Title
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Journal
Journal of Childrens Orthopaedics, 6(3)

ISSN
1863-2521

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Publication Date
2012-07-01

DOI
10.1007/s11832-012-0397-z

Peer reviewed

J Child Orthop (2012) 6:161–172
DOI 10.1007/s11832-012-0397-z

CURRENT CONCEPT REVIEW

Hip impingement in slipped capital femoral epiphysis: a changing perspective

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Received: 5 February 2012 / Accepted: 10 March 2012 / Published online: 31 March 2012

Abstract
Background Femoroacetabular impingement (FAI) as a result of slipped capital femoral epiphysis (SCFE) has recently gained significant attention. Seen as an intermediate step toward the development of early osteoarthritis, symptomatic FAI develops in SCFE patients who have residual hip deformity characterized by relative posterior and medial displacement of the capital femoral epiphysis, leading to an anterolateral prominence of the metaphysis which abuts on the acetabular rim. This results in a decreased range of hip motion as well as progressive labral damage and articular cartilage injury, which cause symptoms of FAI. All degrees of slips from mild to severe can develop impingement.
Methods The existing literature on the subject was thoroughly reviewed and all levels of studies that have made any meaningful changes to clinical practice were considered.
Results Based on the literature review, current practice trends, and our own institutional practice pattern, all treatment options for SCFE in the impingement era have been presented with an open discussion regarding potential benefits and limitations.
Conclusions Several surgical options exist for the SCFE patient who develops FAI. These are largely determined by the degree of deformity present and severity of the initial slip. Extraarticular (intertrochanteric, base of the neck) as well as subcapital osteotomies can be utilized with a goal of restoring proximal femoral anatomy in order to minimize the effect of the anterolateral prominence in more severe deformities. Patients with milder deformities can undergo osteochondroplasty of the femoral head and neck to remove impinging structures via either an open or arthroscopic approach. Also, proximal femoral osteotomy and open head–neck recontouring can be combined. Finally, patients who develop pain very early after in situ pinning must also be examined for potential iatrogenic screw-head impingement as a source of their pain and decreased hip motion, in addition to abnormalities in the proximal femoral anatomy. There are many centers that are approaching acute unstable SCFE patients as well as the more displaced stable cases with open reduction techniques that seem to be demonstrating good mid-term results. The goal of treatment is to improve patient function, alleviate hip pain, and to delay or prevent the development of early degenerative changes in adolescents and young adults. Prospective multi-center studies will be necessary so as to determine what methods work best in treatment and delay the onset and progression of osteoarthritis.
Level of evidence V.

Keywords SCFE · Impingement · Slipped capital femoral epiphysis

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Introduction

Only recently has the residual deformity associated with healed slipped capital femoral epiphysis (SCFE) been clearly linked to symptomatic femoroacetabular impingement (FAI) and subsequent degenerative changes leading to osteoarthritis [1–3]. The concept of osteoarthritis of the

hip as an end result of hip impingement (which developed as a result of abnormal anatomy of the proximal femur and acetabulum) has been supported by several reports [1, 4–6]. Anatomic variations in femoral head–neck offset, acetabular retroversion, and femoral anteversion are postulated to lead to abnormal hip mechanics with subsequent abutment, labral tears, and the development of early arthrosis [2, 3, 6–9]. Similarly, the posteromedial displacement of the epiphysis in a typical SCFE places the metaphysis in a pathologic anterolateral position [1, 10]. This not only places the femur in retroversion and varus (leading to a clinical loss of internal rotation), but also leads to a loss of hip flexion as the prominent anterolateral metaphysis impinges against the acetabular rim, leading to progressive degenerative changes [1, 10].

Although SCFE was described as early as 1572 by Paré [11], treatment concepts are still evolving as the pathogenesis of intermediate (FAI) and long-term (osteoarthritis) consequences are better understood. In a global sense, treatment options for SCFE can be broken down into slip stabilization (in situ pinning) with acceptance of deformity and a hope for remodeling (with minimal or no symptoms), chronic deformity correction (proximal femoral osteotomies) after healing has occurred (with or without head–neck recontouring), or correction of FAI with femoral head–neck recontouring alone (femoral head–neck osteochondroplasty, with/without additional rim trim and fixation of labrum). Newer approaches, including open reduction of the capital epiphysis via the modified Dunn procedure in moderately to severely displaced SCFE, seek to achieve all of these goals in one stage via stabilization, deformity correction, and removal of pathologic abutment in the same setting [12, 13]. These newer methods are currently practiced primarily in advanced hip centers and long-term follow-up of these patients will be required in order to document their value.

Traditionally, in situ pinning of a clinically stable SCFE has been the most widely accepted method of treatment and is associated with an acceptable prognosis [14–16]. However, controversy exists regarding the treatment of moderate/severe degree of slips, particularly as relates to residual deformity. Does residual deformity remodel and lead to a benign clinical course or does it remain and progressively lead to symptomatic FAI and subsequent arthritis as outlined above? Proponents of in situ pinning believe that metaphyseal remodeling can be expected with time, and that FAI will not develop in most patients and/or is of minimal clinical consequence. Boyer et al.'s [15] long-term follow-up study from Iowa supports this concept.

In contrast, substantial labral injuries and cartilage damage have been documented as a result of SCFE during open surgical hip dislocation, leading others to believe that open reduction of the slip is critical to preventing hip impingement and the early development of degenerative changes which in situ pinning cannot guarantee [10].

In addition, the question arises as to the exact role of proximal femoral osteotomies (i.e., Southwick, Imhäuser, Kramer/Barmada, Dunn) in the treatment of SCFE and FAI [13, 17–19]. When should they be performed in relation to the injury (acute/chronic) and physeal closure (open/closed)? What is their role in preventing FAI? Furthermore, what is the role of osteochondroplasty alone done via an open surgical hip dislocation, anterolateral (Watson-Jones) approach, or arthroscopic procedure in simply removing the anterolateral "bump" and dealing with acetabular labral/cartilage damage that stems from SCFE-related FAI?

The purpose of this paper is to briefly review the most recent evidence regarding our evolving understanding of FAI in SCFE and to discuss different treatment strategies.

Bony impingement—pathology

Posteromedial displacement of the femoral head in a typical SCFE places the metaphysis in a pathologic anterolateral position. During the healing process, this leads to an anterolateral prominence ("bump") on the proximal femur which can abut against or erode the acetabulum, leading to pain and decreased hip range of motion (hallmarks of FAI). Although common in severe slips, this can be seen in mild slips as well [20–22]. In addition, posteromedial callus formation, as a part of the chronic reactive healing process of SCFE, places tension on the posterosuperior retinaculum, which contains the blood supply to the femoral head, complicating potential corrective surgical options [12, 13, 22].

It is important to note that the degree of slip severity can lead to FAI via two different pathologic states. This was exemplified by a 3D model for impingement (due to residual proximal femoral deformity) described by Rab, which was used to quantify and predict the amount of anterior metaphyseal impingement on the acetabulum in SCFE during the gait cycle [23]. This model included two types of impingement: *impaction* and *inclusion*.

Impaction-type refers to impingement occurring when the prominent proximal femoral metaphysis, usually as a result of more severe slip, contacts the anterior acetabular rim (Fig. 1a). This damages the anterior acetabular labrum and allows for levering of the femoral head out of the acetabulum, which also increases damage to the posterior acetabular cartilage and labrum. This is similar to hinge abduction in Legg–Calvé–Perthes disease [24].

Inclusion-type impingement refers to a prominence on the anterior and medial metaphysis that is either a result of a mild to moderate slip or a slip that has undergone remodeling (Fig. 1b). This prominence is small enough to allow entrance into the acetabulum during hip flexion, yet,

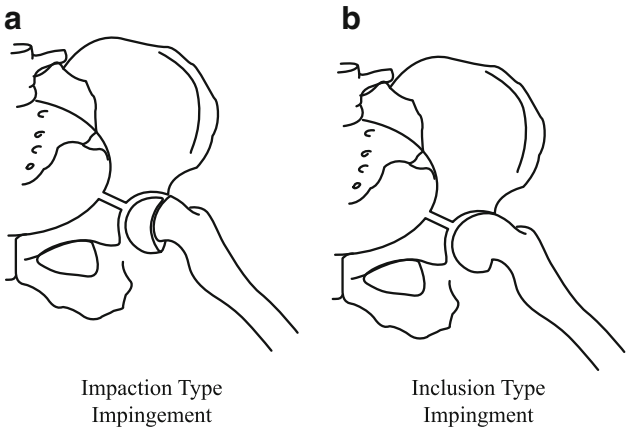

Fig. 1 **a** Diagram suggesting impaction-type impingement with the prominent metaphysis abutting on the labrum and acetabular rim (anteroposterior [AP] view). **b** Inclusion-type impingement (after later remodeling). Joint damage is more likely to be inside the joint (cartilage delamination, also labral injury) (AP view)

its irregularity causes damage to the labrum and increases shear stresses on the acetabular cartilage. It is possible for the femoral metaphysis to cause early *impaction*-type impingement (prior to proximal femoral remodeling), with later *inclusion*-type impingement after metaphyseal remodeling has occurred.

The pathologic relationship between the prominent metaphysis and anteriosuperior acetabulum in patients with slips has been confirmed by multiple authors during open surgical hip dislocation in which direct visualization of the acetabular cartilage and labrum has shown damage from the prominent metaphysis [1, 10]. Although not unexpected in severe slips (*impaction*-type), even patients with mild stable slips (*inclusion*-type) showed evidence of labral injury and chondromalacia in the anterior/superior quadrant of the acetabulum. These studies support the need to address proximal femoral morphology to preclude development of arthrosis from progressive hip impingement.

Although the majority of studies examining FAI as a result of SCFE have concentrated on abnormal proximal femoral morphology, the role of acetabular morphology should be considered (i.e., anteversion versus retroversion) in FAI manifestation. Sankar et al. [25] have shown an increased rate of acetabular retroversion in an SCFE patient's contralateral hip, placing them at risk of developing a "pincer" deformity. Furthermore, in our assessment of a large cohort of SCFE cases with plain radiography and Hip2Norm© Software (Bern, Switzerland), a high incidence of acetabular retroversion was found in the SCFE hip as well as the unaffected contralateral hip, placing them at a risk for focal pincer deformity and potentially increasing the shear forces on the femoral physis during axial loading. The posterior wall sign was positive in 85 % of cases [26]. This is in contrast to Mamisch et al. and Kordelle et al. [27, 28], who, in two separate studies, found no relationships between acetabular version and SCFE. Controversy remains concerning the existence of abnormal acetabular morphology in SCFE and whether it is a primary or secondary phenomenon. Further studies with advanced imaging are needed in order to identify the true nature of acetabular position in SCFE.

Surgical methods to address impingement in SCFE

Methods for treating bony impingement

The indications and options for the treatment of bony impingement of the proximal femoral metaphysis on the acetabulum after SCFE are evolving. Treatment of FAI morphology without symptoms remains controversial, whereas symptomatic FAI certainly needs to be addressed, as it is now known to be a prearthritic condition.

Treatment options can be broken into three major categories:

1. Proximal femoral osteotomies (which reorient the proximal femur as a unit to relieve impingement, especially in severe slips with *impaction*-type disease) (Fig. 2).
2. Femoral head–neck recontouring (dealing with the impinging structures) alone via an anterolateral open approach, open surgical hip dislocation, or hip arthroscopy in patients with mild/moderate slips with *inclusion*-type disease) (Fig. 3).
3. A combination of osteotomy plus femoral head–neck recontouring (Fig. 4).

Femoral osteotomies

Severe slips can cause significant limitations to normal functional activities in the adolescent and lead to significant alterations in proximal femoral morphology. The resultant deformity can be treated via proximal femoral osteotomies 6–12 months after in situ pinning has been performed for stabilization. A number of osteotomy locations exist, including intertrochanteric, base of the femoral neck, and subcapital. Although an intra-articular (head–neck junction) osteotomy location allows for a greater degree of correction (due to its vicinity to the deformity), the risk of avascular necrosis (AVN) is higher due to the proximity of the blood supply to the osteotomy site.

The potential benefits of extra-articular osteotomies are two-fold: (1) correction of proximal femoral anatomy so that the impinging metaphysis is moved away from the acetabular rim and (2) the ability to reorient the central

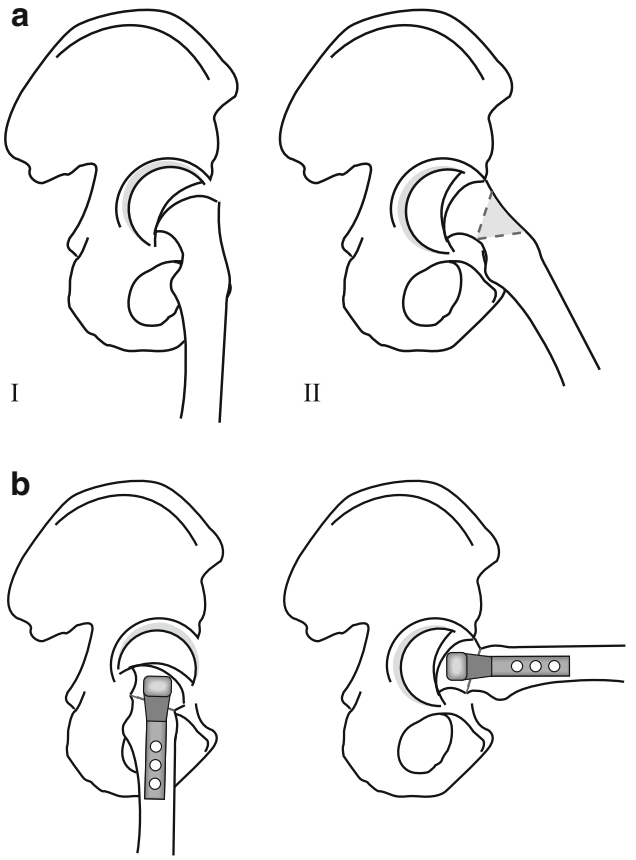

Fig. 2 **a** Diagrams showing a sagittal view of the pathologic anatomy in slipped capital femoral epiphysis (SCFE) (*I*) and its proposed correction by flexion osteotomy alone (*II*). **b** Diagram of the sagittal view after correction utilizing proximal intertrochanteric valgus flexion osteotomy. The articular cartilage is better centered in the dome of the acetabulum; however, the anterior prominence remains

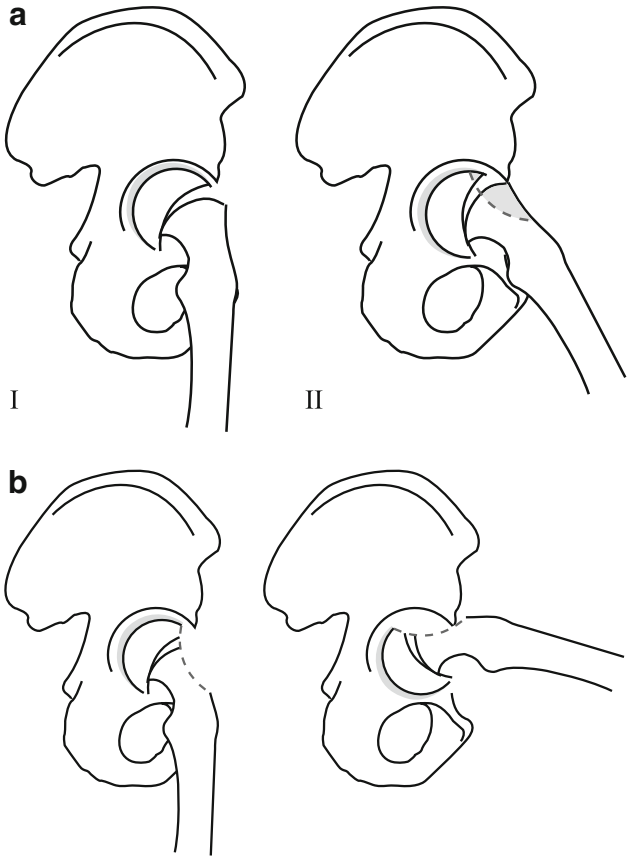

Fig. 3 **a** Sagittal view diagrams demonstrating pathologic anatomy (*I*) and proposed surgical treatment of impingement by anterolateral femoral head–neck recontouring (*II*). **b** After femoral head–neck recontouring. Note that the central cartilage of the femoral head is still directed posteriorly rather than into the dome of the acetabulum

cartilage of the femoral head back into the dome of the acetabulum, which, otherwise, would potentially lead to wear and loss of superior, peripheral articular cartilage. Abraham et al. [29] have emphasized this concept.

The timing of proximal femoral osteotomies in the treatment of SCFE remains controversial and depends on the acuity and severity of the slip. In chronic stable slips, in situ pinning can be performed, which has been traditionally followed by a secondary procedure 6–12 months later. Techniques such as an intertrochanteric osteotomy are commonly advised if the child is symptomatic with less than 90° of hip flexion and 0° or less of internal rotation.

Some surgeons, particularly in Europe, support the role of primary osteotomy and epiphysiodesis [30–33] at the time of SCFE diagnosis. In theory, this will restore normal anatomic head–acetabular anatomy and prevent cartilage and labral damage and premature arthritis that occurs early with residual deformity. Others prefer in situ stabilization with later osteotomy, if needed, as a more conservative, less risky approach.

Intertrochanteric osteotomy

Starting distally, the most common intertrochanteric osteotomies for SCFE have been described by Southwick [17] and Imhäuser [18]. Long-term studies suggest that these osteotomies may decrease the risk of osteoarthritis. Schai and Exner [32] reported on 51 hips that underwent intertrochanteric osteotomy with only a 17 % rate of severe osteoarthritis after a mean of 24 years follow-up. Parsch et al. [34] reported on 130 chronic slips treated with intertrochanteric osteotomy, with only two cases of AVN and the majority of patients showing satisfactory outcomes.

Although intertrochanteric osteotomies are associated with a lower rate of AVN (when compared to head–neck junction osteotomies) and decrease in the rates of future osteoarthritis, chondrolysis and AVN occasionally occur [35–38]. In addition, these osteotomies alter normal hip mechanics, as a deformity is created in the opposite direction in the proximal femur and retroversion is made worse to improve limb alignment and to correct external rotation gait. Furthermore, although the femoral head is

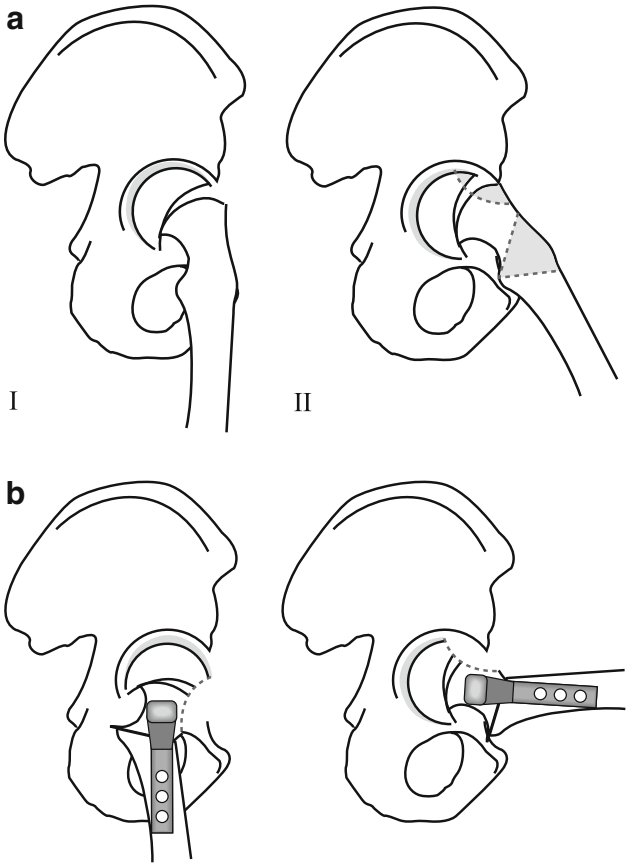

Fig. 4 **a** Sagittal view diagrams demonstrating the pathologic anatomy in a severe slip (*I*) as well as the proposed correction by combining intertrochanteric flexion osteotomy and femoral head–neck recontouring (*II*). **b** Lateral sagittal view after corrective osteotomy plus recontouring. The bump has been removed and the thick central articular cartilage of the femoral head is recentered in the dome of the acetabulum

theoretically anatomically oriented with the acetabulum via a more distal realignment, the significant deformity created by an intertrochanteric osteotomy can complicate insertion of the femoral component should total hip arthroplasty be required in the future [39].

Base of neck osteotomy

Barmada, in 1964, described an extracapsular base of neck osteotomy which was popularized by Kramer et al. in 1976 [19]. This osteotomy corrects the head–shaft and neck–shaft angles while preserving the anatomy of the proximal femur. In addition, the osteotomy has the advantage of improving limb external rotation by correcting, rather than worsening, femoral retroversion (as is the case in inter- or subtrochanteric osteotomy). The results after this osteotomy have been reported to be good to excellent, with a low rate of osteonecrosis in the long term [19, 40]. Abraham et al. [40] reported on 36 hips treated with this procedure, with 90 % of patients having good to excellent results. El-Mowafi et al. [37] reported retrospective data comparing the two techniques (Southwick vs. Kramer) and found no significant clinical or radiologic difference at an average of 3.5 years after surgery.

Unfortunately, only a moderate degree of deformity correction can be achieved by the Barmada/Kramer procedure, which limits its use in preventing FAI and severe osteoarthritis. Furthermore, the risk of AVN increases as the osteotomy proceeds proximally, with Kramer et al. [19] reporting a 3.6 % incidence of AVN in their series.

Subcapital osteotomy

Subcapital osteotomy, performed at the level of the slip deformity, allows for the greatest degree of correction, but also carries the greatest risk for AVN, as the blood supply is in close proximity (i.e., the posterior superior retinaculum contains the blood supply). Dunn described a cuneiform wedge osteotomy at the head–neck junction (at the level of the deformity) that preserved the proximal femoral anatomy, corrected deformity, and, theoretically, protected the blood supply [13]. Yet, the reported rate of AVN is highly variable with this technique, ranging anywhere from 10 to 100 % [12, 13].

As a result, this technique has been modified and combined with an open surgical dislocation approach with a greater focus on protecting the blood supply to the epiphysis via developing an extended posterosuperior retinacular flap with subperiosteal exposure of the femur [12, 22]. The combination of this Dunn osteotomy with the open surgical dislocation approach has been coined the "modified" Dunn procedure by Ganz [12].

Femoral head–neck osteochondroplasty

In the mid 1950s, Heyman described an elegant treatment for SCFE that included simultaneous in situ pinning plus excision of the anterior "bump" created by the prominent anterolateral metaphysis [41]. This was done via an anterolateral open approach, and was one of the first descriptions of femoral head and neck osteochondroplasty to prevent FAI. The use of this procedure likely decreased after Boyer et al.'s work suggested generally good long-term outcomes without having to remove the "bump" [15]. Whether the results reported by Boyer et al. (in a perhaps more agricultural/working laborer environment) hold up in the modern era of urban life, hyper-athleticism, and jogging even into retirement age remains conjectural.

Rather than perform a complete osteotomy to potentially reestablish normal hip mechanics and motion (in essence, bypassing the impinging bone), osteochondroplasty allows for removal of the impinging structures to regain motion

and alleviate pain. This can be performed by an anterior open approach, an open hip surgical dislocation approach as described by Ganz, or by arthroscopic techniques [22, 42, 43]. This method of treatment allows for the improvement of proximal femoral morphology in patients with mild/moderate slips in which enough deformity exists to create an impinging structure, but not enough to warrant a complete osteotomy.

Utilization of the surgical dislocation approach (Ganz) allows the anterolateral cam lesion to be directly visualized and removed. Risks associated with this approach include possible femoral neck fracture (if too much bone is removed from the subcapital region), as well disruption of the vascular supply to the femoral head with subsequent AVN. Also, since the approach includes a greater trochanter osteotomy, mal- or nonunion of the reattached trochanter can potentially occur.

As early as 1992, Futami et al. [42] described the use of arthroscopy in treating pathology associated with SCFE as a means to decrease patients' hip pain and function. Recently, Leunig et al. [43] also reported successful results on a series of patients with mild SCFEs with signs of FAI with in situ pinning and immediate arthroscopic osteochondroplasty. The arthroscopic approaches provide a less extensive, minimally invasive approach to the removal of impinging structures in mild slips, although femoral neck fracture has been reported after arthroscopic treatment as well [44] (Fig. 5).

Clohisy et al. [45] reported a less invasive approach involving combined hip arthroscopy, to assess anatomic abnormalities, followed by limited open osteochondroplasty of the femoral head–neck junction. They found this to be a safe, effective treatment for FAI. In their small series of 35 hips (with FAI), most patients had symptomatic relief, improved hip function, and enhanced activity after 2 years of follow-up.

Combined approach including osteotomy plus femoral head–neck osteochondroplasty

Although removal of the impinging structures alone seems attractive, Abraham et al. [29] have proposed that isolated femoral head–neck osteochondroplasty alone does not place the thick, higher quality central articular cartilage of the femoral head into the dome of the acetabulum (as compared to a connective proximal femoral osteotomy), theoretically leading to poor outcomes. In their 2007 study, the authors compared proximal femoral specimens of SCFE patients undergoing total hip arthroplasty versus those with typical osteoarthritis. The authors found that, unlike patients with osteoarthritis, the SCFE patients had loss of head–neck offset, acetabular–neck impingement, and loss of superior femoral peripheral rim cartilage. In their analysis, osteochondroplasty alone would lead to increased hip range of motion, but would also allow for the thinner peripheral femoral head articular cartilage and prominent metaphysis to articulate even more extensively with the acetabulum. Their thesis suggests that combining proximal femoral osteotomy and osteochondroplasty would lead to better results. Removing the prominence on the anterolateral proximal femoral metaphysis and returning the femoral head to the optimal position within the acetabular dome creates a more normal anatomic relationship between the proximal femur and acetabulum.

However, postoperative protocols are more difficult with the combined procedures. Patients undergoing osteochondroplasty benefit from early motion, which may place the osteotomy site at risk for nonunion if a combined procedure is performed. In addition, subsequent total hip arthroplasty can be more complicated with variations in proximal femoral morphology and the need for modular implants [39]. As a result, osteochondroplasty provides an attractive option for the simple removal of impinging structures without complete reconstruction of the proximal femoral anatomy, particularly in mild slips. Since controversy exists as to the role of isolated osteochondroplasty versus a combined procedures, further long-term study is necessary.

Methods to potentially avoid bony impingement

Procedures that could be classified as potentially preventing primary bony impingement include:

- Acute closed reduction and pinning of an acute, unstable SCFE.
- Acute open reduction via the anterolateral approach [13, 46].
- Urgent open "partial reduction" method plus pin stabilization (Parsch et al.) [34].
- Open reduction and anatomic fixation of SCFE via the open surgical dislocation approach (modified Dunn procedure—Ganz).
- Primary femoral head–neck osteochondroplasty (via open or arthroscopic methods) at the time of "in-situ" fixation of the SCFE [43].

Treatment of unstable (acute) SCFE

Emergent closed surgical reduction of an unstable, acute SCFE with percutaneous screw fixation, often using a fracture table, remains a common treatment method. With AVN rates reported as high as 50 % or higher, this method is declining in popularity, especially in major hip treatment centers.

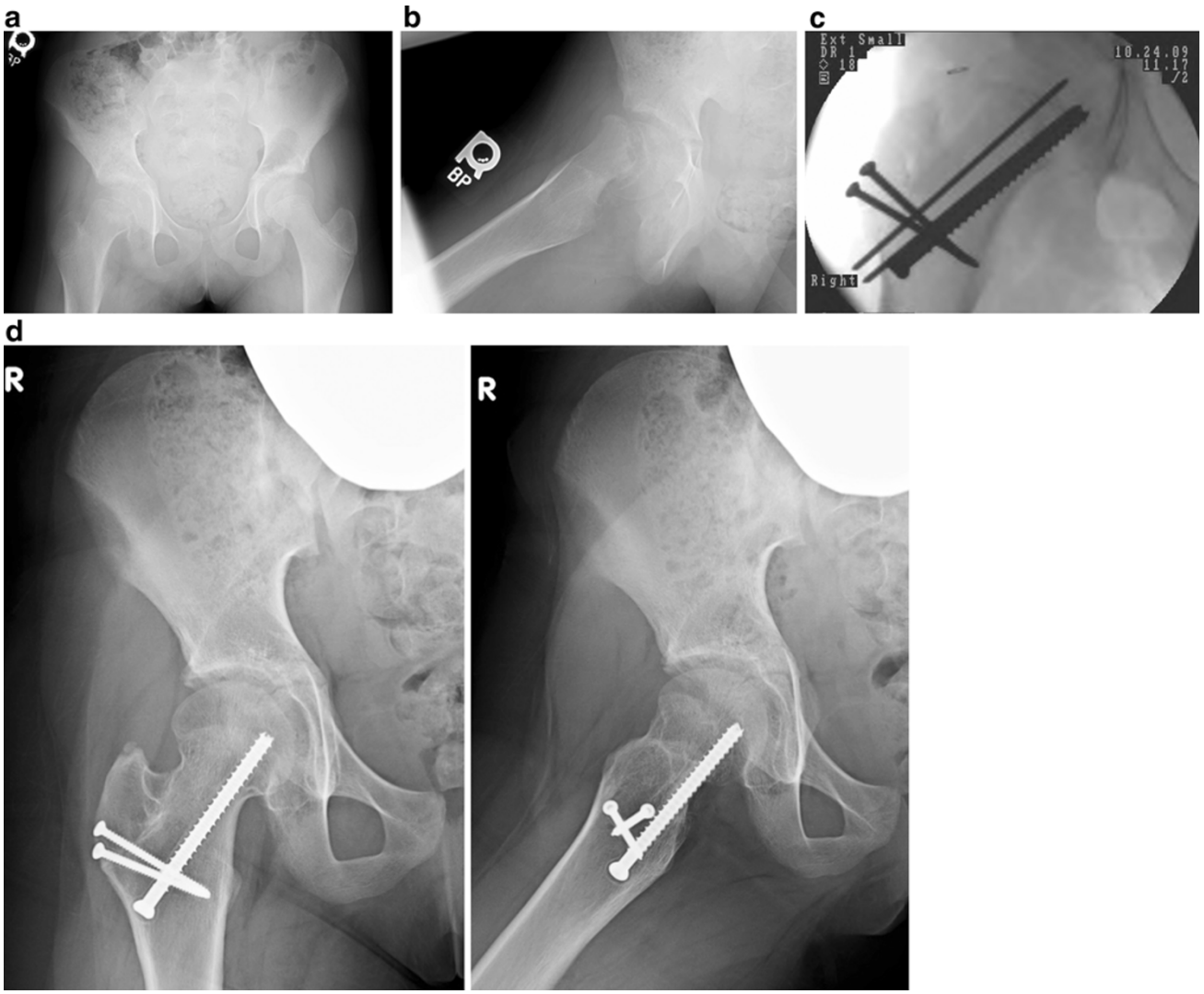

Fig. 5 **a**, **b** AP and frog view in a teenage female with acute, unstable, right SCFE. **c** Intraoperative radiograph after modified Dunn open surgical dislocation, femoral neck shortening, and recentering of the femoral head on the femoral neck (Ganz method). **d** AP and frog view taken 2 years postoperatively. There is no avascular necrosis (AVN) and the femoral head is well centered. The patient is asymptomatic

Dunn and, later, Fish reported satisfactory results in treating acute, unstable SCFE with an urgent pinning open reduction plus pin fixation via an anterolateral approach [13, 46]. This method continues to have some advocates, but is now less commonly used because identification and protection of the vital superoposterior femoral head blood supply is more difficult with this approach (as compared to the open surgical dislocation approach).

The open "partial reduction" approach of Parsch et al. would appear to be a safer approach than either of the above procedures because the head is reduced only to the position where the head was located prior to the acute component of the slip. This decreases the chance for AVN, since there is less tendency to stretch the posterior vessels over posterior callus.

The surgical exposure and subsequent visualization offered by the open hip dislocation procedure (modified Dunn procedure—Ganz) allows for direct reduction of the epiphysis on the metaphysis, with reduced tension on the posterosuperior retinaculum (with the extended retinacular flap). Unlike other osteotomies described, it allows for direct restoration of the head–neck anatomy, while preserving the vascularity of the femoral head.

Ziebarth et al. [12] reported their results utilizing the modified Dunn procedure in 40 patients with no cases of AVN. Slongo et al. reported on 23 cases treated with the modified Dunn procedure and reported two cases with either AVN or severe osteoarthritis [47]. A tertiary level children's hospital presented a series of 14 patients that had undergone the modified Dunn procedure for the treatment

of acute unstable severe slipped capital femoral epiphysis. This series had one case of AVN at a minimum of 1 year of follow-up [48]. In experienced hands, the modified Dunn procedure allows for the correction of proximal femoral morphology at the level of deformity with preservation of the proximal femoral blood supply.

Primary femoral head–neck osteochondroplasty (via open or arthroscopic methods) at the time of "in-situ" fixation of the SCFE is evolving as another treatment option against the extensive open dislocation approach in milder degrees of slips. Leunig et al. [43] reported on a series of patients with mild SCFEs with signs of FAI with in situ pinning and immediate arthroscopic osteochondroplasty. In their series of patients, arthroscopy revealed labral fraying, acetabular chondromalacia, and a prominent metaphyseal ridge which was causing impingement. This ridge was removed arthroscopically. At the final follow-up, all patients were pain-free and had returned to unrestricted activities. Patients had improved hip motion and no clinical signs of impingement. Radiographs showed normalized epiphyseal–metaphyseal offsets and alpha angles.

Screw head impingement

The potential for iatrogenic impingement from the screw head utilized for in-situ pinning must also be understood as a cause for impingement. The classic technique for percutaneous in situ pinning for slipped capital femoral epiphysis was refined by Morrissy [49] and Nguyen and Morrissy [50], stressing the importance of placing the screw tips in the center of the femoral head with the screw shaft perpendicular to the physis. This ensures stability of the construct as well as minimizing the chance for joint penetration. Correct technique is paramount to avoid the common complications of AVN and chondrolysis, which are minimized by avoiding reduction and payting great attention to the screw tip position (Fig. 6).

In mild cases, this technique works well with a low risk for joint penetration and good long-term results [15]. However, with increasing severity of the slip, the starting point of the screw must be placed farther anterior in order to correctly enter the femoral head. As the entry site of the screw is moved anteriorly, the risk for screw head impingement against the acetabulum increases. While pain

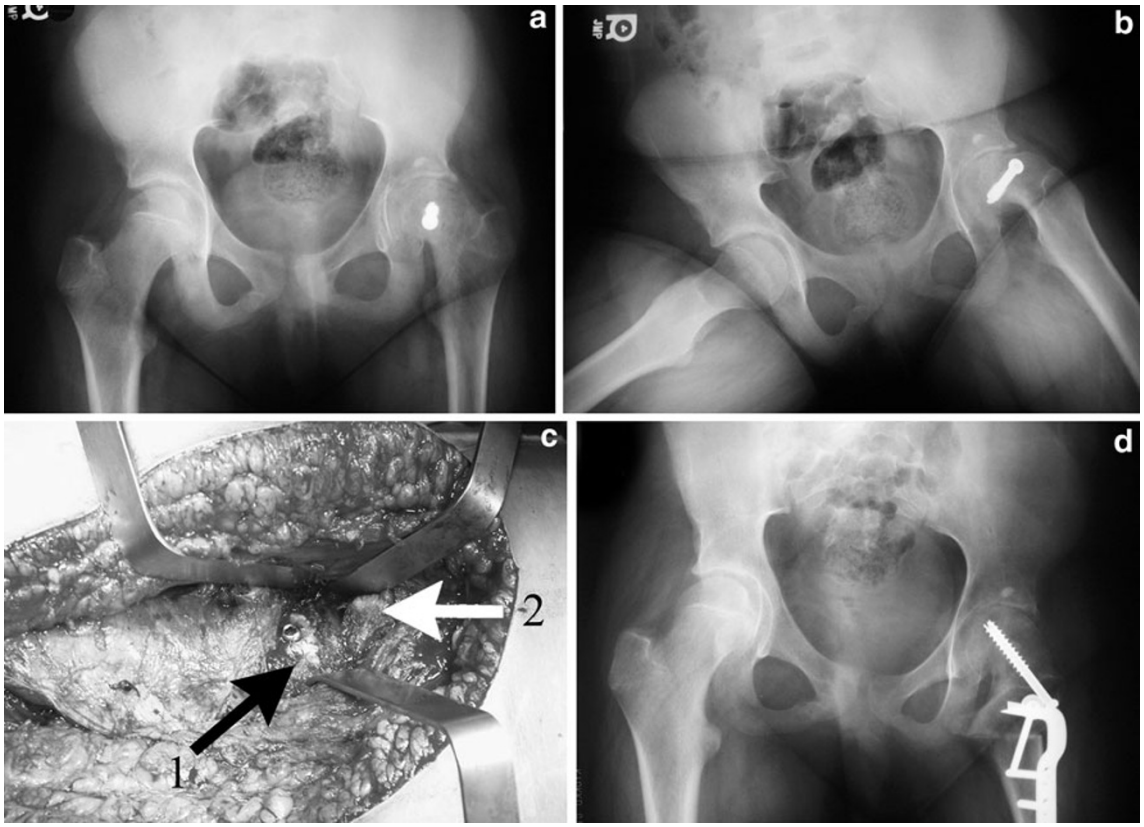

Fig. 6 **a**, **b** Radiographs of a teenager with a severe slip who was treated with in situ fixation but who had significant signs of impingement at follow-up. The screw head appears to be above and medial to the intertrochanteric line. **c** Intraoperative photograph illustrating the screw head (*1*), which was impinging on the acetabular labrum and rim (*2*). **d** After screw repositioning, femoral head–neck recontouring, and Imhäuser-type corrective intertrochanteric flexion osteotomy

and motion loss after severe cases has been commonly attributed to residual deformity of the proximal femur, cartilage and labral injury secondary to a prominent anterior screw head impinging on the acetabulum has been reported [10]. The surgeon should recognize this possibility when assessing a post-SCFE pinning patient who has pain with hip flexion (and also obligatory external rotation), as the pain may be due to screw head abutment. A cross-table lateral or false profile hip X-ray may elucidate the problem.

Goodwin et al. [51] recently performed a biomechanical study to investigate the possible role of a prominent screw head in impinging on the anterior acetabulum. Using a cadaveric model, moderate and severe slips were simulated and compared to normal controls through a full arc of motion to evaluate for impingement during hip flexion. Screw head impingement into the anterior labrum occurred at 70° of flexion in the moderate slip and 50° of flexion in the severe slip. In both models, external rotation was necessary to achieve 90° of hip flexion to avoid screw head impingement, and abduction and internal rotation were also limited in the simulated slips.

To minimize the risk for screw head impingement, the classic "right angle rule" may not be the best choice in more severe cases. A technique incorporating an oblique approach is required, and screw heads must be flush or buried in the femoral neck. This can be challenging, as both the screw head and screw tip must be in the ideal position. Goodwin et al. [51] suggested that impingement was minimized when the screw head was below the intertrochanteric line, and also suggested that using a starting point lateral to the intertrochanteric line would reduce the sequelae associated with screw head impingement. Burying the screw head would also theoretically decrease this risk of screw head impingement. It should be emphasized that, despite this altered starting point in moderate and severe cases of SCFE, the screw tip must still be positioned at the center of the femoral head. The chance for screw head impingement increases when a screw seems "too long" (tip too close to the joint) and is "backed off". Instead, the screw should be replaced with a shorter one. Both the screw tip and the screw head should be in the ideal position (Fig. 7).

In follow-up patients with clear screw head impingement, the screw should be repositioned, with simultaneous correction of any bone impingement also considered. In more severe cases, a corrective osteotomy at the time of screw repositioning can also be added.

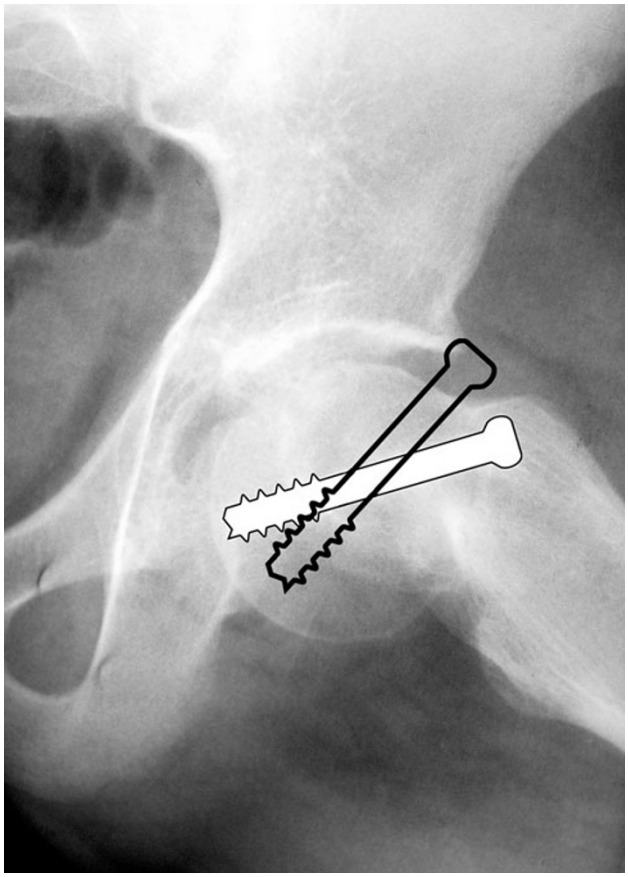

Fig. 7 Diagram demonstrating correct and incorrect screw head position for in situ stabilization of SCFE. The *black outlined* screw head is inappropriately placed and will cause screw head impingement. The *white* screw demonstrates a better screw position, even though it is not placed at right angles to the epiphysis

Our current approach to treating SCFE cases

We recognize that there is considerable disagreement in the management across various institutions for SCFE today and the growing literature may not necessarily be helpful as guidelines for routine clinical practice. We have, therefore, put together our personal approach and recommendations as a regional referral center for SCFE, while recognizing that what works in our institution and setup may not be the most optimal across the board.

- The clinical stability (Loder classification) at this point matters primarily to decide the urgency of fixation, i.e., if a patient has clinically unstable SCFE, they are admitted and SCFE is fixed during that admission within 24–36 h. Stable slips (mild or moderate) are surgically fixed within the week, and all are given wheelchairs until surgical fixation. Severe stable slips are treated like unstable slips and admitted for early stabilization following reduction.
- All SCFEs are fixed on a flat-top radiolucent table and no fracture table is used at our institution.
- No reduction maneuver is advocated in any of our cases (we do not believe that any closed reduction methods should be used for SCFE cases). The "gentle

reduction" or "inadvertent reduction" maneuver may, in fact, be harmful to the retinacular blood flow and cause further ischemia or mechanical damage to the femoral head.

- Moderate and severe slips (stable or unstable) undergo open reduction with the modified Dunn procedure, screw fixation, relative neck lengthening, and trochanteric distalization, with in situ pinning of the opposite hip when considered necessary (tri-radiate open, younger patient [<12 years of age], higher body mass index [BMI], endocrine problems, suspected break in Klein's line on radiograph). We do not perform modified Dunn procedures during the night shift (between 10 pm and 7 am), but, rather, believe that our results are best when performed during routine hours in the Hip OR with well-trained staff and full equipment. In stable cases, we begin with in situ pinning of the opposite side first in the supine position and then position the patient lateral for open reduction and fixation. In unstable cases, the clinically unstable SCFE is always fixed first.
- Mild slips in our practice are treated with in situ fixation and primary femoral head–neck osteochondroplasty. We (H.S.H.) prefer to use part of the modified Gibson exposure (without trochanteric flip) and do this with the aid of an arthroscopic camera and high-speed burr, under vision. We do not use or advocate the pure arthroscopic approach with joint distraction following in-situ pinning, as its safety is not yet widely established. We are aware of other centers using the Watson-Jones approach or mini-anterior approach for this as well, and these are all reasonable approaches. Again, in situ pinning of the opposite hip is performed when considered necessary (tri-radiate open, younger patient [<12 years of age], higher BMI, endocrine problems, suspected break in Klein's line on radiograph).
- Healed SCFEs (with nearly closed or closed physes) are considered as femoroacetabular impingement cases and undergo the FAI pathway with preoperative advanced imaging with a magnetic resonance imaging arthrogram, followed by the management of components of impingement (cam, ± pincer, labral tear), as well as proximal femoral deformity (including trochanteric distalization, relative neck lengthening, possible need for proximal femoral osteotomy including components of valgus, flexion, and derotation, as needed on a case-to-case basis).

Conclusion

Symptomatic femoroacetabular impingement (FAI) has become increasingly recognized as a pathologic circumstance in patients with chronic slipped capital femoral epiphysis (SCFE), leading to pain, decreased hip motion, and an increased risk for early-onset osteoarthritis. Posteromedial displacement of the epiphysis during a slip places the metaphysis in an anterolateral position, causing it to impinge on the acetabulum. The degree of deformity (based on the severity of the slip), the acuteness of the presentation, and clinical stability (stable vs. unstable) determines both the pattern of FAI and potential corrective options. In general, severe slips with FAI can be treated with proximal femoral osteotomies to restore proximal femoral morphology. Combining femoral osteotomy with head–neck recontouring remains a viable treatment option.

The open surgical dislocation approach described by Ganz has allowed surgeons to achieve deformity correction at the most proximal level (closest to the joint) while respecting the proximal femoral blood supply [12, 22]. This approach is safer in acute, unstable slips with a higher risk for avascular necrosis (AVN) if a stable, healed slip has to be "taken down".

In cases of mild stable slips, osteochondroplasty (via open dislocation or arthroscopically assisted approaches) can be utilized to simply remove the impinging anterolateral bone. Controversy exists as to the performance of isolated osteochondroplasty without proximal femoral osteotomy because normal articular "centering" is not achieved.

Improved understanding of FAI and its role in SCFE continues, allowing pediatric orthopaedic surgeons to minimize the risk for future degenerative changes. Future pathways include better biological understanding of the growth plate and etiology of SCFE, advanced imaging modalities to better understand articular cartilage health prior to intervention, as well as better methods to deal with cartilage damage intra-operatively, including the use of biological substitutes.

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