CHAPTER 17

Slipped Capital Femoral Epiphysis

Introduction

During a period of rapid growth in adolescence, weakening of the upper femoral physis and shearing stress from often excessive body weight may cause the femoral capital epiphysis to displace from its normal relation to the femoral neck. Although this disorder is termed slipped capital (or upper) femoral epiphysis (SCFE), this terminology is technically incorrect. The femoral epiphysis maintains its normal relationship within the acetabulum, and it is the femoral neck and shaft that displace relative to the femoral epiphysis and the acetabulum. The usual deformity consists of an upward and anterior movement of the femoral neck on the capital epiphysis. The epiphysis "displaces" primarily posteriorly relative to the femoral neck.

This chapter will adopt the common perspective, that is, to describe the deformity as if the capital femoral epiphysis was displaced relative to the femoral neck. Thus, we will refer to "posterior displacement" of the femoral epiphysis (as occurs in the most common clinical situation) throughout this chapter. Occasionally the slip is in a different direction, with the femoral epiphysis "displacing" either forward (anteriorly)[70,140] or laterally (into a valgus position)[233] relative to the femoral neck.

A slipped epiphysis may occur gradually, acutely with few prodromal symptoms, or acutely after an extended period of milder symptoms. Involvement of the hips may be unilateral or bilateral; involvement of the second hip may develop simultaneously or subsequently. The great majority of affected children will not have a demonstrable endocrine abnormality, even when their body habitus might suggest otherwise; some patients with slipped capital epiphysis* do, however, have an important associated endocrinopathy.

Pare,[206] according to Howorth,[118] should be given credit for the first description of SCFE for describing in 1572 the condition in which "the epiphysis of the head of the femur sometimes becomes disjointed and separates in such a way that the surgeon is misled, thinking that it may be luxation and not separation of the epiphysis of this bone." Others credit Müller for his description of SCFE in 1889 (an English translation has been published); he coined the term *Schenkelhalsverbiegungen im Jungesalter*, meaning "bending of the femoral neck in adolescence."[195] Whitman is credited with reporting the first series of osteotomies for SCFE, in 1909,[280] and Boyd with reporting the first stabilization with pins, in 1949.[33] Howorth[118] provides a thorough and interesting review of the history of the description and treatment of SCFE.

*See references 6, 30, 31, 47, 57, 79, 80, 84, 90, 98, 105, 108, 109, 115, 127, 134, 147, 164, 169, 172, 183, 190, 197, 200, 211, 214, 221, 225, 234, 254, 277, 289.

Incidence and Epidemiology

The incidence of SCFE varies according to race, sex, and geographic location.* The incidence is estimated to be approximately 2 per 100,000 population, but this varies from less than 1 to more than 7 per 100,000, depending on race and geographic area. In the United States, there appears to be a greater risk for developing slipped epiphysis in black males and in adolescents residing in the eastern states.[143] Kelsey reported that the overall annual incidence per 100,000 in the population under 25 years of age in Connecticut was 3.41, whereas in New Mexico it was 0.71.[143]

There is a definite predilection for males to be affected more often than females, and for the left hip to be affected more often than the right. Interestingly, these predilections appear to be decreasing in recent studies.[101,165] Some older reviews found males to be affected up to five times as frequently as females and the left hip to be affected at least three times more often than the right, but this no longer appears to be the case. Hägglund and colleagues in an epidemiologic study in Sweden found a male-female ratio of

*See references 8, 76, 101, 110, 143, 165–168, 284.

approximately 2:1, but noted that this ratio had decreased during the period of study (1910 to 1982).[101] Loder, in an international survey of patients treated in 33 centers between 1954 and 1991, found a male-female ratio of approximately 3:2.[165] Whether this reduction in male prevalence is due to a culturally related increase in female participation in sports activities or to some other cause is conjectural. The predilection for more frequent involvement of the left hip than the right also appears to be decreasing. Loder found a left-right ratio of 3:2,[165] and Hägglund and colleagues found a ratio of approximately 2:1.[101] This is distinctly different from figures reported in museum studies of anthropological specimens, in which the left hip is affected approximately three times as often as the right.[93] Why there is a predilection for left hip involvement is unknown. Based on the presumption that shearing forces across an at-risk proximal femoral physis cause slipped epiphysis, Alexander postulated that the sitting posture of right-handed children while writing could account for this preponderance.[7] Other investigations exploring increased shearing force, however, have not identified any explanation for the disproportionate involvement of the left hip.*

Seasonal variation in the presentation of patients with slipped epiphysis have been identified to some extent.[101,166,167] In a study from Michigan,[167] there was an increased frequency of onset of symptoms in June, and in an international study there was an increased frequency of onset of symptoms in late June in North America and in July in Europe.[166] In the same study, however, no such seasonal variation was observed in centers below the 40th latitude in the Northern Hemisphere, and no seasonal variation was detectable in the Southern Hemisphere. Hägglund and colleagues found that this seasonal variation was identifiable in girls but not in boys.[101] Urban-rural gradients are not reported to be striking, but Hägglund and colleagues did note a tendency for rural children to be affected more frequently than urban children.[101] There are reports of multiple members of individual families developing slips,[67,191] but this is uncommon, and in general there does not appear to be a familial predilection for SCFE.

Race is a factor in the propensity for the development of slipped epiphysis, but whether it is a factor in the risk for developing one of the associated complications of the condition or its treatment (avascular necrosis [AVN] or chondrolysis) is unclear. Kelsey estimated prevalence rates in Connecticut of 7.79 per 100,000 for black males versus 4.74 for Caucasian males and 6.68 for black females versus 1.64 for Caucasian females.[143] In a more recent and far-ranging analysis of 1,993 hips with slipped epiphysis reported by 33 centers on six continents, Loder estimated that Polynesian children had the highest prevalence of slipped epiphysis (a fourfold increase relative to Caucasians) and Indo-Mediterranean children the lowest (a prevalence only one-tenth that of Caucasians).[165] Loder also found an approximately twofold increase in the prevalence of slipped epiphysis in blacks compared to Caucasians, and a prevalence in Hispanic children comparable to that in Caucasians. In another, more limited study, Loder and colleagues did not identify an increased risk in black children for the development of bilateral slipped epiphysis compared to Caucasians.[168] There has also been a question as to whether the complications of AVN or chondrolysis are more frequent in black children than in nonblack children. A propensity for the development of chondrolysis in black children, particularly in black females, has been suggested in a number of studies of children treated in a variety of ways for different manifestations of slipped epiphysis.[22,27,59,111,262] Aadalen and colleagues in 1974 in a study of 50 acute slips found that no female or black patient developed AVN, but two black patients did develop chondrolysis.[1] However, more recent studies have specifically not identified a higher rate of either complication in black patients compared to other patients.[11,13,144,210,239,267]

The onset of slipped epiphysis typically occurs during adolescence (boys, 13 to 15 years, averaging about 14, and girls, 11 to 13, averaging about 12 years),[76,101,165–168,284] a period of maximal skeletal growth. The youngest reported patient without identifiable endocrinopathy has been a girl age 5 years 9 months.[142] SCFE rarely occurs in girls after menarche. The typical age when slip occurs may be within an even narrower range when affected patients are assessed by Oxford bone age of the pelvis,[3,163] When SCFE occurs in a juvenile (age 10 years and under) or in a patient with an open physis more than 16 years old, careful assessment for an underlying endocrinopathy should be considered.[164]

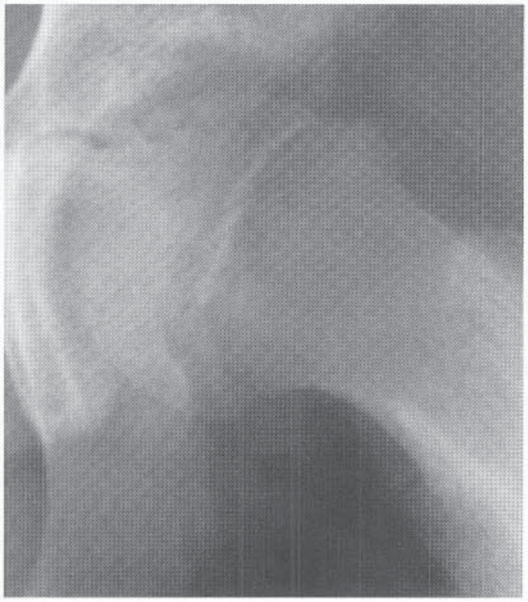
Bilateral involvement of the hips has been reported to occur in as low as 17 percent to as high as 80 percent of cases. Most studies identify bilateral involvement either on initial presentation or subsequently in approximately 20 to 25 percent of patients. Of those with bilateral slips, one-half present initially with both hips involved. In more than 80 percent of patients presenting with unilateral slipped epiphysis and in whom contralateral hip involvement subsequently develops, involvement of the contralateral hip becomes evident within 18 months of presentation for treatment of the first hip. Younger patients and those with endocrine or metabolic abnormalities are at much higher risk for bilateral involvement.

Classification

SCFE may be classified temporally, according to onset of symptoms (*acute, chronic,* or *acute-on-chronic*); functionally, according to the patient's ability to bear weight (*stable* or *unstable*); or morphologically, as to the extent of displacement of the femoral epiphysis relative to the neck (*mild, moderate,* or *severe*), as estimated by measurement on radiographic or computed tomographic (CT) images.

An *acute* SCFE has been characterized as one occurring in a patient with prodromal symptoms for 3 weeks or less (according to some authors, 2 weeks or less). Typically, acute slips present as a sudden, dramatic, fracture-like episode occurring after trauma too trivial to cause displacement of the epiphysis as a Salter-Harris type I fracture; radiographs demonstrate little or no femoral neck remodeling changes typical of chronic SCFE (Fig. 17–1A). This event, in which the patient has an acute, severe, fracture-like pain in the upper thigh, should be distinguished from a purely traumatic separation of the epiphysis in a previously normal hip, that is, a true type I epiphyseal fracture. This distinction is usually not difficult to make clinically. The patient with an

*See references 48, 51, 88, 162, 187, 213, 215, 244.



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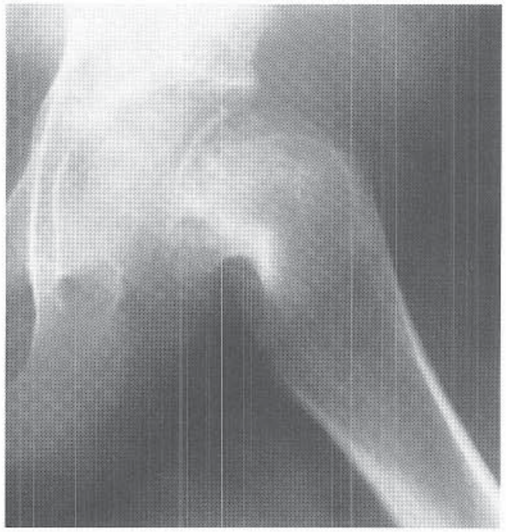

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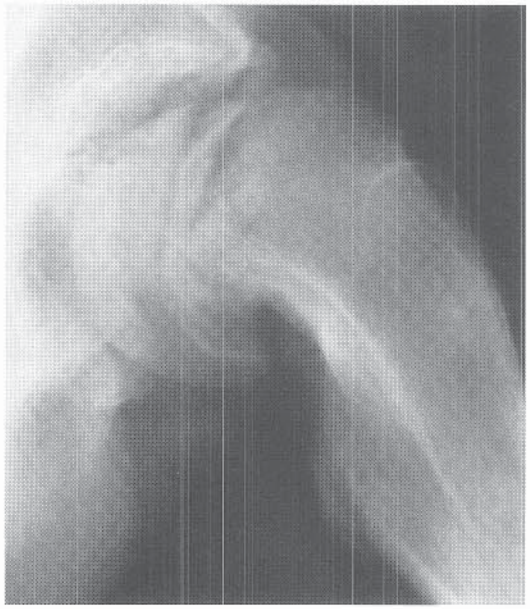

C

FIGURE 17–1 Radiographic appearance of slipped capital femoral epiphysis on presentation. **A,** Appearance of acute SCFE on a frog-leg lateral view. The displacement of the epiphysis is suggestive of a Salter-Harris type I fracture of the upper femoral physis. There are no secondary adaptive changes noted in the femoral neck. **B,** Frog-leg lateral radiographs in a patient with many months of thigh discomfort and a chronic slipped epiphysis. Adaptive changes in the femoral neck predominate, and the epiphysis is centered on the adapted femoral neck. **C,** Frog-leg lateral radiographs of a patient with acute-on-chronic SCFE. The patient had several months of vague thigh pain, with sudden, severe exacerbation of that pain. The acute displacement of the epiphysis is evident. Unlike in acute SCFE (see part A), secondary adaptive remodeling changes are also present in the femoral neck, beyond which the epiphysis has acutely displaced.

acute slip will usually have some, perhaps minor, prodromal pain in the groin, thigh, or knee and will usually report an injury such as a twist or fall that the physician would not normally consider sufficiently violent to produce an acute fracture of this severity. A true type I epiphyseal fracture, on the other hand, occurs in an otherwise completely normal patient without prodromal symptoms, is usually the result of severe, major trauma, is often associated with concomitant traumatic hip dislocation, and has an extremely high rate of subsequent AVN of the capital epiphysis (see discussion of type I fractures of the proximal femur in Chapter 42, Lower Extremity Injuries). AVN is a significant and frequent complication of acute SCFE, with a reported incidence of 17 to 47 percent.*

*See references 1, 34, 66, 103, 112, 138, 171, 176, 208, 210, 219.

Chronic SCFE is the most frequent form of presentation. Typically, an adolescent presents with a few-month history of vague groin, upper thigh, or lower thigh pain and a limp. In an international study by Loder, 85 percent of 1,630 children with 1,993 slipped epiphyses had chronic symptoms, and 15 percent had acute slipped epiphysis, as defined as the child's presenting with less than 3 weeks of symptoms.[165] Radiographs of patients with chronic SCFE show a variable amount of posterior migration of the femoral epiphysis and remodeling of the femoral neck in the same direction (Fig. 17–1B). Thus, the upper end of the femur develops a "bending of the neck," as described by Müller.[195] The clinical symptoms, physical findings, and AP radiographic features especially may be sufficiently minor that the unwary physician fails to make the proper diagnosis.

The *acute-on-chronic* slipped epiphysis is one in which features of both ends of the spectrum are present, that is, prodromal symptoms have been present for more than 3 weeks with a sudden exacerbation of pain, and radiographic evidence of both femoral neck remodeling and further displacement of the capital epiphysis beyond the remodeling point of the femoral neck (Fig. 17–1C).

One of the most significant complications of both slipped epiphysis and its treatment is the development of AVN of the femoral capital epiphysis.* This complication is more frequent in patients with an acute presentation.† Loder and colleagues, in a review of the results of 55 patients presenting with acute SCFE (pain of less than 3 weeks' duration), classified patients based on their ability to bear weight after the acute clinical event, that is, whether the patient's pain was fracture-like and sufficiently severe to prevent the patient from being able to bear weight, even with crutches. Patients who were unable to bear weight after the acute episode were identified as having *unstable* slips, whereas those who were able to bear weight at the time of presentation to a physician were classified as having *stable* slips. Fourteen (47 percent) of 30 patients with unstable slips developed AVN, whereas none of 25 with stable slips did so.[171] This observation has been verified by others,[66,112,138,176,210,250] although with a lower incidence of AVN than the group reported by Loder and colleagues. This observation has led to the preferred temporal classification of slips as stable or unstable.

SCFE may also be categorized by the degree of displacement of the capital femoral epiphysis on the femoral neck. Several methods for categorizing slip based on the extent of displacement exist. Southwick recommended measuring the femoral head-shaft angle on AP (Fig. 17–2A) or frog-leg lateral views (Fig. 17–2B).[237] By this method, *mild* slips are ones in which the head-shaft angle differs by less than 30 degrees from the normal contralateral side. In moderate ones the angle difference is between 30 and 60 degrees, and in severe slips the angle differs by more than 60 degrees from the contralateral normal side. When the contralateral hip is affected or not assessed, the femoral head-shaft angle of the affected hip is calculated from normal values for this angle; according to Southwick, these normal values are 145 degrees on the AP view and 10 degrees posterior on the frog-leg lateral view. Guzzanti and Falciglia[99] and others have pointed out that, owing to the three-dimensional nature of the deformity of slipped epiphysis and inconsistencies of patient positioning for frog-leg lateral radiographs, measurement of the femoral head-shaft angle on this view is subject to substantial error. Head-shaft or head-neck angles can be obtained from either true lateral radiographs or from specifically positioned, modified lateral radiographs (Billing's[24,25,128,129] or Dunlap's[99] techniques). The head-neck angle can be determined most accurately and reproducibly on CT scans of the head and neck (Fig. 17–3),[51,99] but this method is not routinely employed because the majority of patients do not undergo CT to assess the deformity or to facilitate management.

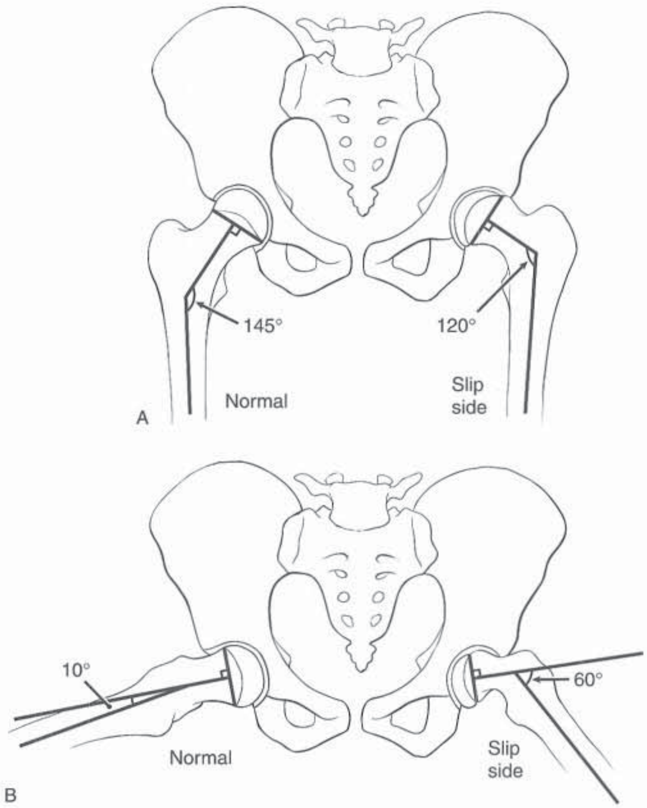

FIGURE 17–2 Southwick method of measuring the head-shaft angle to assess the severity of SCFE. **A,** Lines are drawn corresponding to the axis of the femoral shaft and the base of the capital femoral epiphysis. The head-shaft angle is the angle between the axis of the femoral shaft and the perpendicular to the base of the epiphysis. Normally this angle is 145 degrees. **B,** Similar lines may be drawn on the frog-leg lateral radiographs. Mild slips have less than 30 degrees of displacement, moderate slips have 30 to 60 degrees of displacement, and severe slips have more than 60 degrees of displacement compared to the contralateral normal side.

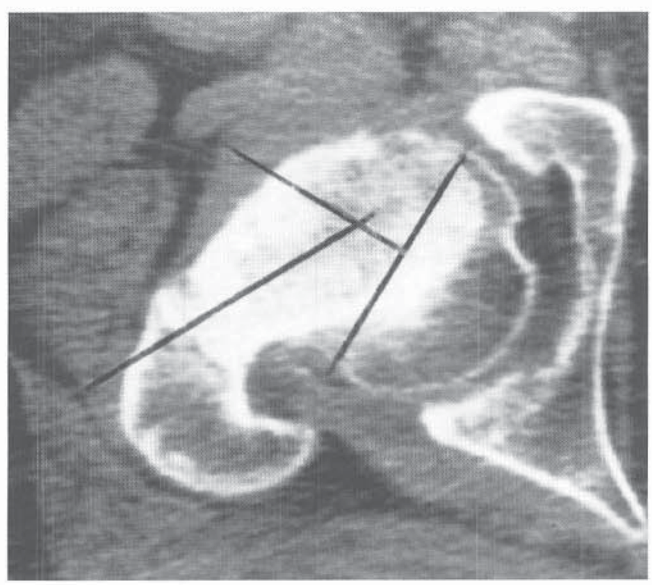

FIGURE 17–3 Measurement of the head-neck angle on CT scan. Although this is the most accurate way to measure the head-neck angle, CT is not necessary in the routine management of patients with SCFE.

*See references 1, 34, 37, 49, 66, 83, 87, 103, 112, 119, 138, 144, 151, 154, 171, 174, 176, 181, 185, 208, 210, 219, 226, 239, 250, 265.

†See references 1, 66, 103, 112, 138, 171, 176, 208, 210, 219.

Etiology

The cause of SCFE is unknown in the vast majority of patients. The stereotype of an obese, hypogonadal male (the so-called adiposogenital syndrome) presenting with chronic bilateral slipped epiphyses has long stimulated the thought that some alteration in the balance of thyroid, growth, and sex hormones was the cause of slipped epiphysis.[73,271] Evidence of hormonal alteration in the majority of patients, even those fitting this image, is lacking.[36,76,197,220,276] Some patients do have an endocrine abnormality, the most common being hypothyroidism (slips can occur either before or during replacement therapy), growth hormone deficiency (slips usually occur during or after replacement therapy), and chronic renal failure (due to uncontrolled secondary hyperparathyroidism).

Mechanical factors created by relative or true femoral neck retroversion, the orientation of the capital epiphysis and the physis on the femoral neck, and alteration of the mechanical strength of the physis, periosteum, and the perichondral ring during adolescence have all been conjectured to play a role in the etiology of slipped epiphysis.*

MECHANICAL FACTORS

A number of features of the adolescent hip in general and of patients with slipped epiphysis in particular make it likely that mechanical causes are at least partly responsible for slipped epiphysis. Three important features of the predisposed hip have been identified that contribute to or may be the primary cause of slipped epiphysis: thinning of the perichondrial ring complex with maturation, relative or absolute retroversion of the femoral neck, and a change in the inclination of the adolescent proximal femoral physis relative to the femoral neck and shaft.

The *perichondrial ring complex* is a fibrous band that encircles the physis at the cartilage-bone junction. Its shear strength is provided by collagen fibers that run obliquely, vertically, and circumferentially. These collagen fibers span the physis, attaching to the ossification groove on the epiphyseal side and to the subperiosteal bone on the metaphyseal side. The perichondrial ring acts as a limiting membrane, giving mechanical support to the physis. Chung and colleagues studied the perichondrial ring complex in 25 pairs of hips obtained post-mortem from children between the ages of 5 days and 15 years.[48] Microscopically, the perichondrial ring complex thinned rapidly with increasing age of the specimens. The specimens were tested mechanically for resistance to shear in pairs, one side with the perichondrial ring intact and the other with the perichondrial ring complex excised. Shear strength varied with age and was dependent on the surrounding perichondrial ring complex, particularly in infancy and early childhood. In the older age group studied (ages 6 to 15 years) the mammillary processes (interdigitating reciprocal protrusions of bone and cartilage at the epiphyseal-metaphyseal interface) became increasingly important in providing of resistance to shearing forces and resulted in more irregular cleavage along the physis during shear testing. Thus, with skeletal maturation, the load-carrying capacity and the shear resistance of the mammillary processes increased and the strength of the perichondrial complex decreased. In the perichondrial ring complex-intact group in Chung's study, shearing was not always through the physis, whereas in the complex-excised group, shearing occurred through the physis in 24 of 25 specimens. The forces required to create the shearing were considered well within a physiologic range, especially for obese children. These features led the authors to suggest that purely mechanical factors may play a major role in the etiology of SCFE. A mathematical reevaluation of Chung's study has reaffirmed that the shearing forces required to displace the capital epiphysis are within physiologic ranges.[162]

Mirkopulos and colleagues measured the slope of the proximal femoral physis on AP radiographs in 307 normal children ages 1 to 18 years and in 107 children with unilateral SCFE.[187] Patients with slipped epiphysis had a slope averaging 11 degrees more on the affected side and nearly 5 degrees more on the unaffected side than the controls. These authors and Pritchett and Perdue[213] believe that this increased obliquity of the proximal femoral physis may be a factor in the development of SCFE.

Another consistent anatomic finding in patients with slipped epiphysis is a relative or absolute femoral retroversion. Analyses of this characteristic by CT[88,244] and direct examination of museum specimens[53] have identified retroversion in patients with slipped epiphysis. In contradistinction, acetabular version and tibial torsion are reportedly normal in patients with slips.[242,243] It seems plausible that increased retroversion makes the proximal femoral physis more susceptible to AP shearing forces.

SCFE has been associated with two other conditions that probably have a mechanical etiology, infantile[231] and adolescent Blount's disease.[69,173] SCFE has also been reported in patients with peroneal spastic flatfoot[68] and Legg-Calvé-Perthes disease.[55] The exact causal relationship to these conditions is unknown.

ENDOCRINE FACTORS

An endocrinologic etiology for slipped epiphysis has long been suspected, based on the common association of this condition with obesity and, and least in boys, hypogonadal features (the so-called adiposogenital syndrome), and the fact that the condition most frequently manifests during the adolescent growth spurt. Furthermore, slips are known to occur in patients with known endocrine abnormalities, most commonly hypothyroidism (treated or not),* abnormalities treated by growth hormone administration,† and chronic renal failure.‡ SCFE has also occurred in patients with prior pelvic irradiation,[15,46,65,170,183,285] Rubinstein-Taybi syndrome,[32] Klinefelter's syndrome,[211] and rarer endocrinopathies such as primary hyperparathyroidism[31,47,134] and panhypopituitism associated with intracranial tumors.[108,164]

In a review by Loder and colleagues of 85 patients with known endocrinopathy, 40 percent were found to be hypothyroid, 25 percent were growth hormone deficient, and 35

*See references 48, 51, 53, 88, 162, 187, 213, 244.

*See references 6, 57, 109, 115, 127, 183, 190, 214, 289.

†See references 30, 79, 80, 127, 220, 221, 225.

‡See references 105, 169, 183, 200, 234, 254.

percent had other endocrinopathy.[164] Patients presented with slips between 7 and 35 years of age; only patients with hypothyroidism or growth hormone deficiency were less than 10 years old on presentation with a slip. All patients with other endocrinopathies presented either at a typical age or were more than 16 years old at the time of diagnosis of a slip. Slipped epiphysis was the presenting symptom in most hypothyroid patients, whereas most of the growth hormone–deficient patients had the endocrinologic diagnosis made prior to presentation with a slipped epiphysis. Correspondingly, the hypothyroid patients developed a slip prior to or during replacement therapy, whereas the growth hormone–deficient patients developed slipped epiphysis during or after growth hormone replacement therapy. Sixty-one percent of the patients had or developed bilateral slips. Thus, prophylactic pinning of the normal contralateral side must be strongly considered in endocrinopathy-associated slipped epiphysis. The other endocrinopathies identified included panhypopituitarism, craniopharyngioma, hypogonadism, hyperparathyroidism, growth hormone excess, multiple endocrine neoplasia 2B, Turner's syndrome, and optic nerve glioma. In a report from the National Cooperative Growth Study, Blethen and Rundle examined the association between SCFE and growth hormone treatment in 16,514 children undergoing growth hormone replacement therapy.[30] Fifteen children developed slipped epiphysis prior to receiving growth hormone, 26 developed slips during treatment, and one patient with a slip on one side prior to growth hormone treatment developed a slip on the contralateral side while receiving growth hormone. The risk of development of a slip during growth hormone treatment was equal in boys and girls. The risk was higher in patients with true growth hormone deficiency, Turner's syndrome, and other known causes of short stature than in children undergoing growth hormone treatment for idiopathic short stature. Blethen and Rundle concluded that the risk for development of SCFE in patients receiving growth hormone treatment for idiopathic short stature was approximately the same as that reported in the general population but was significantly higher in patients with growth hormone deficiency, Turner's syndrome, or chronic renal insufficiency (91 per 100,000 in this study).

Slipped epiphysis associated with chronic renal insufficiency is thought to be secondary to uncontrolled secondary hyperparathyroidism. Loder and Hensinger noted that 95 percent of slips associated with chronic renal failure were bilateral, and almost all of these presented simultaneously.[169] Approximately 50 percent of cases were treated conservatively by medical management of the renal disease, including renal transplantation, while the other 50 percent required surgery for the slip. Males were much more likely to demonstrate progression of their slips and require surgical treatment. These authors emphasized that the goal of medical management should be to achieve control of the hyperparathyroidism within 2 months of the onset of symptoms of slipped epiphysis; if such control cannot be achieved, surgical treatment of the slips should be undertaken. Since there was a relatively high incidence of slip progression after surgical treatment (12 of 21 hips), monitoring of the hips must continue until skeletal maturity in these patients.

In patients without one of the above-described endocrine or metabolic abnormalities (and this represents the majority), search for an endocrine cause for a slip has been largely unrewarding. Evidence of a generalized endocrine abnormality has not been found in a number of investigations. Weiss and Sponseller studied iliac crest biopsy specimens and found no abnormalities in patients with slips, suggesting that histochemical abnormalities noted in the affected proximal femoral physes are secondary to, rather than the cause of, slipped epiphysis.[276] Exner studied height, weight, body proportions, and skeletal and sexual maturation prospectively in 23 patients with slips.[76] Although males in the study tended to be obese and both males and females had relatively longer legs, growth and maturation were not different from normal children. The time of occurrence of slipped epiphysis was most closely related to the patient's bone age and growth spurt peak. Exner concluded that if growth and maturation are sensitive indicators of a well-functioning endocrine system, there was no evidence of an endocrine disorder in this study population. Normal levels of thyroid hormone,[36] growth hormone,[220] and the growth hormone action mediators insulin-like growth factor 1 (IGF-1) and its binding protein 3 (IGFBP-3)[197] have been found in otherwise healthy patients with slipped epiphyses.

However, Wilcox and colleagues found that 71 percent of 138 patients had weights above the 80th percentile, and that active thyroid (T_3) was significantly low in 25 percent of the 80 patients in whom it was tested.[284] Furthermore, testosterone and growth hormone levels were low in 76 and 87 percent of 64 patients tested, respectively. These authors concluded that a "delicate hormonal imbalance" was the basis of slipped epiphysis. Jingushi and colleagues studied parathyroid hormone and 1,25-dihydroxyvitamin D in 13 patients with slips.[134] They found a transient decrease in the serum levels of the midportion of the parathyroid hormone peptide and of 1,25-hydroxyvitamin D. They were uncertain whether these transient deficiencies during the growth spurt were the cause or the result of slipped epiphysis.

In summary, the majority of patients with SCFE prove to be normal by current endocrinologic evaluations, and screening for abnormalities is not warranted unless clinical suspicion exists based on the presence of signs and symptoms other than obesity. In these patients, who constitute the vast majority of those with slips, it seems plausible that mechanical factors, including femoral retroversion, thinning of the perichondrial ring complex with adolescent maturation, obesity, and some as yet unidentified hormonal or biochemical factor that results in weakening of the proximal femoral physis, combine to make the proximal femoral physis more susceptible to shearing forces, which in turn cause the actual displacement of the physis.

Pathology

Grossly, with gradual slipping of the capital epiphysis in the typical posterior position, the periosteum is stripped from the anterior and inferior surface of the femoral neck.[119] The area between the original femoral neck and the posterior periosteum fills with callus, which ossifies and becomes progressively more dense. The anterior, superior portion of the neck forms a "hump" or ridge of bone that can impinge on the rim of the acetabulum. Normally this ridge will remodel, with the anterior portion of the neck contouring into a smoother surface. In cases of acute slipping, the periosteum is torn anteriorly, and hemarthrosis will be present.

The microscopic changes seen in the physes affected by slipped epiphysis have been described in a number of reports (Fig. 17–4).[4,5,119,124,186] Howorth in 1949 provided a comprehensive review of the histopathologic findings in 169 hips with slipped epiphysis that had been treated by open bone peg epiphysiodesis, open reductions, or femoral neck wedge osteotomies.[120] He described a "preslip" stage characterized by widening of the physis both histologically and radiographically without actual displacement of the capital epiphysis. In this stage, the synovial membrane is edematous, as are the capsule and periosteum to a more limited extent. The resting zone of the physis is usually normal in appearance microscopically but accounts for a smaller percentage of the total thickness of the physis, because of the relative increase in the thickness of the proliferative and hypertrophic zones.[124] Both the proliferative and the hypertrophic zones demonstrate an overall decreased number of chondrocytes with an excess amount of matrix tissue. The columnar alignment of chondrocytes is disrupted, and the cells tend to be organized into clumps. The actual displacement of the

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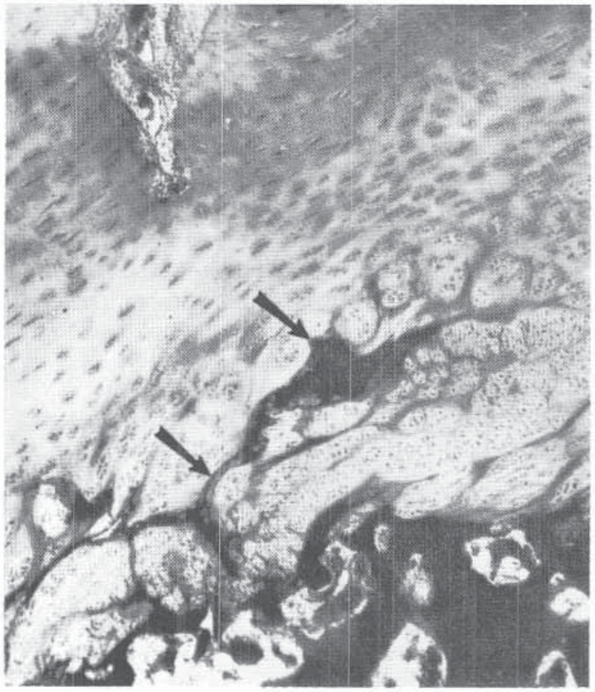

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FIGURE 17–4 Slipped capital femoral epiphysis: photomicrographs of a specimen. **A,** The entire specimen (femoral head and neck). Slipping has occurred through the hypertrophied zone of the physis (hematoxylin-eosin, ×2). **B,** A portion of the growth plate (hematoxylin-eosin, ×50). The zone of hypertrophy is widened and composed of chondrocytes in disarrayed clusters instead of orderly columns. Dark-staining eosinophilic bands (*arrows*) separate the cartilage clusters. **C,** Higher magnification of the growth plate. The chondrocytes of the hypertrophied zone at the cleft (*C*) region are in disordered clusters and irregular columns. The cartilage cell masses are separated by dark-staining eosinophilic septa (*arrows*) (hematoxylin-eosin, ×200). (From Mickelson MR, Ponseti IV, Cooper RR, et al: The ultrastructure of the growth plate in slipped capital femoral epiphysis. J Bone Joint Surg 1977;59-A:1076.)

epiphysis on the femoral neck occurs largely through the hypertrophic zone of the physis, but some of the displacement also occurs through the zone of provisional calcification. Electron microscopic evaluation of biopsies from 23 patients by Agamanolis and colleagues revealed that collagen fibers in the matrix of the hypertrophic and proliferative zones were generally decreased in number, variable in size, and irregularly organized. There were focal areas with increased collagen fibers.[5] These authors noted chondrocyte degeneration and death throughout the proliferative and hypertrophic zones, although Mickelson and colleagues found significant changes in the chondrocytes themselves only in the hypertrophic zone.[186]

In general, anatomic and histochemical observations do not conclusively support or exclude biochemical or biomechanical factors in the etiology of epiphyseal slipping.[4,5,119,124,186] Agamanolis and colleagues concluded that both a deficiency in and an abnormality of the supporting collagenous framework of the physis existed, and they found cellular abnormalities consisting of chondrocyte degeneration and death throughout the proliferative and hypertrophic zones.[4] Whether these changes are secondary to the mechanical disruption of the physis by slippage or are due to some endocrine or biochemical influence on the physis resulting in the slip is uncertain. The study of Weiss and Sponseller, which found no abnormalities in iliac crest biopsies of patients with slipped epiphysis,[276] suggests that the microscopic changes seen in the proximal femoral physis are likely secondary to the slip itself rather than the cause.

Clinical Picture

The symptoms and physical findings vary according to whether the symptoms are chronic, acute-on-chronic, or acute; whether the slip is stable or unstable; with the severity of the resultant deformity; and with the coexistence of the complications of AVN or chondrolysis.

In stable, chronic SCFE, the presenting complaint is usually pain in the region of the groin, which may be referred to the anteromedial aspect of the thigh and knee. In some patients, complaints of pain are exclusively or predominantly localized to the lower thigh or knee; this localization results in the continued problem of delayed or incorrect diagnosis.[158,180] In a study by Matava and colleagues, 15 percent of 106 patients complained of pain *only* in the distal thigh or knee.[180] Those patients were more often misdiagnosed initially, had unnecessary radiographs, had more severe slips on confirmation of the proper diagnosis, and a trend toward a delay in the correct diagnosis. All primary care physicians and orthopaedists must be ever-mindful of the prevalence of slipped epiphysis in the adolescent population, the indolent nature of complaints in patients with stable slips, and the propensity for complaints of pain to be localized to the distal thigh or knee. The adage that any child or adolescent who presents with complaints of pain in the knee region must first undergo careful examination of the hip, including radiography if necessary, before examination of the knee is still true. The pain is typically described as dull and vague; it may be intermittent or continuous, and it is exacerbated by physical activity such as running or sports. The onset of pain may be of several weeks' or months' duration. The patient will have an antalgic limp, with the affected side held in a position of increased external rotation. The examining physician *should not* ask the patient to perform strenuous examination maneuvers such as running, hopping on either foot, or squatting, since these maneuvers could theoretically induce acute displacement of a stable slip. Thigh atrophy may be apparent in unilateral cases; the often associated obesity may make this finding difficult to discern. Local tenderness may be elicited anteriorly over the hip joint. Examination of the arc of motion of the affected hip will reveal a restriction of internal rotation, abduction, and flexion. Commonly, the examiner will note that as the affected hip is flexed, the thigh tends to rotate into progressively more external rotation, and that flexion is limited (Fig. 17–5). The loss of internal rotation on examination, with complaints of pain at the limit of internal rotation, is a key finding in stable SCFE. The limitation of hip motion actually represents a change in location of a relatively preserved arc of motion rather than a loss of motion. Increased hip extension, external rotation, and adduction are usually present, with decreased flexion, internal rotation, and abduction, depending on the severity of the slip. The presence of hip flexion contracture should alert the physician to the possibility of chondrolysis. There may be shortening of the affected extremity of 1 to 2 cm. The stereotypical patient with chronic slipped epiphysis is an obese, hypogonadal male. Other patients have a normal habitus.[36,197,220]

Patients presenting with either *unstable acute* or *acute-on-chronic* slipped epiphysis will characteristically report the sudden onset of severe, fracture-like pain in the affected hip

FIGURE 17–5 Clinical examination of a patient with a stable SCFE. Hip flexion and external rotation are limited. With flexion of the affected hip, the limb rotates externally.

region, usually as the result of a relatively minor fall or twisting injury. The severity of the symptoms will make the patient unable to bear weight and likely to seek prompt medical attention. Occasionally, presentation to the physician will be delayed for some unfortunate reason, and the patient may have resumed weightbearing. A careful history of this acute but resolving event should be sought, as attempts to reduce the femoral epiphysis in the latter situation may significantly increase the likelihood of development of AVN. The patient will usually lie with the affected limb in external rotation and refuse to move the hip. Moderate shortening of the limb will be apparent to the examiner. Severe pain will result from any movement of the limb.

Patients presenting with chondrolysis complicating slipped epiphysis will tend to have a history of more continuous pain and greater interference with daily activities due to the loss of hip joint range of motion. On examination, the affected hip will be held in an externally rotated position at rest, with flexion contracture and global restriction of hip motion. The patient will usually complain of pain throughout the arc of motion rather than just at its extremes.

Since approximately 20 percent of patients will have evidence of contralateral slip on initial presentation, the contralateral hip must always be carefully assessed both clinically and radiographically by the treating physician.

Imaging Studies

PLAIN RADIOGRAPHY

Plain radiography in AP and lateral views is the primary and often the only imaging modality needed to evaluate slipped epiphysis. The earliest radiographic sign is widening and irregularity of the physis with rarefaction in its juxtaepiphyseal portion. This early stage has been termed *preslip* by some authors,[39,119,126,155,181,182] since actual displacement may not be evident on the radiographs. In the earliest phase of mild slips with typical posterior displacement, the AP radiographic findings may be subtle. In the normal hip, a line drawn tangential to the superior femoral neck (Klein's line) on the AP view will intersect a small portion of the lateral capital epiphysis.[148] When typical posterior displacement of the capital epiphysis has occurred, this line will intersect a smaller portion of the epiphysis or not at all (Trethowan's sign) (Fig. 17–6). Steel described the "metaphyseal blanch sign," a crescent-shaped area of increased density overlying the metaphysis adjacent to the physis seen on the AP radiograph (Fig. 17–7).[247] This increased density is due to the overlapping of the femoral neck and the posteriorly displaced capital epiphysis. Scham noted another sign of early slipped epiphysis detectable on the AP radiograph.[229] In the normal adolescent hip, a portion of the diaphysis of the neck inferomedially is intra-articular and overlies the posterior wall of the acetabulum, creating a dense triangular appearance. In most cases of slipped epiphysis this dense triangle is lost as that portion of the neck becomes located lateral to the acetabulum (Fig. 17–8).

Whenever slipped epiphysis is suspected based on the patient's history, physical examination findings, or the presence of any of the above-mentioned subtle findings on the AP radiograph, it is essential to obtain lateral radiographs of the hip as well. The frog-leg lateral view is customarily obtained. This view has several advantages: it is easily obtained by having the patient flex and abduct the hips; soft tissue obscuring of the bony image is minimized; and both hips can be visualized on one film. This view is adequate to confirm the diagnosis of most cases of slipped epiphysis. However, variations in positioning make it an imprecise method of assessing the severity of slip.[99] This view also is not usually adequate for assessing the possibility of penetration of the hip joint by a metallic implant.[266] Alternative lateral radiographic views include a true lateral radiograph, the modified Dunlap lateral radiograph, as described by

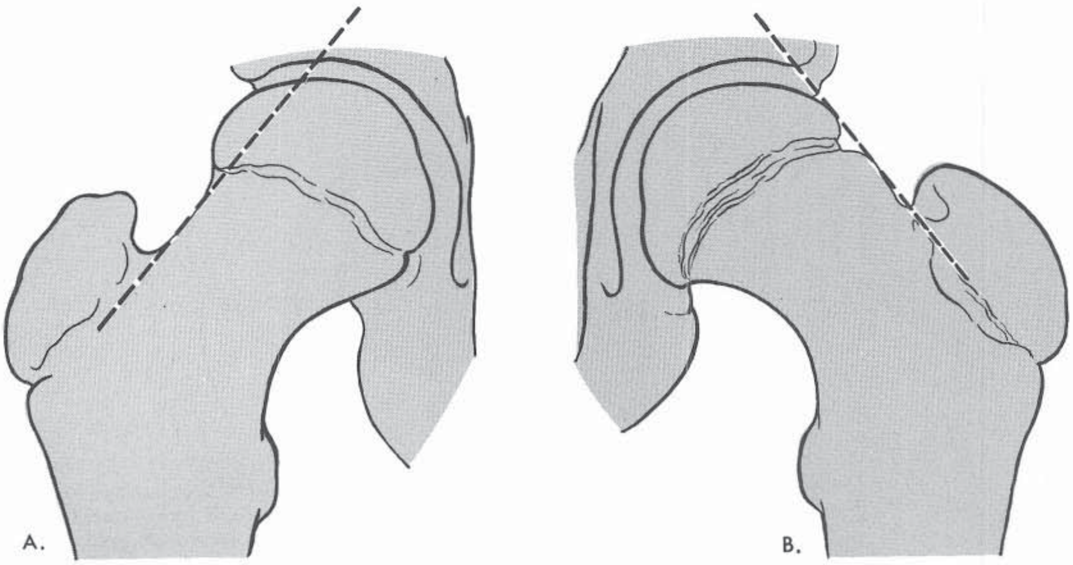


FIGURE 17–6 AP radiographic appearance of a normal hip and a hip with mild chronic SCFE. **A,** Normal hip. A line drawn parallel to the superior femoral neck (Klein's line) will intersect the lateralmost portion of the capital femoral epiphysis. **B,** Hip with mild chronic slip. Klein's line does not intersect the capital epiphysis (Trethowan's sign). Lateral radiographs will confirm the diagnosis.

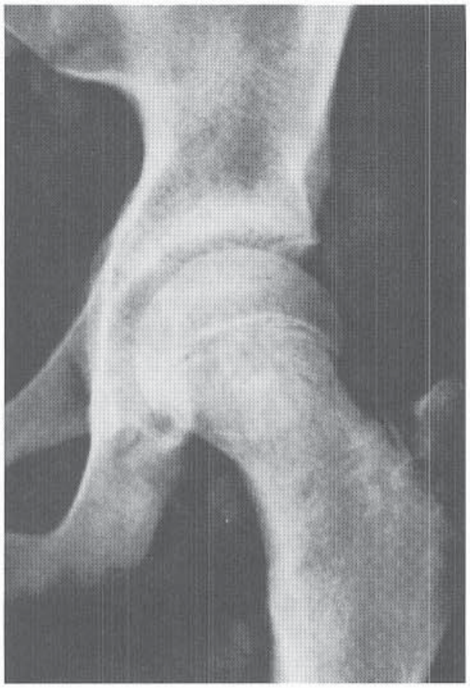


FIGURE 17–7 Metaphyseal blanch sign of Steel in SCFE. A crescent-shaped area of increased density lies over the metaphysis of the femoral neck adjacent to the physis. This density is produced by overlapping of the femoral neck and the posteriorly displaced capital epiphysis on the AP view of the hip. (Courtesy of Howard H. Steel, M.D.)

Guzzanti and Falciglia,[99] and the modified Billing's lateral radiograph, as described by Jerre and colleagues.[128,129] To obtain the modified Billing's view, an AP view of the hip is obtained with the limb resting on a wedge in a position of 90 degrees of flexion, approximately 65 degrees of abduction, and neutral rotation.

When the slip is acute, little or no remodeling of the femoral neck will be apparent on radiographs, only the displacement of the capital epiphysis on the femoral neck through the physis. When the slip has been present for some time, allowing for some remodeling of the femoral neck, this remodeling will appear as a bending of the femoral neck in the direction of the "slipping" capital epiphysis. Appositional new bone will be present on the inferomedial surface of the neck, and the anterosuperior neck resorbs, producing a rounding or "hump" appearance. In patients with a component of acute progression after an initial period of slow displacement of the capital epiphysis with femoral neck remodeling, both radiographic features are present, that is, the femoral neck will be remodeled to some extent and the capital epiphysis will be displaced beyond the margin of the femoral neck remodeling (see Figs. 17–1A and C).

COMPUTED TOMOGRAPHY

CT of the upper femur has been useful in documenting the presence of decreased upper femoral neck anteversion or true retroversion,[88] and it is also believed to be more accurate in the measurement of the head-neck angle (similar to the head-shaft angle of Southwick as described for plain radiographs, but the angle measured is the tangent to the base of the epiphysis and the axis of the femoral neck; see Fig. 17–3).[51] However, CT of the hip is not usually necessary to document or treat slipped epiphysis.[99]

CT can, however, be useful in the management of slips. First, CT of the hip can be very helpful in demonstrating whether or not penetration of the hip joint by fixation devices has occurred (Fig. 17–9). Pin penetration can be difficult to recognize on plain radiographs because hip stiffness due to either AVN or chondrolysis can make patient positioning difficult, or patient obesity may make visualization of the margins of the femoral head difficult. Another indication for CT is to confirm closure of the proximal femoral physis. Documentation of closure can be difficult with plain radiography but may be important in the investigation of continued or recurrent pain in a hip previously treated for slipped epiphysis. Finally, three-dimensional reconstructed CT images can be used to assess the severity of residual deformity of the upper femur,[64] especially when reconstructive osteotomy is being considered.

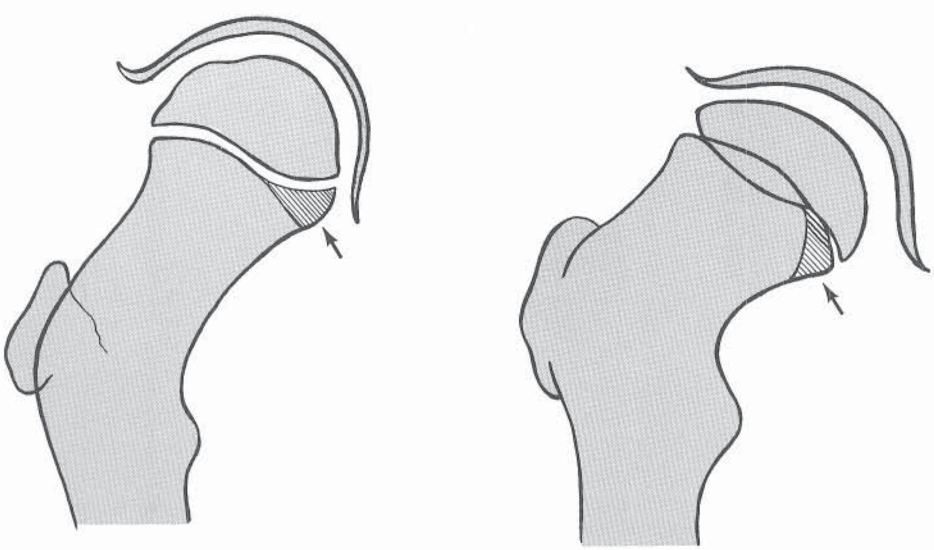
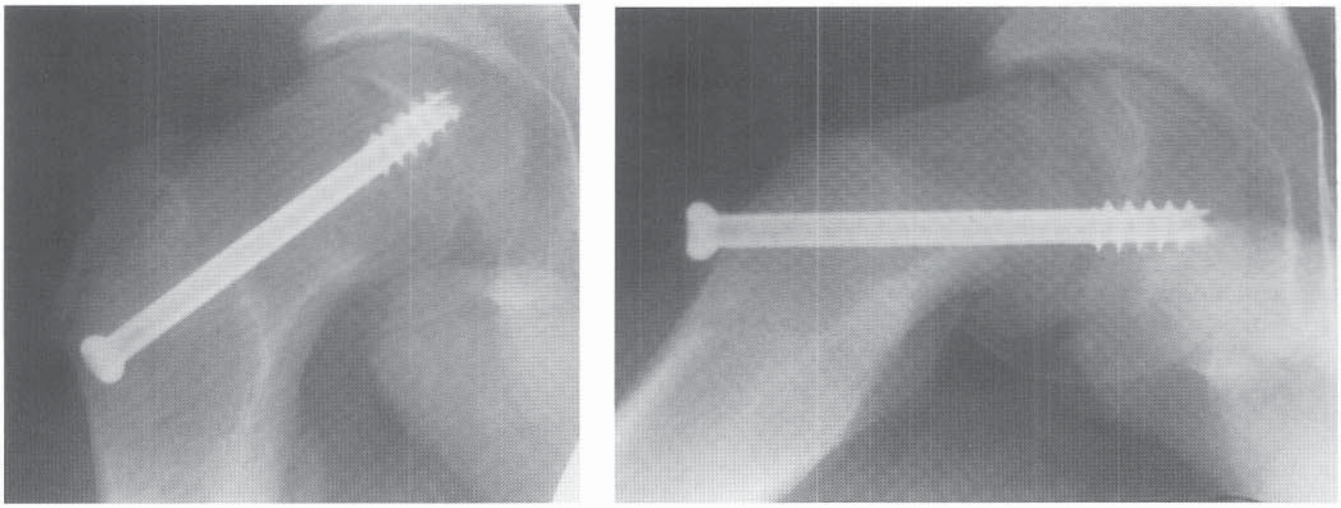


FIGURE 17–8 Scham's sign of SCFE. **A,** In the normal hip, the inferomedial femoral neck overlaps the posterior wall of the acetabulum, producing a triangular radiographic density on the AP view. **B,** With displacement of the capital epiphysis, this dense triangle is lost because this portion of the femoral neck is located lateral to the acetabulum.



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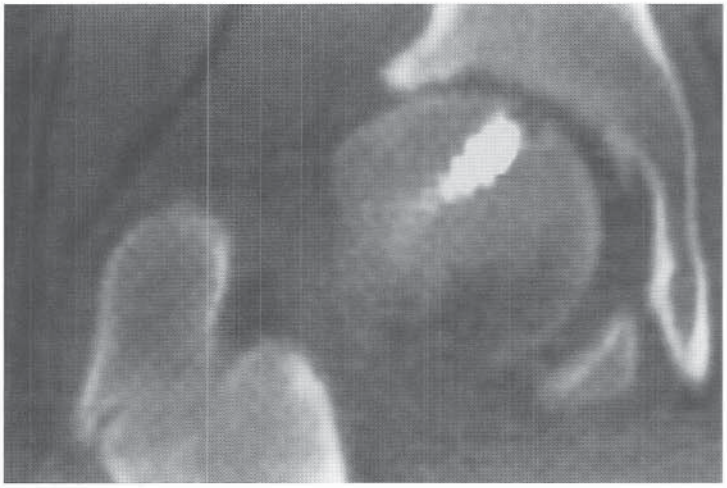

FIGURE 17–9 CT evaluation of implant penetration into the femoral head. **A** and **B**, Plain radiographs show no early evidence of chondrolysis or penetration of the hip joint by the screw on AP (A) or frog-leg lateral (B) projections. **C**, CT scan showing that implant penetration of the joint has nearly occurred and penetration of the joint by a drill probably occurred. Changes in the articular surface due to chondrolysis are present.

C

TECHNETIUM 99 BONE SCAN

Bone imaging with technetium 99 will show increased uptake in the capital femoral physis of an involved hip, decreased uptake in the presence of AVN, and increased uptake in the joint space in the presence of chondrolysis. With respect to the detection of involvement of the hip with slipped epiphysis, however, clinical examination and careful assessment of AP and good lateral radiographs will usually suffice to make the proper diagnosis. If further assessment is required because of equivocal involvement after clinical assessment and plain radiography, either ultrasonography or CT is more sensitive and specific in confirming the presence of an early mild slip, or so-called preslip. Abnormally decreased uptake within the epiphysis is highly specific for the diagnosis of AVN. When chondrolysis is present, there is increased uptake of isotope on both sides of the joint on bone scintigraphy.

ULTRASONOGRAPHY

Ultrasonography has been used in the assessment of slipped epiphysis.[45,136–139,257] Several authors have found that ultrasonography is useful in the detection of early slips by demonstrating joint effusion and a "step" between the femoral neck and the epiphysis created by slipping.[45,137,139] Kallio and colleagues used an anterior longitudinal approach and two transducers, a 5.0-MHz 10-cm linear array transducer for orientation and estimation of joint effusion, and a 4.5-cm linear array transducer to assess epiphyseal displacement.[137] Absolute displacement of 6 mm, or more than 2 mm compared to the normal side, was considered diagnostic of a slipped epiphysis. Kallio and colleagues also felt that the severity of slipping could be accurately staged by determining the step at the anterior physeal outline.[137]

MAGNETIC RESONANCE IMAGING

Although early detection of SCFE has been recorded using magnetic resonance imaging (MRI),[39] plain radiography, CT, or ultrasonography can usually achieve this goal more cheaply and expediently. MRI is a sophisticated imaging technique highly specific for the detection of AVN. However, the presence of a stainless steel implant can seriously degrade the quality of the image and prevent an accurate diagnosis.

Treatment

INITIAL MANAGEMENT OF PATIENTS WITH SUSPECTED SLIPPED CAPITAL FEMORAL EPIPHYSIS

Patients with suspected stable SCFE should be escorted to the radiology suite, preferably in a wheelchair or on a stretcher. Patients with an unstable slip should be immobilized on a stretcher with light skin traction applied to the affected limb to minimize pain with transportation and provided with appropriate analgesics as soon as a plan for definitive management has been formulated. Patients with stable slips may be adequately evaluated with good AP and frog-leg lateral views of both hips. Cross-table lateral radiographs are more accurate for assessing the presence and severity of slips but may be difficult to obtain if the patient is obese or in severe pain. Frog-leg lateral views should not be attempted in patients with unstable slips because of the unnecessary pain the imaging position will induce.

Once the diagnosis has been confirmed and an open capital femoral physis noted, the patient should be admitted to the hospital and placed on bed rest until prompt, definitive management of the SCFE is undertaken. Acute displacement of the epiphysis after diagnosis of mild chronic slip has been documented repeatedly.[26,103] This event can dramatically alter the patient's prognosis.[138,171,176,210,219]

DEFINITIVE TREATMENT

The primary purpose of definitive treatment for SCFE is to stabilize the capital femoral epiphysis to the femoral neck to prevent further slipping. Other goals may include closure of the capital femoral physis and reduction of the epiphyseal displacement. Definitive treatment alternatives for the management of SCFE include in situ internal fixation or pinning; bone graft epiphysiodesis; primary osteotomy through the apex or base of the femoral neck or intertrochanteric area, with or without fixation of the epiphysis to the femoral neck; and application of a spica cast. The choice of treatment depends on the type of slip, its severity, and individual preferences and prejudices. We will discuss the nature of each of these alternatives and the management of slips based on the nature of presentation, and summarize our preferred treatment of SCFE.

Stable Slipped Capital Femoral Epiphysis

IN SITU PINNING. The first description of in situ pinning of SCFE has been attributed to Telson, who used threaded pins in an effort to stabilize the displaced capital femoral epiphysis on the neck.[256] Subsequently, many descriptions of in situ metallic fixation for slipped epiphysis have been reported in the literature.* The goal of in situ pinning with one or more fixation devices is to stabilize the capital epiphysis to the femoral neck to prevent further slippage. The exact mechanism by which this occurs is not certain. Whether these implants do or even should result in premature fusion of the proximal femoral physis is not agreed upon in the literature. As a consequence, many different philosophies regarding precisely how a slip should be pinned have evolved. Various authors have recommended the use of multiple smooth pins to allow continued growth of the physis, multiple threaded pins to arrest physeal growth, multiple screws, and a single screw. Recommended positioning of screw(s) have included placement with threads across the physis to stop growth; placement with threads in the physis and either in the neck or lateral femoral cortex, or with washers between the screw head and lateral femoral cortex, to achieve compression across the physis; or placement with threads only in the epiphysis with the base of the screw deliberately left long to allow continued physeal growth, and the screw exchanged if the head contacts the lateral femoral cortex prior to cessation of growth. Screws may be inserted either percutaneously on a fracture table or on a radiolucent table with the limb free to be moved about for fluoroscopic visualization. All of these techniques have been successfully employed, again suggesting that precisely how and for how long screws work is not clear. What is clear, however, is that the combination of improvement in instrumentation, improvement in fluoroscopic visualization of the femoral epiphysis during surgery, experience with results of single-screw in situ fixation for stable slips, and economic pressures on the health care system encouraging expeditious discharge from the hospital has resulted in the current standard of care to be the insertion of one cannulated screw into the femoral epiphysis from the base of the anterior femoral neck to treat stable slips. Two screws may be considered for addition stability and rotational control for unstable slips, although successful results have been noted with a single screw in such patients as well. We prefer to use a single cannulated screw for "in situ pinning" of a stable SCFE.

Technique of Percutaneous In Situ Fixation with a Fracture Table. The technique of percutaneous in situ fixation of SCFE is diagrammed in Plate 17–1. This technique is specifically indicated for unstable slips and is also appropriate for stable slips, at the surgeon's discretion. Several excellent partially threaded 6.5 to 7.3 mm stainless steel or titanium cannulated screw systems are available. The type selected is at the surgeon's discretion. The surgeon should be familiar with the guide wire, drill, tap, and measuring instrumentation of the system chosen and confirm they are in good working order with an appropriate range of implants available prior to commencing the procedure. The patient is placed on a suitable fracture table with the affected leg held in extension and neutral to slight internal rotation (see discussion under Unstable Slipped Capital Femoral Epiphysis, below) and the contralateral limb positioned either in wide abduction and extension in traction or supported in flexion and abduction, to permit fluoroscopic imaging of the affected hip in the lateral position. Excessive internal rotation of the affected limb should be avoided, especially in the case of unstable slips, to protect the intact posterior periosteum of the femoral neck from being torn. In the case of unstable slips, the extent of reduction that this positioning has produced should be noted; however, no efforts at further manipulative reduction should be made. Rather, the surgical procedure should proceed as for stable slips, with the exception that two guide wires and perhaps two cannulated screws for improved stablization are used, at the surgeon's discretion. The surgeon should confirm that the C-arm fluoroscope is

*See references 10, 13, 21, 22, 58, 61, 64, 66, 89, 92, 94, 112, 125, 132, 150, 154, 155, 192, 196, 198, 201, 202, 216, 224, 227, 232, 235, 240, 245, 250, 251, 267, 281, 287.

working well and that the femoral epiphysis is clearly visible on both AP and true lateral projections. The limb is then prepared and draped either using a "shower curtain" barrier draping technique or U-draping the torso and lower leg out of the surgical field and covering the C-arm with a sterile drape.

The desired trajectory of the screw as seen on fluoroscopy is identified by placing a guide wire on the surface of the limb and marked on the skin with an indelible marker in both the AP and lateral projections, as described by Lindaman and colleagues.[161] It is very important for the surgeon to realize that in a typical SCFE, the femoral neck is retroverted and displacement of the capital epiphyis is essentially posteriorly. The ideal placement of a single cannulated screw is as close to the center of the capital epiphysis and as perpendicular to the physis as possible. Thus, the entry point of the screw must be at the base of the femoral neck, and the screw is directed posteriorly into the center of the capital epiphysis. With increasing severity of the slip, the entry point will be found progressively more superior on the femoral neck. Only in the mildest of slips with minimal femoral retroversion will an insertion point on the lateral femoral cortex allow adequate fixation of the capital epiphysis in SCFE. In very severe slips, if the screw is not placed very anteriorly on the femoral neck it may exit the femoral neck posteriorly and reenter the capital epiphysis. This placement should be avoided as it will allow either continued displacement due to inadequate fixation, loss of fixation, or implant breakage due to continued movement between the bone fragments. In addition, a screw exiting the posterior femoral neck may disrupt the blood supply to the epiphysis.

A guide wire is inserted percutaneously at the intersection of the lines drawn on the skin and advanced to the base of the femoral neck. The location and orientation of the guide wire should be confirmed fluoroscopically. The guide wire is advanced into the epiphysis, aiming at the exact center of the femoral head on both fluoroscopic views without encroaching on the joint space. The guide wire is measured and a screw of appropriate length is selected. The bone is then drilled and tapped with cannulated instruments. Several fluoroscopic checks are made during drilling and tapping so that the guide wire is neither advanced into the joint nor withdrawn from its channel. The screw is inserted over the guide wire. After satisfactory placement of the screw has been confirmed, the guide wire is removed and the stab incision closed. The limb should be released from traction and the hip placed through a range of motion while the surgeon evaluates the relationship of the screw to the hip joint fluoroscopically to be certain that the screw has not penetrated into the joint space.

Specific advantages of this technique include more secure draping of the limb, a percutaneous technique with minimal visible scarring, and elimination of the need to manipulate or support the limb during surgery. Disadvantages include inability to move the limb freely to confirm no pin encroachment of the hip joint prior to the end of the procedure, potentially greater difficulty visualizing the femoral epiphysis in the true lateral position, and awkward positioning and draping procedures (usually staged) with bilateral slips. If difficult patient positioning or extreme obesity makes visualization of the femoral head and hip joint inadequate in the true lateral projection, intraoperative arthrography of the hip with contrast agent enhancement can be a great help (Fig. 17–10).

Postoperative management: We allow protected partial weightbearing with crutches as soon as the patient is comfortable, usually witin 24 hours of surgery; patients with unstable slips may be slower to walk. The patient uses crutches for 6 weeks, during which time the pain should resolve completely. Athletic activities are allowed after 3 months. The patient is monitored for the development of complications or contralateral slip by clinical examination and radiography every 3 to 6 months until skeletal maturity.

Technique of Limited Percutaneous In Situ Fixation Using a Radiolucent Table Top. This technique may be used instead of the fracture table/percutaneous technique at the surgeon's discretion, but only if the slip is stable. The technique is detailed in Figure 17–11. The main advantages of this technique include simpler setup and draping; the ability to put the hip through a wider range of motion when assessing for possible joint encroachment by the pin, without breaking the sterile field or having to remove the patient's limb from traction; better lateral visualization of the upper femur in the flexed, abducted position because of a smaller amount of soft tissue overlying the hip; and much simpler positioning and draping for bilateral slips. The disadvantages include the need for a small incision through the fascia lata to prevent this tissue from bending the guide wire when flexing and abducting the hip, and less of a true lateral fluoroscopic view of the hip. This technique is specifically not indicated in the management of unstable slips because hip movement will make pinning difficult, and epiphyseal movement could potentially compromise blood supply to it.

The patient must first be assessed preoperatively both clinically and radiographically to determine that the slip is stable and to establish whether or not there is slip on the

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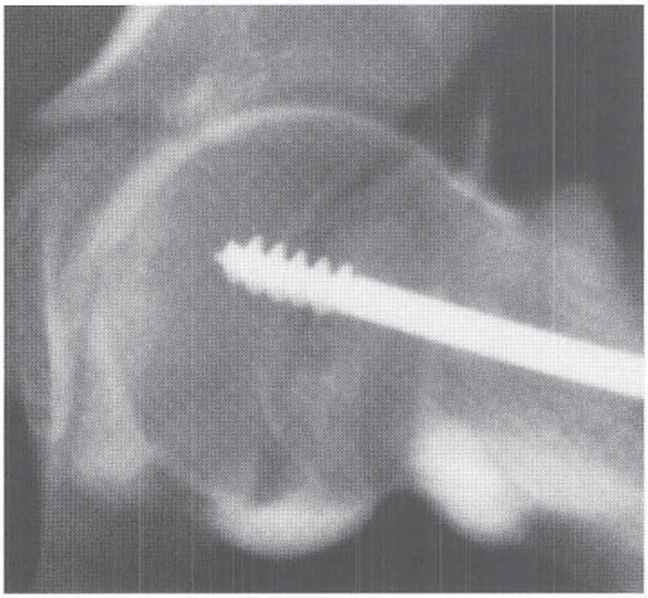


FIGURE 17–10 If difficulty is encountered in visualizing the outline of the capital epiphysis on fluoroscopy during pinning of a slip, an intraoperative arthrogram can be helpful. The radiopaque dye is injected into the hip capsule, allowing better visualization of the femoral head.

Technique of Percutaneous Cannulated Screw Fixation ("Pinning") of Slipped Capital Femoral Epiphysis

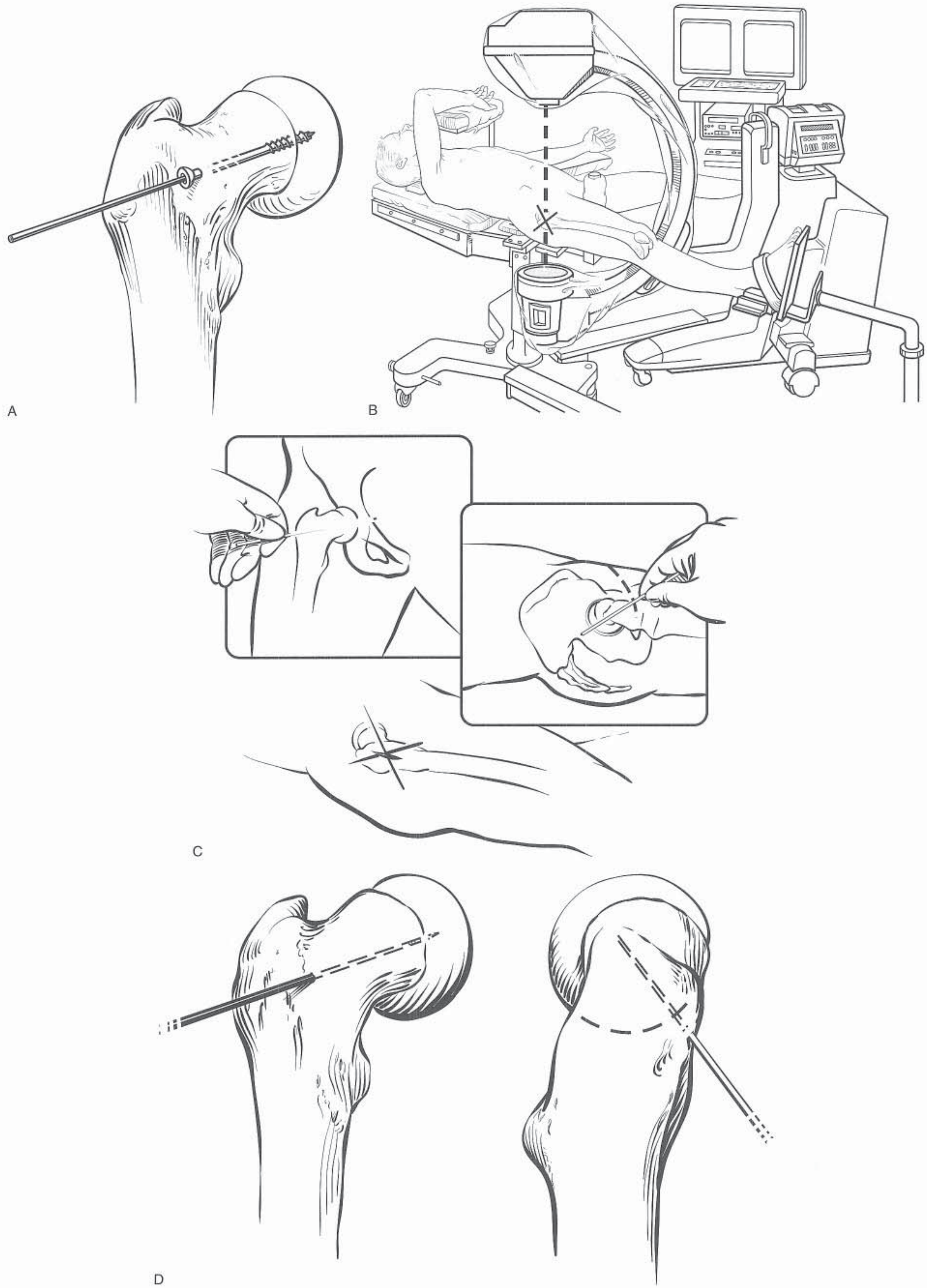
A, The ideal position of a single cannulated screw is in the center of the epiphysis, perpendicular to the physis. In this position, stabilization of the epiphysis to the neck is maximal and the risk of inadvertent penetration of the screw into the joint is lowest. Because of the typical posterior displacement of the femoral epiphysis on the neck, the guide wire and screw must be located on the anterior base of the femoral neck in most cases. The exact location will vary with the severity of the slip.

B, The patient is positioned on the fracture table with the patella facing anteriorly and the limb in neutral to slight abduction. In the case of unstable slips, the epiphysis will usually be noted to have reduced to some extent in this position. No further efforts at reduction should be made. The opposite limb can be placed in traction and maximum abduction, or flexed and abducted to clear it of the lateral fluoroscopic projection. Proper functioning of the fluoroscope with adequate AP and lateral visualization of the femoral epiphysis should be confirmed at this time. The C-arm fluoroscope is then draped out of the surgical field.

C, The ideal trajectory is identified and marked on the patient's skin by placing a free guide wire against the skin while assessing the position of the guide wire under fluoroscopy on both the AP and lateral projections. The intersection of these two lines indicates the proper point of insertion of the guide wire into the patient's limb. A stab incision in the skin is made at this point.

D, Under fluoroscopic guidance, and following the trajectories marked on the patient's skin, the guide wire is pushed onto the base of the femoral neck, then advanced into the neck, across the physis and into the epiphysis. If the location of the guide wire is not ideal, it should be repositioned, or temporarily left in place as a guide for the insertion of a second guide wire in the proper position. Great care must be exercised that the guide wire (and subsequently the drill, tap, and screw) is not advanced into the hip joint. For unstable slips, a second guide wire is inserted parallel to the first, preferably into the inferomedial quadrant of the epiphysis. This will provide some rotational stability in the case of unstable slips and can be used for the insertion of a second cannulated screw if desired.

PLATE 17–1. Technique of Percutaneous Cannulated Screw Fixation ("Pinning") of Slipped Capital Femoral Epiphysis



A B C D

Technique of Percutaneous Cannulated Screw Fixation ("Pinning") of Slipped Capital Femoral Epiphysis *Continued*

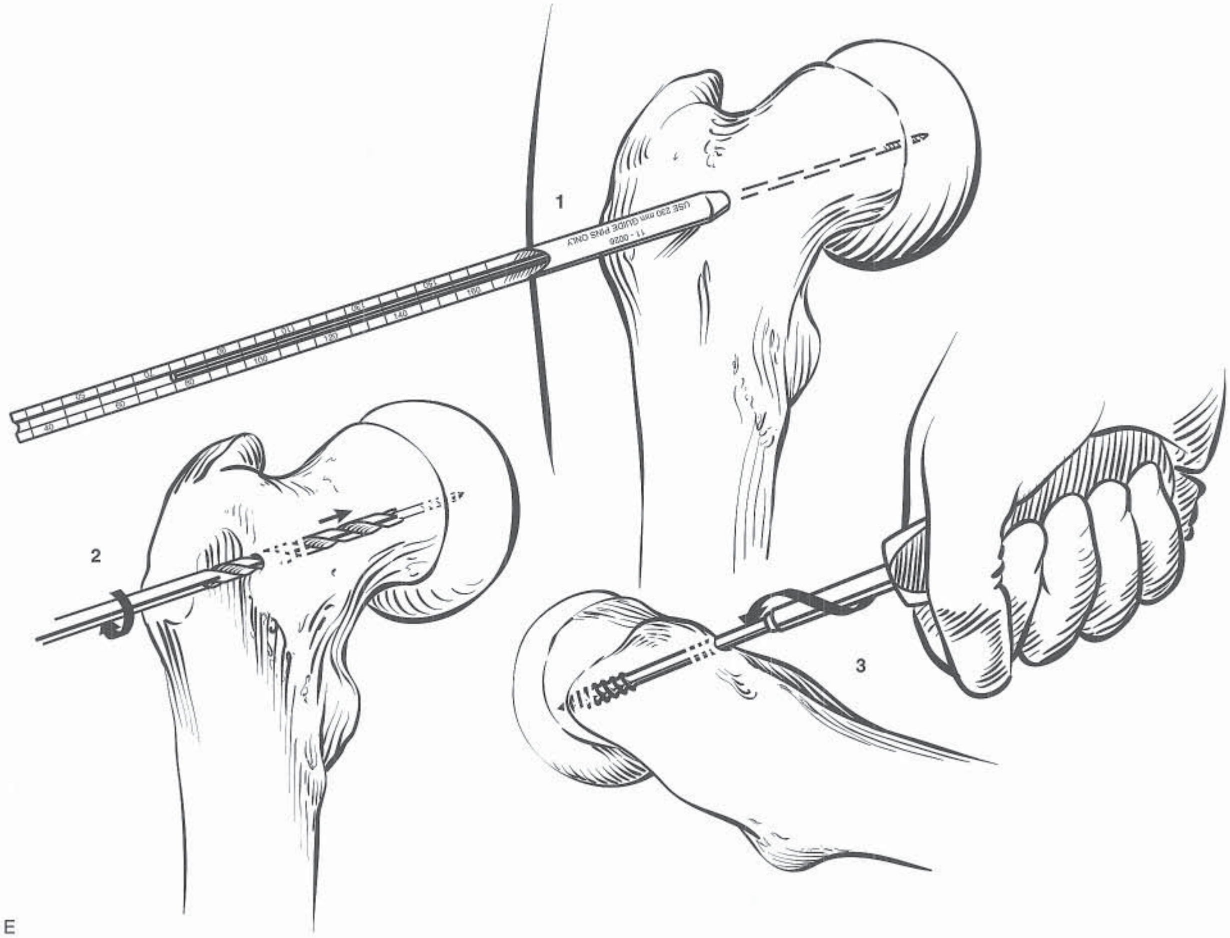
E, The length of guide wire inserted into the bone is measured either with the cannulated depth gauge instrument or by placing a second guide wire against the femoral neck parallel to that in the femur and measuring the difference of exposed ends of the guide wire. The femoral neck and epiphysis are then drilled and tapped using the cannulated instruments. The position of the guide wire is checked periodically to make sure it is not being inadvertently advanced into the hip or withdrawn from the femur with the drill or tap.

F, A screw of proper length is inserted across the physis into the epiphysis. We prefer to have threads cross the physis, and we do not try to achieve compression between the femoral cortex and the threads of the screw. The screw head should not be left protruding through the femoral cortex more than a few millimeters or it may irritate the soft tissues and cause symptoms. In the case of unstable slips, a second screw may be inserted. The guide wire is withdrawn. Careful assessment that the screw does not penetrate the joint should be made prior to closing the skin. The incision can be closed with one or two absorbable subcutaneous and skin sutures.

POSTOPERATIVE MANAGEMENT

The patient is taught to use crutches as soon as comfortable. We allow patients with stable slips to bear weight as tolerated, and those with unstable slips to bear partial weight for 6 weeks. The patient is subsequently periodically reexamined with radiographs to confirm physeal closure and to monitor the contralateral hip until skeletal maturity.

PLATE 17–1. Technique of Percutaneous Cannulated Screw Fixation ("Pinning") of Slipped Capital Femoral Epiphysis



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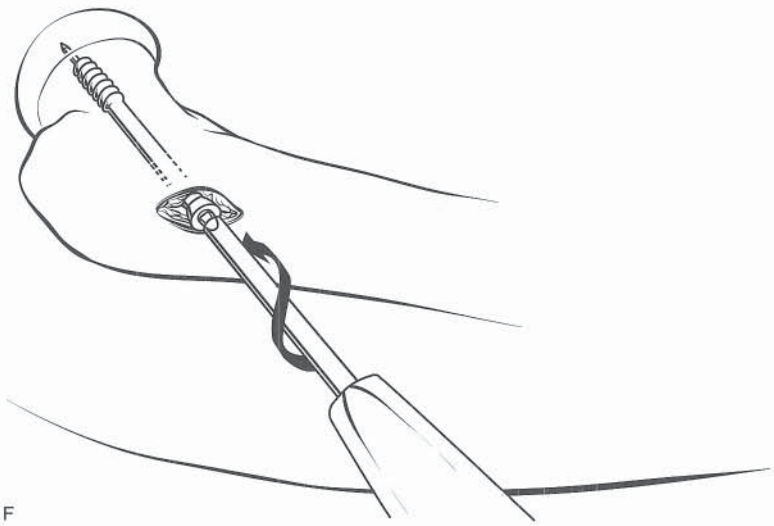

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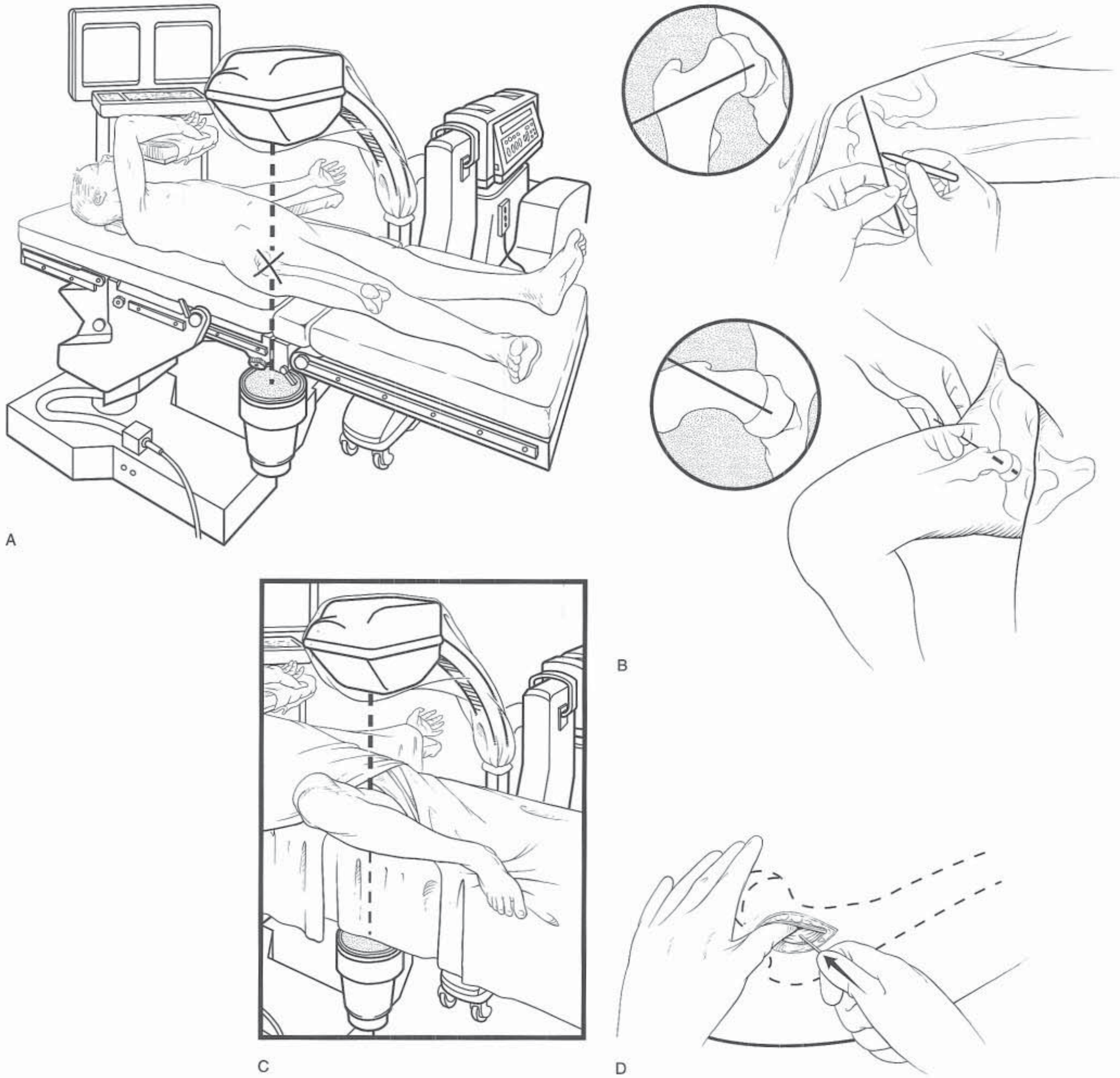


FIGURE 17–11 Technique of pinning a stable SCFE on a radiolucent table top. This technique of cannulated screw fixation is indicated only for stable slips, at the surgeon's preference. **A,** The patient is positioned on a radiolucent table top and the fluoroscope is positioned over the patient. The affected extremity is prepared and draped free. In cases of bilateral slips, both lower extremities may be draped into the surgical field. **B,** The trajectory of the guide wire is marked on the skin, as described for the percutaneous technique (see Plate 17–2). A 2- to 3-cm incision is made at this point and carried through the fascia lata. **C,** The guide wire is advanced through the fascia lata incision and onto the base of the femoral neck, as in the percutaneous technique. To obtain the lateral radiograph, the hip is flexed to 90 degrees and then abducted maximally. **D,** The surgeon must insert a finger into the wound to prevent the anterior edge of the fascia lata from bending the guide wire on flexion of the hip. After satisfactory guide wire placement has been achieved, the length of screw needed is measured, and drilling, tapping, and screw insertion are performed as in the percutaneous technique. After removal of the guide wire, the hip is placed through full range of motion while the surgeon assesses the position of the screw in the epiphysis fluoroscopically. The wound is closed in routine fashion.

contralateral side. After induction of anesthesia, the patient is positioned on a radiolucent table top. The C-arm fluoroscope should come from the opposite side of the table to be unobtrusive to the surgical team, and adequate visualization of the capital epiphysis in both the AP and flexed/abducted lateral positions is confirmed. The patient's affected extremity (or both extremities, in the case of bilateral slips) is draped free. The intended trajectory of the guide wire can be marked on the skin as for the percutaneous technique. This will facilitate limiting the incision required. The lateral projection of the capital epiphysis is obtained by flexing the hip 90 degrees, then abducting it maximally in a position of neutral rotation. Since the hip will rarely abduct 90 degrees, this does not represent a true lateral projection. With the patient lying in this position and the patient's upper thighs supported on the radiolucent table top, placing the guide wire along the posterolateral thigh to determine the trajectory of the guide wire in this position may be awkward. A 2- to 3-cm incision is made at the intersection of the lines drawn on the skin, and sharp dissection is carried through the fascia lata. A self-retaining retractor can be placed under the edges of the fascia lata to hold the wound open. From this point, the surgical procedure is conducted much as for a percutaneous technique. After the guide wire has been placed through the incision in the fascia lata, it is positioned on the base of the femoral neck under fluoroscopic control. After initial advancement of the guide wire into the proximal femur, the hip is flexed and abducted for the lateral projection. The surgeon must hold the anterior cut edge of fascia lata away from the guide wire during this maneuver and on returning the limb into the neutral position, or the fascia lata will bend the guide wire. The position of the guide wire is confirmed in this lateral position. The limb is returned to the neutral position. If the first guide wire is not adequately positioned, a second is placed, using the first as a guide to making the appropriate changes in the trajectory of the guide wire. Once satisfactory positioning of the trajectory has been confirmed, the guide wire is advanced into the center of the epiphysis under fluoroscopic control. Drilling, tapping, screw insertion, and confirmation of adequate placement of the screw without encroachment on the joint are then performed as in the percutaneous technique. Advancement of the screw such that two or three threads have crossed into the epiphysis should be confirmed in the lateral projection. With severe slips, advancement will not appear adequate on the AP view. The hip is then taken through as full a range of motion as possible while the surgeon assesses the position of the screw within the epiphysis under fluoroscopy. The wound is irrigated and the fascia lata, subcutaneous tissue, and skin are closed with sutures. Postoperative management is as for the percutaneous technique.

Cannulated Screw. Design and Positioning: A number of well-designed partially threaded cannulated screw systems are available, and the selection is at the surgeon's preference. Essential features include a large core diameter and thread (at least 6.5-mm thread diameter with a 4.5-mm core diameter or larger), reverse cutting threads with an adequate effective extraction system should the screw have to be repositioned or removed, and a stout guide wire to avoid bending and jamming problems during screw insertion. The length of the threaded portion is at the surgeon's preference; we prefer the longer partial thread designs to facilitate placing of the threads across the physis. Implant material (either stainless steel or titanium) is also at the surgeon's discretion; either material is acceptable as long as the aforementioned essential features are present in the implant system.

Reviews of the adequacy of cannulated screws in the management of SCFE with fewest complications have demonstrated that single screws should be placed either directly in the center of the capital epiphysis[10,267] or at a position slightly inferior and posterior to this ideal position.[240] The more eccentric the screw placement from this central position, the greater is the risk of either inadequate fixation and further migration of the capital epiphysis or inadvertent protrusion of the end of the screw into the hip joint, or both. Because of the typical posterior-inferior migration of the capital epiphysis, the screw must be inserted in a similar direction beginning at the anterior base of the femoral neck or superior to this point, depending on the severity of the slip.

Number of screws: The earliest implants used for in situ fixation of SCFE were either multiple smooth or threaded pins or a larger solid nail device, such as the Smith-Peterson nail. The latter was quickly determined to be an inappropriate device because of often inadequate fixation and the damage caused by the heavy pounding necessary to introduce the nail into the femoral neck and head.[103] Multiple pins were supplanted by multiple smaller-diameter screwlike devices, such as the Knowles or Hagie pins.* Thus, with the introduction of larger cannulated screws, multiple screws were often used. Improvement in implant performance coupled with an appreciation of the problems of implant penetration into the hip joint[266] led to the question of just how many screws were necessary to treat SCFE. Many in vitro and clinical studies have attempted to address this issue for both stable and unstable slips.†

Kruger and colleagues found that two pins were better than one for fixation of the epiphysis in an unstable slip in an in vitro animal model.[153] However, Belkoff and colleagues compared one screw to two smooth pins in a similar in vitro model of acute slip and found that the failure strength of two-pin fixation was significantly less than that of one-screw fixation.[18] Two studies using similar animal models compared one- and two-screw fixation strengths.[141,146] Two-screw fixation yielded only a 33 percent increase in stiffness compared to single-screw fixation, and the authors concluded that the gain in stiffness with a second screw did not offset the increased risk of complications.[141]

Clinical studies have repeatedly demonstrated that single screw fixation yields satisfactory if not superior results to multiple pin or screw fixation for both stable and unstable slips.‡ Blanco and colleagues, in a study of 114 hips treated with one, two, or three screws or pins, found that the incidence of pin-related complications was directly related to the number of pins (4.6 percent with one pin or screw, 19.6 percent with two, and 36 percent with three).[28] Physeal closure occurred between 5 and 6 months after surgery and was not influenced by the number of pins or screws. Aronson and Loder in a study of black children found satisfactory results in 74 percent of patients treated with multiple pins and in 91 percent of patients treated with a single screw.[11]

In another study, Aronson and Carlson rated 54 of 58 hips, including 8 acute slips, as excellent or good on follow-up after fixation with a single cannulated screw.[10] They did not find an association between the severity of slip and the clinical result. De Sanctis and colleagues reviewed results in 51 patients with 55 acute or acute-on-chronic slips treated with either one or two percutaneous cannulated screws and concluded that fixation with a single cannulated screw was

*See references 17, 20, 21, 44, 54, 63, 125, 157, 227, 245, 287.

†See references 10, 11, 18, 19, 28, 62, 64, 92, 94, 112, 132, 141, 146, 153, 240, 250, 267.

‡See references 10, 11, 28, 64, 92, 94, 112, 132, 250, 267.

stable, safe, and reliable.[64] Goodman and colleagues, in a review of 21 acute or acute-on-chronic slips treated with a single screw, found 20 to be good or excellent in follow-up; no patient developed AVN or chondrolysis.[94] They too concluded that single screw fixation is adequate for acute and acute-on-chronic SCFE. Denton, however, reported a single case in which progression occurred after treatment of an acute-on-chronic slip by traction, reduction and single screw fixation.[62]

The location of the single cannulated screw does influence the result of in situ fixation. Stambough and colleagues, in a review of results in 80 patients, found that complications were least when a single screw was used and was placed in a relatively inferior position, avoiding the superior and anterior quadrant of the epiphysis.[240] Aronson and Carlson, in their study of 58 hips treated with a single cannulated screw, noted that the patient with the most eccentrically placed screw had further progression of the slip, as did another patient with an acute slip.[10] Ward and colleagues found that increasing eccentricity of a single screw led to progressively longer time to physeal fusion.[267] In that study the capital epiphyses grew off the screw in three patients, none of whom required treatment.

Screw-related complications: Complications directly related to the use of screws include perforation into the joint space by the screw or guide wire, either transiently during insertion or persistently afterwards; failure of physeal fusion, with growth of the epiphysis off the end of the screw and/or progression of the slip; loss of fixation either in the femoral neck or in the epiphysis; implant failure (fracture) secondary to failure-producing stress concentration at the physis or posterior neck in cases in which the device exits the neck and reenters the epiphysis; fracture of the femoral neck or intertrochanteric area at the site of screw insertion secondary to stress concentration; and difficult or failed efforts at screw extraction. By far the most important of these complications is implant protrusion into the hip joint.

Walters and Simon were the first to carefully identify the potential for joint space violation by metallic implants (despite apparently "safe" placement on radiographs) and to clearly implicate the association of metallic pin encroachment on the joint and chondrolysis.[266] They noted in an in vitro study that pin penetration may go unrecognized on AP, true lateral, and especially frog-leg lateral radiographs, because these views are usually not obtained perpendicular to the axis of the pin or screw. In their study, the amount of actual pin protrusion that could go undetected on a frog-leg lateral radiograph when the implant appeared to be at the articular surface of the femur on the AP or true lateral radiograph was 1 and 2 cm, respectively. The closer the tip of the implant was to the center of the head and the more closely it was positioned to a plane passing through the center of the femoral head parallel to the plane of the x-ray film, the greater the correlation between apparent pin depth and actual pin depth. In their clinical study of 102 patients, 90 percent had no evidence of penetration on available radiographs, while 10 percent had 1 to 2 mm of protrusion. However, when the "true" position of the implant was calculated, only 40 of the patients were judged unlikely to have pin penetration of the joint. Walters and Simon analyzed results by grouping patients into those whom they calculated to have no pin penetration, those with probable penetration of one or more pins less than 5 mm beyond the subchondral cortex, and those with penetration of one or more pins more than 5 mm beyond the subchondral cortex. Ninety percent of patients without pin penetration had no pain, restriction of joint motion, evidence of joint destruction, or chondrolysis defined as loss of more than one-half of the contralateral normal joint space. Only 4 percent of patients with penetration less than 5 mm had no pain, 68 percent had femoral or acetabular subchondral bone changes, and 35 percent had chondrolysis. All patients with at least one pin calculated to extend more than 5 mm beyond the subchondral cortex had pain, restricted joint motion, and subchondral bone changes, while 77 percent had chondrolysis.

It is clear, however, that pin penetration cannot be the sole factor in the development of chondrolysis, because chondrolysis can occur without treatment and in patients in whom pin penetration of the joint has never occurred. Furthermore, not all cases of pin penetration result in chondrolysis.[22,266] Nevertheless, no good can come from having a metallic device extruding from the epiphysis, and such positioning must be studiously avoided. Walters and Simon outlined a "safe area" (Fig. 17–12) and recommended that pins lie within this crescent on AP and lateral radiographs to maximize the likelihood that devices are intraepiphyseal and extra-articular.[266] Other authors have not found this technique helpful as the sole criterion for prevention of pin penetration.[250] Intraoperative endoscopic inspection via the channel drilled to receive the screw[16] and attempted joint arthrography via the cannulation in the screw after its insertion[160] have been recommended as ways to document no penetration into the joint. Caution must be exercised if either technique is used, because debris could be irrigated

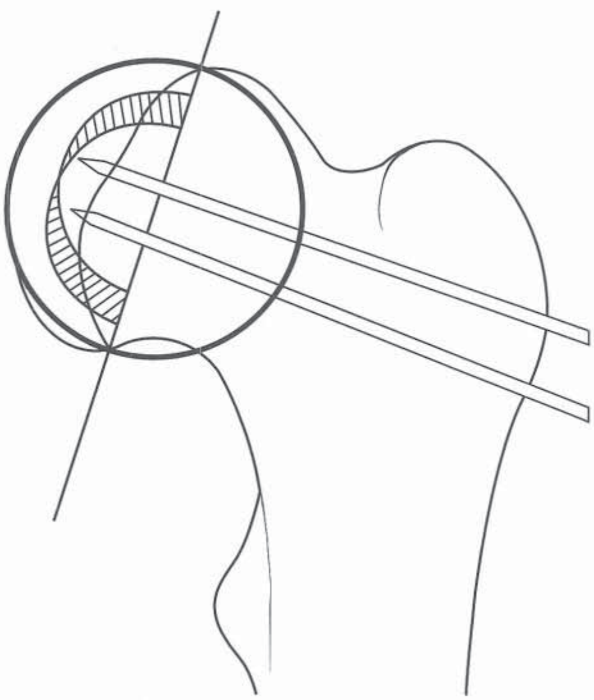


FIGURE 17–12 "Safe" area of screw placement as described by Walters and Simon.[266] If the tip of the screw is no closer to the hip joint than the described arc on the AP or frog-leg lateral view, joint penetration is unlikely. This conclusion must be supported by clinical evaluation and CT if necessary.

into the joint if penetration has in fact occurred. We believe that the potential for joint encroachment can be minimized by placing the screw in the middle of the epiphysis and advancing the screw only far enough to engage the physis with the threads of the device, staying well shy of the subchondral bone. At the end of the procedure, before the sterile field is broken, the hip should be taken through a full range of motion under fluoroscopic visualization to confirm that at no point does the screw extend beyond the subchondral bone and that there is no crepitus with movement. Postoperatively, if there is any question of pin protrusion, CT of the hip should be undertaken.

Fractures of the femoral neck[17,40] and the subtrochanteric area[10,39,222] after in situ pin fixation have been reported. Of the four patients reported to incur femoral neck fracture, AVN developed in two and nonunion of the fracture site in one. This is a serious but apparently very rare complication of in situ fixation. The subtrochanteric fractures reported by Canale and colleagues occurred through unused drill holes,[39] an observation that emphasizes the importance of careful surgical technique with a minimum number of perforations of the femoral cortex.

Undue prominence of the implant at the entry site anteriorly has led to loss of fixation due to a "windshield wiper" effect in which the overlying soft tissues cause toggling of the implant within the femoral neck[177] and, in one case, due to the development of a false aneurysm.[114] Finally, exit of the implant from the posterior femoral neck led to implant fracture in one series[222] but to no problems in another.[202]

Routine removal of screws: In the past, fixation devices were routinely removed after physeal fusion in patients with SCFE. Reasons for removal included concerns regarding the potential long-term toxic complications of a retained implant; the possible induction of local malignancy; difficult to impossible extraction at a later date, making revision surgery likewise more difficult or impossible; and the risk of fracture at the entry site of the implant. As a practical matter, the usual reason for removing Steinmann pins was the fact that they were most commonly left protruding from the lateral femoral cortex or anterior femoral neck and caused symptoms from soft tissue impingement. Routine removal was in fact used as an argument by some authors against using implants in the first place and for using bone graft epiphysiodesis instead.[54,222] However, with the use of cannulated and relatively low-profile screws, symptoms are uncommon unless the screw has been inadvertently or deliberately left protruding excessively from the femoral neck, infection is present, or the screw has penetrated into the joint. As a consequence, routine removal of screws is now more controversial.* Removal of some screw designs has proved difficult, especially the early varieties without reverse-cutting threads or, in the case of titanium implants, without satisfactory extraction instrumentation.[20,21,54,159,261,269] Present-day devices generally pose little problem with extraction, and their removal is primarily to be considered on general principles. First, extraction requires a general anesthetic and surgical procedure that is costly to the patient and the health care system and not without risk.[222] Second, removal of the implant does not completely eliminate the risk of fracture, as fracture can occur through the insertion hole irrespective of whether there is metal in that hole or not. We do not routinely remove asymptomatic cannulated screws.

*See references 20, 21, 40, 54, 96, 159, 202, 261, 269.

Summary of In Situ Pinning. We believe that in situ pinning with a single cannulated screw inserted either percutaneously or through a limited exposure is the procedure of choice for stable SCFE, regardless of severity. The screw should be placed as close to the center of the capital epiphysis as possible. Although one such screw may suffice for unstable slips, we insert two guide wires, followed by one or two cannulated screws. We prefer to position the threads across the physis without attempting to achieve compression between the head of the screw and the threads, although we believe that attempting to achieve this is a reasonable alternative technique. We will consider open bone graft epiphysiodesis for SCFE when the severity of the slip is such that insertion of the screw without exiting the posterior femoral neck and reentering the capital epiphysis appears impossible, or when osteopenia or some other factor has resulted in inadequate fixation and continued progression of the slip. We do not advocate routine removal of cannulated screws but do so after closure of the physis for symptoms, if deep wound infection or joint encroachment is considered possible, or to respect parental concerns about retention of an implant.

BONE GRAFT EPIPHYSIODESIS. "Open bone peg epiphysiodesis," or simply "open epiphysiodesis" of the capital femoral physis, was first described by Poland in a patient he operated on in 1896.[113] Modern credit for the development of the technique goes to Ferguson and Howorth,[78] who reported it in 1931, and to Heyman, who apparently began using the technique independently in 1943 and described it in 1954.[116] The technique and its results have been described by many authors.* In this procedure, a portion of the residual physis is removed by drilling and curettage, and a dowel or "peg" of autologous bone graft (usually harvested from the ipsilateral iliac crest) is inserted across the femoral neck into the epiphysis through a drill hole fashioned to receive the graft. This procedure may be combined with open reduction of the epiphysis and may be used to treat either stable or unstable slips. In unstable slips, supplementary internal fixation, postoperative traction, or spica cast immobilization for 3 to 8 weeks until early stabilization has occurred have all been recommended.

Operative Technique. The technique of open bone graft epiphysiodesis is summarized in Plate 17–2. The patient is placed on a radiolucent table top or fracture table with fluoroscopy available, and the affected hip is prepared and draped. Either a Smith-Peterson anterior or a Watson-Jones anterolateral surgical approach can be used. The latter approach is recommended by Weiner and colleagues because it is more familiar to most surgeons and the incision can be incorporated into subsequent revision surgery or total joint arthroplasty.[274] The joint is opened through an H- or T-shaped incision into the capsule. Soft tissue retractors are placed within the capsule, with care taken not to violate the posterior periosteum of the femoral neck where the residual blood supply to the femoral head courses. A guide wire is driven through the anterior femoral neck across the physis into the

Text continued on page 736

*See references 97, 113, 116, 117, 125, 208, 210, 218, 224, 230, 255, 268, 272–274, 287.

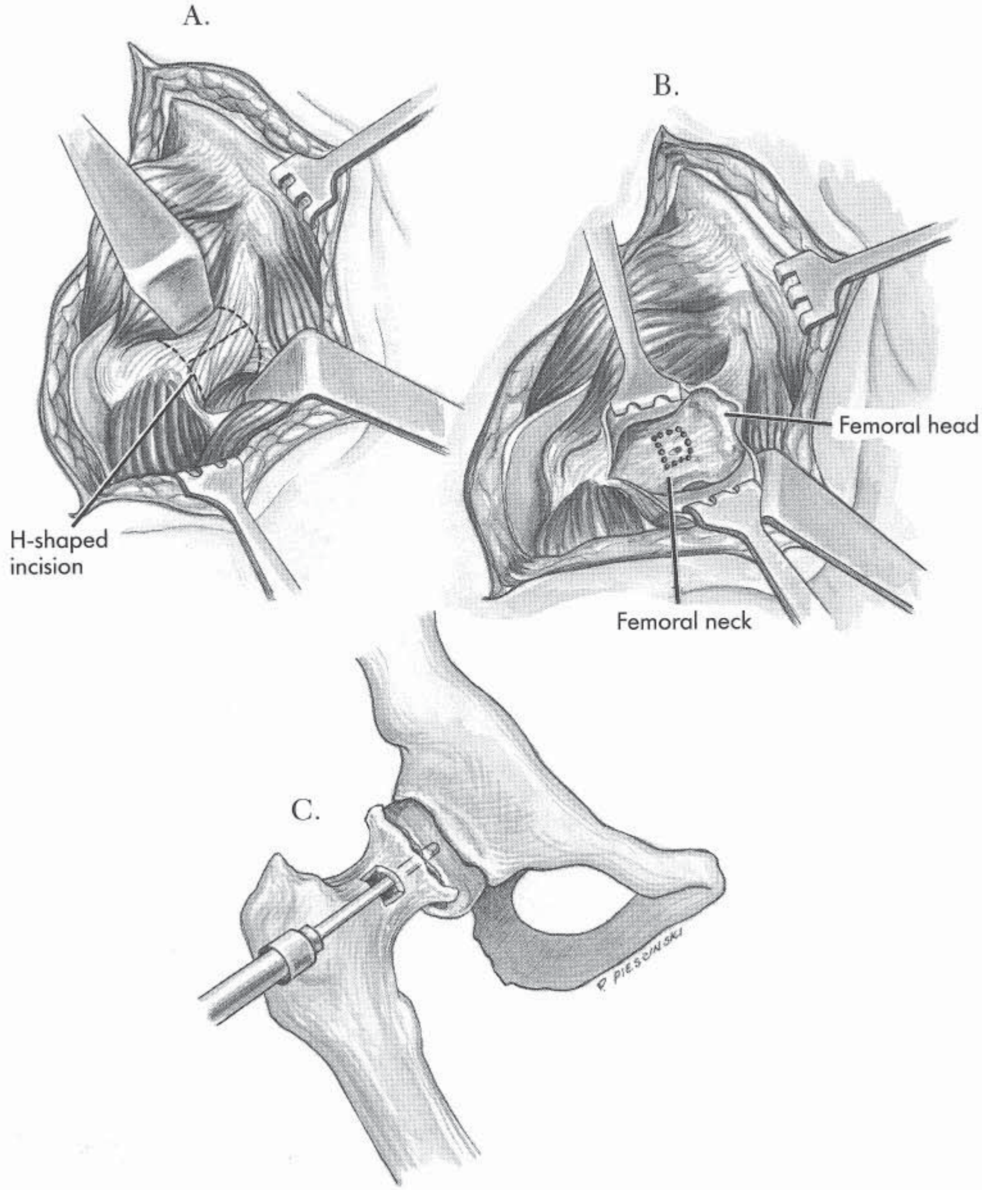
Open Bone Graft Epiphysiodesis for Slipped Capital Femoral Epiphysis

A, The patient is positioned on a fracture table or radiolucent table top with C-arm fluoroscopy available. The hip may be approached from either an anterior Smith-Peterson approach or an anterolateral Watson-Jones approach. The hip capsule is exposed and opened with an H-shaped incision. Care must be taken not to damage the posterior periosteum with retractors placed in that area.

B, A cortical window is fashioned on the anterior aspect of the femoral neck and removed.

C, A heavy guide wire or Steinmann pin is directed across the neck and physis into the capital epiphysis. This should be done under fluoroscopic control.

PLATE 17–2. Open Bone Graft Epiphysiodesis for Slipped Capital Femoral Epiphysis



Open Bone Graft Epiphysiodesis for Slipped Capital Femoral Epiphysis *Continued*

D, A hollow-mill or large cannulated drill is used to remove residual physis and create a tunnel from the femoral neck into the capital epiphysis. A curet may be used to remove more physis via this channel.

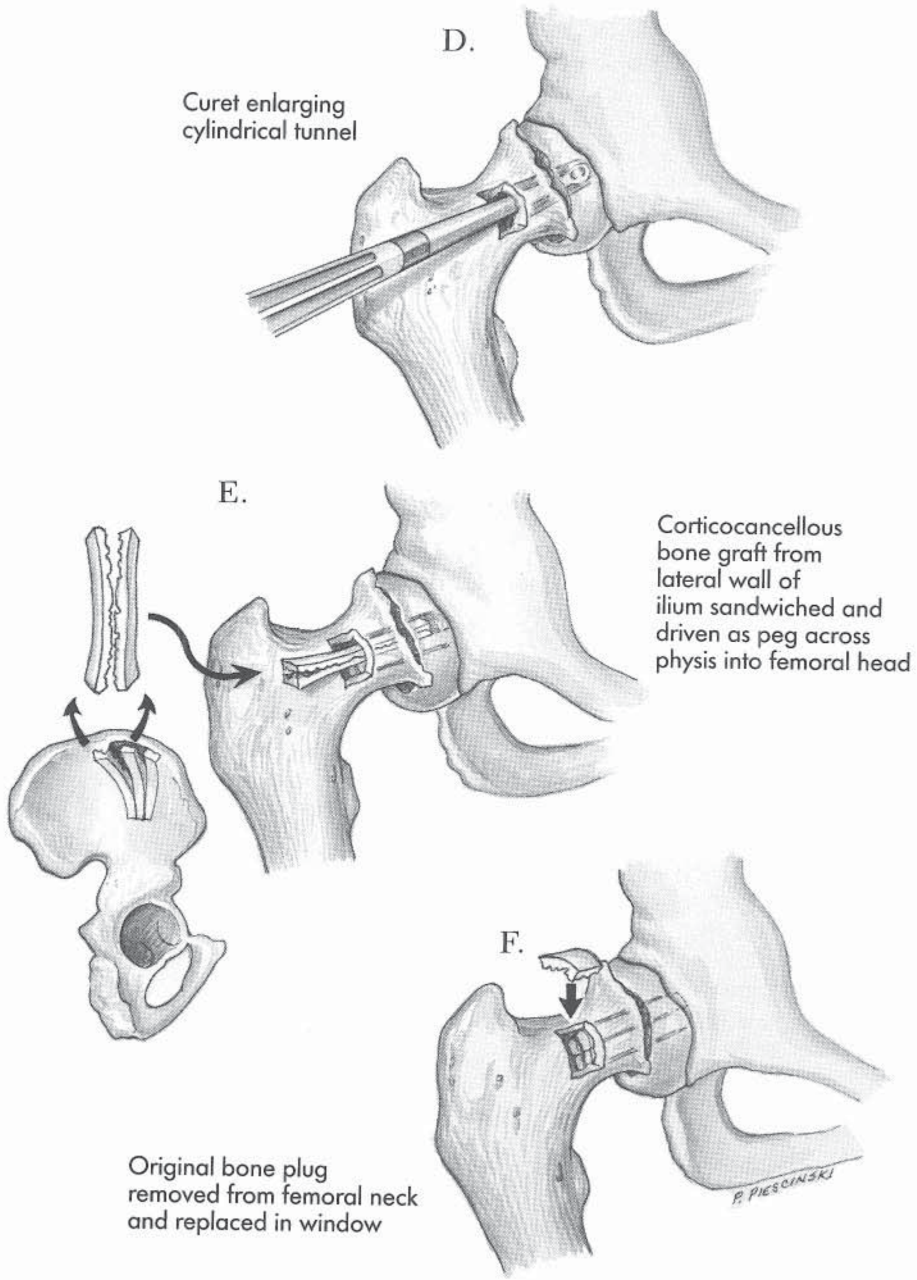
E, Corticocancellous strips of bone graft are obtained from the ipsilateral iliac crest. They are inserted into the tunnel in the femoral neck across the physis into the epiphysis.

F, The cortical window may be replaced into the femoral neck.

POSTOPERATIVE MANAGEMENT

Patients with stable slips may be allowed toe-touch weightbearing with crutches once comfortable, until physeal healing is noted radiographically (usually 6 to 12 weeks). Patients with unstable slips should be kept in traction in bed until early healing, or placed in a spica cast for 3 to 6 weeks, at which time protected weightbearing with crutches is allowed until healing is complete radiographically.

PLATE 17–2. Open Bone Graft Epiphysiodesis for Slipped Capital Femoral Epiphysis



epiphysis under fluoroscopic control. The femoral neck is perforated over the guide wire with a cannulated drill bit or large hollow mill drill (3⁄16 to ½ inch in diameter), and the drill is advanced into the epiphysis over the guide wire. If a hollow mill drill is used, the cylindrical core of bone, containing the portions of capital epiphysis, physis, and metaphysis, is removed. A curet is used to enlarge the cylindrical tunnel and to curet additional portions of the physis. Strips or a cylinder of corticocancellous bone are harvested from the iliac crest and driven into the tunnel from the femoral neck across the physis into the capital epiphysis. If a cortical window has been removed from the femoral neck, it is replaced, and the wound is closed in the usual fashion.

Schmidt and colleagues have described a modification of the procedure that uses a percutaneous graduated cannulated drill technique and freeze-dried allograft in place of iliac crest autograft.[230]

Postoperative Management. Patients with a stable slip may be allowed out of bed with protected weightbearing using crutches or a walker until radiographic evidence of physeal closure has occurred. Patients with unstable slips should either be placed in a spica cast for 3 to 6 weeks or maintained in split Russell traction until comfortable, and then allowed protected weightbearing as for stable slips.

Results. Weiner and colleagues reviewed results in 159 patients with 185 SCFEs treated over a 30-year period by open bone graft epiphysiodesis, including 26 acute and 159 chronic slips.[273] In the 159 chronic slips, there were six cases of further slippage, including two with acute progression, one case of AVN, and no cases of chondrolysis. In the 26 acute slips, there were two cases of AVN and one case of chondrolysis. The authors recommended this technique for both acute and chronic slips because rapid physeal closure occurs without risk of implant encroachment into the joint, there is no need to consider secondary implant removal, and the overall incidence of complications is low.

However, Ward and Wood found that of 17 patients who had undergone open bone graft epiphysiodesis, fusion was achieved in only 12.[268] Eight grafts either resorbed, moved, or fractured postoperatively. One patient had radiographic joint space narrowing, and significant myositis ossificans developed in three. Rao and colleagues evaluated 43 patients who had undergone 64 open bone graft epiphysiodeses.[218] Healing occurred in all cases at an average of 17 weeks after surgery. Surgery time averaged 2 hours, and blood loss averaged 425 mL. Complications included four hips with AVN, three with chondrolysis, three infections, four delayed wound healings, seven cases of transient anterolateral thigh hypesthesia, and 44 hips with heterotopic ossification. Neither of these groups recommended bone graft epiphysiodesis as a primary procedure for stable slips because of these results.

Summary. Most authors who have compared the techniques of in situ fixation and open epiphysiodesis have concluded that the former is a simpler procedure, with less intraoperative blood loss, fewer postoperative complications, and comparable postoperative results.[125,218,268,287] The technique of bone graft epiphysiodesis should not be abandoned altogether, however. Bone graft epiphysiodesis is probably best indicated in the management of chronic slips of such severity that the treating surgeon is uncomfortable with the feasibility of pinning in situ, or for slips that have progressed despite apparently adequate pinning (especially if there is evidence of loss of fixation due to osteopenia).

PRIMARY OSTEOTOMY. Primary upper femoral osteotomy to prevent further slippage and simultaneously correct preexisting deformity has been addressed by many authors.* Described procedures include reduction or osteotomy through the fracture callus or femoral neck with fixation of the capital epiphysis to the residual neck,† referred to as cuneiform osteotomy of the femoral neck by some authors (which we will refer to in this chapter as the Dunn procedure),‡ closing wedge osteotomy at the base of the neck (either intracapsular, as described by Kramer and colleagues, or extracapsular, as described by Barmada's group[2,14]), or intertrochanteric osteotomy, as described by Imhauser[131,207,228] and Southwick.§ The goal of preventing further slippage is achieved either by curetting the physis and securing the capital epiphysis to the neck, or by fixing the capital epiphysis with a bone graft epiphysiodesis or metallic implant, or indirectly by inducing fusion by reorienting the plane of the capital physis into a more horizontal position to subject it to compressive forces. The intent of these procedures is to correct symptomatic loss of motion (specifically hip flexion and internal rotation), to provide a mechanical environment more conducive to healing of the physis by reducing or eliminating shearing forces on (it in the case of severe slips), and, ideally, to improve the longevity of the hip with respect to the development of degenerative arthritis by improving the mechanics of hip function. The array of procedures described to achieve these goals has developed from attempts to strike a balance between the dilemma of addressing the deformity at or as near its apex (at the metaphyseal-epiphyseal junction) as possible and reducing the high rate of severe complications (chondrolysis and, particularly, AVN of the capital epiphysis) unarguably associated with these procedures. The rate of complications is more or less directly related to the proximity of the osteotomy to the apex of the deformity, being highest for osteotomies at the apex (intracapsular in the superior neck) and lowest for osteotomies performed extracapsularly in the intertrochanteric area. On the other hand, the greater the distance between the corrective osteotomy and the apex of deformity, the more severe the secondary compensating deformity will be, and the greater the difficulty of further reconstructive procedures, such as total joint arthroplasty. Opinions as to the indications for these procedures vary from as little as 20 degrees of head-shaft deformity for the performance of intracapsular osteotomy[152] to rarely or never, regardless of the severity of the deformity.[43,87,131] The locations of the osteotomies described in this section are diagrammed in Figure 17–13.

Dunn Procedure. According to Pearl and colleagues,[209] the original description of intracapsular osteotomy or wedge resection of the femoral neck was by Whitman in 1909.[280] DeRosa and colleagues,[63] however, credit Bradford with describing

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*See references 2, 14, 27, 41, 43, 49, 52, 56, 60, 63, 71, 72, 81–83, 86, 87, 97, 107, 123, 130, 131, 145, 152, 154, 181, 185, 198, 199, 205, 207–209, 215, 217, 224, 226, 228, 236–238, 252, 253, 255, 260, 263, 279, 280, 282, 283, 286.

†See references 38, 41, 49, 71, 72, 131, 145, 198, 199, 224, 228, 255, 260.

‡See references 56, 63, 81–83, 87, 107, 154, 208, 209, 263, 282, 283.

§See references 41, 49, 86, 131, 181, 185, 198, 217, 226, 236–238.

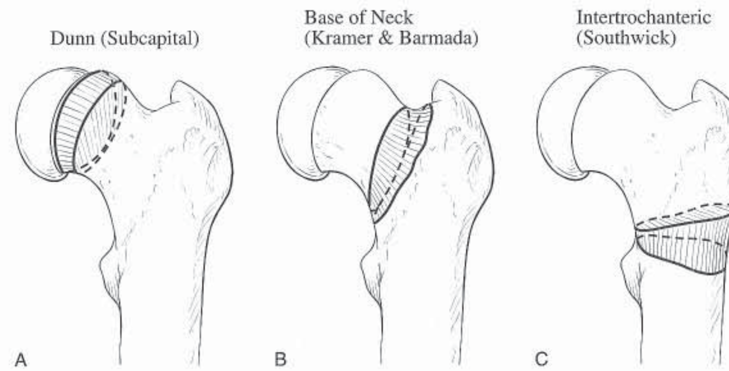


FIGURE 17–13 Location of proximal femoral osteotomies for SCFE. **A,** Dunn osteotomy. An anterosuperior wedge of the most superior part of the femoral neck is removed, carefully preserving the posterior periosteum. The femoral epiphysis is reduced on the neck under no tension, and secured with screws passed percutaneously. A cuneiform osteotomy is identical in concept; the base of the wedge is located in the central portion of the femoral neck. **B,** Base-of-neck osteotomy as described by Kramer and colleagues[152] and Barmada and colleagues.[14] The neck is exposed intracapsularly or extracapsularly and an anterosuperiorly based wedge is removed from the base of the neck. The apex of the wedge may be extracapsular posteriorly. Reduction and pinning are carried out as in the Dunn osteotomy. **C,** Intertrochanteric osteotomy as described by Southwick[236] and Imhauser.[122] The osteotomy is designed to correct extension/varus deformity with flexion/abduction of the distal fragment, and internal rotation as needed.

the first femoral neck osteotomy, in 1895.[35] Dunn in 1964 described a "trapezoidal" osteotomy of the femoral neck through a lateral approach, with the capital femoral epiphysis held reduced with pins.[71] In a later publication, he referred to the procedure as "an open replacement of the displaced femoral head."[72] At least some of the confusion in terminology can be attributed to whether a distinction should be made between an open reduction of a SCFE with resection of the superior neck and physis, and a formal wedge or "cuneiform" osteotomy in the same region. We do not make this distinction, and in this chapter we will refer to both as the Dunn procedure. The intent of this procedure is to reduce the capital femoral epiphysis on the femoral neck by resecting a portion of the superior femoral neck, carefully preserving the posterior periosteum of the femoral neck and preventing tension on it during reduction. More recently, the procedure has been described by Fish,[81–83] DeRosa and colleagues,[63] Velasco and colleagues,[260] and others.*

Technique: The proximal femoral neck and epiphysis (such as it may be visualized) is exposed either (1) through a lateral approach with osteotomy of the trochanter, as originally described by Dunn, (2) anterolaterally, without trochanteric osteotomy, through the Watson-Jones approach, or (3) through an anterior approach such as the Smith-Peterson approach. A superolaterally based wedge of superior femoral neck, including residual physis, is resected using osteotomes, curets, and rongeurs, with great care used not to violate the periosteum of the posterior neck with these instruments or with the retractors placed around the neck (Fig. 17–13). Sufficient bone must be resected to allow reduction of the capital epiphysis on the neck without tension on the posterior periosteum. The reduction is performed by internally rotating the hip to bring the neck to the head. The capital epiphysis is then secured to the femoral neck with pins or screws. The patient is either placed in a spica cast or allowed protected weightbearing with crutches until radiographs demonstrate union between the femoral neck and the capital epiphysis.

*See references 41, 49, 87, 107, 263, 282, 283.

Results: Although the Dunn procedure in theory provides the best anatomic restoration of the proximal femur, it has always done so at high risk of complication, the most severe being AVN and chondrolysis. The best results have been recorded by Fish,[83] who reported good or excellent clinical results in 61 of 66 hips, with AVN developing in three hips and chondrolysis in two. Dunn himself reported 13 cases of chondrolysis and 11 of AVN in a series of 73 hips; AVN developed in only one of 40 stable slips with an open physis at the time of surgery. DeRosa and colleagues reported that four cases of AVN and eight cases of transient joint space narrowing occurred in 27 hips treated by cuneiform osteotomy.[63] Gage and colleagues reported AVN in 28 percent and chondrolysis in 38 percent of 77 hips treated by cuneiform osteotomy, and they recommended that this procedure be abandoned.[87]

Base-of-Neck Osteotomy (Kramer and Barmada Procedures). Two base-of-neck osteotomies have been described to correct the deformity created by slipping of the capital epiphysis. These procedures may be indicated to correct residual deformity after closure of the physis, and in theory pose less risk to interruption of the blood supply to the femoral head than the Dunn procedure.

Kramer and colleagues described an intracapsular "compensating osteotomy" performed at the base of the femoral neck which they recommended for chronic slips with 20 degrees or more of deformity on either radiographic view (Fig. 17–13B)[152] They believed that since the base of the posterior femoral neck is extracapsular, the femoral head blood supply is avoided by this osteotomy. They determined the amount of bone to be removed by measuring the head-neck angle on the AP radiograph, using a normal range of 70 to 90 degrees, and confirmed their estimation at surgery by measuring the width of the callus by direct inspection. Initially these authors used an anterior approach, but subsequently they adopted the Watson-Jones anterolateral surgical approach. Kramer and colleagues recommended that the wedge resected be based more superiorly than anteriorly to prevent excessive retroversion and inadequate varus deformity correction. The reduced osteotomy was held with threaded Steinmann pins, which extended into the capital epiphysis if the physis was still open (Plate 17–3). Reporting the results of 56 osteotomies in 55 patients, they noted three cases of AVN and five patients who required further corrective procedure (to increase valgus, internal rotation, or to transfer the greater trochanter).

Barmada's group described an extracapsular base-of-neck osteotomy performed slightly more distally than as described by Kramer and recommended it for moderate to severe chronic SCFE with a greater than 30-degree head-shaft angle on lateral radiographs (Fig. 17–13C).[2,14] Through an anterolateral approach, a triangle of bone is delineated by marking the line from the greater to lesser trochanter along the edge of the capsule and from the lesser trochanter to the base of the greater trochanteric apophysis. In their experience, the wedge required typically measured 15 mm superiorly. The osteotomy following the intertrochanteric line at the base of the capsule was performed perpendicular to the axis of the femoral neck, whereas the more distal cut was angled toward the first at an angle determined by the analysis of the preoperative lateral radiograph. The osteotomy was reduced and fixed with cannulated screws, one of which was positioned across the physis (Plate 17–4). In the series reported by Abraham and colleagues, all patients had a chronic SCFE with open physis; the surgical procedure was aborted if, when the capsule was opened, fluid was encountered, indicating an unstable slip.[2] These authors reported 90 percent good or excellent results on follow-up by Southwick's[237] criteria, with five cases of chondrolysis, three of pin penetration, and one patient with broken pins who underwent revision valgus osteotomy. There were no cases of AVN. However, 10 of 11 hips followed for at least 13 years had radiographic evidence of joint space narrowing.

Intertrochanteric Osteotomy (Imhauser/Southwick Procedure). Because of the risk of development of AVN associated with intracapsular procedures, extracapsular intertrochanteric osteotomy has long had proponents as a preferable method to correct deformity associated with SCFE.* Credit for the description of intertrochanteric osteotomy to correct deformity associated with SCFE has been extended to both Southwick† and Imhauser.[122,131,207,228,237] Southwick's procedure has been termed "biplane osteotomy," and he recommended that it be performed at the level of the lesser trochanter. Imhauser's procedure is performed slightly higher in the intertrochanteric region of the proximal femur. Because the principles, technique, and results are comparable, we will not make a distinction between them in this section (Fig. 17–13D).

Southwick recommended osteotomy for chronic or healed slips with head-shaft deformities between 30 and 70 degrees. Although he performed his osteotomy for slips with a head-shaft deformity as much as 70 degrees, he recommended not correcting more than 60 degrees of posterior tilting, as flexion of the distal fragment results in excessive shortening of the limb. Southwick felt that internal rotation of the distal fragment was rarely necessary after the anterolaterally based wedge was removed. Initially, he held the osteotomy with four pins in a pin-holding device and spica cast,[237] but he subsequently used a custom compression plate.[236] Other authors have used AO compression plates, AO blade plates, or compression hip screws.* He thought only acute (unstable) slips needed to have the physis pinned simultaneously. Although some authors agree with this,[226] other recommend simultaneous pinning of all open capital physes,[228] and still others only if "further growth is expected."[207]

Technique: Preoperative assessment involves calculating the amount of deformity from AP and lateral radiographs. Southwick described the head-shaft angle on both the AP and frog-leg lateral radiographs (see Fig. 17–2); because of the variability in patient positioning for frog-leg lateral views, other authors have used more specifically positioned lateral views.[207,228] Based on analysis of the head-shaft angle on radiographs, Southwick planned an intertrochanteric anterolaterally based wedge resection (Fig. 17–14) to produce simultaneous flexion and abduction (or valgus). The degree of deformity is calculated in both planes and serves as a guide as to the amount of wedge to be removed from the anterolateral cortex of the femur at the intertrochanteric level. Deformities measuring more than 50 to 60 degrees, particularly on the lateral radiograph, probably should not be completely corrected with this osteotomy, since excessive shortening may result. Intracapsular osteotomy or, better yet, incomplete correction are probably the wiser courses when such severe deformity is encountered. Southwick recommended an anterolaterally based wedge, while Imhauser and others have described a more anteriorly or laterally based wedge with rotation of the distal fragment internally as necessary to complete the deformity correction.

With the patient on a radiolucent table top, or preferably on a fracture table, and C-arm fluoroscopy available, the entire affected extremity is draped free. The proximal femoral cortex is exposed through a lateral incision. The proper level of osteotomy is confirmed with fluoroscopy. A longitudinal mark should be made along the anterolateral margin of the proximal femur spanning the anticipated wedge of bone to be resected to serve as a rotation-orientation mark. Southwick recommended fashioning a triangular template incorporating the two angles calculated from the AP and lateral radiographs to be overlaid on the anterolateral edge of the proximal femoral cortex to guide the surgeon in fashioning the wedge to be resected (Fig. 17–14). An alternative is simply to mark the angle of the wedge to be resected directly on the bone or to insert guide wires at the desired angles to guide proper wedge resection. The type of fixation to be used and the orientation of the wedge to be resected must be carefully considered. If a 90-degree blade plate is to be used, the chisel should be inserted perpendicular to the long axis of the distal fragment and at an anteriorly inclined angle corresponding to the desired amount of flexion to be corrected. Planning the osteotomy such that the distal cut is perpendicular to the axis of the femur will allow internal rotation of the distal fragment on the proximal without altering the amount of flexion or valgus correction obtained. If a larger-angled blade plate or hip compression screw is used, the insertion angle should be adjusted superiorly from the plane of the osteotomy corresponding to the amount of angle greater than 90 degrees.

Results: In Southwick's original series, results were excellent in 21 of 28 hips followed for more than 5 years, good

*See references 41, 86, 181, 185, 198, 207, 217, 226, 228, 236, 237, 279.
†See references 10, 21, 41, 56, 86, 181, 198, 202, 226, 228, 237.

*See references 131, 181, 185, 207, 217, 226, 228.

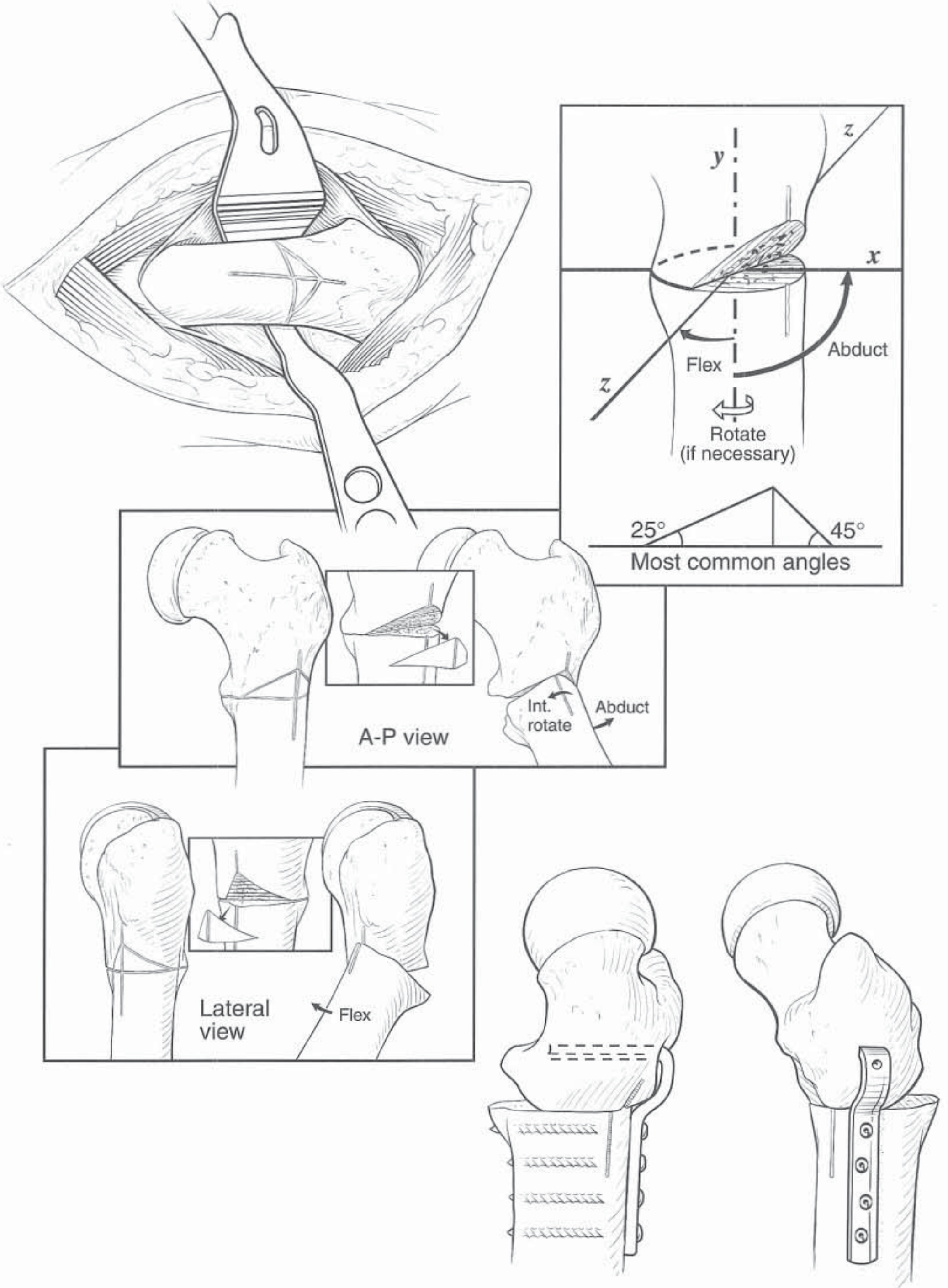


FIGURE 17–14 Detail of the Southwick intertrochanteric osteotomy. An anterolaterally based wedge (based along the anterolateral crest of the proximal femur) is resected. The size of the wedge angles are determined from the head-shaft angles noted on the AP and frog-leg lateral radiographs.

The osteotomy produces flexion and valgus of the distal fragment. It can be fixed with a dynamic compression plate, an AO blade plate, or a dynamic hip screw and plate device.

in five, and fair in two. There were no cases of AVN, but in two hips "considerable" narrowing of the joint space developed postoperatively.[237] Frymoyer[86] reported chondrolysis in five of nine patients treated with osteotomy as described by Southwick, and subsequently many authors have noted this complication.* Although Southwick noted no AVN in his series, several authors have observed this complication, even in apparently stable slips.[181,185,207,226]

*See references 41, 181, 185, 198, 207, 226.

SPICA CAST. Although immobilization in a hip spica cast is most commonly used as an adjunct to closed reduction, pinning, bone graft epiphysiodesis, or osteotomy of the upper femur, it has also been described for the definitive management of slipped epiphysis.[23,43,50,121,142,184] Betz and colleagues

Text continued on page 744

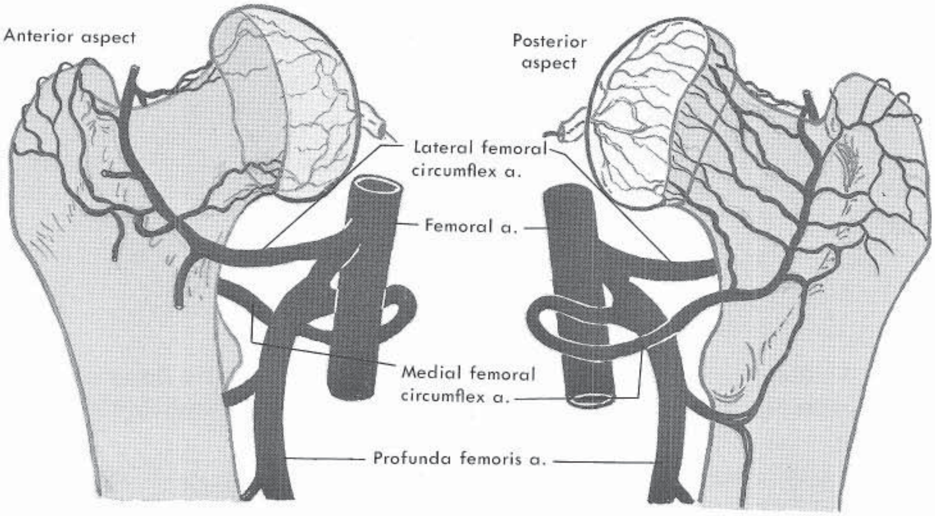
Scheme and Principles of the Dunn Procedure (Open Reduction of the Capital Epiphysis with Shortening of the Femoral Neck)

A, Schematic representation of the blood supply to the capital epiphysis. The predominant system is the medial circumflex artery and the lateral epiphyseal system, with a variable and relatively minor supply from the ligamentum teres and perforating metaphyseal vessels.

B, With posterior slipping of the capital epiphysis, the posterior periosteum is stripped away from the femoral neck, along with the epiphyseal blood supply. The vessels likely shorten in this position. The vessels may be damaged by any attempt to reduce the epiphysis (open or closed) with the vessels in this shortened condition.

C, By resecting the callus and posterior "beak" and carefully preserving the vessels from direct injury, the operator can reduce the epiphysis and fix it to the femoral neck without stretching the vessels.

PLATE 17–3. Scheme and Principles of the Dunn Procedure (Open Reduction of the Capital Epiphysis with Shortening of the Femoral Neck)



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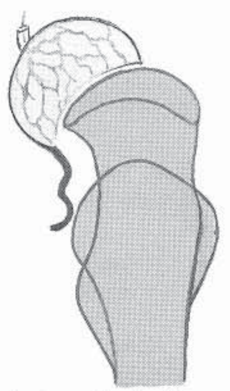
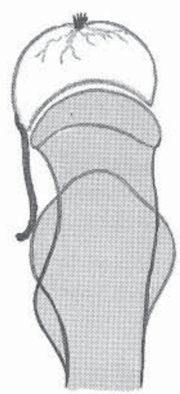
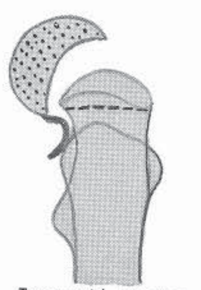


Acute on chronic slip. Retinacular vessels shorten after few days



Attempted closed reduction will stretch blood vessels. Only blood supply to head is from artery of lig. teres

B



Trapezoid osteotomy of neck

Neck shortened. Retinacular vessels relaxed

C

Technique of Kramer/Barmada Osteotomy of the Base of the Femoral Neck for Slipped Capital Femoral Epiphysis

A, With the hip joint opened, the degree of slip is assessed by inspection. Also, the amount of callus between the cartilage of the femoral head and the normal cortex of the femoral neck is determined. In general, the wedge of bone to be removed is two-thirds of the width of the callus as measured directly anteriorly. The inferior osteotomy line is made first, perpendicular to the femoral neck and following the anterior intertrochanteric line from above downward. The osteotomies extend posteriorly, leaving the posterior cortex intact. The vessels in the intertrochanteric fossa should be protected from injury.

Next, a threaded Steinmann pin is drilled into the proximal part of the femoral neck to control the upper fragment. The second, or upper, osteotomy line is made with the blade of the osteotome or saw directed obliquely and posteriorly.

B, The posterior cortex should be left intact. This will permit a greenstick fracture in the posterior cortex when the osteotomy site is closed.

C and **D,** Guide wires for cannulated screws are inserted through the outer cortex of the upper femoral shaft toward the osteotomy site. The osteotomy site is closed by medial rotation and abduction of the distal segment. The guide wires and the screws are then drilled into the femoral head.

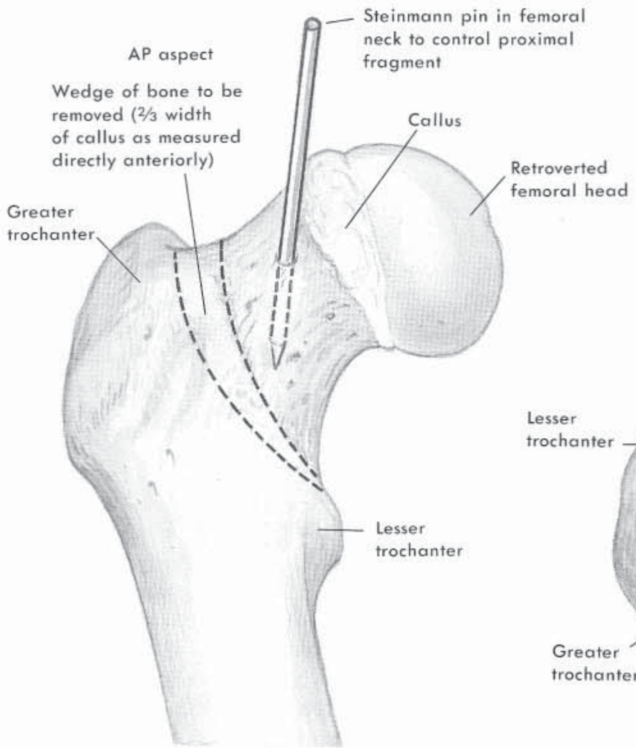
Kramer recommends apophyseodesis of the greater trochanteric growth plate to prevent overgrowth of the greater trochanter. This is done in a child who is relatively young, less than 14 years old for boys and less than 12 years old for girls.

Barmada has described a similar osteotomy, but rather than approaching the base of the femoral neck intracapsularly, the osteotomy site is prepared at the base of the femoral neck extracapsularly, stripping the anterior hip capsule superiorly as need for exposure. See text for further explanation.

POSTOPERATIVE CARE

The patient is allowed protected toe-touch weightbearing until healed.

PLATE 17–4. Technique of Kramer/Barmada Osteotomy of the Base of the Femoral Neck for Slipped Capital Femoral Epiphysis



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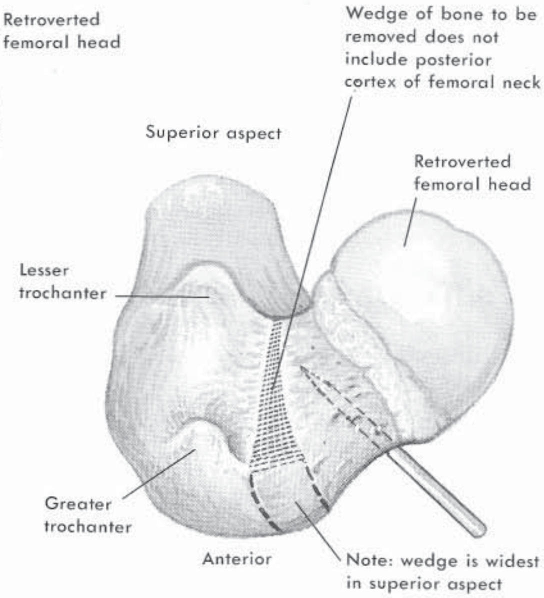

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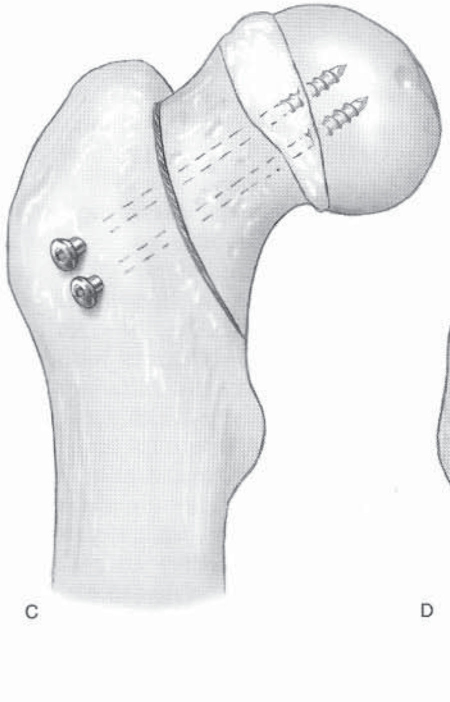

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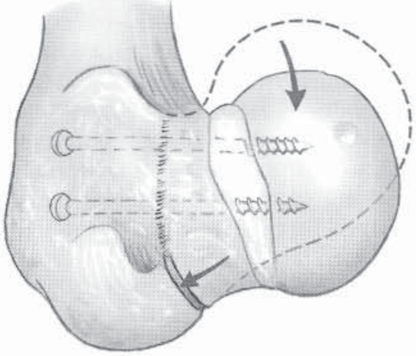


D

described the results of spica cast immobilization of 37 hips in 32 patients with acute-on-chronic or chronic SCFE.[23] These patients were treated with traction followed by spica cast immobilization for 8 to 16 weeks. Casts were removed when a metaphyseal-juxtaphyseal radiolucency disappeared on radiographs. In one hip the slip progressed after removal of the cast, five hips (19 percent) had chondrolysis, and no patient had AVN. The authors encountered no medical problems in the patients treated in a spica cast and recommended its consideration when discussing treatment alternatives with families. Interestingly, Hurley and colleagues found that only 7 percent of 30 hips treated in a spica cast for a slip subsequently developed a contralateral slip, while 36 percent of 169 hips treated surgically did so.[121]

On the other hand, Meier and colleagues noted complications in 14 of 17 hips managed with a spica cast for an average of 3 months.[184] These complications included three pressure sores, further slipping in three hips, and chondrolysis in nine hips. These results caused the authors to abandon this modality as definitive treatment for slipped epiphysis.

There is little indication for this modality in modern management. Because affected patients are frequently obese, nursing management becomes a monumental task. We feel that spica casting as definitive management for chronic SCFE should be reserved for the occasional desperate situation in which other treatment options are not feasible or have failed, and in which no other reasonable treatment alternative exists. Spica casting may occasionally be an option in very young patients or those with chronic renal failure whose medical management may improve their associated hyperparathyroidism promptly and in whom surgery is considered inadvisable.

Unstable Slipped Capital Femoral Epiphysis. Patients with an unstable SCFE present with sudden, severe, fracture-like pain in the affected hip and are unable to bear weight, even with crutches.[171] Usually, presentation to the surgeon is virtually immediate because of the severity of the pain. If there is a history of trauma, with or without prodromal symptoms of variable duration, the traumatic episode will generally be trivial relative to the severity of the patient's discomfort (such as minor falls or twisting movements). Radiographs demonstrate displacement of the capital epiphysis on the femoral neck suggestive of a Salter-Harris type I physeal fracture with or without remodeling changes in the femoral neck, depending on the duration of prodromal symptoms. In this section, we will use the terms acute and acute-on-chronic when citing literature that used these terms; the terminology is not specific with respect to the patient's ability to bear weight. The reported results must therefore be compared with some caution, because there may be some inherent differences in the patient populations reviewed.

Identification of a slip as unstable is important not so much for differences in treatment but rather for differences in the prognosis after treatment for unstable slips compared to stable slips. With the exception of the opportunity for closed reduction, either by preliminary traction or by manipulation under anesthesia, treatment modalities are essentially the same for unstable slips as for stable slips. It has long been recognized that the prognosis of an unstable slip is poorer, primarily owing to the markedly increased risk of developing AVN.*

The presence of an unstable SCFE provides the surgeon with an opportunity to correct the displacement by either closed or open reduction. Caution regarding the reduction of unstable slips has long been advised since some early studies suggested that reduction caused AVN.[116] However, Fahey and O'Brien reported favorable results in patients treated by gentle closed reduction and pin fixation, without AVN.[77] Controversy over the advisability of reduction continues. Loder and colleagues found that factors such as age, sex, race, obesity, side affected, duration of symptoms, severity of slip, amount of reduction, number of pins, or the use of preoperative traction did not influence the incidence of AVN.[171] Dietz reviewed the cases of 30 patients with acute or acute-on-chronic SCFE and found no difference in the rate of AVN when traction was used compared to closed reduction without traction.[66] All three patients with AVN were from a group with 14 unstable slips. Dietz concluded that preliminary longitudinal-medial rotational traction was safe but often ineffective in the management of acute SCFE.[66]

The importance of the amount of time between the onset of symptoms and reduction has been addressed in several studies. In the series reported by Loder and colleagues, hips treated more than 48 hours after admission had a lower rate of AVN than those treated within 48 hours of admission.[171] The authors were unable to explain this finding and so were also unable to recommend immediate reduction and internal fixation of unstable slips. A contradictary finding was reported by Peterson and colleagues, who, in a review of 91 unstable slips treated by different methods, noted that AVN developed in three (7 percent) of 42 hips treated by reduction within 24 hours of presentation, compared to 10 (20 percent) of 49 hips treated by reduction more than 24 hours after presentation.[210] Peterson and colleagues concluded that manipulative reduction was safe in the management of unstable SCFE and should be accomplished within 24 hours of presentation. Aadalen and colleagues noted no AVN in 50 patients treated within 24 hours of the acute onset of pain; overall, AVN developed in nine of the 50 patients.[1]

There is some debate as to how many cannulated screws are necessary when this method of fixation is selected. Studies in animal models suggest that single screw fixation is adequate for unstable slips.[18,141,146] Aronson and Carlson, in a clinical series of slips treated with a single cannulated screw, found that one of eight acute slips lost fixation.[10] Goodman and colleagues found no case of AVN, chondrolysis, or screw complications in 21 acute and acute-on-chronic slips treated with a single screw and no attempt at reduction.[94] Other groups have reported similar results.[250,267] We have noticed instances of rotation or distraction of the epiphysis during insertion of a single screw in cases of unstable slip. Therefore, we insert two guide wires and consider placing a second screw after insertion of the first.

Whether AVN is due to damage to the blood supply of the capital epiphysis caused by its acute displacement or by its replacement during reduction is also uncertain. Forcible closed and open reductions certainly provide an opportunity for iatrogenic disruption of the blood supply of the capital

*See references 1, 12, 34, 44, 64, 66, 77, 103, 145, 171, 176, 210, 219, 241.

epiphysis. However, recent work suggests that the acute displacement itself is more likely the cause of damage. Kallio and colleagues in a ultrasonographic study found that joint effusion was associated with unstable slips.[138] Three of 12 unstable hips studied by technetium bone scan on admission to the hospital were avascular initially, but in only one did the condition progress to AVN. These findings suggest that the original injury rather than the treatment caused the AVN.

In summary, we believe that the classification of SCFE into stable and unstable is clinically meaningful and should be preferred over the classification into acute, acute-on-chronic, or chronic slips. Unstable slips are characterized by the patient's inability to bear weight, intra-articular effusion, and epiphyseal instability on the femoral neck. Unstable slips are at much higher risk for a poor outcome after treatment, largely owing to the much higher risk of development of AVN. Clearly, open or forcible closed reduction may jeopardize the blood supply to the femoral head, but in the majority of cases, recent work strongly suggests that the damage to the blood supply occurs as a result of the acute displacement, not the treatment. Families must be informed of this increased risk. To reemphasize, because of the great prognostic implication of progression of a stable to an unstable slip, all physicians must be very aggressive in identifying patients with stable slips and in ensuring prompt, effective stabilization of the epiphysis to prevent instability from developing. We believe that patients with an unstable slip should be managed by prompt reduction under anesthesia and that this reduction should be no more vigorous than simple positioning of the patient's limb on the fracture table. Unstable slips should then be fixed with at least one cannulated screw placed in the center of the epiphysis, accepting whatever residual deformity is present after patient positioning. We prefer to insert two guide wires prior to drilling and tapping to prevent any risk of spinning or distracting the epiphysis on the neck during these procedures. A second screw may be inserted at the surgeon's preference to enhance stability if deemed necessary, but several studies suggest that fixation with a single well-placed cannulated screw is adequate for unstable slips.

Anterior and Valgus Slips. In the vast majority of cases of SCFE, the capital epiphysis is displaced primarily posteriorly and inferiorly relative to the femoral neck. In rare cases, the displacement is either superior and posterior (so-called "valgus" slip)[120,156,233] or, even more rarely, anterior.[70,140] The two patients with valgus slip reported by Segal and colleagues had increased femoral anteversion,[233] in contradistinction to the much more typical decreased anteversion or true retroversion seen in patients with typical SCFE. These unusual patterns have occurred both as acute and chronic slips.[70,120,140,156,233] Presumably, the direction of shear forces on a hip with a predisposed capital physis result in these unusual patterns of displacement.

The clinical picture of anterior or valgus slip is predictably both similar to and different from that of typical slips. First, like patients with typical slips, the patient with an anterior or valgus slip may present with either an unstable or a stable slip. Different from typical slips, however, is the restriction of motion noted on physical examination of stable anterior or valgus slips. In valgus slips there is a restriction of adduction as well as of flexion. In anterior slips there is a limitation of extension and external rotation—exactly the opposite of what is found in typical slips.

Radiographs of a patient with a valgus slip will show superior and/or lateral displacement of the capital epiphysis on the femoral neck on the AP projection and posterior displacement on the lateral projection. Anterior slips may appear little different from typical slips on the AP projection, but the anterior displacement of the capital epiphysis is identified on the lateral projection.

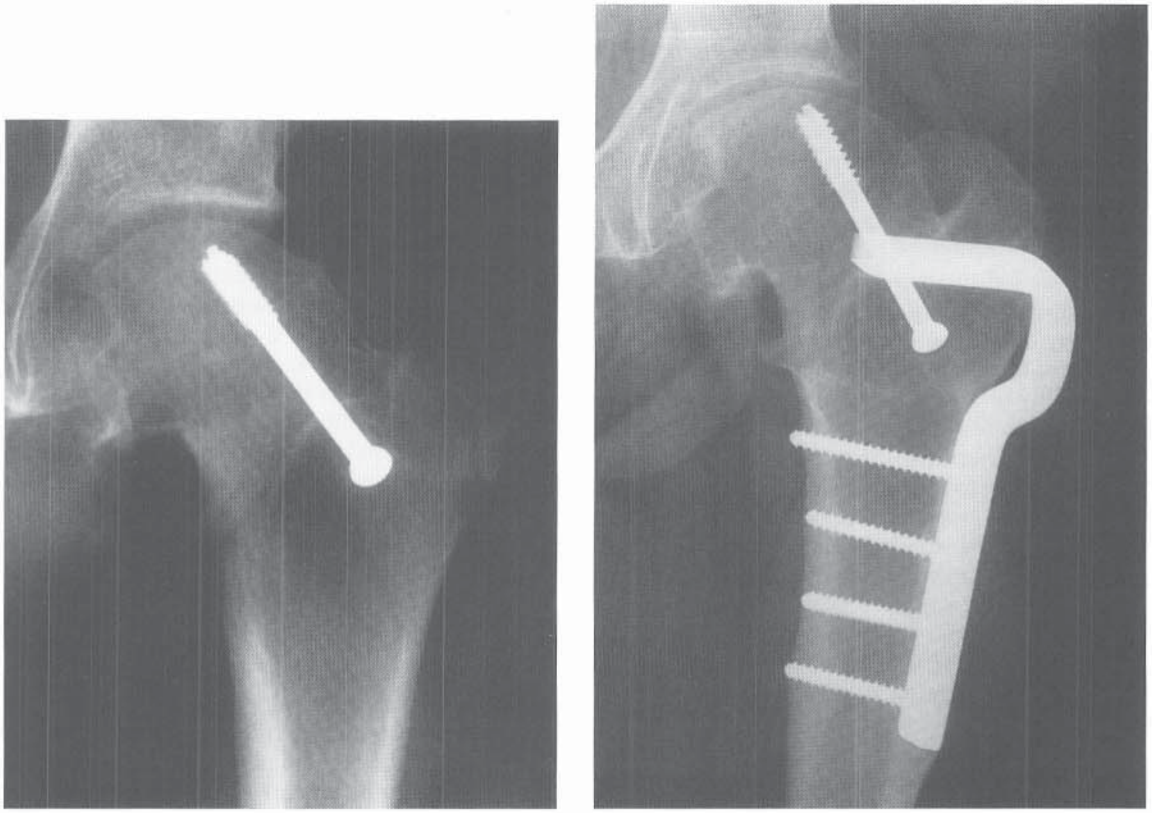
Treatment for valgus or anterior slips must be individualized. Successful pinning in situ has been described for both types of slip.[70,233] With valgus slip, the surgeon must be careful to protect the femoral neurovascular bundle. Segal and colleagues recommend a limited open approach for in situ pinning when the entry point for the guide wire is close to the neurovascular bundle.[233] Open bone graft epiphysiodesis seems a reasonable alternative approach if percutaneous pinning is inadvisable or unsuccessful.

RESIDUAL DEFORMITY AFTER CLOSURE OF THE PHYSIS

The need for correction of residual deformity after closure of the physis is the subject of some debate. Evidence that corrective osteotomy favorably influences the long-term prognosis for the development of osteoarthrosis is uncertain at best, even in the absence of postoperative complications, and several series suggest that no such favorable influence occurs.[34,43,131,181] Nevertheless, some patients, because of the severity of their residual deformity at skeletal maturity and the nature of their activities, will be dissatisfied with or impeded by their arc of motion. The most common complaints are of excessive external rotation, limitation of flexion, a Trendelenburg lurch, or a combination of these. Intracapsular osteotomies are specifically *not* indicated after closure of the capital physis, since such procedures are virtually certain to result in AVN. One option is the intertrochanteric osteotomy of Southwick and Imhauser, described in the previous section, although the treating surgeon must recognize the difficulties with total joint arthroplasty that may subsequently arise because of the deformity created by the osteotomy (Fig. 17–15). Another option is osteoplasty of the femoral neck and head as originally described by Heyman and colleagues (Fig. 17–16)[117] and subsequently reviewed by others.[113,255,279] This procedure has been described as an independent procedure,[117] in conjunction with open epiphysiodesis,[113,255] or performed simultaneously with intertrochanteric osteotomy.[279] We believe that this procedure is only very rarely indicated, and only in patients with a significant restriction of motion (usually flexion) clearly documented to be due to this protrusion with a closed physis in whom intertrochanteric osteotomy will not restore an adequate arc of motion. The procedure should *not* be performed as an isolated procedure without fixation of the capital epiphysis to the femoral neck prior to skeletal maturity, as there is a risk of further displacement of the epiphysis.

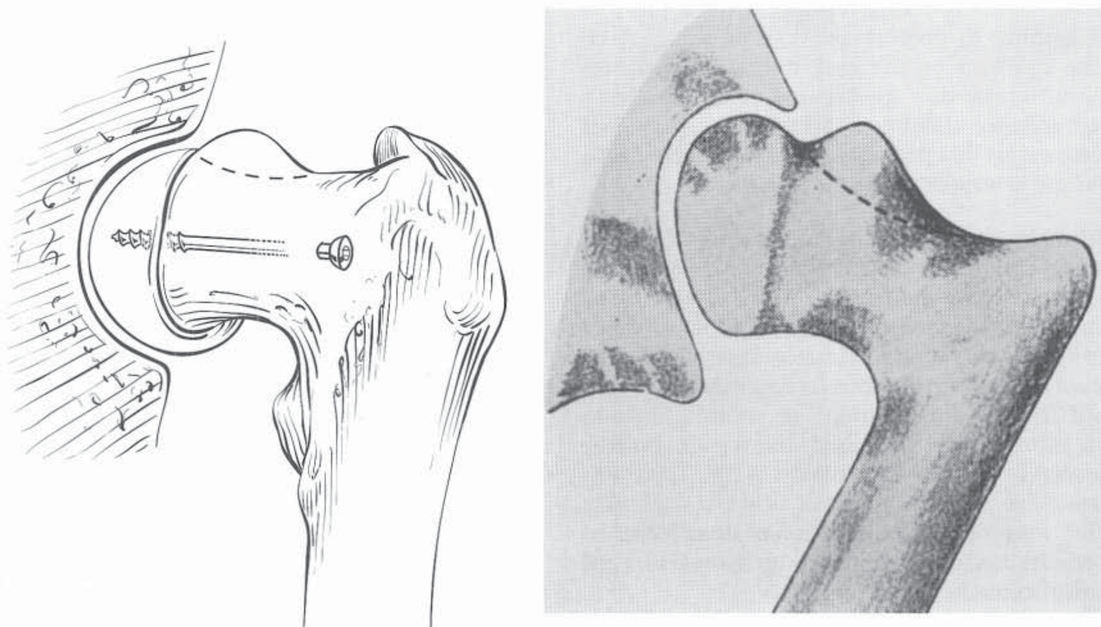
PROPHYLACTIC TREATMENT OF THE CONTRALATERAL HIP

The advisability of treating the contralateral hip on a prophylactic basis in a patient presenting with unilateral SCFE is



A B

FIGURE 17–15 Intertrochanteric repositioning osteotomy performed for complaints of restricted flexion and internal rotation after in situ fusion. **A,** Before intertrochanteric osteotomy. **B,** After intertrochanteric osteotomy. The patient was pleased with the more functional position of the hip arc of motion, with increased flexion and internal rotation.



A B

FIGURE 17–16 Osteoplasty of the femoral neck as described by Heyman and Herndon.[117] **A,** The "bump" of the anterior femoral neck, limiting hip flexion. **B,** The procedure, as originally diagrammed by Vulpius and Stöffel and published by Heyman and Herndon, may be done in conjunction with fixation of the epiphysis (usually epiphysiodesis) or independently, after closure of the physis. (Part B from Heyman CH, Herndon CH, Strong JM: Slipped femoral epiphysis with severe displacement: a conservative operative treatment. J Bone Joint Surg 1957;39-A[2]:302. Originally from Vulpius and Stöffel: Orthopädische Operationshlehre 1913, p 382.)

a source of constant debate.* Approximately 20 percent of patients with typical SCFE will present with bilateral involvement, and in an additional 20 percent or so a symptomatic contralateral slip will subsequently develop.[128,129,168] Long-term studies suggest an even higher incidence of unrecognized contralateral slip.[93,100,128] Many of the patients may be asymptomatic.[128,129] Hurley and colleagues found that whereas a contralateral slip developed in 37 percent of patients who underwent surgical treatment for unilateral SCFE, it did so in only 7 percent of patients treated in a spica cast.[121]

The prevalence of contralateral slip, even in an asymptomatic patient, has led many authors to recommend prophylactic pinning.[100,155,207,224] All authors agree that acute displacement of the capital epiphysis should not be allowed to occur. Proponents of routine prophylactic pinning with a single cannulated screw argue that this technique is sufficiently free of complications that pinning of the contralateral hip should be undertaken, as the patient is already undergoing a surgical procedure.[100,155]

On the other hand, it is also clear that true unilateral SCFE occurs in up to 65 percent of cases without the other hip ever being involved, even on long-term follow-up.[93,128,129] Therefore, routine prophylactic pinning without a doubt results in at least one surgical procedure on hips that never required one. Jerre and colleagues evaluated 61 patients treated for unilateral SCFE at an average of 46 years after initial presentation.[129] In 36 patients a contralateral slip never developed, whereas 25 had evidence of contralateral slip either at the initial presentation or subsequently; only two of these 25 patients were symptomatic. Osteoarthrosis was evident in seven of 36 hips without slip, in five of 16 with untreated slip, and in one of nine hips treated with in situ pinning. These authors estimated that prophylactic in situ pinning would have been unnecessary in 59 percent of these patients, and they recommended observation with serial radiographs to skeletal maturity rather than prophylactic pinning.

Some cases clearly warrant at least strong consideration of contralateral prophylactic pinning. Because the prevalence of bilateral slips is 95 percent in patients with chronic renal insufficiency,[169] these patients should have both hips treated appropriately (see previous discussion under Endocrine Factors in the Etiology of Slipped Capital Femoral Epiphysis). Patients with endocrinopathy-related SCFE also have a relatively high frequency of bilateral slips (61 percent in the review by Loder and colleagues[164]), and strong consideration should be given to prophylactic pinning of the contralateral side in these patients as well. At a minimum, regular radiographic assessment and strong parental vigilance for the development of symptoms and prompt reporting of the same to the surgeon are required.

Younger patients should also be considered for bilateral pinning because they have a higher likelihood of contralateral slip. In Loder's report on the epidemiology of bilateral slips, patients who presented with a unilateral SCFE and in whom a slip of the contralateral side subsequently developed were on average 1 year younger than patients with a unilateral slip in whom a contralateral slip did not develop (12 versus 13 years).[168] Stasikelis and colleagues found in a prospective study of 50 patients with a unilateral slip that chronological age was a predictor for the development of contralateral slip in boys but not in girls.[246] Specifically, all boys younger than 11 years 7 months at diagnosis of the first slip developed a contralateral slip, nine of 22 boys between the ages of 11 years 8 months and 14 years 11 months did so, and no male 15 or older at the time of diagnosis of the first hip developed contralateral involvement. These authors further found that a modified Oxford bone age score[3] of the pelvis was highly predictive of the development of a contralateral slip. In their study, contralateral slip developed in 85 percent of patients with a score of 16, in 11 percent of patients with a score of 21, and in no patient with a score of 22 or more. The scheme of the modified Oxford bone age is outlined in Figure 17–17.

If prophylactic pinning is not carried out in the contralateral hip of a patient presenting with unilateral SCFE, the patient and parents must be carefully warned of the potential risk of development of a slip on the contralateral side and instructed to report immediately the development of any lower extremity symptoms in the contralateral limb. In addition, the contralateral limb should be assessed with lateral radiographs at least every 6 months in the absence of symptoms. Most contralateral slips develop within 6 months of presentation of the index hip: in the series of bilateral slips reported by Loder and colleagues, 88 percent had manifested within 18 months of presentation of the index hip.[168] However, monitoring for the development of slip in the contralateral hip must continue until skeletal maturity.

Complications

Two complications, chondrolysis and AVN, are specifically associated with SCFE. One unique aspect of these complications is that either may occur spontaneously or may be related to treatment.

CHONDROLYSIS

Chrondrolysis (also occasionally referred to as "acute cartilage necrosis") as a complication of SCFE was first described by Elmslie in 1913.[75] Waldenström, in 1930, established chondrolysis as a definite pathologic entity distinct from AVN.[264] Chondrolysis has subsequently been described and discussed by many authors.*

Clinical Presentation. Patients with chondrolysis present with complaints of stiffness and persistent pain in the groin or upper thigh. On examination the hip is usually held in flexion, abduction, and external rotation and there is substantial reduction in the arc of motion of the hip in all planes. There is usually pain with movement of the hip. Walking and other activities are adversely affected by the hip stiffness.

Radiographically, there is loss of joint space. The radiographic criterion for the diagnosis is loss of more than 50 percent of the joint space compared to the unaffected contralateral side, or an absolute measurement of 3 mm or less.

*See references 41, 100, 101, 121, 128, 129, 149, 155, 168, 212, 224, 235, 246.

*See references 1, 9, 11, 13, 22, 27, 29, 54, 59, 73, 74, 86, 91, 106, 111, 123, 144, 150, 175, 176, 178, 184, 193, 194, 236, 239, 249, 250, 259, 262, 264, 266, 270, 278, 288.

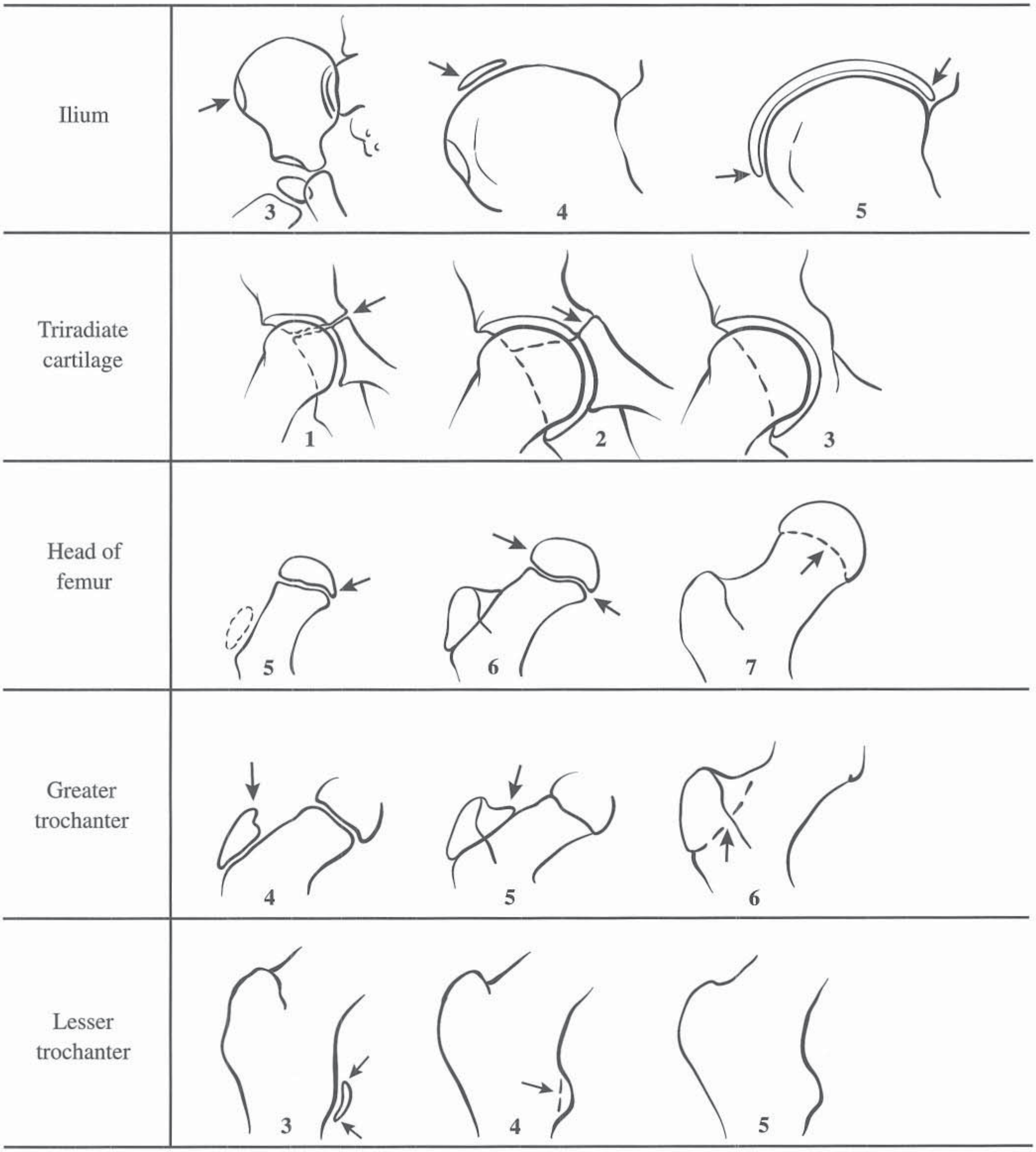


FIGURE 17–17 Modified Oxford bone age of the pelvis as described by Stasikelis and colleagues.[246] In Stasikelis' series, 85 percent of patients with a score of 16 developed contralateral slip, whereas no child with a score of 22 or more developed a contralateral slip.

Between the characteristic clinical picture of pain and stiffness and the radiographic feature of loss of cartilage space, the diagnosis is usually not difficult to make (Fig. 17–18). A technetium bone scan will show increased uptake in an affected joint space, but this investigation is seldom necessary to make the diagnosis.

Epidemiology. The incidence of chondrolysis in SCFE has been reported to be as low as 1.5 percent in a series of patients treated by percutaneous in situ pinning[144] to over 50 percent in a series of patients treated with a spica cast.[184] Females are more likely to be affected than males. Chondrolysis can occur spontaneously, without treatment of the

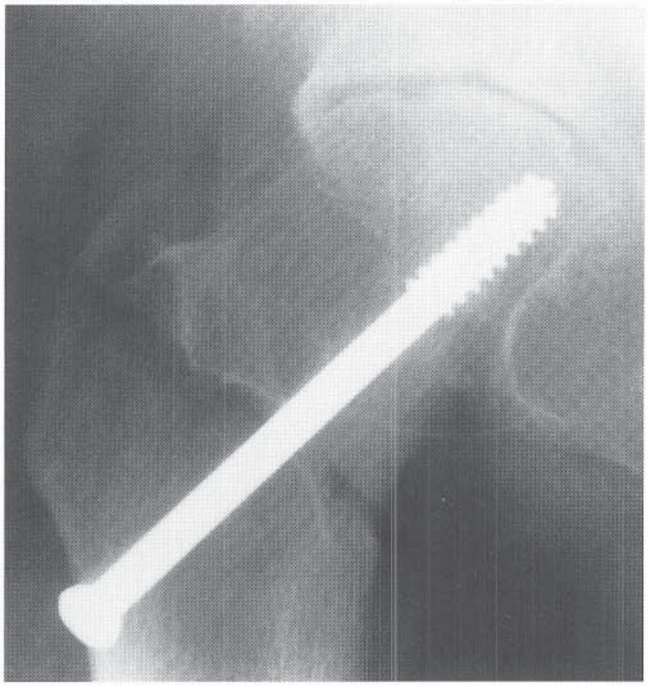


FIGURE 17–18 AP radiograph of a patient with chondrolysis of the hip. Generalized osteopenia and narrowing of the cartilage space are present. Clinically, the patient had stiffness and pain.

slip, or may become evident when the patient first presents with SCFE. It is reported to occur in conjunction with any type of treatment for slip, but it is particularly associated with pin penetration of the joint and with intertrochanteric osteotomy.

Initial reports regarding chondrolysis[22,59] and some clinical series[111,123,204,262] suggested that black patients were more likely to develop chondrolysis than persons of other races; however, other larger and more recent investigations have not found that to be true.[11,13,144,239]

Etiology. The precise etiology of chondrolysis is not known. Waldenström[264] and later Cruess[59] proposed that it is caused by failure of nutrition of articular cartilage due to a paucity or complete lack of synovial fluid production. Eisenstein's group, in a prospective study of 34 patients with slips, found that all patients had significant elevations in serum immunoglobulins and C3 component of complement but the nine patients with chondrolysis had a greater elevation in the IgM fraction as well.[73,179] The authors felt that SCFE could produce an antigen that induces an autoimmune state, and that a genetically determined subgroup of patients might develop chondrolysis. Subsequently, Morrissy and colleagues also demonstrated that the immune system is activated in some patients with SCFE, including patients in whom chondrolysis developed, but they could not establish the precise relationship between the immune system activation and SCFE or chondrolysis.[193,194]

Walters and Simon were the first to point out the important association of metallic implant penetration into the cartilage space of the hip joint and chondrolysis.[266] These authors noted that the correlation between pin penetration and chondrolysis is not complete: some patients with pin penetration did not develop chondrolysis. Walters and Simon thought the incomplete correlation might be due to an even higher frequency of pin penetration than their calculations predicted. Stambough and colleagues suggested that even transient penetration of the hip joint by either a guide wire or the implant itself might lead to chondrolysis, presumably by initiating an autoimmune response to cartilage fragments within the joint space.[240] However, other authors have documented transient intraoperative joint penetration in clinical series without the subsequent development of chondrolysis.[150,262,288] Even more confusing, perhaps, is that some authors have noted no direct association between chondrolysis and obvious penetration of the joint space.[22,95,102] In experimental investigations, Aprin and colleagues found cartilage changes after transient penetration of the hip joint, although not as severe as when the pins were left in place.[9] On the other hand, Sternlicht and colleagues were unable to produce chondrolysis by joint penetration alone in another experimental model.[249]

Pathology. The anatomic findings vary with the stage of the disease in its natural history.[59,111,119,23] The initial findings are those of a nonspecific inflammatory process: the synovium is thickened, with large, boggy, villous projections; later, the synovial membrane undergoes fibrotic changes. The capsule is thickened. The initial gross appearance of the articular cartilage is normal; however, as the disease progresses the articular surface becomes thin, attenuated, and soft. The articular cartilage of both the femoral head and the acetabulum is affected. True pannus formation is not seen. With progression of the disease, granulation tissue gradually invades the articular surfaces and fibrous adhesions form between the capsule, acetabulum, and femoral head. In the chronic stage the articular cartilage may be almost completely destroyed, exposing raw bone in the femoral head and acetabulum.

Histologic sections in the initial stage show the synovium to be hypertrophied and hypervascular with perivascular infiltration with round cells consisting of plasma and lymphoid elements. With progression of the chondrolytic process the synovium is gradually replaced by fibrous tissue, and the amount of functioning synovium is progressively diminished.

Degenerative arthritic changes with spurs of the joint margin and narrowing or near obliteration of the joint space develop later on in life.

Natural History. The patient initially presents with pain and restriction of joint motion and radiographic joint space narrowing. Typically, symptoms develop between 6 weeks and 4 months after treatment, but occasionally they are present on the initial presentation for evaluation of a slip. Progressive joint space narrowing occurs, with the maximum reduction in joint space usually reached within 6 to 12 months of onset. The joint space may then reconstitute to a variable extent, with improvement in the joint space noted as long as 3 years after the onset of chondrolysis.

The extent to which joint space narrowing and range of motion recover varies. Lowe reported recovery of range of motion clinically and joint space radiographically in six patients with chondrolysis.[175] Heppenstall and colleagues reported that of 17 patients with chondrolysis, only four hips had some restoration of joint space radiographically, while three required hip fusion and one a cup arthroplasty for continued pain and restricted joint motion.[111] Tudisco and colleagues evaluated nine patients with chondrolysis. Resolution of the acute phase occurred an average of 10 months after onset.[259] Seven to 19 years after onset of chondrolysis, five patients had mild hip pain after prolonged activity and one (with associated AVN) had severe pain. All patients had some restriction of hip motion, which was judged to be severe in two. The authors concluded that the overall prognosis was benign and was determined by the degree of slip. Vrettos and Hoffman found in a group of 15 patients with chondrolysis that maximum joint space narrowing developed within the first year afer onset of chondrolysis, improvement in joint space and range of movement continued for up to 3 years afterward, and on follow-up averaging 13 years no patient had pain, but five hips had restricted range of motion.[262] The long-term study of Carney and colleagues found that chondrolysis was more frequent in severe slips and those treated by osteotomy or cast.[43] There was significant clinical and radiographic deterioration in the function of hips with chondrolysis over time.

Treatment. Treatment for chondrolysis has historically been nonspecific and supportive. The surgeon must be assured that there is no evidence of infection or of implant penetration into the joint space. Aspiration of the hip may be necessary to rule out a low-grade infection. CT of the hip may be necessary to confirm that no implant encroachment is present. If pin penetration has occurred, the implant must be removed or replaced if the physis is not fused.

Supportive care includes modification of activities, use of crutches, gentle range-of-motion exercises to maintain motion, and anti-inflammatory medications. More aggressive traction or surgical treatment, including muscle releases or capsulotomy, have been described for idiopathic chondrolysis, but the efficacy of these treatments is not established. Patients who do not recover adequate range of motion or who have severe continued pain may require arthrodesis or total joint arthroplasty.

AVASCULAR NECROSIS

The most severe complication associated with SCFE is the development of AVN of the epiphysis.* Many early authors did not distinguish between AVN and chondrolysis.[133] According to Howorth,[119] Fragenheim[85] was the first to note AVN in association with SCFE, although he did not name it. Axhausen in 1924 used the term "aseptic necrosis" to describe this condition after femoral neck fracture in a child. Moore in 1945 described the pathologic appearance of two specimens of AVN after slip obtained at surgery.[188] That this complication can occur without treatment has been noted since at least 1945[189] and has been repeatedly noted subsequently as a consequence of acute displacement (unstable slip).† AVN is described most frequently in treated cases of SCFE, particularly after closed or open reduction of unstable slips or osteotomy of the femoral neck.[49,87] It has occurred in rare instances after intertrochanteric osteotomy.[181,185,226]

*See references 1, 34, 37, 49, 66, 83, 87, 103, 112, 119, 138, 144, 151, 154, 171, 174, 176, 181, 185, 208, 210, 219, 226, 239, 250, 265.

†See references 1, 34, 66, 103, 171, 176, 210, 219.

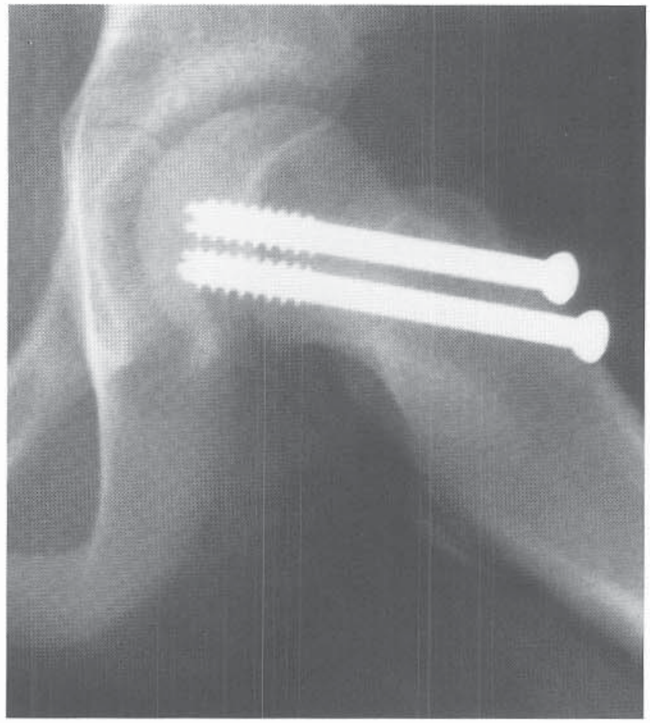
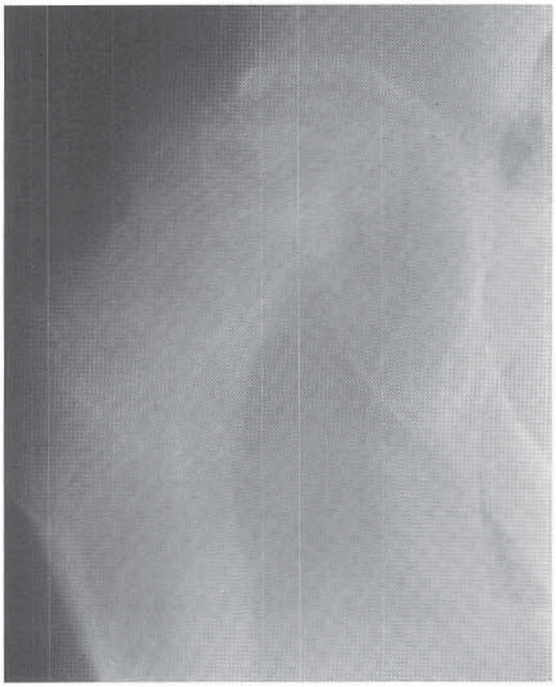


FIGURE 17–19 Early radiographic appearance of AVN of the capital epiphysis. The patient had developed an unstable slip after a fall. The slip was treated by gentle intraoperative (incidental) reduction and fixation with two cannulated screws.

The incidence of AVN is lowest after open epiphysiodesis[272,273] or in situ pinning of stable slips.*

Pathophysiologically, in some way the blood supply to the femoral head is interrupted, leading to devascularization of all or a portion of the femoral capital epiphysis, with subsequent resorption of the necrotic bone. The condition is unlike Legg-Calvé-Perthes disease in that there is a single vascular insult and much less restorative capacity than is typical in Legg-Calvé-Perthes disease. The blood supply to the capital epiphysis in the age group affected by SCFE is primarily via vessels arising from the lateral epiphyseal system entering the epiphysis at its outer posterior margin. The ligamentum teres supplies the epiphysis as well, and in late adolescence, metaphyseal vessels that pierce the physis reappear.[258] The lateral epiphyseal arterial system may be damaged directly by tearing of the periosteum during acute displacement of the epiphysis, as occurs in unstable slips; during forcible attempts at reduction that tear the posterior periosteum; and during intra-articular surgery, as a result of direct injury to the periosteum or indirectly, by tearing of the periosteum with manipulation of the capital epiphysis. Intra-articular tamponade by traumatic effusion associated with acute displacement could theoretically cause loss of blood supply indirectly, although this mechanism has not been substantiated. Likewise, the value of evacuating an intra-articular effusion in the prevention of AVN has not been proved. In addition, multiple pins in the superior posterior quadrant of the femoral head have been thought to pose a risk of injury to the intraepiphyseal blood supply and may produce segmental AVN.[37]

*See references 10, 13, 21, 64, 89, 94, 132, 224, 250, 267.



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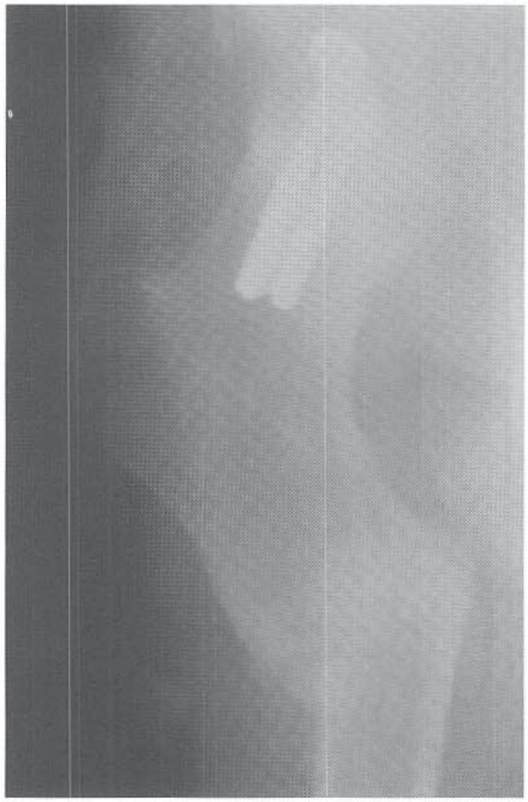

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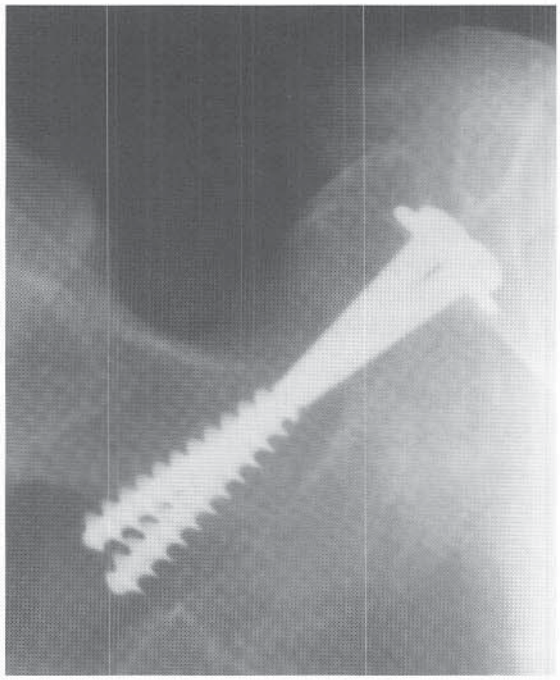
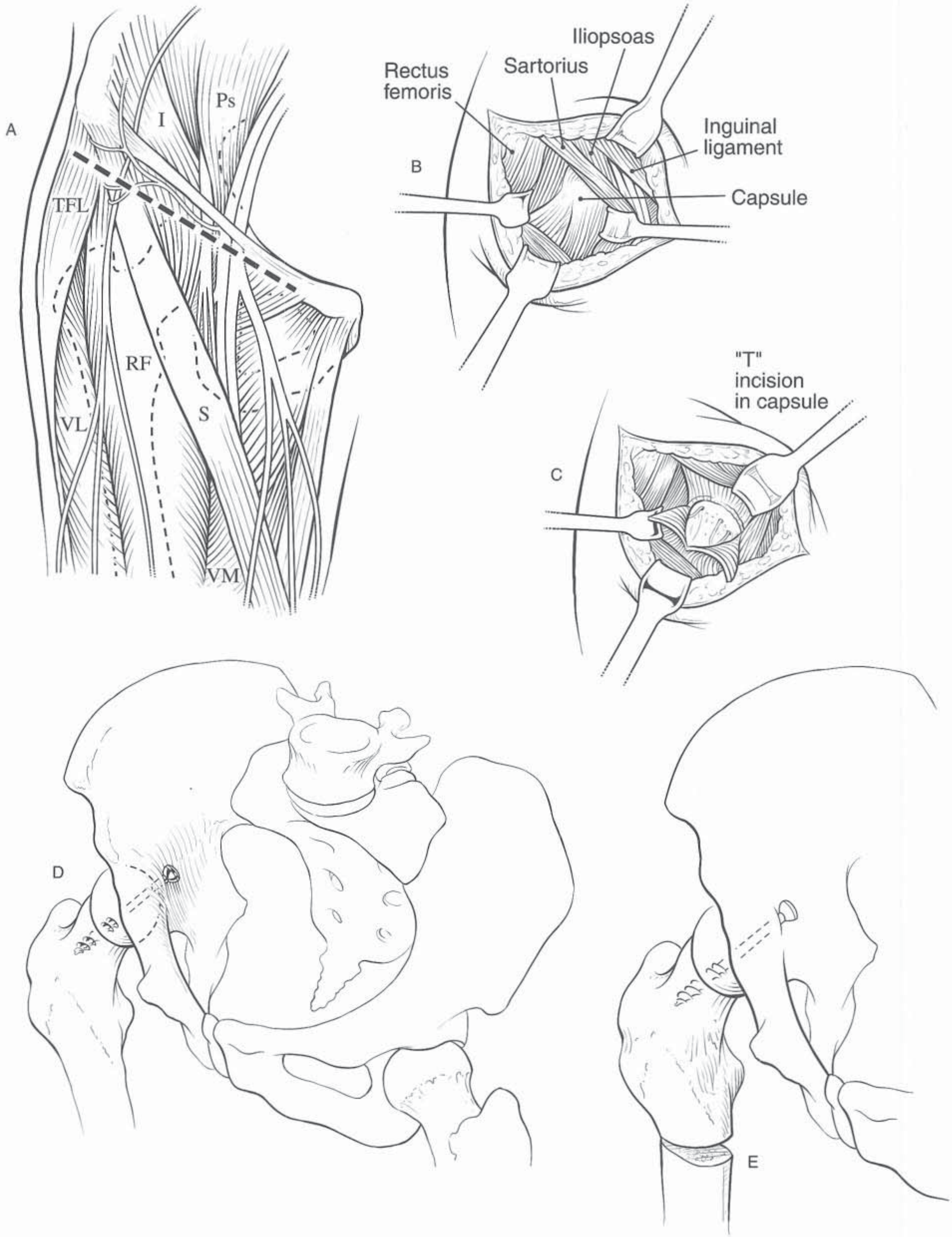


C

FIGURE 17–24 Hip fusion after the development of AVN in a patient with an unstable slipped epiphysis. **A,** Preoperative radiograph of the right hip demonstrating segmental collapse 2 years after treatment for an unstable slipped epiphysis. **B,** AP postoperative radiograph of the same patient after intra-articular hip fusion with internal fixation and intertrochanteric osteotomy to reposition the lower limb. The pain has resolved, but the patient has all the difficulties with activities of daily living associated with hip fusion. **C,** Postoperative lateral view demonstrating placement of screws.

of 41 years after the onset of symptoms.[43] Forty-two percent of the slips were mild, 32 percent were moderate, and 26 percent were severe. Both the Iowa hip rating score and the radiographic score[34] worsened with increasing severity of the slip and when reduction or realignment had been done. AVN and chondrolysis were more likely with increased slip severity or when osteotomy had been done, and led to poor long-term results. Pinning in situ provided the best long-term results, irrespective of the severity of the slip. There was a deterioration in the radiographic appearance and func-

PLATE 17–5. Technique of Intra-articular Hip Fusion for Avascular Necrosis



quence of the disorder or as a consequence of its treatment. Finally, any of the described osteotomies performed to improve the anatomic relationship of the proximal femoral head, neck, and shaft carry varied but significant risks for AVN or chondrolysis. Evidence that these osteotomies, even in the absence of postsurgical complications, specifically alter the natural history of SCFE with respect to the development of osteoarthrosis is currently lacking.

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