

EVIDENCE SUMMARY

Avascular necrosis of the femoral head

ETIOLOGY AND PATHOPHYSIOLOGY

- AVN of the femoral head in children is thought to result from disruption or compromise of the blood supply at the time of initial trauma, specifically displacement of the fracture [2].
- AVN of the femoral head in children is potentially caused by the tamponade effect of hip hemarthrosis [2].
- Type I AVN results from interruption of the lateral epiphyseal and metaphyseal vessels [2].
- Type II AVN is usually caused by interruption of the lateral epiphyseal vessels before entrance into the epiphysis [2].

RISK FACTORS

- Fracture displacement is the most important risk factor for AVN in children [2].
- The presence of a type I or II fracture is a risk factor for AVN in children [2].
- A fracture in an older child (>12 years) is a risk factor for AVN in children [2].

INCIDENCE

- Historically, the incidence of AVN has been reported to be 100%, 50%, 25%, and 15% for types I, II, III, and IV fractures, respectively [2].
- The historical overall incidence of AVN in pediatric hip fractures was reported as 43% [2].
- In a more recent literature review, the incidence of AVN was reported as 38%, 28%, 18%, and 5% for types I, II, III, and IV fractures, respectively [2].
- The overall rate of AVN in a more recent literature review was 29% [2].

CLINICAL PRESENTATION AND DIAGNOSIS

- Symptoms of AVN may occur early with complaints of groin pain [2].
- Radiographic evidence of AVN can be seen as early as 2 months after injury [2].
- Radiographic evidence of AVN is generally present within 1 year of injury [2].
- The median time to presentation of AVN is 7.8 months [2].
- Radiographs may demonstrate osteopenia of the femoral head, followed later by sclerosis, fragmentation, and often collapse and deformity [2].

- MRI is the most sensitive test to confirm the diagnosis of AVN [2].
- MRI defines the extent of femoral head and neck involvement in AVN [2].
- Radioisotope scanning shows decreased uptake in the femoral head or neck (or both) in AVN [2].
- Radioisotope scanning is useful in a hip that has stainless steel internal fixation [2].

PATTERNS OF AVN

- Type I AVN is characterized by severe diffuse necrosis totally involving the femoral head and the proximal fragment of the femoral neck [2].
- Type I AVN is accompanied by various degrees of collapse of the femoral head, from segmental necrosis with minimal collapse to diffuse complete collapse with subluxation [2].
- Type I AVN is the most common pattern of AVN, accounting for more than 50% of cases [2].
- Type I AVN has the worst prognosis [2].
- Type II AVN is characterized by more localized necrotic changes, often in the anterosuperior aspect of the femoral head, with little collapse [2].
- Type II AVN is seen in approximately 25% of cases [2].
- Type II AVN has a better prognosis than type I AVN [2].
- Type III AVN is characterized by sclerosis from the fracture line of the femoral neck to the physis, with sparing of the femoral head [2].
- Type III AVN accounts for 25% of cases of AVN [2].
- Type III AVN has the best results [2].

TREATMENT AND PROGNOSIS

- AVN after hip fractures in children results in poor outcomes in up to 60% of cases [2].
- Treatment of AVN after hip fractures in children has been relatively unsuccessful [2].
- Some investigators have suggested that treatment does not affect the natural history of AVN after hip fractures in children [2].
- The goals of treatment for AVN are to preserve the functional range of hip motion, maintain containment of the femoral head within the acetabulum, and preserve as much femoral head viability as possible [2].
- Treatment of AVN should begin at the onset of symptoms and entail partial weight bearing or non-weight bearing until painful symptoms resolve [2].
- Operative treatment of AVN after hip fractures in children has resulted in poor outcomes principally because of selection bias, with the most severe cases undergoing operative treatment [2].
- When AVN is first recognized and the fracture has healed, the initial step is removal of internal fixation devices to prevent penetration of the hardware into the joint [2].
- Further operative treatment options for AVN include intertrochanteric osteotomy (usually valgus) to place viable head in the weight-bearing zone, capsulotomy, and arthrodesis [2].

- Partial weight bearing or non-weight bearing of the involved extremity is recommended at the first signs and symptoms of AVN until revascularization is complete and painful symptoms have resolved [2].

Anatomy & Pathophysiology

VASCULAR ANATOMY

- The primary blood supply to the femoral head in adults derives from the cervical arteries, which originate from the extracapsular ring at the base of the femoral neck [30].
- The extracapsular arterial ring is formed by contributions from the medial femoral circumflex artery (MFCA) posteriorly and the lateral femoral circumflex artery (LFCA) anteriorly [30].
- The superior and posterior vessels derived primarily from the MFCA constitute the dominant blood supply to the femoral head [30].
- The MFCA supplies the inferior retinacular branch, which runs along the ligament of Weitbrecht and supplies the inferior medial portion of the femoral head [30].
- A minor contribution to the femoral head vasculature arises from the foveal artery, a branch of the obturator artery located within the ligamentum teres [30].
- The foveal artery makes a significant contribution to the epiphyseal portion of the femoral head vasculature in approximately 75% of hips [30].
- In newborns, the main source of femoral head blood supply is derived from vessels arising from the medial and lateral circumflex femoral arteries [27].
- In 79% of cases, the medial and lateral circumflex femoral arteries are branches of the profunda femoris [27].
- At approximately 3 years of age, the lateral circumflex artery regresses, and branches of the medial circumflex femoral artery become the main blood supply of the femoral epiphysis and proximal femoral physeal plate [27].
- The deep branch of the medial femoral circumflex artery is the most important source of femoral head blood supply [27].
- The deep branch of the MFCA gives off the inferior retinacular artery, which runs toward the femoral head in the ligament of Weitbrecht [27].
- The main terminal branch of the deep MFCA, often referred to as the superior retinacular artery, divides into two to four terminal branches that course within the retinacula of Weitbrecht [27].
- The superior retinacular arteries perforate the bone at a distance 2 to 4 mm lateral to the bone–cartilage junction of the head [27].
- The superior retinacular vessels are the main supply of the weight-bearing area of the femoral head [27].
- The lateral group of retinacular vessels is the largest contributor to femoral head blood supply [27].
- A cadaveric MRI study estimated the contribution of the MFCA to femoral head perfusion at 82% and that of the LFCA at 18% [27].

- In children with slipped capital femoral epiphysis (SCFE), the blood supply to the capital epiphysis is primarily by vessels arising from the lateral epiphyseal system entering the epiphysis at its outer posterior margin [41].
- The ligamentum teres supplies the epiphysis in children with SCFE, and in late adolescence, metaphyseal vessels that pierce the physis reappear [41].

PATHOGENIC MECHANISMS

- Osteonecrosis of the femoral head is a progressive disease that generally affects patients in the third through fifth decades of life [6].
- The term “osteonecrosis” is preferred over “avascular necrosis” and is defined as “dead bone” resulting from a loss of circulation [6].
- Risk factors for osteonecrosis include trauma, corticosteroid use, alcohol abuse, smoking, hemoglobinopathies, coagulation disorders, myeloproliferative disorders, hyperbaric decompression, hyperlipidemias, chronic kidney disease, autoimmune diseases, and HIV infection [6].
- Pathogenic mechanisms for osteonecrosis include ischemia from vascular disruption, vascular compression or constriction, and intravascular occlusion [43].
- Vascular compression or constriction can result from increased intraosseous pressure caused by marrow fatty infiltration, corticosteroids, alcohol, or vasoconstriction of arteries perfusing the femoral head [43].
- Intravascular occlusion mechanisms include thrombosis due to thrombophilia (low protein C and S, activated protein C resistance, factor V mutation, high homocysteine, eNOS polymorphisms) and hypofibrinolysis (high PAI activity, PAI-1 polymorphisms, high lipoprotein(a)) [43].
- Intravascular occlusion can also result from embolization of fat or air and sickle cell occlusion [43].
- Direct cellular toxicity from pharmacologic agents, irradiation, and oxidative stress is a proposed pathogenic mechanism for osteonecrosis [43].
- Altered differentiation of mesenchymal stem cells, potentially influenced by corticosteroids and alcohol, is a proposed pathogenic mechanism for osteonecrosis [43].
- In post-traumatic AVN following hip dislocation, the cervical vessels to the head are not normally disrupted by the dislocation but fail to provide adequate circulation due to spasm of larger vessels or the cervical vessels themselves [49].
- The majority of AVN following hip dislocation is secondary to initial ischemia of the femoral head rather than torn vessels [49].
- In pediatric hip fractures, AVN is thought to result from disruption or compromise of the blood supply at the time of initial trauma and potentially from the tamponade effect of hip hemarthrosis [2].
- In SCFE, the lateral epiphyseal arteriolar system may be damaged by tearing of the periosteum during acute displacement, forcible reduction attempts, or intraarticular surgery [41].
- Intraarticular tamponade by traumatic effusion associated with acute displacement in SCFE could theoretically cause loss of blood supply indirectly, although this mechanism has not been substantiated [41].

- Multiple pins in the superior posterior quadrant of the femoral head may pose a risk of injury to the intraepiphyseal blood supply, producing segmental AVN [41].

RADIOGRAPHIC AND IMAGING PATHOPHYSIOLOGY

- The earliest radiographic sign of AVN in pediatric hip fractures is osteopenia of the femoral head, followed later by sclerosis, fragmentation, and often collapse and deformity [2].
- Radiographic evidence of AVN in pediatric hip fractures can be seen as early as 2 months after injury and is generally present within 1 year [2].
- MRI is the most sensitive test to confirm the diagnosis of AVN in pediatric hip fractures and defines the extent of femoral head and neck involvement [2].
- Radioisotope scanning shows decreased uptake in the femoral head or neck in AVN and is useful in hips with stainless steel internal fixation [2].
- In SCFE, the affected epiphysis first fails to become osteopenic because the absence of blood supply prevents normal resorption of bone from disuse [41].
- This abnormality in SCFE is evident as early as a few weeks after onset of the slip, and almost all cases are evident within 1 year [41].
- Resorption of necrotic bone with collapse of the affected portion of the epiphysis usually follows the early radiographic change in SCFE [41].
- Two patterns of distribution are typically seen in SCFE AVN: total head necrosis and partial (or segmental) necrosis [41].
- Noncontrast MRI relies on signal changes from fat degradation in the necrotic epiphysis to detect AVN [8].
- False-negative results of noncontrast MRI have been reported in isolated cases that manifested very early because it takes weeks to months for the fat signal to decrease [8].
- Gadolinium-enhanced subtraction MRI (perfusion MRI) is more effective than noncontrast MRI in delineating epiphyseal necrosis early in the disease process [8].
- Perfusion MRI facilitates the visualization of areas that lack gadolinium distribution (hypoperfusion) by subtracting pre-contrast images from post-contrast images [8].
- Quantitative assessment of femoral head perfusion using perfusion MRI at the initial or early fragmentation stage can predict lateral pillar involvement and radiographic outcome at 2-year follow-up [8].
- Increased apparent diffusion coefficient in the metaphysis and decreased significant enhancement in the central epiphysis are significant prognostic indicators of subsequent femoral head deformation [8].
- The Ficat and Arlet classification Stage 1 is characterized by normal radiography, a cold spot on bone scan, and infarction of the weight-bearing portion of the femoral head on pathology [43].
- The Ficat and Arlet classification Stage 2 is characterized by density change in the femoral head (sclerosis or cysts), normal joint line and head contour, increased uptake on bone scan, and spontaneous repair of the infarcted area [43].

- The Ficat and Arlet classification Stage 3 is characterized by flattening (crescent sign), loss of sphericity, collapse, subchondral fracture, compaction, and fragmentation of the necrotic segment [43].
- The Ficat and Arlet classification Stage 4 is characterized by joint space narrowing, acetabular changes, and osteoarthritic changes [43].
- The combined angle of articular involvement of the head measured from midsagittal and midcoronal MRI cuts has been shown to be predictive of collapse in hips with pre-collapse osteonecrosis [43].

PEDIATRIC PATTERNS AND CLASSIFICATIONS

- Three patterns of AVN after hip fractures in children have been described by Ratliff [2].
- Type I AVN is characterized by severe diffuse necrosis totally involving the femoral head and the proximal fragment of the femoral neck, resulting from interruption of the lateral epiphyseal and metaphyseal vessels [2].
- Type I AVN accounts for more than 50% of cases and has the worst prognosis [2].
- Type II AVN is characterized by more localized necrotic changes, often in the anterosuperior aspect of the femoral head, with little collapse, caused by interruption of the lateral epiphyseal vessels before entrance into the epiphysis [2].
- Type II AVN is seen in approximately 25% of cases and has a better prognosis than Type I AVN [2].
- Type III AVN accounts for 25% of cases of AVN and has the best results [2].
- The Stulberg classification separates outcomes into five groups based on femoral head shape and acetabular fit at skeletal maturity [4].
- Stulberg Group I hips have a completely normal femoral head shape [4].
- Stulberg Group II hips have a spherical femoral head, with possible abnormalities including coxa magna, short neck, or steep acetabulum [4].
- Stulberg Group III hips have an elliptical femoral head that deviates from a circle by more than 2 mm [4].
- Stulberg Group IV hips have a flattened femoral head, with the acetabulum matching the head contour (congruous incongruity) [4].
- Stulberg Group V hips have collapse of the femoral head without acetabular contour change (incongruous incongruity) [4].
- Patients with Stulberg Group I and II hips had a good long-term prognosis, whereas those with Group III, IV, and V had evidence of arthritic changes at an average follow-up of 40 years [4].
- The Bucholz-Ogden Type IV AVN involves the medial head and metaphysis, producing early closure of the medial portion of the physis and resultant growth into a varus deformity [21].
- The Bucholz-Ogden Type II AVN involves the lateral head and metaphysis, leading to caput valgus during adolescence [21].
- The Bucholz-Ogden Type III AVN involves the whole head and metaphysis, resulting in a short femoral neck and high trochanter [21].
- The Kalamchi-MacEwen Grade 1 AVN involves the head only with normal development [21].

- The Kalamchi-MacEwen Grade 2 AVN involves the lateral head and metaphysis, leading to caput valgus during adolescence [21].
- The Kalamchi-MacEwen Grade 3 AVN involves the central head and metaphysis [21].
- The Kalamchi-MacEwen Grade 4 AVN involves the whole head, resulting in a short neck and high trochanter [21].
- Closure of the lateral portion of the capital femoral growth plate during adolescence is a late abnormality that may be a manifestation of AVN [46].
- Progressive valgus tilting of the femoral head on the metaphysis occurs when the lateral portion of the growth plate closes early [46].
- Relative overgrowth of the greater trochanter occurs in Bucholz-Ogden types II, III, and IV AVN, which may result in an abductor limp [46].
- The effectiveness of abductor muscles is decreased as the femoral neck shortens and the direction of pull becomes steeper [46].

HISTOPATHOLOGY

- Epiphyseal and physeal cartilage involvement is a pathologic feature of vascular disruption of the growing epiphysis in Legg-Calvé-Perthes disease [45].
- A thick region of epiphyseal cartilage is found under the normal articular cartilage in the lateral portion of the femoral head and neck [45].
- The fibrillar area of the epiphyseal cartilage shows increased amounts of proteoglycan, a reduction in structural glycoproteins, and collagen fibrils that differ in size from normal epiphyseal cartilage [45].
- The border of the lateral physis contains profuse amounts of large lipid inclusions [45].
- Cell death occurs in the deep layer of the epiphyseal cartilage following the induction of ischemia, with subsequent degenerative changes in the cartilage matrix [45].
- The viable, superficial region of the epiphyseal cartilage highly expresses hypoxia inducible factor-1, a master regulator of cell response to hypoxia [45].
- Vascular endothelial growth factor (VEGF) and interleukin-6 are released in response to hypoxic stress in the viable superficial region of the epiphyseal cartilage [45].
- In a large animal model, necrotic bone was replaced by fibrovascular granulation tissue with compromised mechanical properties of the epiphysis [45].

Classification

ADULT OSTEONECROSIS CLASSIFICATIONS

- The Ficat classification system is referenced in the context of idiopathic bone necrosis of the femoral head [1].

- The Kerboul method is used for predicting collapse in femoral head osteonecrosis, with a modified version utilizing magnetic resonance imaging [1].
- Quantification of the extent of femoral head involvement in osteonecrosis is a recognized clinical assessment [1].

PEDIATRIC ISCHEMIC NECROSIS CLASSIFICATIONS

- The Stulberg classification categorizes radiographic appearance of hips at skeletal maturity into five groups based on femoral head shape and acetabular fit [4].
- In the Stulberg classification, Group I hips exhibit a completely normal femoral head shape [4].
- In the Stulberg classification, Group II hips feature a spherical femoral head that appears as the same concentric circle on AP and frog-leg lateral radiographs [4].
- Stulberg Group II hips may present with coxa magna, a short neck, or a steep acetabulum [4].
- In the Stulberg classification, Group III hips have an elliptical femoral head that deviates from a circle by more than 2 mm [4].
- In the Stulberg classification, Group IV hips are characterized by a flattened femoral head, with the specific degree of flattening not specified in the original description [4].
- A flattened area greater than 1 cm in the weight-bearing area is used to qualify a hip for Stulberg Group IV [4].
- Stulberg Group IV hips exhibit range of motion changes matching the cylindrical shape of the femoral head, resulting in almost normal flexion and extension [4].
- In Stulberg Group IV hips, the hip often rotates externally during flexion and returns to a neutral position with extension [4].
- The motion in Stulberg Group IV hips is likened to the movement of a cow's hip [4].
- Stulberg Groups III and IV are referred to as congruous incongruity because the acetabular contour matches that of the femoral head [4].
- Stulberg Group V hips are characterized by femoral head collapse without corresponding changes to the acetabular contour [4].
- Stulberg Group V is referred to as incongruous incongruity [4].
- Stulberg Group V hips resemble adult avascular necrosis where the central portion of the femoral head collapses without acetabular change [4].
- The Stulberg classification correlates with the development of arthritic changes in hip joints at an average follow-up of 40 years [4].
- Patients with Stulberg Group I and II hips have a good long-term prognosis [4].
- Patients with Stulberg Group III, IV, and V hips show evidence of arthritic changes [4].
- The lateral pillar classification system is based on radiographic changes in the lateral portion of the femoral head during the fragmentation stage on the AP view [22].
- The original lateral pillar classification proposed in 1992 consisted of three groups: A, B, and C [22].

- Herring and co-workers modified the lateral pillar classification in 2004 by adding an intermediate group designated as B/C border [22].
- In lateral pillar Group A, density change in the lateral pillar is minimal and no loss of height occurs [22].
- In lateral pillar Group B, lucency is observed in the lateral segment with loss of height up to, but not exceeding, 50% of the original height of that epiphyseal segment [22].
- Collapse of the central fragment beneath the level of the lateral segment is often an early manifestation of lateral pillar Group B [22].
- In the lateral pillar B/C border group, the lateral pillar may appear as a very narrow band of ossification 2 to 3 mm wide while maintaining height at more than 50% of the original [22].
- In the lateral pillar B/C border group, the lateral pillar may be at exactly 50% of its original height [22].
- In lateral pillar Group C, early or no separation is noted in the lateral pillar with minimal or no separation between the lateral and central segments [22].
- In lateral pillar Group C, the lateral pillar collapses to less than half its original height [22].
- The lateral pillar is frequently lower in height than the central pillar early in the fragmentation stage in lateral pillar Group C [22].
- There is a strong correlation between the lateral pillar classification and subsequent outcome, with Group A having the best outcome and Group C the worst [22].
- The lateral pillar classification system has greater interobserver reliability than the Catterall classification system [22].
- The lateral pillar classification system is a better predictor of final outcome than the Catterall classification system [22].
- The lateral pillar classification system requires only an AP radiograph of the hip during the fragmentation stage for application [22].
- The Catterall and lateral pillar classification systems are best applied during the middle stage of fragmentation [22].
- Applying the Catterall or lateral pillar classifications earlier than the middle stage of fragmentation leads to inaccurate assignment [22].
- The Catterall and lateral pillar classification systems are not applicable at the initial stage of the disease before fragmentation [22].
- The Catterall and lateral pillar classification systems have limited prognostic value for patients older than 12 years who have a poor prognosis despite partial femoral head involvement [22].

Clinical Presentation

PEDIATRIC POST-TRAUMATIC AVN (HIP FRACTURES)

- Symptoms of avascular necrosis (AVN) following hip fractures in children may occur early, with complaints of groin pain [2].

- The median time to presentation of AVN after hip fractures in children is 7.8 months [2].
- Radiographic evidence of AVN after hip fractures in children can be seen as early as 2 months after injury [2].
- Radiographic evidence of AVN after hip fractures in children is generally present within 1 year of injury [2].
- Radiographs of AVN after hip fractures in children may demonstrate osteopenia of the femoral head, followed later by sclerosis, fragmentation, and often collapse and deformity [2].
- Radioisotope scanning shows decreased uptake in the femoral head or neck (or both) in AVN after hip fractures in children [2].
- Radioisotope scanning is useful for diagnosing AVN in a hip that has stainless steel internal fixation [2].
- MRI is the most sensitive test to confirm the diagnosis of AVN after hip fractures in children [2].
- MRI defines the extent of femoral head and neck involvement in AVN after hip fractures in children [2].

PEDIATRIC ISCHEMIC NECROSIS (LEGG-CALVÉ-PERTHES DISEASE)

- The onset of Legg-Calvé-Perthes disease (LCPD) occurs between 2 and 12 years of age, with a peak between 6 and 8 years [20].
- Boys are four times more likely to have LCPD than girls [20].
- 10% of patients with LCPD have bilateral disease [20].
- The mean age at onset of LCPD is 6 years, with 82% of patients between 4 and 9 years of age [20].
- Boys are 3.7 times more likely than girls to be affected by LCPD [20].
- Symptoms of LCPD are frequently mild, causing considerable time to pass before the child is seen by a physician [20].
- On presentation, children with LCPD usually have a limp [20].
- Some children with LCPD complain of pain in the hip, thigh, or knee [20].
- Primary physical examination findings in LCPD include limited range of motion of the affected hip, particularly in abduction and internal rotation [20].
- Primary physical examination findings in LCPD include slight atrophy of the femoral muscles [20].
- Most children with LCPD experience moderate symptoms and endure 12 to 18 months of difficulty [15].
- The age of the patient at onset is the most consistently reported factor affecting the course of LCPD [15].
- Children younger than 4 years of age with LCPD are often asymptomatic and have no deformation of the femoral head [15].
- Children with LCPD onset particularly under 6 years of age usually experience mild disease [15].
- Children with LCPD onset between 6 and 9 years of age normally have moderate symptoms [15].
- Children with LCPD onset after 9 years of age have a more severe course and more frequently have a poor outcome [15].
- Patients with LCPD onset after the age of 12 years have the worst prognosis [15].

- Three patterns of femoral head necrosis are identified in patients with LCPD onset after 12 years: late-onset pattern, segmental collapse pattern, and destructive pattern [15].
- The destructive pattern of LCPD is characterized by severe head collapse without reossification [15].
- The destructive pattern of LCPD often results in severe symptoms and loss of function in late adolescence [15].
- In the increased density stage of LCPD, clinical findings include variable limp and pain, often mild and intermittent [15].
- In the fragmentation stage of LCPD, pain and limp may worsen and range of motion may be lost [15].
- In the reossification stage of LCPD, limp and pain gradually resolve and range of motion improves [15].
- In the healed stage of LCPD, clinical findings include occasional limp, occasional locking or popping, and some patients develop impingement symptoms [15].
- Meyer dysplasia is a variant of LCPD in which hips have delayed and irregular ossification of the capital femoral epiphysis with no deformation of the head over time [20].
- Patients with Meyer dysplasia are usually asymptomatic [20].
- In a few cases of LCPD, hip pain appears late in adolescence after the patient has been asymptomatic for several years [23].
- Complaints of locking, catching, or crepitation in late adolescence after LCPD can indicate the presence of an osteochondrotic lesion in the femoral head [23].
- Radiographs of osteochondrotic lesions in the femoral head may demonstrate a lucent area in the central part of the head [23].
- It is often difficult to differentiate a loose body from softened cartilage and fibrous tissue on radiographs of osteochondrotic lesions [23].

ADULT FEMORAL HEAD FRACTURES

- Complications following a femoral head fracture include osteonecrosis in approximately 20% of cases [3].
- Complications following a femoral head fracture include osteoarthritis in approximately 50% of cases [3].

Investigations

PLAIN RADIOGRAPHY

- Plain radiography in AP and lateral views is the primary and often the only imaging modality needed to evaluate slipped epiphysis [5].
- The earliest radiographic sign of slipped epiphysis is widening and irregularity of the physis with rarefaction in its juxtaepiphyseal portion [5].
- In the normal hip, a line drawn tangential to the superior femoral neck (Klein line) on the AP view intersects a small portion of the lateral capital epiphysis [5].

- When typical posterior displacement of the capital epiphysis has occurred, the Klein line intersects a smaller portion of the epiphysis or not at all, a finding known as the Trethowan sign [5].
- The “metaphyseal blanch sign” is a crescent-shaped area of increased density overlying the metaphysis adjacent to the physis on the AP radiograph [5].
- The metaphyseal blanch sign is produced by the overlapping of the femoral neck and the posteriorly displaced capital epiphysis [5].
- In most patients with slipped epiphysis, the dense triangular appearance of the inferomedial femoral neck overlapping the posterior wall of the acetabulum is lost [5].
- The frog-leg lateral view is customarily obtained to confirm the diagnosis of most cases of slipped epiphysis [5].
- The frog-leg lateral view is an imprecise method for assessing the severity of slip due to variations in positioning [5].
- The frog-leg lateral view is not usually adequate for assessing the possibility of penetration of the hip joint by a metallic implant [5].
- Alternative lateral radiographic views include a true lateral radiograph, the modified Dunlap lateral radiograph, and the modified Billing lateral radiograph [5].
- To obtain the modified Billing 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 [5].
- In acute slipped epiphysis, little or no remodeling of the femoral neck is apparent on radiographs [5].
- When slipped epiphysis has been present for some time, remodeling appears as a bending of the femoral neck in the direction of the “slipping” capital epiphysis [5].
- Remodeling in chronic slipped epiphysis involves appositional new bone on the inferomedial surface of the neck and resorption of the anterosuperior neck, producing a rounding or “hump” appearance [5].
- Plain radiographs will identify the fracture in the majority of femoral neck fracture cases [31].
- Anteroposterior (AP) and lateral radiographs are required for the evaluation of femoral neck fractures [31].
- In equivocal cases of femoral neck fracture, the lateral radiograph can help determine whether the fracture is displaced [31].
- Full-length AP and lateral femur films are standard for femoral neck fracture evaluation [31].
- The anteroposterior (AP) pelvis radiograph is usually the first study available and is the most useful in directing treatment for hip dislocations [40].
- The key to the diagnosis of hip dislocation on the plain AP pelvis is the loss of congruence of the femoral head with the roof of the acetabulum [40].
- On a true AP view, the femoral head will appear larger than the contralateral head if the dislocation is anterior, and smaller if posterior [40].
- In a posterior hip dislocation, the most common finding on AP radiograph is a small head that is overlapping the roof of the acetabulum [40].

- In an anterior hip dislocation, the femoral head may appear medial to or inferior to the acetabulum on AP radiograph [40].
- Rotation is detectable on the AP view of a hip dislocation, with the lesser trochanter appearing less apparent and the femoral neck seen in profile when the femur is internally rotated [40].
- Associated femoral neck fractures, which may be nondisplaced, must not be overlooked on the initial AP pelvis radiograph before reduction is attempted [40].
- Associated femoral head fractures are usually visible as a retained fragment in the joint on the plain AP radiograph [40].
- Acetabular fractures and pelvic ring injuries are visible on the plain AP radiograph of a hip dislocation [40].
- After a hip is reduced, all five standard views of the pelvis are obtained, including AP, both Judet (45-degree oblique) views, and an inlet and outlet of the pelvis [40].
- The congruency of a reduced hip is evaluated by comparing the relationship of the femoral head to the acetabular roof (sourcil) on each view to the contralateral side [40].
- Radiographic evidence of avascular necrosis (AVN) in children can be seen as early as 2 months after injury [2].
- Radiographic evidence of AVN in children is generally present within 1 year of injury [2].
- The median time to presentation of AVN symptoms in children is 7.8 months [2].
- Radiographs of AVN may demonstrate osteopenia of the femoral head, followed later by sclerosis, fragmentation, and often collapse and deformity [2].
- Stulberg group II hips have a spherical femoral head with the same concentric circle on AP and frog-leg lateral radiographs [4].
- Stulberg group III hips have a femoral head that is more elliptical and deviates from a circle by more than 2 mm [4].
- Stulberg group IV hips have a flattened femoral head, with the classification applied when there is a flattened area greater than 1 cm in the weight-bearing area [4].
- In Stulberg group IV hips, the range of motion changes to match the cylindrical shape of the femoral head, resulting in an almost normal range of flexion and extension [4].
- In Stulberg group IV hips, the hip often rotates externally whenever the joint is flexed and resumes a neutral position with extension [4].
- In Stulberg groups III and IV, the contour of the acetabulum matches that of the femoral head, referred to as congruous incongruity [4].
- In Stulberg group V hips, there is collapse of the femoral head but the acetabular contour does not change, referred to as incongruous incongruity [4].
- The Stulberg classification system correlates with the development of arthritic changes in the hip joints at an average follow-up of 40 years [4].
- Patients with Stulberg group I and II hips had a good long-term prognosis [4].
- Patients with Stulberg group III, IV, and V hips had evidence of arthritic changes [4].

- In the healed stage of Legg-Calvé-Perthes disease, no additional changes are noted in the density of the femoral head [7].
- In the healed stage of Legg-Calvé-Perthes disease, the shape of the femoral head may continue to evolve until the completion of skeletal growth [7].
- After healing in Legg-Calvé-Perthes disease, the shape of the femoral head may vary from completely normal to extremely flat and aspherical [7].
- If Legg-Calvé-Perthes disease has disrupted growth of the capital physis, gradual relative overgrowth of the greater trochanter may occur [7].
- The more severe the disease in Legg-Calvé-Perthes, the longer the duration of each stage, particularly the reossification stage [7].

COMPUTED TOMOGRAPHY (CT)

- CT scanning is a more accurate investigation than plain radiographs for detecting occult hip fractures [31].
- Thomas et al. reported 100% specificity and sensitivity for the use of multidetector CT scanning in diagnosis of hip fracture in a series of 209 patients with negative plain radiographs [31].
- Rehman et al. reported on 179 patients presenting with pelvic pain after trauma and imaging with CT missed no occult hip fracture [31].
- Sadozai et al. reported on 78 CT scans and found CT scanning yielded a sensitivity of 86% and specificity of 98% for occult hip fractures [31].
- CT scan should be obtained after reduction of a hip dislocation to evaluate for loose bodies because it is more sensitive than plain radiographs [11].
- Loose bodies can still be missed even by CT, although this omission may be more common in complex fracture-dislocations [11].
- A 2018 systematic review found CT scan was 87% sensitive for detecting intra-articular fragments [11].
- CT with fine cuts through the hip is more sensitive in detecting small intra-articular fragments, femoral head fractures, femoral head impaction injuries, acetabular fractures, and joint incongruity than plain radiographs [40].
- Hougaard et al. reported six cases of minor acetabular fractures and six cases of retained intra-articular fragments visualized on CT and not visible on plain radiographs in patients after closed reductions of posterior hip dislocations [40].
- Baird and colleagues demonstrated CT to be more sensitive than plain radiographs in identifying 2-mm methyl methacrylate beads placed in cadaveric hips [40].
- The congruence of the hip is easily evaluated using CT, with the head appearing in the center of the subchondral ring of the acetabulum as a bullseye [40].
- A difference as small as 0.5 mm in the distance from the anterior articular surface to the femoral head has been reported to indicate a subluxation of the hip on CT [40].
- Impaction injuries and femoral head fractures are much more easily seen on the postreduction CT [40].
- The quality of the reduction of femoral head fractures is apparent on CT and determines treatment [40].

- The CT scan aids in directing follow-up radiographic analysis in the case of reduced femoral head fractures treated nonoperatively [40].
- Moed and Maxey suggested the use of specific angled radiographs based on the CT determination of the fracture direction when obtaining follow-up radiographs of femoral head fractures treated nonoperatively [40].
- Postreduction CT scan of the hip provides information about intra-articular fragments, reduction concentricity, and associated injuries [12].
- In cases where there is a suspected femoral neck fracture but normal or equivocal plain radiographs, CT scanning is a more accurate investigation than bone scan [31].
- Modern modalities of CT imaging may have a role in prediction of complications following femoral neck fracture fixation [31].
- Kumar et al. reported that positron emission tomography/computed tomography (PET/CT) at 6 weeks could detect recovery of vascularity and could predict the risk of vascular necrosis [31].

MAGNETIC RESONANCE IMAGING (MRI)

- MRI is the most sensitive test to confirm the diagnosis of AVN in children and also defines the extent of femoral head and neck involvement [2].
- MRI is an accurate imaging modality for the early diagnosis of Legg-Calvé-Perthes disease (LCPD) and for visualizing the configuration of the femoral head and acetabulum [8].
- Because it takes weeks to months for the fat signal to decrease, false-negative results of noncontrast MRI were reported in few isolated cases that manifested very early [8].
- In a study of nine patients in the early stage of Perthes disease, the extent of epiphyseal involvement was clearly visualized on MRI 3 to 8 months after the first symptoms [8].
- In a comparative study, MRI was found to be more accurate in the early diagnosis than conventional imaging modalities, with a diagnostic accuracy of 97% to 99% for MRI compared with 88% to 93% for radiography and 88% to 91% for scintigraphy [8].
- MRI has been reported to provide earlier and more reliable information about the true extent of femoral head necrosis than radiography or scintigraphy [8].
- Gadolinium-enhanced subtraction MRI has been shown to be more effective than noncontrast MRI in delineating epiphyseal necrosis early in the disease process [8].
- The subtraction MRI technique facilitates the visualization of areas that lack gadolinium distribution in the femoral epiphysis (i.e., areas of hypoperfusion) by subtracting the pre-contrast images from the corresponding post-contrast images [8].
- In subtraction MRI, hypoperfused areas appear black due to the absence of gadolinium enhancement [8].
- A comparison of non-contrast versus contrast-enhanced MRI in the initial stage of LCPD found clearer depiction of the area of head involvement and higher interobserver agreement of the extent of head involvement using the contrast-enhanced MRI [8].

- Preliminary studies show that quantitative assessment of femoral head perfusion using perfusion MRI obtained at the initial or early fragmentation stage can predict the lateral pillar involvement and the radiographic outcome at the 2-year follow-up [8].
- Diffusion and contrast-enhanced MRI in the early stages of LCPD were found to predict the risk of later development of femoral head deformity [8].
- Increased apparent diffusion coefficient in the metaphysis and decreased significant enhancement in the central epiphysis were the significant prognostic indicators of subsequent femoral head deformation [8].
- Perfusion MRI has been shown to provide quantitative information about hip synovitis as it depicts synovial membrane hyperemia and thickening due to synovitis [8].
- Perfusion MRI has been reported to be a safe and feasible imaging technique for LCPD, but younger patients (patients less than 8 years old) generally require sedation or anesthesia [8].
- Subtraction MRI allows recognition of early reperfusion patterns [8].
- In one study, contrast-enhanced MRI better delineated the revascularization patterns in the femoral head than did scintigraphy [8].
- Biplanar MRI has been reported to be as effective as arthrography in evaluating femoral head sphericity and containment [8].
- Sequential MRI studies of LCPD established a correlation with the Catterall classification system [8].
- Studies evaluating single photon emission computed tomography and MRI following hip dislocation were unable to correlate findings with the risk for osteonecrosis [11].
- In cases where there is a suspected femoral neck fracture but normal or equivocal plain radiographs, MRI scanning is preferred as the imaging of choice over CT [31].
- MRI has been shown to be more accurate than a bone scan in the early stages after injury for detecting occult hip fractures [31].
- MRI will demonstrate soft tissue problems that may be causing hip pain in the absence of a fracture [31].
- An MRI scan is the current additional imaging modality recommended where there is uncertainty about the presence of an intracapsular fracture [31].
- Occasionally, there may be some uncertainty regarding interpretation when intense bone edema in the femoral neck is demonstrated on MRI imaging rather than a definite fracture [31].
- In situations of intense bone edema on MRI without a definite fracture, some authors have carried out a CT scan to aid in determining whether a fracture is present [31].
- Morimoto et al. evaluated the prognostic value of dynamic MRI–positive enhancement integral color mapping (PEICM) in 68 patients due to undergo osteosynthesis of undisplaced femoral neck fractures [31].
- On the basis of dynamic MRI-PEICM color mapping, femoral head perfusion was classified as normal, decreased, or completely absent [31].
- The nonunion rate was zero in the normal perfusion group, 6.7% in the reduced perfusion group, and 50% in the absent perfusion group for undisplaced femoral neck fractures [31].

- Early hip arthroscopy is indicated for patients with mechanical symptoms following closed reduction because the cause is typically found to be loose bodies and labral tears, which may improve following arthroscopic treatment [11].
- Persistent pain and pain with activity in the subacute period after hip dislocation should be worked up with MRI [39].

NUCLEAR MEDICINE

- Radioisotope scanning shows decreased uptake in the femoral head or neck (or both) and is useful in a hip that has stainless steel internal fixation [2].
- In cases where there is a suspected femoral neck fracture but normal or equivocal plain radiographs, a technetium bone scan is often considered a useful investigation [31].
- Although usually positive in cases with a femoral neck fracture, there is the possibility of a false negative in osteopenic bone if the technetium bone scan is carried out within 48 to 72 hours of the fall [31].
- Technetium bone scan is sensitive but not specific for femoral neck fracture [31].

FLUOROSCOPY AND STRESS TESTING

- Following a successful closed reduction of a hip dislocation, a fluoroscopic evaluation can be performed to determine the extent of joint stability in the presence of radiographic congruency [10].
- The “stress exam” or manipulation of the hip under fluoroscopy can be performed to help determine if a posterior wall fracture should be fixed [10].
- The fluoroscopic stress examination is performed with the patient under general anesthesia in the operating room on a radiolucent table [10].
- During the stress test, the hip is flexed and internally rotated and enough pressure to rock the pelvis is applied in line with the femur in an attempt to displace the head posteriorly [10].
- The stress test is repeated using the image intensifier on the AP view, the obturator oblique, and obturator outlet oblique views of the pelvis [10].
- Any change in the congruous relationship of the head to the roof during fluoroscopic stress testing indicates posterior subluxation, and the hip should be considered unstable [10].
- In a small series

Treatment

GENERAL PRINCIPLES AND NON-OPERATIVE MANAGEMENT

- It is estimated that 20,000 new cases of osteonecrosis are diagnosed each year in the United States [6].
- Up to 12% of all total hip arthroplasties performed in the United States are done for osteonecrosis [6].
- The term osteonecrosis is now preferred over avascular necrosis [6].

- Risk factors for osteonecrosis include trauma, corticosteroid use, alcohol abuse, smoking, hemoglobinopathies, coagulation disorders, myeloproliferative disorders, hyperbaric decompression, hyperlipidemias, chronic kidney disease, autoimmune diseases, and human immunodeficiency virus infection [6].
- In many cases a cause cannot be identified, and these patients are designated as having idiopathic osteonecrosis [6].
- When symptomatic, osteonecrosis typically leads to collapse of the femoral head and eventual deterioration of the hip joint [6].
- For avascular necrosis after hip fractures in children, treatment should begin at the onset of symptoms and entail partial weight bearing or non-weight bearing until painful symptoms resolve [2].
- In general, avascular necrosis after hip fractures in children results in poor outcomes in up to 60% of cases [2].
- Treatment of avascular necrosis after hip fractures in children has been relatively unsuccessful, and some investigators have suggested that treatment does not affect the natural history [2].
- The goals of treatment for avascular necrosis after hip fractures in children are to preserve the functional range of hip motion, maintain containment of the femoral head within the acetabulum, and preserve as much femoral head viability as possible [2].
- When avascular necrosis is first recognized after a healed hip fracture in children, the initial step is removal of internal fixation devices to prevent penetration of the hardware into the joint [2].
- For slipped capital femoral epiphysis (SCFE) with avascular necrosis evident before articular surface collapse, a revascularization procedure such as a vascularized fibular graft may be considered [19].
- Vascularized fibular grafting for SCFE-related avascular necrosis is best performed at a center with significant experience in its use [19].
- If metallic implants in the epiphysis have secondarily encroached on the articular cartilage due to collapse, the implant should be removed, partially withdrawn, or replaced to stabilize the residual epiphysis without further compromising the articular surface [19].
- For SCFE-related avascular necrosis with little pain but a poor functional position, an intertrochanteric osteotomy may be performed to reposition the limb in a more functional arc of motion and prevent impingement [19].
- Intertrochanteric osteotomy for SCFE-related avascular necrosis should be delayed until radiographic evidence of healing of the residual epiphysis has occurred [19].
- Debilitating pain with progressive radiographic changes in SCFE-related avascular necrosis may be treated with joint arthroplasty (total or partial) or hip fusion [19].
- Total joint arthroplasty for SCFE-related avascular necrosis provides pain relief and maintenance of motion but carries risks of loosening and wear problems due to high patient demands [19].
- Hip arthrodesis is a traditional salvage procedure for SCFE-related avascular necrosis that relieves pain and allows most activities but places stresses on the knee and lumbar spine [19].

- For late-onset osteochondrotic lesions in the femoral head following Legg-Calvé-Perthes disease, nonsurgical treatment including rest, activity modification, and nonsteroidal anti-inflammatory drugs is often successful when symptoms are not severe [23].
- If excision of an osteochondrotic lesion is necessary, it should be attempted arthroscopically with débridement of the lesion bed [23].
- If the lucent area in the femoral head represents softened bone rather than a loose body, drilling the affected area may help trigger ingrowth of blood vessels and healing, but results are mixed [23].
- For Legg-Calvé-Perthes disease in children with onset on or before the sixth birthday, symptomatic treatment is the preferred approach for the initial stage [51].
- For Legg-Calvé-Perthes disease in children with onset on or before the eighth birthday, nonoperative or operative containment treatment is recommended if they develop a loss of hip abduction and lateral extrusion of the femoral head [51].
- For Legg-Calvé-Perthes disease in children with onset after the eighth birthday presenting at the initial stage with >50% head involvement on perfusion MRI, consideration of surgical treatment is recommended [51].
- For Legg-Calvé-Perthes disease in children with onset after the eleventh birthday where the head has not collapsed, multiple epiphyseal drilling or core decompression is recommended [51].
- For Legg-Calvé-Perthes disease in children with onset after the eighth birthday presenting with lateral pillar groups B and B/C border during the fragmentation stage, surgical treatment is recommended [51].
- For Legg-Calvé-Perthes disease in children with onset after the eighth birthday presenting with lateral pillar group C, a stiff hip, and loss of containment during the fragmentation stage, nonoperative containment treatment is recommended [51].
- Nonoperative treatment choices for Legg-Calvé-Perthes disease include prolonged non-weight bearing with crutches and wheelchair, Petrie casts, and wide abduction (A-frame) brace [51].
- Surgical choices for Legg-Calvé-Perthes disease after regaining motion include femoral varus osteotomy, Salter innominate osteotomy, both osteotomies combined (for onset after age 9 years), shelf acetabuloplasty, and triple innominate osteotomy [51].
- Late measures for Legg-Calvé-Perthes disease include femoral valgus osteotomy for established head and acetabular flattening, adducted hip, or short leg gait [51].
- Surgical hip dislocation with possible trochanteric advancement, relative femoral neck lengthening, and osteochondroplasty is a late measure for impingement and labral disorders following Legg-Calvé-Perthes disease [51].
- Hip arthroscopy with removal of an osteochondrotic fragment is indicated for mechanical symptoms following Legg-Calvé-Perthes disease [51].
- Trochanteric epiphysiodesis can prevent relative trochanteric overgrowth and should be performed when major avascular necrosis is recognized and the ossific nucleus of the greater trochanter is present [21].
- Trochanteric epiphysiodesis is most effective if performed when the child is approximately 5 years old and has been found to be ineffective if performed when the child is much older than 8 years old [21].

- Trochanteric advancement may be considered when an objectionable abductor limp results from trochanteric overgrowth, the greater trochanter has reached the level of the top of the femoral head, there is a congruous and concentric reduction of the hip, a Trendelenburg sign can be elicited, and the child is older than 8 years [21].
- Trochanteric advancement in a dysplastic hip will not improve the patient's gait [21].

OPERATIVE MANAGEMENT

- Operative treatment options for avascular necrosis after hip fractures in children include intertrochanteric osteotomy (usually valgus) to place viable head in the weight-bearing zone, capsulotomy, and arthrodesis [2].
- Operative treatment for avascular necrosis after hip fractures in children has resulted in poor outcomes principally because of selection bias, as the most severe cases have undergone operative treatment [2].
- Treatment of femoral head fractures is guided by the Pipkin classification [3].
- For Pipkin Type I femoral head fractures, the fragment is excised if small or fixed if large, usually with counter-sunk screws [3].
- For Pipkin Type II femoral head fractures, treatment is open reduction and internal fixation [3].
- For Pipkin Type III femoral head fractures, the femoral neck fracture is stabilized first before any attempt to reduce and fix the dislocated femoral head [3].
- For Pipkin Type IV femoral head fractures, the femoral head fracture is fixed if large enough [3].
- Hips reduced after 6 hours following traumatic dislocation were five times more likely to develop femoral head osteonecrosis compared to those reduced within 6 hours [16].
- There was no association between grade of dislocation and rates of osteonecrosis in traumatic hip dislocations [16].
- Hips that were dislocated longer than 6 hours were less likely to be successfully reduced in the emergency department with primary conscious sedation (odds ratio, 19.75 [2.06, 189.10]; $P = 0.01$) [16].
- A systematic review of arthroscopy after traumatic hip dislocation found no major complications directly attributable to arthroscopic surgery [16].
- CT scan had a sensitivity of 87.3% for detecting intra-articular fragments after traumatic hip dislocation [16].
- In a multicenter randomized trial comparing sliding hip screw devices with cannulated screws for low-energy hip fractures, avascular necrosis was more common in the sliding hip screw group than in the cancellous screws group (9% vs. 5%) [17].
- A systematic review of open and closed reduction for displaced intracapsular fractures in patients under 50 years found the incidence of avascular necrosis was 17.2% in the closed group and 17.7% in the open group [17].
- Open reduction of intracapsular fractures was associated with a 3.9% wound infection rate compared to 0.49% in the closed reduction group [17].

- There is insufficient evidence to support open reduction of intracapsular fractures, but better evidence from randomized trials is needed [17].
- In a multicenter randomized controlled trial involving 207 patients with displaced intracapsular fractures, the rate of secondary surgery was highest in the fixation group (39%) compared to 5% in the bipolar hemiarthroplasty group and 9% in the total hip replacement group [17].
- Total hip replacement provided significantly better functional outcome scores at 24 months than bipolar hemiarthroplasty or reduction and fixation in healthy older patients with displaced intracapsular fractures [17].
- Arthroplasty is more clinically effective and cost-effective than reduction and fixation in healthy older patients with a displaced intracapsular fracture of the hip [17].
- Salvage total hip arthroplasty following failed internal fixation of intracapsular fractures has a significantly higher overall complication rate than primary total hip arthroplasty [17].
- Salvage total hip arthroplasty is associated with a significantly higher rate of dislocation, infection, and periprosthetic fracture compared to primary total hip arthroplasty [17].
- For undisplaced intracapsular fractures, cannulated screw fixation has equivalent results to sliding hip screw devices [52].
- For displaced intracapsular fractures, the weight of evidence strongly supports the use of arthroplasty as the treatment of choice for the majority of patients, with the exception being a physiologically young patient with good bone stock who understands the risks of fixation [52].
- A cemented hemiarthroplasty is a good choice in the elderly frail patient with displaced intracapsular fractures [52].
- In the fit older patient with displaced intracapsular fractures, better functional outcomes and lower revision rates are achieved with total hip arthroplasty [52].
- Fixation remains the treatment of choice for younger patients with displaced intracapsular fractures, although for patients with significant medical comorbidities, arthroplasty merits consideration [52].
- In a randomized controlled trial comparing bipolar hemiarthroplasty with total hip replacement for displaced intracapsular fractures in elderly patients, hip function measured by the Harris hip score was significantly better in the total hip replacement group at both 4 and 12 months follow-up [17].
- The duration of surgery was significantly longer in the total hip replacement group (102 vs. 78 minutes) and intraoperative blood loss was increased (460 mL versus 320 mL) compared to bipolar hemiarthroplasty, but there were no differences regarding complications or mortality [17].
- There were no dislocations in either the total hip replacement or bipolar hemiarthroplasty groups in the randomized trial for displaced intracapsular fractures [17].

Complications

PEDIATRIC HIP FRACTURES

- Avascular necrosis (AVN) is the most common and most devastating complication associated with hip fractures in children [2].
- AVN is the principal cause of poor results in children's hip fractures [2].
- The historical overall incidence of AVN in children's hip fractures is 43% [2].
- A more recent literature review reported the incidence of AVN to be 38%, 28%, 18%, and 5% for types I, II, III, and IV fractures, respectively [2].
- AVN of the femoral head is thought to result from disruption or compromise of the blood supply of the femoral head at the time of the initial trauma [2].
- AVN is potentially caused by the tamponade effect of the hip hemarthrosis [2].
- Fracture displacement is identified as the most important risk factor for AVN in children [2].
- A fracture in an older child (>12 years) is a risk factor for AVN [2].
- MRI is the most sensitive test to confirm the diagnosis of AVN and defines the extent of femoral head and neck involvement [2].
- Radioisotope scanning shows decreased uptake in the femoral head or neck and is useful in a hip that has stainless steel internal fixation [2].
- Treatment of AVN has been relatively unsuccessful, and some investigators have suggested that treatment does not affect the natural history [2].
- Treatment of AVN should begin at the onset of symptoms and should entail partial weight bearing or non-weight bearing until the painful symptoms resolve [2].
- Operative treatment of AVN has resulted in poor outcomes principally because of selection bias, with the most severe cases undergoing operative treatment [2].

FEMORAL HEAD FRACTURES

- Sciatic nerve palsy is a complication following a femoral head fracture [3].
- Fracture malreduction is a complication following a femoral head fracture [3].
- Non-union is a complication following a femoral head fracture [3].
- Heterotopic ossification is a complication following a femoral head fracture [3].

INTRACAPSULAR HIP FRACTURES

- Avascular necrosis was more common in the sliding hip screw group than in the cancellous screws group (9% vs. 5%) for low-energy hip fractures [17].
- The incidence of AVN was 17.2% in the closed reduction group and 17.7% in the open reduction group for displaced intracapsular fractures in patients under the age of 50 years [17].

CQ HAND + UPPER LIMB

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- Open reduction was associated with a 3.9% wound infection rate compared to 0.49% in the closed reduction group for displaced intracapsular fractures in patients under the age of 50 years [17].
- Salvage total hip arthroplasty following failed internal fixation of intracapsular fractures of the femoral neck is associated with a significantly higher overall complication rate than primary total hip arthroplasty [17].

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