

Slipped capital femoral epiphysis: a review

Slipped capital femoral epiphysis is an important hip condition that is steadily increasing in incidence. Clinicians and health-care workers who regularly work with children or adolescents need to be fully aware of its presenting features and diagnostic pathways to prevent a delay in diagnosis.

Slipped capital femoral epiphysis is a hip disorder affecting adolescents. It is caused by the posterior and inferior displacement of the capital femoral epiphysis in relation to the femoral metaphysis, through the growth plate (physis). In reality, the femoral neck and shaft displace anteriorly and rotate externally in relation to the femoral epiphysis, which remains located in the acetabulum. The incidence of this condition can vary significantly between geographical areas and ethnic groups, ranging from 0.499 cases in boys and 0.142 cases in girls per 100 000 children in Korea to 81 cases per 100 000 among Maori children in New Zealand (Song et al, 2009; Phadnis et al, 2012). In the UK, 9.66 cases per 100 000 children have been reported in Scotland (Murray and Wilson, 2008). The average age of presentation with slipped capital femoral epiphysis in a multi-centre trial was 12 years for girls and 13.5 years for boys (Loder, 1996). Slipped capital femoral epiphysis occurs more commonly in boys than girls (Lehmann et al, 2006; Murray and Wilson, 2008). A steady increase in the incidence of this condition has been noted over time which may be related to the increased prevalence of childhood obesity (Murray and Wilson, 2008; Novais and Millis, 2012).

Slipped capital femoral epiphysis can present in a variety of manners such as hip, groin or upper thigh pain, an undiagnosed limp or solely with referred pain to the knee (Green et al, 2005), which can lead to this condition being missed or the diagnosis being delayed (Rahme et al, 2006; Clarke and Kendrick, 2009). Delay in diagnosis can lead to an increase in the severity of the slip at presentation and is associated with a poorer prognosis (Cowell, 1966; Rahme et al, 2006; Clarke and Kendrick, 2009).

Slipped capital femoral epiphysis can be unilateral or bilateral (bilateral slipped capital femoral epiphysis is usually present in <30% cases) at the time of presentation (Hagglund et al, 1984; Jerre et al, 1994; Koczewski, 2001). Slipped capital femoral epiphysis on the contralateral side may be completely asymptomatic and only identified on radiographs. Hence it is important to obtain radiographs for both hips. A variable proportion of children with unilateral slipped capital femoral epiphysis will also develop slipped capital femoral epiphysis on the contralateral side when followed up over time.

The percentage of children who develop slipped capital femoral epiphysis on the contralateral side can be as high as 70% with long term follow up, although this has been very variable in different studies (Hagglund et al, 1987; Jerre et al, 1994; Hurley et al, 1996; Koczewski, 2001). This increasing incidence of slipped capital femoral epiphysis and a poorer prognosis when the diagnosis is delayed mean that greater awareness and a high index of suspicion is required among clinicians who are likely to encounter this condition, such as orthopaedic surgeons, general physicians, emergency physicians and paediatricians.

Aetiology and pathophysiology

Several aetiological factors have been implicated as contributing factors, although one of the most important is a high body mass index. Almost all studies related to slipped capital femoral epiphysis have shown a strong association with a high body mass index (Loder, 1996; Murray and Wilson, 2008). Physical factors such as high shear forces across the physis, which can occur even with normal routine physical activity in adolescents with a higher body mass index, appear to play the most important part in the development of slipped capital femoral epiphysis (Chung et al, 1976). However, additional factors related to the physis itself can make it more prone to slipped capital femoral epiphysis.

The physis is divided into a resting zone, a proliferative zone and a hypertrophic zone. In slipped capital femoral epiphysis, the slip usually occurs through the hypertrophic zone. In cases where the physis is more prone to developing slipped capital femoral epiphysis, the physis has been found to be thicker than normal with the chondrocytes being distributed in clusters separated by large collections of matrix (Ippolito et al, 1981). The structure of the proliferative and hypertrophic zone may also be abnormal, with reduced cellularity and increased chondrocyte apoptosis (Adamczyk et al, 2005). The nor-

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mal process of endochondral ossification may also be disrupted (Ippolito et al, 1981). These structural abnormalities make the physis plate more prone to fracture, leading to slipped capital femoral epiphysis. Hormonal influences also have been implicated in the pathogenesis of slipped capital femoral epiphysis. These include endocrine abnormalities such as hypothyroidism, pan-hypopituitarism, growth-factor deficiency, hypogonadism and renal osteodystrophy (Rappaport and Fife, 1985; Loder et al, 1995; Loder and Hensinger, 1997; Rahme et al, 2006). The presence of endocrinopathy increases the likelihood of developing slipped capital femoral epiphysis bilaterally (Loder et al, 1995).

Classification

Several classification methods exist based on either the duration of symptoms, the degree of displacement of the femoral head from its resting state (measured on radiographs) or the severity of clinical symptoms at the time of presentation (Figure 1).

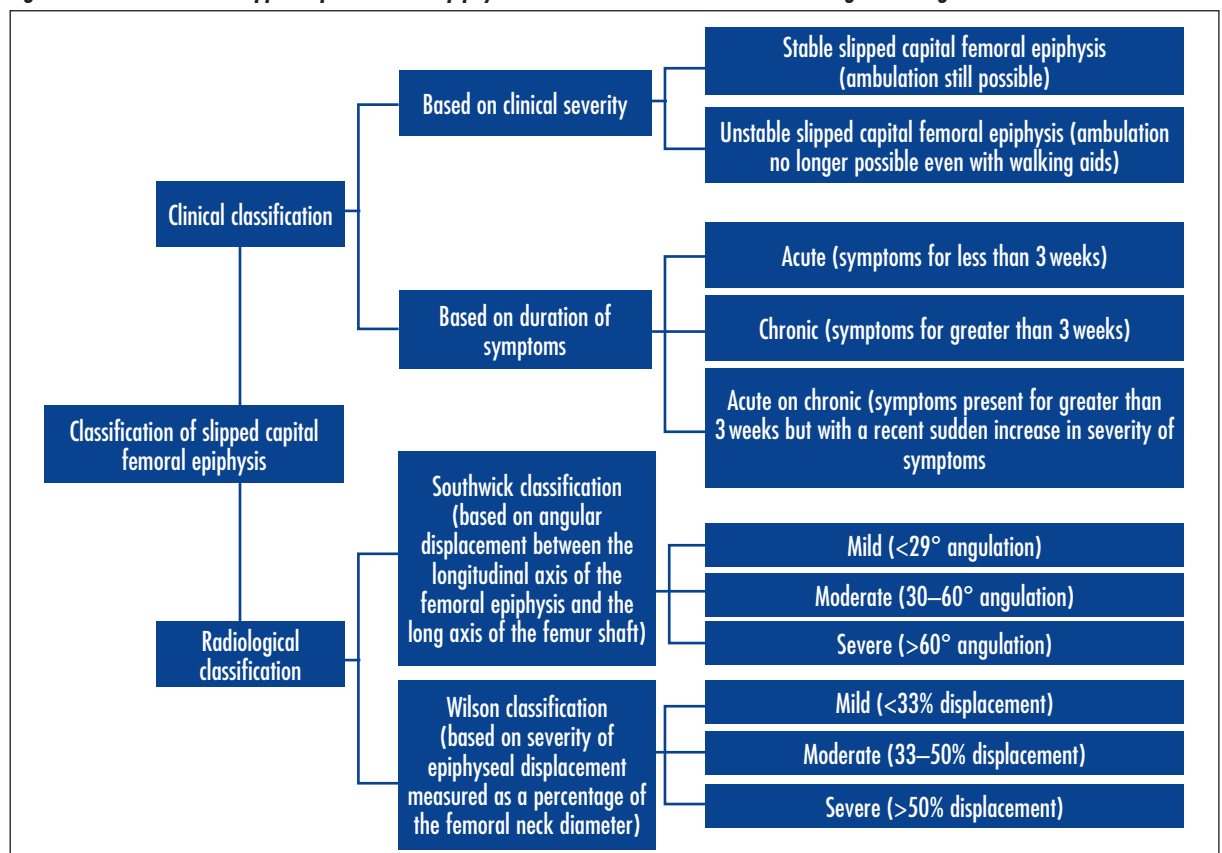
In terms of duration of symptoms, slipped capital femoral epiphysis may be classified as acute (symptoms for less than 3 weeks), chronic (symptoms for greater than 3 weeks) and acute on chronic slipped capital femoral epiphysis (symptoms present for greater than 3 weeks but with a recent sudden increase in severity of symptoms). A more clinically relevant classification differentiates slipped capital femoral epiphysis into stable and unstable. Slipped

capital femoral epiphysis is defined as stable when ambulation is still possible (with or without walking aids such as crutches) and unstable when mobilization is no longer possible (Loder, 2001). Around 5% of all slipped capital femoral epiphyses are unstable and these are associated with poorer prognosis as well as a higher incidence of complications such as avascular necrosis (Loder, 2001), which is described in more detail in a later section.

Imaging modalities can also help classify slipped capital femoral epiphysis based on the severity of the displacement of the femoral epiphysis. Southwick (1967) described a method of assessing the severity of the displacement of the femoral head from its normal anatomical position (using the contralateral hip for reference). This involved calculating the angle between the longitudinal axis of the femoral epiphysis with the long axis of the femur shaft on both antero-posterior and frog-lateral views of the hip (a lateral view of the hip taken with the hip abducted, externally rotated and flexed). Based on this angle, the slipped capital femoral epiphysis may be classified as mild (less than 29° angulation compared to the normal side), moderate (30–60° angulation) and severe (greater than 60° angulation) (Southwick, 1967; Rahme et al, 2006; Green et al, 2009).

Alternatively, the Wilson method of calculating epiphyseal displacement as a percentage of the femoral neck diameter has been described and may be used to calculate the severity of the slip as mild (<33% displacement),

Figure 1. Classification of slipped capital femoral epiphysis based on clinical features and radiological findings.



moderate (33–50% displacement) and severe (>50% displacement) (Rahme et al, 2006; Green et al, 2009). A limitation of these techniques is that the frog-lateral view may not be possible in all cases as a result of hip pain associated with slipped capital femoral epiphysis and the risk of further displacement of the epiphysis in severe or unstable slips. It is also possible to classify the slipped capital femoral epiphysis on the basis of ultrasound imaging of the hip depending on the presence or absence of joint effusion and remodelling of the metaphysis into acute, acute on chronic and chronic slipped capital femoral epiphysis (Kallio et al, 1993). All of the above imaging classifications of slipped capital femoral epiphysis have important implications for the type of treatment used in the management.

Diagnosis

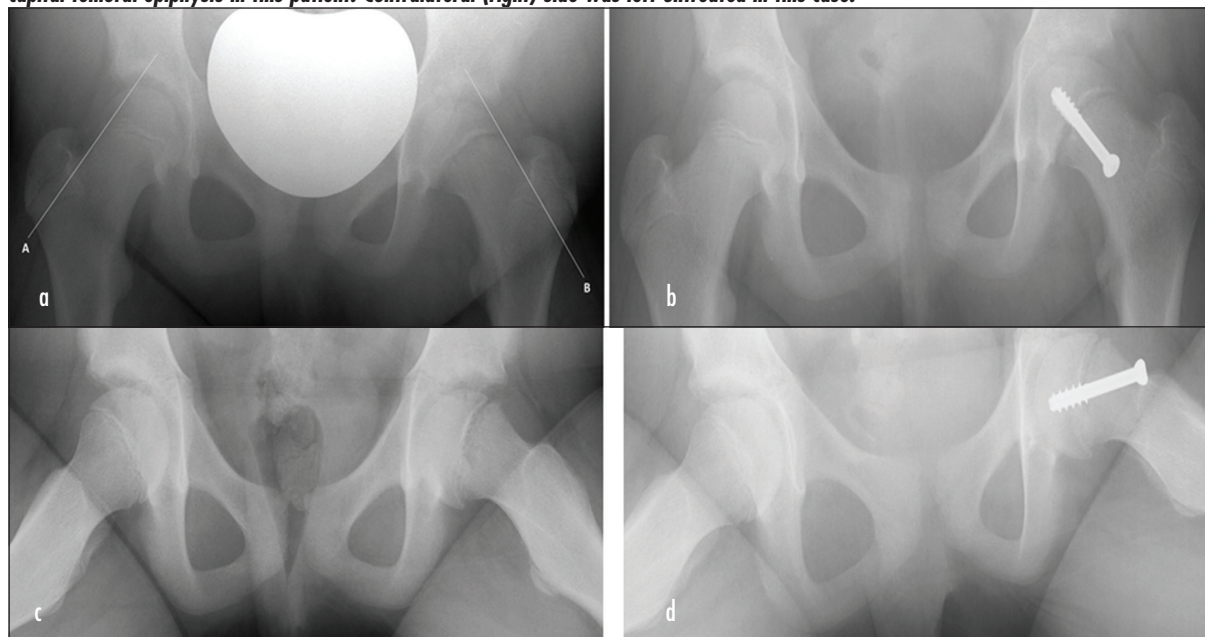
Radiographs of the hip joints are crucial for confirming the diagnosis of slipped capital femoral epiphysis – an antero-posterior pelvic radiograph and a lateral view should be obtained (Figure 2). On the antero-posterior radiograph of the hip, slipped capital femoral epiphysis can be diagnosed by drawing a line along the superior border of the femoral neck which should normally intersect the upper part of the epiphysis. However, in slipped capital femoral epiphysis the femoral neck is displaced so that this line does not intersect any part of the femoral epiphysis (Figure 2a). This radiographic line is called the Klein's line and this radiographic sign is also referred to as Trethowan's sign (Clarke and Kendrick, 2009). However

the Klein's line and antero-posterior radiographs have been reported to have low sensitivity in being able to diagnosis this condition, especially in mild to moderate slips. Therefore, an additional view is indispensable to ensure that the diagnosis is not missed.

One such view is the frog-leg lateral view which is taken with the hips abducted (Pinkowsky and Hennrikus, 2013). In a study comparing it with Klein's line drawn on antero-posterior views of the hip, this view had 100% sensitivity in the diagnosis of slipped capital femoral epiphysis (Pinkowsky and Hennrikus, 2013). However, in some cases this view may be impossible to obtain as a result of the pain associated with manoeuvring of the hip. In fact, this view should not be taken in unstable slipped capital femoral epiphysis because of the risk of further displacing the slipped epiphysis (Loder, 2001). In these circumstances a cross-table lateral radiograph may be obtained (Loder, 2001). The Billing lateral view is another standardized lateral view for this condition in which the femur is externally rotated by 90° and elevated 25° above the horizontal plane (Jerre et al, 1996). This view proved to be more sensitive than the frog-lateral view in detecting contralateral slipped capital femoral epiphysis on follow up in a study involving 100 patients with slipped capital femoral epiphysis in Sweden (Jerre et al, 1996).

Other radiographic signs of a slipped capital femoral epiphysis include widening and irregularity of the physis, a decrease in the height of the epiphysis on the antero-posterior view and a metaphyseal 'blanch' of increased

Figure 2. a. Antero-posterior view of a left-sided slipped capital femoral epiphysis with Klein's lines drawn on both sides. On the right (normal hip) the Klein's line (A) intersects the femoral epiphysis so that a part of the femoral epiphysis lies lateral to the line. On the left side, the Klein's line (B) does not intersect the femoral head suggesting the diagnosis of slipped capital femoral epiphysis. b. Antero-posterior view of the same slipped capital femoral epiphysis post single screw fixation. c. Frog-lateral view of the same patient demonstrating slipped capital femoral epiphysis on the left side. d. Frog-lateral view post single screw fixation of the left-sided slipped capital femoral epiphysis in this patient. Contralateral (right) side was left untreated in this case.



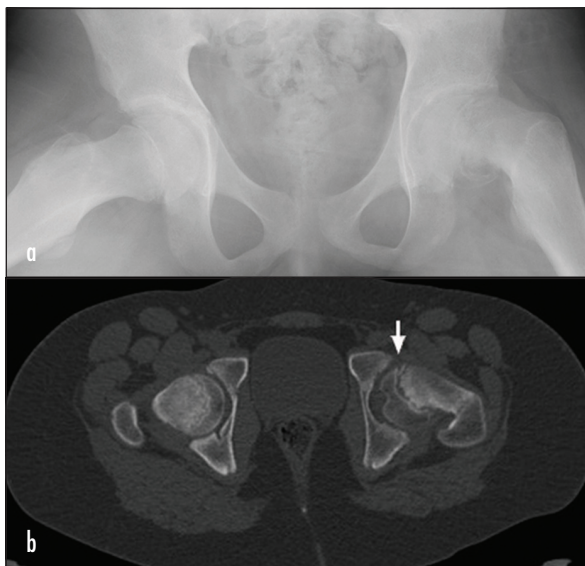
apparent radiodensity in the metaphysis as the epiphysis slips posteriorly. Although the above mentioned radiographic views may be sufficient to make a diagnosis of the condition, a computed tomography scan (Figure 3) or magnetic resonance imaging of the hip(s) may be necessary in advanced slips to plan the appropriate intervention (Koenig et al, 2012; Monazzam et al, 2013). Magnetic resonance imaging of the hips may be extremely useful in the early diagnosis of slipped capital femoral epiphysis when it may not yet be evident on radiographs (Umans et al, 1998) as well as in detecting complications of slipped capital femoral epiphysis such as avascular necrosis.

Management

The aim of treatment is to prevent progression of the slip and to minimize complications. The child or adolescent diagnosed with slipped capital femoral epiphysis should be admitted to hospital. Complete bed rest is recommended until definitive treatment has been delivered. Definitive intervention should be performed as early as possible to prevent any progression of the slip. Single-screw fixation in situ without any active attempt to reduce the slip is the preferred option for the treatment of stable slipped capital femoral epiphysis although there are limited long-term data comparing this with other treatment options for this condition such as spica casting, multiple screw fixation and epiphysiodesis (Sonnega et al, 2011; Sun et al, 2011; Wensaas et al, 2011; Loder and Dietz, 2012).

The best treatment for unstable slipped capital femoral epiphysis is still a matter of debate and in particular the

Figure 3. a. Antero-posterior view of the pelvis demonstrating a severe slipped capital femoral epiphysis on the left side. b. Computed tomography scan of the pelvis showing the slipped capital femoral epiphysis in more detail. Computed tomography scans can be extremely useful in planning the surgical approach, particularly in severe cases like this.



timing of the surgery that is most likely to prevent avascular necrosis is still uncertain (Loder and Dietz, 2012; Rached et al, 2012). However, consensus opinion among orthopaedic surgeons is in favour of early treatment (within 24 hours) for unstable slipped capital femoral epiphysis with either one or two screw percutaneous fixation and closed reduction (through limited manipulation or purely through positioning on table) with or without decompression of the joint before treatment (Peterson et al, 1997; Witbreuk et al, 2007; Sonnega et al, 2011; Loder and Dietz, 2012). A very small proportion of surgeons favours open reduction and internal fixation (Witbreuk et al, 2007; Loder and Dietz, 2012). Newer techniques such as surgical displacement with realignment of the epiphysis and modified Dunn's technique lack sufficient evidence of their superiority over the techniques mentioned above as well as their long-term outcomes but provide an alternative approach to treatment of unstable slipped capital femoral epiphysis (Sankar et al, 2013).

Corrective osteotomy may be required in the case of a severe slip. Numerous techniques have been described. When the physis is closed, the blood vessels of the metaphysis are anastomosed with the blood vessels of the epiphysis (Fish, 1984). Hence an osteotomy through the neck of femur can lead to avascular necrosis as a result of disruption of these anastomosed vessels. A corrective trochanteric region osteotomy described by Southwick (1967) may be attempted in this scenario when the epiphysis is closed to preserve the vascular supply of the femoral head, although this may only correct slips when the epiphysis is displaced by an angle of less than 70° angulation from its normal anatomical state. Subcapital corrective osteotomy techniques that may be used when the epiphysis are still open have been described by Dunn and Angel (1978) and Fish (1984). These are technically demanding and require particular attention to preserve the blood supply to the femoral head to prevent avascular necrosis. However, it is possible to correct slips with a larger slip angle using these two techniques compared to the inter-trochanteric approach described by Southwick (1967). Another approach is femoral neck osteotomy, which can correct a deformity to a lesser extent than the techniques described by Dunn and Angel (1978) and Fish (1984), but is associated with lesser incidence of avascular necrosis (Kramer et al, 1976; Barmada et al, 1978).

There is further controversy regarding prophylactic pinning of the contralateral normal hip in patients with unilateral slipped capital femoral epiphysis. There is divided opinion regarding this issue and the decision is often personalized based on how strongly comorbidities, such as a high body mass index, and other associated risk factors predict a likelihood of occurrence of slipped capital femoral epiphysis in the contralateral hip (Kocher et al, 2004; Witbreuk et al, 2007; Wensaas et al, 2011). In a study by Riad et al (2007), younger age at presentation

was identified as an important risk factor for developing slipped capital femoral epiphysis bilaterally. In this study all girls younger than 10 years of age and all boys younger than 12 years of age developed contralateral slipped capital femoral epiphysis. Younger age was also associated with a higher likelihood of bilateral slipped capital femoral epiphysis in a study by Loder (1996).

Other factors that can predict a higher likelihood of the development of slipped capital femoral epiphysis on the contralateral side are the presence of endocrinopathies (Wells et al, 1993; Loder et al, 1995) and a greater posterior sloping angle on the frog-lateral radiograph (Phillips et al, 2013). Large scale studies comparing the outcome between prophylactic pinning in carefully selected cases and those managed by close monitoring alone with early treatment of slips are missing. Until more studies are available to guide this issue, any decision regarding prophylactic pinning of the contralateral hip is likely to be individualized based on informed decision making by the parents and adolescent involved, guided by the experience and preference of the orthopaedic surgeon.

Complications associated with slipped capital femoral epiphysis

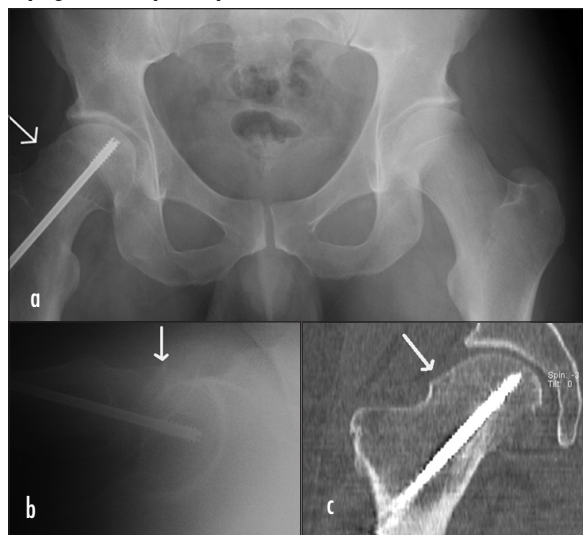
Important complications of slipped capital femoral epiphysis are avascular necrosis, chondrolysis, femoroacetabular impingement and the development of osteoarthritis prematurely in the affected hip (Dunn and Angel, 1978). Avascular necrosis occurs as a result of impairment of the vascular supply to the femoral head following injury to the retinacular vessels located posterior to the femoral neck. This can occur both as a result of the posterior slippage of the femoral head in relation to the neck because of the slipped capital femoral epiphysis as well as by the stretching of these vessels when reduction of the femoral neck is attempted (Dunn and Angel, 1978). Avascular necrosis in stable slipped capital femoral epiphysis is fairly uncommon with an incidence close to 0–2% with single central screw or multiple pin fixation (Loder and Dietz, 2012). Avascular necrosis occurs more commonly in those with unstable slipped capital femoral epiphysis and its incidence is fairly variable, ranging from 3% to 58% (Mullins et al, 2005; Loder and Dietz, 2012; Loder, 2013). It can be a difficult condition to treat. The aim of the therapy is to preserve movement at the hip joint as well as to prevent a collapse of the femoral head, although there is no clear consensus about the best way to manage this condition.

Chondrolysis refers to progressive degeneration of the joint cartilage leading to a narrowing of the joint space and reduction in joint movement as a result (Yarbrough and Gross, 2005). The reported incidence of chondrolysis in those treated for slipped capital femoral epiphysis is also fairly variable (1.8% to 55%)(Ingram et al, 1982; Aronsson and Loder, 1996). Chondrolysis leads to painful joint movements. An unidentified pin penetration through the femoral head during in-situ fixation has been

implicated as one of the causes of the development of chondrolysis after the treatment of slipped capital femoral epiphysis, particularly when multiple fixation devices are used. Treatment is conservative in most cases (Yarbrough and Gross, 2005). Refractory cases may need surgical intervention to relieve symptoms.

Another important late complication of slipped capital femoral epiphysis is femoroacetabular impingement. Cam-type femoroacetabular impingement can arise as a result of abnormal contact between the femoral metaphysis and the acetabulum (Hosalkar et al, 2012). The characteristic rounded shoulder of the femoral head-neck junction on an antero-posterior hip radiograph in cam-type femoroacetabular impingement has also been called a 'pistol grip deformity' as it resembles the curved shoulder of the handle of a gun (*Figure 4*) (Leunig and Ganz, 2014). Clinical signs of femoroacetabular impingement may be present in as many as 30% of cases of slipped capital femoral epiphysis (Dodds et al, 2009). Symptoms of femoroacetabular impingement include hip pain on flexion with internal rotation and reduced range of movements of the hip. This can eventually lead to the development of osteoarthritis prematurely in the affected hip (Hosalkar et al, 2012). Cam-type femoroacetabular impingement is treated with osteochondroplasty which may be done by an arthroscopic approach or via open refashioning of the head-neck junction (through either open surgical hip dislocation allowing complete visualization of the femoral head and acetabulum or through a minimally invasive technique) to reduce the cam impingement (Fayad et al, 2013; Leunig and Ganz, 2014). Arthroscopic management of femoroacetabular impinge-

Figure 4. a. Antero-posterior view of the pelvis showing cam-type femoroacetabular impingement in the right hip. The hip was previously treated for slipped capital femoral epiphysis with a single screw. b. Frog lateral view of the hip with cam-type femoroacetabular impingement. c. Computed tomography scan of the same hip demonstrating the cam-type femoroacetabular impingement very clearly.



ment is rapidly becoming the most preferred choice for the treatment of femoroacetabular impingement, although not all cases of femoroacetabular impingement may be treatable by this approach (Fayad et al, 2013; Leunig and Ganz, 2014).

Premature osteoarthritis is an additional longer term complication of slipped capital femoral epiphysis that develops as a result of disruption of the normal hip joint structure and alignment, such as in femoroacetabular impingement. Osteoarthritis can also develop in the contralateral hip both in the absence and the presence of a preceding slip (Hagglund et al, 1988; Jerre et al, 1994; Wensaas et al, 2011). Other notable complications associated with slipped capital femoral epiphysis are related to the metal implants used for its treatment. Further surgery is often needed for the removal of these implants after fusion of the physis to allow complete remodelling of the bone as well as to avoid complications which are noted when the implants are left in situ, such as femoral fractures, local soft tissue complications and potential risk of neoplasia (Pretell-Mazzini et al, 2012). Screws left in situ can also pose a challenge if subsequent arthroplasty is required. However, screw removal itself can cause complications like bleeding, fractures and infections (Busam et al, 2006). In a number of cases, surgery to remove the fixations screws may fail completely (Pretell-Mazzini et al, 2012). The overall complication rate for the removal of implants in patients treated for slipped capital femoral epiphysis is around 30% (Raney et al, 2008). Hence, elective removal of implants in asymptomatic patients is no longer recommended (Busam et al, 2006; Raney et al, 2008).

Conclusions

Slipped capital femoral epiphysis is an important adolescent hip pathology that can present in a wide variety of manners and hence can pose a diagnostic challenge for physicians. Antero-posterior and frog-lateral views of the hip are crucial for the diagnosis. These should be per-

formed for both hips as contralateral slipped capital femoral epiphysis may be asymptomatic in as many as 70% of cases. Computed tomography and magnetic resonance imaging may also have a role in the early detection of slipped capital femoral epiphysis, in determining the severity, and in planning treatment as well as in the detection of complications associated with slipped capital femoral epiphysis.

Single-screw fixation in situ is the standard treatment of stable slipped capital femoral epiphysis. However, the preferred method of treating unstable slipped capital femoral epiphysis is less clear. For unstable slipped capital femoral epiphysis early treatment (within 24 hours of presentation) with single or two-screw percutaneous fixation with closed reduction (through limited manipulation or purely through positioning on table) is favoured by the majority of orthopaedic surgeons. Prophylactic pinning of the contralateral hip remains a matter of controversy and there is a need for further evidence to address this issue conclusively. Increased awareness and a strong index of suspicion in adolescents is required for early detection of slipped capital femoral epiphysis as well as to minimize complications. This is particularly important as the incidence of the condition appears to be rising in conjunction with the global increase in childhood and adolescent obesity. **BJHM**

Conflict of interest: none.

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KEY POINTS

- Slipped capital femoral epiphysis is an important adolescent hip pathology that can pose a diagnostic challenge for clinicians.
- The incidence of the condition appears to be rising in conjunction with the global increase in childhood and adolescent obesity.
- Anteroposterior and frog-lateral views of the hip are crucial for the diagnosis. These should be performed for both hips.
- Single-screw fixation in situ is the standard treatment of stable slipped capital femoral epiphysis. However, the preferred method of treating unstable slipped capital femoral epiphysis is less clear.
- Prophylactic pinning of the contralateral hip remains a matter of controversy.
- Increased awareness and a strong index of suspicion in adolescents is required for early detection of slipped capital femoral epiphysis as well as to minimize complications.

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