal symptoms for more than 3 weeks are followed by a sudden exacerbation of pain with radiographic evidence of both femoral neck remodelling and further displacement of the capital epiphysis (Figs. 9–17).

The complications of AVN and chondrolysis are more common in acute slips. Loder et al. reviewed 55 patients presenting with acute SUFE, and separated patients by their ability to weight-bear after the acute clinical event. If the patient’s pain was sufficiently severe to prevent the patient from weight-bearing, even with crutches, these patients were identified as having unstable slips. Those who were able to weight-bear, with or without crutches, were classified as having stable slips. Fourteen (47%) of the thirty patients with unstable slips developed AVN, whereas none of the 25 with stable slips did so.

SUFE may also be classified by the magnitude of the displacement of the femoral epiphysis relative to the neck. Southwick’s method was the femoral head-shaft angle on the frog lateral view. When the hip is in painful

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**Figure 9** Image demonstrating the importance of anterior screw placement, to ensure the screw threads enter the epiphysis perpendicular to the growth plate.

**Figure 10** Lateral radiograph of anterior screw placement appropriate for the degree of slip.

**Figure 11** The level of suggested femoral neck osteotomies.
spasm an accurate portrayal of the frog lateral projection is impossible.

Mild: the head shaft angle differs by less than 30°.
Moderate: the angle difference is 30–60°.
Severe: the angle difference is more than 60° in comparison to the contralateral hip, if it is unaffected.

When the other hip is affected or not measured, the femoral head shaft angle of the affected hip is calculated from normal values for this angle. Southwick felt that the normal value was 145° on the AP and 10° posterior on the frog leg lateral.

The degree of slip can also be quantified as a ratio of slip distance to the diameter of the femoral neck at the physis as described by Wilson. Using this method the slips are mild (less than 33%), moderate (33–50%) and severe (more than 50%). This method has some flaws due to inconsistent positioning and can change over time due to proximal femoral remodelling.

**Imaging modalities**

**Plain films**

Radiologically the plain film is the most important investigation. Good quality AP and frog lateral views are essential, if the patient is able to move their hips. The lateral is important as in 14% displacement may not be visible on the AP alone. In mild degrees of slip the lateral projection is more sensitive. Both hips need to be visualised to allow comparison between sides and because of the high incidence of bilateral disease. This also enables Southwick angle measurements to be measured. In unstable cases a lateral film may be omitted if painful and to avoid further displacement.

A number of signs are visible on plain films:

**Trethowan’s sign**

Here Klein et al.’s line does not transect the capital epiphysis or transects less than on the other hip.
Steel’s 28 metaphyseal blanch sign

This is a crescent shaped area of increased density that lies over the metaphysis of the femoral neck adjacent to the physis. This increased density is due to the overlapping of the femoral neck and the posteriorly displaced capital epiphysis.

Scham’s 29 sign

Seen on an AP film, in a normal hip the inferomedial femoral neck overlaps the posterior wall of the acetabulum producing a triangular radiographic density. With displacement this dense triangle is lost because this portion of the femoral neck is located lateral to the acetabulum.

Ultrasound scan

USS can be helpful, though it is rarely used. It can be used to detect early slips by demonstrating a joint effusion and a step between the femoral neck and epiphysis. 31

CT scan

CT can be helpful in the later management of SUFE by providing additional information if joint penetration has occurred with fixation devices, and the exact position of implants, especially when stiffness of the hip makes plain film evaluation difficult. Scans will show if the growth plates have closed and so may help in deciding about contralateral fixation. 3-D reformatted images are especially useful to assess residual deformity of the upper femur when planning reconstructive osteotomy. Axial CT scan images also enable the head–neck angle measurement. This is similar to the Southwick angle, but is more accurate as it measures the angle from a tangent to the base of the epiphysis and the axis of the femoral neck. 32

Bone scan

Tc-99m labelled scintigraphy of the hip joints with pin hole collimation is now rarely used. It can be useful to see if AVN is developing. Abnormally decreased uptake in the epiphysis is highly specific for the diagnosis of AVN. When chondrolysis is present there is increased uptake of isotope on both sides of the joint.

In a study involving pre-treatment bone scan of 62 patients with 73 SUFEs, 63 of which were stable and 10 unstable, none of the unstable epiphyses became ischaemic, as demonstrated by bone scan, and none developed AVN. Of the 10 unstable SUFEs, six demonstrated ischaemia on bone scanning. Of these, five developed AVN. None of the four unstable slips without ischaemia on bone scan developed AVN. This study suggested that the ischaemia that precedes AVN occurred with the slip and not the treatment. 33 Therefore some surgeons feel that scanning may have a role in preoperative assessment of SUFE patients, to document the vascular status of the capital epiphysis, prior to surgery.

MRI

The role of MRI in SUFE is limited. It may have a place in the early detection of AVN but the presence of metallic implants can seriously degrade the images. Some authors have suggested that MRI may be able to detect hips in a ‘pre-slip’ stage, but there is no convincing evidence that these cases could not have been diagnosed on the plain films. 34

Pathology

With gradual slipping of the capital epiphysis the periosteum is stripped from the posterior and inferior surfaces of the neck. The area between the original femoral neck and posterior periosteum fills with callus, which ossifies and becomes progressively denser. The antero-superior portion

Figure 16 Distraction arthrolysis of the hip joint, with an external fixator, post-AVN.

Figure 17 Same patient as in Fig. 16 showing advanced degenerative change of the hip joint.
of the metaphysis forms a ‘hump’ that can impinge on the rim of the acetabulum. Normally this ridge will remodel with the anterior portion of the neck, contouring into a smoother surface. In an acute slip the anterior periosteum is torn and so a haemarthrosis will be present.

Classically, the neck migrates anteriorly and rotates externally in relation to the head. With time, changes occur in the superior neck leading to remodelling and, eventually, cyst formation and degeneration. As the slip severity worsens, more external rotation is required in order to be able to flex the hip without impinging.

Howorth\textsuperscript{35} provided a comprehensive review of 169 SUFE hips, treated by open peg epiphysodesis, open reduction or femoral neck wedge osteotomies. He described a preslip stage characterised by widening of the physis both histologically and radiographically without actual displacement of the capital epiphysis. In this stage the synovial membrane is oedematous, as are the capsule and periosteum to a more limited extent.

There is a thickening and irregularity of the growth plate. The failure occurs through the proliferative and hypertrophic zone in an irregular pattern. The resting zone of the physis is usually normal in appearance microscopically, but accounts for a smaller percentage of the total thickness of the physis because of the relative increase in thickness of the proliferative and hypertrophic zones. The hypertrophic zone can account for up to 80% of physeal width, whereas normally it would be around 15–30%. Both the proliferative and hypertrophic zones demonstrate an overall decreased number of chondrocytes with an excess amount of matrix tissue. Collagen fibrils are decreased in number, variable in size, and irregularly organised in these two zones. The columnar alignment of the chondrocytes is disrupted and the cells tend to be organised into clumps.

Histology taken before and after fixation demonstrates a return to a more normal architecture following fixation. Such finding suggest that mechanical stabilisation of the physis with removal of abnormal shear across the physis allows at least a partial reversal of the pathology seen in SUFE. Guzzanti et al.\textsuperscript{36} showed that histological sections of physis in stable and unstable slips after fixation showed an improvement in the cellular architecture and improved columnar organisation of chondrocytes. In addition, Weiss and Sponseller\textsuperscript{37} found no abnormalities in iliac crest biopsies of patients with SUFE suggesting that the microscopic changes seen in the proximal femoral physis are secondary to the slip rather a manifestation of a generalised disorder.

Natural history

Short term natural history of SUFE is one of gradual displacement. With time the physis closes and so stabilises the slip. All slips eventually stop, the timing of which and the degree of slip prior to physeal closure are unpredictable. Most progress slowly, but some do so rapidly. These are the ones which are at the highest risk of significant complications.

In the long-term SUFE does appear to put the hip joint at increased risk of developing osteoarthritis, with poorer results following increasing severity of slip. Haggland et al.\textsuperscript{12} reported radiographic evidence of OA in 27% of SUFE hips at long-term follow (mean follow up 33 years), compared with 9% of controls.

Carney and Weinstein\textsuperscript{38}, with a mean follow up of 41 years, reported on 28 patients with 31 untreated slips, they correlated the severity of the slip with radiographic and clinical scores. Patients with mild slips did better with regard to radiographic changes and lowa hip scores. At long-term follow up lowa hip scores were at least 80 in all 17 mild slips and in 9 of the 14 hips with moderate or severe slips. There was radiographic evidence of OA in 64% of the mild slips and 100% of the moderate and severe slips.

It is thought that SUFE accounts for 2–9% of end stage hip arthritis, and a cadaveric study noted ‘post slip’ morphology in 8% of skeletons and showed that OA was associated with such morphology.\textsuperscript{39}

Treatment

The goals of treatment are early detection, prevention of further slippage and avoidance of complications. Attention is focused on the affected hip, though care of the unaffected hip must not be overlooked.

Manipulation

Historically this was performed to decrease the proximal femoral deformity and has been described in conjunction with spica casting and internal fixation. Forceful manipulation in cases of SUFE is never safe because of the increased risks of AVN. A serendipitous reduction which may occur with patient positioning on the operating table with the legs extended and gently internally rotated appears not to adversely affect patient outcome.\textsuperscript{40}

Spica casting

The goal of spica casting is to prevent progression of SUFE. High rates of complications occur in children treated this way, with increased rates of chondrolysis in both the affected hip and the unaffected hip, progression of slippage and pressure area problems. With the advent of in situ fixation there is little role for spica casting now.

In situ fixation

With regard to the more common stable or chronic mild and moderate slips (85%), there is little controversy in the diagnosis and treatment since most surgeons fix the slip in situ on a fracture table with a single cannulated screw after no formal manipulation.

Two screw fixation yields only a 33% increase in stiffness compared to single screw fixation and the gain in stiffness with a second screw may not offset the increased risk of complications.\textsuperscript{41} Clinical studies have repeatedly shown that single screw fixation yields satisfactory, if not superior, results to multiple pin or screw fixation for both stable and unstable slips.\textsuperscript{42} Blanco et al.\textsuperscript{43} in a study of 114 hips treated with one two or three screws or pins, found that the
incidence of pin-related complications was directly related
the number of pins or screws (4.6% with one screw/pin, 19.6% with two and 36% with three).
Carney et al.44 looked at slip progression in stable slips fixed in situ with a single screw. They found those slips that
do progress (assessed as a change of greater than 10° from the position achieved at surgery on plain film) had less than
five threads engaging the epiphysis.
The key points in placement of the screw are as follows:
1. an image intensifier and a radiolucent fracture table;
2. anterior entry site on the neck, appropriate for the
degree of slip;
3. no crossing of the physis until bi-planar alignment is
achieved;
4. the pin is in the epiphysis and NOT in the joint by
multiplanar radiographic evaluation.

The operative technique is well described by Morrissy45 who puts the emphasis on pin placement in the central axis
of the femoral head and the use of a single screw. For ease in
screw placement, the ideal system should be cannulated,
fully threaded and easy to remove.
Using the image intensifier in the AP position, a smooth
Kirschner wire is placed on top of the skin to determine the path of the screw, perpendicular to the physis and into the
centre of the head. Mark this line with a marker. Repeat this
with the image intensifier in the lateral position. The skin
incision is then placed where the two lines on the skin bisect.

The most important contribution to the blood supply to
the femoral head is from the lateral epiphyseal vessels.46
Brodetti47 demonstrated that these enter the femoral head
in the postero-superior quadrant and anastomose with the vessels from the round ligament at the junction of the
medial and central thirds of the femoral head. Therefore
the ideal position for a screw is in the central area or neutral
zone of the femoral head. If a pin is placed in the postero-
superior quadrant the risk of damage to the epiphyseal
blood supply is increased.

Once the fixation screw is in situ, an arthrogram may be
performed via the cannulated screw to ensure that joint
penetration has not occurred. Care must be taken not
irrigate the joint with debris from surgery if penetration has
indeed occurred. This is not something that we routinely
perform in our unit. It is better to move the hip through a
range of movement and screen under image intensifier. If
any doubt persists then a later CT scan of the hip should be
performed.

The timing of fixation is also very significant. Recent work
from the Alder Hey hospital48 has shown an increased rate of
AVN in unstable SUFEs if treated between 24 and 72h,
leading to the hypothesis of an ‘unsafe window’ when intervention should be actively avoided.

For the severe slips, treatment is controversial. In situ
pinning can often be very difficult if not impossible. In these
cases primary osteotomy may be indicated. An attempt at
in situ fixation can be undertaken, accepting that there
will be a functional deficit, and depending on the age at
presentation, limited remodelling potential. If the patient
is still symptomatic once the physis has closed it may
then be possible to undertake a late osteotomy to restore
the anatomy.

Femoral osteotomy

Proximal femoral osteotomies are classified in terms of their
timing (early or late) or anatomically by the level of the
femoral neck osteotomy.

1. Early osteotomies are used as part of the acute
treatment in an attempt to improve the joint anatomy
and prevent further slippage and later complications.
They are always accompanied by a pinning of the
epiphysis.

2. Late osteotomies are usually performed at least 1 year
after initial treatment and only if significant symptoms persist and the deformity is significant.

Anatomically, these are:

(A) subcapital (Dunn49 or Fish50);
(B) basal neck (Kramer51 or Barmada et al.52);
(C) intertrochanteric (Southwick53 or Imhauser54).

The closer to the epiphysis the osteotomy, the greater is
the risk of AVN, in Frymoyer’s paper55 reporting 0% AVN using the Southwick procedure compared with up to 30% for
subcapital osteotomies. However, the subcapital osteotomy
gives the highest degree of correction.

Subcapital osteotomy

Slip progression following subcapital osteotomies has not
been reported. The Fish50 osteotomy is a cuneiform
subcapital osteotomy, where a wedge of bone and accom-
panying callus is removed from the neck. The head is then
reduced onto the neck and pinned in place. Fish reported
good to excellent clinical and radiological results in 61 of 66
(92%) patients who had this osteotomy,55 with AVN develop-
ing in three hips (4.5%) and chondrolysis in two (3%). The
Dunn osteotomy is undertaken more acutely and yields 75%
good clinical results.49

Both techniques specify that care needs to be taken in de-
tensioning the blood supply at the posterior neck to
minimise the risk of AVN. As with unilateral screw fixation
limb length discrepancy is a common problem with these
osteotomies, (between 1 and 2 cm, and possibly up to 5 cm55). They are both technically demanding and have a
steep learning curve; it is not an operation for the
occasional user. Complications can be frequent and severe,
leading many authors to recommend caution if you are
considering their use.

Neck osteotomy

The Kramer et al.51 osteotomy corrects the varus and
retroversion of the slip. It is a compensating closing wedge
osteotomy at the base of the neck. The osteotomy is fixed
classically with 3 threaded Steinmann pins that also cross
the epiphysis, but single screw fixation is acceptable.
that a modified Oxford pelvic bone age score and no male older than 15 years did so. These authors found between 11 years 8 months and 14 years 11 months did so, went on to develop a contralateral slip, 9 of 22 aged all boys younger than 11 years 7 months at first slip diagnosis predictive of a contralateral slip.

Intertrochanteric osteotomy

Intertrochanteric osteotomies are generally used after closure of the physis. Southwick describes a tri-planar osteotomy incorporating valgus, flexion and internal rotation of the distal segment to restore proximal femoral alignment, at the level of the lesser trochanter. Imhauser described a bi-planar osteotomy with flexion and internal rotation of the distal portion.

Significant internal rotation is required to restore anatomical relations and a functional arc of movement. They are secured using plates or fixed angle devices. Southwick reported good to excellent clinical results with his series in 87% of patients at 18 years.

Chondrolysis, delayed union, re-operation, LLD, fracture and late OA have been quoted as complications of the intertrochanteric osteotomy. Being the most distal from the site of the deformity they are limited in the correction they can provide. Despite this there is generally sufficient correction to allow for good clinical outcome, with an acceptably low rate of complications.

Contralateral fixation

Prophylactic pinning of the uninvolved hip provokes debate. Proponents of contralateral fixation cite the high risk of bilateral SUFE, the increased risk of OA at long-term follow up, and the decreased risks of prophylactic pinning as technology and technique improve. Opponents of prophylactic pinning cite the complications of prophylactic treatment and the potential risks of pinning a hip that will never slip. With appropriate counselling and close follow up most subsequent slips can be picked up early. The accepted recent frequency for developing a contralateral slip in adolescence following a unilateral slip is 20–25%. If you also consider that 5–10% of slips are unstable, then we can conclude that the risk of developing a contralateral, unstable SUFE after a unilateral slip is 1–2%.

The procedure of fixing a “normal” hip is not without risk, although more recent studies have shown the complication risk to be negligible. Contralateral slips have been reported as late as 5 years following the original but the majority occur by 18 months after the original slip. Age at initial slip seems an important determinant in slippage of a contralateral “normal” hip. The younger the child, the higher the risk especially in boys. Stasikelis et al. showed all boys younger than 11 years 7 months at first slip diagnosis went on to develop a contralateral slip, 9 of 22 aged between 11 years 8 months and 14 years 11 months did so, and no male older than 15 years did so. These authors found that a modified Oxford pelvic bone age score was highly predictive of a contralateral slip.

Puyleart et al. looked at pubertal stage and risk of contralateral slip. He showed that the risk was high as long as the triradiate cartilage was open; reducing to 4% once the triradiate cartilage had closed. He concluded that staging puberty is useful to differentiate the risk of contralateral slip.

Regular radiographic assessment and parental vigilance are essential. If these be assured, the contralateral hip should be prophylactically fixed. All slips in young children (<10 years) and those due to endocrine disease are routinely fixed bilaterally due to the increased risk of a contralateral slip, 61% of endocrinopathy-related SUFE and 95% in chronic renal insufficiency patients are bilateral.

Removal of metalwork

Our view is that metalwork is best removed, to reduce the stress riser effect of the implant and as there is an increased chance of requiring future arthroplasty. Removal of metalwork can be a difficult and time consuming procedure. It means another anaesthetic, more scarring and risk of infection.

Complication rates of 19–53% are reported (implant breakage, extensive bone loss with implant removal, fracture following removal, difficulty in removing titanium screws due to osseo-integration) particularly when the screws/pins have been removed with significant quantities of bone. Provided care is exercised with regard to the choice of hardware and its removal, it is the opinion of the authors that all metalwork should be removed. We routinely use the Richards screw which is fully threaded and has a reverse cutting thread, making removal easier. This should be performed at skeletal maturity or once the physis has closed to prevent the risk of further slippage.

Complications

There are many complications of treatment of SUFE. Avascular necrosis of the capital epiphysis and chondrolysis are the two most feared. These can occur spontaneously or may be related to treatment. Other complications can arise such as implant failure, growing off the screw, slip progression, proximal femoral fracture, femoral neck fracture, and leg length discrepancy.

Chondrolysis

Chondrolysis is acute necrosis of the articular cartilage. It was first described by Elmslie in 1913. Waldenström in 1930 established chondrolysis as a definite pathological entity distinct from AVN.

Risk factors for chondrolysis are:

1. cast immobilisation
2. unreconised permanent pin penetration
3. severe slip
4. prolonged symptoms before treatment.
It usually presents with pain and stiffness, with the hip being held in flexion, external rotation and abduction. X-rays reveal a loss of joint space, the criterion for diagnosis being a loss of more than 50% of the joint space compared to the other hip or an absolute measurement of 3 mm or less. A bone scan may help make the diagnosis but this is seldom necessary (Table 1).

The incidence of chondrolysis varies with treatment. It can occur spontaneously without treatment of the slip, but complications at 0–9% after in situ fixation, rising to over 50% in a series of female patients treated with a spica cast. It is particularly associated with pin penetration of the joint.

Rates of chondrolysis by treatment:

1. spica casting 14–53%
2. subcapital osteotomy 3–18%
3. base of neck osteotomy 2–10%
4. intertrochanteric osteotomy 2–25%
5. in situ fixation and bone peg epiphysiodesis less than 5%.

It affects girls more than boys and black races were thought to be more likely to suffer chondrolysis. This has been disproved but there may be a higher incidence in those of Hawaiian descent.

Presentation is usually between 6 weeks and 4 months after treatment of SUFE. Progressive joint space narrowing occurs between 6 and 12 months. Eisenstein and Rothchild, in a prospective study of 34 patients with slips, found that all patients had significant elevations in serum immunoglobulins and the C3 component of complement; the nine that developed chondrolysis had a greater elevation in the IgM fraction as well. The authors felt that SUFE could produce an antigen that induces an autoimmune state and that a genetically determined subgroup of people may develop chondrolysis. Walters and Simon first implicated joint penetration with metallic implants although some patients with pin penetration did not develop chondrolysis.Transient penetration in experimental models produces less severe cartilage changes than if the pins are left in place. In the rabbit model the severity of the chondrolysis is related to the duration of pin penetration. Multiple fixation devices appear to cause higher rates of chondrolysis because of the risk of unrecognised pin penetration. The risk of chondrolysis is lessened if the penetration occurs in the inferior head or fovea or if penetration is recognised at the time of surgery and the device is removed.

Pathologically the findings are those of a non-specific inflammatory process, with thickening of the synovium and large villous projections. The synovium then becomes fibrotic and the capsule thickens. The articular cartilage is initially grossly normal but eventually thins and softens. Both femoral and acetabular cartilage are affected but there is no pannus. With progression, granulation tissue gradually invades the articular surfaces and the fibrous adhesions form between the capsule, the acetabulum and the femoral head. When raw bone is exposed on both sides of the joint, osteoarthritis is inevitable.

Treatment of chondrolysis is largely supportive. Firstly infection must be ruled out. Secondly, a CT scan of the hip should be undertaken to ensure that penetration of the joint has not occurred. If penetration has occurred then the screw should be removed, or replaced if the physis has not closed.

Patients who do not recover adequate movement or who have severe continued pain may require arthrodesis or arthroplasty.

### Avascular necrosis (AVN)

Avascular necrosis is a serious complication of SUFE as the prognosis is poor.

Most cases of AVN occur in slips that have been treated. The incidence is lowest after open epiphysiodesis or in situ pinning of stable slips where no reduction is attempted. The two main causes are disruption of the blood supply preoperatively by the slip or by the treatment.

The condition is unlike Perthes’ disease in that there is a single vascular insult and much less restorative/remodelling capacity, probably because the children are older. Femoral head necrosis may be total or partial (segmental). Radiographs initially show few changes. Eventually, resorption of necrotic bone becomes apparent. Most cases are recognised by 1 year with the occasional rare case by 18 months. It is possible to diagnose earlier on bone scan or MRI. However these methods serve only to document the condition, not to help in planning treatment.

There is debate as to whether the degree of the slip influences the incidence of AVN. In Tokmakova et al.’s paper, none of 204 hips with a stable SUFE developed AVN of the hip, regardless of grade of slip. In addition AVN did not occur in any of the unstable hips that had not undergone reduction. The rate of AVN increased in unstable hips that had been partially or completely reduced (mild, 12.5%; moderate 70%; severe 75%). This supports the view that reduction of the unstable SUFE causes AVN. Timing of the intervention may affect AVN rates, which increase from 0% to 9% before 24 h from symptom-onset to 20% after this time.

### Salvage options

If chondrolysis and necrosis are avoided then most treated hips will function well into later adult life. Re-directional osteotomies, vascularised fibular grafting and standard bone grafting procedures have been attempted in children, but there are no convincing outcome studies. The results of distribution arthrolysis are variable and difficult to predict so that all that can be offered in the medium and long term is later arthrodesis or arthroplasty.

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**Table 1** Normal values for cartilage thickness, by age of child.

<table>
<thead>
<tr>
<th>Age (year)</th>
<th>Normal values (mm)</th>
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<tbody>
<tr>
<td>1–7</td>
<td>6</td>
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<tr>
<td>8–12</td>
<td>5</td>
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<tr>
<td>13–17</td>
<td>4</td>
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References

48. Personal communication, from C. Bruce. Alder Hay Children's Hospital, Liverpool, UK. Paper accepted for publication by JPO.