Review article

Surgery for slipped capital femoral epiphysis in adolescents

S. Abu Amara *, J. Leroux , J. Lechevallier

Clinique chirurgicale infantile, centre hospitalier universitaire de Rouen, 1, rue de Germon, 76031 Rouen, France

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The treatment of slipped capital femoral epiphysis (SCFE) in adolescents remains controversial. The goal of initial treatment is to prevent further slippage of the epiphysis. In mild forms, both stable and unstable, in situ fixation is widely accepted as the reference treatment. In contrast, several techniques are available for stable moderate-to-severe SCFE. In unstable moderate-to-severe SCFE, emergent reduction with decompression and internal fixation is currently the preferred method. Selection of the surgical technique rests on an appraisal of advantages versus drawbacks. The goal of this review is to discuss the various surgical methods available for SCFE in adolescents.

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1. Scope of the instructional course lecture

This instructional course lecture focuses on the surgical techniques available for the initial treatment of slipped capital femoral epiphysis (SCFE) in adolescents. We will discuss techniques for stable SCFE and unstable SCFE; some techniques are common to both presentations.

2. Stable SCFE

Stability is defined by the ability to walk, with or without crutches [1].

2.1. In situ fixation

The objective is to secure the proximal femoral epiphysis to the metaphysis in order to prevent further slippage [2,3].

2.1.1. Installation

An image amplifier is indispensable. The patient is on a traction or regular table, if possible made of radiolucent material, a feature associated with decreases in operative times [4] and radiation doses [5]. The operative time and radiation dose can be further decreased by using two image amplifiers, one for each incidence [6].

With a regular table, the lateral views are easier to obtain by moving the limb than by moving the image amplifier arm. When a traction table is used, its purpose is only installation of the patient; no traction is applied. The lateral view is obtained by swivelling the image amplifier arm (Fig. 1). On a regular table, the patient is supine with a pad under the ipsilateral buttock and the lower limb entirely covered by the drapes. A lateral view can be obtained by moving the hip in flexion, abduction, and external rotation (Fig. 2A and B). We prefer to have the patient in the strict lateral decubitus position with the image amplifier arm across the table, which provides the antero-posterior view. The lateral view is obtained by moving the lower limb. This position provides better access to the entire lateral aspect of the hip, particularly in patients with obesity and fixed external rotation of the hip (Fig. 3A, B, and C). In situ fixation is theoretically possible regardless of the extent of epiphyseal slippage. In practice, however, screw placement is challenging and the risk of penetrating the joint cavity is increased when the slip angle is greater than 60°.

2.1.2. Material

Several types of material can be used depending on the age of the patient and usual clinical practice of the surgeon.

2.1.2.1. Screws. We will describe in situ fixation using a fully threaded cannulated screw.

2.1.2.1.1. Screw insertion site. The screw insertion site depends on the extent of the slippage. In early forms, the screw is inserted under the greater trochanter. When slippage is marked, the insertion site is on the anterior aspect of the femoral neck at the neck-shaft junction, and the distance between the insertion site and the growth plate decreases with the extent of slippage (Fig. 4A, B, C, and D).

A 1-cm incision is made in the skin for insertion of a threaded-tip guidewire, using a motorized wire driver. Advancement of the wire along the trajectory of the femoral neck is monitored on the image amplifier. The wire tip is positioned at the centre of the epiphysis. As
the guidewire can be pushed forward by the bit and/or auger, a useful precaution consists in stopping guidewire advancement a few millimetres from the subchondral bone to avoid penetrating the joint cavity. A specific ancillary device is available for determining the optimal screw length.

The screw trajectory is prepared by drilling along the guidewire. Drilling is best stopped 5 mm from the guidewire tip to avoid guidewire backup upon withdrawal of the auger. The screw is inserted over the guidewire.

2.1.2.1.2. Position of the screw in the epiphysis. The screw should be as central as possible to ensure optimal stability and to avoid focal epiphyseal necrosis.

Senth et al. [7] evaluated screw position after in situ fixation by comparing intra-operative radiographs to post-operative computed tomography (CT) images. They concluded that screw tip location within 6 mm of the subchondral bone on the anteroposterior radiograph and within 4 mm on the lateral radiograph may result in penetration of the subchondral bone.

2.1.2.1.3. Number of screws. Several studies have established the efficacy of in situ fixation using a single screw [8–11]. However, in other studies, the use of a single screw was followed in 20% of cases by further slippage, by 10° on average [12,13].

Use of a single screw can also be considered in unstable SCFE, although the risk of material breakage is higher [11].

2.1.2.1.4. Thread. Several types of threading are used.

2.1.2.1.4.1. Fully threaded cannulated screws. These screws allow fixation and exert an epiphysiodesis effect.

2.1.2.1.4.2. Distal threading. In an animal study by Miyani et al. [14], fully threaded screws did not provide greater stability during loading compared to partially threaded screws (Fig. 5). Other studies [15,16], however, found greater stability of the construct when fully threaded screws were used.

Carney et al. [10] reported that stability was optimal in hips with at least five screw threads engaging the epiphysis.

2.1.2.1.4.3. Proximal threading. The goal is to stop slippage progression while avoiding epiphysiodesis. The designers of the proximally threaded screw [17] have reported that the smooth surface of the distal portion allows continued growth of the femoral neck while ensuring optimal fixation of the epiphysis, with bone remodelling that may avoid complications due to architectural disorders (Fig. 6).

2.1.2.2. K-wires. K-wires of varying diameters can be used to achieve fixation of the epiphysis. At least two or three wires are needed to ensure sufficient stability. The K-wires should be uniformly distributed in the epiphysis. Advocates of K-wire fixation argue that the ease of insertion and removal and the absence of adverse effects on femoral neck growth are important advantages [18]. However, Seller et al. [19] reported a high rate of migration due to inadequate anchoring in bone.

2.1.2.3. Threaded pins. Rynning et al. [20] showed that fixation with threaded pins was as stable as other fixation modalities (Fig. 7). Two or three guidewires should be used. In theory, threading confined to the epiphyseal portion of the pin should allow continued femoral neck growth. Longer threading that bridges the growth plate without inducing compression can be used. Morissy [21] reported that the risk of breaching the joint cavity increased in proportion to the number of pins. Lehmann et al. [22] found no difference between fixation with two versus three pins. Slippage progression did not exceed 10°.
2.2. The Dunn procedure

In 1964, Dunn [23,24] described a procedure for treating chronic severe SCFE in patients with open growth plates, as assessed by CT at the slightest doubt. The use of this procedure is controversial, as there is a 10% to 21% rate of avascular necrosis [25–28].

2.2.1. Operative technique
The patient is supine with a pad under the ipsilateral buttock if the antero-lateral approach is to be used or in strict lateral decubitus for a lateral approach. We will describe the procedure as performed on a regular table. The first part of the incision is oblique, from the antero-superior iliac spine to the greater trochanter; and the second part is vertical, along the femoral shaft (Fig. 8A).

After incision of the subcutaneous tissue and superficial fascia, the gluteus maximus muscle is retracted posteriorly and the ilio-tibial tract and rectus femoris muscle anteriorly. The vastus lateralis muscle is detached as an inverted L to expose the greater trochanter. Trochanterotomy is performed, taking care not to injure the collateral trochanteric artery, which is located medially. Identification of this branch of the circumflex artery allows visualisation of the vascular bundle. Care should also be taken to preserve the medial cortex, which is cautiously breached subperiosteally (Fig. 8B). Dissection of the medial circumflex bundle is unnecessary and perhaps dangerous.

These steps provide access to the joint capsule, which is opened by a T-shaped incision whose vertical branch is parallel to the axis of the femoral neck.

Traction sutures are placed in the edges of the capsular incision to expose the periosteum and synovial membrane. Inflammation of the synovium is common. The periosteum is opened along the axis of the femoral neck (Fig. 8C).

A blunt-edged spatula is less aggressive and therefore preferable over a rasp for elevating the periosteum on either side of the femoral neck. Great care should be taken to preserve the periosteum posteriorly, in order to protect the vascular supply. A Lambotte bone hook slipped under the periosteum is used to lift the femoral neck and to avoid vascular pedicle injury by the instruments used for the osteotomy.

At this point, the fibro-cartilaginous callus is clearly visible. The surgeon must have a clear picture of the displacement in the three dimensions before starting the bone resection (Fig. 8D). The goal is to shorten the neck by 1.5 to 2 cm. After starting the cut with a 10-mm osteotome, a bone gouge is used. The resected area is a trapezoid with the longest side lying anteriorly. A large Kerisson rongeur can help to remove the posterior callus.

Posteriorly, particularly when slippage is severe, the close proximity of the posterior aspect of the neck with the epiphysis makes the contact zone difficult to identify. Care should be taken not to continue the bone resection into the cancellous bone of the femoral head.

Once the femoral neck is shortened, reduction can be obtained without tension. No traction should be applied to the lower limb. Gentle internal rotation allows completion of the reduction. The resected zone is completely covered by the edges of the epiphysis.

After temporary pinning by a guidewire inserted before beginning the osteotomy, the reduction is assessed radiologically. Permanent fixation is achieved using one or two cannulated screws (Fig. 8E).

The joint capsule is closed carefully using separate sutures. Fixation of the greater trochanter is achieved using one or two screws that engage the medial cortex.

Fig. 3. A. Installation in the lateral decubitus position on a regular table. B. The lateral view is obtained by mobilising the hip. C. Installation in the lateral decubitus position on a regular table.

2.1.3. Post-operative care
Time to weight bearing varies across authors, from a few days to 3 months. There is no proof that prolonged elimination of weight bearing confers an advantage [21,22].

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2.2.2. Post-operative care
The lower limb is kept in traction for 3 weeks, with early passive mobilization. Weight bearing is started after checking a radiograph obtained 6 weeks after the surgical procedure.

2.3. Modified Dunn procedure

A modification of the Dunn procedure was developed by Leunig et al. to decrease the necrosis rate by allowing continuous intra-operative monitoring of the blood supply to the epiphysis [29].

2.3.1. Anatomic principles
Gautier et al. [30] studied 24 cadaver hips to describe the anatomy of the medial branch of the femoral circumflex artery (Fig. 9). The results showed that integrity of the obturator externus muscle protected this artery from damage during dislocation of the hip in any direction (Fig. 10).

2.3.2. Technique
Advocates of the modified Dunn procedure [29,31,32] believe this technique is indicated in chronic SCFE with more than 30° of slippage. The goal is to restore the normal anatomy of the proximal femur, while keeping the shortening of the neck to a minimum.

The patient is in the strict lateral decubitus position, and the lateral approach is used. After incision of the subcutaneous tissue and superficial fascia, the gluteus maximus muscle is retracted posteriorly and the ilio-tibial tract anteriorly. L-shaped detachment of the vastus lateralis muscle is performed to expose the greater trochanter. Trochanterotomy exposes the joint capsule, in which a Z-shaped incision is made.

When stability of the epiphysis is in doubt, in situ fixation is performed using two threaded pins, without reduction. The blood supply to the epiphysis is monitored either by drilling a 2-mm hole in the anterior aspect of the femoral head or by using laser Doppler flowmetry [33].

The hip is dislocated by an external-rotation and adduction manoeuvre. The ligamentum teres is divided (Fig. 11A and B). An incision is performed in the periosteum along the neck. Osteotomy of the proximal greater trochanter allows gradual elevation of the posterior periosteum with the retinaculum (Fig. 12A and B). No traction should be applied to the periosteum, particularly at the neck-epiphysis junction. Elevation of the periosteum is continued posteriorly and distally until the lesser trochanter is reached. The antero-medial aspect of the neck is released with the hip dislocated. When release of the neck and periosteum is complete, reduction is performed and the blood supply to the head is evaluated.

Fig. 4. A. Stable moderate SCFE, antero-posterior radiograph. B. Lateral radiograph. C. In situ fixation. The screw insertion site is on the anterior aspect of the femoral neck. D. Lateral radiograph.
Fig. 5. Distally threaded screw.

Fig. 6. Proximally threaded screw.

Osteotomy of the neck is performed after repeat dislocation of the hip. Two S-shaped retractors are placed on either side of the femoral neck. If in situ fixation of the epiphysis was performed before hip dislocation, the pins are removed. A Cobb rasp is used to gradually separate the epiphysis from the metaphysis, taking care to follow the proper trajectory. The osteo-fibrous callus is removed without shortening the neck, as with the Dunn procedure (Fig. 13A and B). A wide rasp is used as a lever in combination with external rotation of the limb to completely release the femoral neck from its periosteal sheath. This manoeuvre provides sufficient exposure for removal of the posterior callus. The physesal aspect of the epiphysis is abraded. Bleeding indicates a good blood supply to the epiphysis. The surgeon manually reduces the head to the neck while continuously monitoring the tension of the periosteum and posterior retinaculum (Fig. 14A and B). If tension occurs, shortening of the femoral neck is mandatory. A threaded pin inserted through the centre of the epiphysis towards the infra-trochanteric region ensures initial fixation. A radiograph is taken to evaluate the reduction. Permanent fixation is achieved using cannulated screws or fully threaded pins. Tension-free suture of the joint capsule is performed. Fixation of the greater trochanter is performed with two or three screws.

2.3.3. Post-operative care
Rehabilitation of the hip is necessary to avoid contractures. Protected weight bearing is used for walking during the first 6 to 8 weeks then full weight bearing after a radiographic evaluation.

In all the studies published to date, the modified Dunn procedure proved reproducible and associated with a low rate of complications, including avascular necrosis in fewer than 8% of cases [29,31,32,34].

2.4. Reduction by the anterior approach and metaphyseal osteotomy

This method was described by Compère in 1949 [35] then by Lagrange et al. in 1965 [36].

2.4.1. Technique
The patient is supine on a regular table with a pad under the buttck. The extended Smith Petersen approach is used.

After passing between the ilio-tibial tract and the sartorius muscle, the iliac crest cartilage is opened and the iliac fossa is liberally rasped down to the acetabular sourcil. The ilio-tibial tract is therefore detached from the iliac wing and the rectus femoris is detached from the anterior inferior iliac spine and elevated. The result is excellent exposure of the anterior aspect of the joint capsule, in which a T-shaped incision is made, with the vertical branch parallel to the axis of the neck. Traction sutures are placed in the edges of the capsular incision (Fig. 15A). An incision in the same direction is made in the periosteum. Visibility of the fibro-cartilaginous callus increases with the extent of the slippage.

A crucial step is sub-periosteal release of the femoral neck using a Cobb rasp or broad spatula. This step starts at the perios- teum overlying the callus (Fig. 15B and C). The site of contact between the neck and the posterior aspect of the epiphysis is
Fig. 8. A. Dunn procedure: installation and incision [26]. B. Exposure of the joint capsule. C. Incision of the periosteum. D. Exposure of the femoral neck and bony callus. E. Suture of the periosteum after osteotomy and reduction of the epiphysis.

identified and the posterior aspect of the metaphysis is separated from the epiphysis (Fig. 15D and E). Care should be taken to avoid errors in trajectory with penetration of the cancellous bone or growth plate. Further exposure of the femoral neck is achieved by gently releasing the posterior aspect of the neck from the periosteum.

Once this step is completed, two S-shaped retractors are placed sub-periosteally under the femoral neck (Fig. 15F). Osteotomy of the bony callus is performed using a bone chisel. The osteotomy is trapezoidal with the longest side located anteriorly and shortens the neck by 1.5 to 2 cm (Fig. 15G and H). Tension-free reduction of the neck on the epiphysis is achieved by placing the lower limb in
Fig. 9. The terminal branches of the medial femoral circumflex artery travel along the postero-superior aspect of the femoral neck and penetrate into the bone 2 to 4 mm from the bone-cartilage junction (right hip, postero-superior view) [30].

Fig. 10. The obturator externus muscle protects the deep branch of the medial femoral circumflex artery during dislocation of the femoral head.

Fig. 11. A and B. Incision of the joint capsule and dislocation of the hip [31].

Fig. 12. A and B. Osteotomy of the greater trochanter and exposure of the femoral neck.

2.4.2. Post-operative care

Traction is applied to the lower limb for 3 weeks, during which physical therapy is provided. Weight bearing is possible 6 weeks after the surgical procedure.

The advantage of this technique is that it allows anatomic reduction via a conventional anterior approach without trochanterotomy. Its main drawback is that the vascular pedicle cannot be monitored intra-operatively. The same technique can be used in unstable SCFE. We are not aware of any recently published case series.
3. Unstable SCFE

In unstable forms of SCFE, the patient is unable to walk or bear weight with or without crutches [1]. Published data about the management of unstable SCFE are conflicting. There are several important questions:

- What is the best fixation method?
- What is the outcome of unstable SCFE, particularly with severe slippage, after in situ fixation?

These questions must be answered based on the most recently published data [1,37–40].

Advocates of reduction argue that this method avoids complications related to secondary architectural disorders, such as anterior impingement with a risk of early osteoarthritis [29,31,32,34,37]. Opponents of reduction contend that in situ fixation usually provides acceptable functional results while avoiding avascular necrosis [9,10,17].

3.1. Time from admission to reduction

Advocates of reduction [37,41–45] recommend reduction within 24 hours after the occurrence of slippage. They argue that the slippage results in blood vessel compression and that the blood supply to the epiphysis must be restored on an emergency basis.

Kalogrianiitis et al. [43] reported that the rate of avascular necrosis was highest when reduction was performed between day 2 and day 7. They used the term “unsafe window” to designate this period.

3.2. Reduction techniques

Three reduction techniques have been described: immediate non-operative reduction, gradual non-operative reduction, and surgical reduction.

3.2.1. Immediate non-operative reduction

Immediate non-operative reduction is performed under general anaesthesia a few hours after admission of the patient. Use of a traction table is mandatory to avoid having to manipulate the lower limb to obtain lateral views. Patient installation should be performed by the surgeon to avoid worsening the slippage or inducing overreduction. In many cases, simple installation on the traction table is sufficient to reduce acute slips [41–44]. The challenge consists in determining the parts played by the acute and chronic components of the slippage. Remodelling of the femoral neck indicates chronic slippage and therefore a need for caution if reduction manoeuvres are performed. Intra-operative radiological images may be difficult to interpret, particularly in obese patients.

Gordon et al. [42] uses a traction table but only to achieve reduction by positioning the patient. If positioning fails, surgical reduction is performed via the anterior approach.

3.2.2. Indication for joint drainage

Herrera-Soto et al. [46] reported that acute slippage was associated with increased pressure within the joint cavity responsible for blood vessel compression. Parsch et al. [47] pointed out that a blood-tinged or serous effusion was a consistent intra-operative finding.

The mechanical effect of acute slippage combined with pressure elevation within the joint cavity may explain that avascular necrosis can occur in unstable SCFE even in the absence of reduction [1,37,39]. Joint drainage by aspiration or arthrotomy, either at the time of immediate reduction or before progressive reduction, is supported by several studies [37,42,47], which indicate that arthrotomy is probably superior over aspiration.

In a recent literature review, Loder and Dietz [37] found wide variations in the management of unstable SCFE and concluded that the optimal strategy may be emergent reduction with joint aspiration and screw fixation. In contrast, the time to reduction and stabilization does not seem to affect the risk of avascular necrosis.
Fig. 15. A. Exposure of the anterior aspect of the femoral neck and of the periosteum overlying the bony callus (right hip). B and C. Elevation of the periosteum. D. separation of the epiphysis from the metaphysis. E and F. Exposure of the bony callus. G and H. Osteotomy of the bony callus. I and J. Reduction of the metaphysis on the epiphysis.
3.2.3. **Gradual reduction**

To avoid manipulating the hip, gradual reduction of acute slips has been suggested [48,49]. Traction is applied as soon as the patient is admitted, and analgesics are given.

3.2.3.1. **Skin traction.** Traction is applied bilaterally using weights equal to 10% of the patient’s body weight. The initial radiograph serves to analyse the displacement. Traction is applied only along the axis of the limb, and the weight is increased gradually up to no more than one-fourt of the patient’s body weight. Radiographs are obtained at 24-hour intervals.

When reduction is not achieved after 72 h of traction, gradual abduction is started in combination with a medial de-rotation strap attached to a weight of 1 or 2 kg. Once reduction is obtained, the traction is maintained in the same position for 7 to 10 days.

Fixation is performed on a traction table. The surgeon installs the patient in the position used to obtain reduction, without any manipulations.

3.2.3.2. **Skeletal traction.** We prefer skeletal traction, which is better tolerated, facilitates nursing care, and also facilitates the traction weight increase, particularly in obese patients.

As soon as the patient is admitted, a trans-tibial pin is inserted under general anaesthesia, taking care not to penetrate the proximal tibial growth plate. Aspiration of the hip can be performed during the same procedure. The weights are applied only after the patient is fully awake, in order to reduce only the acute component of the slippage. The weight is 15% of the patient’s body weight initially and is increased after obtaining the first radiograph a few hours after traction initiation. In most cases, reduction is achieved within 72 hours.

Radiographs are obtained daily until the desired degree of reduction is achieved. Inadequate reduction can be improved by placing the limb in abduction and moderate internal rotation.

Fixation is achieved using the same procedure.

3.2.4. **Surgical reduction**

Parsch et al. [47] have stated that surgical reduction is in order when a joint effusion is visible by ultrasonography. The patient is supine on a regular table. No attempts at reduction are made. The Watson Jones approach is used. A longitudinal incision is made in the joint capsule. After drainage of the joint effusion and under image amplifier guidance, a central pin is inserted through the greater trochanter into the metaphysis to a few millimetres from the growth plate. The surgeon uses a finger to feel the slip and to control the reduction, while the aid performs gentle manoeuvres of hip flexion, abduction, and internal rotation (Fig. 16).

When reduction is achieved, the pin is advanced to ensure fixation of the epiphysis. The radiological appearance is evaluated and fixation is completed using two or three distally threaded pins. The proximal ends of the pins are bent back and impacted into the cortex to avoid pin migration.

4. **Conclusions**

The primary treatment goal with all the available techniques is to prevent further slippage. In every case, the risk of iatrogenic avascular necrosis should be borne in mind.

In mild forms, whether stable or unstable, *in situ* fixation is the reference standard. Fixation is achieved using cannulated pins or screws with various threading patterns.

In contrast, several techniques have been advocated for the treatment of stable moderate-to-severe SCFE. They range from *in situ* fixation to osteotomy after hip dislocation, which is acquiring an increasingly prominent position within the therapeutic armamentarium.

In unstable moderate-to-severe SCFE, the best reduction indications and technique remain controversial. However, reduction of acute slippage and decompression of the joint cavity are gaining popularity.

**Disclosure of interest**

The authors declare that they have no conflicts of interest concerning this article.

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