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Developmental Dysplasia of the Hip

J. Richard Bowen, MD
Anastacio Kotzias-Neto, MD

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Chapter One

Introduction

Many thousands of children have been prevented from being crippled since orthopaedists learned to treat developmental dysplasia of the hip (DDH) effectively. DDH is a condition caused by abnormal development of the hip joint that presents clinically in infancy as a wide spectrum of abnormalities. These abnormalities can range from instability to complete dislocation of the joint. In utero, the hip with DDH is thought to form normally during the fetal period of development and to undergo abnormal growth of the chondro-osseous components during the embryonic period. The precise etiology of DDH is unknown; however, both genetic and environmental factors have statistical associations. In some infants, mild dysplasia will resolve spontaneously; however, in others the untreated hip abnormality will become progressively worse, resulting in pain, limited motion, an abnormal gait, and eventually degenerative arthritis in adulthood. Untreated severe dysplasia or dislocation of the hip results in an abnormal gait and degenerative arthritis in young adulthood. When the abnormalities of DDH are diagnosed and treatment is started soon after birth, the outcome is generally good; however, when treatment is delayed, the outcome is often poor.

DDH has also been called congenital dislocation (and dysplasia) of the hip (CDH). The authors believe both names correctly describe some components of the condition, and they often use the names interchangeably. "Congenital dysplasia of the hip" implies that the hip is abnormal at birth, distinguishing this condition from other diseases that cause dysplasia and dislocation in childhood, such as cerebral palsy, polio, muscular dystrophy, and other neuromuscular diseases. "Developmental dysplasia of the hip" emphasizes that the etiology is a developmental abnormality that results in a hip disorder with a wide spectrum of problems, ranging from instability to complete (frank) dislocation. DDH is currently the most popular name for this condition and is therefore the one that will be used in this text.

This text will cover many concepts of developmental dysplasia of the hip and will include a brief history of some important articles, normal and dysplastic hip development, screening and diagnosis, and treatment, with outcomes and complications.

DISEASE HISTORY OF DDH

Prior to Its Recognition as a Disease

The disability of a dislocated hip has been mentioned for centuries, but understanding of the condition was poor. Hippocrates (460–357 BC)[257] clearly described the disabling effects of a dislocation of the hip. The British Museum has a specimen of a dysplastic hip from Neolithic times and a bronze figurine with congenital dislocation from Hellenistic times. Although the disability of infantile dislocated hip was very well known in the Mediterranean world by the end of the first millennium BC, its etiology was poorly understood. In France, Andry mentioned the condition in 1741.[9] Hip dislocation was considered either accidental or spontaneous (symptomatic) until Guillaune Dupuytren (1777–1835) described a failure of fetal hip development and classified it as a third variety called "original or congenital dislocation."[137,138] He considered the condition incurable.

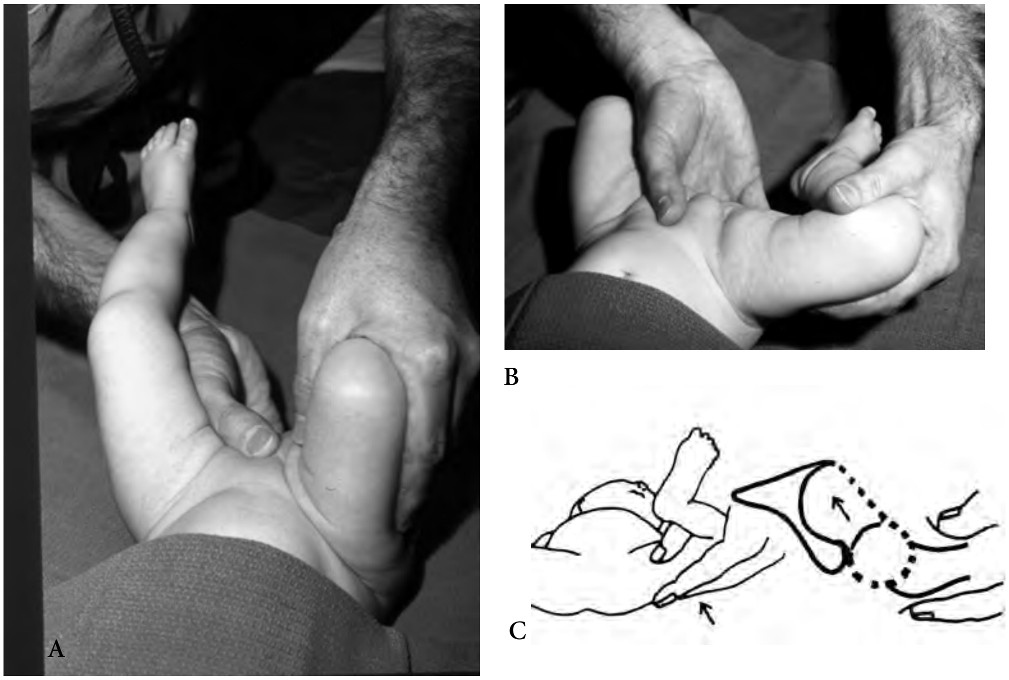
Recognition of DDH as a Disease

The first classical monograph about congenital hip dislocation was written by Charles Gabriel Pravaz of Lyon in 1837.[468] For treatment he recommended manipulation of the hip in extension and abduction, with pressure on the greater trochanter to bring the femoral head into the acetabulum. The reduction was maintained by prolonged traction. Paci (1887)[442] and Adolf Lorenz[355,356] described a forcible reduction by manipulation and casting (frog-leg position), which was later modified by Denuce (1898);[125,126] however, complications of these treatments were common and severe. At the turn of the twentieth century, the diagnosis of a congenital dislocated hip was usually made in older children of walking age: the reduction was by forceful manipulation, maintenance of reduction was by splinting the hip in abduction, and the results were frequently poor.

Medical attention was then directed toward more effective techniques of reducing dislocated hips in older children of walking age. Lange developed a method of traction on the extended thigh and application of hip flexion and abduction to obtain the reduction.[335] The reduction was then maintained by casting. Putti[470,471] recognized the problems of forceful reductions in older children and emphasized the importance of early diagnosis and treatment. He even suggested the necessity of beginning treatment at the moment the deformity was observed, even on the day of birth. Most of the classic historical articles address treatment of the persistently dislocated hip, but few had satisfactory outcomes. Craig[100,101] introduced an overhead traction technique to reduce the hip into the acetabulum; the reduction was held by a cast or splint. In 1964, Hoffmann-Daimler[261] developed a flexible bandage in which the hip was flexed and abducted at a slow pace and the reduction was accomplished in 8 to 14 days. Hanausek developed an apparatus with a metallic base plate and movable thigh supports, which were adjusted to achieve the reduction.[29] Kramer used traction and developed pathways of hip reduction by gradual flexion and abduction of the hip.[324] Fettweis[157] developed a technique of hip reduction using a squatting-position cast. These techniques often required prolonged hospitalization and had a significant rate of complication. Gradually the knowledge developed that diagnosis at an early age and gentle reduction were necessary for success.

Diagnosis of DDH at an Early Age

Ortolani,[438,440] an Italian paediatrician, believed that congenital hip dysplasia was the result of endogenous factors involving heredity and mechanical exogenous factors influencing the fetal hip in utero. He examined the hips of three generations and found heredi-



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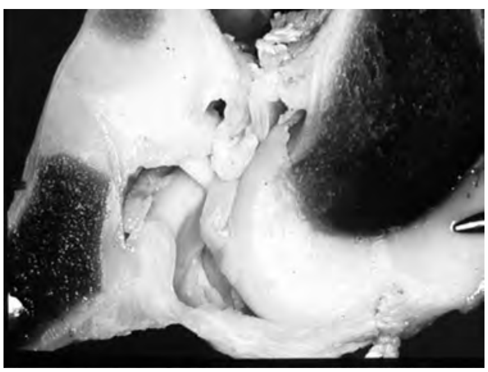


D

Figure 1-1 Ortolani test. **A, B.** With the pelvis stabilized, the leg is abducted and with pressure over the greater trochanter the femoral head is felt to reduce into the acetabulum. **C.** Schematic drawing demonstrating the Ortolani test modified from Visser JD: Functional treatment of congenital dislocation of the hip, Acta Orthopaedica Scand 55 (Suppl 206): 1–109, p 19, Figs 8, 9, 1984). **D.** Specimen of a dislocated hip demonstrating the structures producing the Ortolani "click."

tary causes in 70 percent of the cases of congenital hip dysplasia. In 1948, he described a clinical sign for diagnosing unstable dislocated hips, which he termed "sbalzo" (slip) or "scatto" (click).[439] To perform the Ortolani test, the baby is placed in a supine position with the hips flexed at a right angle and the knees flexed. The hips are abducted and the dislocated head of the femur slips toward the acetabulum, creating the movement described as a scatto. Ortolani's test diagnoses an unstable dislocated hip.

In Stanford, England, Barlow (1962)[17,18] commenced a prospective investigation to determine the incidence of hip instability in the first week of life, to discover if any dislocation had occurred during or soon after birth, and to determine the indications of early treatment. He concluded that the Ortolani test was satisfactory for children with a dislocated hip, but was not entirely satisfactory in newborn babies who had instability. For this reason, he developed the Barlow maneuver, in which the hips are flexed to a right angle and

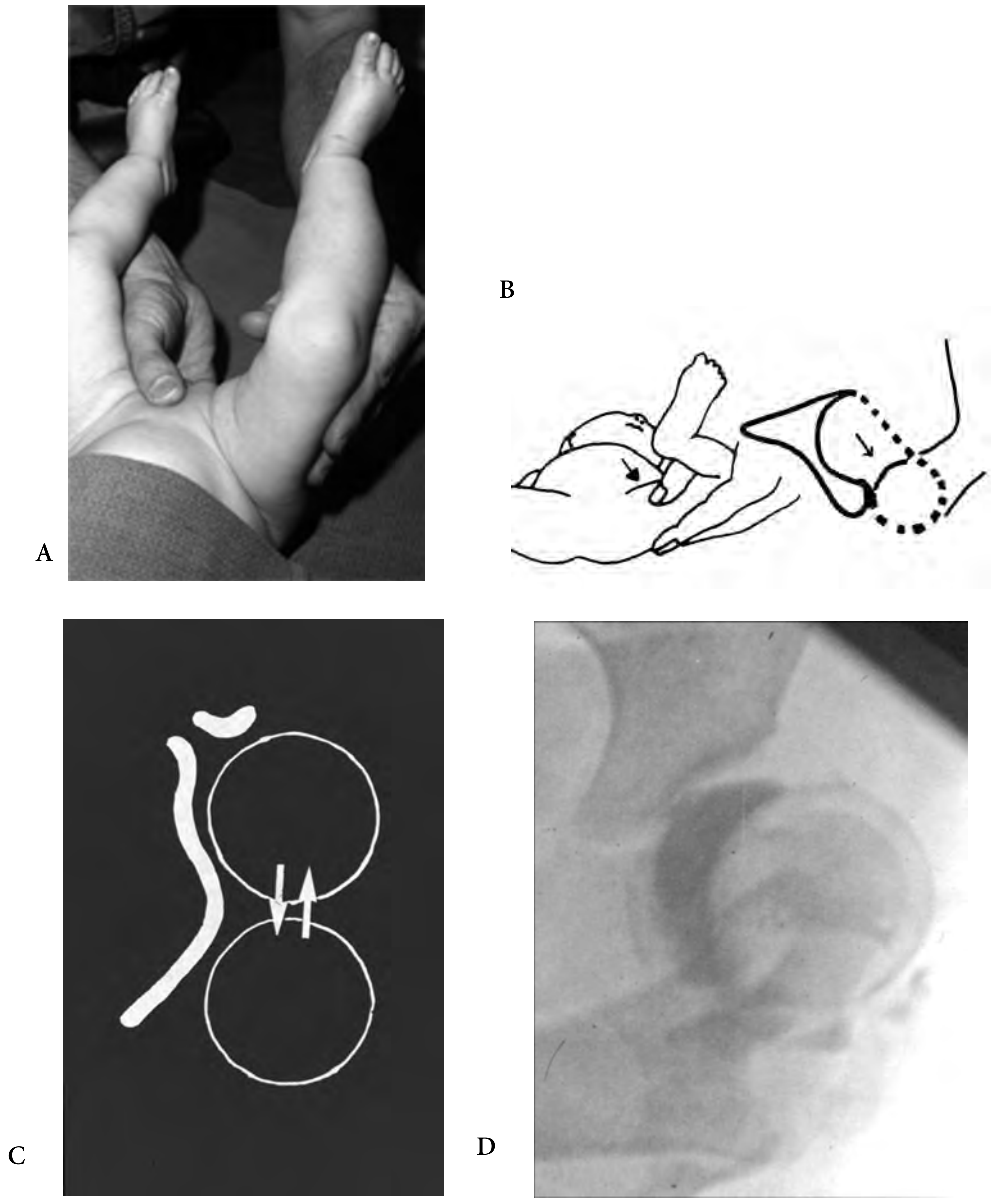


Figure 1-2 Barlow maneuver. **A.** Grasp the thigh with the palms of the hand to stabilize the pelvis. Place the thumb on the medial aspect of the thigh and the index and middle finger on the greater trochanter, and with pressure downwardly the femoral head is felt to dislocate. **B.** Schematic drawing showing the Barlow maneuver (modified from Visser JD: Functional treatment of congenital dislocation of the hip, Acta Orthopaedica Scand 55 (Suppl 206): 1–109, p 19, Figs 8, 9, 1984). **C.** Schematic drawing to demonstrate motion of the femoral head. **D.** Arthrogram showing the movement of the femoral head out of the acetabulum with the Barlow maneuver. Notice the wide medial dye pool.

the knees are completely flexed. The examiner's middle fingers are placed over the greater trochanter and the thumb is applied to the lesser trochanter. The thigh is carried into mild adduction. Pressure is applied to the lesser trochanter by the thumb producing a backward and outward movement of the femoral head. If the femoral head slips out over the posterior rim of the acetabulum with pressure from the thumb and slides back into the acetabulum again after the pressure is released, the hip is unstable (Barlow positive). The Barlow positive hip is "not dislocated but dislocatable." The Barlow "maneuver" and the Ortolani test have become the major components of physical examination for the early diagnosis of DDH.

From the 1930s to the 1980s, radiographic imaging was the only available technique to screen, to confirm the diagnosis of DDH, or to follow the progress of treatment. In older children with an ossified femoral epiphysis, radiographs were excellent in confirming the diagnosis of DDH but were confusing in infants in which the cartilaginous femoral head was not visible. On anterio-posterior radiographs, Hilgenreiner's and Perkins's lines were drawn to help determine the infant's hip position, but indistinct bony landmarks made the interpretations difficult and often inaccurate. S. Sophus von Rosen[617–622] in Sweden screened 99 percent of all children who were born in the city of Malmo. He showed that the clinical diagnosis could be made and confirmed by his special radiographic view. To obtain Von Rosen's view, the child's legs are placed in abduction and internal rotation, and an anteroposterior radiograph is obtained. In children with dislocated and nonreducible hips, the view is helpful; however, in infants the abduction and internal rotation of legs often reduces the hip, making the study valueless. Currently, radiographs are used in children over 6 months of age to confirm the diagnosis of DDH, follow the progress of treatment, and evaluate bony dysplasia.

In 1978, Graf[202–204] developed a static sonographic technique to detect DDH. He examined 3,500 infants from 9 days to 21 months of age and compared the sonograms with radiographs that had been taken simultaneously. The sonographic evaluation of the hip was superior to radiographs in infants less than six months of age. Morphometric standards were established based on a static coronal image of the hip obtained from the lateral approach with the femur in the anatomic position.[203,204] Harcke[223–230] used a dynamic technique of hip sonography utilizing a multiplanar evaluation method to determine the degree of hip instability. He performed dynamic sonographic hip examinations in over 8,000 infants. The multiplanar evaluation method allows infant hip evaluations in three dimensions. Sonography offers an advantage over radiography in the ability to visualize the femoral head and acetabulum when they are composed of cartilage; also, sonography has no radiation exposure.

Treatment principles that have evolved in the past 75 years include diagnosing DDH during early infancy, performing a gentle reduction (either closed or operatively), maintaining the reduction by hip flexion with limited abduction, and correcting residual acetabular dysplasia. Basic scientific studies in animals have enhanced the knowledge of hip dysplasia; a few examples have been included. In dogs, Smith[529] determined that a normal hip joint could develop after a dislocated femoral head was replaced in the acetabulum. In rats, Harrison[237,238] developed models to produce acetabular dysplasia, deformities of the femoral head, and changes in the femoral neck angle similar to abnormalities observed in children with DDH. Kalamchi et al.[296] developed dog models to demonstrate different types of avascular necrosis and used the information to classify types of avascular necrosis in children.

Treatment of a dislocated hip in an infant is generally much easier than in an older patient. In infants under six months of age, a dislocated hip can usually be reduced by positioning the dislocated hip in flexion and mild abduction. If the affected hip joint is reduced adequately and is maintained in an orthosis for 10 to 12 weeks, the joint will usually remain stable and the hip joint will typically undergo normal development. Von Rosen[617–622] developed a molded metal splint to hold the dislocated hips of infants in a reduced position. The Von Rosen splint is bent to fit the infant properly and can be adjusted for the child's growth. It has the disadvantage of requiring special hygienic care for diapering. Frejka[166] developed a pillow restraint that fits between the legs of the child to maintain the hip in flexion and abduction. The Frejka pillow is placed over the diaper and has been successfully used in children who have "luxated" hips. However, the necessity of reapplying the Frejka pillow after every diaper change increases the possibility of redislocation and greatly limits its use.

Independently, Felix Bauer (1880–1947) in 1934 in Vienna ("spreizband" or abduction band),[26,27] Marino Ortolani (1904–1983) in 1947 in Ferrara, Italy ("bretelle" or semirigid bandage),[439,440] and Arnold Pavlik (1902–1962) in 1950 in Brno, Czechoslovakia, developed similar harnesses to treat DDH. The three harnesses are almost identical in their mechanisms of function. The Pavlik[447] harness combines gentle flexion and passive abduction for the acquisition of hip reduction and stabilization. Currently, the Pavlik harness is

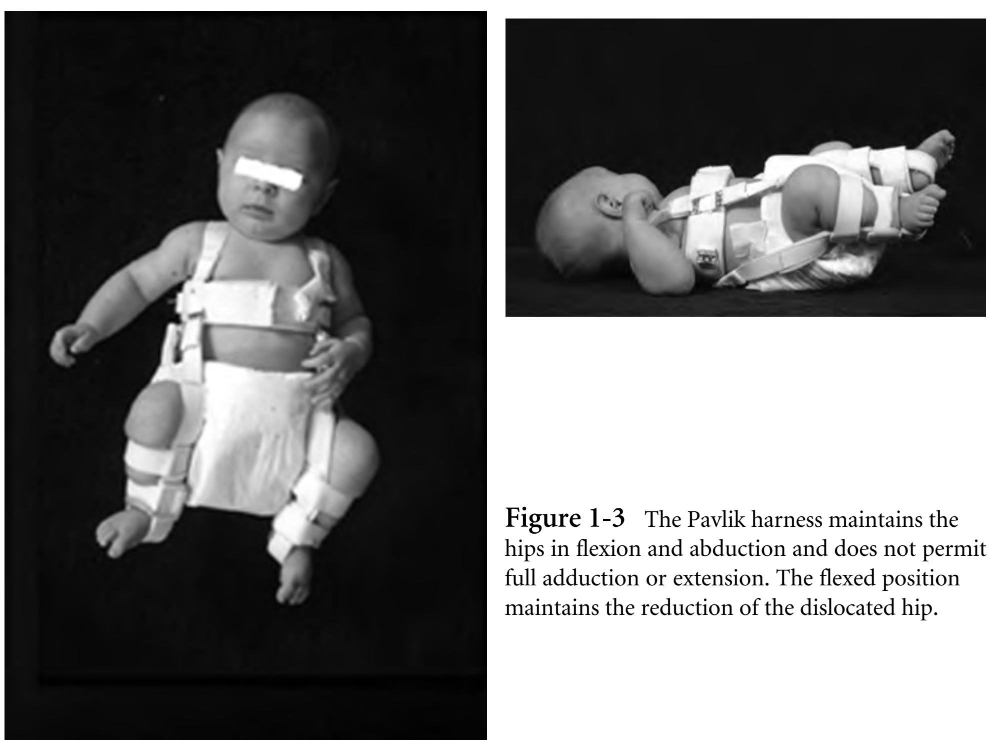


Figure 1-3 The Pavlik harness maintains the hips in flexion and abduction and does not permit full adduction or extension. The flexed position maintains the reduction of the dislocated hip.

the most commonly used orthosis for treating infants up to about 6 months of age with DDH, and the outcomes of treatment are excellent.

Treatment of a persistently dislocated hip in a child over 6 months of age with a Pavlik harness is difficult. Most newborn dislocated hips reduce with the Pavlik harness; however, some hips will not reduce and will require a closed or open reduction. In cases in which the dislocation is not treated during infancy, structures about the hip contract, making the dislocation extremely difficult to reduce. In these more difficult dislocated hips, techniques for reduction range from traction to manipulations or extensive operations. Maintenance of the reduction is usually by prolonged casting or orthosis. Some hips that were persistently dislocated will continue to have dysplasia after successful reduction and will require operations to correct the persistent bony dysplasia.

Operative Treatment of DDH

In 1912, Ludloff[360] reported a medial operative approach to the dislocated hip through the adductor muscles, which allowed some hips to center better in the acetabulum. Postoperatively, these patients were maintained in a cast for six weeks. This approach has a high incidence of avascular necrosis of the femoral head and subsequently has lost popularity. Colonna[95] developed a two-stage procedure for reduction of the dislocated hip. Initially, a subcutaneous adductor tenotomy was performed and the patient was subsequently maintained in skin or skeletal traction on the dislocated side for two or three weeks. The skeletal traction allowed the soft tissue to stretch. In the second stage, the hip joint was exposed through an antero-lateral incision and the impeding tissue that blocked reduction in the area of the acetabulum was curetted. The femoral head was gently placed into the newly made acetabular socket and the leg was immobilized in internal rotation. If there was marked femoral internal torsion, a supracondylar osteotomy of the femur was performed several weeks later. This operative procedure allowed good reduction of the femoral head in the acetabulum; however, degenerative arthritis developed in young adulthood and the procedure was thereafter abandoned. In 1973, Derqui[128,129] described a procedure in which the medial aspect of the acetabulum was reamed to permit femoral head reduction and the proximal femur was rotated, varused, and shortened for the correction of the “intrinsic and extrinsic” hip dislocation factors. The Derqui procedure was associated with necrosis of the femoral head and later degenerative changes of the acetabulum and has since been abandoned. Crego and Schwartzmann (1948),[105,106] Pawels (1951),[448] and Somerville (1953)[533] performed open reduction of the dislocated femoral head through an anterior lateral operative approach and corrected excessive femoral torsion and valgus with a proximal femoral osteotomy at the time of open reduction. They reported better outcomes than previous articles.

In 1976, Klisic[316] described a one-stage operation on older children, which consisted of an open reduction of the hip joint through an anterior lateral approach, shortening of the femur to avoid compression of the femoral head, correction of excessive femoral anteversion, reconstruction of the acetabular roof, and anterior transposition of the iliopsoas muscle. Postoperatively the hip was maintained in a cast until the soft tissue healed. Klisic reported good results, and many of the recent operatives are based upon Klisic’s procedure.

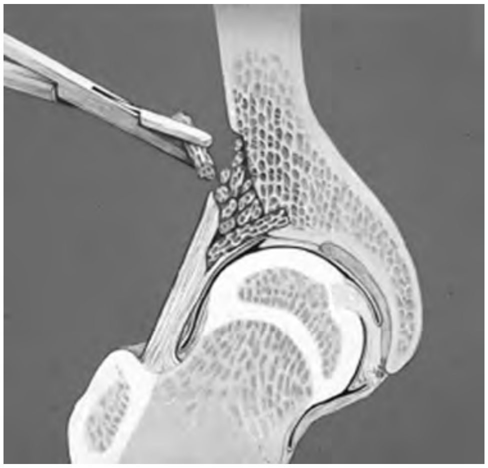


Figure 1-4 Schematic drawing of the shelf procedure (from Kumar and MacEwen, Shelf Operation in Congenital Dislocation of the Hip by Tachdjian, Churchill Livingstone, New York, p 701, Fig 37.10, 1982).

Residual Dysplasia in DDH

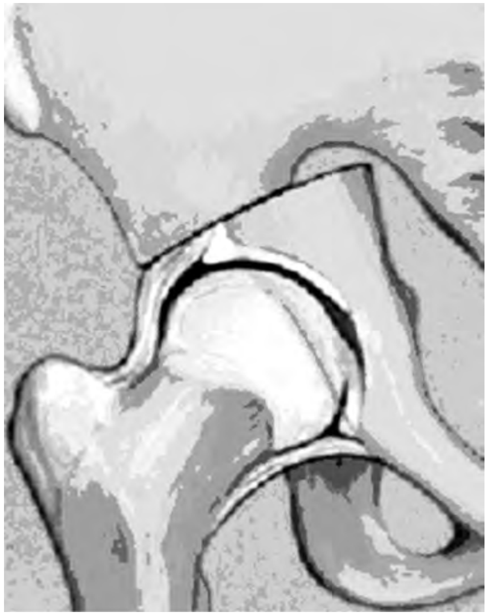
Residual dysplasia of the hip is a common problem associated with DDH treatment. Residual dysplasia may consist of a deformed acetabulum, a growth disturbance of the proximal femur, and a maldirection of the acetabulum or antiversion of the femur. Bowen[133] described five types of residual dysplasia: maldirected acetabulum, capacious acetabulum, lateralized acetabulum, false acetabulum, and proximal femoral dysplasia.

Historical treatments of persistent dysplasia consist of abduction bracing and operative procedures. The idea of brace treatment is that the femoral head centers in the acetabulum with the leg held in abduction and flexion, which encourages acetabular development. Numerous braces have been tried, but their success and role in treatment are still questionable.

Operative treatments of persistent acetabular dysplasia include extra-articular bony buttresses from the joint margin (shelf capsuloplasty operation),[188,189,191,192,541] correction of the abnormal slope of the acetabulum roof by incomplete osteotomies (acetabuloplasty)[3,120–124,450,451] redirectional osteotomies of the acetabulum (innominate osteotomies),[493–495] osteotomies of the proximal femur,[366,628] and osteotomies of the greater trochanter.

The shelf capsuloplasty procedure, which consists of building an extra-articular bony buttress from the joint margin to provide stability of the "reduced dislocation" (shelf procedure), was described by Gill[189,192] in 1935 and again in 1948,[191] and by Bosworth et al. in 1960.[48] In the shelf procedures, the lateral margin of the acetabulum is enlarged to support the femoral head. The hip capsule is the interposing structure beneath the shelf and the femoral head. Staheli (1981)[541] reported a "useful," "safe," and "simple" shelf procedure to correct a deficient acetabulum that could not be corrected by a redirectional pelvic osteotomy.

Chiari (1955)[75–78] reported a complete osteotomy of the pelvis above the acetabulum in which the distal segment containing the hip is slid medially. The proximal segment rests above the femoral head to prevent upward subluxation. Kawamura (1958)[301] reported a



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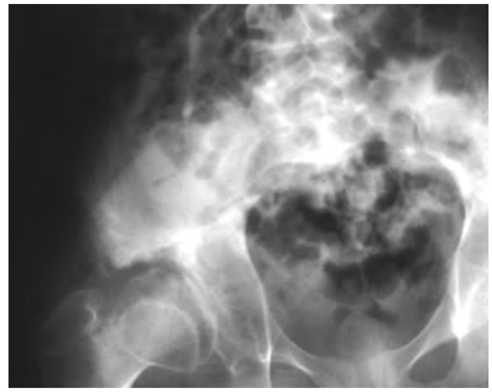
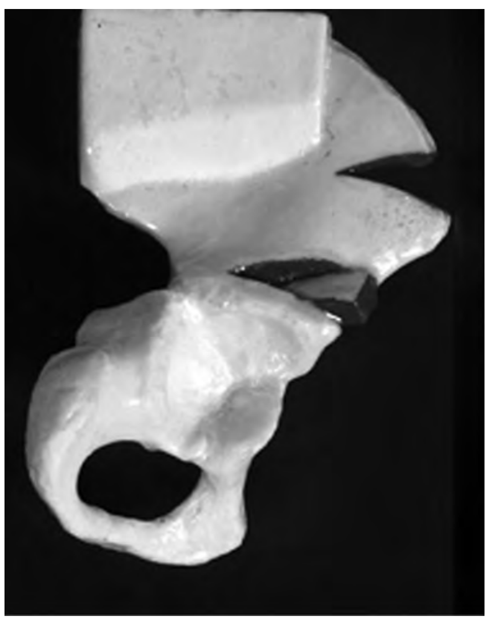


B

Figure 1-5 **A.** Schematic drawing of the Chiari osteotomy (from Dr. G. Dean MacEwen). **B.** Radiograph of the hip after a Chiari osteotomy.



A

B

Figure 1-6 **A.** Model of the Pemberton osteotomy: Notice that the graft is inserted anteriorly in the iliac osteotomy. **B.** Radiograph of the hip after a Pemberton osteotomy.

similar procedure with a dome osteotomy of the pelvis, which avoided the apparent incongruity between the round femoral head and the flat surface of Chiari's osteotomy.

Currently these capsuloplasty operations are useful as salvage procedures in treating the lateralized and false acetabulum types of persistent dysplasia.[133]

An acetabuloplasty is an operative procedure with the goal of creating a change in the slope of the acetabular roof by performing an incomplete opening osteotomy just above the hip joint. A bone graft is often used to maintain the position of the osteotomy. In these

A

B

Figure 1-7 **A.** Model of the Dega osteotomy: Notice that the graft is inserted from a lateral direction into the iliac osteotomy. **B.** Radiograph of the hip after a Dega osteotomy.

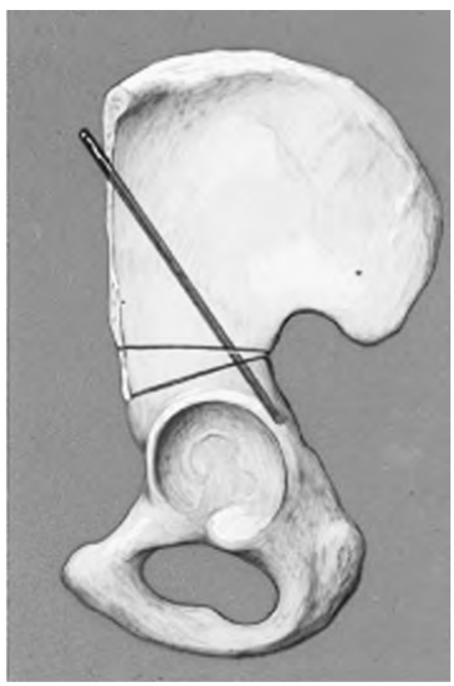


Figure 1-8 Schematic drawing of the Salter osteotomy.

procedures, the shape and volume of the acetabulum is changed to accommodate the reduced femoral head. Albee (1915),[3] Crego and Schwartzmann (1948),[106] and Wiberg[652] described types of acetabuloplasty for the treatment of a dislocation in older patients. Modifications of the acetabuloplasty were developed later by Dega (1953)[120–124] and Pemberton (1958)[450,451] in 1965. Pemberton performed his "capsular arthroplasty" of the acetabulum and an oblique subperiosteal intertrochanteric osteotomy in 398 hips in patients aged 3 to 12 years. He performed an iliac osteotomy, turning down the acetabular roof and increasing the depth of the acetabulum, on 50 hips in 40 patients from 18 months to 49 years of age. Tönnis (1969)[583,584,586,590,594] described an acetabuloplasty combined with a detorsion varus osteotomy of the proximal femur. Currently the acetabuloplasty procedures are useful in treating the capacious acetabulum type of persistent dysplasia.

The malrotation type of persistent dysplasia can be treated by a redirectional osteotomy of the acetabulum. In 1957, Salter[493–495] described an innominate osteotomy and reported excellent results. He considered the indications to include hips with anterior deficiency from a maldirected acetabulum, hips with a concentric reduction, and in patients who are 18 months or older in age. In adolescent or older patients, limited motion of the pubis can restrict the rotation of the acetabulum following Salter's osteotomy; therefore, additional osteotomies of the pelvis have been developed to allow specific acetabular correction.

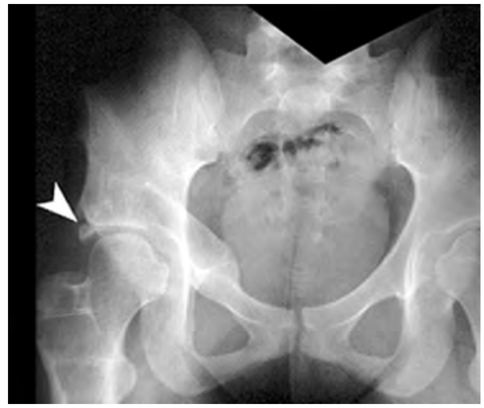
A double innominate osteotomy was developed by Sutherland and Greenfield (1977),[556] and good results were reported in 25 patients older than 6 years of age. LeCoeur in 1965[122,123] was the first to report a technique for triple osteotomy of the pelvis to enhance acetabular rotation in older patients. His procedure divides the ischium and the pubis close to the symphysis pubis. Hopf (1966)[262] designed a method that permitted all three osteotomies to be performed through the Smith-Petersen operative approach. In 1973, Steel[547,548] described a triple osteotomy for older children, which involves osteotomies of the ilium, ischium,

A

B

Figure 1-9 **A.** Model of the triple innominate osteotomy described by Bowen. **B.** Radiograph of the hip after the triple innominate osteotomy.

A



B

Figure 1-10 **A.** Model with a schematic drawing of the Ganz osteotomy. **B.** Radiograph of the hip after a Ganz osteotomy.

and pubis. Tönnis[586,590,594] developed a juxta-articular triple osteotomy and reported excellent results in 32 hips in patients up to 37 years of age. With his method the ischial osteotomy is above the sacropelvic ligaments, which commonly limit the mobility of the acetabulum. All radiographic measurements utilizing Ullmann's line, the Stulberg and Harris angle, and the center-edge angle of Wiberg were decreased to normal values. Kumar[329] described a modification of Steel's triple innominate osteotomy in which approximately 1 cm of bone is removed from the ischium to allow medialization of the acetabulum. More recently, at the A. I. duPont Institute, a triangular notch has been placed on the outer cortex of the ilium to enhance rotation of the acetabulum (Bowen triple innominate osteotomy).

Wagner, [625] Eppright,[143] and Ninomiya and Tagawa[425] reported osteotomies that were performed within approximately 1 cm around the acetabulum articular surface (peri-acetabular osteotomies). Avascular necrosis of the bone around the acetabulum occurred in some of these osteotomies that were very close to the articular cartilage. In 1988, Ganz et al.[178] described and presented the results of 75 peri-acetabular osteotomies that had been performed since 1984. The Ganz peri-acetabular osteotomy is recommended for older adolescent and adult dysplastic hips. This osteotomy corrects the hip congruence and does not change the inner diameter of the pelvis, which may be important in girls who anticipate vaginal deliveries.

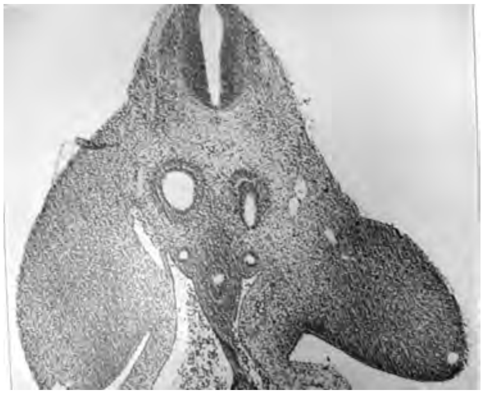


Figure 1-11 Transverse section through the lower limb buds in an 8.5-mm embryo (from Badgley CE: Etiology of congenital dislocation of the hip, J Bone Joint Surg 31A:341–56, p 347, 1949).

EMBRYOLOGY

The Normal Hip

Understanding the controversial problems related to DDH requires understanding basic concepts of normal hip joint development and growth. "Growth" alludes to the multiplication of cells and to the change in size (structure). "Development" refers to maturation of such structures and their activity. There are three periods of intrauterine life: the initial period (from fertilization up to two weeks), the embryonic period (two to eight weeks), and the fetal period (nine weeks to birth).[98,155,637]

The initial period, also known as the ovular phase, begins with fertilization. Less than 24 hours after ovulation and insemination, fertilization occurs; and between 24 to 60 hours after ovulation, cleavage begins. By the third day, the egg passes to the uterus in a morula stage. By the tenth day, there are an 8-mm blastocyte and a primitive blastema of the femur and os innominatum.[84,92,98,155]

The embryonic period extends from two to eight weeks, during which the major differentiation of tissues and organs occurs. In the third week (3 to 4 mm length), the lower limb bud protuberance appears. In the fourth week (5 mm), limb buds are well defined.[15,98]

In the fifth week (10 mm), blastemal cells are transformed into chondroblasts, which form the femur, ilium, pubis, and ischium. In the sixth week (12 mm), three stages of femur differentiation occur: cartilage at the center of the shaft, precartilage on the epiphysis, and blastemal cells at the trochanteric projections. Os innominatum blastemal differentiation begins first in the ilium and then in the pubis and ischium. In the seventh week (15 mm), initial chondrification progresses in the femur and triradiate form the os innominatum. The acetabulum is initially shallow (65–70°), deepening later to 180°. The division between the femoral head and acetabulum forms the hip joint. When the fetus is 17 mm long (seven weeks of gestation), a definite interzone develops between the femoral head and the innominate bone. The hip space interzone is divided into three layers. The middle layer, by diminishing density, will undergo an autolytic degeneration forming the joint space, syno-

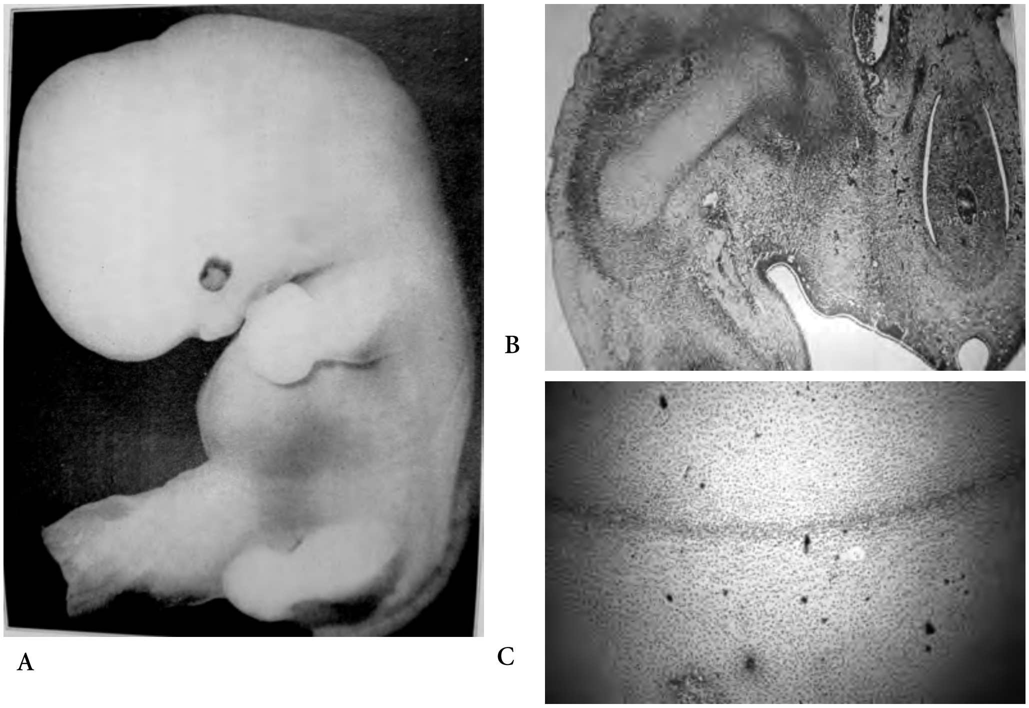


Figure 1-12 **A.** Photograph of a 14.8-mm human embryo showing the alteration of position of the limb buds (from Badgley CE: Etiology of congenital dislocation of the hip, J Bone Joint Surg 31A:341–56, p 348, 1949). **B.** Transverse section of a 14.8-mm human embryo showing the outline of femur (from Badgley CE: Etiology of congenital dislocation of the hip, J Bone Joint Surg 31A:341–56, p 348, 1949). **C.** Transverse section of a human embryo showing outline of the hip joint (from Bowen collection, source unknown).

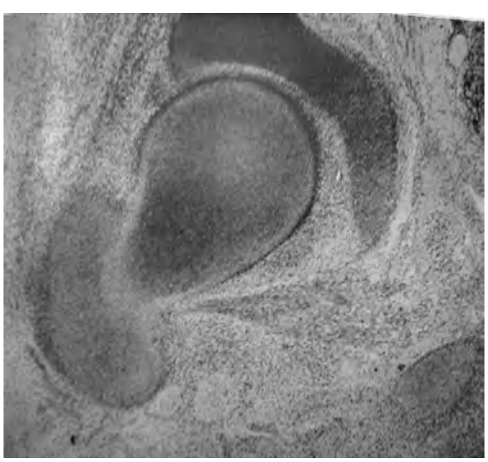
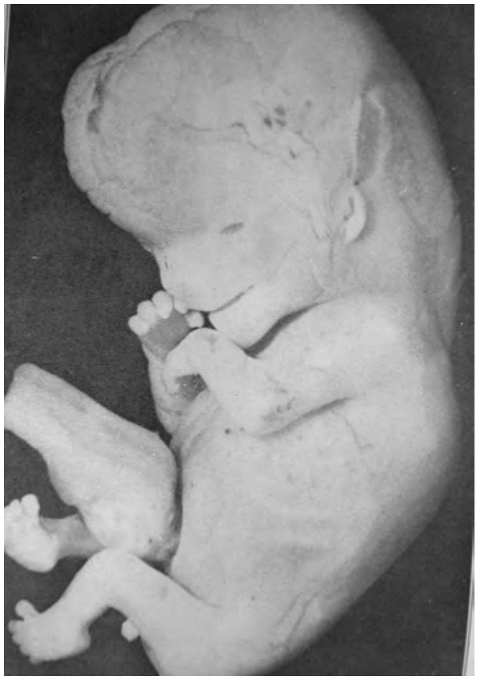


Figure 1-13 Photograph of a section of a 28-mm embryo demonstrating the hip joint (from Badgley CE: Etiology of congenital dislocation of the hip, J Bone Joint Surg 31A:341–56, p 349, 1949).



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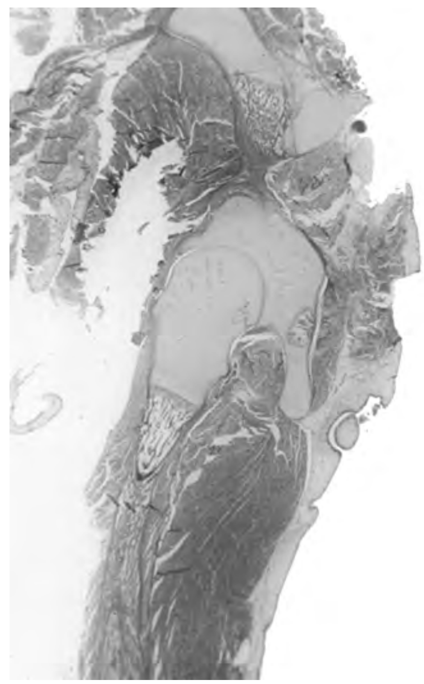

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Figure 1-14 **A.** Photograph of 33-mm human embryo (from Badgley CE: Etiology of congenital dislocation of the hip, J Bone Joint Surg 31A:341–56, p 350, 1949). **B.** Photograph of 33-mm embryo showing the capsule, glenoidal, labrum, muscles, and nerves (from Badgley CE: Etiology of congenital dislocation of the hip, J Bone Joint Surg 31A:341–56, p 350, 1949). **C.** Histomicroscopy of fetal hip (from Bowen collection).

vial membrane, and ligamentum teres. The other layers form the acetabulum and femoral articular cartilage. The labrum glenoidale develops from a marginal condensation of blastemal cells along the acetabular rim. The external side of the capsule is formed by fibroblasts and the inner layer forms the synovial lining. From an orderly arrangement of cells that appear as primitive fibroblasts aligned by the femoral head, the ligamentum teres is formed simultaneously with the opening of the joint cavity by vacuolization, deterioration, and rupture of the cells along its margin. Across the inferior portion of the acetabular rim, the transverse ligament emerges. At 20 mm of embryo length, the femoral neck forms an angle of inclination with the shaft of the femur and the hip muscle groups are formed. At 27 mm in embryo length (eight weeks), the differentiation stage is complete.[84,92]

The fetal period begins with the ossification phase and ingrowth of blood vessels in the femoral shaft. The hip joint space opens into a flattened cell slit cavity, which precedes neuromuscular development. Strayer[551] observed cell splitting and degeneration at the joint margins between eight and nine weeks (37–45 mm) and thus proposed that hip development is definable as both a degenerative and a mechanical process. The hip joint is formed completely at 11 weeks (50 mm), and the femoral head has a diameter of 2 mm in a spherical contour at 11 weeks (50 mm). Trochanters are formed rudimentarily and femoral anteversion is between 5 and 10°. Acetabular articular cartilage is well differentiated and shows an anteversion of 70°.[14,15,637] At this development age, the fetal position maintains the hip joint in flexion, adduction and external rotation. Capsule, ligamentum teres, labrum glenoidale, transverse ligament, and muscle structures are completely formed. By the sixteenth gestational week (120 mm), the femoral head is 4 mm in diameter and the articulating surface is covered by mature hyaline cartilage. Muscular structures are completely developed and active function of musculo-skeletal units initiates and increases hip flexion. From the level of the lesser trochanter to the distal epiphyseal growth plate, the femoral shaft ossification is completed. Primary ossification centers begin in the ilium (38–39 mm) at the end of the embryogenic period and in the ischium (105–124 mm) and pubis (161 mm) early in the fetal period. Blood vessels originating from the epiphyseal and metaphyseal arteries enter from the periphery to the center of the femoral head. At this stage the main source of the blood supply of the proximal femur is from metaphyseal and epiphyseal vessels and scantily from the ligamentum teres.

The first half of prenatal development ends at the twentieth week of gestation, when the fetus measures 170 mm in length. The cartilaginous femoral head has a diameter of 7 mm and the femoral neck begins to elongate. Anteversion increases to 25–30° by birth. By

A

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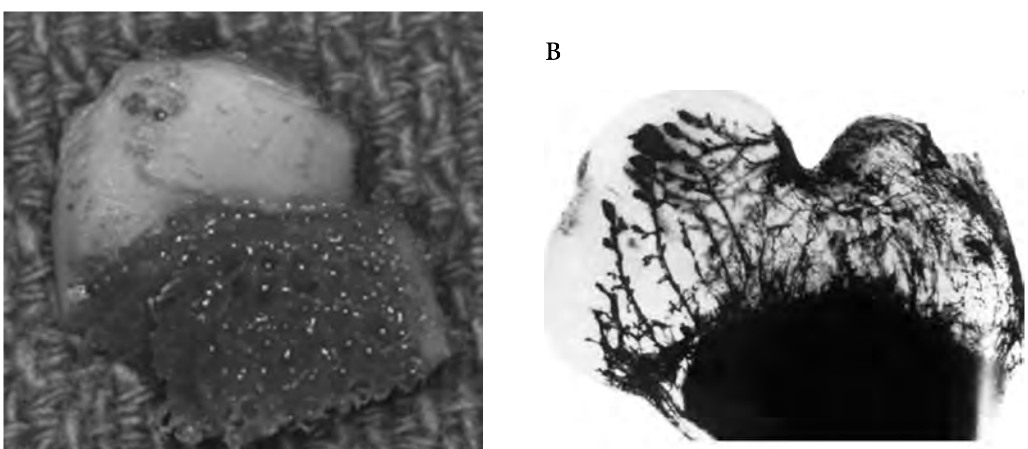
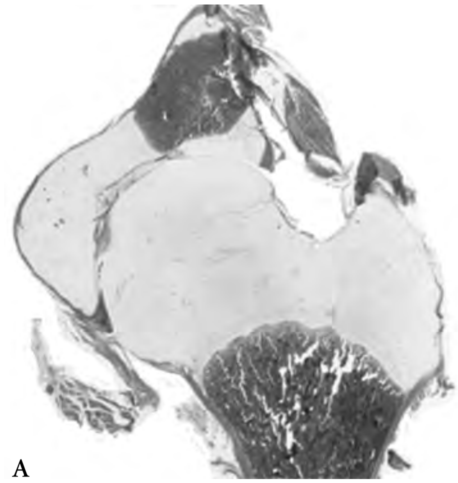


Figure 1-15 **A.** Femoral head at birth. Notice the cartilage canals, which contain both arteries and veins (from Bowen collection, source unknown). **B.** Femoral head at 18 days of age with india ink injection of the vessels within the cartilage canals. Notice that there is no vascular collateral circulation. (From Trueta J: The normal vascular anatomy of the human femoral head during growth, J Bone Joint Surg Br 39-B(2): 358–94, p 361, Fig 2, 1957. Copyright © the British Editorial Society of Bone and Joint Surgery. Reproduced with permission.)



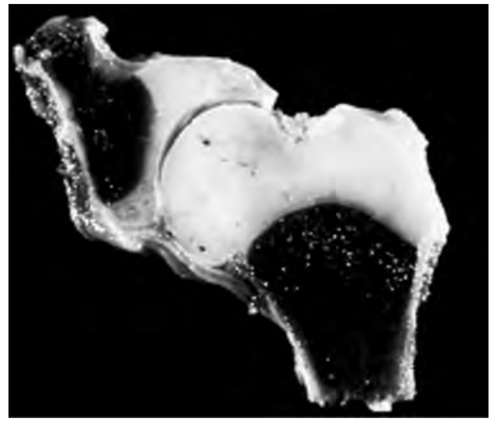


Figure 1-16 **A.** At birth the greater part of acetabulum is still cartilaginous, and the proximal end of the femur (femoral head and greater trochanter) consists of cartilage (from the Crawford Campbell, MD, collection). **B.** Photograph of a micrograph of a hip at birth (from the Dr. Crawford Campbell, MD, collection).

28 to 29 weeks, 250 mm in length, the vasculature becomes numerous and blood supply to the femoral head is perceptible. As the fetus develops to 285 mm in length (32 weeks), the femoral shaft ossifies to the level of the trochanter, which is cartilaginous. The ischium and ilium are almost completely ossified.

At 35 weeks (308 mm), the hip growth involves only increase in size. The normal hip growth is dependent upon the effects of position, pressure, and concentric motion.[84,92,155,156]

The Abnormal Hip

The cause of DDH remains unknown, but there is no doubt that ethnic and genetic factors have an influence on its occurrence. A high incidence of DDH is observed in white neonates in western and northern Europe[1,18,316,384,444,565] and a very slightly higher incidence in Canada and the United States, [544,632] in Lapps,[185,254] and in North American Indians.[64,88,91,325,467,640] In contrast, much lower incidences are found in Africans[140,457,525] and Chinese.[258,259] The influence of positive family history is substantial when compared with the general population. Most studies of dysplasia and dislocation of the hip have shown that girls are more involved than boys by a proportion of four to six times.[213] Faber and Von Rosen[151,617–622] elaborated on a hormone theory first put forward by Thieme et al.[578]

Genetic factors[40,65,136,662,663] are related to abnormal development of the hip in at least three periods in intrauterine life: around the twelfth week of gestation, at the eighteenth week, and the final four weeks of gestation. At the twelfth week the newly formed hip joint is vulnerable; the joint capsule is defined, but it is not strong and the first major positional change occurs, positioning the lower limb in internal rotation. This position forces the hip joint to function as a pivot point, and the joint must be stable to support the forces involved. During this period, synchronized neuromuscular development must occur to avoid unbalanced forces on the hip joint, which may produce dislocation. If the hip joint dislocates at this time, it will continue in dislocation until birth, becoming the most severe type of congenital hip dislocation. In this process, the acetabulum becomes shallow, a false acetabulum develops, the femoral head remains well formed but smaller than normal, the femoral neck remains short, and the greater trochanter remains small. This type of dislocation is typically referred to as teratogenic DDH.

Muscle tone and hip laxity may also be factors associated with DDH.[475] At the second period of risk, the eighteenth week of intrauterine life, the musculature is completely developed and active motion of the joint initiates. If capsular weakness occurs with unsynchronized innervational development in the muscles around the hip joint, the acetabulum (e.g., shallowness, underdeveloped limbus) cannot contain the femoral head and dislocation may result. The femoral head may obtain some irregularities because of the unbalanced muscle traction, and the acetabulum, without the stimulus to grow from the femoral head, will be small and deformed.

In the third period of risk, the last four weeks of gestation, the hip joint is normally developed. Mechanical aspects relating to the position of the fetus, like a breech position with extended legs,[653,655] hormonal action, oligohydramnios, and abnormal hip joint motion, are important factors in the development of DDH.[40,65]

Postnatal Period

Tachdjian[564-566] and Stanisavljevic[543,545] described the "hip-knee-hip triad" in newborns between the first and fourth days of life. The hip-knee-hip triad is observed during the physical examination and is diagnosed when the abduction of the hips is more difficult to achieve than hip or knee extension. In a normal infant, there is a mild flexion contracture of the hip and knee but hip abduction is good. Tachdjian followed these newborns with the hip-knee-hip triad without treatment and found that they often developed hip subluxation or dislocation. He concluded that overpull of the iliopsoas muscle was the major cause of the hip-knee-hip triad in newborns and the development of hip subluxation or dislocation in these patients. The hip-knee-hip triad may account for some congenital hip pathology that is missed in the physical examination at birth. The number of newborns who develop late dysplasia or dislocation of the hip is unknown.

ETIOLOGY

Mechanical, hormonal, genetic, gender, and environmental factors predispose the hip to dislocation. The intrauterine position is an important mechanical factor.[252]. The occurrence of DDH in the normal population with cephalic presentation is 0.7 percent.[561] Breech position is an important risk factor that is independent of whether the delivery is vaginal or by caesarian section affirmed that double or complete breech position has no increased risk, single or double footling breech has a 2 percent risk, and single or frank breech has a 20 percent risk of DDH.[40,65,476,657]

Certain hip postures in newborn infants predispose the hip to dislocation. Some American Indians utilize a cradleboard for carrying babies.[88,632] Japanese[649] and the Turkish in-

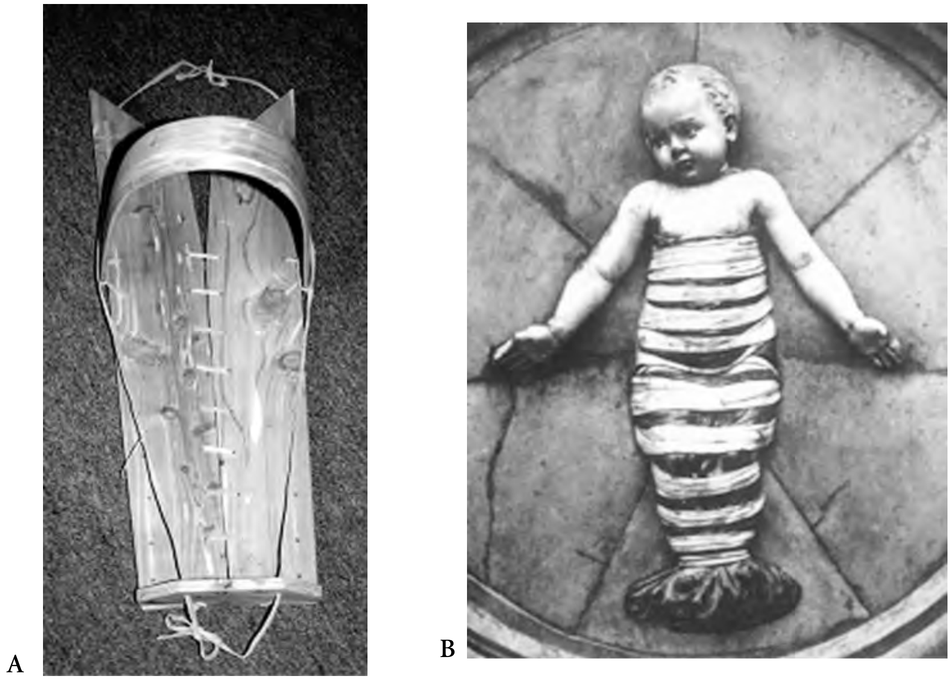


Figure 1-17 **A.** The cradleboard position utilized by American Indians (from Cherokee Museum, Cherokee, NC). The traditional swaddling position of babies maintain the hips in extension and adduction, increasing the risk of postnatal dislocation of the hip. **B.** A hospital emblem showing a baby in swaddling position. (Babies in a backpack or back sling assume a flexion and abduction position of the hips. This more physiologic position probably decreases the risk of dislocation of the hip.)

fants traditionally have their legs wrapped circularly in a cloth after birth. Infants whose hips are held in extended and adducted positions show a higher incidence of hip dislocation than infants carried at the waist, in a backpack, or in a tummy pack with the hips in flexion and abduction. Green and Griffin[206] showed that when one hip has an abduction contraction, the contralateral hip may become dysplastic.

Maternal hormones in female infants may induce neonatal ligament laxity, which contributes to hip dislocation. Vogel et al.[614] evaluated serum relaxin levels by cordocentesis in 2,185 newborns and analyzed hip laxity by an anterior dynamic ultrasound method. Six newborns had unstable hips, and only 3 of the 121 samples showed a serum relaxin level above the limit of 10 mg/ml. No patients with high relaxin levels had unstable hips. An association of high serum relaxin with hip instability was not observed. Hisaw and Wilkinson[653,656] demonstrated in guinea pigs and rabbits that a combination of neonatal position and hormonal joint laxity is necessary to produce DDH. In a study of children with DDH, Carter[65] found 33 percent of girls and 75 percent of boys showing hyperlaxity; however, girls paradoxically had higher rates of DDH. Thieme and Wynne-Davies[578] concluded from their research work that the hypothesis “congenital dislocation of the hip (CDH) is a result of an inborn error of estrogen metabolism” is not supported scientifically.[662,663] Hanson and Smith[221] used the term “fetal hydantoin syndrome” to define children of mothers who had ingested hydantoin anticonvulsants during gestation. Maternal ingestion of this drug has been associated with multiple systemic abnormalities, including cranio-facial anomalies, growth deficiency, and mental retardation. Trousdale[600] reported a case of a patient showing the most common orthopedic manifestations of this syndrome, which are postaxial digital hypoplasia and hip dysplasia.

Inleberger reported the incidence of DDH in identical and fraternal twins. In identical twins, if one child has DDH, the chance of the second twin having DDH was 34 percent, but in fraternal twins the chance of the second twin being affected was only 3 percent. Record and Edwards[477] found that 5 percent of siblings of children with DDH also developed hip dislocation, more in girls (10 percent) than boys (1 percent). Muller and Sendon[419] reported 264 patients with DDH. Twenty-eight of their patients (10.6 percent) had relatives with DDH. In 24 of the 28 patients, one relative was affected; and in the other four patients, two relatives were affected. The incidence of breech position associated with oligohydramnios is more common in male than in female newborns.[136] There is an 8–20 percent risk of DDH in association with torticollis,[561] a 25 percent risk with calcaneo-valgus feet,[612] and debatably a 1.5–10 percent risk with metatarsus adductus.[290] A higher incidence of DDH is associated with first-born children and with infants in a breech position.[136] This presentation occurs in only 2–4 percent of vaginal deliveries, twice as many in females as in males. The left hip is dislocated at birth at three times the rate of the right hip (about 60 percent in the left hip, 20 percent in the right hip, and 20 percent bilateral).

In conclusion, the etiology of DDH is multifactorial. Both environmental and genetic factors contribute to the development of hip joint instability. For example, a first-born girl delivered in the breech position, having ligament laxity and torticollis, with a positive family history of DDH, and having her legs strapped in adduction and extension, would be a very, very high risk for DDH.

Figure 1-18 Photograph of a child with torticollis, which is associated with a reported 8–20 percent risk of DDH.

Figure 1-19 Photograph of a child's calcaneovalgus foot, which is associated with a possible risk of DDH.

Figure 1-20 Photograph of a child's metatarsus adductus foot, which is associated with a reported 1.5–10 percent risk of DDH.

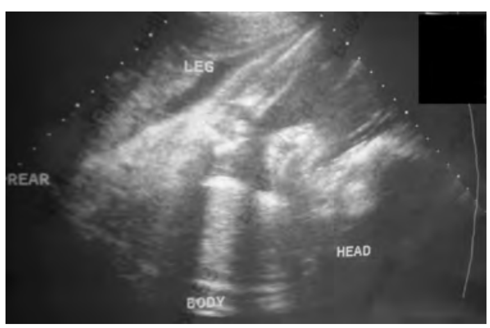


Figure 1-21 Ultrasound of a fetus in the breech presentation, which is related with a high risk of unstable hips. Notice that the hips are flexed and the knees are extended. This fetus was born with bilateral dislocated hips.

INCIDENCE

The incidence of DDH is controversial and maintains a strict relationship with geographic and racial variations. In some areas of the world, an endemically high incidence occurs, while in other places DDH is almost nonexistent. Bialik et al.,[38] after reviewing the literature on CDH and DDH regarding incidence, divided it into three main time periods: the 1920s to the 1950s, when incidence was arbitrarily estimated by various authors (0.06–40 percent for whites and 0 percent for blacks); from the 1950s to the 1980s, when it was based on clinical neonatal screening of unstable hips, adding to this incidence the late-diagnosed patients (0.04–16.8 percent); and the 1980s onwards, when it was based on the screening of neonatal hips using sonographic techniques (4.4 percent for blacks and 7.15 percent as the lowest incidence for whites). See Tables 1-1 and 1-2.

Table 1-1. Estimated Incidence of DDH in the Prescreening Period

Author	Year of publication	Incidence/1,000	Comments
Wessel	1918	50	
Putti	1933	130	
Slavik	1949	200	
Dega	1953	60	
Laurent	1953	0.6	
Severin	1953	0.9	
Getz	1955	1.2	Norway
		40	Laplanders
Record	1958	0.65	
Edelstein	1966	0	Blacks
Medalie	1966	9.8	
Lehmann	1970	0.7	British Columbia
		1.2	Vancouver
Ishida	1977	11–35	
Heikkila	1984	6.8	
Szulc	1990	68	
Kutlu	1992	5–13.4	
Norcuende	1994	1–1.5	
Patterson	1995	1.75	

Modified from Bialik et al., 1999.[38,39,140,185,471,477]

TABLE 1-2. Incidence of CDH/DDH, as Calculated in the Clinical Screening Period

		Incidence	
Author	Year of Publication	Neonatal	Late Diagnosed
Coleman	1956	9.14	
Andren	1958	0.97	
Dega	1959	44.5 (32.45)**	
Stanisavljevic	1961	10	
Barlow	1962	1.55*	
Von Rosen	1962	1.7	
Barlow	1962	14.9	
Finlay	1967	0.41	
Von Rosen	1968	4.7	+0.07
Hiertonn and James	1968	20	
Hiertonn	1968	20.7	
Weissman	1969	2.71	
Wilkinson	1972	5.9 (1.7)*	
Mitchell	1972	6.65	+0.12
Williamson	1972	79 in 34.840(+/-0.2%)	18 in 34.840
Mackenzie	1972	21.8	
Czeizel	1974	28.7	
Bjerkreim	1974	6.69	+2.01
Klisik	1975	7.51	
Fredensborg	1976	9.32	+0.07
Jones	1977	2.6	+0.23
Noble	1978	1.04	
Lehmann	1981	5	+0.8
6+0.3			
Tredwell	1981	9.8	
Hoaglund et al.	1981	0.1	
Seringe	1981	17	
Mackenzie	1981	53.7 (28,4)*	
Bertol	1982	6.02	+0.6
Mauning	1982	20	
Fulton-Fraser	1982	14.6	
Hansson	1983	0.07	
Cunningham	1984	5.58	+5.23
Palmen	1984	12	+0.6
Dunn	1985	19	
Bialik	1986	5	+2
Guarniero	1987	5.01	
Bernard	1987	9	+0.9
Tönnis	1987	1 to 83.9	+0.07–17.2
Bernard	1987	9.9	

Miranda	1988	6.4	4.5**	
Hadlow	1988	32	(16)*	
Vizkelety	1988	65	30	
Hazel	1989	0.5		+0,3
Tredwell	1989	10.1		
Jones	1989	15.5		
Burger	1990	9.8		+10.16
Macnicol	1990	5.56		+0.5
Daoud	1990	168.6		
Garvey	1992	10.39		+3.37
Poul	1992	18.45	10.9**	
Garvey	1992	0.9		
Bjerkreim	1993	10.5		+2.3
		2.3+0.8 luxations		
		+1.5 subluxations		
Lennox	1993	49.99		
Fiddian	1994	5.3		+0.3
Al-Umran	1994	43		
Darmanov	1996	6.07		
Yiv	1997	8.81		+1.68
Ferris	1997	12.8	(7.19)*	
Bajerova et al.	1998	5.5		+1.3

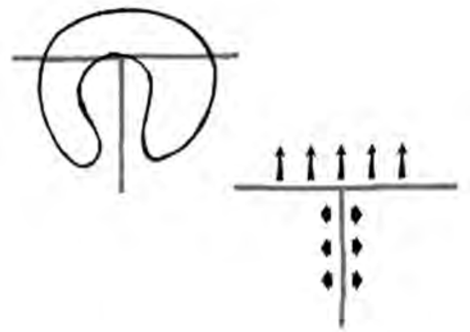
*Close to "true" incidence.
Modified from Bialik et al.,1999.[17,30,34,38,39,114,115,123,182,213,222,254,259,289,317,368,409,466,545,616,621,656,659]
**Infants' hips.

ANATOMY OF THE HIP

The hip is a diarthrodial joint. This means that there exists a spherical femoral head that articulates with a reciprocally shaped acetabulum. The joint cavity is lined with synovial membrane and reinforced by ligaments and surrounding musculature. Therefore, a considerable range of motion and stability is possible. The acetabulum is a cup-shaped cavity formed in its upper part by the ilium, infero-laterally by the ischium, and medially by the pubis. At the center of the lateral aspect of the innominate bone, these three bones merge to form the triradiate (Y) cartilage.

A Haversian fat pad fills the central nonarticular acetabular fossa. The hyaline cartilage articular surface has a lunate shape and laterally has a labrum (limbus) that deepens the acetabular cavity. In the adult, the average width of the acetabular labrum is 5.3 mm. The labrum is wider anteriorly and superiorly than posteriorly. The surface area of the acetabulum without the labrum is 28.8 cm^2 and with the labrum is 36.8 cm^2. The labrum adds 28 percent of potential surface area for femoral head articulation.[513] There is a nonarticular notch at the acetabular floor, and the transverse acetabular ligament spans

A



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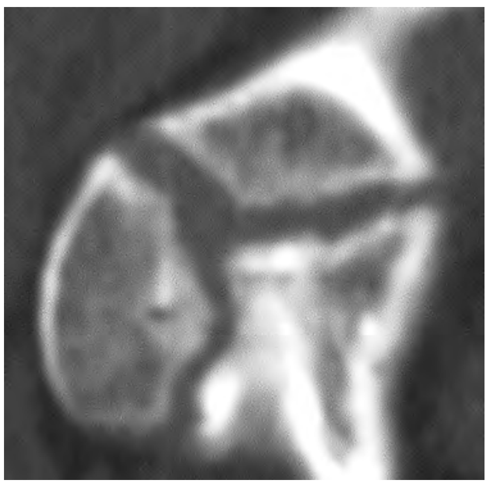
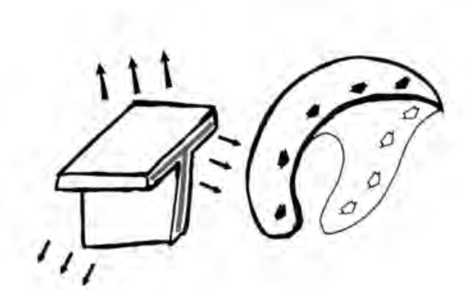


C

Figure 1-22 **A.** Model of the frontal view of the triradiate cartilage. The three primary ossification centers are in the ilium, ischium, and pubis and meet at the triradiate cartilage of the acetabulum. **B.** Schematic drawing demonstrating the normal growth of the triradiate cartilage, which offers height and width to the acetabulum. **C.** Photograph of a CT of the frontal view of the triradiate cartilage.



A

B

Figure 1-23 **A.** Schematic drawings of the triradiate cartilage showing its "Y" or "T" shape and the labrum. **B.** Schematic drawing showing growth of the lateral acetabulum and labrum, which offer depth to the acetabulum.

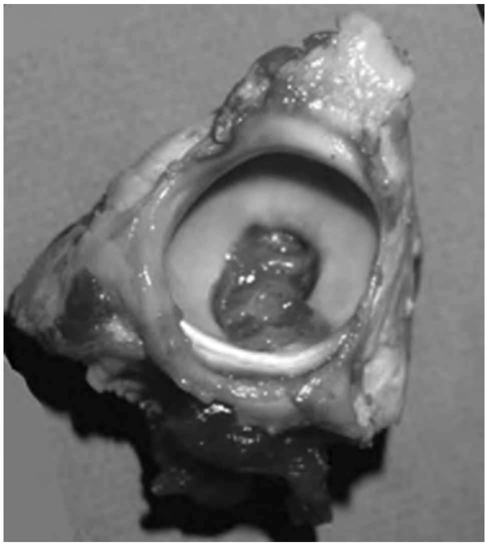


Figure 1-24 Photograph of the acetabulum.

the notch from the pubis to the ischium.[142]

During intrauterine development, the pelvis is preformed in cartilage and the ossification occurs from eight centers,[211] three primary and five secondary. These primary centers are in the ilium, ischium, and pubis and meet at the triradiate cartilage of the acetabulum. The secondary ossification centers occur at the crest of the ilium, the anterior inferior iliac spine, the tuberosity of the ischium, the pubic symphysis, and the acetabulum growth cartilage. Ossification begins in the ilium, in the eighth or ninth week of fetal life, above the greater sciatic notch. Approximately four weeks later, the ossification of the ischial bone center begins at its upper extension into the acetabulum and in the superior pubic ramus between the base and the pubic tubercule. The ossification spreads out the three bones, but at birth the greater part of the acetabulum is still cartilaginous. In the eighth year of age, the inferior ischial and pubic branches are united, and by the age of 12 years ossification has developed into the acetabular fossa. Only a Y growth cartilage remains. By puberty, several small secondary centers appear in the triradiate cartilage and fusion occurs. Before puberty, the secondary centers ossify and fuse with the rest of the pelvis.

The proximal femur is composed of the femoral head and neck and the greater and lesser trochanters. During prenatal and postnatal development, femoral head shape is spherical. In the third trimester, fetal size increases rapidly, which may restrict a full range of joint movement. Biological plasticity can change the shape of the femoral head to "out-of-round" (ellipsoid).[430] The femoral head joins the femoral neck at the subcapital sulcus. The deepest part of the neck and the lateral and medial head hold the intra-articular subsynovial vascular ring.[358] Studies conducted by Chung[82] on dried adult or macerated adolescent proximal femur specimens have shown that blood vessels penetrate the femoral neck most often laterally and medially, supplying the proximal femur surface. Blood vessels divide in the great trochanteric fossa before they pass into the capsule to the femoral head and neck or continue laterally to supply the greater trochanter.

From the anterior aspect of the greater trochanter to the lesser trochanter of the femur a slight bone ridge extends. This is the intertrochanteric line, where the iliofemoral ligament is attached. The trochanteric crest occupies a similar position posteriorly between the trochanters and is the insertion point for the short external rotator muscles (piriformis, obturator internus, gemelli, and quadratus femoris muscles). The gluteus medius and minimus muscles attach to the upper and lateral greater trochanter, and the psoas muscle attaches to the lesser trochanter.

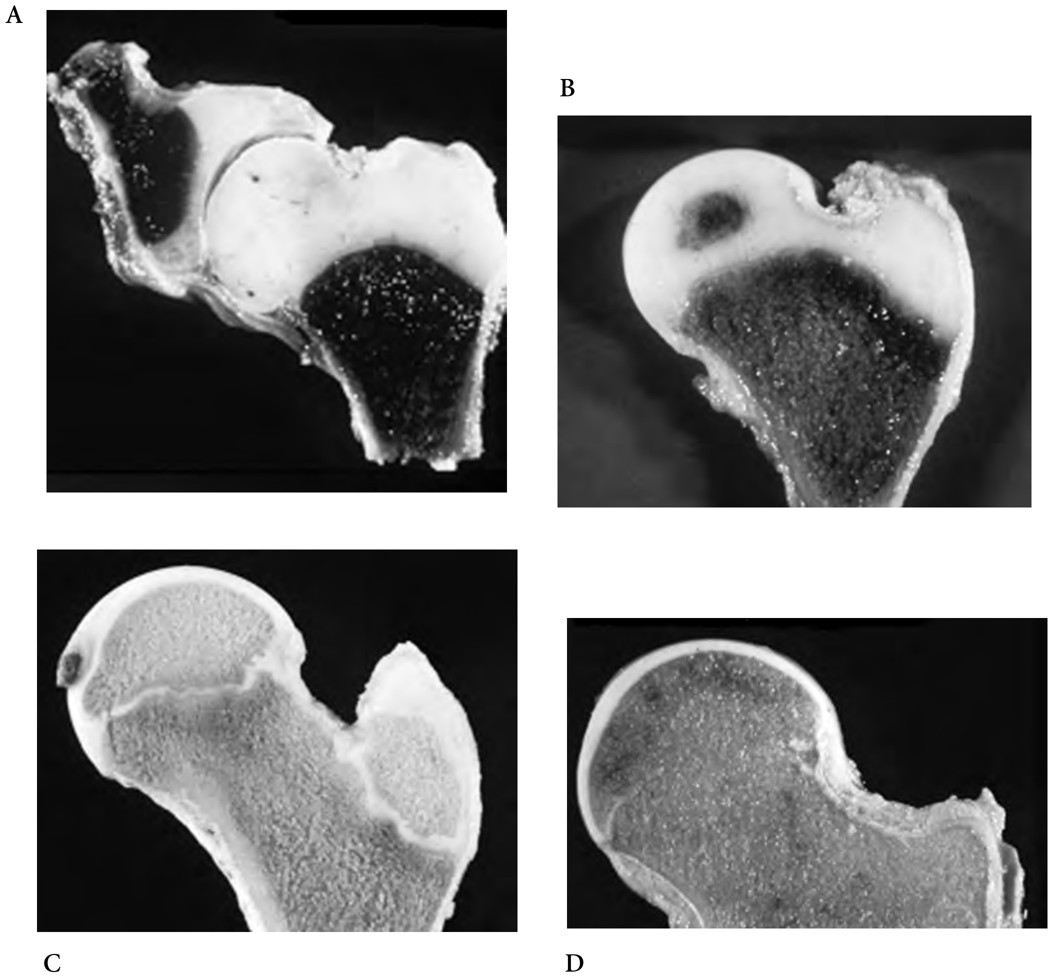


Figure 1-25 Photograph of sagittal sections through the upper end of the femur (from the Crawford Campbell, MD, collection). **A.** Birth. **B.** Two years. **C.** Adolescent. **D.** Mature patient.

The synovium extends from the subcapital sulcus to the femoral neck base, at this level reflecting upward to the inner capsule surface, continuing over the acetabular labrum, and finally fixing itself to the acetabular rim.[84] In the acetabulum, the synovium surrounds the ligamentus teres, passes above the transverse acetabular ligament, and fixes itself to the Haversian fat pad, which covers the many intra-articular ring blood vessels on the lateral and medial subcapital sulcus with fat. Another, but not constant, blood supply to the medial femoral neck and head comes from the peripheral capsule attachment at the femoral neck base: it is a capsular reflection covered with synovium, known as the *retinacula of Weitbrecht.*[634]

The internal architecture of the proximal femur is composed of articular cartilage, growth plates, the secondary ossification centers in the femoral head and greater and lesser trochanters, mamillary processes, the perichondrial fibrocartilaginous complex, Ward's and Babcock's triangles, and the calcar femorale.[8,180,181] At birth, the femoral shaft is mainly ossified and the entire femoral head consists of cartilage. At this point, the common physis of the femoral head and greater trochanter is above the level of the lesser trochanter, whose physis is parallel to the longitudinal axis of the femur and whose cell columns are perpendicular. In the opposite situation is the physis, whose cell columns are parallel to the femoral shaft and whose contour is transverse to the longitudinal axis. At the histologic level and coextensive with the greater trochanter are the lesser trochanter and femoral head, which persist throughout the greater part of postnatal development.[430] During the first six months after birth, the cartilaginous head is invaded by osteogenic cells, and between four and seven months, the secondary ossification center appears, forming the epiphyseal growth plate or physis, which advances up to the femoral neck and fuses with the metaphysis in adolescence. Like the proximal femoral physis, the greater trochanter also fuses in adolescence (see Table 1-3).[162]

Table 1-3. Chronology of Growth Plate Fusion in the Proximal Femur and Acetabulum

Location	Gender	Age at fusion As early as	In at least 50%
Femoral head	Male	14 yr	17yr
	Female	13 yr 4 mo	14 yr
Greater trochanter	Male	15 yr 10 mo	16 yr
	Female	14 yr 4 mo	14 yr
Triradiate cartilage	Male	13 yr 7 mo	15 yr
	Female	10 yr 6 mo	13 yr

From Flecker, 1942.[162]

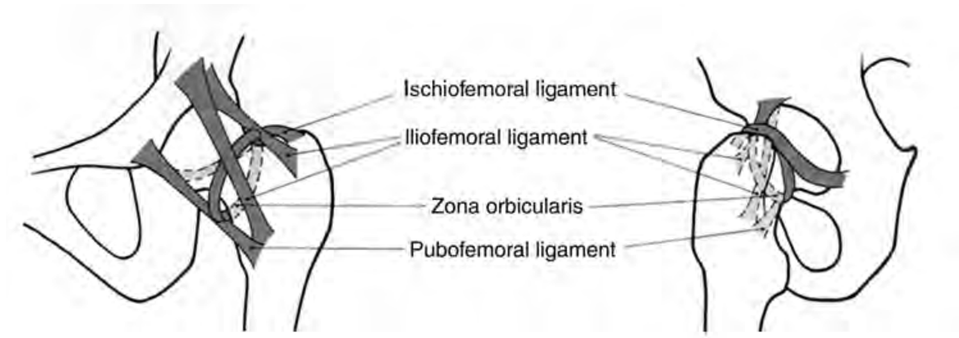
The junction between the physis and metaphysis is relatively smooth up to 1 year of age. From 14 months to 5 years, the mamillaries of the physis processes produce a progressively corrugated interface with an interlocking bone and cartilage that will provide physeal resistance during weightbearing in adolescence.[83] Ranvier described a tissue encircling the growth plate in human and animal embryos, the *zone of Ranvier.* This tissue is a fibrous band, which may be a progenitor cell pool for circumferential expansion of the growth plate and also contributes as a mechanical reinforcement to the growth plate.[83] A peri-

A

B

C

D



E

Figure 1-26 Photograph of a specimen showing the attachments of the capsule/ligaments. **A.** Anterior view: the ilio-femoral ligament ("Y" ligament or ligament of Bigelow) lies anterior to the joint capsule and spreads into a flat triangular band, which connects between the anterior inferior iliac spine and the intertrochanteric line of the femur. **B, C.** Posterior view: The ischio-femoral ligament (ligament of Bertin) lies posterior to the joint capsule and spreads into a flat triangular band, which arises from the ischium and posterior wall of the acetabulum and connects in a supero-lateral direction into the circular fibers of the capsule. **D.** Inferior view. **E.** Schematic drawing of the ligaments of the hip (modified from Tönnis D, Legal H, Graf R: Congenital Dysplasia and Dislocation of the Hip in Children and Adults, p 7, Fig 1.10, Berlin, Springer-Verlag, 1987).

chondrial fibrocartilaginous complex develops in the proximal femur from 8 to 12 months after the appearance of the secondary ossification center in the femoral head. This perichondrial fibrocartilaginous complex is intra-articular. At the age of 5 years it becomes a thick cartilage sheet, which blends into the greater trochanteric physis and, between the ages of 10 and 13 years, forms a thin rim at the articular aspect and femoral neck junction.

There are two sites of condensed lamellae bone in the femoral head and neck. One, the most prominent, extends from the upper femoral head to the lower neck and supports maximum compressive forces. The other begins at the upper femoral neck and ends laterally at the trochanteric flare, supporting the maximum tensile forces. Distal to the intersection of these condensed lamellae, where mechanical stress is minimal, exists an area of low bone density described as *Ward's triangle,* which is less obvious in small children but is easily identified in the roentgenograms of adolescents and adults.[241,242] Ward's triangle is easily recognized in normal femurs and in coxa vara, but is more difficult to see in coxa valga.

The calcar femorale is a thick cortical bone reinforcement spreading from the inferior femoral head along the neck to the medial shaft, supplying support to the femoral head during weightbearing. Hip joint stability is influenced by the form and orientation of the acetabular cavity in relation to the upper end of the femur. The most important components that affect the normal joint are the alignment of the femoral neck, the configuration (size, orientation, and depth) of the acetabulum, the coverage of the femoral head, and the peri- and intra-articular soft tissue structure and morphology. Morville[416] believed that the acetabulum depth decreases during the last three months of gestation. This was confirmed by Ralis and McKibbin[474] after 44 hip joints in children and fetuses from birth to 11 years of age were dissected and anatomic measurements were taken. They reported that "the acetabulum at birth is more shallow than at any time during its development." Gardner and Gray[180,181] have shown that the acetabulum continues to deepen by the growth of the limbus over the femoral head. However, this is a controversial factor implicated in human hip morphogenesis. Tan[569] evaluated the acetabular labrum in the adult hip and determined that the average width of the acetabular labrum is 5.3 mm (SD 2.6 mm). The labrum is wider anteriorly and superiorly than posteriorly. The surface area of the acetabulum without the labrum is 28.8 cm^2 and with the labrum is 36.8 cm.[2,569]

The hip is a ball-and-socket joint capable of triaxial motion. The normal range of motion differs with age. Neonates have a hip flexion contracture ranging from 50–80°[260] have more external rotation than internal rotation.[164] Even though a neonate has up to 40°, the limited motion of the hip prevents its detection by clinical examination. The normal motion of the hip at different age is expressed in Table 1-4.[207]

TABLE 1-4. Normal Hip Motion at Different Ages

(Mean + or – *d*)	Neonate	4 year	8 year	11 year	adult
Extension	30 (3.9)	29 (6.3)	27 (6.3)	25 (14)	9 to 19
Flexion	128 (4.8)	150 (12.5)	146 (11.3)	138 (14.5)	120
Abduction	79 (4.3)	54 (9)	49 (7.3)	45 (10.8)	39 to 42
Adduction	17 (3.5)	30 (5)	28 (6)	29 (6.3)	27 to 32
Internal rotation	76 (5.6)	55 (17.8)	54 (17.5)	48 (16)	32 to 44
External rotation	92 (3)	46 (16.8)	43 (17.5)	42 (15.3)	32 to 44

Modified from Green WB, Heckman JD, eds: The Clinical Measurement of Joint Motion, p 102, Table 11-1, Chicago, American Academy of Orthopaedic Surgeons, 1994.

RADIOGRAPHIC MEASUREMENTS[255]

The *Hilgenreiner line* is a horizontal line drawn on an antero-posterior radiograph of the pelvis connecting the superior aspect of the right and left triradiate cartilages. Hilgenreiner[255,256] also reported a "point" at the center of the proximal end of the femur. A vertical line arising from this point of the femur at right angles to the Hilgenreiner horizontal line allows determination of the distance *h,* which is a measure of the height of the upper end of the femur to the Hilgenreiner line. Usually the normal value of *h* is 1 cm, but in dislocated hips this value decreases. Distance *d* is a measurement made perpendicular from the *h* line to the triradiate cartilage. Distance *d* is 1.0–1.5 cm, but in cases of dislocation this value increases. Hilgenreiner also described the acetabular angle (alpha).

The *Ombredanne-Perkins line*[435,453] is a perpendicular line drawn through the outer edge of the acetabular rim at right angles to the Hilgenreiner line on an antero-posterior radiograph of the pelvis. The crossing of these two lines establishes four quadrants. In a normal hip, the ossification of the infero-medial metaphysis of the femur is in the inner lower quadrant. In a dislocated hip, the infero-medial metaphysis of the femur is usually in another quadrant.

The *acetabular angle (index)*[57,91,255,314,340,341] is formed by the intersection of Hilgenreiner line and a line drawn from the supero-lateral margin of acetabular ossification to the lower outer tip of the iliac component of the acetabulum along the Hilgenreiner line. The acetabular angle is a measure of the obliquity of the acetabular roof and is used as an index of acetabular growth. The normal acetabular angle decreases from infancy until the age of 8 years, when the adult value is reached. Harris[234,236] reported the upper limit of normal values as follows: under 1 year of age, less than 30°; 1 to 3 years of age, less than 25°; four years to adulthood, less than 21°. He proposed an angle of 21° or less as a normal acetabulum, 22–24° as mild dysplasia, and 27° or over as severe dysplasia.

Skaggs et al.[524] studied the variability in measurement of the acetabular index. They reported greater variability in dysplastic than in normal hips, and also greater variability before either closed or open reduction than after reduction. They also observed more significant variability after open reduction than after closed reduction. They concluded that the acetabular angle is more accurate after a closed reduction of a dysplastic hip. Spatz et al.[538] reported an accuracy of +/- 4° in the measurement of acetabular angle in children aged 6 months to 2 years when performed by experienced pediatric orthopedists. Kay et al.[303] suggested the same observer should read the radiographs, using the same goniometer and marking pen and with previous radiographs for comparison, to minimize variability in the assessment. The *center-edge angle of Wiberg* (CE angle)[651,652] is measured on an antero-posterior radiograph of the pelvis while the hips are in a neutral position. The CE angle constitutes an evaluation of the relationship between the center of the femo-

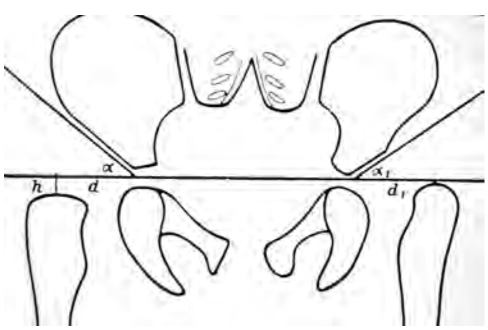


Figure 1-27 Drawing showing Hilgenreiner line, which is a horizontal line drawn through the triradiate cartilage at the most inferior aspect of the ilium bones, line d1 (from Hilgenreiner H: Hilgenreiner on congenital hip dislocation, J Pediatr Orthop 6(2), p 207, Fig 1, 1986).

A

B

Figure 1-28 **A.** Radiograph showing Perkins line (red), which is a vertical line through the outer edge of the acetabular margin. Perkins and Hilgenreiner lines divide the acetabulum into four quadrants. The inferior-medial margin of the femoral metaphysis is within the inner lower quadrant in the normal infant hip. **B.** Radiograph of an infant pelvis with a unilateral dislocated hip. Notice that the inferior-medial margin of the femoral metaphysis of the dislocated hip is not within the inner lower quadrant.

Figure 1-29 Schematic drawing of the acetabular angle (index).

ral head and width of the acetabular roof. To determine the CE angle, a line is drawn between reference points at the center of the femoral head (C) and at the lateral edge of the acetabulum (E). Then a vertical line is drawn from the center of the femoral head (C) upwards until it intersects with a horizontal line across the roof of the acetabulum. The angle of intersection of these two lines is the CE angle. The normal value is greater than 20°, and the acetabulum is considered dysplastic when this angle is less than 20°. The CE angle is not recommended in children less than 5 years of age because the femoral head ossification center may be absent or asymmetrically positioned and some children have multiple ossification centers.

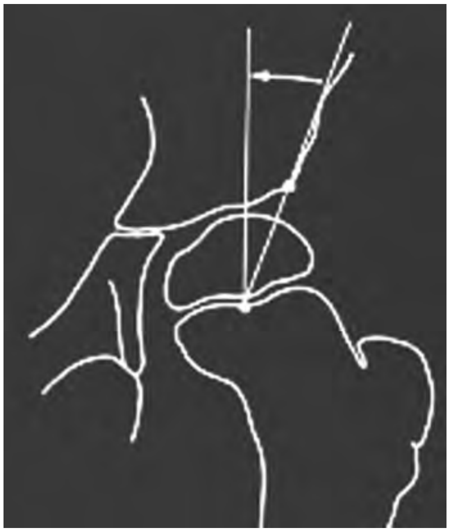


Figure 1-30 Schematic drawing of the center-edge angle. A normal value is greater than 20° and a dysplastic hip is less than 20°.

Laredo Filho[339] measured the CE angle of Wiberg on radiographs of 1,096 individuals (2,192 hips) whose ages ranged from 1 to 91 years. He demonstrated that the angle varied from 15–60° and that values below 26° and above 80° were uncommon. He also established the normal values and standard deviation for each year of age. For example, for the age of 18 years the CE angle was 37.6°, with a standard deviation of 6.36°. Thirty-five patients from different families with DDH and their nearest relatives were studied, and their radiographies showed 43 individuals with hip dysplasia. In a comparison between the DDH and the normal populations, he observed that the incidence of hip dysplasia was ten times greater in the DDH families. He also had difficulty in measuring radiographies from children below 5 years of age. Milani et al.[393] described a new methodology for measuring the CE angle of Wiberg using radiographs of 14 children utilizing Pavlik harness treatment. All hips presented positive Ortolani and Barlow maneuvers, as confirmed by Graf's ultrasound technique. The ages ranged from 45–135 months. Measurement of the CE angle using the method proposed by Wiberg and modified by Laredo[393] with computer graphics software developed for this purpose yielded similar values using both methods, and they concluded that it is possible to measure the CE angle from radiographs in children under 6 years of age.

The *Shenton and Menard line* is a gentle and continuous curve of the obturator foramen and the medial aspect of femoral neck on an antero-posterior radiograph of the pelvis. If this curved arch is disrupted, the hip joint is subluxed or dislocated. The *line of Calve* (ilium femoral arch)[59] is a continuous curve drawn from the lateral aspect of the ilium to the lateral border of the femoral neck on an antero-posterior radiograph of the pelvis. If this curved arch is disrupted, the hip joint is abnormal.

The *neck-shaft angle* is an angle formed between the femoral neck axis and the shaft of the femur axis on an antero-posterior radiograph of the femur. Strayer[551] measured the inclination angle of the femoral neck and shaft at 8 weeks of gestation and 23 mm in length. The values ranged from 150–155° but decreased to 130° at birth. It decreases from fetal to adult life in normal development[234,235] (Table 1-5). This angle increases in paralytic diseases such as polio, myelomeningocele, and cerebral palsy. An increased angle is called *coxa valga* and a decreased angle is called *coxa vara.*

A B

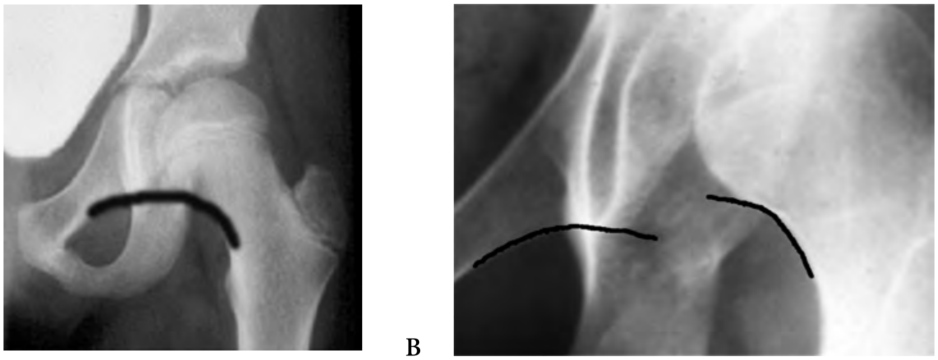


Figure 1-31 **A.** Shenton line drawn on a radiograph of a normal hip. The Shenton or Menard line is a gentle and continuous curve from the obturator foramen to the medial aspect of the femoral neck. (The line or arch of Calve is drawn from the lateral margin of the ilium to the lateral border of the femoral neck.) A break of the Calve line and the Shenton-Menard line suggests subluxation/dislocation of the hip joint. **B.** Radiograph of a dysplastic hip showing a break of the Shenton line.

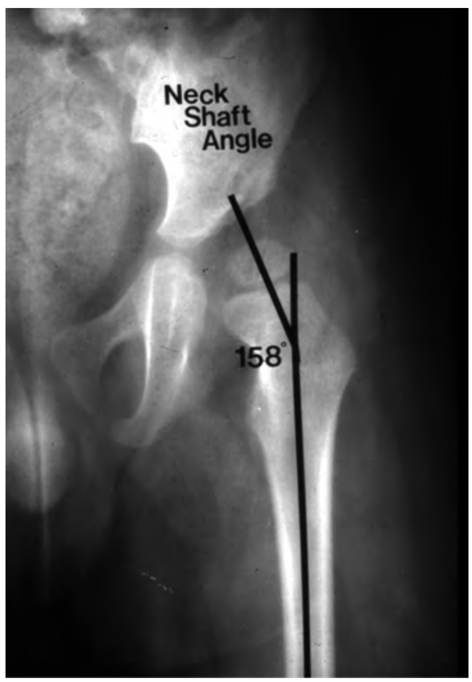


Figure 1-32 Radiograph with a drawing of the neck-shaft angle.

TABLE 1-5. The Normal Neck-Shaft Angles

Age:	Birth	1–2 yrs	2–4 yrs	4–6 yrs	6–8 yrs	8–12 yrs	Adult
Degrees:	137	145	143	135	134	133	125–120

The *femoral anteversion angle* is the angle formed by a line between the center of the femoral neck and femoral head to the coronal plane of the posterior aspect of the femoral condyles. *Femoral anteversion* and *femoral torsion* are frequently used interchangeably. Femoral anteversion cannot be measured in fetuses younger than 11 weeks because the hip joint and femur are not yet completely formed.[84] The value of femoral anteversion at birth ranges from +15 to +53°, with a mean of +30° (to a range of +18 to +35°, with a mean of +27.5°), and gradually decreases until adult life, when it ranges from +18 to +41°, with a mean of +14°. Several authors[135,365,366,368,371,489] have described radiographic methods for measuring femoral anteversion that demand accurate patient positioning and roentgenograms in two planes: an antero-posterior view to measure the neck-shaft angle and a lateral view to measure the torsion angle. However, this may result in errors of +/- 10°. Currently, computerized axial tomography (CAT scan) is frequently used to measure femoral anteversion.[160,271] CT slices are obtained at the hip joint level and through the patellae and femoral condyles with the knees in a neutral position.[454] In patients who are very obese, have severe coxa valga, or have severe osteoporosis, a satisfactory CAT scan may not be obtained.

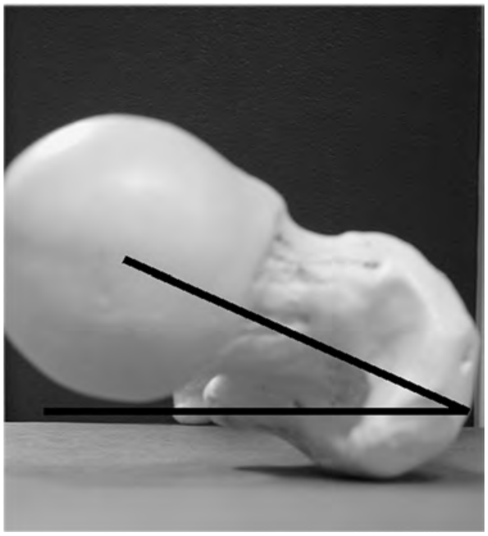
Craig[101] described a clinical method to estimate femoral anteversion. The patient is placed in a prone position with the knees flexed at 90° and held together. The investigator's thumb is placed on the posterior aspect of the greater trochanter and the other fingers are placed on the anterior aspect. The tibia is grasped with the investigator's other hand and the hip is rotated internally until the trochanter is parallel to the examination table top (first position). Then the hip is rotated externally until the tibia and foot point upward directly to the ceiling (second position). The anteversion angle is the angle formed by the tibia between the first and second positions.

The Acetabular Head Index

The percentage of coverage of the femoral head by the acetabulum is a parameter for the evaluation of the acetabular depth. It may be measured on an antero-posterior radiograph of the hip by measuring the diameter of the femoral head *a* and the horizontal width (depth) of the acetabulum *b.* Acetabular head index = *b/a* ´ 100. The normal value is up to 20 percent, and greater values are characteristic of subluxation or dysplasia.

The *acetabular angle of Sharp*[518] is formed by the intersection of a horizontal line between the inferior margins of the right and left "teardrops" and a second line drawn from the supero-lateral edge of the acetabulum to the inferior aspect of the teardrop on an antero-posterior radiograph. The angle is considered normal between 33 and 38°. Angles from 39–42° are in the upper limit of normality. Angles above 47° are considered to show dysplasia.[518]

The *physeal plate-shaft angle* is measured at the perpendicular intersection of a straight line drawn through the superior and inferior extents of the physeal plate of the proximal femur and the center shaft line of the femur on an antero-posterior radiograph of the femur. The growth plate at the upper femur in the fetus and infant is horizontal, and it becomes more vertical with growth.[242]



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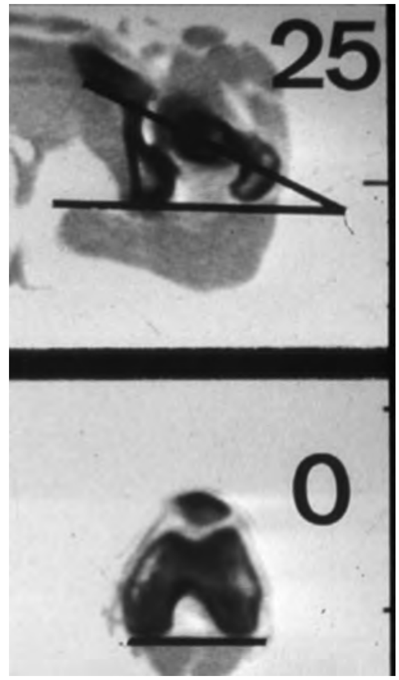


B

C

D

E

Figure 1-33 **A.** Photograph of a model of a femur lying on a table; the forward inclination of the femoral neck represents anteversion (torsion) B. Photograph of a CT of the femur. The femoral anteversion is the angle formed by a line between the center of the femoral neck and femoral head to the coronal plane of the posterior aspect of the femoral condyles. **C, D, E.** Photographs of patients with femoral anteversion. Notice the increased internal rotation of the hips.

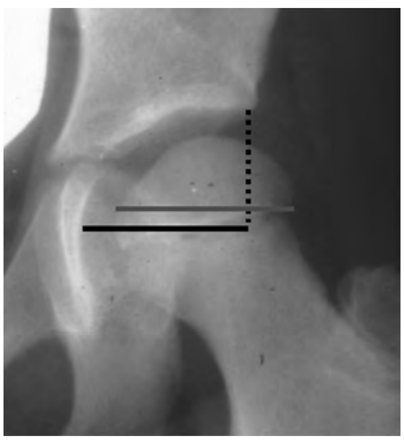


Figure 1-34 Radiograph with a line drawing of the acetabular head index. Acetabular head index is a method of assessing percentage of uncoverage of the femoral head by the ratio of the depth of the acetabular socket (black line) to that of the diameter of the femoral head (red line).

Acetabular Depth[97,284]

On an antero-posterior pelvic radiograph, a line *a* is drawn from the lateral edge of the acetabulum to the inferior tip of the teardrop. A line *b* is drawn perpendicular to line *a* to a point vertical to the most lateral aspect of the teardrop. The distance of line *b* represents the depth of the acetabulum. The acetabular depth is calculated by the formula *b/a ´* 100. A depth of less than 25 percent is pathologic.

U figure or *teardrop of Koehler*[4] is a normal radiographic appearance consisting of three lines: a medial line that corresponds to the wall of the lesser pelvis, a lateral wall that corresponds to the medial acetabulum, and an inferior arc that corresponds to the acetabular notch. Progressive abnormal widening of the teardrop is associated with subluxation of the femoral head.

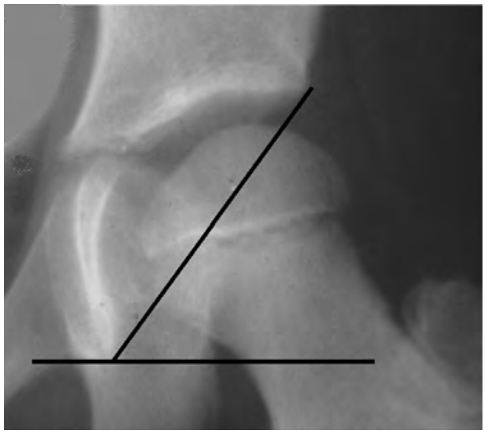


Figure 1-35 Radiograph with a line drawing of the acetabular angle of Sharp: The upper limit of normality is 42°.

Figure 1-36 Radiograph with a line drawing of the plate-shaft angle.

To calculate *instability index of Smith,*[529] three lines are drawn on an antero-posterior pelvic radiograph. First a vertical line is drawn through the center of the sacrum and pubic symphysis to determine the pelvic midline. Hilgenreiner and Ombredanne-Perkins lines are then drawn. The lateral displacement of the proximal femur is indicated by the ratio *c/b,* where *c* is the distance from the pelvic midline to the medial aspect of the proximal femur metaphysis and *b* is the distance between the pelvic midline and the Ombredanne-Perkins line. The normal value ranges from 0.6 to 0.9. The superior displacement of the femoral head is demonstrated by the ratio *h/b,* where *h* is the distance between the Hilgenreiner line and the supero-lateral aspect of the upper end of the femur. The normal value range from 0.1 to 0.2 and dislocation is identified by negative values ranging from –0 to –0.7.

Instability index of Reimers[479] is a ratio (expressed as a percentage) in which the denominator is the width of the entire femoral head (*A* = black line) and the numerator is the width of the femoral head that is lateral to the Ombredanne-Perkins line (*B* = red line). The instability index of Reimers = *B/A* ´ 100. Normal values are considered to be from birth to 4 years old, 0%, and from 4 to 16 years of age, 10 percent. Subluxation is from 33 to 99 percent and dislocation is 100%.

On an antero-posterior radiograph of the pelvis, a vertical line (*C,* for center line) is drawn crossing the pubic symphysis. The second and third lines are drawn tangentially to the ossified acetabular roof (line *A*) and the femoral upper metaphysis (line *B*). These lines must either be parallel or must only cross one another after line *C.* If lines *A* and *B* cross before line *C,* the hip is considered pathologic.

Epiphysis-triradiate cartilage angle (EY angle) of Cramer (1920) and Haike (1969)[102,218,219] shows the position of the epiphysis and is independent of the shape of the femoral neck. It must be measured with the thigh in a neutral position. Specifically, it is an angle between a

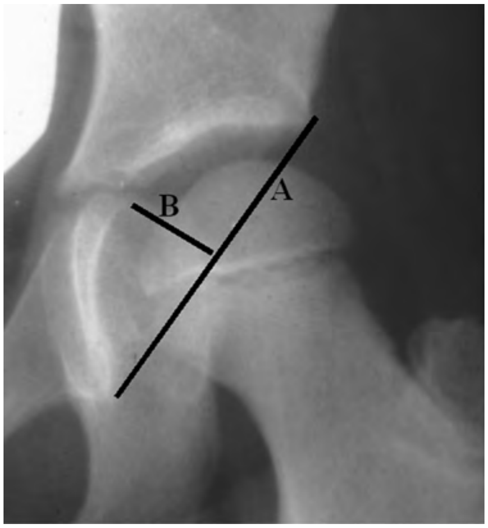


Figure 1-37 Radiograph of a line drawing of the acetabular depth.

Figure 1-38 Radiograph with a line drawing of the teardrop of Koehler.

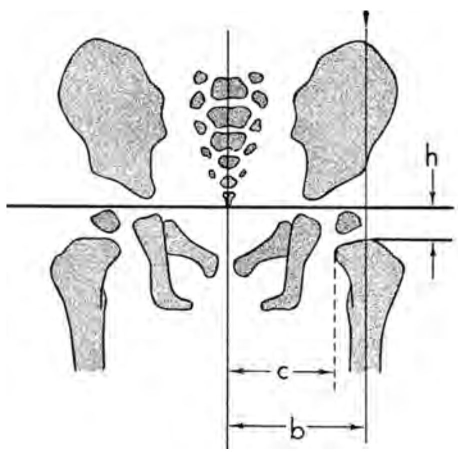


Figure 1-39 Antero-posterior radiograph of the pelvis with a line drawing of the instability index of Smith. This index is determined using three lines. The Hilgenreiner line passes through the triradiate cartilages. The Perkins line passes through the outermost border of the acetabular roof and is perpendicular to the Hilgenreiner line. The center line passes through the center of the pelvis and is perpendicular to the Hilgenreiner line. Measurements include distance from the center line to the most medial portion of the femoral neck (*c*); distance from the most superior part of the femoral neck to the Hilgenreiner line (*h*); and distance from the center line to the Perkins line (*b*). Values of *h* below the Hilgenreiner line are regarded as positive, and values above the line are negative. Lateral position = *c/b,* superior position = *h/b* (from Smith WS, Badgley CE, Orwig JB, Harper JM: Correlation of postreduction roentgenograms and thirty-one-year follow-up in congenital dislocation of the hip, J Bone Joint Surg Am 50(6):1081–98, p 1082, Fig 1, 1968).

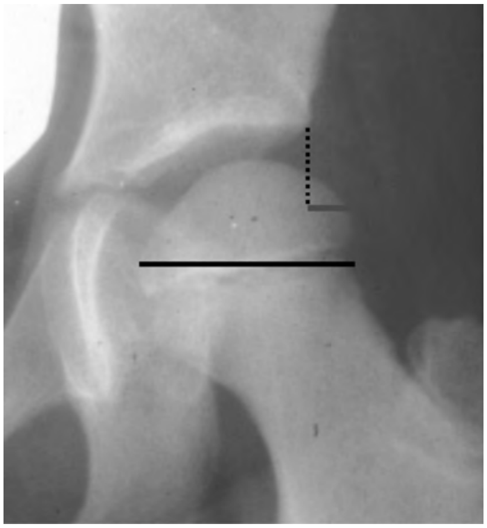


Figure 1-40 Antero-posterior radiograph of the pelvis with a line drawing of the instability index of Reimers. **A** = lower horizontal line and **B** = upper horizontal line. The instability index of Reimers = *B/A* ´ 100.

horizontal plane (Cramer) of the triradiate cartilage (Haike) and a line drawn through the lowest points of the epiphysis.

Epiphysis-femoral neck angle (KE angle) of Jäger and Refior[286,287] determines the position of the epiphysis. It is perpendicular to the femoral neck axis and the epiphyseal line.

Epiphysis-shaft angle of Jones and Immenkamp[289–292,584] is used for determining the position of the epiphysis. It is formed between the epiphyseal line and the shaft axis.

Shape of the surface of the epiphysis, method of Mose:[417] The sphericity of the femoral head may be determined with a template of concentric circles outlined on a transparent material. To be classified as spherical, the surface of the femoral head "must follow the same circle on the template within a variation of two mm or one mm."[342] Hefti developed a method of assessing sphericity and the contact area between the acetabulum and femoral head.[247]The *Calve line* is drawn from the lateral margin of the ilium to the lateral border of the femoral neck.

BLOOD AND NERVE SUPPLY TO THE HIP

The hip joint vasculature is complex and rich, but during postnatal development the blood supply to the femoral head alters with maturation. For this reason, numerous anatomical studies of the vascular supply to bone, cartilage, and soft tissue of this joint have been carried out. [82,429,599,601,606,639,658]

At birth, the descending branch of the superior gluteal artery, the ascending branches of the lateral and medial circumflex vessels, and the inferior gluteal artery form a ring of arteries that surround the hip joint.[107] Trueta[601,602] observed five main phases of the vasculature of the human femoral head. The first phase begins at birth. Vessels come laterally to the head and other vessels emerge from the shaft. Vessels from ligamentum teres are not constant. The second phase, the infantile phase, occurs from 4 months to 4 years of age. Blood flows from the metaphyseal and lateral epiphyseal vessels and there is minimal blood supply from the ligamentum teres. The third phase, the intermediate phase, occurs from 4 to 7 years: the epiphyseal plate has constituted a barrier between epiphysis and metaphysis and from the lateral epiphyseal vessels that only supply blood to the epiphysis. The fourth phase occurs at preadolescence, 9 or 10 years of age. Arteries from the ligamentum teres supply the epiphysis and become anastomosed to other vessel branches of the lateral epiphyseal arteries. In the fifth phase, the adolescent phase, the barrier of the epiphyseal plate is bridged by vascular anastomosis. Finally, the epiphyseal and ligamentum teres vessels are joined with the metaphyseal vessels.[612]

The *lateral femoral circumflex artery* stems from the profunda femoris near its origin or, less frequently, from the femoral artery. This artery crosses the iliopsoas tendon and goes between the two heads of the rectus femoris origin, extending to the anterior proximal femur. Its distribution is primarily to the trochanteric region.

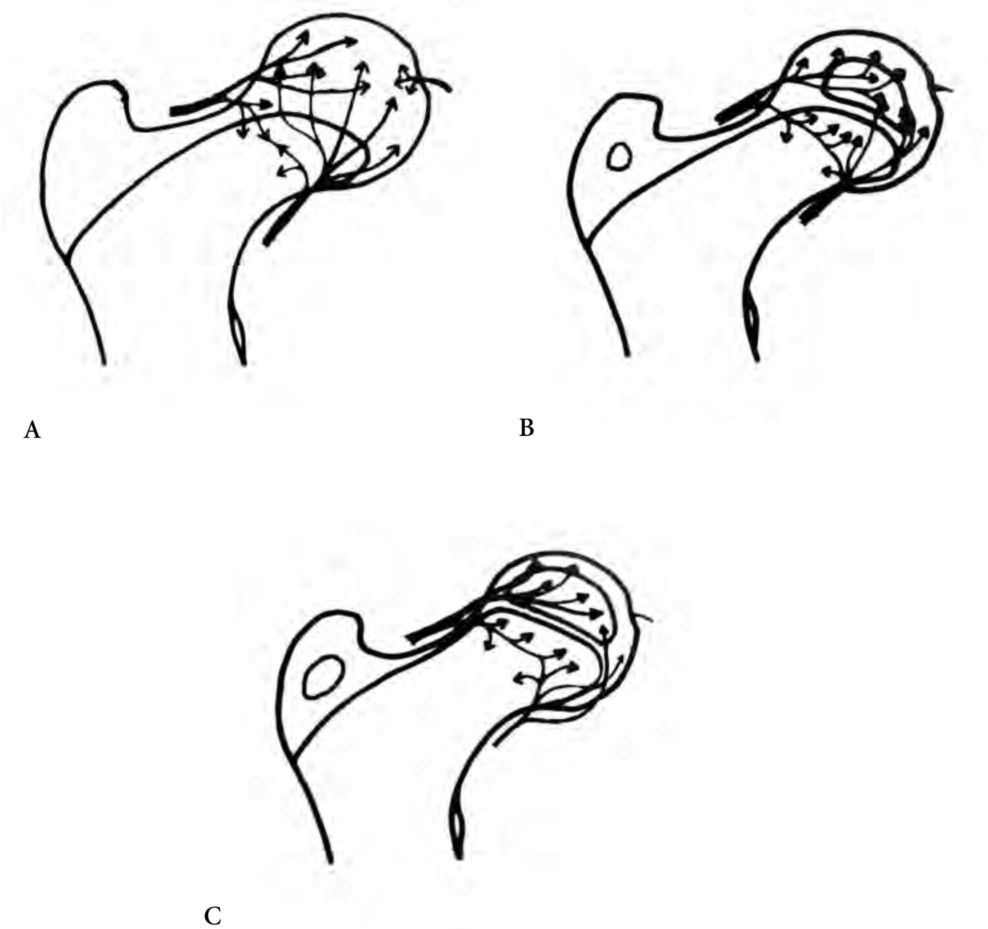
The *medial femoral circumflex artery* (circumflexa femoris medialis; internal circumflex artery) stems from the profunda femoris artery, or less commonly from the femoral artery. The medial femoral circumflex artery winds around the medio-posterior aspect of the femur, passing between the pectineus (medially) and psoas major (laterally) muscles, and then courses laterally upon the inferior border of the obturator externus muscle (between the obturator externus and the adductor brevis muscles). It then gives off five branches: the ascending branch (to adductors, gracilis, obturator externus), superficial branch, acetabular branch, descending branch, and deep branch.[183] The deep branch runs obliquely cranialward upon (posterior to) the tendon of the obturator externus and in front of the quadratus femoris muscle (space between the quadratus femoris) and anterior to the inferior gemellus, obturator, and superior gemellus muscles toward the intertrochanteric fossa. It then perforates the capsule of the hip just cranial to the insertion of the tendon of the superior gemellus and distal to the tendon of the piriformis muscle. The artery divides into two to six terminal branches (medial ascending cervical branches, also called superior posterior-lateral retinacular branches) that course beneath the reflected portion of the capsule onto the intrasynovial postero-superior aspect of the femoral neck. The ascending retinacular branches provide the blood supply to the osteo-chondral juncture of the femoral head (chondroepiphysis and medial portion of the growth plate). At maturity these vessels supply the major blood to the femoral head.

From the acetabular notch and the transverse acetabular ligament originates the round ligament (ligamentum teres), which attaches to the medial femoral head surface, called the *fovea.* The *ligamentum teres arteries* originated from the obturator artery branches in 54.4 percent of the 134 specimens studied by Weathersby.[639] In 23.9 percent there was an anastomotic connection between the obturator and medial femoral circumflex arteries near the adductor brevis muscle. In 14.9 percent the only branch to the fovea was furnished by the medial femoral circumflex artery. In the last 6.7 percent an acetabular branch from both the medial femoral circumflex and obturator arteries formed a direct foveolar artery to the femoral head. The blood supply is precarious, going to a small portion of the nearby head to which the arteries are attached, and are practically nonfunctional and supply little blood until the age of 8 years.[601] The first perforant artery supplies the posterior aspects of the greater and lesser trochanters, and the nutrient artery supplies the femur fatty marrow cavity.[107,658]

The blood supply to the acetabular fossa is from the posterior division of the obturator vessels. The acetabular branches (an artery and a vein) pass through the acetabular foramen, entering in the acetabular fossa, where they ramify in the fatty areolar tissue, and the branches radiate to the margin of the fossa and enter a nutrient foramina. The acetabular branches from the obturator and gluteal arteries frequently join at the obturator vessel ring and supply the inferior posterior portion of the acetabular rim and adjacent ligamentous capsule. The superior gluteal artery supplies the superior and posterior portions of the acetabulum, upper parietal ligamentous capsule, and a small portion of the greater trochanter.[7,82,84,639,658] The nutrition to the articular cartilage and outer area of the labrum is via the synovial fluid.[512]

The veins are parallel to arteries in the proximal femur. Venous blood flows from the capital femoral secondary ossification center by cervical inferior (medial) and superior (lateral) veins to the venous circumflex ring. At the superior (lateral) side, venous blood flows to superior and inferior gluteal veins, then to the obturator vein. From the inferior (medial) side, it goes to the femoral vein. Both obturator and femoral veins flow to the external iliac vein.[7,84]

The nerves that supply the hip joint are the same as those to the pelvic girdle and lower limb muscles: the femoral nerve, the sciatic nerve, and a branch from the obturator nerve.[599]



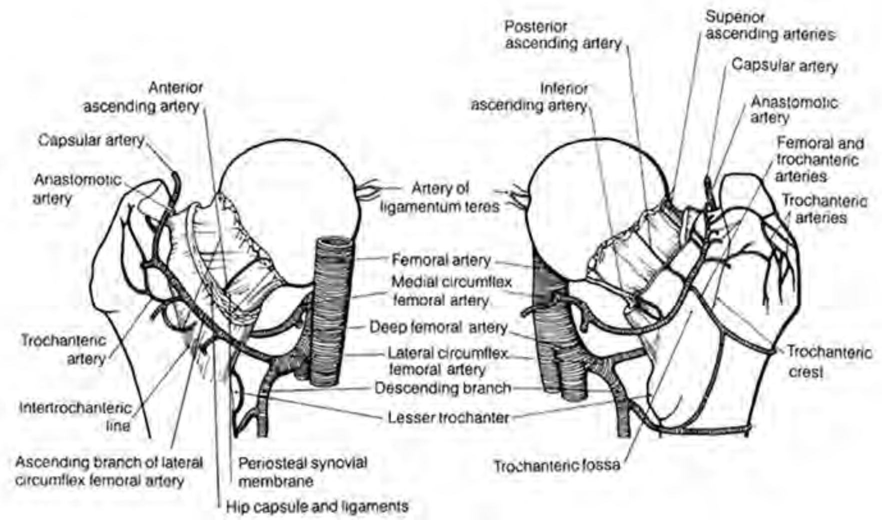


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Figure 1-41 Schematic drawings showing changes in the arterial vascular pattern of the femoral head during growth. **A.** Vascularization at birth. **B.** Vascularization between 4 months and 4 years. **C.** Vascularization between 4 years and 7 years. **D.** Vascularization from the seventh year until the end of puberty (modified from Visser JD: Functional treatment of congenital dislocation of the hip, Acta Orthopaedica Scand 55 (Suppl 206): 1–109, p 59, 1984). **E.** Schematic drawing of the anterior and posterior views of the vascular supply of the hip (from Tönnis D, Legal H, Graf R: Congenital Dysplasia and Dislocation of the Hip in Children and Adults, p 10, Fig 1.12, Berlin, Springer-Verlag, 1987). **F.** Photograph of the branches of the medial femoral circumflex artery (from Gauthier E, Ganz K, Krugel N, Gill TJ, Ganz R: Anatomy of the medial femoral circumflex artery and its surgical implications, J Bone Joint Surg 82-B: 679–83, p 681, 2000).

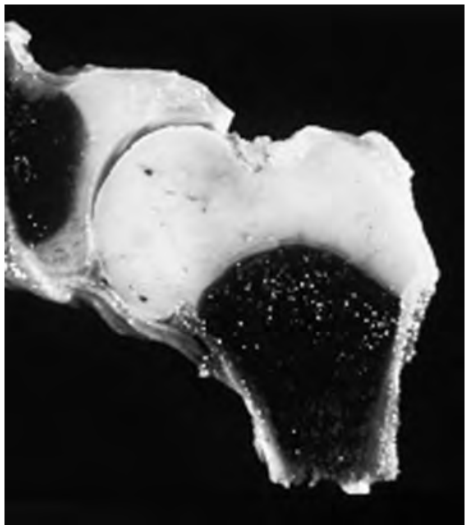

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Figure 1-42 **A**. Anatomic section of a newborn hip showing the cartilage canals, which contain arterioles and venules in the chondroepiphysis (from the Crawford Campbell, MD, collection). **B.** Histologic section of a newborn hip. **C.** Schematic drawing of blood supply to the femoral head (from Schwarz E: A typical disease of the upper femoral epiphysis, Clin Orthop Relat Res 1986 (209): 5–12).

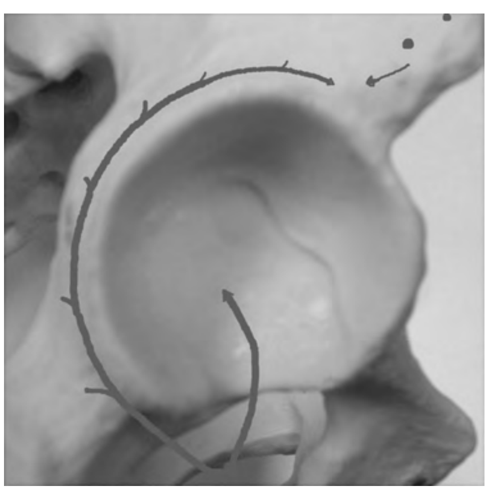


Figure 1-43 Schematic representation of the blood vessels of the acetabular fossa and rim of the acetabulum. The acetabular artery branches from the obturator and gluteal arteries frequently join at the obturator vessel ring and supply the inferior posterior portion of the acetabular rim and adjacent ligamentous capsule. The foveolar artery (which passes through the ligamentum teres to the femoral head) is derived from the acetabular artery. The superior gluteal artery supplies the superior and posterior portions of the acetabulum, upper parietal ligamentous capsule, and a small portion of the greater trochanter.

Chapter Two

The Natural History of DDH

Many authors have reported pathologic findings in the newborn period relating to developmental dysplasia of the hip (DDH) to be abnormalities of the acetabulum, labrum, ligaments, or proximal femur.[14,15,136,534,662] However, the only common factors observed in these reports are the elongation of the ligamentum teres and the joint capsular laxity at the time of dislocation.[387]

Barlow[18] (1962) reported that 1 in 60 infants is born with "instability" of one or both hips. These "unstable and dislocatable" hips are usually diagnosed during a neonatal screening examination, and approximately 60 percent improve spontaneously after one or two weeks. The physical examination generally shows full range of hip motion and equal leg lengths. By 2 months of age, 88 percent of these hips become stable.[17,18,278,289,663] Although most unstable hips resolve spontaneously, some of these joints developed subluxation or progressed to a complete dislocation. Hips that were dislocated completely at birth seldom reduce spontaneously, and the vast majority will become permanently dislocated hips unless treated.

NATURAL HISTORY OF DYSPLASIA WITHOUT SUBLUXATION

"Dysplasia" alludes to inadequate development of the hip joint, including the acetabulum, femoral head, or both.[92] Dysplasia without subluxation in childhood is usually asymptomatic, the physical examination is normal, and its diagnosis is often fortuitous. On radiographs showing dysplasia, Shenton's line is intact, the acetabular angle is increased, and the CE angle is reduced. The real incidence remains unknown, and without subluxation the natural history of dysplasia is not predictable. However, there is an explicit relationship between dysplasia and roentgenograph findings of degenerative joint disease in adults, particularly in females.[645,646] Observation of the opposite hip, the "health side," is mandatory. Portinaro et al.[463,464] described a notch at the superolateral part of the acetabulum where the iliac wing joins the acetabular roof in dysplastic and/or unstable hips. The notch can be observed by sonography and also in radiographs. Persistence of the notch is believed to represent damage to the lateral acetabular ring epiphysis and delayed maturation of the lateral acetabulum. They believed the notch to be a consequence of eccentric pressure on the acetabular rim. Stulberg and Harris[552,553] reported that 50 percent of their patients having dysplasia associated with degenerative joint disease suffered dysplasia in the opposite hip joint and would undergo their first reconstructive procedure before the age of 60 years.

Usually, degenerative joint disease does not occur prior to the end of the fourth decade in dysplastic hips without subluxation. Cooperman et al.,[97] in a roetgenograph study of degenerative joint disease in ten dysplastic cases, reported that none of these patients had degenerative changes prior to the age of 39 years. They showed joint disease at an average age of 57 years. Severin[514–516] reported that later results of the treatment of DDH seemed to be worse than had been expected. He concluded that if the acetabular roof has not developed, the femoral head tends to sublux or dislocate. The most important factors in achieving a normal hip are good development of the bony roof of the acetabulum and the cartilaginous limbus.

A

B

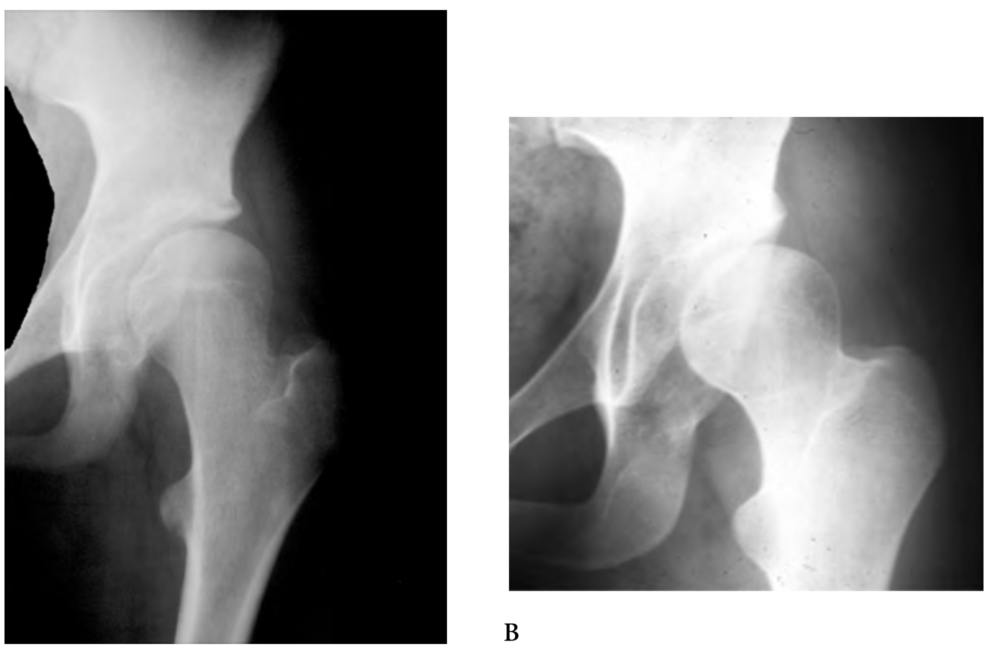
C

Figure 2-1 Dysplastic hip. **A.** Schematic drawing of a normal hip and a dysplastic hip that is well reduced (from Kumar SJ, MacEwen GD: Shelf operation, in Congenital Dislocation of the Hip, edited by Tachdjian MO, 695–704, p 700, Fig 37.8, New York, Churchill Livingstone, 1982). **B.** Radiograph of a notch at the supero-lateral part of the acetabulum where the iliac wing joins the acetabular roof in dysplastic and/or unstable hips (from refs. 463, 464). **C.** Antero-posterior radiograph of a hip showing the femoral head with AVN that is centered in the acetabulum, and an increased upward tilt of the lateral margin of a very dysplastic acetabulum.

NATURAL HISTORY OF SUBLUXATION

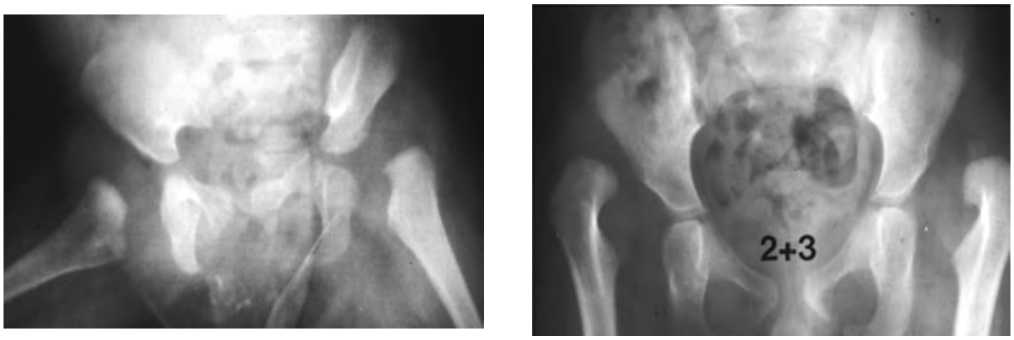
Subluxation is defined as a dysplastic joint with abnormal contact between the acetabulum and the femoral heads. The femoral head usually is displacing superiorly and laterally from the acetabulum. Wiberg,[652] in his studies of congenital subluxation, observed that joints reaching the age of 50–60 years show osteoarthritic changes. There is an association between the degree of subluxation and the age of onset of symptoms. In cases with severe involvement of the hip joint, the symptoms begin after skeletal maturity. Symptoms of moderate hip involvement in women frequently begin during the first or second pregnancy. The mean age of onset of symptoms is 35 years for women and 55 years for men. For coxarthrosis detected by radiographs, the mean age is 45 years for women and 70 years for men.[651]

Acetabular sclerosis alone is not a sign of arthrosis. The early radiographic signs are a narrow joint cartilage space, double acetabular floor, cyst formation, and infero-medial femoral head osteophyte formation.[15,642,657] Cooperman et al.[97] reported the outcome of a group of patients with a CE angles averaging 2°. All of these patients had arthrosis by the age of 42 years. Patients who presented with early symptoms rarely showed the classic radiographic signs of degenerative changes. They usually presented with an increase in sclerosis secondary to augmenting osteoblastic stimulation and with a decrease in width of the weightbearing cartilage surface.



A B

Figure 2-2 Subluxated hip. **A.** Radiograph of a young adult with mild subluxation of the hip. Notice the wide medial joint space. **B.** Radiograph taken 8 years afterwards showing progressive subluxation and a breach of Shenton's line. The patient is now having mild hip pain.



A B

Figure 2-3 Dislocated hip. **A.** Antero-posterior radiograph of the pelvis showing dislocation of the left hip, delay of the ossific nucleus of the femoral head, and displacement of the femur is displaced laterally and upwards. **B.** Radiograph of a child with bilateral dislocation of the hips. A false acetabulum has formed in the area of contact of the femoral head and the iliac wing.

Wedge and Wasylenko[640,641] demonstrated the rapidity with which the hip joint is destroyed, emphasizing the necessity of early procedures to redistribute the forces around the hip and to correct the subluxation "before or very shortly" after the radiographic appearance of changes.

NATURAL HISTORY OF COMPLETE DISLOCATION

The natural history of complete dislocation of the hip typically demonstrates a relationship between two factors: the presence or absence of a well-developed false acetabulum and bilaterality.[249,445,467,584,612,613,640,641] When hip dislocation becomes established, abnormalities develop that involve both the femoral head and the acetabulum. The femoral head, in losing the congruous association with the acetabulum, responds by altering its spherical shape to become flattened medially. Typically a secondary recess, called a *false acetabulum,* forms on the ilium at the level of contact of the dislocated femoral head and iliac wing.

In a very few cases, the hip dislocates superolaterally into the gluteal muscles and a false acetabulum fails to form. The primary acetabulum fails to keep its original hemispherical contour and developmental changes take place in the acetabular bones and soft tissues. The capsule along the dislocated femoral head at the ectopic site becomes elongated and an inferior constriction develops that is further compressed by the overlaying psoas tendon. This capsular constriction, described as an *hourglass deformity,* is an additional impediment to hip reduction. The bone of the infero-medial aspect of the acetabulum becomes hypertrophied, reducing the volume of the acetabulum and appearing on radiographs as a widened teardrop. The muscles and ligaments adapt by contraction to the dislocated location of the femoral head, improving the stability of the dislocated state but impeding reduction.

Figure 2-4 CAT scan reconstruction in which the hip dislocates supero-laterally into the gluteal muscles and a false acetabulum fails to form.

Pain is uncommon in young children but becomes progressively more severe as the patient matures. Some patients complain of aches in the lower back, as well as thigh pain and fatigue when they engage in extensive walking. In general, pain occurs when the patients reach their mid-40s or 50s. Patients with bilateral dislocations may complain of back pain from a secondary hyperlordosis of the lumbar spine. Knee pain may develop from repeated excessive valgus stress and from increasing the load on the lateral compartment of the knee. Often a valgus malalignment develops in the knee on the same side as the hip dislocation, which leads to degenerative arthritis of the knee. Wedge and Wasylenko[640,641] reported degenerative changes also in the medial compartment in several patients, but they did not find any correlation among the height of the dislocated head with backache, knee deformities, and false acetabular development. Wedge and Wasylenko[640,641] showed that only 17 of the 42 dislocated hips they studied received a good score according to their classification. They did not find a correlation between patient age and the height of the dislocation. Alternately, they found a correlation between the development of a false acetabulum and degenerative changes in 76 percent of their patients. Crawford et al.[104] reported 10 cases of untreated complete dislocations, but all patients were doing well at the time of their evaluation. Milgram[403] reported on a 74-year-old man with no articulation between his femoral head and any portion of the ilium. Degenerative changes appeared only when the lesser trochanter touched the acetabular rim.

In summary, patients with complete dislocations may suffer crippling levels of pain and dysfunction that severely alter their lifestyles. They may develop a profound limp and may complain of fatigue. Over 40 years of age, they may complain of excessive back pain. Patients who do not develop a false acetabulum may have fewer degenerative changes of the dislocated hip. In those who develop a false acetabulum, arthritis of the hip and a valgus knee deformity followed by arthritic changes are likely to develop.

Chapter Three

Diagnosis of DDH

EARLY DIAGNOSIS (BIRTH TO 3 MONTHS OF AGE)

The crippling effects of an untreated dislocated hip, described by Hippocrates (460–357 BC),[257] have been well known since the Greek era. Until the first half of the twentieth century, no significant advance in DDH diagnosis or treatment had been made. Finally, Roser,[564] Putti,[471] Ortolani,[438,440] and later Barlow[18] reported the importance of early diagnosis and treatment to obtain satisfactory results and to avoid the disabling outcome of this pathology. A complete physical examination of newborns is extremely important to locate disturbances in the musculo-skeletal system and prevent diseases. Developmental dysplasia of the hip occurs in two types: typical and teratologic (antenatal). In the teratologic type, the hip is firmly dislocated and the thigh adductor muscles are strongly contracted at birth. In the typical, type the hip is flexible and reducible at birth. This text deals with the typical type only.

Ideally, the dysplastic hip is detected by history and physical examination in the first days of a baby's life. An important step in the history is an in-depth interview with the parents; asking about a family history of DDH, intra-uterine position, breech position (30 percent of breech deliveries are associated with DDH, even though these make up only 3 percent of all births), number of pregnancies (instabilities are more common in first-born children), and oligohydramnious. Hip instabilities are from two to five times more predominant in girls than in boys.[663] Other congenital deformities associated with DDH are torticollis,[136,272,635] calcaneo-valgus feet,[612] and possibly metatarsus adductus.[327]

The Ortolani test and Barlow maneuver may be carried out to identify hip instability. In the Ortolani test,[440] the baby is placed in the supine position with the hips flexed at 90° and the knees bent. The examiner's hands are placed over the knees with his thumbs on the medial aspect of the baby's thighs and the other fingers on the lateral side of the thighs. Initially, a slight internal rotation is performed, followed by slow abduction of the thighs with light upward stress on the greater trochanter. If the hip is reducible, the dislocated head of the femur slips toward the acetabulum and the examiner feels a hip reducing sensation described as a "click," "clunk," or "scatto" (positive Ortolani).

The Barlow[18] maneuver involves evaluating only one hip at a time and is carried out in two stages. In the first stage, the patient is placed with his hips flexed at 90° and the knees completely bent. The examiner's middle fingers are positioned over the greater trochanter and the thumb is applied to the lesser trochanter. The thigh is guided into mild abduction and the examiner's thumb applies pressure to the lesser trochanter. If the hip is subluxable/ dislocatable, the femoral head slips posteriorly over the rim of the acetabulum. In the second stage, the examiner releases pressure at the lesser trochanter on the inner aspect of the thigh. The hip joint is unstable when the femoral head slips out over the posterior rim of the acetabulum and returns after the pressure is reduced (positive Barlow).

In infants, the degree of instability may be classified into three types: *dislocated hip,* evidenced by a positive Ortolani test; *dislocatable hip,* shown by a positive Barlow test in which the femoral dislocates posteriorly from the acetabulum; and *subluxable hip,* in which the examiner can feel the femoral head protruding posteriorly but not dislocating from the acetabulum during the Barlow maneuver.

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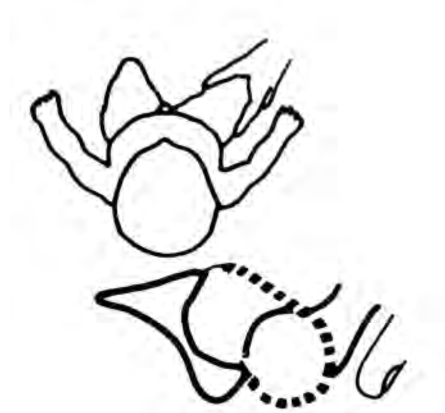

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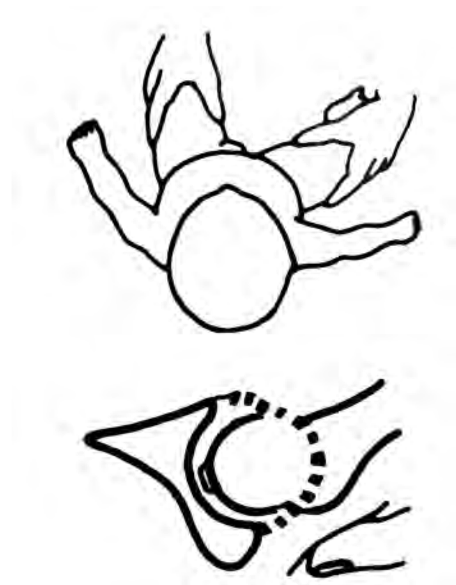

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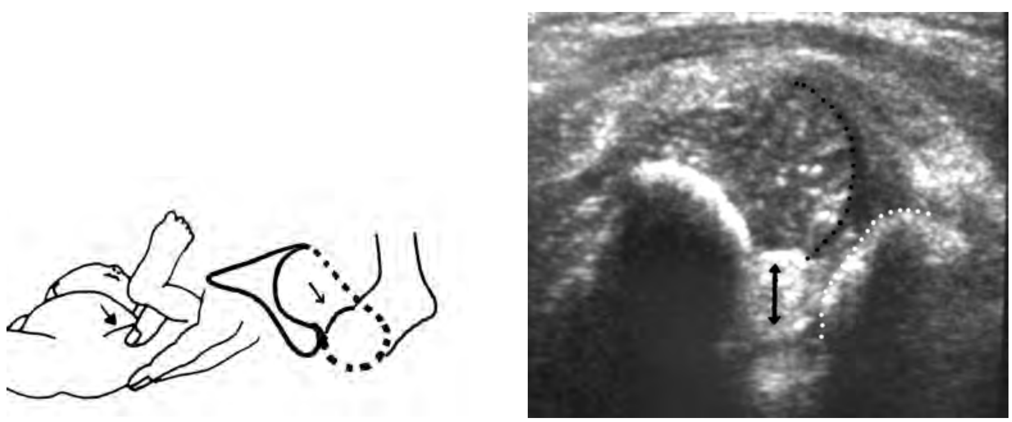
Figure 3-1 Ortolani test. **A, B.** Place the baby in the supine position with the hips flexed at 90°. Grasp both lower limbs with the palms of the hands positioning the thumbs on the medial aspect of the thighs and the index and middle fingers on the greater trochanters. **C, D, E.** Perform a slight internal rotation followed by slow abduction with stress on the knees. At that moment the index finger pushes the greater trochanter and the femoral head slips into the acetabulum. The examiner can feel the hip reducing, described by Ortolani as a "scatto" (click). With the thigh in the adduction position and with pressure of the thumb, the femoral head is dislocated again and the click sign is again felt (modified from Visser JD: Functional treatment of congenital dislocation of the hip, Acta Orthopaedica Scand 55 (Suppl 206): 1–109, p 19, Figs 8, 9, 1984).



A B

Figure 3-2 Barlow maneuver. **A.** Schematic drawing. The infant is laid on the back with the hips and knees flexed. The examiner's thumb is placed in the medial aspect of the thighs and the index and middle finger over each greater trochanter. The thigh is guided into mild abduction and forward pressure is applied. The dislocatable femoral head slips posteriorly out of the acetabulum. With forward and inward pressure on the outer aspect of the thighs, the dislocatable head slips back into the acetabulum (modified from Visser JD: Functional treatment of congenital dislocation of the hip, Acta Orthopaedica Scand 55 (Suppl 206): 1–109, p 19, Figs 8, 9, 1984). **B.** Sonography (transverse view, Harcke technique) of a Barlow positive hip, showing the femoral head subluxated posteriorly. The femoral head reduces into the acetabulum with abduction.

Clinical Findings

Newborns and infants less than three months of age with DDH may have asymmetry of the thigh or inguinal folds and popliteal creases from pelvic obliquity, a shortened limb, and an adduction contracture of the dysplastic hip.

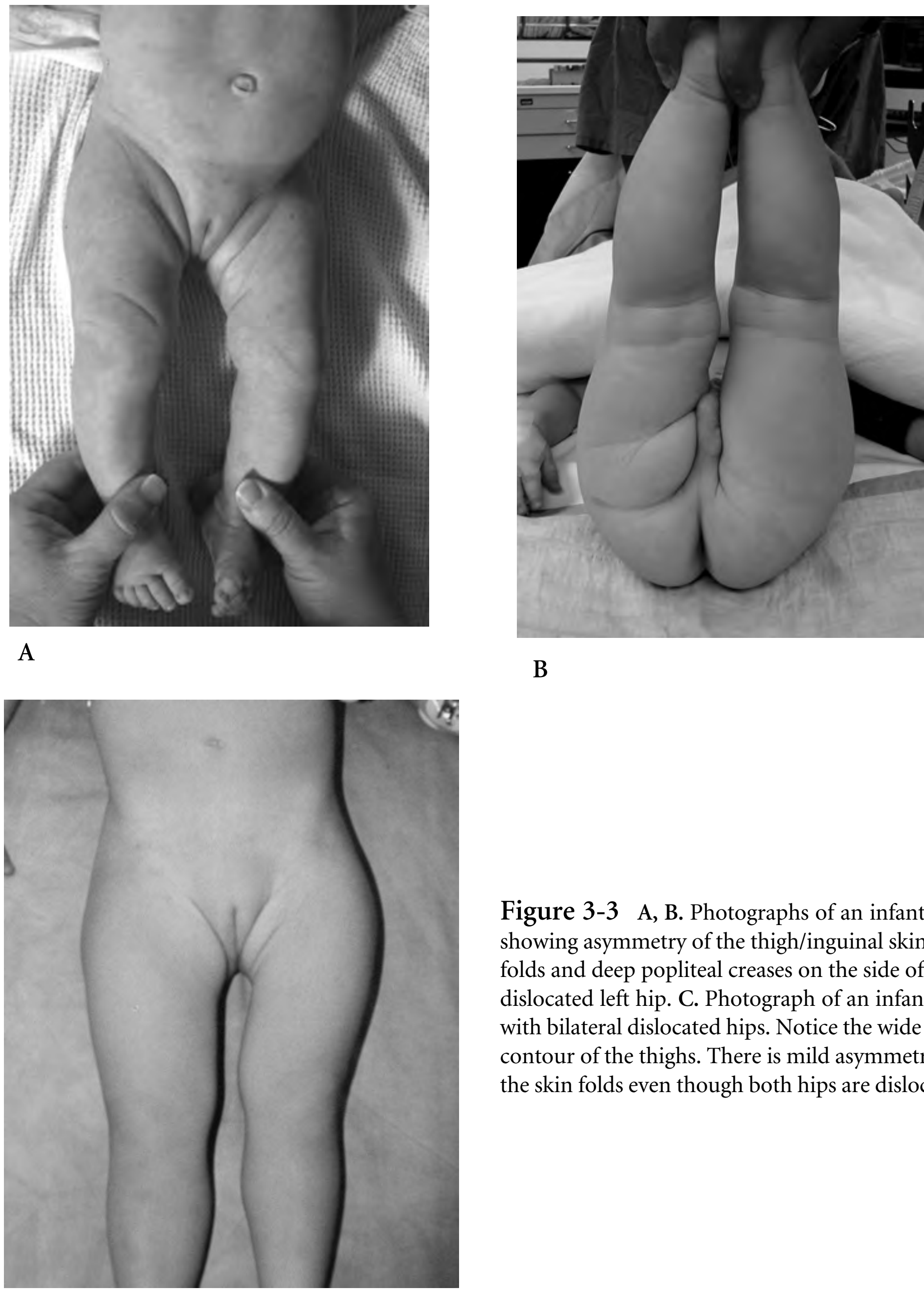


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Figure 3-3 **A, B.** Photographs of an infant showing asymmetry of the thigh/inguinal skin folds and deep popliteal creases on the side of the dislocated left hip. **C.** Photograph of an infant with bilateral dislocated hips. Notice the wide contour of the thighs. There is mild asymmetry of the skin folds even though both hips are dislocated.

Commonly, normal inguinal folds are slightly symmetric and stop before the anal aperture. When a posterior and superior dislocation of the femoral head occurs, the inguinal folds are asymmetric, with the skin fold of the affected side extending posteriorly and laterally beyond the anal aperture. When dislocation is bilateral, these folds may be symmetric but end after the level of the anal aperture. A mild flexion contracture of the hip is a normal finding in the clinical examination of a newborn infant, and excessive looseness of the normal flexion of hip and knee is a probable sign of hip dislocation. The Klisic line is a projected line between the tip of the greater trochanter and the anterior superior iliac spine, prolonged supero-medially towards the umbilicus. In the normal hip joint, this projected line bisects the umbilicus, but when the hip is dislocated, this line passes below the umbilicus.

Adduction contracture of a dislocated hip is usually not present in the newborn infant; however, it develops usually within the first 2 to 3 months of age.

Radiographic Findings

The newborn hip joint is cartilaginous and the femoral head is not visible radiographically. For this reason, sonography is preferred rather than radiography. On radiographs, lines can be drawn on the bony surfaces to localize the femoral head in relation to the acetabulum; however, they only indirectly determined the position of the femoral head. On an antero-posterior radiographic view with the pelvis positioned with the antero-superior iliac spine flattened and the lower limbs in extension, the Hilgenheiner ("Y") and Perkins lines can be drawn and the acetabular index can be measured.[256,453]Measurements according to the ratio of the distances between the highest point on the femoral neck and the triradiate cartilage and between the intersection and the "Y" line can be drawn to study the relationship between femoral head and the acetabulum. The Perkins line can be used to classify the relationship of the proximal femur to the acetabulum. The normal acetabular-femoral relationship is shown when this line crosses the proximal femoral metaphysis. When the proximal metaphysis of the femur remains lateral to the Perkins line, the hip is considered dysplastic, subluxed, or dislocated.[91]

The Andren Von Rosen view is an antero-posterior radiograph taken with the infant's lower extremities positioned at 25° of internal rotation and 45° of abduction.[617–622] In a fixed-dislocated hip joint, the femoral shaft points towards the ilium. If the hip is reduced, the shaft points towards the triradiate cartilage. This method is most helpful when the hip joint is dislocated and irreducible. The abduction and internal rotational position of the lower limbs can reduce a dislocation in some infants and give a false negative result.[367]

Bertol et al.[34] measured the distance between the proximal femur and a line drawn perpendicular to the lateral aspect of the ischium in 271 radiographs of patients with DDH. They concluded that a distance between the proximal femur and a line drawn perpendicular to the ischium over 5 mm is suspicious and over than 6 mm is indicative of hip dislocation.

Suzuki et al.[560] report a study using magnetic resonance imaging (MRI) to locate the femoral head in 21 hips of infants from 2 to 5 months of age with typical DDH. They classify their cases into three types according to the position and contact of the femoral head in relationship to the acetabulum.

Figure 3-4 Radiograph of unilateral dislocated hips in an infant. The proximal metaphysis of the femur remains lateral to the Perkins line (red line) in the dislocated hip and is in the inner lower quadrant in the reduced hip.

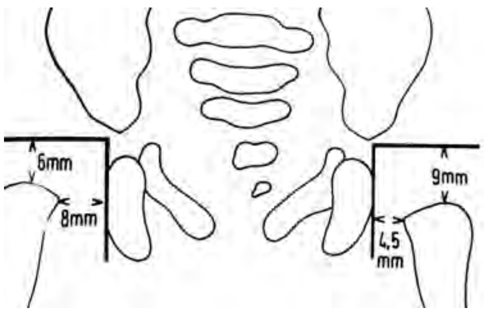


Figure 3-5 The Bertol method of radiographic measurement. An increase of the medial gap over 6 mm suggests dislocation. (From Bertol P, Macnicol MF, Mitchell GP: Radiographic features of neonatal congenital dislocation of the hip, J Bone Joint Surg Br 64(2): 176–79, p 177, Fig 1, 1982. Copyright © the British Editorial Society of Bone and Joint Surgery. Reproduced with permission.)

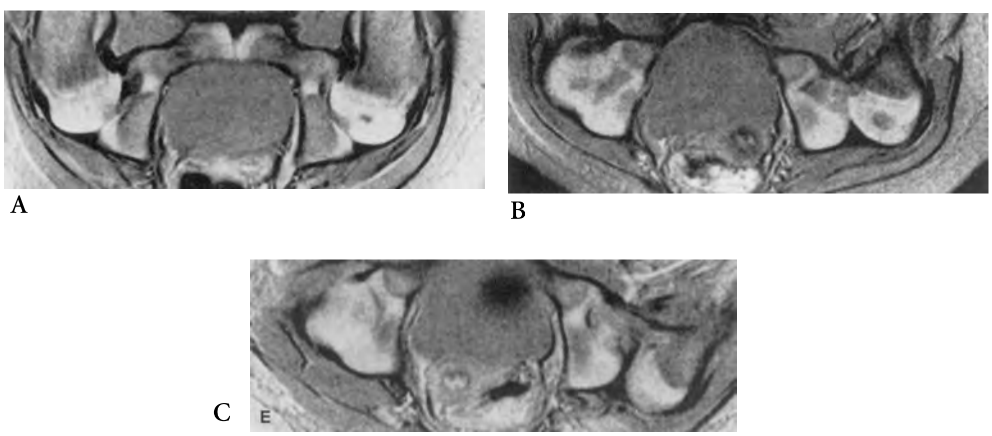


Figure 3-6 MRI demonstrating the Suzuki method. **A.** In type A, the femoral head is displaced posteriorly but is within the socket. **B.** In type B, the femoral head is in contact with the posterior margin of the acetabulum but there is no contact between it and the inner wall of the acetabulum. **C.** The femoral head is completely dislocated (from Suzuki S, Kashiwagi N, Seto Y, Mukai S: Location of the femoral head in developmental dysplasia of the hip: three-dimensional evaluation by means of magnetic resonance image, J Pediatr Orthop 19(1): 88–91, pp 89, 90, 1999).

Sonographic Findings

Sonography has become the most common and useful method employed in the analysis of the hip joint, especially in infants below 6 months of age. Sonography is a sensitive indicator of position, acetabular development, and instability, and is more accurate than radiographs.[43,85,86,202–204,223,224,226,228–230,367,558,575] This technique is used as a screening tool at the first examination of the newborn's hips, in the screening of infants with risk factors of DDH, or to monitor treatment in known cases of DDH.[21,85,86,111,145,150,210,250,291,372,397,410,441,446,466,488,559,563,572,574,577,594] Sonography is also used to prevent overtreatment of neonatal hip dysplasia in infants with resolving dysplasia.[39] To evaluate sonographic findings properly, the examination requires the use of appropriate equipment, a good basic knowledge of sonography, and persistent training on the part of physician.[168,228] Sonography has evident advantages over other imaging techniques in that the examiner can see the cartilaginous components of the hip joint without exposing the patient to ionizing radiation. In 2003, Rudigern von Kries et al. reported the results of a national ultrasound screening program in Germany.[623] The screening program included an examination within the first 6 weeks of life and accessed the effect on the rate of first operative procedures. Ninety percent of all children were screened over a 5-year period, and the rate of operative procedures dropped to a rate of 0.26 per 1,000 live births. Prior to ultrasound screening the rate had been about 1 per 1,000 live births. Although the screening program significantly lowered the operative rate, not all dysplastic hips could be identified.[623]

There are different forms of hip evaluation based on two basic philosophies. Graf[202–204] developed a static morphological approach to evaluate the proximal femur and the surface contour of the pelvis. Harcke et al.[223,224,226,228-230] described real-time sonography, which permits dynamic evaluation and observation of the hip motion based on the Barlow maneuver and Ortolani test. Graf's method measures cartilage dysplasia, and Harcke's measures hip stability.

Song and Lapinsky considered ultrasound examination to be superior to antero-posterior radiography for measuring hip position in treatment.[535]

The Graf Sonographic Technique

The Graf[202-204] sonographic method establishes measured values of the hip joint, allowing morphometric evaluation. The patient is placed laterally on a special support, and each hip is examined individually utilizing a 5-MHz linear transducer. The physician classifies the morphologic changes in the acetabular roof into four types, utilizing images from the cartilaginous and osseous areas of the acetabulum. Two angles are measured from three lines. First, the base line, which connects the osseous acetabulum convexity to the point where the joint capsule and the perichondrium merge with the iliac bone, is drawn. Second, the inclination line, which connects the osseous convexity to the labrum acetabulare, is constructed. Third, the acetabular roof line, which connects the lower edge of the os ilium to the osseous convexity, is drawn. The angle alpha indicates the formation of the osseous acetabular convexity and is determined by the intersection of the acetabular roof line and the baseline. The angle beta measures the formation and size of the cartilaginous convexity. This angle is formed by the intersection of the inclination line and the base line.

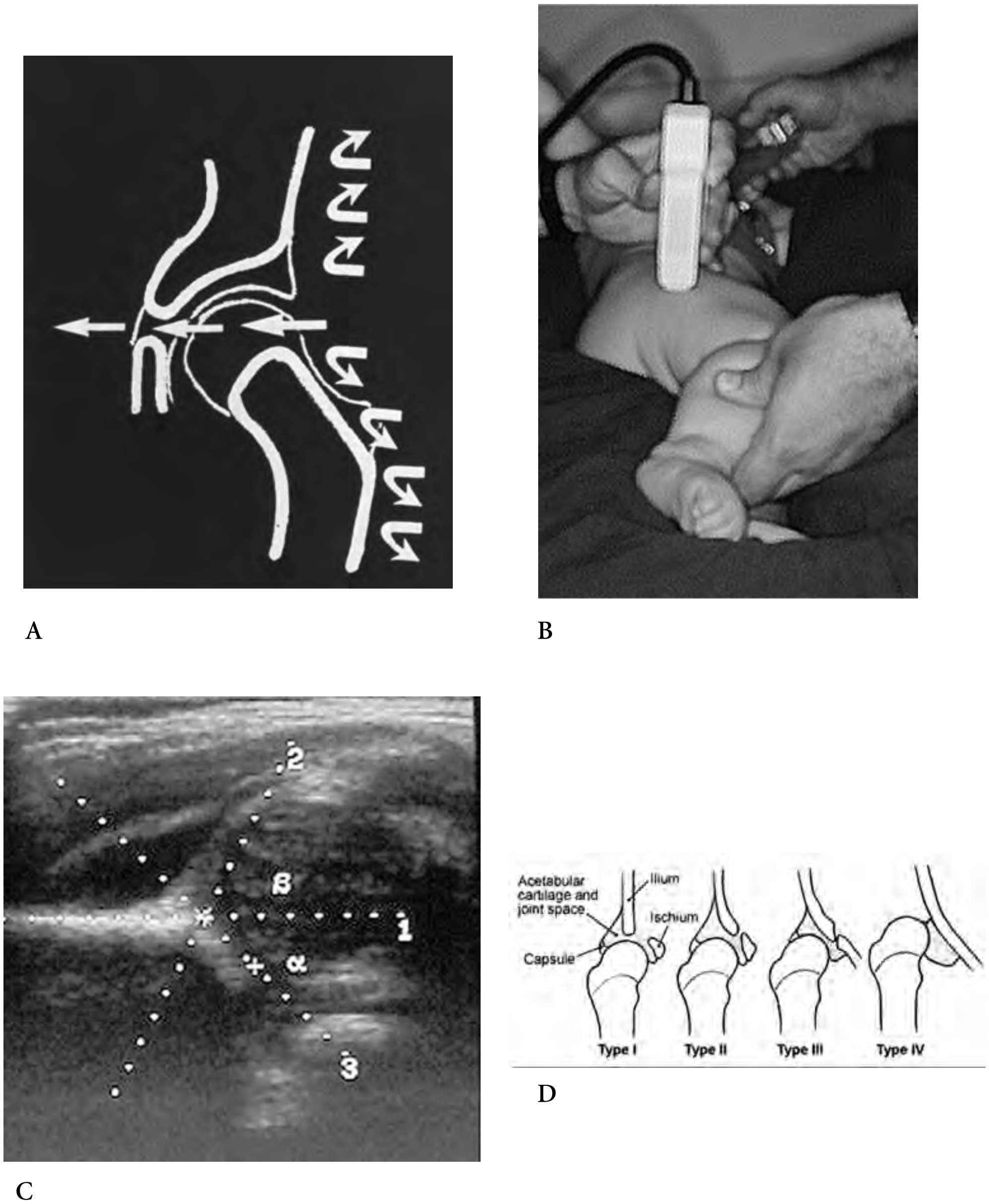


Figure 3-7 The Graf method for sonographic measurements. **A.** Schematic drawing demonstrating that sonography penetrates soft tissue but not bone. **B.** Position of the infant to perform sonography of the hip by the Graf method. **C.** Schematic drawing and a sonographic image showing the alpha and beta angles of Graf. **D.** Schematic drawing depicting the Graf types of hip dysplasia (from Graf R: Fundamentals of sonographic diagnosis of infant hip dysplasia, J Pediatr Orthop 4(6):735–40, 1984).

Graf's classification consists of four hip types: types I, II, III, and IV. Type I is considered the normal hip joint. The angle alpha is greater than 60° and angle beta is less than 55°. In type II hips, the ultrasound image shows the relationship between the osseous roof and the cartilaginous convexity, in which there is more cartilage than ossification of the acetabular roof. This signifies delay in ossification. The angle alpha ranges from 43–60° and the angle beta from 55–77°. In type IIIa hips, the femoral head pushes the cartilaginous edge outward and upward when subluxation occurs. This is described as *lateralization* in radiologic diagnostics and is considered by Graf as "grade I subluxation without histological transformation of the acetabular convexity." In type IIIb hips, the subluxation progresses and the femoral head increases pressure on the cartilaginous area of the acetabulum, promoting changes in its histological structure. The image shows the acetabular roof pressed upward and bent. Graf described this situation as a "grade II subluxation with histological transformation of the acetabular roof." For types IIIa and IIIb, the angle alpha decreases below 43° and the angle beta increases more than 77°, indicating a dysplastic osseous convexity. In type IV, the hip joint loses its congruency and the ultrasound images show the femoral head lying in the soft tissue, with an empty acetabulum.

TABLE 3-1. Angle of α and β in the Four Hip Snographic Classification of Graf

Types	α	β
I (normal)	>60°	<55°
II	43–60°	55–77°
III and IV	<43°	>77°

Graf described type Iα and IIβ angles as "transition variants."

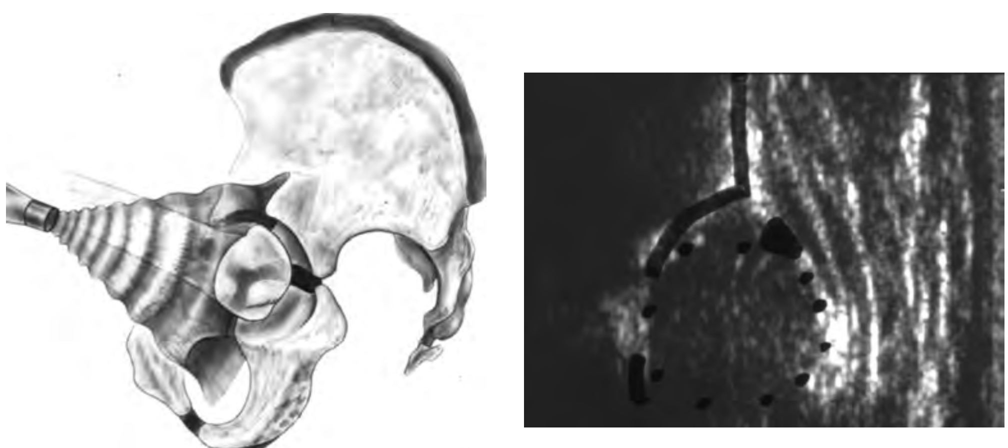
The Harcke Sonographic Technique

Harcke et al.[223,224,226,228–230,414,456] described a real-time ultrasound examination in which the examiner is able to move the hip and determine the position of the femoral head at rest and after manipulation. Initially, a 3-MHz transducer was utilized in most examinations. Currently,[228] for infants up to 3 months of age, the 7.5-MHz transducer is utilized. From 3 to 7 months of age, the 5-MHz transducer is normally used. To evaluate a large baby, increase the field of view, or include more of the femoral and iliac anatomy; a lower-frequency transducer of 3 MHz is necessary.

The "dynamic four-step method sonography protocol" was proposed to investigate stability (subluxation and dislocation) and acetabular morphology, and optionally to make measurements.[225] This method produces four different sonographic views of the hip: a *coronal neural view,* a *coronal flexion view,* a t*ransverse flexion view,* and *a transverse neutral view.*

The first step is to obtain a coronal neutral sonographic view. The patient is placed in a supine or lateral decubitus position. The hip is in a physiologically neutral position (slight flexion) and the transducer is positioned coronally (longitudinally), lateral to the pelvis. In this view, superiorly, the examiner sees a straight iliac line, the gluteal muscles and the labrum; medially, the ilium, triradiate cartilage, and ischium; and laterally, the capsule and femoral metaphysis. In a normal finding, the acetabulum is well formed and the femoral head is well covered by the labrum. The alpha and beta angles of Graf may be measured. If abnormal, the following three conditions can been seen: (1) in bony acetabular dysplasia (Graf type II), the femoral head is placed inside the acetabulum, which has a margin around it, and the labrum is wide; (2) in subluxation with acetabular dysplasia (Graf type III), the femoral head is displaced, the acetabulum is shallow, and the labrum is thick and cranially displaced; and (3) In dislocation with severe dysplasia (Graf type IV), the femoral head is dislocated superiorly and laterally, the acetabulum shows serious bone deficiency, and the labrum is deformed and interposed between head and acetabulum.

The second step is to obtain a coronal flexion sonographic view in two planes: mid-acetabular and posterior lip. With the patient in a supine position, the transducer is oriented longitudinally and laterally to the pelvis and the hip is positioned at 90° of flexion. (1) In the mid-acetabular plane, superiorly, the image shows the iliac wing, the gluteal muscles, and the labrum; medially, the medial aspect of the acetabulum and the triradiate cartilage; and laterally, the gluteal muscles. In this view, the examiner does not see the femoral metaphysis echo, but may make a dynamic evaluation by positioning the thigh in adduction and abduction. Some orthopaedists believe the coronal flexion view of a normal hip to resemble a "ball on a spoon," with the femoral head being the ball, the acetabulum being the bowl of the spoon, and the iliac wing being the handle of the spoon. Nor-

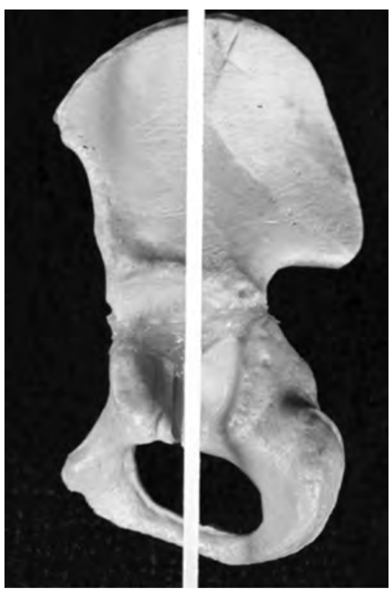


A B

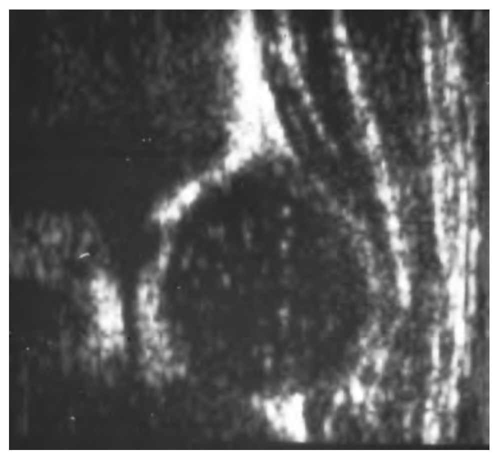
Figure 3-8 Coronal sonographic view of Harcke: The ultrasound is coronal and the hip is almost extended (coronal neutral view) or the hip is flexed (coronal flexion view). **A.** Drawing demonstrating the level for the coronal flexion sonographic view. **B.** Sonography of a normal hip with the femoral head outlined (drawing from Dr. T. Harcke).

mally, the femoral head is settled inside the acetabulum, which is deep and forms a sharp angle with the iliac wing. The labrum covers the femoral head and does not show changes with adduction or abduction positioning. When the exam is abnormal, laxity is diagnosed in a stress maneuver when the femoral head slips over the posterior lip of the acetabulum; at rest, the femoral head is placed normally. Subluxation shows the femoral head displaced laterally but maintaining contact with the acetabulum. At rest, part of the head may appear over the posterior rim of the acetabulum, but with stress, the head appears more posteriorly. When the head dislocates or is dislocatable, it is lateral, superior, or posterior in relation to the acetabulum, which is dysplastic. The labrum is deformed and may be interposed between the head and acetabulum. The dislocation can be partially or completely reducible or irreducible. (2) At the posterior acetabular lip, the ultrasound image shows superiorly the iliac bone, medially the triradiate cartilage, and inferiorly the ischium. The femoral head never appears in the normal hip, either at rest or during a stress maneuver. When posteriorly displaced, the entire head appears over the posterior rim of the acetabulum. Anterior and posterior pistoning of the femur will show the femoral head moving in and out of the posterior lip plane when there is instability.

The third step is to obtain a transverse flexion sonographic view. The patient is in a posterior oblique position with the hip to be examined antero-oblique. The hip is flexed at 90° and the transducer is placed transversely (axially) in relation to the acetabulum. This



A



B

Figure 3-9 Coronal flexion sonographic view of Harcke (the ultrasound is coronal and the hip is flexed). **A.** Drawing demonstrating the level of the coronal flexion sonographic view. **B.** Sonography of a normal hip.

transverse flexion view permits the examiner to take two images of the hip, one at rest and the other in adduction and stress. Normally, the femoral head and metaphysis are shown anteriorly and the ischium is shown posteriorly. This is visualized as a "u"-shaped image. The stress view is visualized as a "v" shaped image, similar to a Barlow maneuver including adduction with pistoning. Harcke described three different characteristics of the abnormal hip as laxity, subluxation, or dislocation. With laxity, the hip joint appears normal at rest, but under stress or adduction the femoral head displaces laterally. Soft tissue is seen between the femoral head and acetabulum. With subluxation, the femoral head is displaced at rest but maintains contact with part of the acetabulum. Under stress, as in the Barlow maneuver, the hip is not dislocatable but is partially reducible with abduction. With dislocation, the posterior acetabular rim is observed. The ischium is often difficult to visualize. The femoral head is laterally displaced (dislocated) and does not touch the acetabulum. The ligamentum teres and labrum or pulvinar (fibrofatty tissue) occupy the acetabulum, disabling the reduction of the femoral head with the Ortolani test.

The fourth step is to obtain a transverse neutral sonographic view. The patient is placed in a supine position with the leg in physiological extension (15–20° of flexion). The transducer is positioned transversely (axially), lateral to the pelvis. The normal findings are the femoral head with or without ossific nucleus, pubis, ischium, and surrounding soft tissue. A single hip image is taken in cases where there is no ossific nucleus, but two images are taken if ossification is present, the first showing the ossific nucleus and the other the triradiate cartilage. Harcke described three types of abnormal hips as subluxation, lateral dislocation, and superior/posterior dislocation. With subluxation, the femoral head is posteriorly and/or laterally displaced and soft tissue appears between the pubis, ischium, and femoral head. The femoral head contacts part of the acetabulum. With lateral dislocation, the femoral head appears more displaced than in subluxation and has no acetabular contact. In superior/posterior dislocation, the head is seen and the examiner has difficulty in observing the bony acetabular landmarks.

While a complete examination utilizing the Harcke sonographic technique calls for four views, two views are considered adequate when they consist of one coronal view (neutral or flexion) and the transverse flexion view with stress. When a child is being treated with the Pavlik harness, stress is not done until the time of weaning from the harness.

DIAGNOSIS FROM 4 MONTHS TO WALKING AGE (ABOUT 1 YEAR)

As a child matures, new clinical signs and symptoms develop in the dislocated hip. The hip adductors, iliopsaos, and hamstring muscles become progressively contracted. The asymmetry of the skin folds of the thighs becomes more obvious as the baby grows, and inguinal and gluteal folds also become more evident.[438] Flattening of the buttock is seen when the child is in the prone position and is more pronounced as the natural infantile gluteal fat disappears. This flattening is more easily observed in unilateral than in bilateral cases of DDH.[654] In unilateral cases, the increased height of the greater trochanter in comparison with the opposite side is most evident. This difference can be observed when the patient is placed in a supine position and has both legs extended. The examiner places

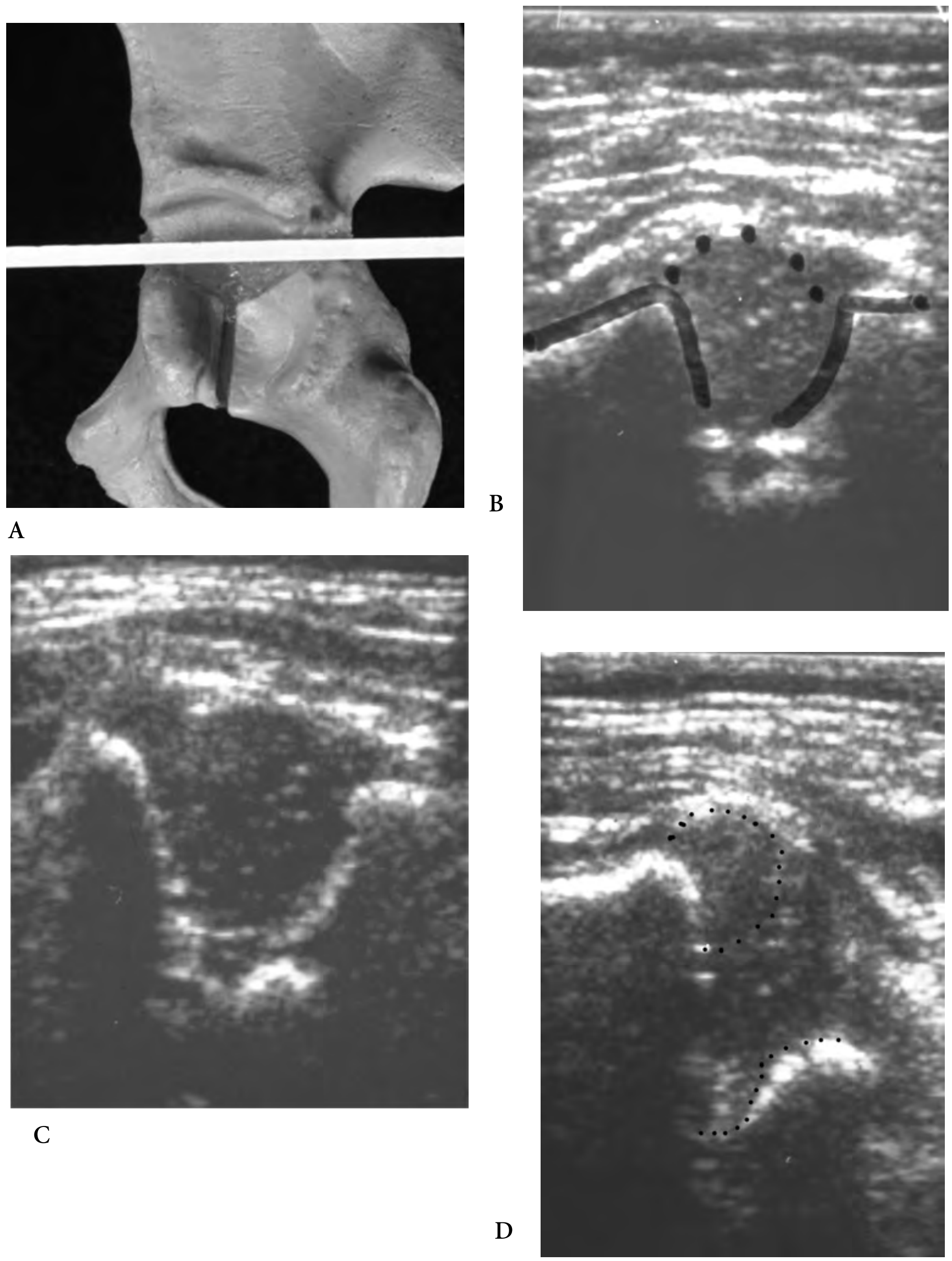


Figure 3-10 Transverse flexion sonographic view of Harcke (the ultrasound is transverse and the hip is flexed). **A.** Drawing demonstrating the level of the transverse flexion sonographic view. **B.** Sonography of a normal hip with the femoral head outlined. **C.** Sonography of a normal hip. **D.** Sonography of a dislocated hip.

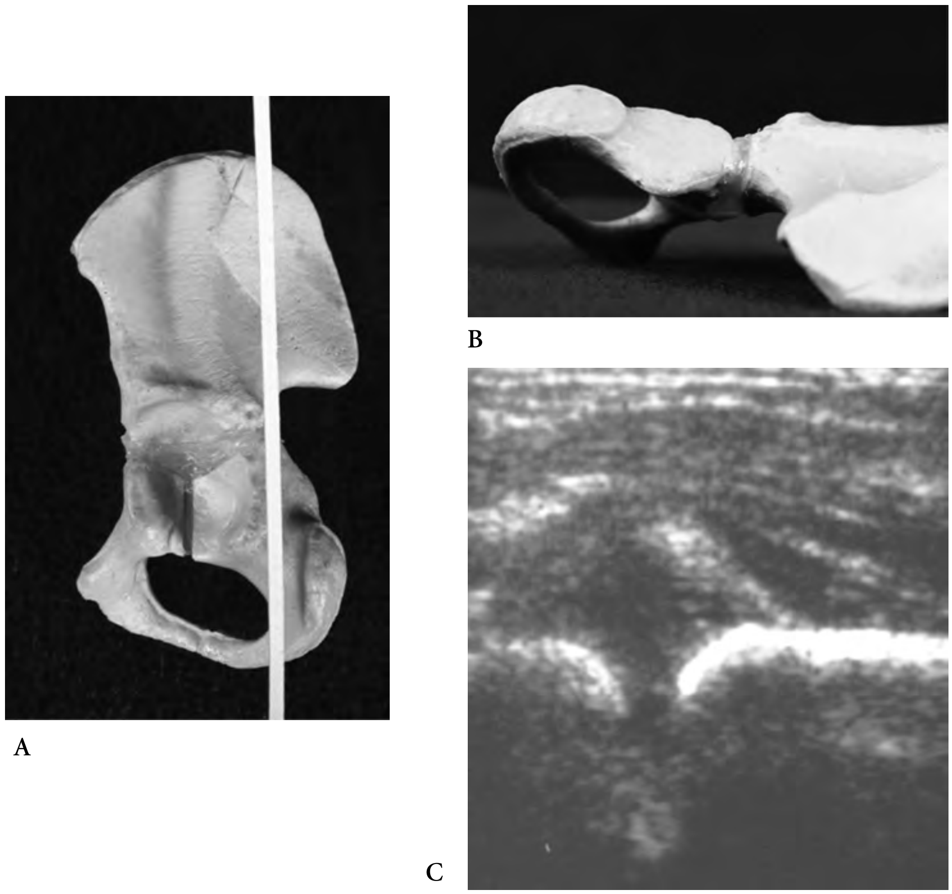


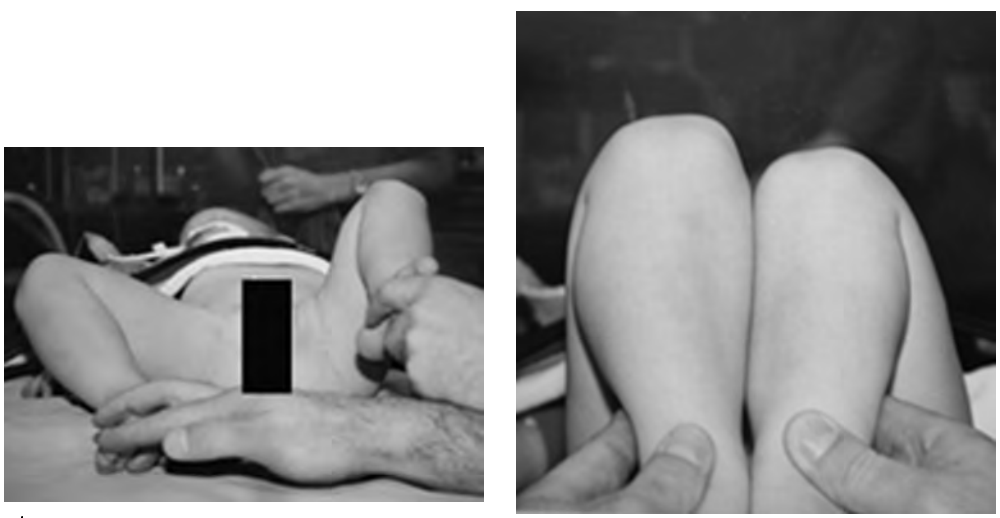
Figure 3-11 Coronal sonographic view of the posterior aspect of the acetabulum. In the normal hip, the femoral head is not seen. If the Barlow maneuver is applied to an unstable hip, the femoral head will be seen to move dynamically over the posterior rim of the acetabulum. If the hip is dislocated, the femoral head will be observed. **A.** Drawing demonstrating the level of the coronal flexion view of the posterior aspect of the acetabulum (posterior lip of the triradiate cartilage). **B.** Model demonstrating the posterior aspect of the acetabulum. **C.** Sonograph of the posterior aspect of the acetabulum. Notice that the triradiate cartilage (ilio-ischial part) is visible but no femoral head is observed in the normal hip.

the thumbs on the anterior superior iliac spines and the index fingers on the top of the greater trochanters. In a dislocated hip, the distance between the examiner's thumb and index finger will be greater than on the normal side. This displacement can also be detected in bilateral cases, but clinically is more difficult to distinguish from normal, demanding experience on the part of the examiner. The Ortolani positive test usually disappears by this age as contractures form, restricting potential hip reduction, but also may persist in 13 percent of the cases after the first 5 months of life.[367] The greater trochanter is palpable above Nelaton's line, an imaginary line drawn from the anterior superior iliac spine to the ischial tuberosity. In normal hips, the greater trochanter is at or below this line. In complete dislocation, the top of the greater trochanter is situated proximal to this line. With a dislocated hip, the lower limb postures commonly in 15–25° of lateral rotation. The telescoping sign shows an abnormal mobility of the femoral head during passive manipulation. This test is done by the examiner grasping the distal thigh with one hand, placing the index finger of the other hand on the greater trochanter and placing the other fingers over the ilium, and then pushing and pulling the thigh with the adducted hip in flexion and extension. In the normal hip, the hip feels stable. In the unstable hip, the examiner feels instability as a sensation of shortening and lengthening of the limb through the hip joint. The Galeazzi sign is the difference in the knee height or level with the patient in a prone position and the knees flexed at 90°, showing apparent shortening of the femur in the same side as the dislocated hip.[565]

Radiographic Findings of DDH

Radiographic study of DDH is difficult before ossification of the proximal epiphysis. After the capital femoral epiphyseal ossification, radiographic studies of the hip become the most commonly used methods to evaluate DDH. The ossification of the proximal femoral epiphysis varies widely between gender and among persons. It tends to develop earlier in girls than in boys. Yamamuro[664] and Chen[74] reported that in girls it could be seen radiographically in 50 percent of normal hips at 4 months of age and in 100 percent at 8 months of age. In boys, 50 percent could be seen at 6 months of age and 100 percent at 10 months of age.

In the normal hip joint, the Shenton or Menard line is a continuous arch drawn from the medial aspect of the femoral neck to the top of the obturator foramen. The ilio-femoral



A

B

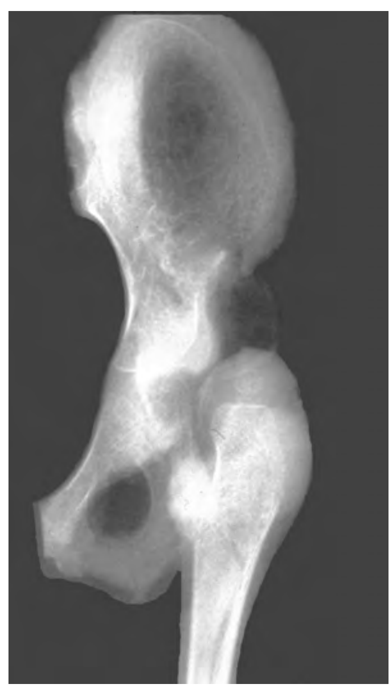
Figure 3-12 Physical findings in developmental dysplasia of the hip from 3 months to 1 year. **A.** Photograph of contracture of hip adductor muscles. **B.** Photograph of "shortened" femur in the dislocated hip.

line is a perfect arch that follows the lateral margin of the ilium to the lateral aspect of the neck of the femur. When these lines are broken or interrupted, the hip joint is subluxed. The Shenton line may be slightly interrupted if the pelvis is tilted or the hip is in external rotation and adduction.

The Hilgenreiner and Perkins lines are utilized to locate the proximal femur in relation to the acetabulum. From the Hilgenreiner line, the acetabular index is calculated and the Perkins line is drawn. The acetabular index measured by Kleinberg and Lieberman[314] and based on 300 normal hip radiographs, determined the average index of 27.5°. They also observed a slight increase in the average acetabular index in females, which was not statistically significant, and did not find correlation with the size of the infant. In the dysplastic hip joint, the acetabular index is increased. The Perkins line[91] is drawn from the most lateral point of ossification of the acetabular roof, perpendicularly to the Hilgenreiner

A

B



C

Figure 3-13 **A.** Photograph of an infant positioned for an antero-posterior radiograph of the hips. The hips are held in slight flexion of about 15°, the patella is directed forward, and the rotation of the hip is neutral. **B.** Antero-posterior radiography showing bilateral DDH in an infant aged 4 months. **C.** Radiograph of a specimen of an infant with a dislocated hip (Bowen collection).

line. Perkins employed this reference line to determine the relationship of the femoral head to the acetabulum in older children after the appearance of the ossification center. A study of 300 normal hip radiographs showed the beak of the femoral neck (most medial ossification of the proximal metaphysis of the femur) in relation to the Perkins line with exceptional constancy.[453] The significance of this observation appears to reflect the approximate depth of the cartilaginous acetabulum. It is the most accurate criterion to detect hip dislocation prior to ossification of the femoral head, and is better than the use of the ilio-femoral and Shenton line. After 6 months of age, the ossification of the proximal femoral epiphysis is diminished in size or absent on the dysplastic or dislocated side. Tönnis et al.[582–584,586,590,594] described a system for the grading of the femoral head dislocation based on

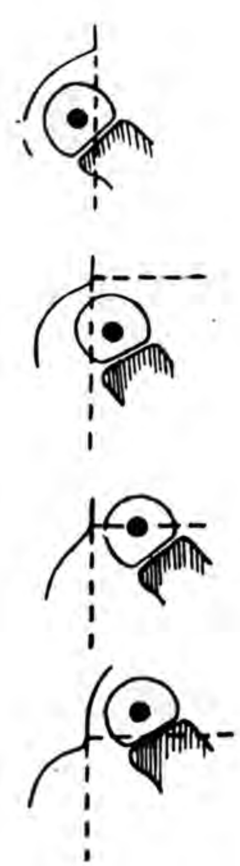


Figure 3-14 Schematic drawing of the Tönnis grading for DDH. Grade 1: the ossific nucleus is in the inferior-medial quadrant. Grade 2: the ossific nucleus is lateral to the Perkins line and below the Hilgenreiner line (it is located at the inferior-lateral quadrant). Grade 3: The ossific nucleus is lateral to the Perkins line and leveled to the Hilgenreiner line. Grade 4: The ossific nucleus is located in the superior-lateral quadrant (from Tönnis D: Radiological classification and diagnosis, Mapfre Medicina 3 (Suppl 1): 42–45, p 43, 1992).

the position of the ossific center in relation to the Hilgenreiner and Perkins lines on an antero-posterior radiograph. In grade 1, the ossific center is medial to the Perkins line (normal). In grade 2, the ossific center is lateral to the Perkins line but below the acetabular edge. In grade 3, the ossific center is at the level of the acetabular edge, and in grade 4, it is above this acetabular edge.

Rosen et al.[487] published the results of a radiographic analysis of 81 patients (103 hips), in which the rotational index, the acetabular index, the amount of femoral head uncovering, and the Tönnis grade of dislocation were identified. The patients' ages ranged from 0 to 116 months (average, 14.9 +/- 20.2 months), and the follow-up ranged from 12 to 139 months (average, 49.3 +/- 33.7 months). They concluded that the Tönnis grade of dislocation predicts the results of treatment. An increase in the Tönnis grading was associated with double the probability of failure in patients treated with a Pavlik harness or with a closed reduction (odds ratio, 2.2 and 2.0, respectively).

Koehler in 1929 reported the "teardrop," which refers to an aspect of the floor of the normal acetabulum. The medial line represents the outline of the pelvic wall, and the lateral line is the anterior edge of the acetabulum. The teardrop is delayed in the formation in DDH, and is often "v"-shaped or spread out in cases of residual subluxation.[4] In dislocations, the involved hemi-pelvis is small, the acetabulum is shallow, a false acetabulum may be present, and femoral anteversion is increased.

Arthrography of the Hip Joint

Arthrography is a radiographic method utilized to study the joints by injecting radiopaque dye. This invasive investigation usually is performed under general anesthesia in infants of 3 months to 1 year of age and sedation in older children. The patient is prepared for surgery under strict aseptic conditions, and image intensifier radiographic control is helpful to guide the needle placement in the hip. The instruments necessary for this procedure include an 18- or 20-gauge lumbar puncture needle with an inside stylet, a 20-cc syringe, intravenous tubing, radiopaque dye (Hypake 3 ml) and sterile physiologic saline

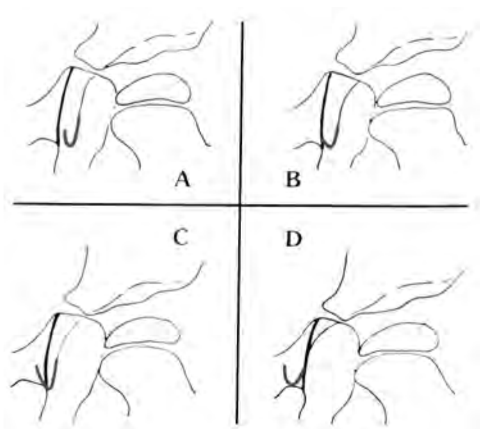


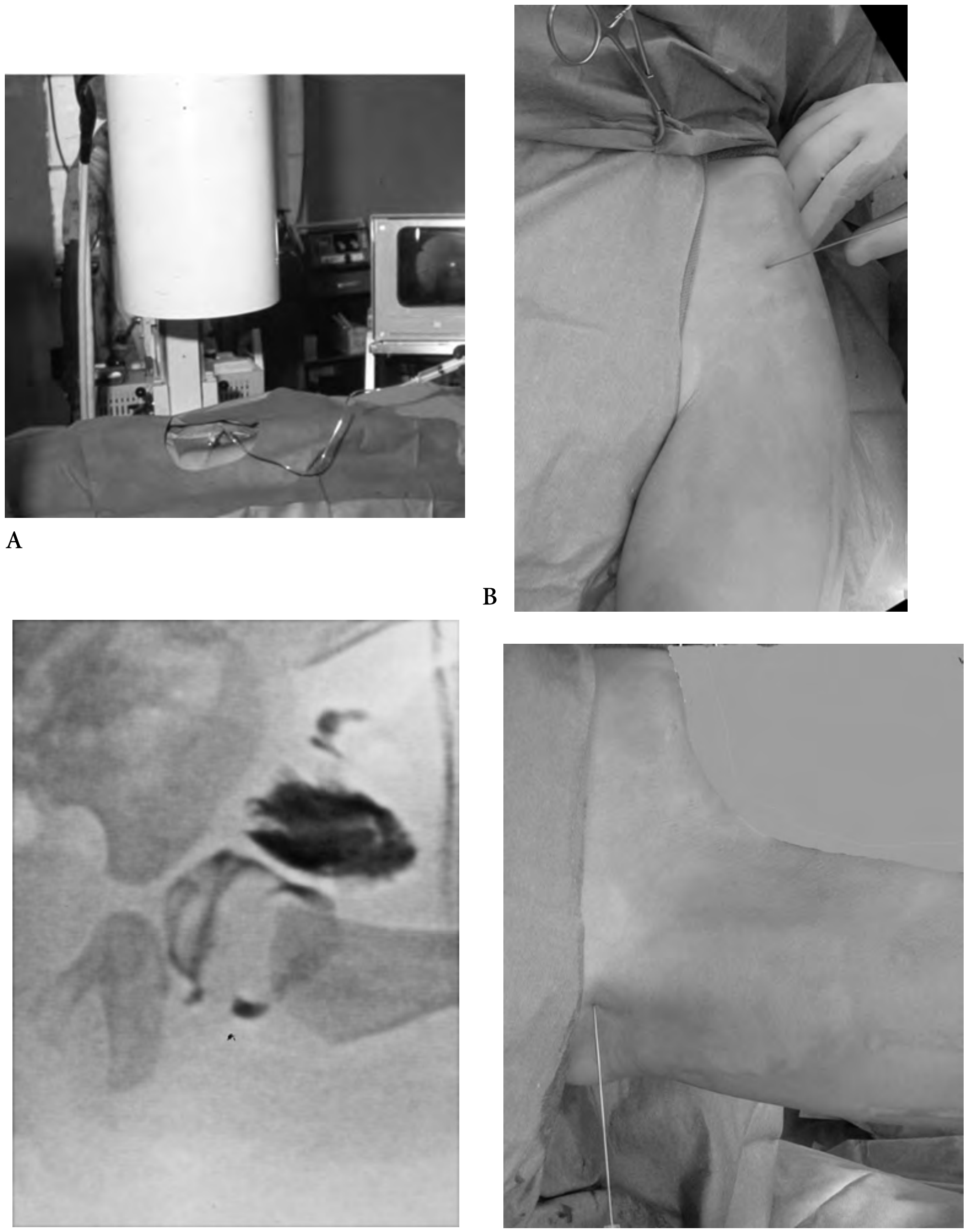
Figure 3-15 Koehler's schematic diagram of the radiographic types of teardrops. Type A is open, type B is closed, type C is crossed, and type D is reversed (from Albiñana J, Morcuende JA, Weinstein SL: The teardrop in congenital dislocation of the hip diagnosed late. A quantitative study, J Bone Joint Surg Am 78(7): 1048–55, p 1049, Fig 2, 1996).

for dilution of the Hypake to a ratio of 1:1 (50 percent dye and 50 percent physiologic saline solution). The Hypake should be diluted; otherwise the concentrated Hypake will create such a density in the hip that many intra-articular structures are obscured.

Different skin needle approaches to injecting the hip joint are possible, including anterolateral (cranial), lateral, anterior, and caudal (inferior), and adductor. (1) In the anterolateral (cranial) approach, the examiner inserts the needle 1–2 cm distal to the anterior superior iliac spine. The needle points downwards and medially to the femoral neck. (2) In the lateral approach, the examiner palpates the tip of the greater trochanter and introduces the needle horizontally just above, pointing directly to the lateral aspect of the femoral neck of the hip joint. (3) In the anterior route, the examiner introduces the needle laterally to the femoral artery, pointing it downward to the hip joint. It is advisable to direct the needle to the lateral side of the femoral head, avoiding the medial course of the femoral artery.[593] Ishii et al.[281] proposed the technique of introducing the needle just below the inguinal ligament, lateral to the adductor longus muscle. (4) In the caudal (inferior) approach, the hip joint is flexed 45° or more. The examiner palpates the ischial tuberosity and introduces the needle immediately anterior and lateral, between the adductor muscles located anteriorly, and the ischiocrural muscles located posteriorly. (5) In the adductor approach, the patient is in a supine position with both hips flexed 90°, abducted, and laterally rotated. The needle is introduced posterior to the tendon of the adductor longus muscle. The needle is placed horizontally, pointing upwards and medially through the inferior aspect of the capsule of the hip joint.

Independent of the approach utilized by the orthopaedic surgeon, a sensation of resistance is felt when the needle perforates the capsule. The needle position should be confirmed by fluoroscopic screening with an image intensifier. Carefully, the hip is minimally moved medially and laterally, and the surgeon feels the contact of the needle against the femoral head. A very small amount of contrast (approximately 1 mm) is injected and confirmed by the image intensifier. If the needle is correctly placed intra-articularly, the dye will spread from the tip of the needle; however, if the tip is not intra-articular, the dye will pool at the needle tip. If the needle is correctly positioned intra-articularly, 2 or 3 ml of contrast are slowly injected until the entire acetabulum and femoral head are clearly outlined. The authors prefer removing the intravenous tubing from the needle hub to allow any excessive intra-articular pressure to decrease, as any extra dye can egress from the hub of the needle. The needle is then removed. The hip is moved to disperse the contrast within the joint. Antero-posterior radiographs are taken with the hip in neutral position, in abduction, in extension with medial rotation, and in 90° of flexion with maximal abduction and external rotation. Lateral radiographs may also be performed to study the radiolucent portions of the hip joint and soft-tissue structures. Joint motion and stability can be determined by observing hip motion with the image intensifier.

The authors prefer the antero-lateral approach for the initial investigative arthrogram of the dislocated hip. If the child has been in a cast with the hips in flexion and mild abduction, the caudal or adductor approaches are very useful. Complications are rare but may occur, and take the form of allergy to the dye, infection, and, less frequently, artery or nerve injuries.[99]



A B C D

E

Figure 3-16 Photographs of arthrographic approaches to the hip joint. **A.** Image intensifier is used to locate the hip. **B.** Photograph demonstrating the cranial approach (anterolateral). **C.** Radiograph of an arthrogram utilizing the anterolateral approach. Notice the extravagated dye is anterolateral in the soft tissue. **D.** Photograph of an arthrogram utilizing the caudal (inferior) or "adductor" approach. **E.** Radiograph of an arthrogram utilizing the caudal approach. Notice that the extravagated dye is inferior in the soft tissue.

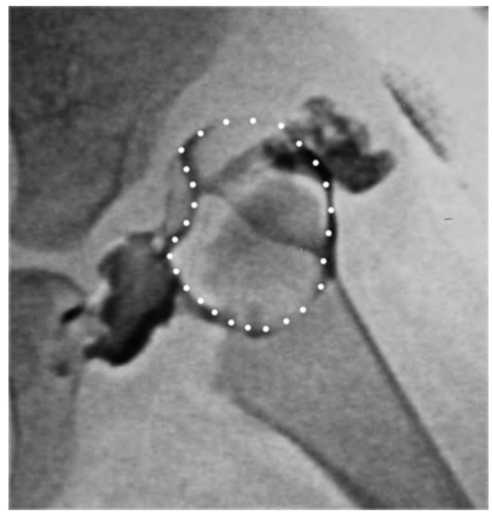
Arthrography of the Normal Hip Joint

In arthrographic examination of a normal hip of a small child, the orthopaedic surgeon must consider that a large portion of the hip joint is still cartilaginous. The lateral edge of the acetabulum is still immature. The dye forms a thin meniscus between the articular surface of the femoral head and the acetabulum. The labrum is contained within the joint capsule and can be identified as a triangular structure projecting into the dye-filled cavity of the joint. Faber[151] reported that in normal joints the labrum covers the femoral head as far as the Hilgenreiner line. There is a small recess adjacent to the labrum, described as the "superior articular" recess. The inferior articular recess is continuous with the labrum at the lower acetabular edge, distal to the outline of the transverse ligament, which crosses the acetabular fossa and closes the joint inferomedially. Above the transverse ligament outline, the thicker dye-filled area represents the acetabular fossa. Wiberg[643] showed that a tiny medial pooling of dye of about 1 mm could be seen in normal children. This occurs because the femoral head and the acetabulum acquire a slight elliptical shape during the intrauterine flexion of the hip joint. When the legs are extended, the arthrogram may show a relative minimal incongruity.

Arthrography of the Developmentally Dysplastic Hip

The arthrograms are studied to find the relationship between the femoral head and the acetabulum, the stability of the hip joint, the structures that obstruct entry of the femoral head into the acetabulum, and the factors that increase the risk of ischemic necrosis. First, the superior acetabulum is evaluated with regard to acclivity and shape and to establish whether its floor is free of interposed tissue, especially fat or enlarged ligamentum teres. When such interposed tissue exists, the labrum may be everted or pushed back toward the acetabulum by the femoral head, and inferiorly the transverse ligament may also

A



B

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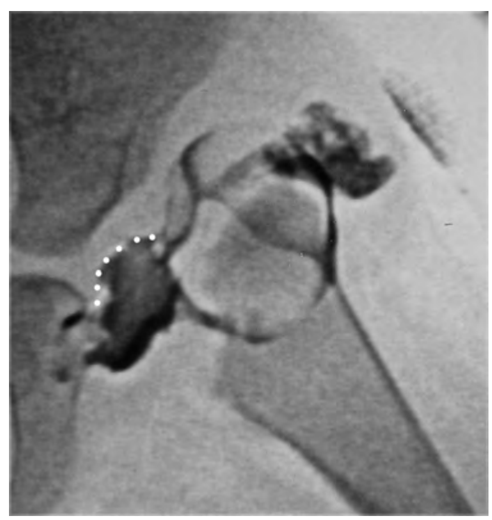

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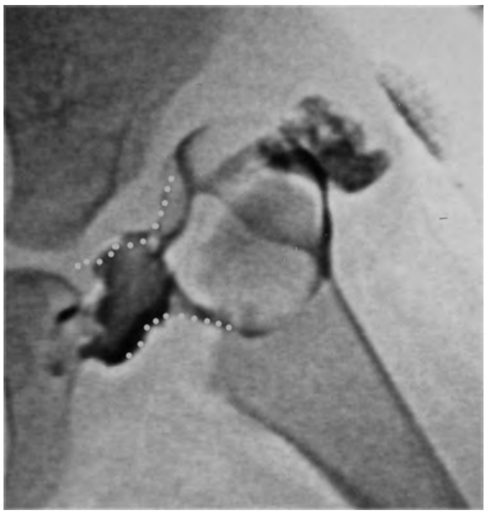

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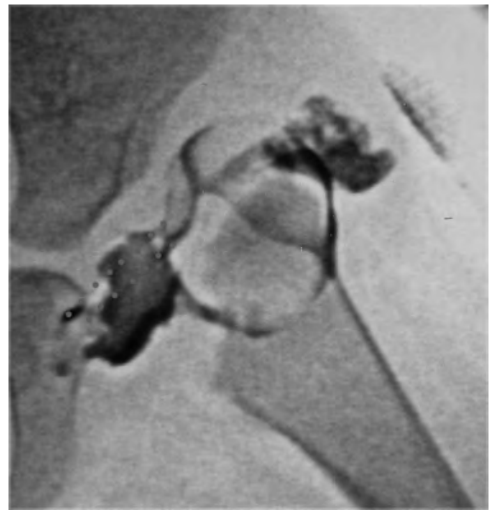

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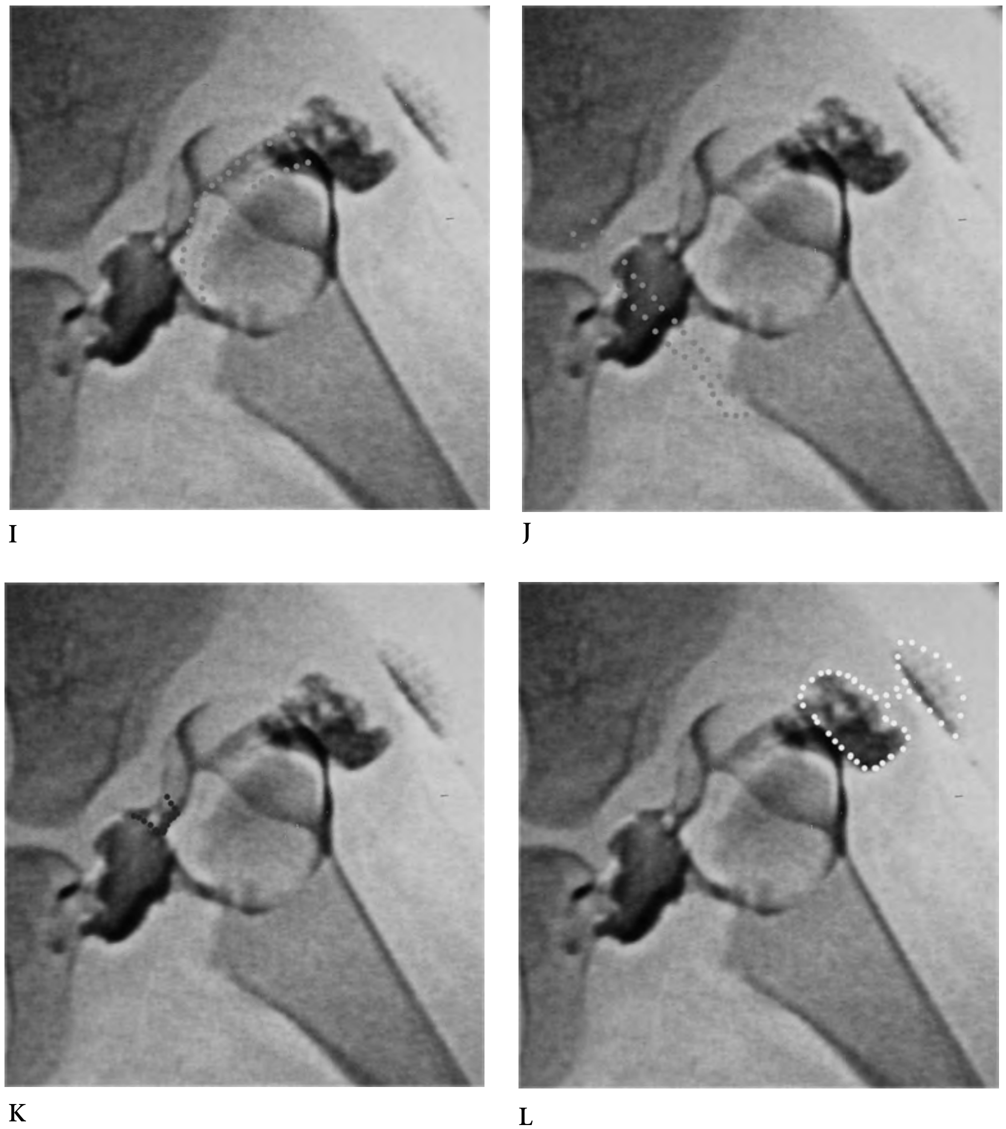

Figure 3-17 Photographs of an arthrogram of a dislocated hip. **A.** Dislocated hip. **B.** Outline of the femoral head. **C.** Outline of the false acetabulum. **D.** Outline of the roof of the true acetabulum. **E.** Outline of the hourglass shape of the capsule. **F.** Outline of the elongated ligamentum teres. **G.** Outline of the folvia of the femoral head. **H.** Outline of the transverse acetabular ligament. **I.** Outline of the zona orbicularis. Notice that the superior articular recess and the inferior articular recess are almost obliterated from the tight capsule. **J.** Outline of the indention of the capsule from iliopsoas tendon. **K.** Outline of the deformed labrum. **L.** Outline of the leakage of dye.

be enlarged and constricted as a consequence. The capsule may be constricted, narrowing the entrance of the femoral head into the acetabulum.

Arthrograms provide more pathologic highlights than ordinary radiographs, and they are useful to understand what is happening inside the hip joint and to orient the therapeutic decision. For this reason, various authors present their classifications or guidelines based on arthrography. A description of eight classifications is presented in the following pages. Each classification has individual merit, but the authors believe the Bowen criteria[133,165] or the Tönnis classifications[583,584,586,590,594] are the easiest to use for making treatment decisions.

Bowen's Prognostic Criteria for a Successful Closed Reduction[165]

The arthrogram of the closed reduction of a dislocated hip should show a concentric reduction with the femoral head positioned under the labrum and medialized into the acetabulum as the hip is positioned within the safe zone of Ramsey. Immediately after a closed reduction and arthrogram, three factors were found to be statistically predictive of a successful outcome: the proximal femoral metaphysis was below the Hilgenreiner line; two-thirds of the horizontal radius of the cartilaginous femoral head was medial to the Perkins line (medialization ratio of 0.66); and the femoral head was reduced beneath the lateral margin of the limbus. These criteria were developed by evaluating the outcome of patients with dislocated hips treated by a closed reduction at the A. I. duPont Hospital for Children. They are logical in that the dislocated hip must be lowered to the level of the acetabulum and must be medially positioned into the acetabulum, and only limited obstruction to the femoral head entering the depths of the acetabulum can be tolerated. In hips in which the metaphysis was above the Hilgenreiner line and the femoral head was not adequately medialized, subluxation or redislocation was common. Avascular necrosis occurred frequently if the femoral head was not reduced beneath the lateral margin of the labrum.

Other factors were often helpful but not statistically significant, including age at closed reduction, side of involvement, gender, performance of an adductor tenotomy, grade of initial displacement, initial acetabular index, traction station, and width of the medial dye pool. The authors found several factors that made the width of the medial dye pool less reliable than expected. The width of the medial dye pool varied by the amount of dye injected into the hip and the thickness of the pulvinar.

Although the width of the medial dye pool was not a statistical predictor of outcome of closed reduction treatment in the Forlin et al. article, Race and Herring[473] found it to correlate with stability of the femoral head within the acetabulum at the initial closed reduction. A good rate of stability was found when the medial dye pool was a narrow rim of contrast material medially. A fair rate of stability occurred when the medial dye pool was 5–6 mm in width, and poor stability existed when the medial dye pool was greater than 6 mm.

If a dislocated hip cannot be reduced to the criteria listed above, the authors recommend that the closed reduction be abandoned and the DDH be treated with an open reduction.

Grades of Dislocation According to Tönnis[583–585]

In his classification, Tönnis combines Peic's morphologic description of the labrum with the position of the femoral head.[449] For this reason, radiographs must be taken with the hip in strict neutral position.

Grade 1: The femoral head is laterally displaced by "no more than two-thirds of its width" in relation to the superior bony edge of the acetabulum. The labrum is everted but still covers the femoral head.

Grade 2: The femoral head is laterally displaced "more than two-thirds of its width" in relation to the superior bony edge of the acetabulum but "has not yet crossed the cartilaginous rim by more than one-third of its height in the vertical direction." The labrum is: (a) "thinned, everted, and still covers the head" and (b) "short, rounded, folded, or deformed."

Grade 3: The femoral head is displaced upward more than one-third of its height in relation to the cartilaginous rim of the acetabulum. The labrum is (a) "thinned, everted, and still covers the femoral head" and (b) "short, rounded, mildly inverted, and deformed."

Grade 4: The femoral head is "completely dislocated, and is separated from the acetabulum by the labrum or constricted capsule." The labrum (a) hangs vertically, generally accompanied by inlapped capsule and (b) is large and inverted into the acetabulum and impedes the reduction.

Classification of Leveuf and Bertrand[593]

Leveuf and Bertrand considered the hip to be dislocated only when the labrum was interposed between the acetabulum and the femoral head. The position in which the head is dislocated but is still covered by the acetabulum and the labrum they called the "intermediate" stage. This condition is classified by other authors as a subluxation.

Classification of Howorth, Mitchell, Dörr, and Dunn[136,266]

These authors described a grading system to classify arthrograms of the hip joint:

Grade 0: Arthrogram showing normal hip joint morphology.

Grade 1: Arthrogram showing unstable and subluxable hip joints owing to capsular laxity. The labrum and acetabulum are slightly deformed and reduction by the Roser-Ortolani maneuver of the femoral head into the acetabulum is complete.

Grade 2: Arthrogram showing a subluxed hip joint. The femoral head is displaced upward and exerts pressure on the acetabular rim, producing a depression with which it joins. The labrum and rim of the acetabulum are deformed, but the femoral head still does not migrate over the labrum and the capsular insertion.

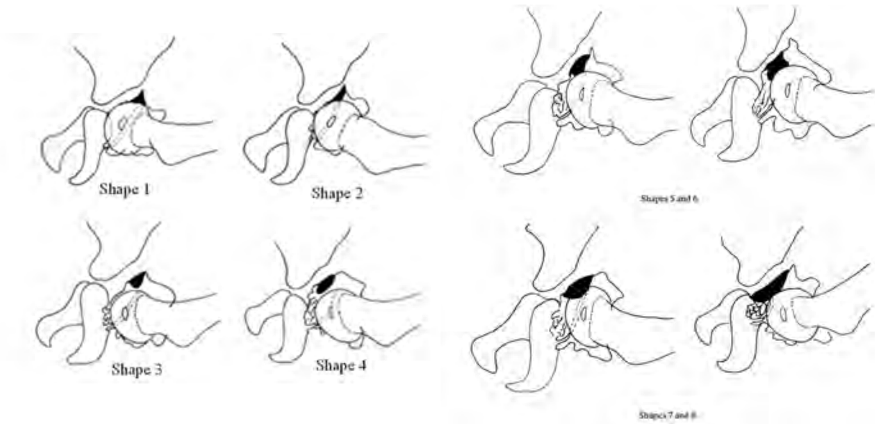

Figure 3-18 **A, B.** Drawing of an arthrogram demonstrating Bowen's prognostic criteria for a successful closed reduction. Eight shapes of limbus are identified on the arthrogram. Shapes 1 to 4 are associated with good results following a closed reduction. Shapes 5 to 8 show a blunted and interposed limbus. These particular shapes of limbus are related with a higher incidence of avascular necrosis and poor result (from Forlin E, Choi IH, Guille JT, Bowen JR, Glutting J: Prognostic factors in congenital dislocation of the hip treated with closed reduction. The importance of arthrographic evaluation, J Bone Joint Surg Am 74(8): 1140–52, p 1144, Fig 4, 1992).

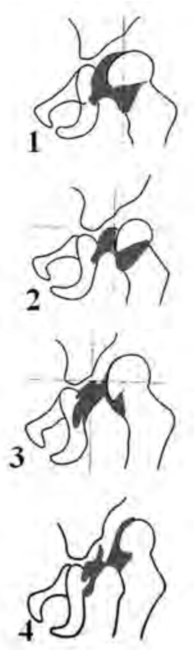

Figure 3-19 Schematic drawing of the Tönnis arthrographic classification for DDH. Grade 1: lateral displacement no more than two-thirds of the femoral head width. Grade 2: lateral displacement more than two-thirds. Grade 3: upward displacement, more than one-half of the femoral head height. Grade 4: complete dislocation of the femoral head (from Tönnis D, Legal H, Graf R: Congenital Dysplasia and Dislocation of the Hip in Children and Adults, p 153, Fig 10.10, Berlin, Springer-Verlag, 1987).

Grade 3: Arthrogram showing complete dislocation. The femoral head is outside the acetabulum, passing over the labrum and shifting it backward toward the acetabulum.

Grades of Dislocation According to Guilleminet[593]

Grade 1: The labrum is deformed but not inverted.

Grade 2: The labrum is between the acetabulum and the femoral head.

Grade 3: The labrum is inverted and projected into the acetabulum.

Grade 4: The femoral head is out and cannot be brought to the level of the acetabulum.

Grades of Dislocation According to Mitchell[409]

Grade A: "Tight" dislocation: The labrum is inverted and interposed posteriorly between the acetabulum and the femoral head.

Grade B: "Loose" dislocation: The head is displaced upwards and the labrum and the capsule are interposed between the acetabulum and the femoral head.

Classification of Schwetlick[593]

Class A: For joint laxity, the patient is placed in the Lorenz position with lateral traction applied to the hip. The width of the air crescent visible in this position is utilized to estimate the three grades. Grade 1: little laxity; grades 2 and 3: greater laxity and possible subluxation.

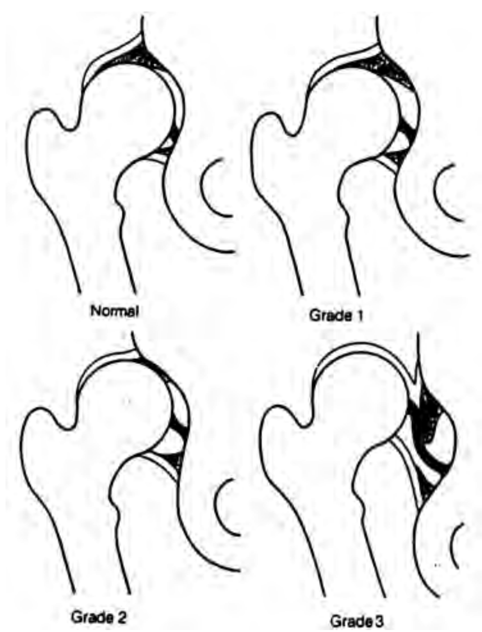

Figure 3-20 Schematic drawing of Dunn's grading of DDH. Grade 0: normal. Grade 1: unstable and subluxatable. Grade 2: subluxated joint. Grade 3: complete dislocation (from Tönnis D: Radiological classification and diagnosis, Mapfre Medicina 3 (Suppl 1): 42–45, p 42, Fig 1, 1992).

Class B: "Dislocations amenable to conservative treatment." The dislocated femoral head is completely mobile and the soft structures around the hip joint are lax. The capsule is elongated and wide, without adhesions, and permits free delivery of the femoral head into the acetabulum. The labrum is inverted but reassumes its original position during or after reduction, and the ligamentum teres is normal.

Class C: "Dislocations requiring primary operative treatment." (1) The capsule continues to be evidently constricted after the joint is distended with air, physiologic saline, or carbon dioxide. (2) The capsular hood is incompletely evinced or is absent. (3) The capsule exhibits a marked honeycomb structure because of adhesions. (4) The ligamentum teres is widened and hypertrophied.

Classification of Peic[449]

The morphology of the labrum is a very important issue related to closed reduction of DDH. The labrum presence, position, and morphology can interfere with reduction of the femoral head into the acetabulum. Peic studied 400 arthrograms, identifying 12 different morphologic types of labrums arranged into groups of 3 for classification purposes.

Types 1–3: The upper portion of the labrum is displaced or resorbed.

Types 4–6: The labrum is round, short, and slightly inverted.

Types 7–9: The labrum is hanging.

Types 10–12: The labrum is inverted and adherent.

Miyake Classification[406,411]

Based on an anteroposterior flexion and abduction (frog) view of the arthrogram, this classification defines types of limbus as follows:

Type 1, everted: The limbus has a blunt and turned-outward aspect.

Type 2, intermediate: The limbus is blunted and has an infolded form, which causes minimal obstruction to reduction of the femoral head into the acetabulum.

Type 3, inverted: The limbus is infolded and interposed between the femoral head and the acetabulum.

Type 4, blockaded: The limbus has an ill-defined form that impedes the entrance of dye into the true acetabulum.

Type 5, impossible: The limbus does not permit reduction of the hip joint.

DIAGNOSIS AFTER WALKING AGE (1 YEAR OF AGE AND OLDER)

As a child with DDH begins to walk, the clinical signs vary according to the severity of disease. With only acetabular dysplasia, no clinical signs may be detected. With subluxation, the clinical signs may include a delayed Trendelenburg sign or a limp after extensive walking. With a complete dislocation, the child limps in the standing phase of each step on the side of the dislocated hip by a contralateral downward tilt of the pelvis, and the spine shows a lateral deviation toward the dislocated side (Duchenne compensation of a Trendelenburg gait).[598] In unilateral involvement, often the child tries to compensate for the shortening by toe-walking or flexing the contralateral knee. There is a vertical telescoping movement during gait because of the instability of the dislocated hip, which contributes to confirm the diagnosis. At the clinical examination, the affected lower limb is short, the greater trochanter is prominent, and the buttocks are broad and flat. The hip movements of abduction and extension are limited. The Trendelenburg test is positive (the pelvis drops on the opposite normal side when the child stands on the affected lower limb because of the weakness of the hip abductors). In bilateral involvement, the typical gait is described as a "duck-like waddle" or "sailor's gait." The distance between the thighs is increased and the perineal space is widened. The increased forward inclination of the pelvis and the posterior displacement of the femoral heads cause hyperlordosis of the lumbar spine and a protuberant-appearing abdomen. Albinara et al.[5] and Jones and Powell[291] reported that DDH could have been diagnosed early and treatment provided in 56 percent and 60 percent of cases, respectively, if patients had been included in a screening program.

Radiographic Findings

At this age, DDH is easy to detect on radiographs. The examiner can see an ossified femoral head displaced from the acetabulum.

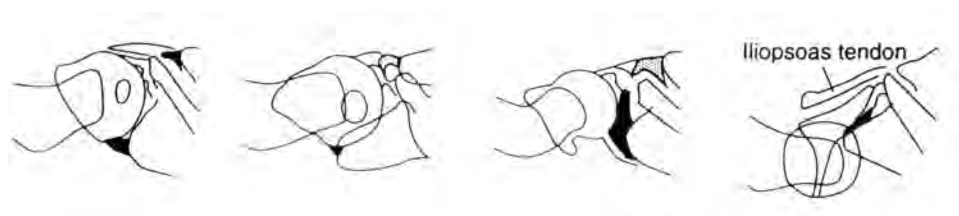

Figure 3-21 Schematic drawing of the Miyake classification of the limbus. Types A normal, type B everted, type C intermediate, type D inverted, type E blockaded, type F impossible. Miyake recommends closed reduction for types B and C; the other types should be treated by open reduction. (From Mitani S, Nakatsuka Y, Akazawa H, Aoki K, Inoue H: Treatment of developmental dislocation of the hip in children after walking age. Indications from two-directional arthrography, J Bone Joint Surg Br 79(5): 710–18, p 713, Fig 5, 1997. Copyright © the British Editorial Society of Bone and Joint Surgery. Reproduced with permission.)

A B

Figure 3-22 Photographs of girls with dislocated hip. Clinical signs after walking age include: **A.** Hyperlordosis. **B.** Positive Trendelenburg test/gait and shortening of the lower limb in the dislocated hip.

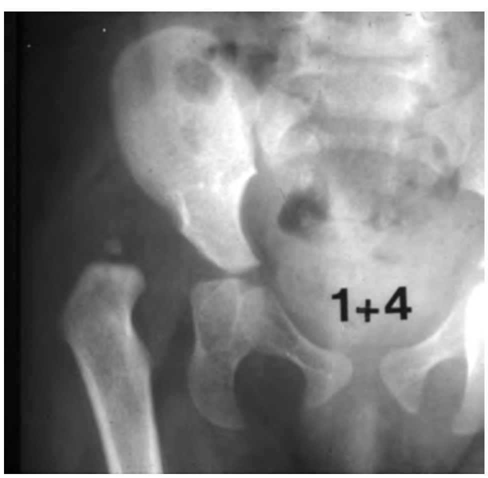

Figure 3-23 Antero-posterior radiograph of a dislocated hip showing proximal and lateral displacement of the femoral head out of the acetabulum. Notice the false acetabulum.

Chapter Four

Treatment of DDH, Birth through 3 Months of Age

The main objective of treatment is to promote nontraumatic relocation of the hip at as young age as possible and to maintain the reduction so that the hip joint can continue normal development. Many authors[1,74,109,154,168,172,197,290,351,445,460,461,476,507,595,596,622,648] agree that the major goals in the management of DDH are early treatment, a concentric relationship between the femoral head and the acetabulum, and stability in a safe position.

FROM BIRTH THROUGH 3 MONTHS OF AGE

The indications for treatment include all typically dislocated and subluxed hips and all persistently unstable or dysplastic hips. Hips that are Barlow positive at birth often become stable within the first 3 weeks. For this reason, the authors usually do not treat the Barlow-positive hip in the first 3 weeks; however, these hips need thorough evaluations to ensure normal hip development. We recommend that the follow-up evaluation include sonography and also recommend treatment in hips with persistent instability at 3 weeks of age. Persistently unstable/dysplastic hips are very difficult to diagnose through physical examination. The authors believe that children with high risk factors such as a positive family history for DDH or breech position during pregnancy and children with a questionable physical examination of the hip deserve a sonographic evaluation. Some communities perform hip screening by sonography, which detects dysplastic or immature hips. Immature hips that progress to normality do not need treatment. Persistently dysplastic hips do deserve treatment, but there is debate concerning the length of time that is allowable for dysplasia to resolve before treatment is instituted. The authors recommend treatment in hips that remain dysplastic after 3 to 6 weeks.

When the diagnosis is made in early infancy and secondary pathological changes have not yet developed, the dislocated hip often can be reduced by a gentle maneuver without the necessity of using traction or anesthesia. The treatment is based on the concept that positioning a reduced hip in flexion and mild abduction will stimulate normal joint development. The maintenance of the reduction is an important issue in the treatment. The Pavlik harness is currently the most widely used treatment orthosis.[447] There are a number of other orthotics available that have been developed to maintain the hip in flexion and abduction, including the Von Rosen splint,[115,617–622] the abduction pillow,[248] the Derqui splint,[128,129] the Frejka pillow,[167,465] the Petit splint,[345] and the Craig or Infeld splint.[101] These devices need to be readjusted frequently, demanding knowledge on the part of parents of how to replace them in the correct position after diapering. They are often too soft or too rigid, permitting free motion of the hips or forcing the hip into severe abduction, which causes problems such as redislocation or avascular necrosis of the femoral head.

The Pavlik harness is a dynamic splint that utilizes the concept of positioning the thighs to allow spontaneous reduction. It demonstrates a low incidence of avascular necrosis, is easily applied, and is adjustable as the infant grows.[159,172,209,220,231,297,447,465,476] To achieve and maintain reduction, the hips are flexed at 90–110° and allowed to abduct up to about 65° in the Pavlik harness. The principles of treatment are to maintain hip flexion and limited adduction with the Pavlik harness and to allow free hip abduction from the weight of the lower limb. The weight of the lower limb associated with gravity is the source of power for stretching the hip adductor muscles. Although many orthopaedists use the Pavlik harness in children under 6 months of age, the authors usually do not recommend the Pavlik harness in children with dislocated hips over 3 to 4 months of age. Older children who require many months of treatment are often difficult to manage in a Pavlik harness. We believe a closed reduction and casting may give better results in these older children with dislocated hips.

INDICATIONS FOR THE USE OF THE PAVLIK HARNESS

- Child up to 4 to 6 months of age with dysplastic, subluxed, or dislocated hips
- Typical DDH, easily reduced by an Ortolani test
- Dislocated (but reducible hip in the Pavlik harness)
- Dislocated, nonreducible hip initially but with potential to improve toward the acetabulum within about 3 weeks and that attains a complete stable reduction during Pavlik harness treatment

ADVANTAGES OF USING THE PAVLIK HARNESS

- Is easily accepted by parents and well tolerated by the infant
- Does not need hospital admission for device placement or control
- Does not interfere in child care (e.g., diaper changes)
- Reduction is attained in the physiologic position of the neonate, with the hip in flexion
- Adductor muscles are gently stretched by the weight of the legs and the reduction is obtained spontaneously without anesthesia or forced maneuvers
- Active movement is preserved in the safety zone of reduction of Ramsey, thus avoiding hip extension and adduction to the thighs passing the midline
- Knee flexion of the hamstrings, which contributes to the maintenance of hip reduction

- Avoids forced abduction of the hip, which reduces the risk of avascular necrosis of the femoral head

CONTRAINDICATIONS FOR THE USE OF THE PAVLIK HARNESS

- Child sufficiently old and strong to stand (9 months or older)
- Typical DDH that cannot be reduced by the Ortolani test and is irreducible
- The femoral head needs more than 110° of flexion to point toward the triradiate cartilage.
- Fetal (antenatal or teratologic) DDH that cannot be reduced
- Anatomic changes occur in the hip joint, blocking the concentric reduction of the femoral head into the acetabulum
- Stiff hip with muscle imbalance
- Congenital extension contracture of the knee (before correcting the extension deformity)
- Other disease processes that limit reduction, such as connective tissue disorders associated with generalized ligamentous and capsular laxity, including Down syndrome, osteogenesis imperfecta, arthrogryposis, spina bifida, and Marfan disease
- Anterior or inferior dislocation that will not reduce with hip flexion

APPLICATION OF THE PAVLIK HARNESS

The Pavlik harness consists of three parts: the body, the right leg, and the left leg parts. The child is placed in a supine position and the body part is donned around the chest, just below the nipple mamillary line. The shoulder straps must be placed over the scapula, pass over the shoulders, and attach to the anterior buckles. The leg parts are donned by positioning the proximal Velcro strap immediately distal to the popliteal fossa, and the distal Velcro should be approximately 1 cm above the ankle. The leg parts must be adjusted positioning the anterior and posterior straps at the medial and lateral aspect of the proximal leg, respectively. To connect the leg parts with the body part, the anterior straps should be adjusted to flex the hip 90–110° by the buckles at the anterior axillary line. Turn the baby to the prone position with the legs in abduction and flexion and adjust the posterior straps to the body part to limit adduction. Return the child to a supine position and test abduction and adduction of the hip. Maximal adduction should be to a limit of 0° and maximal abduction should be obtained passively by the weight of the child's legs. The posterior leg strap should be loose and only limit adduction, not cause abduction of the hip.

Figure 4-1 Photograph of a Pavlik harness.

Figure 4-2 Photograph of a child in a Pavlik harness. Typically, the hips are flexed from 90–110°.

FUNCTION OF THE PAVLIK HARNESS

The anterior straps provide hip flexion, which should be 90–110° in order to direct the femoral head toward the triradiate cartilage (center of the acetabulum). The function of the posterior straps is to control the hip adduction and not to pull the hip into abduction. The posterior strap should be lax (not tight), and to avoid redislocation, the adduction of the thighs should not be allowed to pass the midline. The positioning of the proximal Velcro strap of the leg part immediately distal to the popliteal fossa should permit good control of hip flexion and avoid excessive knee flexion. In some cases, the adductor muscles are tight at the beginning of treatment. Hip abduction is passively carried out by the weight of the child's lower limb, minimizing the risk of avascular necrosis because the harness does not force abduction of the hip.

TREATMENT WITH THE PAVLIK HARNESS

Bowen[231] has divided the treatment of DDH into stages that are ranked progressively: dislocated/subluxed (and not reducible); unstable (but reducible); stable; weaning; and residual dysplasia.

Treatment of the Unstable but Reducible Hip in a Pavlik Harness

Most newborns requiring Pavlik harness treatment have an unstable but concentrically reducible hip. These children present and are classified in the unstable progressive treatment stage. For treatment, the Pavlik harness is applied and used constantly (24 hours per day). The harness is not removed for bathing or diapering. When the harness is applied initially, an antero-posterior radiograph is taken or sonography is performed with the child in the Pavlik harness to confirm that the hips are in the desired position with the proximal femoral neck pointing to the triradiate cartilage (center of the acetabulum). The parents are taught about the pathology, the opportunities for treatment, how to use the harness, how to care for the infant, and the possible problems or complications involved. The authors prefer that the patient return for harness reevaluation at the outpatient clinic on the following day, or that a phone call to the parents be made to ensure the harness is being tolerated. If all involved (parents, grandparents, siblings, and the infant) are doing well, an appointment is made for the following week. Hip sonography by the dynamic technique of Harcke is performed in the harness to evaluate the reduction and stability after the second week. *The hip should not be redislocated during the sonographic examination.* The authors prefer weekly outpatient evaluations until the hip becomes stable as demonstrated by the Harcke technique of sonography, at which time the hip enters the stable progressive treatment stage. The full-time use of the harness depends upon the age of the child at the beginning of this stage. After the stable stage is attained, a rule of thumb is that the harness should be worn full time for the number of weeks corresponding to the age in weeks of the child, to a minimum of 6 weeks and a maximum of 6 months. For example, if a hip reaches the stable treatment stage when the infant is 6 weeks of age, the harness is continued full time for an additional 6 weeks. The authors prefer to reexamine the child at least every 3 weeks to adjust the harness for growth. After the allotted duration of full-time harness use, the hip enters the weaning treatment stage. During this stage the harness is progressively discontinued, increasing at 2-week intervals from 4 hours to 8 hours, and then to nights only for 2 weeks. Sonograms are obtained during weaning to ensure hip stability. The hip then enters the residual dysplasia treatment stage. Radiographs are taken to establish a baseline and to evaluate bony dysplasia as shown by the acetabular index. All dysplasia should resolve spontaneously or be treated (see section on residual bony dysplasia, chapter 7).

If a concentrically reduced hip in a child under 3 months of age does not develop stability within 6 weeks or becomes unstable after the designated duration of full-time Pavlik harness treatment, the authors recommend discontinuation of the harness and treatment by casting be instituted (see section on reduction and casting, chapter 5).

TABLE 4-1. Algorithm for the Treatment of Unstable but Reducible Hips in Children under 3 Months of Age

Unstable but reducible hip

Initiate full-time Pavlik harness

↓

Weekly evaluations and sonograms until stable

↓

Continue full-time harness the designated duration
according to the age at hip stability

↓

Wean from Pavlik harness and evaluate for recurrence of instability

↓

Follow for evaluation and treatment of residual dysplasia

Treatment of the Dislocated/Subluxed Nonreducible Hip in a Pavlik Harness

Children with dislocated or subluxed hips that will not concentrically reduce are classified in the dislocation/subluxation progressive treatment stage. For these hips, the Pavlik harness is applied and sonography is performed to ensure proper positioning of the lower extremities. The philosophy and standards of patient care while in the Pavlik harness apply, as stated above in the section on treatment of the unstable but reducible hip. The authors recommend weekly evaluations and sonography to determine the degree of hip progression toward reduction. The degree of hip dislocation can be measured sonographically by the scale of Harding and Bowen.[231] Level 5 is a posterior and superior dislocation of the femoral head with no acetabular contact. Level 4 is a posterior dislocation with the femoral head touching the acetabulum. In level 3, the femoral head is at rest in subluxation without reduction. Level 2 is subluxation with reduction by hip abduction. Level 1 is a concentrically reduced but unstable hip, and level 0 is a concentrically reduced stable hip. With successful treatment using the Pavlik harness, the hip should progressively achieve lower levels as demonstrated with weekly sonograms. When the hip reaches the unstable but reducible treatment stage, further Pavlik harness treatment follows the protocol and algorithm as listed above in the section on treatment of the unstable but reducible hip. In the A. I. duPont Hospital for Children series, no patient achieved successful treatment with the Pavlik harness unless the sonographic scale of level 5 lowered within 3 weeks. If progress has not occurred to level 2 within 3 weeks, the authors recommend that the Pavlik harness be abandoned. If a dislocated or subluxated hip is maintained without reduction in the Pavlik harness, secondary changes will occur that will severely damage the hip. A special warning is necessary when a nonreducible dislocated hip is treated in a Pavlik harness for more than 3 to 4 weeks and reduction is not being achieved: iatrogenic injury to the hip may occur.

The authors agree[231] that the best results are obtained when the treatment begins within 3 weeks of life. It is extremely important to confirm reduction during treatment with the Pavlik harness. If no reduction is achieved, the Pavlik harness is discontinued and the dislocated hip is treated by reduction and casting (see section on reduction and casting, chapter 5). Jones et al.[292] reported that prolonged positioning of the dislocated hip in flexion and abduction implies dysplasia and increases the difficulty of obtaining a stable closed reduction. If concentricity and stability are attained but bony dysplasia persists, the use of an abduction orthosis may allow the acetabular dysplasia to resolve.

TABLE 4-2. Algorithm for the Treatment of Dislocated/Subluxed Hips

Dislocated/subluxed nonreducible hip

↓

Apply Pavlik harness

↓

Sonography weekly up to 3 weeks

↙ ↘

Hip progressed to at least level 2
(sonographic scale of Harcke and Bowen)

↓

Continue as protocol algorithm for unstable
but reducible hip (see Table 4-1)

Hip did not progress
abandon Pavlik harness

Complications of Pavlik Harness Treatment

Despite strict criteria for the use of the Pavlik harness, the treatment fails in 2 percent of unstable hips and in up to 26 percent of patients with dislocated hips.[611]

1. Treatment fails because of problems with using the harness. The parents do not adequately accept or collaborate with the treatment because of social or cultural norms or prejudices, or they manifest misplaced sympathy for their child.
2. Problems with adjusting the harness may cause complications.

In excessive hip flexion:

1. Femoral nerve palsy, which is usually transient, may occur with excessive hip flexion. The nerve is entrapped under the inguinal ligament. This may be more common in obese children.[233,564] To treat the femoral nerve palsy, the excessive flexion of the hip is reduced until the nerve recovers.
2. Iatrogenic inferior or obturator subluxation of the femoral head may also occur following excessive flexion of the hip.[354392] Treatment is to reduce the flexion; however, if unsuccessful, skin traction to the extremity may be necessary.
3. If the anterior buckle to the leg of the body part of the Pavlik harness is too medial, the strap will cause the hip to flex, rotate, and adduct, resulting in failure to stretch the contracted hip adductor muscles.[564]

In excessive abduction in the harness:

1. Anterior dislocation of the hip may be present, associated with significant external rotation of the leg. During the physical examination, the hip becomes stiff and painful and the femoral head is prominent and palpable in the groin.[564] For treatment, the Pavlik harness is discontinued and skin traction is applied to the limb, which places the hips in progressively increasing flexion and adduction. After reduction, the hip should be immobilized in a spica cast.
2. Medial knee joint instability may be present, associated with medial rotation of the hip caused by the posterior strap being too tight or the harness being too small for the child. The valgus stress on the flexed knee stretches the medial collateral ligament. The correct use of the Pavlik harness and its periodic adjustment for growth avoid this complication.[564] Medial knee joint instability corrects after proper fitting of the Pavlik harness.
3. Avascular necrosis of the femoral head (AVN), although rare after treatment with this harness, may occur. Initially, in 1944, when Pavlik[447] recommended maximal and forced abduction, his patients showed a high percentage of avascular necrosis. The incidence decreased after physicians began using the posterior strap of the leg part of the Pavlik harness only to limit adduction and not to force abduction of the hip. The reported incidence varies from 0–28 percent.[170,209,220,296,297,557,582,597] Several articles report an increased incidence of avascular necrosis in hips reduced before ossification of the femoral epiphysis; however, its relationship to the Pavlik harness treatment is unclear. The authors believe the advantages of an early reduction are presently more important. Segal et al.[510,511] have reported that there is a statistical significance in predicting AVN by the presence or absence of the ossific nucleus. Its presence, detected by radiographs or sonography, before open or closed reduction suggests a decrease in the risk. Luhmann et al.[361] disagree with this theory, reporting a study on 124 patients (153 hips). Closed reduction was used on 112 hips and open reduction was employed on 41 hips. They identified ischemic necrosis in five hips. Their analysis of the data did not support the hypothesis that the presence of the ossific nucleus at the time of reduction is associated with a lower incidence of AVN. A prone sleeping position may force the hips into excessive abduction. Alternating the sleeping posture between prone and supine positions prevents the femoral head from suffering this severe complication.

Other complications of treatment with the Pavlik harness are associated with failure to achieve a reduction of the hip:

1. Muscle contractures can occur. The dislocated hip allows malpositioning of the leg and shortening, contributing to muscle contracture. The authors suggest discontinuing the Pavlik harness and instituting skin traction to stretch muscles, followed by closed reduction and casting. If contractures persist, myotomies at the hip-reduction procedure may be necessary. In the authors' experience, an adductor myotomy under general anesthesia is often necessary.

2. Acetabular deformity may occur in a persistently dislocated or subluxed hip treated excessively with a Pavlik harness. The force derived from the harness causes the femoral head to further injure the acetabulum. Treatment of this deformity is very difficult, often necessitating closed or open operative reduction and casting.

Late acetabular dysplasia following early successful treatment by a Pavlik harness was reported by Tucci et al.[605] Seventeen percent of 74 hips (61 patients) presented with changes in the acetabulum (upward tilt of the outer portion or sclerosis in this area). Continued

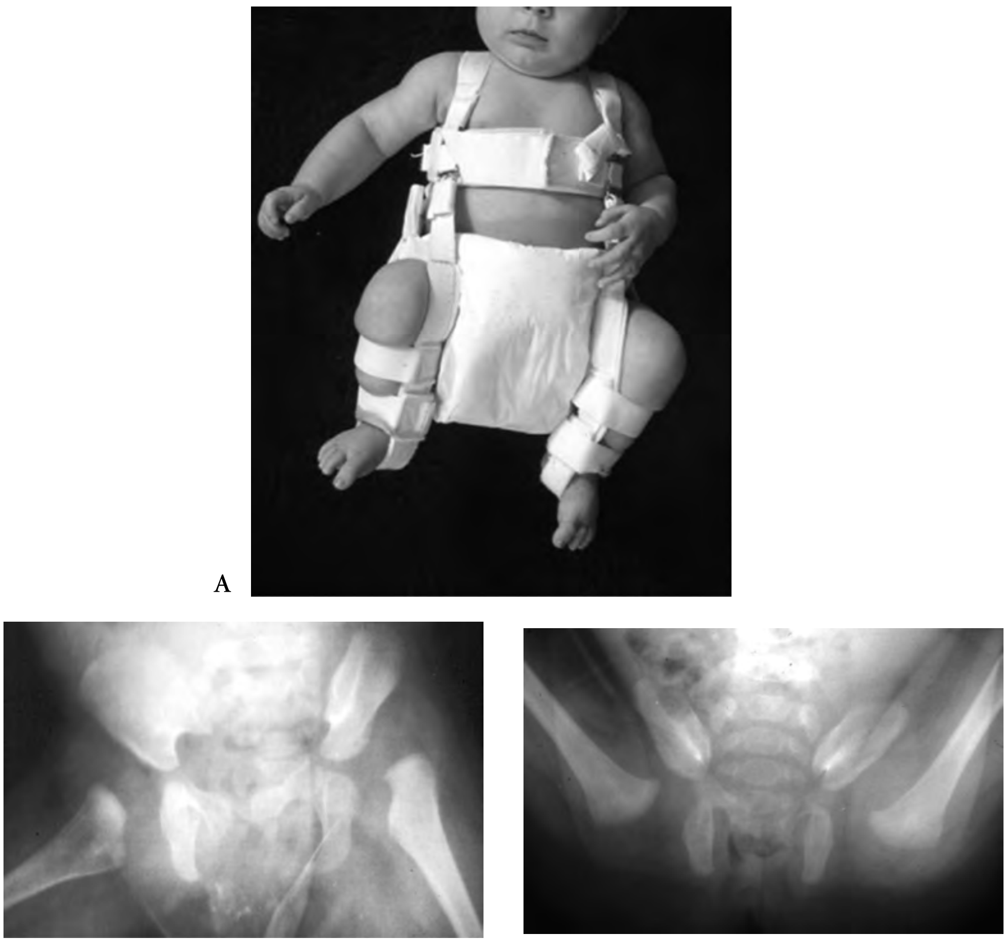

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Figure 4-3 **A.** Photograph of an infant in a Pavlik harness. Notice that the left hip is inadequately flexed. Typically, the hips are flexed from 90–110°. **B.** Insufficient flexion: radiograph of the pelvis with an infant in double diapers. Notice that both hips are dislocated and neither is appropriately positioned by the double diaper technique. **C.** Radiograph with excessive hip flexion and with inferior dislocation of the hip.

follow-up until skeletal maturity is recommended, and residual dysplasia may require treatment (see chapter 7).

Sanpath et al.[497] analyzed the indications for abduction splints for the treatment of DDH. They prospectively evaluated 797 newborns between 1996 and 1998 as part of an ultrasound screening program. The babies were studied in two groups. In the first group, those who presented with hip instability at the first scan were splinted with a Pavlik harness. In the second group, the babies who had persistent instability at 2 weeks were placed in a Pavlik harness. Sanpath et al. encountered a splintage rate of 1.6/1,000 live births in the first group and 0.8/1,000 live births for the second group. They did not find any increase in the rate of dysplasia requiring a surgical procedure between the groups. This study supports the concept that Barlow-positive hips at birth may be observed several weeks to allow natural correction; however, persistent instability for over 3 to 6 weeks needs treatment.

Schott[508] reported on the use of the Pavlik harness from 1981 onward and concluded that infants under 3 weeks of age with a positive Ortolani maneuver have good results in most cases. Infants between 3 weeks and 3 months of age with a positive Barlow maneuver and negative Ortolani test obtained similarly good results. He also observed that 50 percent of children from 3 months to 6 months of age were able to obtain a "dynamic reduction" of the hip dislocation. This study supports the idea that the Pavlik harness is very effective in treating DDH within the early weeks of age and becomes much less effective after 6 months of age.

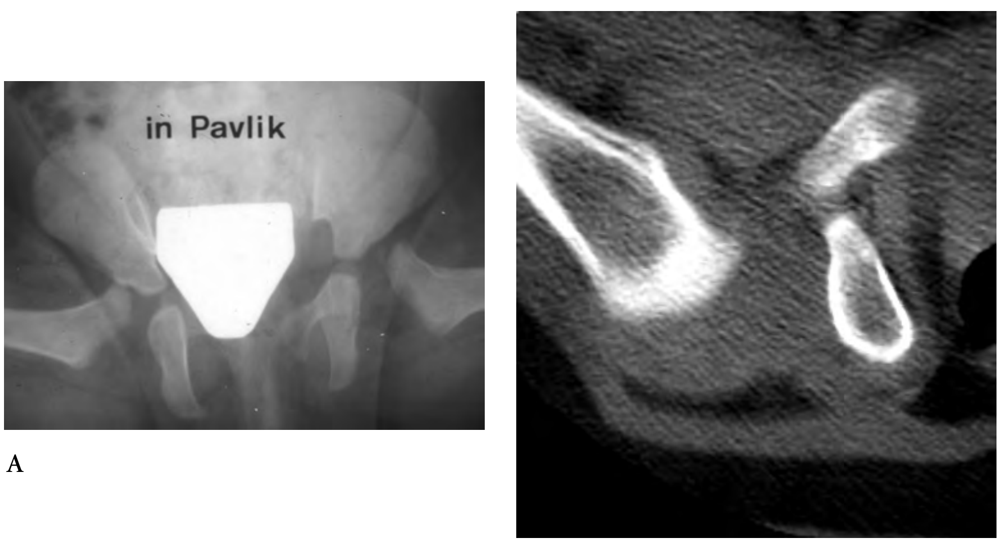

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Figure 4-4 **A.** Radiograph showing acetabular deformity following prolonged use of the Pavlik harness with the hips being persistently dislocated. **B.** CT showing deficiency of the posterior cartilage of the acetabulum following prolonged use of the Pavlik harness with the hip being persistently dislocated.

Chapter Five

Treatment from 4 Months to Walking Age

With neonatal screening and the utilization of sonography, late diagnosis of DDH is becoming less common; however, some dysplastic hips and even dislocated hips escape early diagnosis. Occasionally an apparently normal hip will dislocate at an older age, and the etiology of this phenomenon is unknown. In this event, the physician should question the family in regard to tightly swaddling the legs in extension, history of DDH in the family, and any change in the neurological status of the child. The treatment of DDH in children from 4 months to 1 year occurs in four steps: (1) bringing the femoral head down to the joint level; (2) achieving concentric reduction; (3) maintaining stability of reduction; and (4) resolving dysplasia.

STEP 1: BRINGING THE FEMORAL HEAD DOWN TO THE JOINT LEVEL

Currently, prolonged hospitalization, both parents working outside the home, and high cost are making traction less popular. In children with a dislocated hip, traction may be used to pull the femoral head down in an attempt to recover the relationship between the acetabulum and the femoral head. Traction is most useful in children with a dislocated hip that is Ortolani negative, with a high dislocation and a severe soft-tissue contraction. The type of traction utilized for the treatment varies among orthopaedic surgeons; a choice exists among Russell, Bryant, Buck, or skeletal traction. In Russell "split" traction, the hips are positioned at 30–60° of flexion and the knees are flexed 20–30°. These hip and knee positions facilitate the stretching of the pelvic and femoral muscles, especially the iliopsoas and the hamstrings. The hips are abducted to stretch the abductor muscles when the femoral head is lowered to the level of the acetabulum. However, the limit of 45° of abduction should not be exceeded. Bryant overhead traction, with the hips at a right angle of flexion and the knees in extension, lowers the posterio-superiorly dislocated femoral head to the level of the acetabulum. Some orthopaedists[564] disagree with this position because vertical traction does not elongate the shortened hip flexors, particularly the iliopsoas muscle, and may cause circulatory problems in the lower limbs. Buck unilateral traction with the lower limb in complete extension provides a stretching of the hip muscles, but the compression of the capsule by the iliopsoas tendon may interrupt the blood supply to the femoral head. To bring the femoral head down, skeletal traction through the distal femur exerts strong force on the femur and hip. It should not be applied to the proximal tibia, because the knee may become unstable. Skeletal traction may give rise to complications such as pin infection,

Figure 5-1 Photograph of a child in home traction. Home traction offers greater comfort to both child and parents by reducing prolonged hospitalization and travel.

damage to the distal femoral physis, femur fracture through the area of pin penetration, and disuse atrophy. Patients may also be confined to bed for long periods. Frequently, patients must be hospitalized for 2 or 3 weeks (rarely, up to 3 weeks) of traction. The parents must be advised that the duration of traction depends on the level of the femoral head and varies from one child to another. Home traction is utilized to offer greater comfort to both child and parents, maintaining the entire family at home and thus avoiding a stay in the hospital that can lead to inconveniences such as upper respiratory infections and adverse psychological reactions to hospitalization. Joseph et al.[293] have made an extensive review comparing home traction with traction in the hospital. The important issue described in their paper is the incidence of avascular necrosis of the femoral head, which, out of a total number of 42 patients, occurred in 2.4 percent of those treated by traction at home and in 7.5 percent of those treated in the hospital.

Indications for the Use of Traction

- The hip is not reducible with the Ortolani test.
- The femoral head is high-riding above the acetabulum.
- Soft tissues are contracted.

Prerequisites for the Use of Skin Traction

- No skin lesions on the lower limb
- Medical infrastructure to support careful observation of lower limb vascular and neurovascular status when applying either the hospital or the home traction program[293,294]
- Parents are sufficiently well informed for the utilization of a home traction program

Advantages of the Use of Skin Traction

- Safety
- Well accepted by parents
- Well tolerated by the infant
- Baby's body weight serves as counteraction
- May be done at home (home traction program)

- Reduces the incidence of complications such as AVN[175,267]
- Less painful to remove (compared to skeletal traction)

Disadvantages of the Use of Skin Traction

- After 2 to 3 weeks of traction, may cause disuse atrophy
- Possibility of fracture
- Skin ulceration and ecchymosis
- Foot edema
- Neuromuscular and/or vascular troubles
- Problems with internal fixation when femoral shortening is performed[566]

Technique of Application of Skin Traction

In children from 3 months to 1 year of age, the authors prefer skin traction with the hips flexed about 45°. The utilization of nonadhesive straps is the best way to avoid skin lesions. The straps may be removed several times a day to permit washing and other skin care and to allow affection through physical contact of the baby with its relatives.[566] Another method of fastening skin traction is to apply nonallergenic adhesive or tincture of benzoin to a snug stockinette on each lower limb and then to apply the medial and lateral adhesive straps over the stockinette and fix them in place with elastic bandages. A foot plate is necessary to keep the traction straps away from the malleoli of the ankles and thus avoid pressure sores.

Traction begins at one pound, distally pulling down each lower limb. It is then increased by steps of 0.5 pound to a maximum of five pounds and is maintained 20 to 24 hours per day. Strict control of neurological and vascular status of the ankle, foot, and toes is performed every few hours by well-trained helpers, orthopaedic surgeon, nurse, or parents. Weekly antero-posterior radiographs of the pelvis are taken to evaluate the level of the femoral head in relation to the acetabulum. When the femoral head reaches the level of the acetabulum, abduction is gradually increased. These radiographs help determine the correct period for increasing the abduction of the lower limbs and avoiding premature abduction when the femoral head is on the lateral aspect of the ilium, thus preventing increased risk of avascular necrosis of the femoral head.

Gage and Winter[175] described traction stations to quantify the effectiveness of the traction. This classification refers to the position of the femoral head in relation to the acetabulum. On the pelvis, the reference points are the obturator foramen and Hilgenreiner line, and on the femur the reference point is the medial ossified aspect of the proximal medial metaphysis. When the medial aspect of the femoral metaphysis is above the Hilgenreiner line, the hip is at the minus-one station. If the medial femoral proximal metaphysis is at the level of the triradiate cartilage between Hilgenreiner line and the upper border of the obturator foramen, it is at the zero station. When it is level with the superior border of the obturator foramen, it is at the plus-one station (i.e., the normal position), and when the femoral head is pulled down below the opposite normal hip, it is at the plus-two station. Ideally the hip should be at the plus-one or two stations prior to a closed or open reduction, which indicates that the traction has adequately elongated the contracted soft tissue.

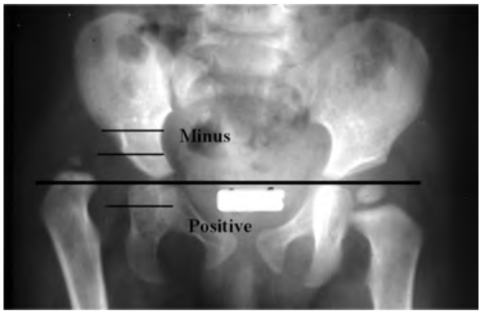

Figure 5-2 Schematic representation of the Gage and Winter traction stations. Zero station occurs when the medial corner of the metaphysis of the femoral neck is between the reduced position and the Hilgenreiner line. Plus-two station occurs if the medial corner of the metaphysis of the femoral neck is below the opposite normal hip. The hip is at a minus-one station if the corner is above the Hilgenreiner line.

STEP 2: ACHIEVING REDUCTION OF A DISLOCATED HIP

Reduction may require either operative or nonoperative (closed reduction) methods. In children from 3 months to 1 year of age, closed reduction is usually adequate. Closed reduction must be carried out gently to avoid avascular necrosis of the femoral head, redislocation, or persistent dysplasia. Reduction may be achieved with traction (slowly over weeks) or by manipulation in the operating room. Reduction by traction has currently been abandoned by the authors except in extreme circumstances in which anesthesia is not safely allowed.

Closed Reduction and Spica Cast Treatment

Indications

- Dislocated or subluxed hip when the Pavlik harness (or similar orthosis) is inappropriate
- Dislocated or subluxed hip in children after the age of orthotic treatment
- After achieving an adequate hip stations by traction
- About 3 or more months of age (possibly up to about 18 months)

Advantages

- Safety
- Noninvasive method
- Decreased tendency to persistent stiffness of the hip after treatment

Disadvantages

- Months of casting
- Residual dysplasia is frequent

- Potential for redislocation or subluxation
- Possibility of avascular necrosis of the femoral head
- Hospitalization, anesthesia, cost
- Repeated roentgenograms to control the evolution of treatment
- Difficulty of nursing and caring for the patient in a cast

The steps of closed reduction by operative manipulation in children are first, arthrogram; second, manipulative reduction; third, evaluation of reduction and fourth, casting.

The first step is to perform an arthrogram under general anesthesia. Arthrography is used to evaluate the anatomy of the hip in the search for soft-tissue impediments to a concentric relationship between the femoral head and the acetabulum, as well as to control the reduction obtained. With the patient under general anesthesia, the authors recommend injecting diluted radiopaque dye, using fluoroscopy to control the amount of contrast to be injected. A concentration that is too dense may obscure detail, and a volume that is too great may deform soft-tissue relationship.[199] The different approaches to the examination of the hip joint and normal and abnormal arthrographies were discussed in chapter 3.

Closed reduction is performed gently by repositioning the femoral head into the acetabulum under general anesthesia. With the patient in a supine position, an assistant stabilizes the pelvis. The orthopaedic surgeon holds the affected lower limb by the distal third of the thigh and flexes the hip 90–110°. Then the hip is abducted while gentle traction is employed in the longitudinal axis of the thigh. Pressure is applied over the greater trochanter and the femoral head is placed gently into the socket by lifting it anteriorly over the posterior edge of the acetabulum.

The reduction must be confirmed by antero-posterior radiographs and, if available, by dynamic ultrasound, as reported by Terjensen.[573] This is a useful technique in guiding closed reduction and in stimulating the effects of positioning on the stability of the hip joint. Two critical decisions are made after the radiographs are taken: first, is the hip within the safe zone of Ramsey, and second, is the reduction adequate?

Ramsey et al.[476] defined the safe zone of reduction as the arc between the angle of maximum abduction and the adduction angle that allows redislocation. To determine the safe zone, the hip is reduced and held in 90° of flexion. The hip is allowed to abduct fully and the angle of abduction is recorded. The thigh is then adducted until the hip dislocates, and the degree of adduction at dislocation is recorded.

Sometimes the safe zone is too narrow, between 40 and 55°, because the adductor muscles are contracted. An adductor muscle tenotomy is indicated to increase the safe zone of reduction and to alleviate pressure on the femoral head after reduction. This procedure can be carried out according to the surgeon's preference, either percutaneously or by an open approach. The incidence of avascular necrosis of the femoral head is related to the difficulty of reduction and the degree of abduction of the thighs in the cast. The ideal safe zone is between 30 and 65°.

The adequacy of reduction can be determined by the degree of the concentricity between the femoral head and the acetabulum. Severin initially accepted a mild degree of hip

A B

Figure 5-3 The safe zone of Ramsey is the arc between the angle of abduction and the angle that allows redislocation. **A.** Schematic drawing of the safe zone of Ramsey (from Coleman SS: Developmental dislocation of the hip from 10 to 18 months, Mapfre Medicina 3 (suppl 1): 90–92, p 92, Fig 4, 1992). **B.** Photograph of an infant demonstrating a small safe zone of Ramsey.

joint incongruity, applying the notion that with time the femoral head will locate into the acetabulum.[514–516] This process of the hip slowly settling deeply into the acetabulum is often referred to as "docking" of the femoral head. The authors warn against using the docking concept to the extreme. We believe the hip should reduce under the labrum to get an adequate result from a closed reduction.[165] To evaluate the congruity of the hip joint and prognosticate the results of closed reduction, Forlin et al.[165] reported the medialization ratio, the acetabular coverage ratio, and the displacement of the cartilaginous femoral head superior to the Hilgenreiner line. The medialization ratio is the percentage of the horizontal radius of the cartilaginous femoral head medial to the Perkins line.

The acetabular coverage ratio is the percentage of the horizontal radius of the cartilaginous femoral head medial to the line drawn between the limbus and the transverse

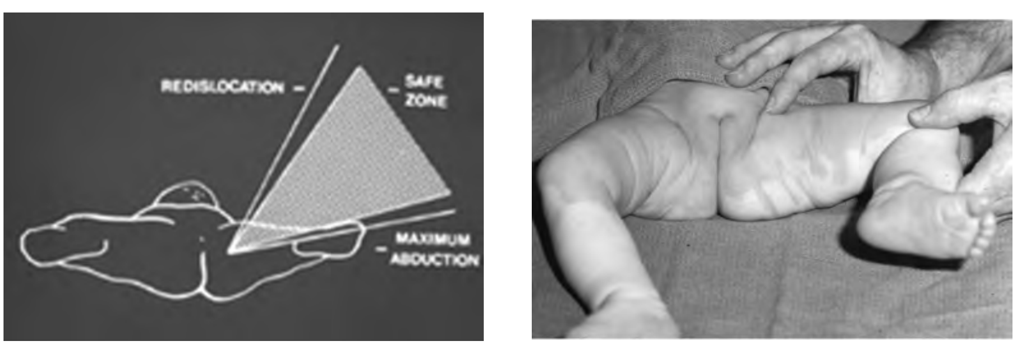

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Figure 5-4 **A.** Schematic drawing of the safe zone of Ramsey, which is enlarged by an adductor muscle tenotomy (from Coleman SS: Developmental dislocation of the hip from 10 to 18 months, Mapfre Medicina 3 (suppl 1): 90–92, p 92, Fig 4, 1992). **B.** Photograph of an infant after an adductor muscle tenotomy, demonstrating a wide safe zone of Ramsey. The hip is not usually abducted more than about 65–75° in the postoperative cast because forced wide abduction may cause AVN for the femoral epiphysis.

acetabular ligament. The position between the upper aspect of the cartilaginous femoral head in relation to the Hilgenreiner line is classified as negative (–) when it is superior and positive (+) when it is inferior to it.

Forlin et al.[165] also described eight different shapes of the limbus representing the "apparent progressive obstruction to the femoral head." The conclusion of this study on 72 dislocated hips in 61 patients, all of whom had been classified as Grade III or IV according to Tönnis, is that the shape of the limbus is an indicator of outcome. Shape types 1 to 4 are associated with good results and types 4 to 8 with poor results. Medialization rates above 67 percent are associated with good results, and the authors believe that this measurement is more accurate than the width of the medial pool of contrast medium because the width may be altered by the amount of dye from the arthrogram and interposing soft tissue.[245,353,516,523] For example, the surgeon can increase the medial dye pool during the arthrogram by injecting a large volume of dye. Based on the concept of progressive reduction, some authors believe that the interposed soft tissue will gradually disappear if the femoral head is kept against the acetabulum.[413,509,523] The authors and others prefer a more concentric reduction.[354,409,472,532]

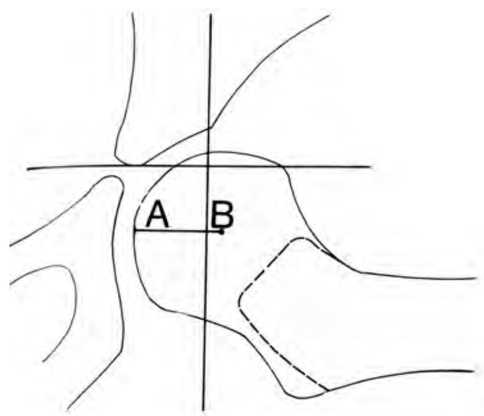


Figure 5-5 Schematic drawing of the medialization ratio, which is the percentage of the radius of the cartilaginous femoral head medial to the Perkins line. The percentage more than two-thirds of the horizontal radius with the hip in a position of reduction is related to a good or fair result (from Forlin E, Choi IH, Guille JT, Bowen JR, Glutting J: Prognostic factors in congenital dislocation of the hip treated with closed reduction. The importance of arthrographic evaluation, J Bone Joint Surg Am 74(8): 1140–52, p 1143, Fig 1, 1992).

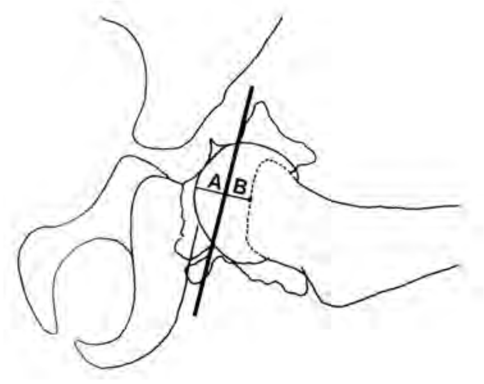


Figure 5-6 Schematic drawing of the acetabular coverage ratio, which is the percentage of the cartilaginous femoral head radius medial to a line drawn from the limbus to the transverse acetabular ligament (from Forlin E, Choi IH, Guille JT, Bowen JR, Glutting J: Prognostic factors in congenital dislocation of the hip treated with closed reduction. The importance of arthrographic evaluation, J Bone Joint Surg Am 74(8): 1140–52, p 1143, Fig 2, 1992).

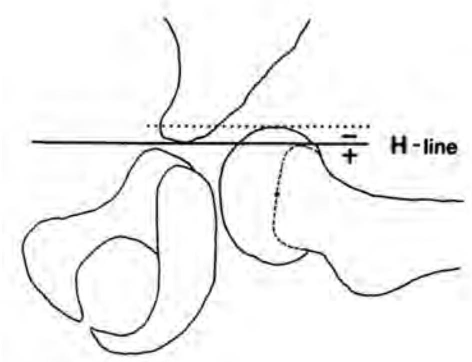


Figure 5-7 Schematic drawing: The relationship between the top of the femoral head and the Hilgenreiner line is positive (+) when the femoral head is inferior to it, and negative (-) when the top of the femoral head is superior to that line (from Forlin E, Choi IH, Guille JT, Bowen JR, Glutting J: Prognostic factors in congenital dislocation of the hip treated with closed reduction. The importance of arthrographic evaluation, J Bone Joint Surg Am 74(8): 1140–52, p 1143, Fig 3, 1992).

The authors recommend Bowen's prognostic criteria to determine the adequacy of a closed reduction for DDH:[165]

- The proximal femoral metaphysis is below the Hilgenreiner line.
- Two-thirds of the horizontal radius of the cartilaginous femoral head are medial to the Perkins line.
- The femoral head is reduced beneath the lateral margin of the limbus.

The arthrogram of the closed reduction should show a concentric reduction with the femoral head positioned under the labrum and medialized into the acetabulum as the hip is positioned within the safe zone of Ramsey (with the hip flexed 110° and no greater than 65° abduction); otherwise, we recommend an open reduction.

STEP 3: MAINTAINING STABILITY OF THE REDUCTION

The spica cast is applied carefully to immobilize the hips if a concentric reduction is attained. The surgeon holds the affected hip by exerting mild pressure on the greater trochanter and thigh and places the hip in the best position for the reduction. When the dislocation is bilateral, an experienced and skilled assistant holds one hip while the surgeon holds the other. It is imperative that the reduced hip joint be maintained, avoiding extreme positions of flexion, abduction, or internal rotation. The recommended position is 90° of flexion, but this may vary from 90–110°. The hip should also be abducted up to 65°, affording better stability of the reduction and considering the safe zone of Ramsey.

A small 1-cm-thick towel is placed over the abdomen, and webril (cast padding) is rolled from the level of the nipples down to the ankle. The bony prominences are protected with felt or sponges. One or two layers of casting are applied and molded over the greater trochanters and sacral region. Some orthopaedists reinforce this cast with plastic tape,[566] but it is not essential. Jaykumar prefers to apply the plaster in two sections, a proximal section from the nipples to the knee and a distal section from the knee down to the ankles. The assistants can hold the legs and maintain the reduction as the proximal section is being

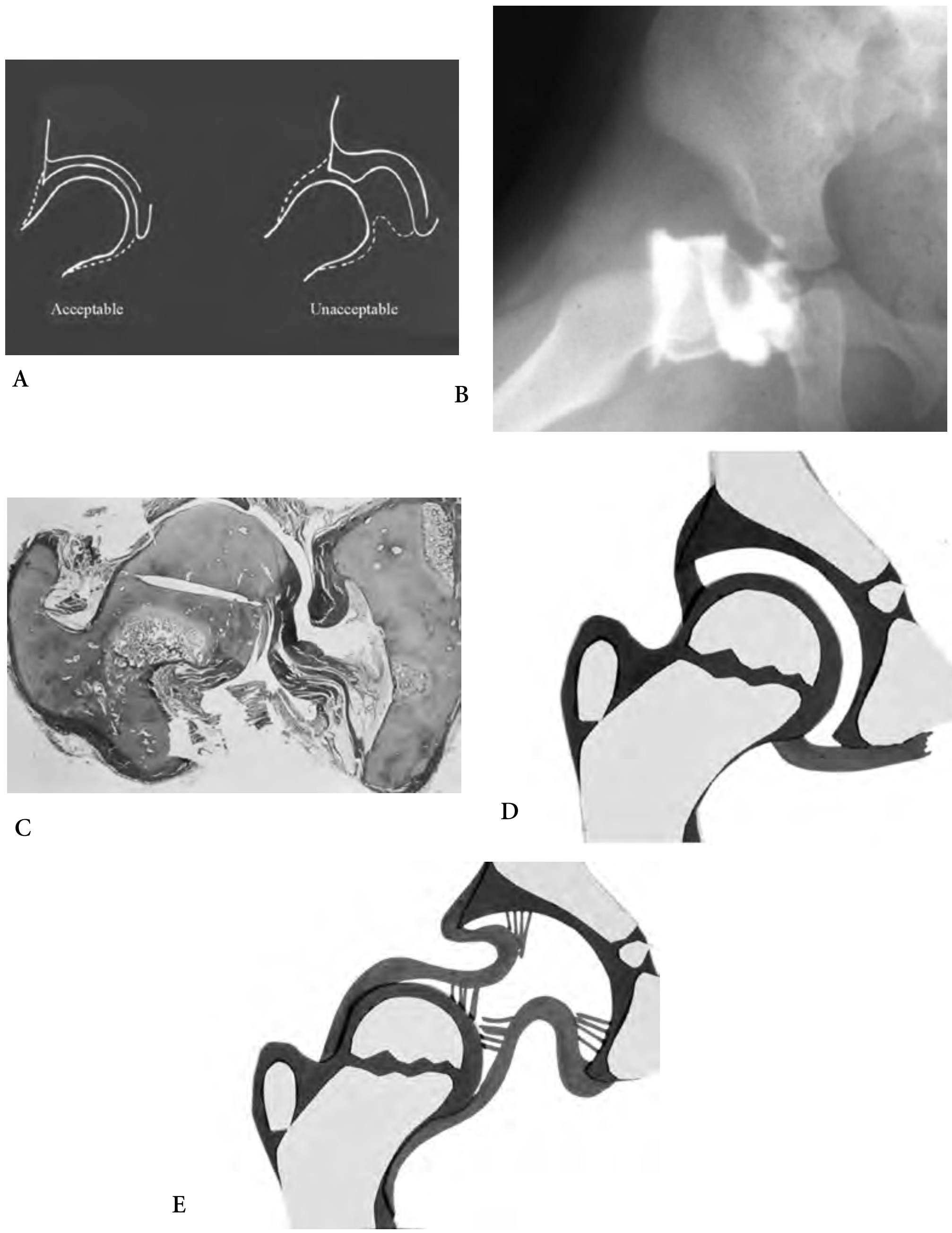
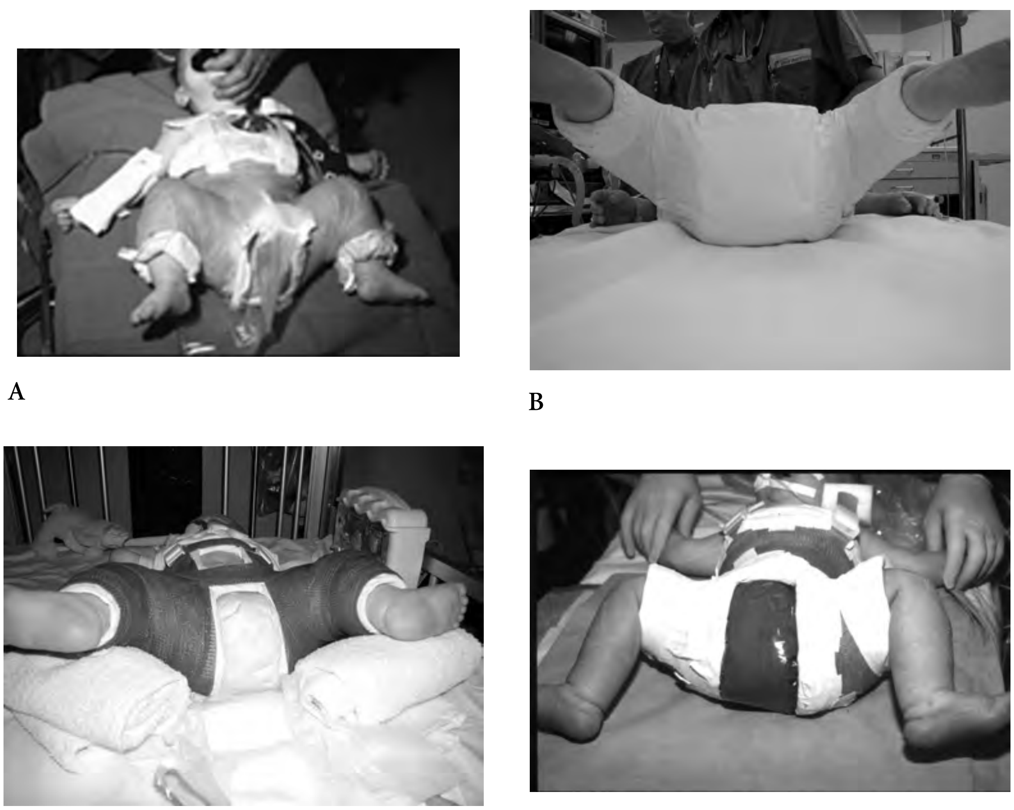


Figure 5-8 **A.** Schematic drawing showing acceptable and unacceptable limbus shapes of a closed reduction. **B.** Radiograph of an arthrogram showing blunting of the limbus in an unacceptable attempted closed reduction of a dislocated hip. **C.** Photograph of a histological section showing the femoral head blunting the limbus in an unacceptable attempted closed reduction of a dislocated hip. **D.** Schematic drawing from Dr. Mercer Rang showing an acceptable reduction. **E.** Schematic drawing from Dr. Mercer Rang showing an unacceptable reduction.

applied. He utilizes splints to reinforce the cast.[195,326] The perineal region should be left open to permit easy maintenance of hygiene and diaper changes. After cast application the small towel over the abdomen is pulled out from the cast, allowing room for the child's stomach to expand during eating. An antero-posterior radiograph is taken to confirm the maintenance of a concentric reduction in the cast. Some surgeons prefer fiberglass cast material because of its radiolucency.[90] The authors prefer using Goretex cast padding and fiberglass so the child can be bathed. If the cast is applied expediently after the arthrogram, enough radiopaque dye will remain in the joint to confirm the reduced hip position in the cast.

If there is doubt, the orthopaedic surgeon may order a CT or MRI to confirm the position within the cast.[373,546,661] The risk of CT involved in obtaining this further information is acceptable, but only when radiation protection measures are properly carried out.[315,363] In places where computed tomography is not available, a single-cut laminagram, made at the level of the urethra in the female and at the penis-scrotal angle in the male, will help to visualize the hip.

The minimum period of use of the spica cast is 8 to 12 weeks for a small child and up to 24 weeks for an older child, depending on the age of the infant at diagnosis and beginning



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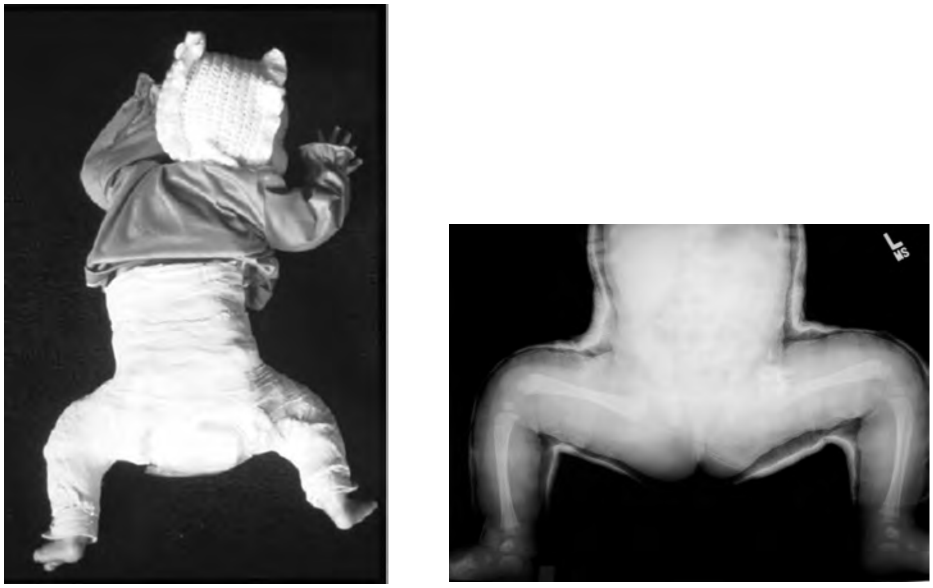


E F

Figure 5-9 Photographs of children with dislocated hips that were treated by closed reduction and casting. **A, B, C.** Photographs of spica casts demonstrating hip flexion and mild abduction to maintain the closed reduction. **D.** Photograph of a short leg spica cast. This child was treated initially with a long leg cast for 6 weeks and a short leg cast was then applied because the hip was stable. **E.** Photograph of a patient immobilized in a cast with the legs in the "frog" position. This position is associated with a high incidence of AVN. **F.** Radiograph of the infant in the "frog" position in a cast.

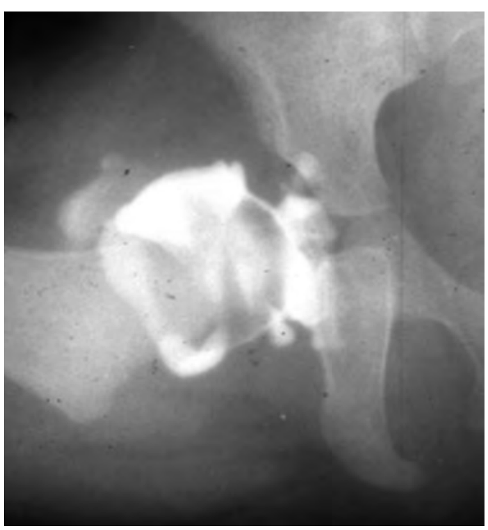
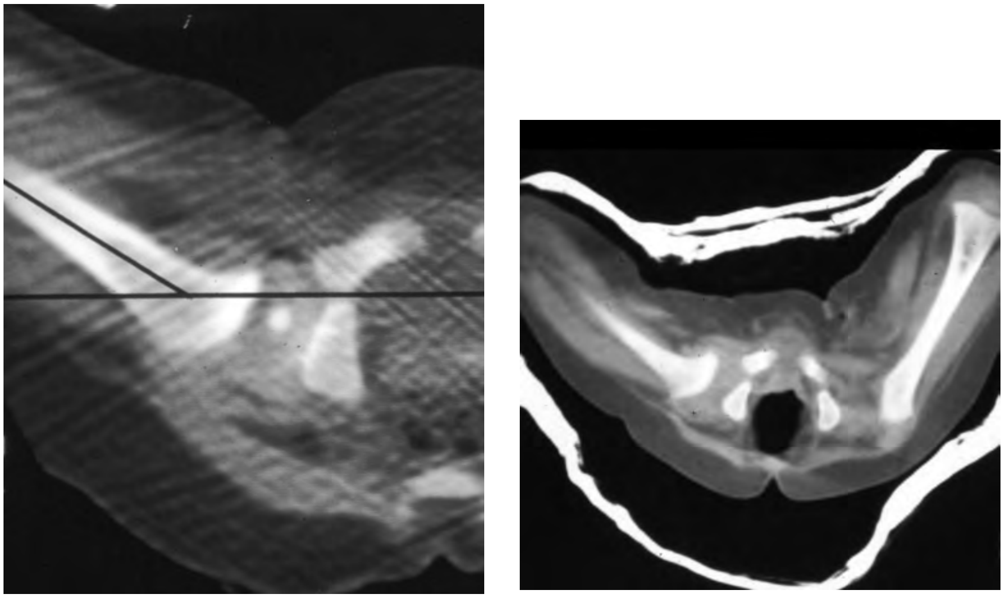


Figure 5-10 Arthrogram of the right hip after an attempted closed reduction. Notice the wide medial dye pool, demonstrating an unacceptable reduction. (Measurements may also be made from the inner wall of the pelvis to the physis. No more than a 2-mm difference between the reduced side and the normal side is acceptable.)



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B

Figure 5-11 **A.** CT scan of a child with a reduced hip in a spica cast. Notice the poor quality of the cast. **B.** CT scan of a child with a posteriorly dislocated hip. This child had been in a spica cast for two months with the hip dislocated. Notice the flattening of the posterior lip of the acetabulum.

of treatment. The rule of thumb for the duration of casting is 1 month in the cast for each month of age at closed reduction, to a maximum of 6 months' casting. Radiographs are usually taken monthly to follow the development of the hip joint and ensure a concentric reduction. If a question develops concerning the adequacy of the reduction, a CT is performed.[546] If the hip redislocates, it must be rereduced quickly; otherwise the persistently dislocated hip will cause an iatrogenic deformity of the acetabulum. Children usually outgrow the cast about every 6 weeks, necessitating a cast change. The patient is admitted as an outpatient, and under general anesthesia the cast is removed, the skin is cleaned, and the hip is gently examined (do not redislocate the hip in the examination). The reduction must not be lost during the cast change; therefore, the lower extremity position must be guarded. If the ossific center of the femoral head is present, antero-posterior radiographs are taken to evaluate the reduction; and if the ossific center of the femoral head is absent, an arthrogram is helpful. The authors prefer that the new cast be applied from the nipple line down to the ankles with the same lower extremity position as the first cast. If the hip is stable as demonstrated during arthrography, Tachdjian recommends applying the second spica cast extending to a position above the knee.[564,565] Children usually outgrow the second cast at a similar rate as the first. The authors frequently remove the second cast in the cast room without sedation and apply the third cast, which usually extends to a position above the knee. Concentric reduction of the hip is verified by radiographs in the new cast.

Following removal of the final cast, radiographs are performed to evaluate residual bony dysplasia. If the acetabular index is normal and avascular necrosis does not develop, the child is followed with periodic radiographs until skeletal maturity. In the authors' experience, most children who are reduced at an older age will have residual bony dysplasia and radiographs will show an abnormal acetabular index. We frequently recommend an orthosis to maintain the hip in flexion and abduction to treat the residual dysplasia: however, outcome results of orthotic treatment are not available. There are many different kinds of flexion-abduction orthosis, including hip-knee plastic orthosis, a Denis Browne hip abduction splint, and a Scottish-rite brace, or the posterior half of a bivalved hip spica cast. We recommend hip-knee plastic orthosis for younger children and the Scottish-rite

A B

Figure 5-12 Photograph of a postcasting abduction orthosis. **A.** Atlanta brace. **B.** Rhino abduction brace.

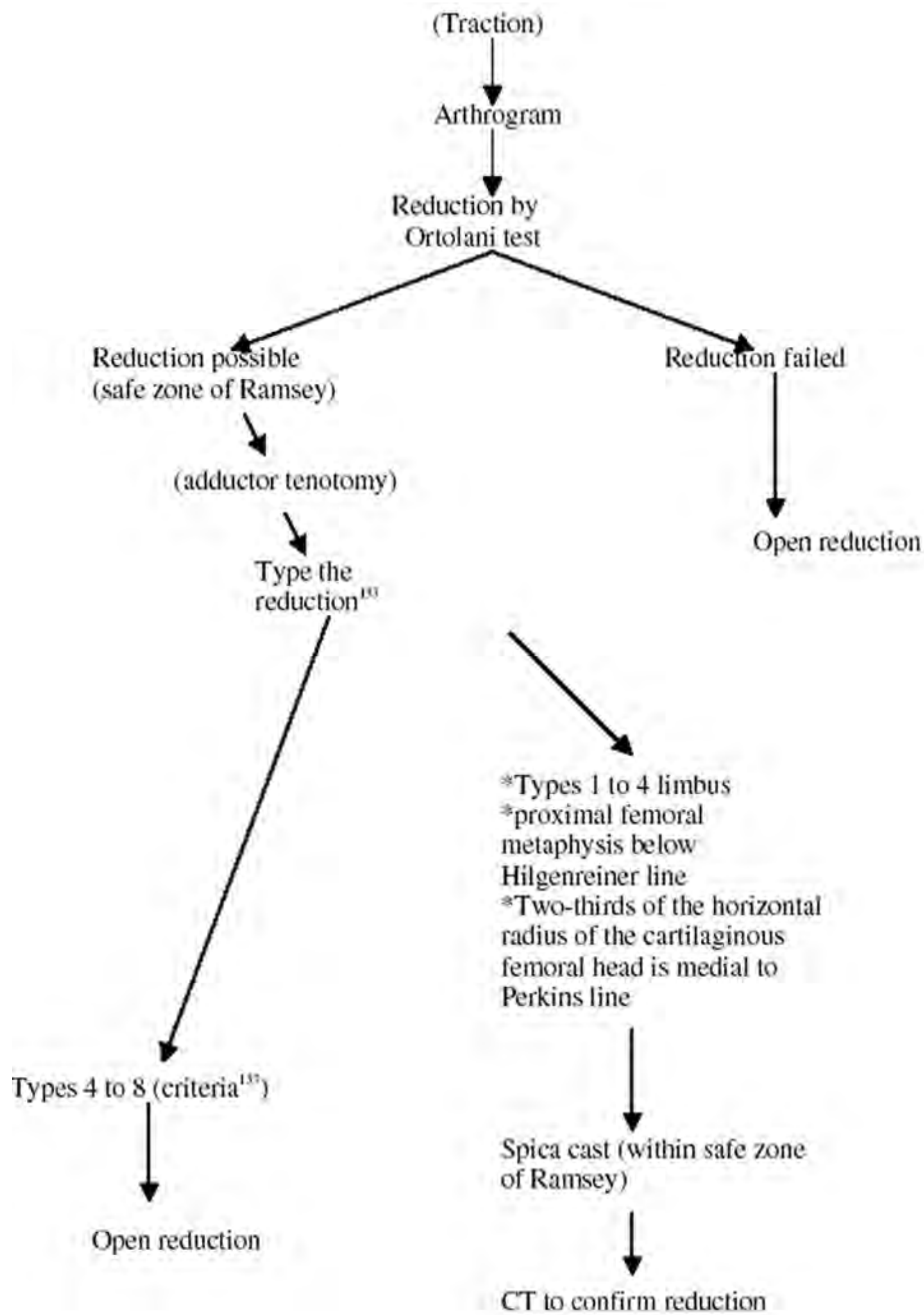
brace for walking patients. Further treatment recommendations for residual dysplasia are in chapter 7.

Long-term studies demonstrate closed reduction and casting for DDH to be a good treatment option, confirmed by significant improvement in the acetabular index in the years following reduction.[74,362] However, sometimes dysplasia is detected in older patients who are treated after 9 months of age, and in this case secondary extra-articular surgery may be required.[305]

Avascular necrosis, residual dysplasia, and subluxation or redislocation are major complications following treatment. Fogarty and Accardo[163] reported a study on 222 dislocated hips where 173 patients were treated by closed reduction and spica casting. The patient's hips were flexed at 90° and two distinct styles of abduction were employed. Group I included the patients whose hips were abducted up to 90° and group II consisted of those with no more than 60° of abduction. Total AVN occurred in 17 percent of hips in group I and 9 percent of the hips in group II. The incidence of partial necrosis was not affected by the degree of hip abduction.[163]

Redislocation of the hip during closed-reduction-casting treatment can be a severe problem (dislocation occurring after the application of the cast). If the hip redislocates during the treatment, the cast should be removed immediately. Persistent casting of a dislocated hip can result in an iatrogrenetic dysplasia of the posterior aspect of the acetabulum, which makes future treatment exceedingly difficult. The authors have seen redislocation of the hip to occur in severely dysplastic hips, in hips that have an infolded labrum (see reduction criteria), and in incidences of casting problems. Treatment of a redislocation may require a repeat closed reduction or an open reduction.[423]

TABLE 5-1. Algorithm of Treatment from 3 Months to 1 Year



Chapter Six

Treatment after Walking Age

Developmental dysplasia of the hips is usually diagnosed prior to the onset of walking; however, some children's dislocations are missed and some hips dislocate late. Biological problems, such as contractures, growth distortion of cartilage and bony deformity, and false acetabulum, make concentric reduction more difficult to achieve and to maintain. In some patients closed reduction and casting can be successful, but in many children of this older age operative (open) reduction is necessary. Also, persistent residual dysplasia after reduction is common and often difficult to manage in this older age group.

The approach and types of treatment offered to patients who are diagnosed after walking age are controversial.[33,35,90,114,235,432] Many authors agree that there should be an initial attempt at closed reduction in children who have begun to walk and that open reduction should be reserved for hips when the femoral head cannot be reduced by non-operative methods.[212,666] Albiñana et al.[4,5] reviewed the initial radiographs of 45 children followed until 10 years of age who had unilateral DDH treated with closed reduction. They evaluated the shape, type, and width of the teardrop; the thickness of the acetabular floor; the acetabular index; and the articular-trochanteric distance. They concluded that the superior and inferior widths of the teardrops in dislocated hips were significantly greater than those of normal hips and that the presence of a "v"-shaped teardrop of enlarged superior width and thickened acetabular floor suggested residual acetabular dysplasia. For orthopaedic considerations, this article supports the view that the medial wall of the acetabulum begins to fill in with bone and cartilage in hips that have been dislocated for many months. Therefore, reduction of a dislocated hip into the depth of this abnormal acetabulum may still result in a lateralization of the femoral head. Milani et al.[393-397] used two directional arthrograms to analyze the anterior, superior, and posterior portions of the limbus. Albiñana et al.[4,5] utilized Miyake's classification and concluded that when the hips show good stability and lack of interposed limbus in the antero-posterior and lateral arthrograms, the results will be excellent; however, if there is interposition in any arthrographic position, the results will be less satisfactory. They also recommend closed reduction only for the everted and intermediate types of limbus, and open reduction for the other types. Staheli et al.[542] reported the effect of the inverted limbus on closed reductions of dislocated hips, concluding that this led to the performance of more surgery, usually acetabular procedures, than when the limbus was not inverted. The type of treatment depends on the level of the femoral head in relation to the acetabulum, presence of a well-formed false acetabulum, and the tissue contracture. For orthopaedic considerations, the soft tissues undergo profound changes as the hip remains dislocated. These abnormal soft tissues block reduction by positioning (nonoperative techniques) the femoral head, demanding operative procedures to address the distorted soft tissue.

CLOSED REDUCTION

Attempted closed reduction is indicated in lower-level femoral head dislocations as in Tönnis types 1, 2, and 3.[506,583,584] The attempt at reduction can be preceded by traction to the lower limbs. The traction and closed reduction techniques are the same in these older children as was described in chapter 5 for children of 4 months to walking age.

Daoud et al.[114] and Schoenecker et al.[506] reported the results of closed reduction of DDH in older children (older than 18 months). Initially, the great majority of patients had successful reduction. Some hips had progressive subluxation during the cast treatment, and more than 50 percent of hips that had successful treatment required additional surgical procedures later to correct acetabular dysplasia for failure in remodeling. The authors believe that a closed reduction can be achieved successfully in some children between walking age and about 18 months; however, the dislocated femoral head cannot be forced into the acetabulum, otherwise avascular necrosis will destroy the joint. For a successful closed reduction in this age group, the femoral head must gently reduce concentrically into the acetabulum and under the labrum. Approximately 6 months of casting will be necessary to maintain stability, and residual dysplasia is almost inevitable.

OPEN REDUCTION

When hip dislocation does not respond to nonoperative treatment of a closed reduction and a stable, concentric reduction is not attained, open reduction is necessary to restore the normal anatomy of the hip joint. The need for open reduction does not depend on the child's age. It depends on the level of the femoral head in relationship to the acetabulum, on a false acetabulum, and on a failed attempt at closed reduction. However, children of walking age (especially if over 18 months of age) will often require open procedures to achieve a concentric reduction.

Indications for Open Reduction

- Incapacity to obtain concentric and stable closed reduction
- Incapacity to maintain concentric and stable reduction
- Reduction attained, but extreme and forced positions to maintain the reduction required

Advantages of Open Reduction

- Less prolonged hospitalization

- Fewer roentgenograms
- Associated deformities such as femoral anteversion and acetabular dysplasia can be corrected

Disadvantages of Open Reduction

- Technically difficult, demands experienced surgeon Possibility of stiffness
- Possibility of stiffness
- Possibility of avascular necrosis for the femoral head
- Possibility of infection

OPERATIVE REDUCTION TECHNIQUE FOR A DISLOCATED HIP

Procedural steps for the treatment of DDH by open reduction include operative approach and reduction of the hip; testing the stability of the reduction, the pressure upon the femoral head, and dysplasia; and postoperative care, casting, and bracing. There are two common operative approaches to the hip joint for the treatment of DDH: antero-lateral and medial (adductor). The authors prefer the antero-lateral approach because all anatomical factors can be addressed through this approach.

Antero-lateral Operative Approach to the Hip

Indications and advantages

- For children after walking age (failed closed reduction)
- Permits direct approach to the anterior, superior, posterior, and inferior sides of the capsule and overall structures that impede the concentric reduction
- Can be associated with acetabular procedures

Description of the antero-lateral approach

1. Place the patient in a supine position with a sandbag under the chest (the buttock area is free for sterile preparation of the skin).
2. Prepare the skin for surgery from lower part of the chest distally to include half of the pelvis and affected lower limb.
3. Make the skin incision obliquely (bikini incision) from a point 1 cm inferior and medial to the anterior superior iliac spine for approximately 6 cm laterally beneath the iliac crest following in Langer's skin lines. Some surgeons prefer an incision extending from the middle third of the iliac crest to the anterior superior iliac spine, continuing distally to the thigh approximately 8–10 cm; however, this incision is not as cosmetic as the bikini incision.

Figure 6-1 Photograph of the bikini skin incision. The skin incision is made obliquely from a point 1 cm inferior and medial to the anterior superior iliac spine for approximately 6 cm laterally beneath the iliac crest following in Langer's skin lines.

4. Incise the subcutaneous tissue and the fasciae latae along the iliac crest to the anterior superior iliac spine and distally to the thigh. Divide the deep fascia over the iliac crest. Avoid disturbing the lateral femoral cutaneous nerve, which crosses the sartorius muscle 2.5 cm distal to the anterior superior iliac spine. The nerve may be retracted medially.
5. Dissect the groove located between the tensor fasciae latae muscle laterally and the sartorius and rectus femoris medially, exposing the anterior aspect of the hip joint. When the ascending branches of the lateral femoral circumflex artery cross the wound, they may be ligated and sectioned.
6. There are two methods to incise the cartilaginous iliac apophysis: by splinting through the middle from the middle thirds to the anterior superior iliac spine, or by osteotomy just below the cartilaginous iliac apophysis from the outer side, displacing medially. The authors prefer to use the osteotomy to preserve growth of the cartilaginous iliac apophysis.
7. From the iliac wing, subperiostically strip the tensor fascia lata and gluteus medius and minimus muscles and reflect them to the superior edge of the acetabulum and to the greater sciatic notch posteriorly.
8. Disconnect the sartorius muscle from the anterior superior iliac spine, and after marking it with a suture for later reconnection, reflect it distally and medially.
9. Divide the two heads of the rectus femoris at their origin, mark them with a suture, and reflect them distally.
10. Medially retract gently the femoral vessels and the femoral nerve.
11. Dissect the iliacus muscle from the capsule.
12. Expose the capsule superiorly, anteriorly, and inferiorly.

Figure 6-2 Photograph demonstrating an osteotomy of the ilium just below the iliac crest to preserve growth of the cartilaginous iliac apophysis.

13. Lengthen the iliopsoas tendon at the muscle-tendon junction. Do not disturb the medial circumflex artery. Hyperextend the hip to lengthen the iliopsoas muscle. (Lengthening of the iliopsoas tendon and not tenotomy is recommended, because tenotomy may result in atrophy of the muscle.)[24]
14. Open the hip joint capsule with a "T"-shaped incision. The longitudinal incision should be along the axis of the femoral neck and the transverse incision should be along the margin of the acetabulum. Mark the capsule with a suture for later plication.
15. Look for intra-articular factors obstructing the reduction. The ligamentum teres is usually enlarged and elongated and must be excised. The transverse ligament should be sectioned and the pulvinar (fibrofatty tissue) resected. Avoid injuring the articular cartilage.
16. Evaluate the limbus, which may be inverted in the acetabulum. If inverted, it should be everted using a blunt hook. Do not excise the limbus. Do not injure the growth zones of the margin of the acetabulum.
17. Evaluate the depth and inclination of the acetabulum, the aspect of the femoral head, the articular hyaline cartilage of the femur and acetabulum, and the degree of femur anteversion.
18. Reduce the hip and evaluate with an image intensifier to ensure a concentric reduction of the femoral head.
19. Perform the tests for stability of the reduction, for pressure upon the femoral head, and for acetabular dysplasia.

- *Stability test* (opinion of J. R. Bowen): To test stability of the reduction, the hip is placed in 90° of flexion, 45° of abduction, and neutral rotation. Then the hip is extended gradually to 25° of flexion and 10–15° of abduction. If the femoral head does not dislocate, the hip is considered stable. If it is unstable, the reason must be

Figure 6-3 Photograph demonstrating the iliopsoas tendon across the anterior aspect of the capsule of a dislocated hip.

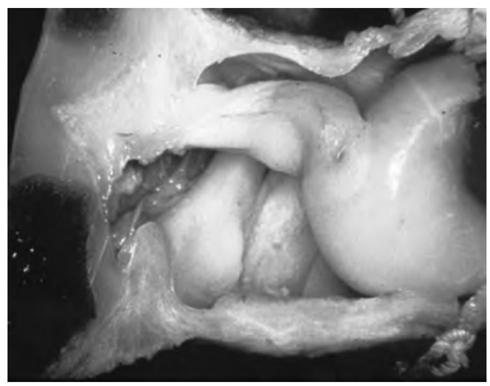


Figure 6-4 Photograph of a hypertrophic ligamentum teres in a dislocated hip.

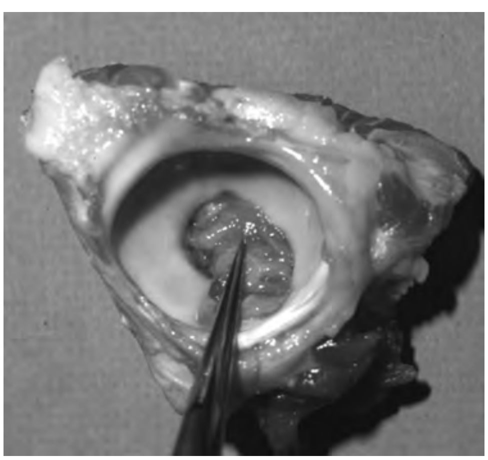


Figure 6-5 Photograph of the pulvinar and transverse ligament.

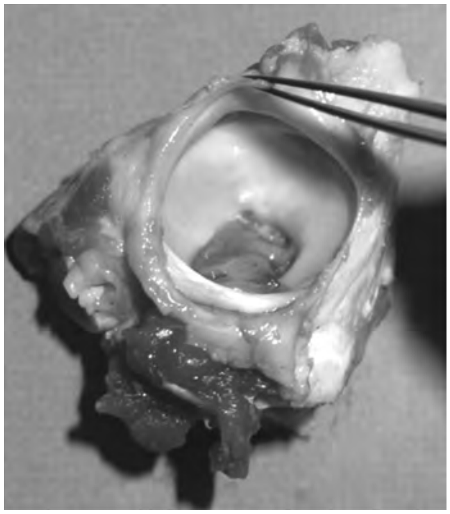


Figure 6-6 Photograph of an acetabulum, demonstrating an inverted limbus.

determined. Factors to consider are excessive femoral anteversion (refer to femoral derotation osteotomy) or severe acetabular dysplasia above 30° (refer to Salter innominate osteotomy, Pemberton osteotomy, or Dega osteotomy).

- *Pressure test* (opinion of J. R. Bowen): To evaluate the pressure of reduction upon the femoral head, gentle traction is applied to the thigh. The reduced femoral head should distract approximately 1 mm from the acetabulum. If the femur head does not distract easily, contracted muscles may be lengthened (refer to adductor tenotomy or iliopsoas tenotomy) or a femur-shortening osteotomy is indicated to prevent avascular necrosis (refer to femur osteotomy).
- *Acetabular dysplasia evaluation* (opinion of J. R. Bowen): When the acetabulum is oblique and does not cover the femoral head anteriorly and superiorly (i.e., the acetabular index is greater than 30°), a pelvic osteotomy is indicated. The authors recommend Pemberton osteotomy in children younger than 18 months of age, with high degree of acetabular index angle, and Salter innominate osteotomy in patients over 18 months of age to reorientate the acetabular roof and achieve a normal acetabular index (refer to osteotomies).

20. If the achieved reduction is stable and the femoral head is well covered, the capsule can be closed with the hip held at 30° of flexion and abduction and 20–30° of internal rotation.
21. If the capsule is redundant and lax, a portion may be excised.
22. The capsule is stitched with interrupted sutures, beginning from the supero-lateral segment of the "T," which is brought into an infero-medial position and sutured with the inner surface of the capsule. The infero-lateral segment is brought up and over the supero-lateral segment and is then sutured to the inner supero-posterior aspect of the medial part of the capsule. Finally, the medial segment is pulled down

over the lateral segments and sutured over the infero-lateral segment. Do not stitch the capsule too tightly, otherwise the femoral head will be forced to dislocate posteriorly.

23. Replace the retracted iliac apophysis over the iliac crest.
24. Reattach the rectus femoris, sartorius, and abductor muscles to their origins.
25. Suture the fascia, subcutaneous tissue, and skin.
26. Take a radiograph of the pelvis to control the reduction.
27. Apply a 1-1/2 spica cast with the affected hip held at 60–70° of flexion, 45 degrees of abduction and 20–30° of internal rotation. The knee is flexed from 45–60° to control the rotation and to relax the hamstrings.

Discussion of the open reduction

To achieve a good open reduction, the femoral head must be placed concentrically into the socket without pressure, be well covered by the acetabulum, and be stable. The stability depends on the contracture of the soft tissues (adductors, iliopsoas, and hamstring muscles) and the bone orientation (acetabulum maldirection and femur anteversion).

The capsulorrhaphy is performed to help maintain the femoral head in the acetabulum and increase stability; however, its use is controversial. Ferguson[153] recommends not stitching the capsule; however, Tachdjian[564–566] reports that it is imperative to repair the capsule by plication and overlapping of its edges. When the hip is stable without necessitating a tight capsulorrhaphy, the authors prefer only a loose approximation of the capsule to avoid ligating the capsular vessels. Also, a tightly approximated capsule may force the femoral head to dislocate posteriorly.

Bassett et al.[24] evaluated the effect of psoas-muscle lengthening during open reduction in five cases. At an averaged 4-year follow-up, the cases were studied for strength with isokinetic dynanometer and by MRI. They concluded that lengthening results in some weakness and atrophy of the iliacus muscle. They cautioned against a complete ilio-psoas tenotomy at the level of the lesser trochanter for patients undergoing open reduction of a dislocated hip. The authors prefer lengthening of the ilio-psoas tendon by a muscular-tendon slide technique at the level of the brim of the iliac wing.

Postoperative care

The authors prefer a CT or MRI scan postoperatively with the patient in the spica cast to ensure the complete reduction of the femoral head within the acetabulum.[389,546] The patient is followed for cast control and radiographic examination 3 weeks after surgery. The spica cast is removed at 6 weeks following surgery, at which time radiographs are taken to ensure that a concentric reduction has been maintained. After the cast is removed, active exercises are encouraged, but passive exercises must be avoided to prevent redislocation of the hip. Some authors hypothesize that passive motion can stretch the retinacular vessels, increasing the risk of AVN.[564] The postoperative use of abduction bracing is controversial. The authors use a nighttime bivalved spica cast or an abduction orthosis for up to 6 months to allow resolution of residual acetabular dysplasia. We use a nighttime abduction orthosis until the acetabular index becomes normal. If the acetabular index does not improve to normal, an acetabular reconstructive procedure may be indicated (refer to treatment of residual acetabular dysplasia.)

The senior author (Bowen) uses the rule of thumb that the acetabular index needs to be near 24° at 24 months after reduction.

Results of open reduction for DDH

Akagi et al.[2] reviewed radiographies of 20 patients (22 hips) treated by open reduction, without future surgical procedures, up to the age of puberty. In the 14 hips that had a satisfactory outcome, acetabular improvement continued throughout growth. In the other 8 hips that had an unsatisfactory outcome, the acetabulum did not improve after 3 to 5 years of age. Chen et al.[74] described a radiographic measurement to prognosticate the acetabular development after reduction. They compared different methods of taking measurements, such as the acetabular index, Wiberg's CE angle, and Shenton's line, to evaluate the evolution and enlargement of the acetabulum. They confirmed that "age at reduction and significant improvement in the acetabular index in the first year after reduction are important predictors" of a good outcome. They concluded that the best predictor of success of treatment in unilateral cases is the center head distance discrepancy (CHDD) measured at 1 year after reduction. If the discrepancy is less than 6 percent, the result will be satisfactory. If it is more than 6 percent, the result will be unsatisfactory. In 96 percent of their cases with less than 6 percent CHDD, the results were satisfactory, and when the CHDD was more than 6 percent, 78 percent of their cases showed unsatisfactory results. Their mathematical formula to estimate the CHDD is (CA - NC)/NC ´ 100.

Bassett[23] reported using laser Doppler flowmetry during an open reduction to evaluated the vascularity. The authors tested Doppler flowmetry in pigs and did not find it reliable in detecting minor blood flow detects. To our knowledge, this technique is not currently being used during open reduction for DDH.

McNally et al.[389] reported the advantages of using MRI on 13 patients to evaluate effective open reduction. They attained concentric reduction in 12 patients, and the 1 patient with redislocation after treatment was easily identified. They observed that MRI is an adequate, quick, and inexpensive method of confirming reduction in DDH, without the risks of radiation. Other authors have reported the advantages of MRI for detecting obstacles in reduction,[11] confirming and documenting the reduced position of the hip joint.[436,661]

Olney et al. [434] published a retrospective study of 13 patients (18 hips), looking for efficacy and complication rates associated with treating children with DDH who were ambulatory with open reduction combined with femoral and pelvic osteotomies. The patients' ages at the time of surgery ranged from 15 to 117 months (mean age of 29 months), and follow-up ranged from 24 to 78 months (mean follow-up of 43 months). Preoperatively, using Tönnis classification, six hips were classified as class II, seven as class III, and five as class IV. For follow-up based on the Severin classification, 16 hips were categorized as class 1A and two hips as class 2A. Based on McKay criteria, all patients were pain- free with ambulation and had excellent results. One patient developed AVN. They concluded that using open reduction in association with pelvic or femoral osteotomies in ambulatory children was safe and effective.

Criteria for adequacy of an open reduction of a dislocated hip (opinion of J. R. Bowen)

There are no statistically established published criteria to judge intra-operatively the adequacy of an open reduction and predict outcome. An attempt to establish criteria was made at the A. I. duPont Hospital for Children in Wilmington, Delaware, by reviewing all open reductions and analyzing relevant factors. Review of the radiographs clearly demonstrated the need for a concentric and stable reduction of the dislocated hip. However, the precise criteria for a concentric and stable reduction were statistically impossible to determine because there are too many associated factors for the number of cases. The authors believe that a concentric reduction can be determined with intra-operative radiographs taken after reduction and with the limb held in the desired position for casting. With a concentric reduction, the proximal femoral metaphysis is below the Hilgenreiner line and the femoral head is medialized into the acetabulum. Medialization is determined in unilateral cases by comparing the normal hip to the newly reduced hip, and an equal horizontal distance along the Hilgenreiner line from the center of the femoral head to the symphysis pubis is desired. In bilateral cases, establishing a criterion for adequate medialization is more difficult; however, the authors recommend using the medialization ratio as with a closed reduction (see closed reduction) in which two-thirds of the diameter of the cartilaginous femoral head is within the Perkins line. In dislocated hips with a hypertrophic medial wall of the acetabulum, the femoral head cannot be completely medialized and the surgeon can only place it deeply in the available acetabulum.

Intra-operative stability can be evaluated (see stability test) and if the reduced hip is unstable, additional procedures can be performed. However, in the DuPont series, we observed a few cases of "delayed instability." In these cases, the hip appeared stable and reduced in the immediately postoperative radiographs; however, months later the femoral head gradually subluxed. The hip often had a high preoperative acetabular index (greater than 30°) or was classified as either having a capacious or lateralized type of acetabular dysplasia. In cases with an acetabular index over 30°, even if the hip appears stable intra-operatively, the authors recommend an acetabular procedure to help prevent delayed instability. A rotational osteotomy (Salter) is preferred in the malrotated acetabulum, and a periacetabular osteotomy (Pemberton or Dega) that alters the shape of the acetabulum is preferred in the capacious acetabulum (see chapter 7).

Medial (Adductor) Operative Approach

Indications

- For younger children before walking age, up to 12 months, before standing and weightbearing[564]
- For typical DDH
- For cases where a direct approach to the inferior and medial structures that impede the reduction is possible

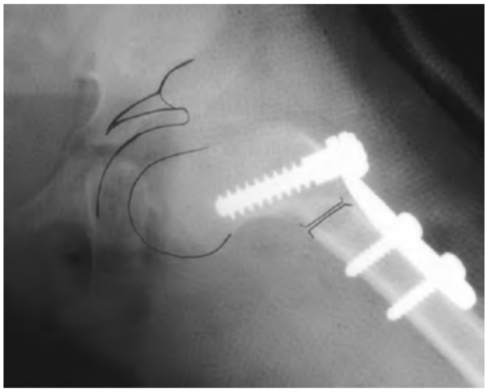


Figure 6-7 Radiograph, demonstrating an adequate open reduction of a dislocated hip.

- For cases of unstable closed reduction in which arthrography shows the iliopsoas tendon constricting the capsule, a hypertrophied ligamentum teres, or a taut transverse ligament

Advantages

- A simple surgical procedure
- Minimal tissue dissection is required
- Minimal blood loss, no need for blood transfusion
- Easy approach to the iliopsoas tendon, transverse ligament, ligamentum teres, pulvinar and infero-anterior capsule of the hip joint

Disadvantages and contraindications

- Child over 18 months of age
- Insufficient visualization of the hip joint
- Insufficient exposure of the antero-superior and posterior capsule of the hip joint
- Demand for secondary surgical procedures in about 40 percent of cases
- Inability to expose the false acetabulum

Discussion of the medial approach

The medial approach was described by Ludloff[360] in 1908 and divulged by Mau.[380] Ludloff described a medial skin incision parallel to the axis of the femur and dissection from Poupart's ligament downward on the lateral border of the adductus longus muscle. The large vessels and femoral nerve are retracted laterally and the adductor and pectineus muscles are retracted medially. The medial femoral circumflex artery crosses the exposure and must be retracted or ligated. The iliopsosas tendon can be lengthened and the hip capsule entered near the brim. The advantages of the medial approach are minimal operative dissection with a cosmetically acceptable scar, excellent access to the pulvinar and transverse ligament, and no injury to the growth of the Iliac crest or to the abductor muscles. The disadvantages are increased risk of avascular necrosis of the femoral head (injury to the medial femoral circumflex vessels), inability to address the false acetabulum, and inability to perform a capsulorrhaphy.

Ferguson[153] in the 1970s modified the medial approach of Ludloff by dissecting an operative plane between the adductor brevis muscle and the gracilis muscle. The pectineus, adductor longus, and adductor brevis muscles are retracted laterally while the gracilis and adductor magnus muscles are retracted medially. The medial femoral circumflex artery is retracted or ligated and the iliopsoas tendon is lengthened. The hip capsule is then entered near the brim of the acetabulum.

Weinstein and Ponseti[647] further modified the medial approach. They utilized a transverse skin incision, which was made parallel and distal to the groin crease, extending from the medial border of the adductor longus muscle to a point slightly medial to the femoral neurovascular bundle. The adductor longus muscle is sectioned at its origin and retracted. The operative plane is developed with adductor brevis muscle and pectineus muscles retracted medially while the iliopsoas tendon and neurovascular bundle are retracted laterally. Weinstein tries to preserve the medial femoral circumflex artery; however, if this fails it is ligated. The capsule of the hip is incised from its attachment at the acetabulum down to the distal attachment on the femoral neck. The ligamentum teres is excised, the pulvinar is removed, and the transverse acetabular ligament is incised.

The use of Ludloff's (Weinstein and Ponseti) or Ferguson's medial approach has been controversial. There are many discrepant variations in outcomes, from very good to bad. The high incidence of avascular necrosis has been most perplexing, with rates reported as high as 67 percent of hips.[66,298,320,321,374,413,433,485,536] The authors suggest that the medial approach method be used only occasionally and in hips of children less than 12 to 18 months of age and without a well-formed false acetabulum. Because the medial approach has a restrictive use and the potential for a high complication rate, many surgeons prefer the antero-lateral approach.

Description of the medial approach

1. Place the patient in a supine position.
2. Preparation for surgery to include the hemipelvis, hip, and lower limb.
3. Skin incision can be longitudinal or transverse.

There are two choices for skin incisions: longitudinal and transverse. Both afford good exposure. With the longitudinal skin incision, the hip is flexed 70–80°, abducted, and externally rotated. Make the longitudinal incision behind the adductor longus muscle from the pubic tubercle, extending distally 6–8 cm. Divide the subcutaneous tissue and the deep fascia along the same line as the incision. The transverse skin incision is about 6 cm in length and is centered over the anterior aspect of the adductor longus muscle, approximately 1 cm distal and parallel to the inguinal creases.

4. Divide the deep fascia, avoiding damage to the saphenous vein. If this should occur, the vein may be ligated and sectioned.
5. Select the plane of operative dissection.

Posterior plane of dissection (i.e., posterior to the adductor brevis muscle):

6. Dissect the anterior and posterior borders of the adductor longus muscle, section the muscles through the tendon at their origin, and then retract them distally.
7. Retract the adductor brevis anteriorly.
8. Visualize the anterior branches of the obturator nerve and vessels. Do not disrupt the nerve.
9. Perform a blunt dissection between the adductor brevis and magnus muscles.
10. Palpate the lesser trochanter (see below)

Anterior plane of dissection to adductor brevis and posterior to pectineus muscle:

6. Dissect the anterior and posterior borders of the adductor longus muscle, section the muscles through the tendon at their origin, and then retract them distally.
7. Identify the pectineus muscle at the anterior margin of the adductor longus muscle.
8. Perform a blunt dissection posterior to the pectineus muscle.
9. Palpate the lesser trochanter. (see below)

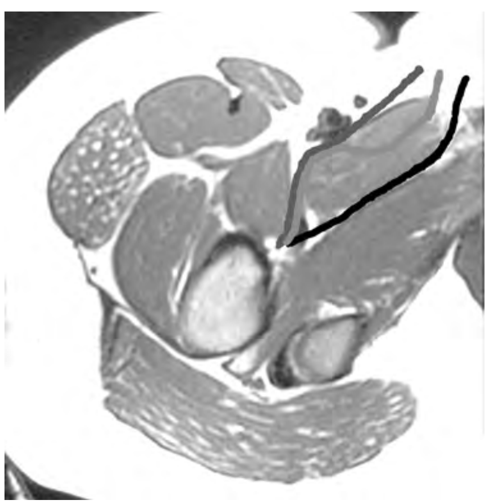


Figure 6-8 Cross-section CT of the thigh at the level of the hip joint through the femoral neck. The top line compares to the Ludloff interval (between the vessels and the pectineus muscle), the middle line to the Mau and Weinstein interval (antero-medial approach), and the bottom line to the Ferguson and Hoppenfeld interval (medial approach, which is between the adductor brevis and gracilis muscles).

Anterior plane of dissection to the pectineal muscle:

6. Dissect the anterior and posterior borders of the adductor longus muscle, section the muscles through the tendon at their origin, and then retract them distally.
7. Identify the pectineus muscle at the anterior margin of the adductor longus muscle.
8. Identify the pectineus muscle and perform a blunt dissection anterior to the pectineus muscle, then retract it medially and inferiorly.
9. Retract laterally and protect the femoral vessels and nerve.
10. Palpate the lesser trochanter (see below).
11. Palpate the lesser trochanter and the insertion of the iliopsoas tendon.
12. Divide or lengthen the iliopsoas tendon by a transverse incision. It will retract proximally.
13. Expose the hip capsule proximally until the femoral head is palpable.
14. Place retractors around the capsule of the femoral neck (supero-laterally and infero-medially).
15. Open the hip joint through a "T"-shaped incision in the capsule. The longitudinal incision should be along the axis of the femoral neck and the transverse incision should be along the margin of the acetabulum.
16. Within the hip joint, excise the ligamentum teres and the pulvinar if they are hypertrophied, and section the transverse acetabular ligament.
17. Reduce the hip and test stability of the reduction by range of motion lower limb.
18. Close the capsule, positioning the hip at 15° of flexion, 30° of abduction, and 20° of internal rotation.
19. Close the fascia, the subcutaneous tissue, and the skin.
20. Apply a 1-1/2 hip spica cast, molding the casting over the greater trochanter and positioning the affected hip at 30° of flexion and abduction and 10–25° of internal rotation.

Weinstein[645–647] reported the incidence of AVN following a medial approach to the treatment of hip dislocation as being 10 percent. This incidence may be higher if traction has not been applied previously.[540,564] Tumer et al.[607] report the results of 56 hips with DDH affecting 37 children who were treated by the medial approach following preliminary traction. The follow-up averaged 8.1 years (ranging from 3 to 17 years). Ninety-eight percent of hips were classified as Severin I and II (excellent and good results). Eleven hips (19 percent) required secondary procedures. Evidence of AVN occurred in 5 hips (8.9 percent). Recently, Ucar et al.[608] reported longer-term outcomes of these 56 hips. The mean age at open reduction was 10.7 months and the mean age at follow-up was 20.7 years. There was no subluxation or redislocation observed. AVN was detected in 20 percent of the hips. Milani et al.[394,395] reported a study of 44 children (52 hips) to determine loss of reducton and aseptic necrosis (AVN) of the femoral head. The patients' ages ranged from 12 to 114 months and they divided them into two groups. In the first group, 21 children (26 hips) were treated with open reduction and Salter's innominate osteotomy, associated with a femur-shortening procedure. They utilized the segment of the femur as an allograft to the iliac osteotomy. Based on the Bucholz and Ogden classification, they observed aseptic necrosis in 12 hips (46.15 percent) in the first group and in 2 hips (7.9 percent) in the second group, and they reported that the high incidence of necrosis occurred in patients who had undergone previous traction. All of these patients had type III dislocations based on Zionts and MacEwen criteria. They considered "iatrogenic performance" to be the cause of bad results and complications in their study. Koizumi et al.[320] analyzed 35 hips in 33 patients after 19.4 years of follow-up (ranging from 14 to 23 years). Sixteen hips (45.7 percent) were classified as Severin I and II types and were considered acceptable in terms of results, while 19 (54.3 percent) were classified as Severin groups III, IV, and V and were considered unacceptable. The incidence of AVN was 42.9 percent (15 hips). They concluded that Ludloff's medial approach to open reduction was unsatisfactory for the treatment of DDH.

The authors caution against the medial approach in walking-aged children (above 18 months) due to the high incidence of AVN and the inability to address all pathologic components of DDH.

Chapter Seven

Residual Dysplasia Following Treatment

Understanding the developmental features of DDH demands knowledge of the growth and maturity of the hip joint. In the embryological period, the femoral head and the acetabulum develop from the same mesenchymal block of cells. The limb buds initially appear at 4 weeks of gestation; and at 8 weeks a cleft occurs between the acetabulum and the femoral head, developing into the hip joint, which will be complete by 11 weeks. The acetabulum continues its development during the entire intrauterine life. The triradiate cartilage enlarges the diameter of the acetabulum, and labral growth is responsible for increasing the acetabular depth.[430,459,460,637] The confluence of the proximal femoral physis, the greater trochanteric physis, and the femoral neck isthmus promotes the growth of the proximal end of the femur. The hip joint, formed by the acetabulum, the proximal femur, and the femoral head, is cartilaginous at birth, and normal development depends on the further growth of these structures. This means that hip dysplasia or dislocation may occur in utero, perinatally, and with growth.[12] Developmental dysplasia of the hip includes a wide spectrum of hip disorders; its pathologic anatomy depends on the type, grade, and duration of the dislocation (see section on pathologic anatomy, chapter 3).

FEMORO-ACETABULAR IMPINGEMENT

Impingement implies inappropriate contact between the femur and acetabulum within a normal range of hip motion that blocks functional activities. Impingement of the hip occurs in many disease processes, such as slipped capital femoral epiphysis and DDH, as well as iatrogenically from operative procedures. For example, a deformity of the femoral neck may block the ability to sit appropriately because the bone of the femoral neck abuts against the acetabular margin before adequate hip flexion is achieved. Also an innominate bone osteotomy may rotate the acetabulum excessively to the extent that the rim of acetabulum abuts against the femur, blocking functional motion. Persistent microtrauma may damage the labrum, articular cartilage, and rim of the acetabulum. Seldes et al.[513] dissected 55 embalmed and 12 fresh-frozen adult hips with a mean age of 78 years and found that 96 percent had labral tears and that in 74 percent the tear was located in the antero-superior quadrant. They described two distinct types of tears of the labrum: detachment of the fibrocartilaginous labrum from the articular hyaline cartilage at the transitional zone, and tears in which there were cleavage planes of variable depth with the substance of the labrum. Walker[631] performed an anatomic evaluation of 74 normal fetal acetabula and found 14 percent to have a cleft on the antero-superior acetabular quadrant between the labrum and the cartilaginous socket. He considered this to be a weak area predisposing it to detachment with femoro-acetabular impingement, which may explain the high incidence of labral tears in patients with hip dysplasia. Evaluation of impingement may require arthrography, computed tomography, or magnetic resonance imaging. Treatment may require osteotomies, hip arthroscopy, repair of labral tears, removal of osteo-cartilage loose bodies, and/or debridement of bony impingement by hip dislocation or arthroscopy repair of labral tears.

The authors consider femoro-acetabular impingement in DDH as one of three types: acetabular rim impingement ("pincer"), cam impingement, or internal impingement.

Acetabular rim impingement implies damage to the outer margins of the acetabulum by excessive pressure. With persistent dysplasia in children treated for DDH, the femoral head becomes poorly covered anteriorly and superiorly[214,479] by the acetabulum, which concentrates weightbearing forces over a small area of articular cartilage. Stulberg[552,553] reported that the CE angle of Wiberg is commonly less than 20° in symptomatic patients. Salter[492] reported that in the dysplastic hip, the acetabular labrum becomes thicker in its attempt to "contain" the femoral head. McCarthy et al.[382] reported an arthroscopic study on 20 mature patients who had radiographic evidence of dysplasia. These patients complained of inguinal pain, locking, buckling, and falling episodes. They observed an enlarged labrum and slight invagination in these areas, in direct proportion to the magnitude of bony acetabular uncovering, due to the repeated torque of the femoral head impinging on the labrum. This impingement produces a labral tear. In all cases, the acetabular chondral lesion was located immediately adjacent to the lateral tear on the anterior or antero-superior aspect of the joint. Noguchi et al.[427] also reported a similar arthroscopic study on 120 hips and observed that the osteoarthritic changes begin on the antero-superior portion of the weightbearing area and the cartilage degeneration of the acetabulum precedes that of the femoral head.

In a mildly subluxated hip, overloading of the acetabular rim can cause a labral separation or a fatigue fracture of lateral border of the acetabulum, giving the appearance of a loose fragment.[158] Klaue et al.[311] described a clinical test to diagnose *acetabular rim syndrome,* in which the hip is passively held in flexion-adduction and rotated into internal rotation, in which pain is elicited. They classified the dysplastic acetabuli into two radiologic types: in type I there is an incongruent shallow acetabulum and in type II the acetabulum is congruent but the coverage of the femoral head is deficient. Leunig et al.,[348] Kim et al.,[309] and Czerny[110] suggested using MRI arthrography to evaluate the integrity of the acetabular labrum.

Leunig and Ganz[347] used the term *pincer* to describe femoro-acetabular impingement predominately involving an acetabular deformity. This pincer effect may occur in protrusia acetabulae, with acetabular osteophytes, in malrotation of the acetabulum, and iatrogenically in cases in which the acetabulum is excessively rotated (see sections on complications of acetabular osteotomies, chapters 8 and 9).

Treatment of acetabular rim impingement often requires reorientation of the acetabulum (see chapters 8 and 9). Tears of the labrum may require repair or debridement.

CAM impingement implies that asphericity of a deformed femoral head or neck, as seen in some dysplastic hips, can abut against the acetabulum, resulting in repetitive microtrauma to the labrum and lateral bony rim of the acetabulum. Impingement secondary to variations in the proximal femoral anatomy causes a "cam" effect as abduction of the hip forces the lateral aspect of the femoral head and neck against the acetabular rim. This type of impingement can originate from a "pistol grip"-shaped femoral neck, a retroverted acetabulum,[179] or a proximal femoral deformity. Siebenrock et al.[521] described an abnormal extension of the femoral head epiphysis onto the neck of the proximal femur. Also, AVN of the proximal femur may deform the shape of the femoral head and neck, causing the cam-type impingement (see chapter 11). Ito et al.[283] described an MRI technique to study quantitatively the anatomical femoral head-neck offset.

Treatment of cam impingement may require osteotomies to redirect the deformed femoral head or neck, repair of labral tears, or debridement of the obstructions of motion (see chapter 10). Debridement of areas of the femoral neck may be accomplished by arthroscopic techniques[16,51,55,132,382] or by partial dislocation of the hip.[28,177,343,404,405,498,503,520]

Internal impingement (a term used by the authors) implies abnormalities within the hip that block hip motion and cause abnormal pressure against the cartilage surfaces. An example of internal impingement would be an osteocartilagenous loose body that blocks (locks) motion. Frequently osteo-cartilage loose bodies can be removed arthroscopically and avoid dislocation of the hip.[16,51,55,132]

PATHOGENESIS OF RESIDUAL DYSPLASIA

The pathogenesis of residual dysplasia is reported by Doyle and Bowen[133] as

1. *Primary:* influenced by genetics and the environment
2. *Instability:* which may be due to excessive capsular laxity or insufficiency, a small Ramsey safe zone, shallow acetabulum, or insufficient immobilization during treatment
3. *Incomplete hip joint reduction,* which may be caused by an imperfect reduction or insufficient time of immobilization
4. *Avascular necrosis* of the femoral head

Residual dysplasia is a serious problem that may develop into premature osteoarthritis of the hip joint. Residual dysplasia can consist of acetabular or femoral abnormalities and can be classified into five types as described by Bowen:[133]

1. *Maldirected acetabulum:* The acetabulum is inappropriately directed; however, the *femoral head is concentrically reduced.* This results in a deficiency of antero-lateral coverage of the femoral head during weightbearing.
2. *Capacious acetabulum:* The acetabulum is enlarged and open, allowing instability of the femoral head. *With abduction and internal rotation of the limb, the femoral*

head seats appropriately; however, the femoral head subluxes laterally with the leg in a neutral position and with weightbearing. Capsular laxity allows the proximal femur to slide about in the enlarged acetabulum.

3. *Lateralized acetabulum:* The acetabulum is enlarged and the femoral head is fixed in subluxation. The *femoral head cannot be reduced by abduction and internal rotation of the limb* because the medial aspect of the acetabulum has thickened with cartilage and bone. The condyloid cavity of the acetabulum fills from long-standing lateral subluxation, dislocation, or triradiate cartilage premature closure.
4. *False acetabulum:* An atopic fibrocartilage cavity (false acetabulum) forms from the presence of a dislocated femoral head on the lateral aspect of the pelvis.
5. *Femoral deformities:* Dysplasia for the proximal femur may be from residual torsional (version) abnormalities or avascular necrosis of the femoral epiphysis and physis. These abnormalities include deformities in the frontal plane (varus and valgus), sagittal plane (flexion and extension), and axial plane (anteversion or retroversion); femoral head asphericity; capital femoral physeal growth arrest (coxa brevis); and lever arm discrepancy between the greater trochanter and the femoral head.

Figure 7-1 Maldirected acetabulum. The acetabulum is inappropriately directed; however, the femoral head is concentrically reduced. CT of a maldirected acetabulum.

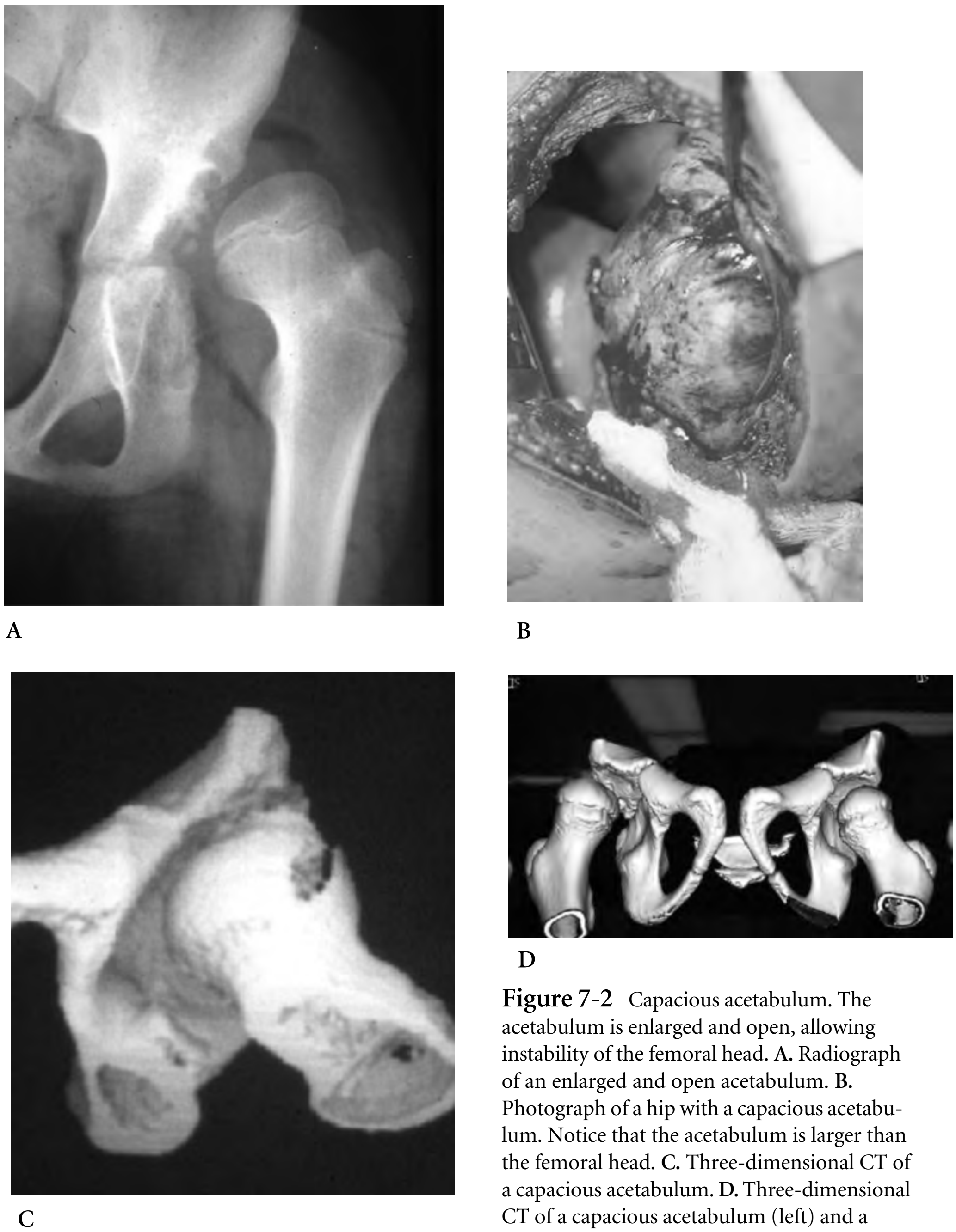


Figure 7-2 Capacious acetabulum. The acetabulum is enlarged and open, allowing instability of the femoral head. **A.** Radiograph of an enlarged and open acetabulum. **B.** Photograph of a hip with a capacious acetabulum. Notice that the acetabulum is larger than the femoral head. **C.** Three-dimensional CT of a capacious acetabulum. **D.** Three-dimensional CT of a capacious acetabulum (left) and a normal acetabulum (right).

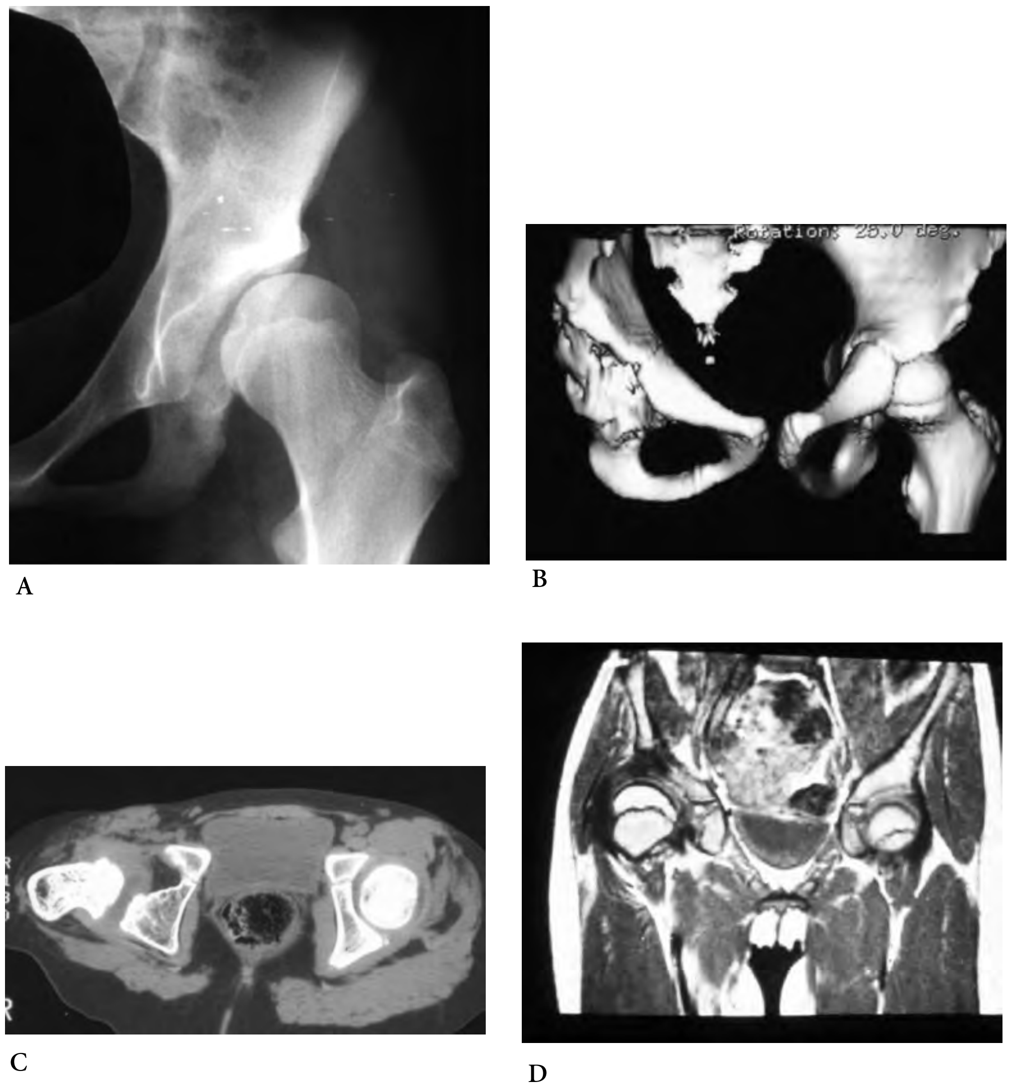
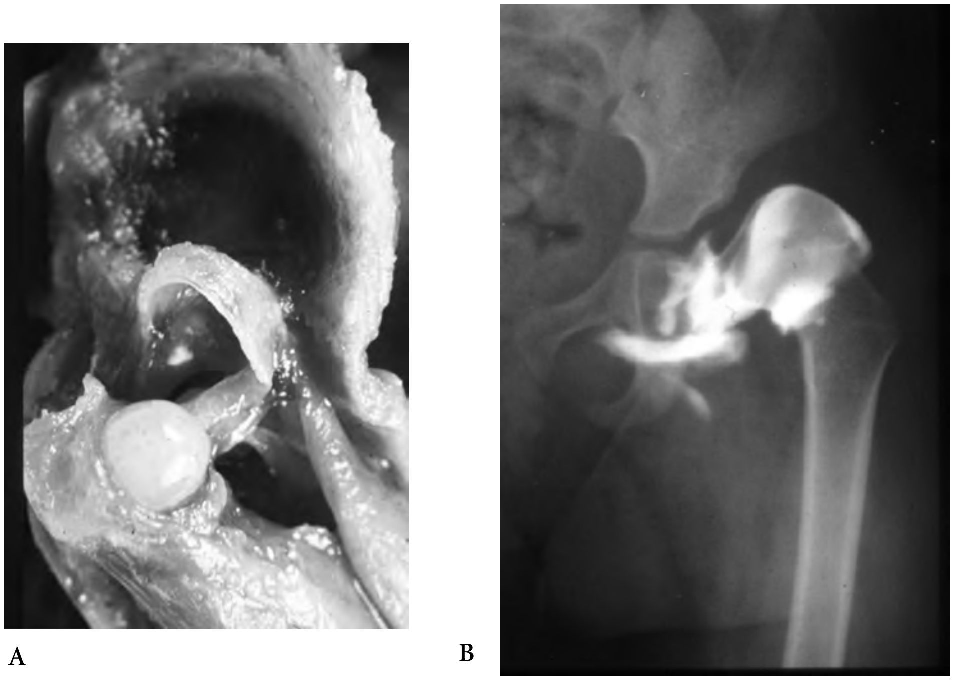


Figure 7-3 Lateralized acetabulum. The acetabulum is enlarged and the femoral head is fixed in subluxation because the condyloid cavity of the acetabulum is filled with cartilage and bone. **A.** Radiograph of a lateralized acetabulum. **B.** Three-dimensional CT showing the the condyloid cavity of the acetabulum to be filled with bone. **C.** Tranverse section of a CT showing bone from the ischial component of the acetabulum to be filling the acetabulum and preventing reduction of the femoral head. **D.** MRI showing a subluxated femoral head that cannot be reduced because of excessive cartilage in the acetabulum.



A B

Figure 7-4 False acetabulum. An atopic fibrocartilage cavity (false acetabulum) forms from the presence of a dislocated femoral head on the lateral aspect of the pelvis. **A.** Gross specimen of a dislocated hip with a false acetabulum. **B.** Arthrogram of a dislocated hip with a false acetabulum.

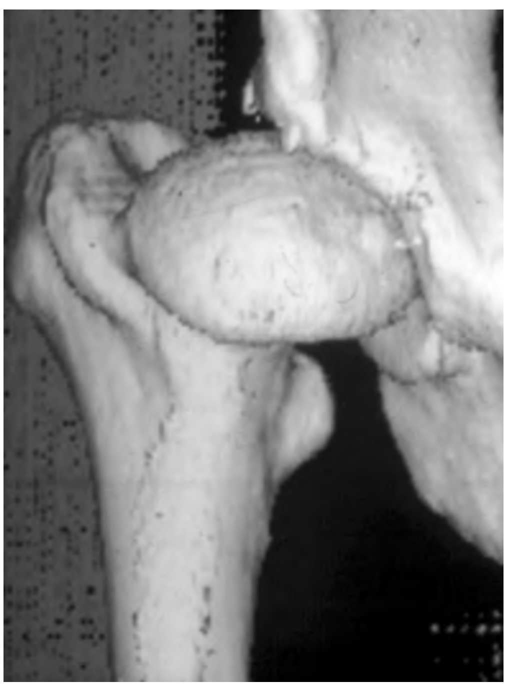


Figure 7-5 Femoral deformity. CT demonstrating femoral head asphericity and anteversion.

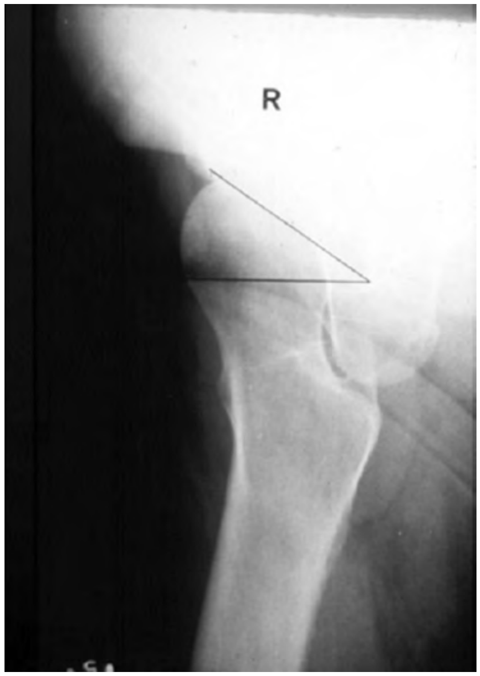
ASSESSMENT OF RESIDUAL DYSPLASIA

After initial management of a hip with DDH, some degree of residual dysplasia is frequently present. This residual dysplasia requires evaluation and treatment to achieve a lasting quality hip joint. With mild residual dysplasia, the child has a normal gait, negative Trendelenburg sign, and good range of motion. With moderate residual dysplasia, the child may have a limp and pain with prolonged walking, but in early adult life begin to complain of constant hip joint pain in the groin or thigh. With severe dysplasia, the child has a Trendelenburg gait, increased lumbar lordosis, fatigue from prolonged walking, and episodes of pain.

The residual dysplasia may manifest as a defect in the cartilage model of the hip or as delayed ossification of the cartilage model, or both. After Pavlik harness treatment, closed reduction, or open reduction; periodic radiographs of the hip should be taken to evaluate the evolution of any residual dysplasia. The authors suggest an antero-posterior radiograph of the pelvis after the initial treatment of DDH to establish a baseline for determining the degree of residual dysplasia. In children older than 4 months of age, antero-posterior radiographs of the pelvis should be taken with the hips at 25° flexion to negate the anterior pelvic tilt.[593] In children who walk, radiographs in a standing position are recommended. These radiographs should be taken about every 3 to 6 months until the acetabular index improves toward normal. With good evolution of treatment, the acetabular index reduces with age, and the authors allow up to 2years following reduction for the acetabular index to return to normal.

For an easy rule of thumb, remember that the normal acetabular index is about 24° when the child is 24 months of age. If the acetabular index is not consistently reducing toward normal and the dysplasia persists, the orthopaedist must look for the cause of the delay. Common causes include instability, inadequate reduction, avascular necrosis, and lack of ossification of acetabular cartilage. A dynamic arthrogram is helpful to evaluate cartilage dysplasia, stability, and the internal anatomy of the hip.

The false profile radiographic view has been helpful in evaluating the antero-lateral edge of the acetabulum.[346] This view is an oblique lateral technique in which the patient's involved hip is placed against the cassette and the buttocks are obliqued to an angle of 65° (25° to the beam of the radiographic tube). The foot of the involved hip is placed parallel to the cassette and weight is borne on both legs. The false profile coverage of the femoral head can be measured as a center-edge angle (lateral center-edge angle) and the antero-lateral femoral head as the percentage of coverage of the femoral head by the acetabulum (horizontal diameter coverage expressed as a percentage). The normal lateral center-edge angle is 28° (SD 5.5, minimum of 13°, maximum of 40°) and the normal antero-lateral femoral head coverage ranges from 70–90 percent. Tönnis finds the view very helpful in evaluating dysplastic hips.[584]



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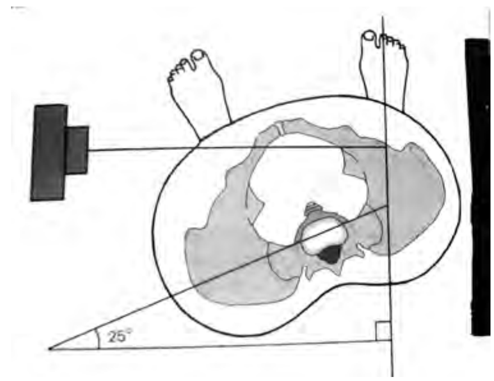


B

Figure 7-6 **A.** Schematic drawing of the false profile view. **B.** Radiograph of the false profile view. The normal lateral center edge angle is 28° (13–40°).

COMPUTED TOMOGRAPHY

Computed tomography can be used to evaluate the reduction and the shape of the acetabulum. The CT scan is more useful in older patients and supplies the investigator with internal measurements such as the femoral head diameter, the real acetabular bone angles, and the relationship between the femoral head and the acetabulum. Recently, techniques have been developed to permit three-dimensional evaluation of the hip joint by MRI and CT (refer to sections on acetabular index, center-edge angle, and arthrograms, chapter 1).

Computed tomography is useful in adolescents and young adults to evaluate residual dysplasia. It is less useful in infants and young children in whom significant components of the hip are cartilaginous and not visible by CT. To determine the values of CT acetabular indexes and acetabular orientation, transaxial CT should be carried out. The patient is positioned in the supine position with the pelvis leveled and the physiologic lumbar lordosis rectified to avoid anterior tilting of the pelvis. The knees, ankles, and feet are positioned parallel with each other and held with a belt to avoid rotation of the lower limbs.[613] The axial tomographic cuts should be made every 5 mm or less based on the data of the scout view. The cuts must include anatomical landmarks of the pelvis to orient the reconstructions for accurate measurements. These can include both triradiate cartilages, both anterior superior iliac spines, both anterior inferior iliac spines, the pubic symphysis, both ischial tuberosities, both posterior iliac spines, and other sites. No significant angular variation should be observed at different levels of sections, for example through the triradiate cartilage.[455] To analyze acetabular morphology, the anterior acetabular index (AAI), the posterior acetabular index (PAI), the axial index (AxAI), and the acetabular version (AV) angle described by Gugenheim[214] and Buckley[53] may be utilized. Jacquemier et al.[285] designed the technique to measure the acetabular anteversion angle (AAA), and Weiner et al.[644] reported a method to calculate the anterior and posterior CE angles (ACEA and PCEA).

Kotzias[322] measured 100 normal transaxial CT scans of Brazilian children whose ages ranged from 6 months to 13 years on the day of the tomographic exam. The methodology of measuring angles and indexes and their respective values (average, median, and standard deviation) were statistically analyzed based on the Student's t-test and Scheffé test. The AAI, PAI, AxAI, AV, and AAA were measured in relation to the baseline, which passes through the center of the triradiate cartilage, and its parallel, which passes tangential to the posterior aspect of the iliac bones, was used to measure the ACEA and PCEA.

The *anterior acetabular index* is the angle formed by the intersection of a line drawn through the anterior aspect of the triradiate cartilage (baseline) and a line from the anterolateral corner of the triradiate cartilage to the anterior acetabular rim. This index measures anterior acetabular development.

TABLE 7-1. Anterior Acetabular Index (AAI) in Normal Children According to Age and Gender

Age in years	<2	2–3	4–5	6-7	8-9	10–11	12–13
Average	59	58	60	55	56	49	44
Median	60	57	59	54	58	49	44
Standard deviation	12	8	8	5	5	7	10
Number of cases	22	14	6	22	4	22	10

Analysis of variance F Calculated = 6.39* F Critical = 2.20

Scheffé contrast test < 2 > 10–11 e 12–13 2–3 e 4–5 > 12–13

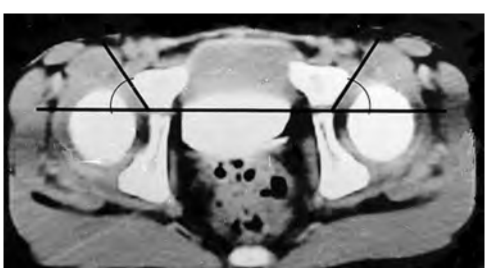


Figure 7-7 The anterior acetabular index (AAI) measures the anterior acetabular development (from Kotzias Neto A: Estudo dos valores angulares em tomografia axial computadorizada de crianças com quadris normais, master's thesis, Ortopedia e Traumatologia da Escola Paulista de Medicina, Universidade Federal de São Paulo, 1997).

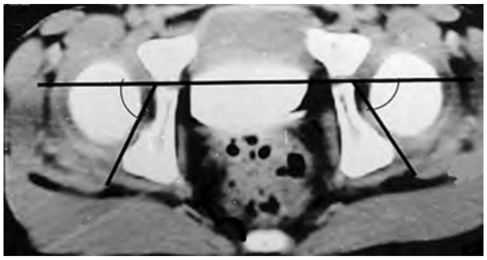


Figure 7-8 The posterior acetabular index (PAI) measures the posterior acetabular development (from Kotzias Neto A: Estudo dos valores angulares em tomografia axial computadorizada de crianças com quadris normais, master's thesis, Ortopedia e Traumatologia da Escola Paulista de Medicina, Universidade Federal de São Paulo, 1997).

The *posterior acetabular index* (PAI) is an angle formed by the intersection of a line drawn through the anterior aspect of the triradiate cartilage (baseline) and a line drawn from the postero-lateral corner of the triradiate cartilage to the posterior acetabular rim. This index measures posterior acetabular development.

TABLE 7-2. Posterior Acetabular Index (PAI) in Normal Children According to Age and Gender

Age in years	<2	2–3	4–5	6–7	8–9	10–11	12–13
Average	59	64	57	56	57	52	46
Median	60	61	57	55	58	53	47
Standard Deviation	11	7	3	4	5	8	8
Number of cases	22	14	6	22	4	22	10

Analysis of variance F Calculated = 6.69* F Critical = 2.20
Scheffé contrast test < 2 > 12–13 2–3 > 10–11 e 12–13

The *axial acetabular index* (AxAI) is the sum of AAI and PAI indexes and represents the depth of the acetabulum in the axial plane. An increase in value indicates acetabular shallowness. In normal development, the acetabulum becomes deeper as the child grows.

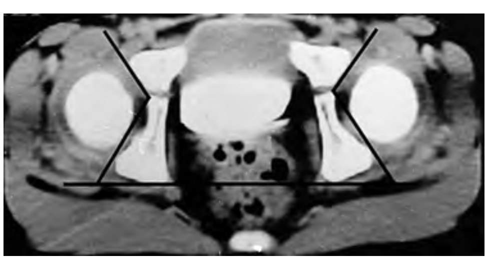


Figure 7-9 The axial acetabular index (AxAI) represents the depth of the acetabulum (from Kotzias Neto A: Estudo dos valores angulares em tomografia axial computadorizada de crianças com quadris normais, master's thesis, Ortopedia e Traumatologia da Escola Paulista de Medicina, Universidade Federal de São Paulo, 1997).

TABLE 7-3. Axial Acetabular Index (AxAI) in Degrees in Normal Children According to Age and Gender

Age in years	<2	2–3	4–5	6–7	8–9	10–11	12–13
Average	116	121	118	111	113	101	90
Median	120	121	115	110	114	102	91
Standard deviation	21	10	9	7	8	10	12
Number of cases	22	14	6	22	4	22	10

Analysis of variance F Calculated = 8.21* F Critical = 2.2
Scheffé contrast test < 2 e 2–3 > 10–11 e 12–13 4-5 e 6–7 > 12–13

Acetabular version (AV) is an angle formed by the intersection of a line drawn through the anterior aspect of the triradiate cartilage (baseline) and a line that bisects the axial acetabular index (AxAI). This angle indicates the acetabular version. If the value is positive, it represents anteversion; if negative, it represents retroversion.

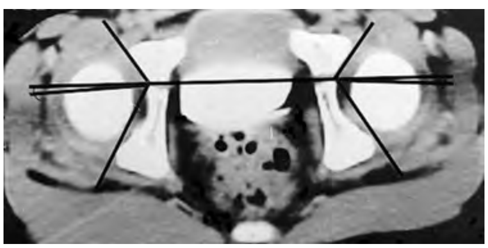


Figure 7-10 Acetabular version (AV). A positive value represents anteversion and a negative value represents retroversion (from Kotzias Neto A: Estudo dos valores angulares em tomografia axial computadorizada de crianças com quadris normais, master's thesis, Ortopedia e Traumatologia da Escola Paulista de Medicina, Universidade Federal de São Paulo, 1997).

TABLE 7-4. Acetabular Version (AV) in Degrees in Normal Children According to Age and Gender

Age in years	<2	2–3	4–5	6–7	8–9	10–11	12–13
Average	7	6	8	2	3	5	5
Median	4	5	8	2	3	3	5
Standard deviation	6	4	7	2	2	5	4
Number of cases	22	14	6	22	4	22	10

Analysis of variance F Calculated = 2.94* F Critical = 2.20
Scheffé contrast test < 2 > 6–7

The *anterior center-edge angle* (ACEA) has its apex at the anterior rim of the acetabulum. It is formed by the intersection of two lines that start from the apex, one to the center of the femoral head and the other perpendicularly to the baseline. To determine the center of the femoral head, the Mose method[417] is utilized and confirmed by the crossing of the

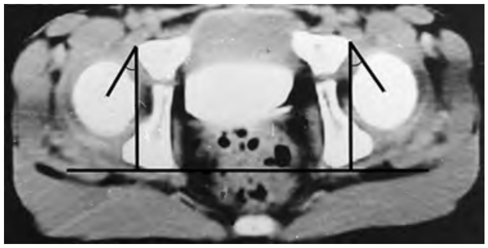


Figure 7-11 The anterior center-edge angle (ACEA) represents the anterior coverage of the femoral head in the axial plane (from Kotzias Neto A: Estudo dos valores angulares em tomografia axial computadorizada de crianças com quadris normais, master's thesis, Ortopedia e Traumatologia da Escola Paulista de Medicina, Universidade Federal de São Paulo, 1997).

bisecting lines of two secants that cut the femoral head randomly. This angle represents the anterior coverage of the femoral head. As the bony acetabulum develops anteriorly, the angle becomes smaller.

TABLE 7-5. Anterior Center-Edge Angle (ACEA) in Degrees in Normal Children According to Age and Gender

Age in years	<2	2–3	4–5	6–7	8–9	10–11	12–13
Average	39	34	31	32	34	27	21
Median	40	35	32	30	34	30	20
Standard deviation	7	5	4	6	4	9	4
Number of cases	22	14	6	22	4	22	10

Analysis of variance F Calculated = 11.59* F Critical = 2.20
Scheffé contrast test < 2 > 6-7; 10–11; 12–13 2-3 e 6–7 > 12–13

The *posterior center-edge angle* (PCEA) has its apex at the posterior rim of the acetabulum. This angle is measured by the intersection of two lines, the first extending from the apex to the center of the femoral head and the second perpendicular to the baseline. This angle shows the posterior coverage of the femoral head in the axial plane. As bony coverage increases posteriorly, this angle decreases.

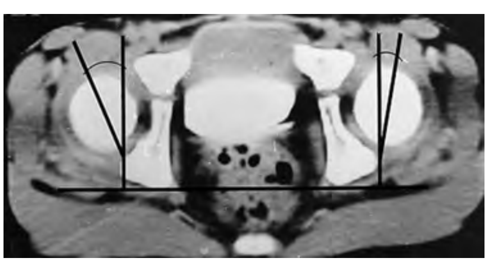


Figure 7-12 The posterior center-edge angle (PCEA) represents the posterior coverage of the femoral head in the axial plane (from Kotzias Neto A: Estudo dos valores angulares em tomografia axial computadorizada de crianças com quadris normais, master's thesis, Ortopedia e Traumatologia da Escola Paulista de Medicina, Universidade Federal de São Paulo, 1997).

TABLE 7-6. Posterior Center-Edge Angle (PCEA) in Degrees in Normal Children according to Age and Gender

Age in years	<2	2–3	4–5	6–7	8–9	10–11	12–13
Average	23	16	9	8	16	9	11
Median	23	14	10	9	17	10	8
Standard deviation	10	12	3	6	4	3	8
Number of cases	22	14	6	22	4	22	10

Analysis of variance F Calculated = 8.97* F Critical = 2.20
Scheffé contrast test < 2 > 4–5; 6–7; 10–11 e 12–13

The *acetabular anteversion angle* (AAA) has its apex at the anterior rim of the acetabulum. This is measured by the intersection of the tangential line drawn from the anterior to the posterior rim of the acetabulum and the perpendicular line to the baseline. The AAA shows the acetabular orientation in the axial plane.

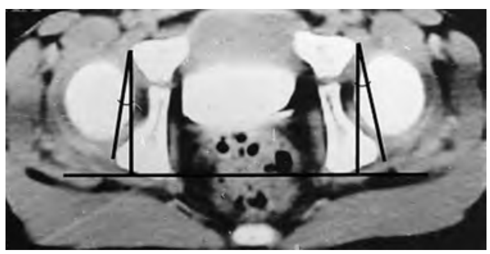


Figure 7-13 The acetabular anteversion angle (AAA) shows the acetabular orientation on the axial plane (from Kotzias Neto A: Estudo dos valores angulares em tomografia axial computadorizada de crianças com quadris normais, master's thesis, Ortopedia e Traumatologia da Escola Paulista de Medicina, Universidade Federal de São Paulo, 1997).

TABLE 7-7. Acetabular Anteversion Angle (AAA) in Degrees in Normal Children According to Age and Gender

Age in years	<2	2–3	4–5	6–7	8–9	10–11	12-13
Average	12	13	12	14	15	15	16
Median	12	10	11	14	15	15	16
Standard deviation	4	10	2	4	6	6	2
Number of cases	22	14	6	22	4	22	10

Analysis of variance F Calculated = 1.09 F Critical = 2.20
There is no significant difference among groups for level 0.50.

Results

In the study by Kotzias[322] of 50 pelvic CT scans, no significant differences by the Student's t-test were found between the values obtained for gender (30 males and 20 females), right and left sides, and race (38 white and 12 nonwhite children). The values of seven different age groups were compared by analysis of variance as criterion of classification. When this test showed a significant difference, the specific analysis was complemented by Scheffé contrast test. In all tests, a confidence ratio curve with a 0.05 (5 percent) error margin was used. The averages of angles calculated for children younger than 13 years of age are AAI, 54°; PAI, 56°; AxAI,110°; AV, 5°; ACEA, 31°; PCEA, 13°; and AAA, 13°.

The anterior, posterior, and axial acetabular indexes and the anterior and posterior center-edge angles tend to decrease as the child grows, demonstrating that the acetabulum becomes deeper and that the hip joint becomes more stable. The values and conclusions reported in this study are consistent with the observations by Buckley[53] for the AAI, AxAA, and AV. For PAI, the average angle was 55.8° in our study, and Buckley's angles were 49.4 ± 4.3°. The reason for this difference may be the different average ages in the two studies (6.2 years in Kotzias and 9.6 years in Buckley). Smith et al.[527] report similar values for PAI, AV, and AAA. For AAI and AxAI, the values reported were greater than in the Kotzias study, which may be accounted for by the differences in the patients' ages. Weiner and associates[644] report the same observations for AxAA and ACEA. For the PCAE, the values were similar for patients up to 7 years of age, but for older children the values were greater than those obtained in the Kotzias study. However, in both studies the decreasing tendency in the angles with growth was observed. The AV and the AAA values did not show any alterations in the age groups from 2 years and under to 12 and 13 years of age. This means that the spatial orientation of the acetabulum did not change significantly with growth. The values obtained for the acetabular anteversion by Kim et al. [308] in 27 normal hips varied from 8–27° (average 18°), which were greater than the average value calculated in the Kotzias study. They also did not find any significant difference between the AA in children younger than 15 years and those over 15 years of age. The AAA values were similar to those found in the studies by Visser[613] (16.5°) and Jacquemier[285] (13°). Weiner et al.[644] reported lower values in children between 6 and 10 years of age. All these reports show the tendency of the acetabulum to maintain its anteverted orientation during growth up to 15 years. Reynolds et al.[481] reported a retroverted orientation of the acetabulum as a cause of articular pain or rim syndrome due to impingement between the femoral neck and the anterior acetabular margin.

The morphology and morphometry of the dysplastic femur have been studied by many researchers.[103,135,146,310,330,368,371] The values obtained based on radiographs or CT of patients with DDH showed large ranges in the degree of severity. The size and shape of the human femur varies with age, stature, gender, and ethnic origin of the individual. Sugano et al.[554] report a morphometric study of 35 femora from 31 female patients with DDH, and another 15 for a control group. They observed that the femora with DDH had 10–14 ° more anteversion than the control group, independent of the severity of subluxation of the hip. The normal value of femoral anteversion at birth is about 30° (range from +15 to + 53°) and gradually decreases until adult life, when it ranges from -18 to +41 degrees (mean +14°). Mitchell and Parisi[407] described a variety of pelvis osteotomy techniques and

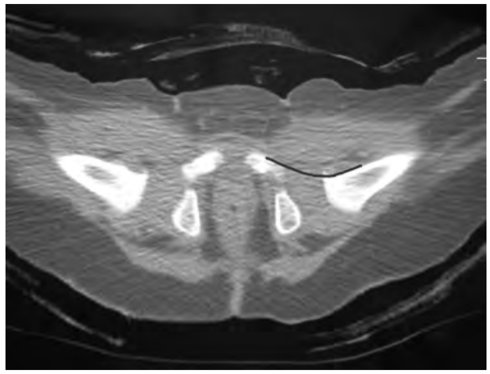


Figure 7-14 The anterior Shenton line drawn on a CT scan of a reduced hip.

analyzed whether the size and the orientation of the acetabulum are significantly radiographically altered to improve hip joint congruence and to provide a more normal weightbearing interface. They classified the acetabular procedures into three categories: (1) rotational or redirectional procedures, which reorient the articular surface of the acetabulum; (2) augmentation or capsular procedures, which are salvage procedures for an aspheric femoral head; and (3) reduction or pericapsular procedures, which reduce the capacity of the joint to create a more congruent joint surface.

Farber[151] described the Shenton line on the CT scan as a helpful radiographic sign to evaluate the reduction obtained in DDH. In the normal or well-reduced hip, the CT Shenton line is a gentle curve between the femoral neck and acetabulum. If this line is interrupted, the reduction is not attained.

Although CT provides two-dimensional images, which help the surgeon determine and evaluate proposed or actual treatment, it demands extensive and complex spatial interpretation. Based on the CT data points, three-dimensional reconstruction can be used to assess the surface of the acetabulum overlapping the femoral head.[307,313] These data will improve the preoperative planning aimed at choosing the most adequate surgical method to obtain hip joint congruency and optimal coverage of the femoral head.

THREE-DIMENSIONAL COMPUTED TOMOGRAPHY ANALYSIS

Three-dimensional computed tomography (3-DCT) analysis allows visual assessment of the hip joint preoperatively by computer manipulation of the data. The surgeon can make a visual assessment of the acetabular shape, potential congruency, and value of surface contact between the femoral head and acetabulum[484] Kim and Wenger[307] described the anatomy of the acetabulum in hip dysplasia resulting from DDH in children, reporting four types of acetabular deficiency. They analyzed the "topographic contact map" to estimate the contact between the femoral head and the acetabulum. Acetabular deficiency was classified by its location on the antero-posterior and lateral views of the 3-DCT hip images. On the antero-posterior view, the 3-DCT image allows comprehensive judgment of the ilio-pubic area (antero-superior segment of the acetabulum). On the lateral view, they drew a guideline *G* that connected the anterior superior iliac spine and anterior margin of the pubis. In a normal child, this line is nearly perpendicular to the ground in the standing position. When the triradiate cartilage is open, a second line can be drawn on the lateral view. This line connects the anterior and posterior ends of the iliac part of the acetabulum and is used to demarcate an acetabular slope. In the normal hip, this line is directed downward and anteriorly (but only slightly) or is parallel to the ground (i.e., tends to be perpendicular to the guideline *G*). When this line is nearly parallel to the ground, it is described as neutral = 0, and if it slopes slightly downwards anteriorally, it is described as negative = -1.

Normal hip: The antero-posterior view shows an intact ilio-pubic bony contour and an intact Shenton line, and the femoral head is centered in the acetabulum. In the lateral view, the superior aspect of the acetabulum shows a smooth concavity, the acetabular slope is neutral (0) or negative (-1), the femoral head is centered inside the acetabulum, and the acetabular roof is barely visible.

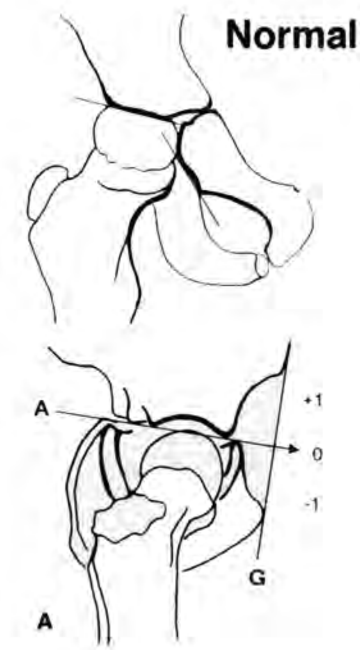


Figure 7-15 Characteristics of a normal right hip as visualized in a plain radiograph and 3DCT study (from Kim HT, Wenger DR: The morphology of residual acetabular deficiency in childhood hip dysplasia: three-dimensional computed tomographic analysis, J Pediatr Orthop 17(5): 637–47, p 639, Fig 1, 1997).

Type I (minimal dysplasia): The antero-posterior view shows disruption of the Shenton line and mild lateral uncoverage or occasionally subluxation of the femoral head. In the lateral view, the superior aspect of the acetabulum is irregular and notched and has lost its smooth concavity.

Type II (antero-superior deficiency): The antero-posterior view shows an abnormal ilio-pubic contour and occasionally subluxation is present. In the lateral view, the acetabular slope is positive (+1) and sometimes anterior subluxation is present.

Figure 7-16 Characteristics of a type I minimal dysplasia of the right hip as visualized in a plain radiograph and 3DCT study (from Kim HT, Wenger DR: The morphology of residual acetabular deficiency in childhood hip dysplasia: three-dimensional computed tomographic analysis, J Pediatr Orthop 17(5): 637–47, p 641, Fig 2, 1997).

Figure 7-17 Characteristics of a type II anterosuperior deficiency of the right hip as visualized in a plain radiograph and 3DCT study (from Kim HT, Wenger DR: The morphology of residual acetabular deficiency in childhood hip dysplasia: three-dimensional computed tomographic analysis, J Pediatr Orthop 17(5): 637–47, p 642, Fig 3, 1997).

Type III (midsuperior deficiency): The antero-posterior view shows an abnormal ilio-pubic contour and lateral subluxation is usually present. Sometimes dislocation is seen. This antero-posterior view is similar to the normal or type 1 view. In the lateral view, the acetabular slope is positive (+1) or neutral (0). Deficiency in the midsuperior or slightly anterior to the midsuperior margin of the acetabulum is seen and anterior subluxation or dislocation is sometimes present.

Type IV (global deficiency): The antero-posterior view depicts an abnormal ilio-pubic contour and lateral subluxation or dislocation. In the lateral view, the entire acetabulum is deficient and shallow (IV-a) or ballooned (IV-b) and a midsuperior or anterior subluxation or dislocation is seen.

Figure 7-18 Characteristics of a type III midsuperior deficiency of the right hip as visualized in a plain radiograph and 3DCT study (from Kim HT, Wenger DR: The morphology of residual acetabular deficiency in childhood hip dysplasia: three-dimensional computed tomographic analysis, J Pediatr Orthop 17(5): 637–47, p 643, Fig 4, 1997).

Figure 7-19 Characteristics of a type IV global deficiency of the right hip as visualized in a plain radiograph and 3DCT study (from Kim HT, Wenger DR: The morphology of residual acetabular deficiency in childhood hip dysplasia: three-dimensional computed tomographic analysis, J Pediatr Orthop 17(5): 637–47, p 644, Fig 5, 1997).

Kim and Wenger[307] divided their 48 patients (70 hips) into four groups according to the type of prior treatment. The first group consisted of the patients who had received nonsurgical treatment (15 patients, 24 hips). The frequency of acetabular type I was 38 percent; type II, 25 percent; type III, 33 percent; and type IV, 4 percent. The second group of patients had operative treatment (17 patients, 21 hips). The frequency of acetabular type I was 5 percent; type II, 57 percent; type III, 23 percent; and type IV, 15 percent. In the third group classified as dysplasia with no prior treatment (10 patients, 19 hips), the frequency of acetabular type was type I, 37 percent; type II, 10 percent; type III, 53 percent; and type IV, 0 percent. In the last group, identified as complete dislocation with no prior treatment (6 patients, 6 hips), the frequency of acetabular type III was 67 percent and type IV, 33 percent. They concluded that 3-DCT presents little added value in cases of type I but is helpful for type II and necessary for clinical judgment in types III and IV. Disadvantages of 3-DCT are a high radiation exposure, high cost, and the absence of correlation between the Kim and Wenger classification and other protocols of treatment. 3-DCT is a very useful procedure to evaluate the osseous components of an adolescent hip with acetabular dysplasia; however, it has a disadvantage in evaluating the cartilaginous components.

Lin et al.[350] developed a cartilage-window technique to evaluate the cartilage of the hip joint based on CT densitometry and a pseudocoloring process. They observed that the bony acetabular margin in normal hips was less spherical than the acetabular surface and the femoral head, which were both cartilaginous. The diameter of the bone segment of the acetabular rim was greater than the diameter of the cartilaginous segment. In dysplastic hips, the bony and cartilaginous diameters of the femoral head were smaller than the acetabular surface diameters. In their patients with dysplastic hips, the acetabular cartilaginous surface area was 29 percent larger than the osseous surface area, and the acetabular cartilage had a greater capacity (63 percent) than the bone component in the acetabular volume. The calculated acetabular height was 42 percent and the acetabular-opening angle was 31 percent. The containment of the femoral head by the osseous acetabulum was 12.9 percent and by the cartilaginous acetabulum was 30.1 percent. This cartilage-viewing window is helpful in evaluating the immature hip, especially in children younger than 10 years of age and in planning osteotomies. For example, the orthopaedist can determine acetabular directional changes; global and local acetabular deficiencies; and abnormal, irregular, or fragmented cartilage surfaces.

New techniques have been developed to assist surgeons performing pelvic osteotomies for the treatment of DDH. An image-guided freehand navigation system based on preoperative CT images provides substantial data for the surgeon to choose the best sites to perform the osteotomies, thus reducing potential risks and increasing safety and precision. Langlotz et al.[337] reported greater accuracy and safety in 14 pelvic osteotomies performed using image guidance.

MAGNETIC RESONANCE IMAGING (MRI)

Magnetic resonance imaging provides information about the cartilaginous components of the hip such as acetabular cartilage deformity and even a torn acetabular labrum. Three-dimensional MRI presents additional advantages such as improved views of carti-

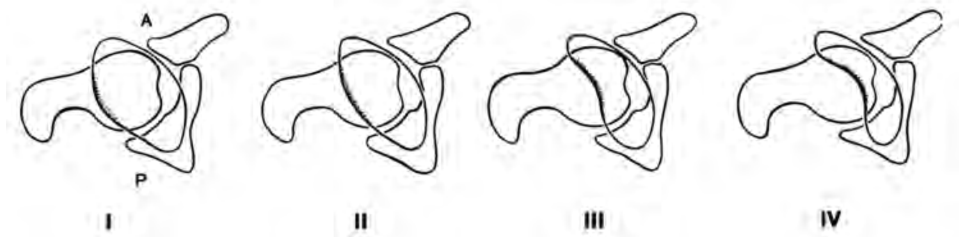


Figure 7-20 Schematic drawing of the Ogata classification of head coverage from CT (from Lehman WB, Atar D, Grant T, Strongwater A: CT, MRI, and 3-D reconstruction findings in children with developmental dysplasia of the hip (DDH), Mapfre Medicina 3 (Suppl 1): 50–58, p 53, Fig 8, 1992).

lage articular components and avoidance of exposing patients to radiation. It is especially helpful in the evaluation of hip joints in children younger than 6 months of age.[333,334] Loar et al.[338] reported a study of 18 "limited" MRI examinations carried out on 10 patients whose mean age was 9 months within 4 hours after surgery for DDH. The mean imaging time for two sequences was approximately 3 months apart. They concluded that MRI was a good method to image DDH without involving irradiation or sedation.

Horii et al.[264] measured MRI from 38 patients (51 hips) with dysplasia and compared them with healthy controls. They reported that the labra of the dysplastic hips were larger than those of the normal controls. They did not find any correlations between the size of the labrum and the acetabular coverage in the antero-superior positions among the dysplastic hips.

TREATMENT OF RESIDUAL DYSPLASIA

After successful management of dislocation, subluxation, or instability of the hip; some degree of dysplasia is common. The authors recommend an antero-posterior radiograph after removal of the first stabilizing device (cast, Pavlik harness, or orthosis) and every 4 to 6 months thereafter until the hip becomes normal or treatment of the residual dysplasia is instituted. The acetabular index is the most commonly used radiographic measurement to evaluate acetabular dysplasia in infants and children. The center-edge angle of Wiberg or the Sharp index is useful in adolescents and adults. The acetabular index is expected to decrease progressively to normal within 2 to 3 years after a stable reduction, and persistence of a high acetabular index represents a poor prognosis. An easy-to-remember rule of thumb is that the acetabular index is about 24° in a normal child at 24 months of age. The authors' goal of treating dysplasia is to have a normal hip by 4 to 5 years of age.

The type of dysplasia and the age of the patient are important factors in determining treatment of residual dysplasia of the hip. The treatment of persistent dysplasia can be divided into three phases: *initial, reconstructive,* and *salvage.* These phases are conceptual in that they denote a philosophy of treatment. The initial phase implies that the dysplasia may resolve without surgical treatment. The reconstructive phase implies that the dysplasia will not resolve without surgery and that the surgery can establish a successful outcome. The salvage phase implies that the hip will not have a successful long-term outcome and treatment should be directed toward maintaining useful function until a hip fusion or total hip replacement is required.

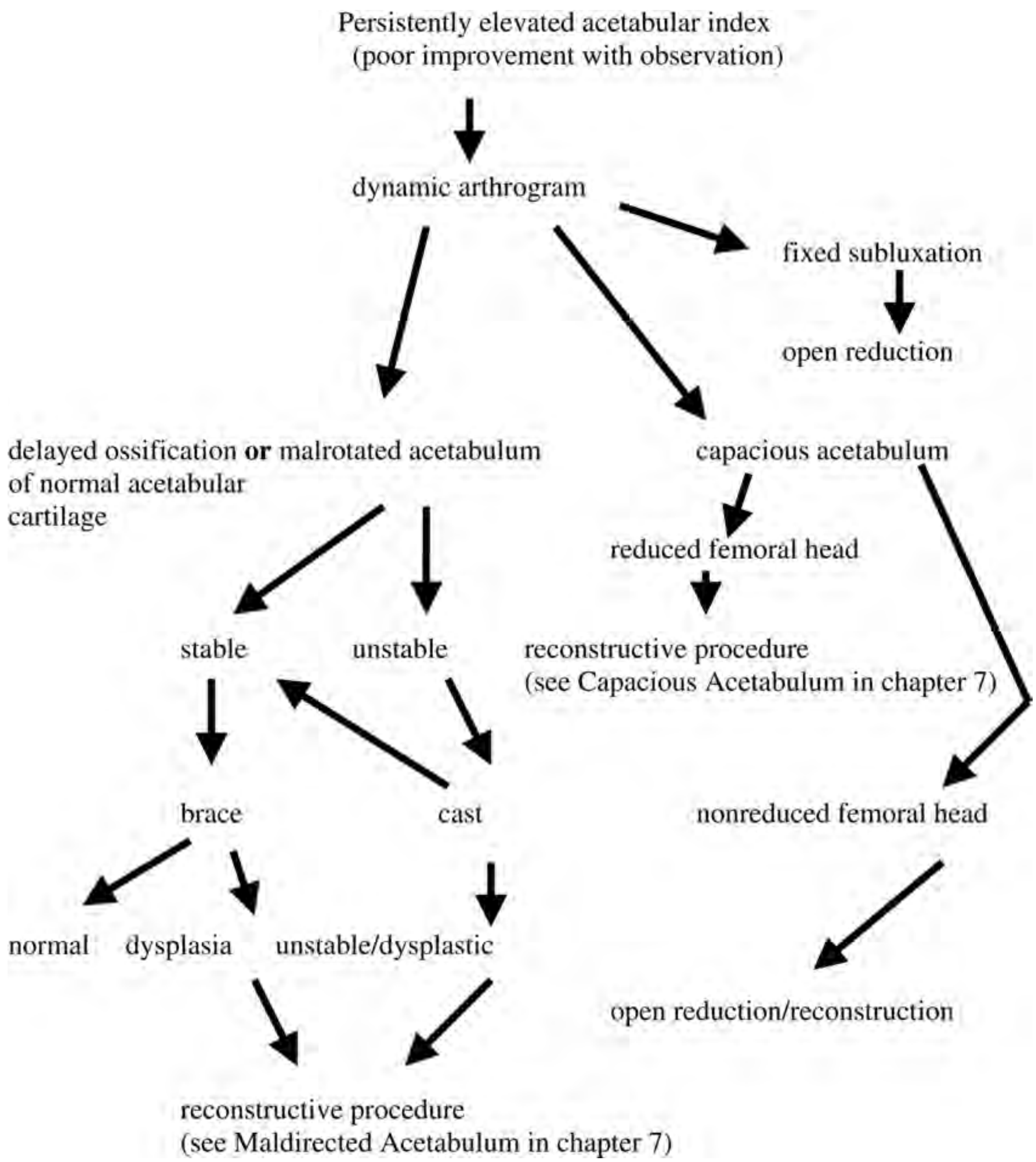
The Initial Phase of Treating Residual Dysplasia

The initial phase begins immediately after removal of the first stabilizing device for treating DDH (Pavlik harness, cast, etc.). During the initial phase, the children are usually young and have good healing capacities. The philosophy of treatment in this phase is based on the belief that growth of a stable and concentrically reduced hip will resolve most cases of dysplasia and that nonoperative treatments such as orthosis or casts can aid this growth. Nonoperative treatments may be used in children up to 4 or 5 years of age; however, consistent correction of the dysplasia should be observed, otherwise reconstructive treatment is recommended.

In the adequately reduced hip, dysplasia is demonstrated typically by an elevated acetabular index. The most severe dysplasia occurs in cases in which treatment fails due to late diagnosis or to misuse of the Pavlik harness or other stabilizing devices. For example, the dislocated hip may be inadequately reduced or may be held in a position of subluxation by a cast or orthosis. The goal of treatment during the initial phase is to correct the factors that cause persistent dysplasia, such as instability, incongruity (not concentrically reduced), and growth disturbance. The common types of residual dysplasia observed in the initial phase are maldirected or capacious acetabulum and femoral anteversion (see section describing Bowen's classification, chapter 7).[133] If pelvic radiographs show the hip to be concentrically reduced and stable, the tendency is for the acetabular index to decrease gradually and show progressive correction to normal within 2 to 3 years after reduction. In these cases, observation of hip development with radiographs taken every 3 to 6 months is recommended until the acetabular index is normal. Caution: to continue only observation, the dysplasia must be continually correcting.

If the dysplasia persists and its cause cannot be determined radiographically, a dynamic arthrography is recommended to provide information about the cartilaginous aspect of the acetabulum, hip stability, and internal anatomy of the joint. If the arthrogram shows a normal cartilage model of the acetabulum, which is delayed in ossification, or a malrotated acetabulum with the hip is stable, an abduction brace is often useful. However, if the joint is unstable, and the femoral subluxes with motion, the recommendation is to place the child in a cast with the hip in a concentrically reduced position. The cast is applied with the hip flexed 90° and abducted about 55–60° and the cast is maintained several months until stability is obtained. Caution: if stability cannot be obtained by casting, a reconstructive procedure is recommended.

TABLE 7-8. Algorithm for Treatment in the Initial Phase



In some cases, dynamic arthrography shows severe cartilage dysplasia, in which the cartilage model of the acetabulum is capacious (enlarged and deformed until the acetabular diameter is much greater than the size of the femoral head) and the femoral head subluxes within the enlarged acetabulum with motion of the leg. In these cases, closed reduction of the subluxation and casting with the hip concentrically reduced is recommended. These children must be followed carefully, and if hip stability is not achieved within 3 to 4 months, a reconstructive procedure is recommended.

If the dynamic arthrogram presents an unstable or subluxed hip joint and intrinsic factors (hypertrophic ligamentum teres, enlarged pulvinar, enfolded labrum, capsular constriction) obstruct a perfect reduction of the femoral head into the acetabulum, open reduction is the treatment of choice.

The Reconstructive Phase of Treating Residual Dysplasia

In the reconstructive phase, treatment of dysplasia is based in the philosophy that the dysplasia cannot be adequately treated by nonoperative methods and that surgery can help achieve a satisfactory hip. Typically, the residual dysplasia has persisted despite attempted treatment carried out in the initial phase. The age of the child and type of dysplasia are crucial factors in determining the operative procedure for achieving and maintaining a stable and concentrical reduction with good coverage of the femoral head by the acetabulum. The types of residual dysplasia that respond best to reconstructive procedures include the maldirected acetabulum, the capacious acetabulum, and femoral anteversion. The lateralized type of acetabular dysplasia can often be improved by a reconstruction procedure performed during early childhood; however, excellent lasting results are uncommon when the procedure is delayed into adolescents or adulthood. In children less than 7 to 9 years of age, a dislocated hip with a false cetabulum can be treated by an open reduction and reconstructive procedures.(see section describing Bowen's classification, chapter 7).[133]

To correct the maldirected acetabulum type of residual dysplasia, redirectional innominate osteotomies are indicated. These procedures rotate the acetabulum to achieve coverage of the femoral head. For children from 18 months to 6 years of age, the Salter innominate osteotomy is often used to correct the maldirection of the acetabulum. For children of 7 years or older, the surgeon may choose the modified Salter osteotomy of Kalamchi,[295] the double innominate osteotomy of Sutherland,[556] the Ganz periacetabular osteotomy,[178] or a triple innominate osteotomy. These procedures allow the acetabulum to rotate by additional osteotomies of the pubis and ischium. The specific choice of procedure depends upon the degree of desired rotation, displacement, and fixation.

To correct the capacious acetabulum type of residual dysplasia, pericapsular osteotomies of Albee,[3] Pemberton,[451] and Dega[124] are suggested. These operations consist of incomplete osteotomies of the ilium just above the acetabulum, and the roof of the acetabulum is bent downward over the reduced femoral head. The contour of the capacious acetabulum is changed from an opened, elongated, shallow acetabulum in which the femoral head subluxes with movement of the femur to a deep cup shape in which the hip is stable. Caution: to obtain good results from these procedures, the femoral head must be reduced into the proper position at the base of the acetabulum prior to bending of the acetabular roof over the femoral head. Forced reduction of the femoral head may cause AVN or chondrolysis.

To improve the lateralized acetabulum type of residual dysplasia, several procedures have been tried; however, no procedure addresses all aspects of this severe deformity. By definition, the lateralized acetabular type of residual dysplasia consists of a subluxed femoral head that cannot be reduced because the condyloid cavity of the acetabulum has filled medially with hypertrophic cartilage and bone. The teardrop area of the acetabulum is wide, forcing the femoral head into an unreducible subluxation. The acetabular roof is deficient and is usually elongated, which results in poor support for the femoral head. Occasionally the acetabular roof may contour to the subluxed femoral head. To reduce the subluxed femoral head, Colona reamed the entire acetabulum, which destroyed the articular cartilage. The Colona procedure[95] has an extremely high failure rate and is almost contraindicated. Derqui[128,129] modified the procedure by reaming only the medial area of the acetabulum, thereby preserving the cartilage of the acetabular roof; however, long-term results show this procedure to have a high rate of failure, and it is now very seldom performed. The authors are unaware of a procedure that fully reconstructs the lateralized acetabulum type of dysplasia in adolescents or adults. In cases in which the subluxed femoral head is stable within a congruent but shallow acetabulum, the authors perform combined operations consisting of a rotational osteotomy and a shelf procedure to offer better coverage of the femoral head. The Salter osteotomy or a triple osteotomy has been most frequently used with the Staheli shelf.[541] Most adult patients with a severe lateralized type of acetabular dysplasia will require salvage procedures such as a Chiari osteotomy[77] or pelvic support osteotomy.[280]

Excessive anteversion and valgus of the proximal femur probably contribute to persistent residual dysplasia by inappropriately directing muscular and weightbearing forces into the acetabulum. In these cases, a proximal femoral varus-derotation osteotomy redirects the femoral head within the acetabulum and corrects the abnormal proximal femoral relationship to the acetabulum. The authors have found the proximal femoral osteotomy to be helpful in cases in which the cartilage model of the acetabulum is normal but poorly ossified, the proximal femur is severely anteverted, and the involved limb is longer than the uninvolved side or has excessive valgus. The proximal femoral osteotomy is also helpful as a combined procedure with an acetabular procedure in cases of very severe residual dysplasia.

Residual dysplasia due to femoral deformities includes valgus and anteversion of the femoral neck, femoral head asphericity, coxa brevis, discrepancy between the greater trochanter and the femoral head, and capital femoral growth arrest.

The authors' choice of treatment for a dislocated hip and a false acetabulum in children up to 9 years of age in unilateral cases and up to 7 years of age in bilateral cases is an open reduction with correction of the intrinsic and extrinsic factors, such as inverted limbus, fibro-fatty pulvinar, ligamentum teres, and psoas tendon, associated with femoral shortening and acetabular reconstruction. In children over 7 to 9 years of age with dislocated hips, adequate reduction and reconstruction is frequently inadequate to achieve a satisfactory hip. The older patients may require procedures described in the salvage phase of treatment (see chapter 12).

The Salvage Phase of Correction of Residual Dysplasia

In the salvage phase, treatment is based on the philosophy that the dysplastic hip is so abnormal that a satisfactory long-lasting joint cannot be obtained by an operative procedure. In these cases, operative procedures are indicated to relieve pain, improve function, and delay the need for a total hip or hip fusion. The types of residual dysplasia that most frequently require salvage procedures are severely lateralized acetabulum, false acetabulum in adolescence or adults, capacious acetabulum with arthritis in adults, and avascular necrosis of Kalamchi types III or IV in adolescents or adults.

The false acetabulum in adolescents and adults can occur in two different patterns. In one pattern, the false joint consists entirely of soft tissue surrounding the femoral head and the femoral head does not have bony contact with the pelvis. These patients tend to have severe lumbar lordosis and a Trendelenburg gait; however, early adult arthritis is uncommon. In the other pattern of false acetabulum, the femoral head is positioned against the pelvis, promoting a contact indentation of the pelvis with a fibro-cartilaginous joint (false acetabulum). These patients may develop degenerative arthritis by early adulthood.

In the salvage phase, operative procedures can include a Chiari osteotomy,[78] a shelf operation,[541] and (rarely) a hip arthrodesis, a valgus proximal femoral osteotomy (pelvic support osteotomy),[67,280] or a total hip replacement. Chiari and shelf operations provide coverage of the femoral head by enlarging the capacity of the deficient and false acetabulum. In older children, these procedures increase joint stability and the surface area for weightbearing and prevent supero-lateral migration of the femoral head. In older adults with severe degenerative hip disease following DDH, total hip replacement can be helpful but is associated with many complications. The authors rarely perform arthrodesis of the hip, but it is an option for treatment in the young adult with unilateral hip involvement and severe pain due to degenerative arthritis.

Outcome Evaluation of Residual Hip Dysplasia

The Ponseti criteria[458] are used to evaluate the clinical outcome:

Grade 1: Asymptomatic

Grade 2: Slight hip pain after excessive walking

Grade 3: Limp, free movement, and no pain

Grade 4: Limp and limitation of movement, no pain

Grade 5: Limp and pain

Grade 6: Limp, limitation of movement, and pain

TABLE 7-9. The Modified McKay Criteria for Clinical Evaluation[385]

Rating	Criteria
Excellent	Stable, painless hip; no limp; negative Trendelenburg sign; full range of motion
Good	Stable, painless hip; slight limp; slight decrease in range of motion
Fair	Stable, painless hip; limp; positive Trendelenburg sign; limited range of motion; all of these
Poor	Unstable and/or painful hip; positive Trendelenburg sign

TABLE 7-10. Radiological Outcome According to Severin Classification System[514–516]

Class	Radiological Appearance	Center-Edge Angle	Result
I	Normal hip		Excellent
Ia		>19° (6–13 yr old) >25° (≥14 yr old)	
Ib		>15–19° (6–13 yr old) 20–25° (≥14 yr old)	
II	Moderate deformity of the femoral head, femoral neck, or acetabulum		Good
IIa		>19° (6–13 yr old) >25° (≥14 yr old)	
IIb		>15–19° (6–13 yr old) 20–25° (≥14 yr old)	
III	Dysplasia without subluxation	<15–19° (6–3 yr old) <20° (≥14y old)	Fair
IV			Poor
IVa	Moderate subluxation	≥0°	
IVb	Severe subluxation	<0°	
V	Femoral head articulates with pseudoacetabulum in superior part of original acetabulum		Failure
VI	Redislocation		Failure

TABLE 7-11. Modification of Severin's Classification for Radiographic Evaluation of Results[562]

Class	Description	Center-Edge Angle
I	Normal appearance	>15° (4–13 yr) >20° (>14 yr)
II	Mild deformity of the femoral head and neck or the acetabulum	>15° (4–13 yr) >20° (>14 yr)
III	Dysplasia or moderate deformity of the femoral head and neck or the	10–15° (4–13 yr) 15–20° (14 yr)

	acetabulum, or both
IV	Subluxation of the femoral head
V	Articulation of the femoral head with a false acetabulum
VI	Redislocation

The Severin classification is frequently used to assess the outcome of treatment of residual dysplasia. Recently, Omeroglu et al.[437] and Ward et al.[636] have questioned its accuracy because there were low levels of intra- and interobserver reliability; however, in the authors' opinion no more reliable classification is currently available.

Chapter Eight

Osteotomies for the Treatment of a Malrotated Acetabulum

SINGLE INNOMINATE OSTEOTOMIES

Innominate Osteotomy of Salter

Salter[493–495] studied the basic causes of hip instability after reduction for DDH and concluded that the acetabulum is directed antero-laterally more than normal. For this reason, the femoral head is insufficiently covered anteriorly when the hip is extended, and laterally when the hip is adducted. He concluded that if the acetabulum could be oriented in a normal direction, the reduced hip joint would be stable in a functional position. The Salter innominate osteotomy redirects the entire acetabulum over the uncovered femoral head by opening an ilium osteotomy site antero-laterally, combining a hinging and rotation through the symphysis pubis. Coleman[93] and Bohn[44,45] reported good results with the Salter osteotomy in correcting the maldirected acetabulum in patients from walking age to young adulthood.

The authors have had good results in correcting a malrotated acetabulum with Salter's procedure in children from 18 months to adolescence. The acetabular index can be corrected approximately 15°. The hip must have a concentric reduction to achieve good results.

Prerequisites

- Capacity to bring the femoral head to the level of the acetabulum. Originally, Salter recommended preoperative traction.
- Contractures of the adductors and the iliopsoas muscles must be released.
- Concentric reduction of the femoral head in the true acetabulum must be performed.
- Appropriate congruity of the acetabulum and femoral head. Joint should have a rounded circumference.
- No fixed deformity. Good motion of the hip joint is necessary, especially flexion, abduction, and internal rotation.
- Patient must be over 18 months of age
- A flexible symphysis pubis is required

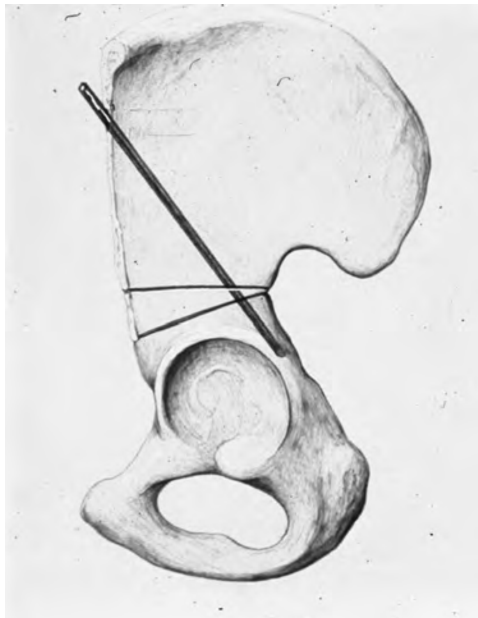


Figure 8-1 Drawing of the Salter procedure.

Indications

- To correct acetabular maldirection from DDH in children over 18 months of age
- To correct acetabular dysplasia
- To cover the antero-laterally exposed femoral head
- To stabilize a concentrically reduced hip in a functional position of weightbearing
- For dislocation after the age of 2 years when closed reduction is contraindicated (a concentric reduction is a prerequisite)
- Residual subluxation following previous treatment failure in patients from 18 months to approximately 6 years of age (a concentric reduction is a prerequisite)
- Residual dislocation following previous treatment failure in patients from 18 months to approximately 6 years of age (a concentric reduction is a prerequisite)

Contraindications

- Patient older than 6 years with dislocation (relative contraindication)
- Incapacity to carry the femoral head to the acetabulum
- Incapacity to reduce the femoral head into the true acetabulum
- Joint incongruity
- Range of motion significantly limited

- Remaining tightness of the adductors and iliopsoas muscles, even after release
- Early degenerative arthritis of the hip joint in the older child

Advantages

- Corrects the abnormal direction of the acetabulum, promoting immediate stability in a single operative procedure
- Provides coverage of the femoral head with a hyaline cartilaginous acetabulum
- Does not disturb the triradiate cartilage or the acetabular lip; consequently, does not alter the growth of the acetabulum
- Permits early resumption of function of the hip joint
- Does not change the configuration and capacity of the acetabulum

Disadvantages

- Does not provide posterior femoral head coverage or medialization of the acetabulum
- Reduces inferior and posterior acetabular coverage of the femoral head

Factors of instability of the reduced hip in the older child

- Acetabular maldirection
- Capsular elongation
- Contracture of the adductors and iliopsoas muscles

Salter's innominate osteotomy procedure[491,493–495]

1. Place the patient on the operating room table in a semiprone position (partly on the side with a sandbag behind the chest).
2. Prepare the lower limb to allow free movement during the surgical procedure.
3. Drape the hip to the midline anteriorly and posteriorly and behind the costal margin. (Separately drape the lower limb, which may be movable during surgery.)
4. Perform adductor tenotomy to release any contracture and obtain maximum abduction movement.
5. Begin the skin incision just below the inguinal ligament at its midpoint and continue laterally inferior to the anterior superior spine to a point beyond the middle of the iliac crest. This is the "bikini incision," which provides a satisfactory cosmetic appearance.
6. Open the subcutaneous tissue along the same line as the skin.
7. Expose the iliac crest and incise the cartilaginous iliac apophysis from the anterior superior spine to the midpoint of the iliac crest.
8. Protect the lateral femoral cutaneous nerve and then perform a longitudinal incision in the deep fascia, below the anterior superior iliac spine.

9. Expose the groove between the sartorius and the tensor fasciae latae muscles, and by blunt dissection open this space to expose the rectus femoris muscle. Usually a small vessel crosses this region over the spine and should be cauterized.
10. Dissect the rectus femoris muscle from the capsule and divide the reflected head.
11. Extend the incision in the iliac apophysis downward to the anterior inferior iliac spine.
12. Elevate the periosteum from the outer surface of the ilium with a periosteal elevator, exposing the outer aspect of ilium down to the sciatic notch.
13. Elevate the periosteum from the inner aspect of the ilium. This procedure is easily performed on this side of the ilium.
14. Stay within the periosteum for the purpose of keeping away from the gluteal artery and the sciatic nerve. Utilize a sponge to facilitate the dissection, to dilate the space between the ilium and the periosteum, and to prevent any bleeding from the elevated tissues.
15. Expose the capsule superiorly, anteriorly, and medially to the inner edge of the acetabulum by blunt dissection.
16. Place retractors in the sciatic notch and pass subperiosteally a curved forceps from the medial to the lateral sides of the ilium.
17. Introduce a Gigli saw through the sciatic notch from the lateral to the medial side of the ilium. Grip the Gigli saw with the teeth of the forceps placed on the inner side.
18. Perform the osteotomy from the sciatic notch directly anteriorly and vertically to the anterior inferior iliac spine, holding the ends of the Gigli saw far apart with continuous tension on each end of the saw. The pelvis is stabilized by downward pressure on the iliac wing from an assistant.
19. After the osteotomy is completed, the distal fragment should *not* displace posteriorly.
20. Cut a triangular bone graft, removing it from the iliac crest with bone cutters or an oscillating saw. The base of this graft should correspond to the distance between both iliac spines (anterior superior to anterior inferior) forming an angle of 30–40° at its apex.
21. Grasp the ilium with a towel clip to keep it steady. Use a second towel clip to grasp the distal fragment, which should then be pulled downward and forward. The figure 4 maneuver of the leg facilitates the opening of the osteotomy (flexing and externally rotating the affected hip, flexing the knee and placing the heel on the opposite knee, then extending the hip gradually and carefully). The capsule pulls the distal fragment downward and forward. The rotation occurs at the symphysis pubis. The distal fragment should never be displaced posteriorly in relation to the proximal fragment of the ilium. If this occurs, no redirection of the acetabulum has been attained.

22. Shape the bone graft with bone cutters or a power saw and insert it at the osteotomy, which must be opened anteriorly and closed posteriorly. The distal fragment should be rotated and in a position slightly anterior to the proximal fragment.
23. Drill the proximal fragment and thread a Kirschner wire through, across the graft and into the distal fragment medial and posterior to the acetabulum, avoiding entry into the joint and triradiate cartilage.
24. Drill the proximal fragment again and thread a second Kirschner wire parallel to the first to increase the stability of the osteotomy.
25. Make sure that the Kirschner wires are not inside the joint.
26. Confirm the stability of the reduction and mobility.
27. Suture the cartilaginous iliac cap. There is no need to close the space between the tensor fascia lata and the sartorius muscles. Leaving it open helps to avoid damage to the lateral femoral cutaneous nerve.
28. Cut the pins at their ends, permitting palpation under the skin.
29. Suture the subcutaneous tissue and skin.
30. Apply a single spica cast with the hip flexed at 30°, abducted 30–40°, in neutral rotation.
31. Take antero-posterior radiographs to ensure position of the osteotomy and hip.

Open reduction of a dislocated hip and a Salter innominate osteotomy

In dislocations, Salter's innominate osteotomy may be performed in association with an open reduction. The steps of the osteotomy are listed in the following pages.

Perform the open reduction for a dislocated hip as described in prior sections until the step for reduction of the dislocated hip (chapter 6).

- Reduce the femoral head into the acetabulum. Test the stability and recognize the acetabular maldirection. If the hip is unstable from maldirection of the acetabulum or if the acetabular index is excessively high (about 30° or greater) and if the patient is over 18 months of age, a Salter innominate osteotomy may be indicated.
- Identify the iliopsoas muscular-tendon junction at the inner wall of the ilium. Separate the tendon from the muscular portion and perform an intrapelvic tenotomy. When the hip is flexed and extended, the tendon is easily identified as a tight band. This maneuver protects the femoral nerve.

16. Place retractors in the sciatic notch and pass subperiosteally a curved forceps from the medial to the lateral side of the ilium.
17. Introduce a Gigli saw through the sciatic notch from the lateral to the medial side of the ilium. Grip the Gigli saw with the teeth of the forceps placed on the inner side.

18. Perform the osteotomy from the sciatic notch directly anteriorly and vertically to the anterior inferior iliac spine, holding the ends of the Gigli saw far apart with continuous tension on each end of the saw. The pelvis is stabilized by downward pressure on the iliac wing from an assistant.
19. After the osteotomy is completed, the distal fragment should be stabilized by the assistant.
20. Cut a triangular bone graft, removing it from the iliac crest with bone cutters or an oscillating saw. The base of this graft should correspond to the distance between both iliac spines (anterior superior to anterior inferior) forming an angle of 30–40° at its apex.
21. Grasp the ilium with a towel clip to keep it steady. Use a second towel clip to grasp the distal osteotomy fragment (acetabular fragment), which should then be pulled downward and forward. The figure 4 maneuver cannot be used with an open reduction of the hip. The capsule is incised; therefore, it cannot be used to rotate the acetabulum. The rotation of the acetabulum is induced by motion of the instrumentation (towel clips). The rotation occurs at the symphysis pubis. The distal fragment should never be displaced posteriorly in relation to the proximal fragment of the ilium. If this occurs, no redirection of the acetabulum has been attained.
22. Shape the bone graft with bone cutters or a power saw and insert it at the osteotomy, which must be opened anteriorly and closed posteriorly. The distal fragment should be rotated and in a position slightly anterior to the proximal fragment.
23. Drill the proximal fragment and thread a Kirschner wire through, across the graft and into the distal fragment medial and posterior to the acetabulum, avoiding entry into the joint and triradiate cartilage.
24. Drill the proximal fragment again and thread a second Kirschner wire parallel to the first to increase the stability of the osteotomy.
25. Make sure that the Kirschner wires are not inside the joint.

- Complete operation as described for an open reduction (chapter 6).

Postoperative care

The patient returns after 2 weeks for the cast to be evaluated, and radiographs are taken to monitor the position of the osteotomy. After 6 weeks the cast and pins are removed under general anesthesia and radiographs are taken. Once consolidation of the osteotomy is confirmed, crutches and therapy are initiated until full weightbearing can be authorized.

If open reduction was performed in association with the Salter procedure, a bilateral long leg abduction cast is applied to maintain the hips in abduction of 20–40° and internal rotation of 15° for a total of 10 weeks.

In bilateral cases, the second hip is operated on 2 weeks after the first. It is very important to leave the child in the spica cast to protect the first hip during the second operation. Half of the spica cast is removed longitudinally to permit the surgery of the contralateral hip. Another choice in bilateral cases is to perform the operation on the second hip after the prior hip has been removed from the cast.

Complications

- Infection
- Avascular necrosis (related more with open reduction associated with innominate osteotomy)
- Premature closure of the triradiate cartilage,[415] probably correlated with an extensive periosteal exposure of the inner aspect of the pelvis during surgery
- Loss of position of the osteotomy site
- Subluxation
- Redislocation
- Anterior or posterior displacement[161,235]

Results

Salter and Dubos[495] report the results of their cases treated between 1958 and 1968, discussing their first 10 years of personal experience. They divided their patients into two groups. In the first group, called the primary operation group, there were 140 dislocations and 28 subluxations. In the second group, called the secondary operation group, representing the failures of the previous treatment, there were 47 residual dislocations and 110 residual subluxations. The results of the combined open reduction and innominate osteotomy for dislocated hips of the first group, based on the Severin classification, show 93.6 percent to be excellent and good in patients from 18 months to 4 years of age, and 56.7 percent from 4 to 10 years of age. For hip subluxation, where innominate osteotomy was performed alone, they had 100 percent excellent and good results in patients from 18 months to 4 years of age, and 91.6 percent from 4 to 16 years of age.

In the second group, the secondary operation group, avascular necrosis of the femoral head occurred in 30 percent as a complication of the previous treatment, and cartilage necrosis was found in 6.4 percent of the 157 hips. They classified these 157 hips before and after innominate osteotomy, with or without combined open reduction. After failure of previous treatment, and before the innominate osteotomy, the hips were classified as Severin types III, IV, V, and VI (fair, poor, and failure). After innominate osteotomy (the secondary operation), these patients improved to 61.1 percent excellent and good results (Severin I and II).

Salter and Dubos observed the following common errors committed by orthopaedic surgeons:[495]

- Failure to observe the prerequisites and to adhere to the indications and contraindications of the method.
- Errors in operative technique such as inadequate exposure of the anatomic structures.

- Failure to perform adductor and iliopsoas tenotomies, to achieve a concentric reduction, and to perform an adequate capsulorrhaphy
- Failure also in rotating the distal fragment of the ilium, in leaving the osteotomy open posteriorly, and in allowing posterior and medial displacement of the distal fragment.
- Inadequate placement of the Kirschner wires and performing bilateral innominate osteotomies in a one-stage procedure.
- Imperfect postoperative management, immobilizing the reduced hip in a forced position, maintaining it much longer or much less than 6 weeks, or permitting unsupervised walking after weightbearing is allowed.

Morin et al.[415] reported results similar to those of Salter and Dubos. They reviewed 180 congenitally dislocated, subluxed, and dysplastic hips in 122 patients at skeletal maturity. In their cases, the acetabular angle at maturity was 23.6° on average (14° improvement from preoperatively), similar to that of Gulman et al.,[216] who achieved 21°. Utterback and MacEwen[364,609] reported an improvement of 10° and Barrett et al.[22] one of 16°.

Mellerowicz et al.,[391] comparing the long-term results of Salter and Chiari pelvic osteotomies in DDH, concluded that Salter's procedure performed on patients younger than 3 years of age was capable of rendering long-term pain relief and enabling normal hip development. On the other hand, the Chiari procedure showed satisfactory to good coverage radiographically, but the subjective and functional factors were poor and unsatisfactory.

Huang and Wang[270] reported their observations comparing the results of treatment of DDH in 48 patients (49 hips) whose ages ranged from 13 to 17 months. The patients were divided into two groups and were followed-up for 2 years and 3 months. In the first group, 16 patients (17 hips) were treated by closed reduction and casting. One hip redislocated and four showed mild AVN. Based on the Severin criteria, the results were classified as class I in one hip, class III in nine hips, class IV in six hips, and class VI in one hip. In the second group, which consisted of 32 patients (32 hips), open reduction and Salter osteotomy were performed without preoperative traction. One hip redislocated and 2 hips showed a mild degree of AVN. Thirteen hips were classified as Severin class I, 18 hips as Class II and 1 hip as Class III. They concluded that DDH in patients of walking age could be treated efficiently by open reduction associated with Salter innominate osteotomy.

Borges et al.[47] reported difficulties in the treatment of 55 boys (78 hips) who had DDH from 1965 to 1990. They divided the patients into three groups. Group I consisted of 22 patients (30 hips) in which the patients were treated initially with a Pavlik harness. The harness was considered to have excellent results in two hips (7 percent), but the other 28 hips (93 percent) needed additional treatment. The final results of these hips were 14 excellent, 10 good, and 4 fair. Group II consisted of 29 patients (42 hips) treated by closed reduction. Initially, 29 (69 percent) were considered stable, but later 15 of these hips (52 percent) needed additional treatment for remaining dysplasia or subluxation. The results attained for these patients were 14 excellent, 13 good, and 2 fair. The remaining 13 (31 percent) were considered unstable after the closed reduction and were then treated by operative reduction. The results were 4 excellent, 6 good, and 3 fair. In Group III, 4 patients (6 hips) had been treated initially by open reduction. In 2 hips, open reduction was associated with pelvic osteotomy, and 4 of the hips required a secondary procedure. Two of these secondary procedures were for redislocation of the hip, and 2 were to correct the residual dysplasia. The results of this group were 2 excellent, 2 good, and 2 fair. They concluded that DDH in boys is probably secondary to laxity and an intrinsic deficiency of acetabular development. They also noticed a high incidence of complications, for example, redislocation and absence of acetabular remodeling after open reduction alone. They suggested performing a pelvic osteotomy to correct acetabular malalignment at the time of the open reduction, and a femoral osteotomy if correction of anteversion was necessary. Other authors have reported the biologic stimulating effect of the Salter innominate osteotomy on the acetabulum, which reverses the dysplastic changes,[265] and other authors have observed that the acetabular correction obtained at surgery continues until bone maturation.[568]

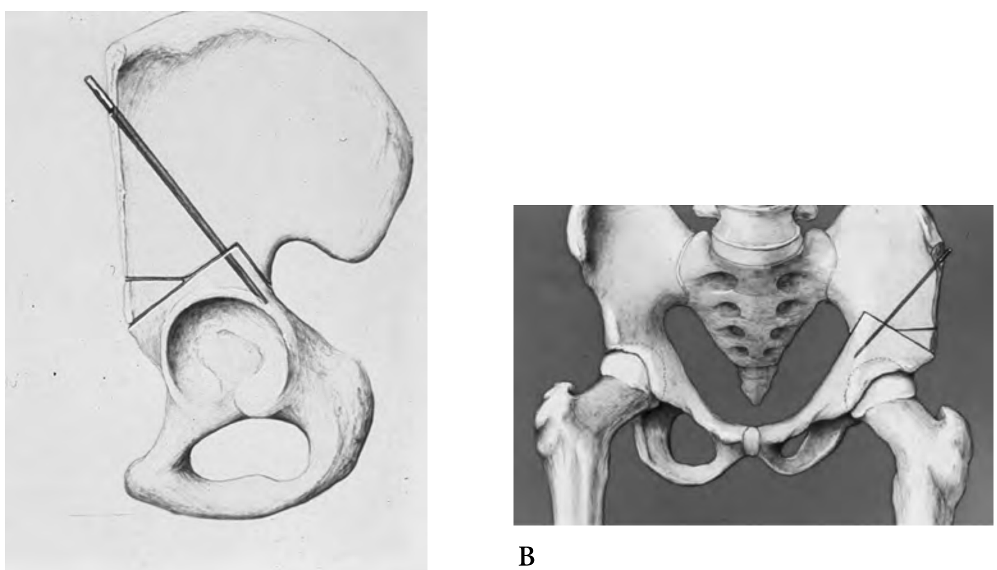
Santili in 1996[500] reported a study of 32 patients (42 hips) treated by Salter's innominate osteotomy, associated with femur shortening. The mean age at operation was 4 years (ranging from 2 to 10 years). The mean age at follow-up was 17 years. He evaluated the results based on the patient complaints and Severin's radiological criteria. He also evaluated the limb length discrepancies. The results of the patient opinions were 37 excellent, 2 good, 1 regular, and 2 poor. Based on Severin's criteria, the results for 37 hips were considered satisfactory, 3 unsatisfactory, and 2 doubtful. The residual limb length discrepancy was 0.65 cm in 29 patients. He concluded that the Salter procedure provides good results in the treatment of DDH and that the correction persists.

Bertol (1998)[32] analyzed 103 hips treated by Salter's procedure associated with a femur osteotomy in patients whose ages ranged from 18 to 60 months. He concluded that this association did not alter the results in patients between 18 to 30 months of age, but increased the good results in the older children. Milani[396] concurred with these results.

Bohn and Weber (2003)[45] reviewed 58 patients (69 hips) with DDH submitted to Salter's innominate osteotomy. The age of the patients at operation ranged from 13 to 37 years (mean age 22 years). They concluded that Salter's procedure promoted encouraging results in adolescents and young adults whose hips presented have minimal to no arthritic changes.

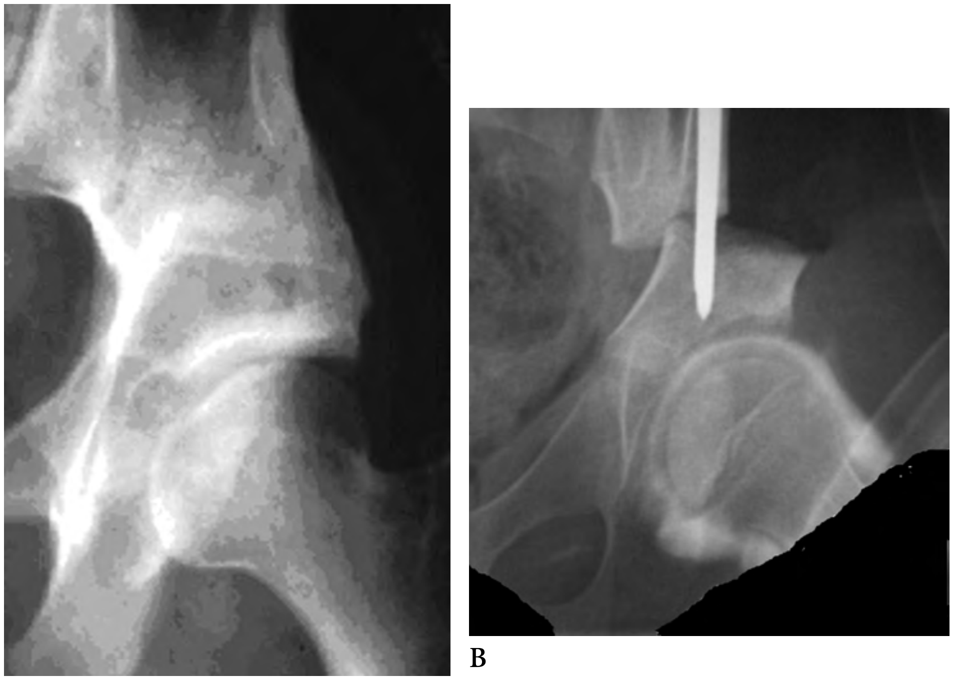
Kalamchi Modification of the Salter Innominate Osteotomy[295]

Kalamchi reported a modification of the Salter innominate osteotomy in which he resected a triangular wedge of bone from the most posterior aspect of the proximal segment of the iliac bone without disturbing its posterior cortex.[295] He recommended this operation for patients with unilateral hip involvement, especially if the ipsilateral lower limb was long preoperatively. He believes that his modification provided more stability to the osteotomy, eliminated the risk of posterior and medial displacement of the distal segment of the ilium, and decreased intra-articular pressure. The proximal anterior margin of the triangle to be resected from the proximal segment of the ilium should be inclined upwards at an angle of 30°, approximately coinciding with, and parallel to, the superior margin of the distal fragment. Then, pulling forward and rotating distally, the distal fragment is engaged by its posterior corner into the triangular slot created in the proximal segment of the ilium. An iliac bone graft is placed to fill the triangular gap of the anterior aspect of the osteotomy, and one or two Steinmann pins are introduced to stabilize the osteotomy. The patient is immobilized in a single spica cast with the affected hip at 30° of flexion, 30° of abduction, and neutral rotation for six weeks. Kalamchi observed five patients with a follow-up of 2 years. All patients were asymptomatic and had full range of motion. Synder et al.[562] reviewed 27 patients, 30 hips, operated on between 1979 and 1988, with 2 years of follow-up. They divided their patients into three groups according to the operative procedure. The first group had a Kalamchi osteotomy alone. The second group had an associated shelf operation when the surgeon thought osteotomy alone would not provide adequate coverage. The third group had an associated femoral varus osteotomy. Based on the Severin classification, 97 percent of the operated hips were excellent and 93 percent were excellent or good using McKay's criteria for clinical results. Bowen modified the Kalamchi procedure by cutting the triangular bone segment in the outer cortex only of the ilium. This modification prevents medial displacement of the osteotomy, which increases stability, and postoperative spica casting can be minimal or abandoned in cases with rigid pin fixation.



A B

Figure 8-2 Kalamchi procedure. **A, B.** Schematic drawing of the Kalamchi modification of Salter osteotomy, which resects a triangular segment from the most posterior aspect of the proximal fragment of the iliac bone (both the inner and outer cortex of the iliac bone).



A B

Figure 8-3 **A, B.** Radiographs of a modification by Bowen of the Kalamchi procedure in which the triangular segment is resected only from the outer cortex of iliac bone. This modification prevents medial migration of the osteotomy (personal communication, J. R. Bowen).

DOUBLE INNOMINATE OSTEOTOMIES

The desire to restore hip stability and congruity in older children and adolescents with hip dysplasia has stimulated many surgeons to design new techniques. Salter's innominate osteotomy permits a correction of about 10–15° abduction and 15–20° of acetabular flexion (hip extension). For when more correction is desired or the age of the patient does not allow motion in the symphysis pubis, complex pelvic osteotomies that allow more acetabular mobility have been developed. The double osteotomies may be used in the maldirected type of acetabular dysplasia to improve antero-lateral coverage. Currently, the authors do not use double innominate osteotomies because the triple and peri-acetabular osteotomies are effective.

Double Innominate Osteotomy of Hopf[262,263]

Hopf designed his operation to perform two osteotomies of the pelvis. The first osteotomy is similar to Salter's procedure and the second is performed at the inferior margin of the acetabulum through the thin isthmus between the acetabulum and the pubis and ischium at the obturator foramen. This procedure may be useful in adolescents in which stiffness of the pubic symphysis prevents acetabular rotation with the Salter osteotomy alone and the additional double osteotomy of Hopf allows the rotation.

Prerequisites

- Concentrical reduction of the hip joint
- Hip joint congruity
- Satisfactory cartilage space
- Functional range of motion

Indications

- Hip dysplasia in an adolescent that needs more than 25° of abduction to contain the femoral head into the acetabulum
- Bilateral subluxation or dislocation
- Hip joint pain
- Hip instability

Contraindications

- Incongruous hip joint
- Degenerative arthritis
- Stiffness of the hip joint

Advantages

- No upper age limit
- Permits greater versatility of correction
- Does not disturb the growth of the triradiate cartilage
- Does not jeopardize the blood supply to the femoral head

Disadvantages

- Difficult technique[66,587]
- Can compromise the blood supply to the hip joint[564]
- Can damage the articular cartilage[564]
- Does not enlarge the capacity of the acetabulum

Procedure

1. Place the patient in a supine-oblique position with a sandbag under chest of the affected hip. Prepare the lower limb and drape it to allow free movement during the surgical procedure.

2. Adopt the same approach as that of the Salter innominate osteotomy, which uses the "bikini incision," or perform an inguinal incision.
3. Elevate the medial aspect of the acetabulum to expose the isthmus between the acetabulum and the obturator foramen.
4. Perform the osteotomy through the thin isthmus between the acetabulum and the obturator foramen. Do not disturb its inner side.
5. Perform the Salter osteotomy.
6. Mobilize the acetabular segment, pulling downward and forward. The medial end of the acetabular segment is pulled upward and medially. This maneuver rotates the acetabulum anteriorly and laterally and displaces the hip joint medially, covering the femoral head.
7. Fix the Salter innominate osteotomy using two threaded Kirschner wires, directing them posteriorly and medially to the acetabulum and crossing the bone graft.
8. Fix the distal osteotomy using one or two threaded Kirschner wires directing them anteriorly and medially to the pubis fragment.
9. Close the wound using sutures.
10. Apply a hip spica cast.
11. Take an anterior posterior radiograph to verify adequate acetabular correction.

Postoperative care

Postoperatively, a spica cast is worn for 6 weeks in young children and 8 weeks in adolescents, and ambulation is not permitted. Typically, the patient returns after 2 weeks for cast care and radiographs to confirm the position of the osteotomy. After the osteotomies have healed, the cast and pins can be removed under general anesthesia. Three-point crutch ambulation and therapy are recommended until full motion and strength are restored.

Complications

- Infection
- Damage to the articular cartilage
- Loss of position of the osteotomy site

Double Innominate Osteotomy of Sutherland[556]

Sutherland's double osteotomy is useful in correcting maldirected acetabular dysplasia in adolescents and adults. It allows acetabular rotation in patients in whom the symphysis pubis is stiff and will not rotate easily. The first osteotomy is similar to Salter's osteotomy and the second osteotomy is just lateral to the symphysis pubis.

Prerequisites

- Hip joint congruity
- Concentric reduction of the hip joint

- Satisfactory cartilage space
- Functional range of motion

Indications

- Hip dysplasia that needs more than 25° of abduction to contain the femoral head in the acetabulum in adolescents and children over 6 years of age
- Bilateral dislocation or subluxation
- Hip instability
- Hip joint pain
- Malrotated type of acetabular dysplasia

Contraindications

- Stiffness of the hip joint
- Incongruous hip joint
- Degenerative arthritis

Advantages

- No upper age limit
- Promotes an adequate medial displacement of the hip
- Does not disturb the growth of the triradiate cartilage
- Does not jeopardize the blood supply to the femoral head
- Does not disrupt the articular cartilage

Disadvantages

- Difficult technique
- Unfamiliarity with the anatomy of the symphysis pubis region
- Risk of damage to the pudendal vessels and nerves
- Does not alter the capacity or contour the acetabulum

Procedure

1. Place the patient in a supine position. Place a Foley catheter into the bladder. (This catheter remains in place for approximately 2 days postoperatively.) Prepare and drape the skin, including the contralateral hip joint.
2. Perform a Salter osteotomy.
3. Perform a transverse suprapubic incision, centered over the symphysis pubis, about 6–10 cm in length.
4. Incise the subcutaneous tissue along the same line as the skin incision.

5. Laterally retract the spermatic cords in males or the round ligaments in females. Do not disturb these structures.
6. Identify the aponeurosis of the external abdominal muscle.
7. Identify the origin of the rectus abdominus and pyramidalis muscles and divide them on the upper border of the pubis. Mark the muscles with 2-0 suture for posterior reattachment.
8. Identify the tendons of the adductor longus and gracilis muscles at their origin. Elevate them away from the anterior aspect of the pubis.
9. Localize the symphysis pubis by inserting a Keith needle, and confirm with an antero-posterior radiograph of the pelvis.
10. Transversely section the periosteum of the symphysis pubis and elevate it anteriorly and posteriorly. By gentle subperiosteal dissection, insert Chandler retractors to protect the soft structures such as the internal pudendal artery, which passes around the medial margin of the inferior ramus of the pubis.
11. Mark the level of the osteotomy by introducing a Kirschner wire vertically just lateral to the symphysis pubis and medial to the obturator foramen. Control the site of the osteotomy by using fluoroscopy.
12. Utilize a small rongeur to remove a wedge of 0.7–1.3 cm from the pubic bone. Do not injure the structures that are attached to the inferior aspect of the pubis, such as the urogenic diaphragm, which is pierced in the midline by the deep dorsal nerve and vessels of the penis. Do not enter the obturator foramen.
13. With a towel clip, gently pull up the lateral pubic segment and free 2–3 cm of the attached periosteum from the lower side of the pubis.
14. Hold both sides of the acetabular segment, utilizing towel clips. Mobilize the lateral side of the acetabular segment pulling downward and forward. The medial end of the acetabular segment is pulled upwards and medially. This maneuver rotates the acetabulum anteriorly and laterally and displaces the hip joint medially.
15. Fix the pubic osteotomy with one or two threaded Steinmann pins, directing them transversely from the normal hip side to the affected side.
16. Fix the Salter innominate osteotomy using two threaded Kirschner wires, directing them posteriorly and medially to the acetabulum.
17. Close the Salter osteotomy.
18. On the side of the pubic osteotomy, reattach the rectus abdominus muscles and close the fascia and the subcutaneous tissue.
19. Close the incisions.
20. Apply a hip spica cast
21. Take an antero-posterior radiograph to verify correction.

Postoperative care

The cast is maintained for 6 weeks in young children and 8 weeks in adolescents. Typically the patient returns after 2 weeks for evaluation of cast. Cast and pin removal is performed under general anesthesia after the osteotomies have healed. Three-point crutch ambulating and therapy are recommended until full range of motion and strength is restored.

Complications

- Infection
- Damage to the pudendal vessels and nerves
- Doss of position of the osteotomy site

Sutherland et al.[556,564] performed this procedure in 25 patients between 1974 and 1976. In their report, 12 patients had congenital subluxation or dislocation of the hip, 6 were attributed to cerebral palsy, and the remaining were attributed to other diseases. Follow-up ranged from 7 to 41 months (average of 20 months). Stability of the hip joint was achieved in 23 cases. The center-edge angle was improved in all patients by an average of 22°, and the acetabular index decreased an average of 19.5°. They recommend the double innominate osteotomy for the treatment of subluxation of the hip in children older than 6 years of age.

TRIPLE INNOMINATE OSTEOTOMIES

In adolescents and adults, correction of a maldirected acetabulum may be difficult with a single osteotomy of the ilium because inflexibility of the symphysis may prevent rotation of the osteotomy. The difficulty in rotating the acetabulum inspired some surgeons to develop additional osteotomies of the ischium and pubis to increase mobility and promote efficacious rotation and tilting of the acetabular segment. The locations of the pubic and ischial osteostomies have been controversial; however, the closer the osteotomies are to the hip joint, the greater the ability to rotate the acetabulum and obtain better femoral head coverage.

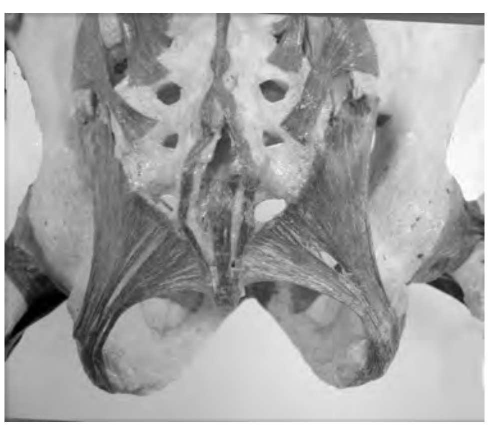
Posterior Pelvic Anatomy[205,424]

In older children, adolescents, and adults, the muscles and ligaments of the posterior aspect of the pelvis restrict mobility during acetabular procedures. Many procedures to allow more acetabular mobility have been developed; however, each procedure addresses the anatomy differently. Understanding the anatomy is paramount to selecting the best procedure for each patient. Deep in the gluteus maximus is the ischial bursa, which is superficial to the ischial tuberosity and covers the origin of the three hamstring muscles. The biceps femoris is the most superficial and lateral of the hamstring muscles. The semitendinosus is medial to the biceps femoris muscle, and the semimembranosus muscle is proximal and medial to the semitendinosus muscle.

The sciatic nerve, after exiting from the greater sciatic foramen, courses posteriorly to the ramus of the ischium and parallel and laterally to the semimembranosus muscle. Care must be taken to avoid confusing the anatomical structures; the semimembranosus muscle is tendinous at its origin and resembles the sciatic nerve. To preserve the stability of the spine, the sacro-spinous and sacro-tuberous ligaments resist the tendency of the sacrum to rotate under the full weight of the upper body. The sacro-spinous ligament converts the greater sciatic notch into the greater sciatic foramen. The sacro-spinous ligament is attached at its apex to the ischial spine, and its wide base raises from the lower aspect of the sacrum and coccyx. The sacro-tuberous ligament is flat, long, and triangular. It converts the lesser sciatic notch into the lesser sciatic foramen. Its fibers arise from the postero-

A

B



C

Figure 8-4 Photographs of the ligaments of the hip capsule and the posterior area of the pelvis. **A.** Anterior capsule of the hip. **B.** Posterior capsule of the hip. **C.** Posterior view of the sacro-ischial ligament. This ligament can limit rotation of the triple innominate osteotomy.

superior and postero-inferior iliac spines, from the posterior and lateral aspects of the sacrum, and from the side of the coccyx, converging downward to the ischial tuberosity.

The authors believe the triple innominate osteotomy is useful in adolescents with a maldirected acetabular dysplasia, in which the triradiate cartilage is open and its growth is necessary, and also works well in adults in whom rigid screw fixation prevents the need for spina casting. Adults tend not to tolerate spica casts well. Also, in women, the surgeon should consider distortion of the contour of the pelvis, which may impede vaginal delivery. In general, the triple innominate osteotomy gives good results and the complication rate is acceptable. The choice of the osteotomy depends upon the desired repositioning of the acetabulum. The "20-20" rule of thumb was used in the past as a guideline; that is 20° of flexion and 20° of abduction of the acetabulum can be achieved by a triple innominate osteotomy. The authors caution against the use of this rule of thumb and suggest the use of modern imaging techniques such as three-dimensional computed tomography to allow more specific planning. Excessive external rotation of the acetabulum can cause acetabular retroversion, which may predispose to early onset degenerative arthritis.[481,591] Excessive flexion and abduction of the acetabulum can cause impingement of the femoral neck against the lateral rim of the acetabulum, which may block motion (as in sitting) and damage the acetabular labrum. Aminian et al.[6] compared the motion of the acetabular fragment between the Ganz, Tönnis, and Carlioz osteotomies.

TABLE 8.1. Motion of the Acetabulum in Degrees

	Ganz	Carlioz	Tönnis	P value
Primary flexion	58 (3)	18(1)	41(2)	0.01
Primary abduction	18(2)	3(0.2)	7(0.4)	0.01
Primary external rotation	16(1)	10(1)	17(1)	0.03
External rotation during primary abduction	8(1)	4(1)	1(1)	0.001

Modified from Aminian A, Mahar A, Yassir W, Newton P, Wenger DR: Freedom of acetabular fragment rotation following three surgical techniques for correction of congenital deformities of the hip. J Pediatr Orthop 25(1): 10–13, pp 12, 13, Tables 1, 2, 2005.

In the authors' opinion, most of the modern triple innominate osteotomies and periacetabular osteotomies allow for excessive mobility of the acetabulum. The issue is placing the acetabulum in the proper position and not the limitation or inability to rotate the acetabulum. Excessive rotation of the acetabulum may result in impingement of the femoral neck against the rim of the acetabulum and thus failure of the outcome. Also, untreated deformity of the femoral head and neck may result in impingement even if the acetabulum is positioned in an anatomical position (see Femoro-acetabular Impingement in chapter 7). Preoperative planning of the entire hip mechanics in a three-dimensional manner is essential.

Preoperative Impingement Test with Arthrography

The authors perform a hip arthrogram and position the leg in variable degrees of abduction and flexion until the image on fluoroscope approximates the desired position of the hip that simulates the postoperative acetabular-femoral head relationship while standing. The degrees of abduction and flexion are recorded and the leg is then flexed an additional 90° to simulate the postoperative acetabular-femoral head relationship while sitting. The leg is then abducted and adducted to simulate functional motion. Images on fluoroscope are evaluated carefully to ensure no impingement at the acetabulum rim and femoral head-neck areas. The antero-lateral aspect of the rim of the acetabulum must be evaluated carefully for CAM impingement.

Triple Innominate Osteotomy of LeCoeur

LeCoeur[564,593] was one of the first surgeons to describe a triple osteotomy of the pelvis. He utilized a small incision on the medial side of the upper thigh to make two separate osteotomies through the superior and inferior rami of the pubis close to the symphysis. By a Smith-Petersen approach, the ilium is divided with a transverse osteotomy above the hip joint similar to Salter's innominate osteotomy. Then the "loosened" acetabulum is turned to the desired position to cover the femoral head with hyaline cartilage. Since the osteotomies of the ischium and pubis were far from the acetabulum, soft-tissue attachments of the sacro-spinous and the sacro-tuberous ligaments restricted acetabular repositioning.

Triple Innominate Osteotomy of Hopf

Hopf[262,263,567] developed a technique to perform the triple osteotomy in which all osteotomies are near the acetabulum. Using a Smith-Petersen approach, the tensor fascia lata, the sartorius, and the rectus femoris muscles are detached and the pubis is osteotomized just medial to the hip joint. Then the tendinous portion of the psoas is sectioned to facilitate access to the ilio-pubic eminence. The ischium is divided near the acetabulum by a difficult and deep approach, with a slightly oblique and infero-medial osteotomy. The osteotomy of the ilium is made using Salter's technique. Afterwards, the acetabulum can be positioned laterally and inferiorly over the femoral head. Many surgeons consider this technique difficult and risky.

Triple Innominate Osteotomy of Steel[547,548]

Steel developed an operative technique that was relatively easy to perform.[147,547,548] The ischium is divided at the tuberosity through a postero-inferior approach with the patient placed in a supine position. The ilium and pubis are divided through an anterior approach similar to Salter's approach. Since the ischial osteotomy is below the sacro-tuberous and sacro-spinous ligaments at the ischial tuberosity, rotation of the acetabulum is acceptable for mild dysplasia but limited by these ligaments for patients needing greater acetabular mobility.

Prerequisites

- Maldirected type of acetabular dysplasia
- Reasonable concentricity of the hip joint
- Good joint space with adequate cartilage surface
- Good range of motion of the hip joint
- Ischial epiphysis closed
- Children over 8 years of age and young adults

Indications

- Significant and symptomatic dysplasia of the hip joint
- Necessity of 25–30° of abduction to concentrically reduce the femoral head into the acetabulum (using an antero-posterior pelvis roentgenogram)
- To recover the stability of the hip joint at its anatomical level in cases where the hip is dislocated or subluxed
- Bilaterality in an older patient in whom the symphysis pubis is closed and stiff

Contraindications

- Other previous diseases of the hip joint that have destroyed the femoral head, the acetabulum, or both
- Degenerative arthritis
- Ankylosis of the hip joint
- Muscular imbalance (cerebral palsy, myelomeningocele, spina bifida, or Charcot-Marie-Tooth syndrome)
- When it is impossible to reduce the femoral head into the acetabulum by traction or femoral shortening
- When reduction is not attained with abduction of the thigh

Advantages

- Promotes complete covering of the femoral head by normal articular cartilage
- Provides stability of the hip joint for weightbearing

Disadvantages

- Difficult procedure
- Does not enlarge the hip joint capacity
- Causes some distortion of the pelvis, especially if it is performed bilaterally

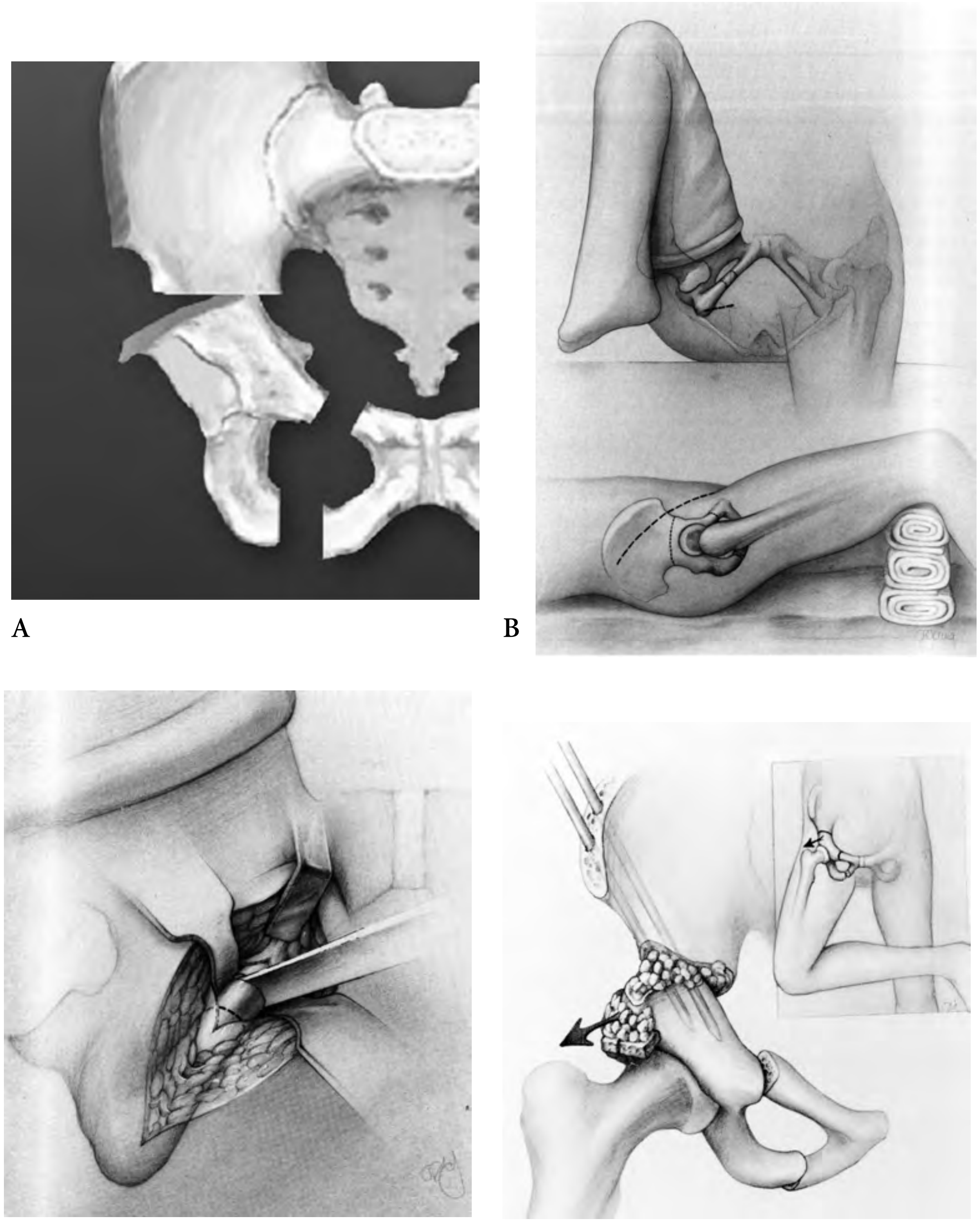


Figure 8-5 **A.** model and schematic drawings of the triple innominate osteotomy of Steel. The cut of ischium and pubis are performed through the obturator foramen, and the ilium osteotomy is similar to Salter's procedure (from G. D. MacEwen). **B, C, D.** Schematic drawings of a modification by Jaykumar (from Kumar SJ, MacEwen GD, Jaykumar AS: Triple osteotomy of the innominate bone for the treatment of congenital hip dysplasia, J Pediatr Orthop 6(4): 393–98, p 394, Figs 3, 4, 5, 1986).

Preoperative care

Skeletal traction is applied to bring the femoral head to the level of the acetabulum. If there is muscle contracture around the hip, surgical release may be necessary.

Procedure

1. Place the patient in a supine position on a radiolucent table. Prepare sterile and drape the affected lower limb, hemipelvis, and lower part of the chest.
2. The affected lower limb is held by an assistant with the patient's hip and knee flexed at 90°.
3. Palpate the ischial tuberosity.
4. Perform an 8–10-cm horizontal incision to approach the ischium, beginning 1 cm proximal to the gluteal crease and extending perpendicular to the axis of the femoral shaft.
5. Laterally retract the gluteus maximus muscle.
6. Expose the hamstrings at their origin on the ischial tuberosity.
7. Dissect the biceps femoris muscle (the most superficial and medial muscle).
8. Expose the gap between the semitendinosus and semimembranosus muscles and insert curved hemostatic forceps behind the ischium into the obturator foramen. The sciatic nerve is lateral to the semimembranosus and lies deep in the medial and inferior aspect of the gluteus maximus. Do not expose the sciatic nerve, although it is necessary to observe it to avoid damage during the surgery. The nerve and the semimembranosus muscle, which is tendinous near its origin, have a similar appearance; do not confuse them with each other.
9. Elevate the origins of the obturator internus and externus muscles, maintaining contact with the bone to avoid damaging the internal pudendal artery, vein, and nerve, whose course is parallel to the ischial ramus in the obturator fascia at Alcock's canal.
10. Perform the ischium osteotomy, utilizing an osteotome of the same width as the ischial ramus. Direct the osteotome laterally and posteriorly 45° from the perpendicular, completely dividing the bone.
11. Suture the gluteus maximus to the deep fascia.
12. Close the wound as usual.
13. Change gowns and gloves and use a different set of instruments the second time this procedure is carried out.
14. Work from an anterior iliofemoral approach.
15. Reflect the iliacus and gluteal muscles from the outer side of the ilium.
16. Detach the sartorius muscle from its origin at the anterior superior iliac spine and reflect it medially.
17. Subperiosteally reflect the muscles from the inner side of the ilium and the iliacus and the psoas muscles. Protect the femoral nerve, artery, and vein, which lie anteriorly to these muscles.

18. Divide the psoas tendon at its origin and expose the pectineal tubercle.
19. Expose the pubic ramus adequately, elevating subperiosteally the pectineal muscle, approximately 1 cm from the pectineal tubercle.
21. Introduce a pair of curved hemostatic forceps superiorly to the pubic ramus into the obturator foramen. A second pair of curved forceps should then be introduced inferiorly to the pubic ramus, to make contact with the upper pair. These forceps protect the obturator artery, vein, and nerve, which are situated medially.
22. Perform the osteotomy introducing the osteotome posteriorly and medially 15° from the perpendicular.
23. Proceed with the iliac osteotomy as in the Salter technique, using a Gigli saw from the greater sciatic notch to the midpoint between the anterior superior and anterior inferior iliac spines.
24. Cut the fascia and the periosteum of the inner side of the ilium to free the distal iliac portion further.
25. If the femoral head is dislocated or subluxed, open the capsule, remove the intrinsic factors (fibro-fatty tissue, ligamentum teres, and transverse ligament) that obstruct the reduction.
26. Reduce the femoral head, directing it to the acetabulum as close as possible to the center of the triradiate cartilage epiphysis.
27. Close the capsule.
28. Grip the anterior inferior iliac spine with a clip towel and mobilize the acetabular segment distally, anteriorly, and laterally to cover the femoral head.
29. Remove a triangular bone graft from the wing of the ilium, place it in the osteotomy, and cut and fix it with two Steinmann pins penetrating from the inner aspect of the proximal ilium to the distal segment, avoiding the hip joint.
30. Reattach the rectus femoris to the anterior inferior iliac spine, and also the sartorius muscle and the lateral end of the inguinal ligament to the anterior superior iliac spine. The pectineal and iliopsoas muscles should be allowed to fall back into place.
31. Close the wound in layers as usual.
32. Apply a spica cast with the affected hip at 20° of abduction, 5° of flexion, and neutral rotation.
33. Take an antero-posterior radiograph.

Comments

There are different surgical approaches to the ischium and pubis for a triple osteotomy. Steel describes the inferior access,[547,548] Tönnis[590] the posterior, and Tachdjian and Edelstein[567] the subinguinal-adductor accesses. Tachdjian and Edelstein detach the origins of the biceps femoris, the semitendinosus, and the semimembranosus muscles. They excise a 1.5-cm wedge of bone from the ischium to facilitate the correction by medializing the acetabulum and later reattaching the hamstring muscles. The approach to the pubis is lateral to the iliopsoas tendon and difficult, increasing the chances of entering into the hip joint along the osteotomy line. For this reason, they also perform the pubic osteotomy medial to the iliopsoas tendon. The iliac osteotomy is carried out according to Salter's description, but the line of osteotomy is curvilinearly inclined medially and inferiorly.

Some disadvantages to the Steel technique are reported. For example, the proximity to the rectum increases the possibility of contamination. Also, the dissection and the osteotomy of the ischium take place near the sciatic nerve. The ischium cut is in the weightbearing sitting position, far from the acetabulum, which restricts the degree of correction. It is very difficult to rotate the acetabulum without lateralizing the hip because this technique does not resect a wedge of bone from the ischium as recommended by Kumar et al.[329] These authors also make an additional acetabular shelf to increase the femoral head coverture.

Postoperative care

The patient returns after 2 weeks for a new antero-posterior radiograph and cast review, and in the tenth week, for cast and pin removal. Passive and active motion is stimulated to recuperate hip motion and muscle strength, especially the gluteus medius muscle. Partial weightbearing is permitted with crutches at 12 to 14 weeks postoperatively, and after full range of motion is recuperated (usually 6 months after surgery), full weightbearing is allowed.

Complications

- Paralytic ilius
- Infection
- Pressure necrosis of the skin over the anterior inferior iliac spine
- AVN (excessive pressure over the femoral head)
- Shortening of the lower extremity
- Myositis ossificans
- Nonunion of the ischium
- Obstetric problems (difficult vaginal delivery)
- Hip pain after vaginal delivery
- Failure to cover the femoral head adequately
- Postoperative hypertension

Results

Steel reports his results in the treatment of 45 patients, 23 congenital dislocations, and 22 paralytic dislocations, which he followed from 2 to 10 years after surgery in 1973,[547] Forty of the 52 procedures were classified as satisfactory and the other 12 as unsatisfactory. The unsatisfactory results involved patients with myelodysplasia, peroneal atrophy (Charcot-Marie-Tooth disease), and cerebral palsy, whose ages ranged from 7 to 17 years. New reports in 1977[548] showed 86 percent of satisfactory results in 175 hips, 121 congenital dislocations or subluxations, and 54 paralytic dislocations. The patients' ages at the time of surgery varied from 6 to 35 years, and the follow-up ranged from 3 to 13 years. Most of the unsatisfactory results consisted of peroneal muscular atrophy, cerebral palsy, and myelodysplasia, and 70 percent of failures occurred between the ages of 9 and 12 years. Ten unsatisfactory hips were congenitally dislocated; 8 had prior surgical procedures. Steel noted a common denominator in these cases, which was the use of prolonged and excessive traction to reduce the femoral head in the acetabulum. To avoid these complications, he encouraged the utilization of femoral shortening associated with triple osteotomy during the same operative procedure. Steel again reported his results (involving 220 patients) in 1982.[547,548] Ages at surgery ranged from 7 to 38 years and the follow-up ranged from 2 to 15 years. The satisfactory results presented were 86 percent and most of the unsatisfactory cases belonged to the paralytic group, and 70 percent of failures were between 9 and 12 years of age at the time of surgery. Tachdijian[567] showed 11 excellent results and 1 good result from this procedure, involving their modifications, on 12 hips. The mean follow-up was 3.6 years (minimum of 2 years and maximum of 5 years). In 1986, Kumar et al.[329] reported clinical improvement in pain and limping in all 12 hips corrected by Steel's operation modified by removing a segment of the ischial ramus and adding an acetabular shelf to provide complete coverture of the femoral head. The patients' ages at surgery ranged from 9 to 22 years, and follow-up was from 3 to 10 years. Later, in 1992, Guille et al.[215] reevaluated 10 of these patients (11 hips), 10 to 16 years after surgery, whose average age was 12 years. To analyze the evolution of these operated hips, they evaluated pain and function using the Iowa hip test. They did not observe any deterioration in clinical or roentgenographic findings at 5 or 10 years after surgery, except in the cases of patients with Charcot-Marie-Tooth disease. Hsin et al.[269] evaluated the biomechanical aspects of 21 hips in 17 patients treated by the Steel osteotomy technique from 1980 to 1991. The mean duration of the follow-up was 6.8 years, ranging from 2.2 to 13.8 years. A varus derotational osteotomy was associated when the femoral neck shaft angle was more than 155°. The obtained results were 19 excellent or good (86 percent), one fair, and two poor.

Kotzias Neto[323] evaluated the triple innominate osteotomy of Steel in 22 patients (26 hips). All patients reported pain in the hip, and 13 hips showed radiographic signs of degenerative arthritic changes prior to the procedure. The patients' age at surgery averaged 14.5 years (ranging from 9 to 31 years). Postoperative follow-up averaged 39 months. Results, which were classified according to the criteria of Severin and McKay, were 11 hips good (42 percent), 8 hips regular (31 percent), and 7 hips poor (27 percent).

Triple Osteotomy of Tönnis[587–590]

Tönnis[586–590] placed the osteotomy sites close to the acetabulum, similar to Hopf's triple osteotomy technique; however, the operative approach is considered safer. This surgery is performed in two stages: first, the ischium is divided through a posterior approach, then the patient is turned and redraped, and the pubic and iliac osteotomies are carried out by an anterior approach. The ischial osteotomy is above the sacro-spinous and sacrotuberous ligaments, which facilitates rotation of the acetabulum; however, the proximity of the sciatic nerve makes the ischial osteotomy difficult.

Prerequisites

- From 8 to 40 years of age.
- Congruency of the hip joint.

- Free abduction (at least 20°).
- Normal position of the femoral neck (torsional, varus, and valgus osteotomies can be performed 2 weeks before a triple osteotomy).
- Knowledge of the acetabular anteversion (normal range is 12–15°; if abnormal, must be corrected during surgery).
- Osteoarthritis and osteoporosis should not be advanced.
- Tönnis also reported the possibility of performing a femoral osteotomy during the same operation. He proceeds first with the osteotomy of the ischium, followed by the femoral, pubis, and iliac osteotomies. If the patient's condition does not permit a longer operation, the acetabular rotation is conducted 10 days after the femoral osteotomy.

Indications

- Malrotated acetabular dysplasia in patients with DDH
- Hip subluxations
- Hip subluxations or beginning dislocations in children with neuromotor (neuromuscular) diseases

Contraindications

- Severe degenerative arthritis of the hip joint
- Hip joint stiffness

Advantages

- Significant improvement of the hip biomechanics
- Does not increase joint pressure
- Allows lateral and anterior rotation of the dysplastic acetabulum to cover the femoral head[369]
- All the osteotomy sites are clearly visible to the surgeon, decreasing the risks of the procedure
- Good rotation of the acetabular segment due to the close proximity of the osteotomies to the hip joint

Disadvantages

- Difficult procedure
- The ischial osteotomy is in close proximity to the sciatic nerve

Procedure

The operation is performed using three osteotomies: ischial, pubic, and iliac.

- Ischial osteotomy:
  1. Place the patient in a prone position, over the scoliosis support, with the hips at 90° of flexion.
  2. Prepare sterile and drape the affected lower limb and buttocks.
  3. Palpate the ischium tuberosity.
  4. Perform an oblique incision in the same direction as the fibers of the gluteus maximus muscle.
  5. Separate, by blunt dissection, the muscle fibers of the gluteus maximus, to visualize the ischial tuberosity and the sacrotuberal ligament.
  6. Split the fascia.
  7. Dissect and transversely divide the obturator internus and the gemelli muscles. At this time, the ischial ramus is observable from the tuberosity to the sciatic notch.
  8. Retract the gluteal vessels and nerves proximally, and the sciatic nerve laterally and upward, by insertion of blunt retractors into the sciatic notch.
  9. Insert two blunt retractors into the obturator foramen. The medial retractor is inserted medially to the sacrotuberous ligament, and the lateral retractor holds the obturator internus and the gemelli muscles. To preserve the stability of the spine, maintain the sacrotuberous and sacrospinosum ligament intact.
  10. By image intensifier control, make a complete osteotomy, directing the osteotome from lateral to medial and slightly inclined upwards (to the center of the body), from the sciatic notch to the obturator foramen. The plane of the osteotomy must be frontal to permit rotation of the acetabular fragment.
  11. Close the fascia, the subcuticular tissue, and the wound as usual. Commonly, the obturator internus and gemelli muscles are not sutured.
  12. Turn the patient to a supine position, prepare sterile the affected lower limb, hemipelvis, and the lower part of the chest, and redrape.

- Pubic osteotomy:
  1. Make an incision of approximately 4 cm parallel to the inguinal ligament. In this region, the pubis is easily palpable below the skin. Care must be taken to avoid damaging the femoral vein.
  2. Release the pectineus muscle from the pubis and insert retractors subperiosteally to protect the obturator nerve and vessels.
  3. Locate the site of the osteotomy and confirm with the image intensifier. The cut is carried out with an osteotome or oscillating saw, directed at right angles to the pubis, parallel to the acetabulum, and on a slightly oblique plane, into the obturator foramen.
  4. Close the wound in layers.

- Iliac osteotomy:
  1. Perform a lateral inguinal incision.

2. Detach the anterior part of the gluteus medius muscle.
3. Release and distally reflect the sartorius muscle.
4. Dissect the abdominal muscles and the inguinal ligament on the inner side of the iliac crest to expose the sciatic notch.
5. Insert Hohmann retractors into the sciatic notch to expose both sides of the ilium.
6. Drill a Steinmann pin of 4–5 mm diameter into the ilium, guiding medially and downward, parallel to the desired osteotomy. This pin must be placed 1 cm above the acetabular roof and 1.5 cm below the level of the proposed osteotomy and should penetrate the inner side of the ilium to guarantee solid seating. It will serve as a handle to move the acetabular segment ventrally and laterally.
7. Insert a Kirschner wire vertically from front to back to mark the degree of anterior rotation of the acetabulum (anteversion).
8. Perform the osteotomy initially with an oscillating saw and complete with osteotomes. A Gigli saw is difficult to use for oblique osteotomies.
9. Laterally and downwardly (flexion) rotate the acetabular segment to position the sclerotic zone of the acetabular roof (lunate surface) horizontally over the femoral head (CE angle being 30–35°). This maneuver is made grasping the Steinmann pin to rotate the acetabulum while applying upward pressure on the pubis.
10. Push the fragment medially so as to maintain a good contact between the cut ends of the pubis.
11. Take a triangular bone graft from the iliac crest to stabilize the acetabular fragment.
12. Fix the fragment with four Kirschner wires of 2.5 mm in diameter drilled from the iliac crest and guided in diverging directions into the lateral, medial, anterior, and posterior aspects of the acetabulum. To avoid external rotation of the acetabulum during this procedure, the knee should be rotated medially 20°.
13. Insert a cancellous screw in the medial segment of the pubis. Loop a flexible wire around the screw and pass the flexible wire underneath the psoas muscle and soft tissues to one of the Kirschner wires at the acetabulum. Tightening this flexible wire guarantees very good stability so that the cast can be bivalved and exercises initiated earlier. If a part of the pubic osteotomy becomes displaced higher up, a second screw can be inserted medial to the teardrop.
14. Take an anteroposterior radiograph to analyze the position of the acetabulum (rotation and lateral tilt).
15. Close the wound.
16. Apply a spica cast with the operated lower limb in slight flexion and internal rotation.

Postoperative care

Tönnis[590] initially immobilized the patient for 6 weeks in a cast. Recently he advocated using an additional screw across the pubic osteotomy and allowing a bivalved cast. The cast is removed daily for flexion and internal rotation exercises. Walking with the aid of crutches is allowed after 4 to 6 days. Partial weightbearing is allowed at 10 to 12 weeks if radiographs confirm that the osteotomies have healed. Commonly, a complete consolidation is attained between 12 to 16 weeks depending on the age of the patient. The wires are removed from the iliac osteotomy after complete healing of the bones.

Results

Tönnis in 1982[564,590] reported a study of 124 joints evaluated at about 25 months after surgery. The percentage of patients who had pain decreased significantly postoperatively. Initially 18.3 percent of patients reported no pain in the preoperative period, compared with 60.6 percent postoperatively. Pain after more than 1 hour's walking decreased from 34 percent to 26.6 percent. Pain on walks of less than 1 hour diminished from 28.4 percent to 10 percent, and continuous pain reduced from 19.3 percent to 2.8 percent. To analyze the slope of the acetabulum, he divided the patients into two groups. In group I (66 cases), all joints were congruous with some acetabular deformity (elliptical or short roof), and in group II (58 cases) the hip joints were incongruous (subluxed). Measuring the inclination angles of Ullmann, Sharp, Stulberg, and Harris, 99.4 percent of the group I and 85.5 percent of group II patients were within normal limits. On the analysis of the CE angle of Wiberg, normal values were measured in 28.8 percent of the hips in group I and in 15.5 percent in group II. The probable reason was the extreme shortness of the acetabular roof in the vast majority of the cases. Later, Tönnis et al. in 1996[588] published the results of triple osteotomy performed on 197 patients (216 hip joints). In 78 children and 138 adults with a mean follow-up of 8.6 years (ranging from 5 to 16 years). He observed that 23 percent of adolescents and 33 percent of adults had well-centered joints.

Common errors

- The plane of the ischial osteotomy may be too close to the hip joint and does not enter into the obturator foramen.
- Undercutting the bony ridge at the attachment of the obturator membrane (digital palpation helps the surgeon to avoid these situations).
- The orientation of the iliac osteotomy should not be horizontal; this may cause leg lengthening and limited rotation of the acetabular segment and will reduce the contact of the fragments. If the inclination of the osteotomy is too great, the medialization of the acetabulum will not be possible. The difficulty of rotation also may be caused by a high lateral dislocation of the femur or elliptical deformity of the acetabulum.

Complications

- Lesion of the femoral vein (must be repaired)
- Embolism
- Paraesthesiae of the lateral femoral cutaneous nerve
- Fatigue fracture between the pubis and ischium (when a transverse osteotomy is made)

- Delayed union of the osteotomies (pubic fragments were not well opposed or occurred in patients who had severe osteoarthritis and osteoporosis preoperatively)
- Pseudoarthrosis when more extensive acetabular rotation is performed

De Kleuver et al.[118,119] carried out a Tönnis triple pelvic osteotomy on 12 cadaver hips, followed by an anterior, posterior, and intrapelvic dissection of the hip joint. At the ischium, the inferior gluteal neurovascular bundle proximally and the pudendal bundle medially are most at risk. The sciatic nerve is 1–3 cm lateral to the osteotomy site. At the pubis osteotomy, the femoral vein can be found close to the bone. The iliac osteotomy is performed proximal to the anterior inferior iliac spine and extends posteriorly to the sciatic notch. At that point, the superior gluteal neurovascular bundle and the sciatic nerve can be injured. Another study,[118,119] using radiostereometric analysis, was carried out on six osteotomized cadaver hips to evaluate the obtained reorientation. This study showed posterior translation of the centers of the femoral heads between 11 and 41 mm, and distal displacement up to 13 mm. Four femoral heads were displaced laterally up to eight mm and two were displaced medially up to five mm. Changes in measured orientation affected significantly the moment arms of the muscles, their length, the dimensions of the pelvis, and the loads across the hip joint.

Triple Juxtacotyloid Osteotomy by Carlioz[62]

Carlioz developed an osteotomy similar to Tönnis's; however the ischial osteotomy is slightly different. The Ischial osteotomy is just below the acetabulum but between the sacro-spinous and the sacro-tuberous ligaments.

Triple Innominate Osteotomy by Bowen[352]

Bowen developed a triple osteotomy that is simple to perform and allows good rotation of the acetabulum. The ischial osteotomy is similar to the Steel; however, 1 cm of bone is resected, allowing medialization of the distal end of the acetabular fragment. The iliac osteotomy is performed like the modification of the Kalamchi procedure; however, the triangular segment of bone (notch) is resected only from the *outer* cortex of the iliac bone. The proximal end of the acetabular segment is reduced into the resected triangular area. This allows shortening of the pelvis and stability to prevent migration. The position of the triangular notch determines the degree of anterior and rotational movement of the proximal part of the acetabular segment. The shortening releases the tension of the sacro-spinous and the sacro-tuberous ligaments. The triple osteotomy is easy to perform and offers excellent freedom for acetabular realignment. As with all osteotomies that allow marked freedom for acetabular realignment, overcorrection must be avoided.

Prerequisites/indications

- Maldirected type of acetabular dysplasia
- Possibly capacious type of acetabular dysplasia

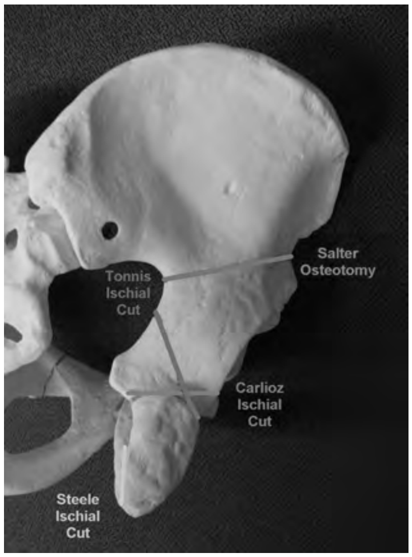


Figure 8-6 Schematic drawing on a model demonstrating the line of the ischial osteotomy for the triple innominate osteotomies of Steel (inferior to the sacro-tuberous and the sacro-spinous ligament), Tönnis (above the sacro-spinous and sacro-tuberous ligaments), and Carlioz (between the sacro-tuberous and sacro-spinous ligaments).

- Concentricity and reduction of the hip joint with 25–30° of abduction as demonstrated with an antero-posterior pelvis roentgenogram
- Good joint space with adequate cartilage surface
- Good range of motion of the hip joint.
- Ischial epiphysis closed

Contraindications

- Other previous diseases of the hip joint that have destroyed the femoral head, the acetabulum, or both
- Degenerative arthritis
- Ankylosis of the hip joint
- When hip reduction is not attainable with abduction of the thigh

Advantages

- Promotes covering of the femoral head by articular cartilage
- Provides stability of the hip joint for weightbearing

Disadvantages

- Difficult procedure

- Does not alter the hip joint capacity of a capacious type of acetabulum
- Causes distortion of the pelvis, especially if it is performed bilaterally, which may affect birthing

Procedure

1. The procedure is performed utilizing two incisions: an ischial incision and a bikini type of ilio- femoral incision.
2. The ischial incision is performed with the patient in a prone position on a radio-lucent table with the hips flexed 90°. The author uses a spine table to achieve the position.
3. The buttock area is scrubbed, prepared, and draped into a sterile field.
4. Palpate the ischial tuberosity to identify the skin landmarks for the incision.
5. Perform a 4–5-cm horizontal incision to approach the ischium tuberosity by beginning 1 cm proximal to the gluteal crease and extending perpendicular to the axis of the femoral shaft.
6. Expose the hamstrings and biceps femoris muscles at their origin on the ischial tuberosity. The biceps femoris muscle is the most superficial and lateral muscle.
7. Expose the gap between the semitendinosus and semimembranosus muscles and insert a curved hemostatic forceps behind the ischium into the obturator foramen. The sciatic nerve is lateral to the semimembranosus and lies deep in the medial and inferior aspect of the gluteus maximus. Do not expose or damage the sciatic nerve. The sciatic nerve and the semimembranosus muscle, which is tendinous near its origin, have a similar appearance: and must not be confused with each other.
8. Elevate the periosteum of the ischium just medial to the ischial tuberosity and place protective retractors medially and laterally around the ischium.
9. Perform the ischial osteotomy and remove about 1 cm of bone utilizing a rongeur.
10. Close the wound as usual.

The remainder of the procedure is performed by placing the patient in a supine position on a radio-lucent operative table. Change gowns and gloves and use a different set of instruments for the ilio-femoral approach. The affected lower limb, hemipelvis, and lower part of the chest are scrubbed and prepared into a sterile field.

11. Palpate the anterior part of the iliac crest and the anterior-superior iliac spine to identify skin landmarks. Begin the skin incision just inferior to the anterior- superior iliac spine and continue laterally to a point beyond the middle of the iliac crest. This is the "bikini incision," which provides a satisfactory cosmetic appearance.
12. Expose the anterior part of the iliac crest and subperiosteally reflect laterally the origins of the gluteus medius and minimus muscles from the outer cortex of the ilium to the greater sciatic notch.

13. Detach the sartorius muscle from its origin at the anterior superior iliac spine and reflect it medially.
14. Subperiosteally reflect the iliacus and psoas muscles from the inner cortex of the ilium to the greater sciatic notch. Protect the femoral nerve, artery, and vein, which lie anteriorly to these muscles.
15. Retract the psoas muscle and tendon medially and expose the pectineal eminence.
16. Expose the pubic ramus adequately, elevating subperiosteally the pectineous muscle, approximately 1 cm from the pectineal eminence.
17. Introduce a curved hemostatic forceps superiorly to the pubic ramus into the obturator foramen. A second curved forceps should then be introduced inferiorly to the pubic ramus to make contact with the upper forceps. These forceps protect the obturator artery, vein, and nerve, which are situated medially.
18. Perform the pubic osteotomy with an osteotome.
19. Proceed with the iliac osteotomy as in the Salter technique using a Gigli saw from the greater sciatic notch to the midpoint between the anterior superior and anterior inferior iliac spines.
20. A triangular wedge of bone with the base along the line of the osteotomy from the proximal part of the ilium is removed from the outer cortex. The resected triangle is from the outer cortex only. The triangular wedge is typically about 1 cm in height. The resection can be achieved by an osteotome and curette.
21. Grip the anterior inferior iliac spine with a bone clip and mobilize the acetabular segment distally, anteriorly, and laterally to cover the femoral head as determined in the preoperative plan. Then draw and rotate the distal-posterior part of the ilium into the slot created in the lateral cortex of the ilium (the resected triangle wedge of bone).
22. A bone graft can be removed from the wing of the ilium and can be placed in the iliac osteotomy; however, grafting has not often been necessary.
23. Fix the iliac osteotomy with two cannulated screws of about 7.3 mm penetrating from the inner aspect of the proximal ilium to the distal segment, avoiding the hip joint.
24. Reattach the rectus femoris to the anterior inferior iliac spine, and also the sartorius muscle and the lateral end of the inguinal ligament to the anterior superior iliac spine. The pectineal and iliopsoas muscles should be allowed to fall back into place.
25. Close the wound in layers.
26. If adequate fixation is obtained with the cannulated screws, a cast may not be necessary. Otherwise, apply a spica cast with the affected hip at 20° of abduction, 5° of flexion, and neutral rotation.
27. Take an antero-posterior radiograph to verify the position of the acetabulum.

Postoperative care

The patient returns after about 2 weeks for an antero-posterior radiograph and in about the tenth week to verify healing of the osteotomy. Crutch walking is advised until adequate healing is determined by radiographs. Passive and active motion are recommended to recuperate hip motion and muscle strength, especially the gluteus medius muscle.

Endoscopic Assisted Triple Innominate Osteotomy by Wall

The operative exposure for a triple innominate osteotomy or a peri-acetabular osteotomy is extensive. Wall et al.[633] suggest that endoscopic assisted triple innominate osteotomy offers the advantages of magnified visualization for the bone cuts, minimal operative dissection, and rapid postoperative recovery. There are currently no large series that demonstrates the risk-benefit factors.

There are also intra-articular factors that predispose a dysplastic hip to develop degenerative arthritis that are not addressed by innominate osteotomies. Byrd and Jones[56]

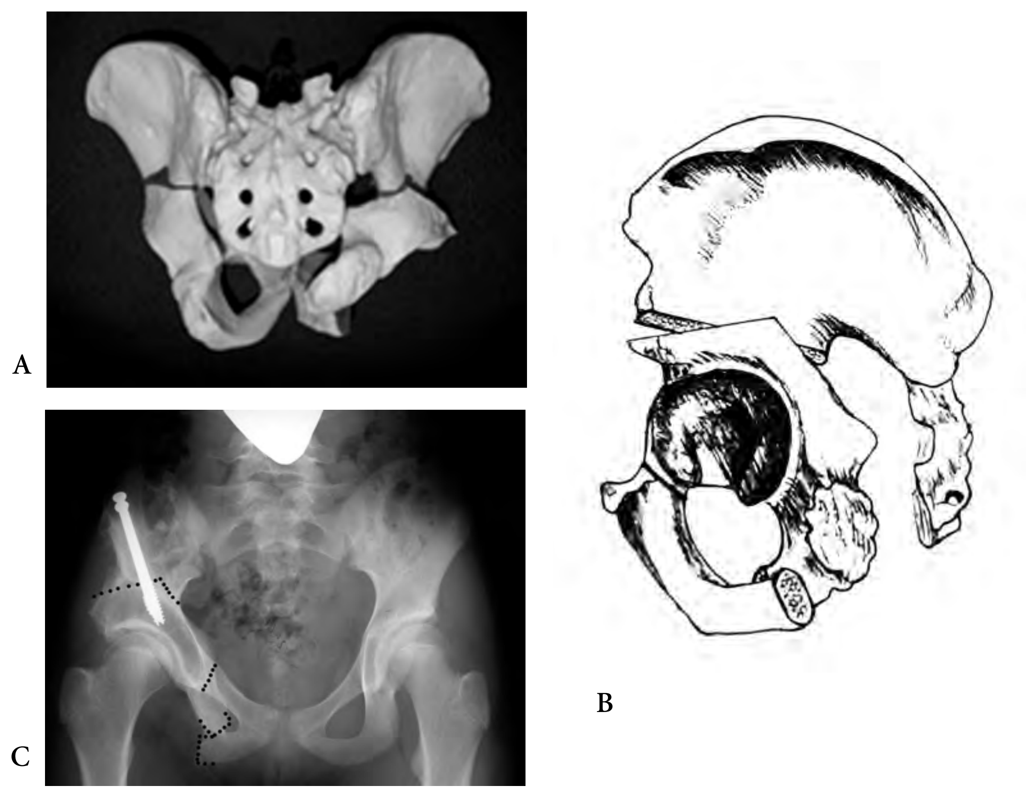


Figure 8-7 **A, B.** Model and schematic drawing of the triple innominate osteotomy described by Bowen. The ilium osteotomy is similar to Kalamchi's modification of Salter's procedure except the notch is made only in the outer cortex of the ilium. The ischial osteotomy is inferior to the sacrotuberous and sacro-spinous ligaments. The ischium is shortened through the osteotomy and the osteotomy is overlapped, which relaxes both ligaments and allows excellent rotation of the acetbulum. The pubic cut is as in the Steel osteotomy. **C.** Radiograph of the triple osteotomy of Bowen. Notice the overlapping of the ischial osteotomy and the displacement of the distal part of the iliac osteotomy into the notch in the lateral wall of the ilium.

performed 220 arthroscopic hip procedures and identified 9 patients with secondary arthritis caused by an inverted labrum. Their study attempts to define the radiological characteristics of the hips and report the results of arthroscopic treatment. In the hips with the inverted labrum, the labrum was resected and a chondroplasty performed.

Bernese Peri-acetabular Osteotomy of Ganz[178,383]

In young adults with DDH, deficiency of the acetabulum in surface area, orientation, and quality motivated Ganz and associates to develop an osteotomy to correct the malorientation of the acetabulum in relation to the femoral head. The goals of the osteotomy are to achieve a more normal configuration of the hip joint and improve the loadbearing capacity while arresting the degenerative process. The osteotomy redirects the acetabulum but does not change its shape or volume. The procedure is ideally performed before significant articular cartilage degeneration has occurred. The advantage of this osteotomy over triple innominate osteotomies is that the posterior column of the ischium remains intact, which gives stability to the pelvic ring. The shape of the inner pelvis is minimally altered, which is an advantage for women of childbearing age since the procedure offers no obstruction to normal childbirth.

Prerequisites

- The triradiate cartilage must be closed (adult).
- At least 120° of flexion, 30° of abduction, and 25° of external rotation are required
- Radiographs of the pelvis in the following positions must be obtained:
  - Antero-posterior in neutral and abduction positions to determine the most favorable relationship between the femoral head and the acetabulum.
  - Lequesne and deSeze (false profile) view to evaluate the anterior coverage of the femoral head.
  - CT scan at 2-mm magnified cuts of both hip joints to create a contour map of the hip joints. This map will demonstrate the extent of the coverage of the femoral head provided by the acetabulum. Do not confuse the nonarticular area of the acetabular fossa with a joint surface. Calculate the angles in sagittal, coronal, and axial planes for an adequate repositioning of the acetabulum. The calculated angles vary between cases, usually from 5–25°.[369]
  - Three-dimensional computed tomography allows analysis of the femoral head cartilage in relation to the cartilage of the acetabulum to determine the exact angular correction of the acetabulum and if necessary the proximal femur.
  - Image intensifier

Indications

- From skeletal maturity up to 50 years of age
- Treatment of residual hip dysplasia in adolescents and adults
- Correction of the malorientation of the articular surface of the acetabulum in relation to the femoral head

- Correction of congruency and containment
- For coxarthrosis in young adults who have supero-lateral degenerative radiographic changes

Contraindications

- Severe degenerative changes
- Severe dysplasia with torn/frayed labrum

Advantages

- Allows an extensive acetabular orientation
- Allows medial and lateral displacement of the acetabulum
- Does not disturb the blood supply to the acetabulum
- Utilizes a single anterior approach
- The posterior column of the affected hemipelvis remains mechanically intact, requiring minimal internal fixation and allowing early ambulation[383]
- Does not alter the shape of the true pelvis (internal pelvic shape)
- Provides better anatomical reconstruction
- Promotes greater correction with less distortion of the pelvic symmetry

Disadvantages

- Difficult technique
- Does not change the diameter of the acetabulum
- Occasional bone necrosis of the reorientated acetabulum[273,275,377]

Procedure

1. Place the patient is on the operating table in a supine position. Prepare sterile and drape the pelvis and the affected lower limb to allow free movement during the surgical procedure.
2. Approach the hip by using a Smith-Petersen approach.[379,530]
3. Incise laterally the tensor fascia lata to protect the lateral cutaneous nerve.
4. Detach, with the hip positioned in extension and in slight abduction, the tensor fascia lata subperiosteally from the ilium up to the tubercle of the gluteus medius muscle to expose the antero-superior aspect of the hip joint capsule. The greater sciatic notch, the posterior part of the capsule, and the transition to the bony posterior edge, although not visible, should be palpable.
5. Expose the antero-inferior parts of the capsule and the pubis with the hip placed in slight flexion and adduction.
6. Elevate the iliacus and sartorius muscles subperiosteally from the anterior superior iliac spine and from the ilium.

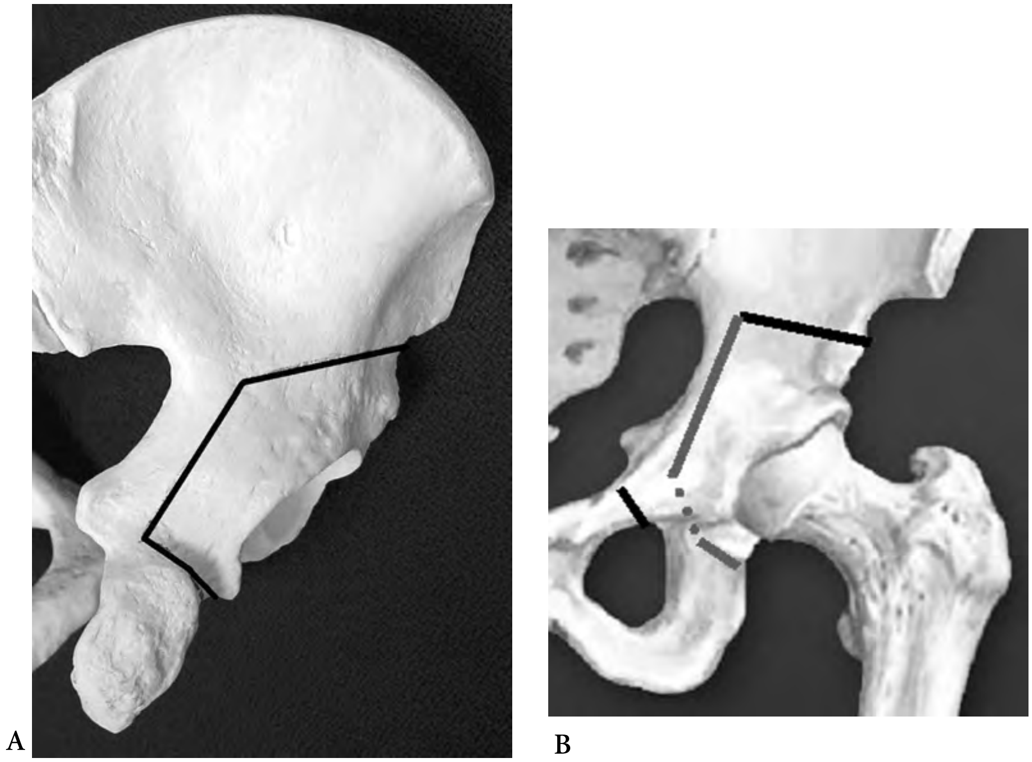


Figure 8-8 **A, B.** Schematic drawings of the Bernese periacetabular osteotomy of Ganz (from Dr. G. Dean MacEwen).

7. Divide the reflected tendon of the rectus femoris.
8. Detach the direct tendon of the rectus femoris from the anterior inferior iliac spine.
9. Expose the tendon of the psoas muscle and the os pubis by dissecting the fibers of the iliacus muscle from the anterior side of the capsule. The corpus of the pubis should be visible beyond the iliopectineal line.
10. Widen the gap between the psoas tendon and the distal joint capsule to reach down to the os ischium, at the infra-cotyloid groove, distal to the posterior and inferior edge of the acetabulum. The os ischium can be palpable but should not be visible. Ganz et al.,[178] in their studies dissecting cadavers, observed that the obturator vessels are not disturbed medially and that the medial circumflex artery is not jeopardized postero-laterally if the dissection adopts these anatomic criteria.
11. Place the hip in flexion.
12. Introduce a special chisel (with a 15-mm blade and 30° angle to the shaft of this osteotome) into the gap between the psoas tendon and the distal hip joint capsule, immediately adjacent to the posterior border of the acetabulum.
13. Insert the blade 5–10mm into the os ischium and by image intensifier verify whether the cut is in the right place.

14. Complete the osteotomy of the ischium.
15. Maintain the hip in a position of slight flexion and adduction.
16. Protect the iliopsoas tendon and the femoral neurovascular structures by inserting a retractor beside the os pubis.
17. Dissect subperiosteally the os pubis and insert two blunt retractors to protect the adjacent soft tissue and the obturator nerve, which lies immediately under the bone.
18. Perform the osteotomy of the pubis close to the acetabulum.
19. The supra-acetabular part of the osteotomy has two legs and is performed at the inner and outer aspects of the ilium.
20. Place the hip in extension and slight abduction for the outside cut and in slight flexion for the inside cut.
21. The anterior leg of the osteotomy is similar to that in Salter's technique. It is marked with an osteotome and ends approximately 1 cm from the brim of the pelvis, about 3 cm in front of the line of the sacroiliac joint. The osteotomy begins proximal to the anterior inferior iliac spine and is carried out with an oscillating saw.
22. The posterior leg of the osteotomy is also marked with an osteotome in both inner and outer walls of the ilium. It points towards the ischial spine and forms an angle of 110–120° with the anterior leg of the osteotomy. This cut is made with an osteotome, and the first 15 mm at least demands osteotomization. The remaining part of the ilium will break spontaneously toward the ischial spine. Care must be taken to avoid breaking into the joint or the sciatic notch. Check the osteotomy by image intensifier.
23. Insert a Schanz screw into the acetabular fragment; avoid entering the hip joint.
24. Lift up the firm connective tissue in order to visualize the quadrilateral surface up to the obturator foramen.
25. Perform the osteotomy with the angled chisel 4 cm below the pelvic margin and oriented 50° to the quadrilateral surface. This region is easily visualized and, based on cadaver studies in the normal pelvis, this distance and angular orientation is recommended. Usually, the length of the osteotomy needs two or three chisel widths. Care must be taken to maintain the pelvic ring intact.
26. Apply pressure to the Schanz screw to fracture the infracotyloid groove completing the previously begun osteotomy (posterior leg). The acetabular fragment becomes loose and can be repositioned.
27. Perform gentle traction on the lower limb to loosen the acetabulum. Mobilizing the hip in flexion and extension can be helpful.
28. Rotate internally the acetabular fragment around the center of the femoral head in order to put it in the desired position. Avoid lateralizing the acetabulum because dysplastic hips have an innate lateral displacement. Sometimes it is necessary to displace medially the femoral head and the acetabular fragment to achieve better coverage of the femoral head and improvement of the biomechanics of the hip joint.

29. Insert four Kirschner wires to fix the acetabulum temporarily. Two Kirschner wires are placed vertically, one in the iliac crest and the other on the anterior inferior iliac spine. The other two Kirschner wires are placed horizontally, parallel to one another on the inner side of the ilium and the anterior-inferior iliac spine, respectively.
30. Analyze the acetabular reorientation in all three planes and the flexion, abduction, and anteversion of the hip.
31. Insert two or three guide wires from the iliac wing to the acetabulum as widely separated as possible for later definitive fixation.
32. Take a radiograph to evaluate the new position of the acetabulum, which should be placed at the position previously calculated from the preoperative radiograms. Evaluate also the position of the guide wires. This radiograph permits evaluation of the horizontal position of the sclerotic acetabular roof, the supero-lateral coverage of the femoral head, the position of the fossa acetabuli relative to the weightbearing area, the amount of cranial displacement of the teardrop, and the shape of the Shenton line.
33. Fix the osteotomies with two or three cortical screws. The first screw is oriented in a medial and distal position, passing from the iliac crest to the proximal surface of the pubic ramus. This screw rarely needs to be shorter than 120 mm. Its mid-length stands some millimeters prominent from the inner aspect of the ilium and acetabular fragments, lying deep to the psoas muscle. This screw position does not interfere with the psoas muscle function. The second and, if necessary, the third screw are passed through the ilium anteriorly directly toward the iliac osteotomy into the acetabular fragment, forming an angle as wide as possible with the first screw. Usually, the screw lengths are between 80 and 90 mm.
34. Move the affected lower limb to check the stability of the osteosynthesis and joint penetration by the screws.
35. Place a suction drain in the true pelvic cavity, emerging over the anterior inferior iliac spine.
36. Reattach the rectus, sartorius, and tensor fasciae latae muscles to their original positions on the bone.
37. Close the subcutaneous tissue and skin as usual.
38. Take an antero-posterior radiogram to verify the osteotomy and the screw positions, oblique views to visualize the integrity of the posterior column, and a false profile view to analyze the coverage of the femoral head.

Reynolds[482] described another approach for the Bernese peri-acetabular osteotomy:

1. Perform an incision that starts medially, 2.0 cm proximal to the line of the inguinal ligament, extending laterally and parallel to this ligament up to the anterior superior iliac spine. Then continue the incision following the iliac crest to the junction of its middle and posterior thirds.

2. Make an incision into the iliac crest and carefully retract the abdominal muscles medially.
3. Incise the external oblique fascia in order to expose the ilio-inguinal nerve and round ligament.
4. Elevate the abdominal muscle and the combined iliacus/psoas mass from the inner side of the ilium subperiosteally.
5. Identify the attachment of the inguinal ligament to the anterior inferior iliac spine and the conjoined tendon of the internal oblique and transversus muscles (these structures form the posterior wall of the inguinal canal).
6. Incise the reflection of the inguinal canal from the anterior-inferior iliac spine to the inguinal ring. The psoas muscle is visible at the lateral one-third of the incision, upon which runs longitudinally the lateral cutaneous nerve of the thigh and the medial aspect of the femoral nerve. Medial to this, halfway along the conjoined tendon, the femoral vessels (artery and vein) pass superficially. The lateral cutaneous nerve is dissected and identified because it will be carefully mobilized proximally and distally, but sometimes it does not survive the rest of the surgery.
7. Elevate the psoas muscle by blunt dissection to the true pelvic edge, inserting the index finger on its medial aspect between the muscle and the fascial extension. This maneuver separates the psoas muscle from the femoral nerve and vessels. Repeat this finger dissection on the lateral aspect of the psoas muscle.
8. Introduce a retractor behind the psoas muscle. This will protect the muscle and the femoral nerve. At this time, it is possible to see the rim of the pelvic inlet, from the sacro-iliac joint at the back to the pubic ramus anteriorly.
9. Position blunt Hohmann retractors on both sides of the posterior column, at the sciatic notch and in the pelvic inlet, in the area that represents the deep surface of the acetabulum and is known as the *quadrilateral surface*. All of these retractors are carefully inserted subperiosteally, especially those that must be passed exactly vertically into the true pelvis.
10. Replace these Hohmann instruments with Chiari retractors, which are malleable and have sufficient substance to be used as elevators.
11. Follow steps 10 to 35 as described above.
12. Perform several drillings at the iliac crest along its inner aspect to reattach the transversus abdominus and internal oblique muscles, thus recreating the posterior wall of the inguinal canal.
13. Reattach the external oblique fascia to the superficial layer of the inguinal ligament. (Do not disturb the ilio-inguinal nerve.)
14. Reattach the external oblique muscle to the fascia over the abductor mass.
15. Follow steps 37 and 38 as described above.

Postoperative care

The patient is confined to bed for 48 hours with the hip placed in a soft splint in neutral position and using anti-embolic stockings. Indomethacin, to prevent ectopic bone formation, and low-molecular-weight heparin, to prevent thromboembolism, are given. After 48 hours the suction drains are removed. On the third day the anti-embolic stockings and heparin are discontinued and the patient gets up for the purpose of taking radiographs. Crutch walking with partial weightbearing is permitted. Active movements are discouraged for 6 weeks until complete cicatrization of the musculature. After 8 to 10 weeks, radiographs are taken to confirm satisfactory healing of the bones. Walking with the help of a cane is permitted until the abductor muscles become strong and Trendelenburg's sign disappears.

Complications

- Intra-articular osteotomy[178,275]
- Excessive lateral displacement
- Ischial fracture [116]
- Insufficient anterior coverage correction[522]
- Loss of correction[275,522]
- Anterior femoro-acetabular impingement[421]
- Bleeding[116]
- Hematoma[116]
- Damage to the femoral artery
- Proximal vein thrombosis (Reynolds[482] reported two cases that occurred during third and fourth postoperative weeks)
- Deep vein thrombosis and pulmonary embolus[116]
- Transient femoral nerve palsy
- Sciatic nerve palsy[116]
- Peroneal neuropraxia[116]
- Temporary loss of function of the lateral cutaneous nerve
- Reflex sympathetic dystrophy (treated with blocks)[116]
- Protrusion of the femoral head
- Symptomatic hardware[116]
- Resubluxation[178,275]
- Delayed union (ischium and ilium)
- Failure of hardware (nonunion ilium) [116,275]
- Nonunion (os pubis) [275]
- Persistent Trendelenburg's sign (performed by anterior approach) for several months
- Ectopic bone formation provoking limitation of flexion[178,275]

- Osteonecrosis[273,275]
- Chronic abdominal strain[116]

Results

Ganz et al.[178] reported their preliminary clinical experience on 75 peri-acetabular osteotomies performed between 1984 and 1987. Twelve patients had bilateral surgeries. Twenty-three hips had been operated on previously (ranging from one to four procedures). The mean age of the patients at the time of surgery was 29 years (range 12 to 56 years). Fifty-two procedures were performed for classical hip dysplasia and 18 cases had a significant secondary osteoarthritis. An analysis of the center-edge angle of Wiberg demonstrates that the procedure produces adequate coverage of the femoral head. The CE angle, which was between –28 and +25° before surgery, improved from 9–53° (average 31°). In the sagittal plane, the vertical center anterior edge of Lequesne and deSeze was between –21 and +18° preoperatively and improved to 15–35° (average 26°), demonstrating that this procedure produces an effective coverage of the femoral head. All clinically significant complications occurred in the first 18 cases: two intra-articular osteotomies, a protrusion of the femoral head due to an excessive adduction of the acetabular fragment, and one excessive lateral displacement, corrected by another surgery but complicated by a transient femoral nerve palsy. Two resubluxations, two overcorrections with no clinical symptoms, and two delays of union, of which one was in the ischium and the other in the pubis, were secondary to an overcorrection. Ectopic bone formation caused limitation of the flexion at 90° in four patients. In 13 patients, the implant was removed by local anesthesia due to shin pressure problems. They concluded that this osteotomy, carefully planned and executed, could be used to achieve more anatomic and satisfactory corrections of hip dysplasias.

Siebenrock et al.[522] reported the late results of 63 patients (75 hips) with a follow-up of 11.3 years (ranging from 10 to 13.8 years). Based on radiographic measurements of the acetabular index, the anterior and lateral center-edge angles, lateralization of the femoral head, and the integrity of the Shenton line in 71 hips (95 percent) of 75 hip joints (100 percent), they observed that the hip joint was preserved in 58 patients (82 percent) and 73 percent showed good-to-excellent results. Matta et al. [379] published the results of 58 patients (66 hips) treated by Berne peri-acetabular osteotomy between 1987 and 1998. The minimum follow-up was 2 years (average 4 years). They graded the results as 17 percent excellent, 59 percent good, 12 percent fair, and 12 percent poor, and recommended this operation for patients with hip pain and radiographic evidence of acetabular dysplasia. Mayo et al. [381] reported no significant differences in outcome between the two groups of patients who might or might not have had previous hip surgery undergoing peri-acetabular osteotomy. Hussell et al. [274,275] compared different surgical approaches for this osteotomy and recommended the modified Smith-Peterson approach, lateral to the lateral cutaneous nerve, to provide appropriate exposure with minimal risk and morbidity. Trumble et al. [604] detailed the results of 123 Berne osteotomies in 115 patients with a minimum follow-up of 2 years (average of 4.3 years). The preoperative diagnosis was DDH in 101 hips, Legg-Calvé-Perthes disease in 10 hips, Charcot-Marie-Tooth disease in 4 hips, epiphyseal dysplasia in 3 hips, congenital coxa vara in 2 hips, slipped capital femoral epiphysis in 1 hip, and postinfectious and posttraumatic dysplasia in 1 hip each. The mean age of the patients at the time of surgery was 32.9 years (range of 14 to 54 years). They observed the improvement of the Harris hip score from 65 points preoperatively to 89 points at latest follow-up, and the Merle d'Aubigne score increased from 13.6 points preoperatively to 16.3 points at latest follow-up. Eighty-three percent of the hips were classified as having good to excellent results, and based on the Tönnis criteria for radiographic severity of osteoarthrosis, 117 hips (95 percent) improved or were unchanged. In 6 hips (5 percent), the osteoarthrosis progressed. They concluded that peri-acetabular osteotomy "is a biologic solution to the mechanical problem" existing in dysplastic hips. Crockarell et al.[108] published the Mayo Clinic experience showing early results of the first 21 osteotomies in 19 patients. The average age at the time of surgery was 21 years (range 17 to 43 years) and the follow-up averaged 38 months (range 24 to 52 months). They observed improvement of the Mayo hip score from an average of 46 points (range 34 to 58 points) preoperatively to an average of 68 points (range 42 to 80 points) at the latest follow-up. The lateral center-edge angle of Wiberg improved from an average of 2° to an average of 24°. They concluded that the early results of this operation achieve good radiographic correction and improve hip joint function. Dagher et al.[112] reported a study of 57 patients submitted to 64 Ganz peri-acetabular osteotomy procedures. The Merle d'Aubigne score improved from 13 to 16.5 at follow-up, and they did not find any statistical relationship. They considered that the Bernese peri-acetabular osteotomy improves function and controls hip joint degeneration, providing good results, and moreover in young patients may prevent joint degeneration. Clohisy et al.[87] reported the results of 16 hips in 13 patients at an average age of 17 years of age with severe acetabular dysplasia (Severin classification group IV or V). The early clinical results were very good at an average of 4 years postoperatively. They also reported two major complications, which are excessive medial translation of the acetabulum and loss of fixation of the acetabulum.

Peri-acetabular Osteotomies of Eppright and Wagner

Eppright[143] and Wagner[625,627] suggested procedures in which the osteotomy was near the acetabulum to allow better rotation of the socket and coverage of the femoral head. These procedures need a congruous hip joint and a large hyaline cartilage surface in order to cover the femoral head.

The authors caution against these procedures. The osteotomy is performed within millimeters of the articular surface of the acetabulum, and avascular necrosis of the bone of the roof of the acetabulum may result in collapse with early degenerative arthritis.

The Eppright[143] technique, described as a "dial" osteotomy, utilizes an anterior approach and achieves a spherical osteotomy by an irregular antero-posterior and curved cut parallel to the articular surface of the acetabulum. The osteotomy is cut with an arced oscillating saw, creating an almost barrel-shaped osteotomy. The redirection of the acetabulum is restricted to the degree of freedom of this arced osteotomy. The osteotomy is guided by image intensifier radiographic control, and by utilizing spreaders, the acetabulum is loosened and rotated down and laterally over the femoral head. Two Steinmann pins fix the osteotomy. The medial part of the osteotomy is similar to Hopf's osteotomy, which passes through the junction of the pubis and ischium. The patient is immobilized in a single spica cast for 3 or 4 weeks. When the osteotomy is healed as demonstrated on radiographs, the cast and pins may be removed.

Blavier[41] described a peri-acetabular osteotomy that was spherical and allowed multiple degrees of rotation. Therefore, the acetabulum could be rotated through the arc of the sphere to achieve femoral head coverage. Wagner[624–629] developed a special spoon-shaped osteotome in order to divide the pelvis around, above, and below the acetabulum to achieve a spherical shape to the osteotomy. The anterior and posterior cuts are controlled by palpation, and the cut through the ischium, below the acetabulum, is observable only by image-intensifier radiographic control. The ideal thickness of the cut is 10–15 mm to avoid damage or trophic disturbances of the acetabulum. When the acetabulum is too shallow, even special osteotomes do not fit well, increasing the risk of entering into the acetabular cavity along the osteotomy line, injuring the hyaline cartilage, and increasing the possibility of provoking chondrolysis. Care should also be taken so that the blade does not enter into the obturator foramen, jeopardizing the obturator artery. Wagner designed three types of osteotomies to be performed after the closure of the triradiate cartilage. In Wagner type I, the acetabular fragment is rotated laterally over the femoral head to increase its coverage. One or two semitubular plates are cut through to create prongs that will hold the acetabular fragment. The other end of these plates is fixed with cortical screws inserted into the lateral aspect of the ilium. A bone graft is placed over the projecting roof, and a cast is not necessary. Wagner type II was designed for leg-length inequalities. The distal fragment is pulled laterally and downwards with spreads, and a bone graft is placed between the osteotomy surfaces, producing a slight limb lengthening. The bone graft and the acetabulum are fixed with two semitubular plates, and cortical screws are introduced into the lateral surface of the pelvis, The Wagner type III operation combines

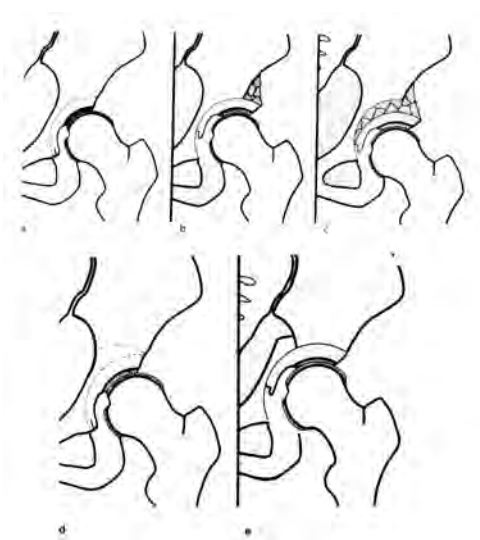


Figure 8-9 Schematic drawing of the Eppright procedure, which is a dial peri-acetabular osteotomy. Two Steinmann pins are used to hold the rotated acetabular fragment. Schematic drawing of a modification by Millis (from Millis MB, Kaelin A, Curtis B, Schluntz K, Hey L: Spherical acetabular osteotomy for the treatment of acetabular dysplasia in adolescents and young adults, J Pediatr Orthop 3B:47–53, p 49, Fig 2, 1994).

the cut around the acetabulum with Chiari's osteotomy. The distal fragment is shifted medially and the piece of acetabulum is placed laterally and downwards over the femoral head. The bone graft is packed into the site of the osteotomy and Kirschner wires are bent into staples to fix the fragments. The lower legs of the Kirschner wire staples fix the rotated peri-acetabular fragment and the upper legs are inserted into the lateral face of the ilium. A semitubular plate is bent around the Kirschner wires to fix them and is held by a cortical screw. This system of fixation stabilizes the osteotomy without the necessity of using a cast.

There are no published articles on large series of patients showing the outcome of either the Eppright or Wagner procedure. Millis et al. reported 43 hips treated with a spherical acetabular osteotomy. Their complication rate was low; however, they cautioned surgeons about necrosis of the acetabulum. In three hips the osteotomy entered the hip joint. One hip had an intra-articular fracture and one hip became septic.

We are concerned that the osteotomies may reduce the blood supply to the bone support of the acetabulum, causing avascular necrosis. Until articles are published reporting outcomes, the authors recommend caution in using the Eppright and Wagner procedures.

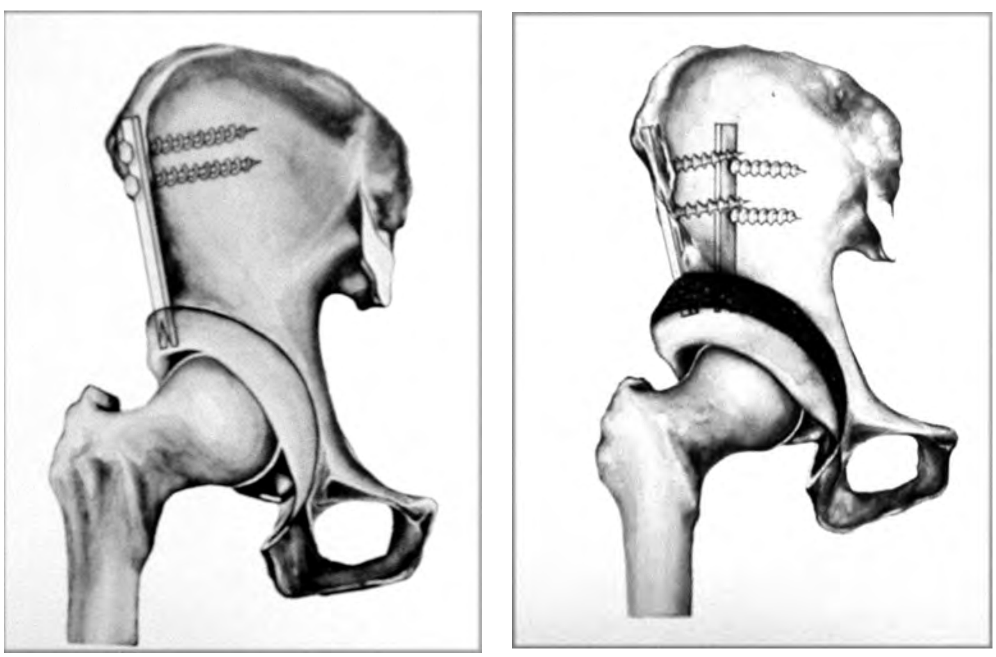


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Figure 8-10 **A.** Schematic drawing of a Wagner I periacetabular osteotomy. One or two semitubular plates are cut at the inferior-most hole to hold the rotated acetabulum (from Tachdjian MO, ed: Congenital Dislocation of the Hip, p 505, Fig 27.8, New York, Churchill Livingstone, 1982). **B.** Schematic drawing of a Wagner II periacetabular osteotomy. A bone graft is inserted at the osteotomy space to lengthen the affected limb. Two semitubular plates and cortical screws are used to fix the osteotomy. (from Tachdjian MO, ed: Congenital Dislocation of the Hip, p 505, Fig 27.9, New York, Churchill Livingstone, 1982). **C.** Schematic drawing of a Wagner III combined periacetabular osteotomy with Chiari procedure (from Tachdjian MO, ed: Congenital Dislocation of the Hip, p 505, Fig 27.10, New York, Churchill Livingstone, 1982).

Chapter Nine

Osteotomies for the Treatment of a Capacious Acetabulum

Acetabuloplasties are a type of peri-acetabular osteotomies. They are incomplete osteotomies above the acetabular roof in the ilium that correct a capacious acetabulum by bending the acetabular roof to the contour of the concentrically reduced femoral head. The two most popular incomplete peri-acetabular osteotomies are those described by Pemberton[450,451] and by Dega.[120–124] These procedures differ in the approach of the osteotomy and the contouring of the acetabular roof. Multiple variations of these osteotomies have been developed to correct asymmetries of a capacious acetabulum. For example, in DDH the anterior aspect of the acetabulum is usually deficient, whereas in patients with neurologic hip dysplasia the posterior or superior aspect is frequently deficient.

In the *Pemberton osteotomy,* both the inner and outer cortices of the ilium are exposed subperiosteally and a curved chisel is directed from the anterior inferior iliac spine just above the acetabulum toward but not into the triradiate cartilage. The chisel cuts both the inner and outer cortices of the ilium.[450,451] The anterior aspect of the osteotomy is open widely to change the contour of the acetabulum and the osteotomy is held open anteriorly by a bone graft (bone graft inserted from anterior toward the triradiate cartilage). A concern is that the osteotomy crosses the triradiate cartilage, which may result in a premature closure.

In the *Dega osteotomy,* the outer cortex of the ilium just above the acetabulum is exposed subperiosteally. The osteotomy is performed by directing a chisel from just above the capsular attachment of the acetabulum through the outer cortex of the ilium, toward but not completely through the inner cortex of the ilium. The inner cortex of the ilium in not completely cut (only the anterior part is cut). The lateral aspect (outer cortex of the ilium) of the osteotomy is opened widely to change the contour of the acetabulum and the osteotomy is held open by a bone graft that is inserted from laterally to medially.[120–124]

João Tavares[570] described a modified Pemberton procedure in which the osteotomy does not extend across the triradiate cartilage as in the Pemberton procedure but instead an incomplete osteotomy is directed toward the sciatic notch. As the roof of the acetabulum is bent to correct the capacious deformity, a greenstick fracture into the notch allows the correction. The modified Pemberton procedure was performed in 17 hips and the mean follow-up was 5 years. Sixteen hips had correction of the dysplasia. One hip sustained a premature closure of the triradiate cartilage and a Chiari osteotomy was required at age 12 years.

Figure 9-1 Capacious acetabulum. **A.** Photograph of a CT showing a capacious acetabulum. **B.** Model of the Pemberton osteotomy. **C.** Radiograph of the Pemberton osteotomy.

Leet et al.[344] performed peri-acetabular osteotomies that extended into the triradiate cartilage of the acetabulum in piglets and created bone bars across the physis. These physeal bars are capable of blocking growth and resulting in a partial premature closure of the triradiate physis. The triradiate cartilage offers height and width to the acetabulum and premature closure results in a shallow acetabulum (acetabular dysplasia). They recommend against cutting into or placing bone graft across the triradiate cartilage when performing either the Pemberton or Dega acetabuloplasty.

OSTEOTOMY OF PEMBERTON[451]

This incomplete iliac osteotomy was designed by Pemberton in 1965 for the treatment of the dysplastic acetabulum. This osteotomy is performed by hinging the upper portion of the acetabulum laterally and inferiorly through the triradiate cartilage to increase the antero-lateral coverage of the femoral head without compromising the posterior aspect of the acetabulum. It is also called a *pericapsular osteotomy*.[61,93,94,450,451,610] The authors recommend the Pemberton osteotomy in treating the capacious type of acetabular dysplasia in infants and young children.

Prerequisites

- Open and flexible triradiate cartilage
- Mobility of the affected hip must be normal or near normal, especially internal rotation and abduction
- Concentrical reduction of the femoral head into the acetabulum (observed on an antero-posterior radiograph with the hip held in mild flexion and internal rotation, i.e., reduction of the hip)

Indications

- To correct the capacious type of residual acetabular dysplasia
- Deficiency of the anterior and supero-lateral walls of the acetabulum
- When more than 10–15° correction of the acetabular index is required
- Instability of the hip at the time of open reduction of a DDH due to a shallow acetabulum
- Acetabular dysplasia after successfully closed or open reduction
- Acetabular dysplasia after closed or open reduction with progressive subluxation of the femoral head
- From infants up to 10 years of age (when the triradiate cartilage becomes inflexible)
- Small femoral head and large acetabulum

Contraindications

- Patients having a skeletal age over about 11 years

- Range of motion significantly limited
- Remaining tightness of the adductors and iliopsoas muscles, even after release
- Incapacity to carry the femoral head to the acetabulum (do not force the femoral head into reduction, there is a risk of AVN or chondrolysis)
- Incapacity to reduce the femoral head into the true acetabulum
- Early degenerative arthritis of the hip joint in the older patient

Advantages

- Great versatility and wide application
- Achieves more than 15° of correction
- Incomplete osteotomy, leaving the posterior and inferior segments of the acetabulum intact
- Changes the shape of the acetabulum
- Wraps the iliac anteriorly and laterally around the femoral head
- Does not require internal fixation
- Low possibility of damaging neurovascular structures
- No preliminary traction is necessary

Disadvantages

- Difficult technique
- Deforms the acetabulum
- Alters the volume of the acetabulum (increases the volume)
- The rotated acetabular fragment exerts excessive pressure on the femoral head

Procedure

1. Place the patient on the operating table in a semiprone position (partly on the side with a sandbag behind the chest).
2. The lower limb must be prepared to allow free movement during the surgical procedure.
3. Drape the hip to the midline anteriorly and posteriorly and behind the costal margin.
4. Separately drape the lower limb, which may be left free during surgery.
5. Perform an antero-lateral oblique skin incision parallel to the inguinal ligament (bikini incision) on the affected hip. Begin the skin incision just below the inguinal ligament at its midpoint and continue laterally inferior to the anterior superior iliac spine to a point beyond the middle of the iliac crest.
6. Deepen the incision to expose the iliac crest.
7. With a scalpel, cut the abductor muscles and the tensor fascia lata near the cartilaginous apophysis of the ilium.

8. Utilize a Cobb elevator or an osteotomy to reflect the cartilaginous apophysis of the ilium to the inner side. (The authors prefer an osteotomy of the ilium just below the cartilaginous apophysis to prevent injury of the growth of the iliac wing.)
9. Reflect subperiosteally the abductor muscles and the tensor fascia lata from the outer aspect of the ilium to expose the bone down to the hip capsule and posteriorly until the sciatic notch.
10. Incise the fascia over the sartorius and tensor fascia lata.
11. Retract medially the lateral femoral cutaneous nerve.
12. Subperiosteally elevate the muscles from the inner aspect of the ilium to expose the medial wall up to the sciatic notch.
13. Place Chandler retractors medially and laterally in the greater sciatic notch to protect the sciatic nerve and gluteal vessels and nerves.
14. Perform the osteotomy through both the inner and outer cortexes of the ilium separately. Utilizing a narrow and curved osteotome, make the cut initially through the lateral side of the ilium. Begin the osteotomy just above the anterior inferior iliac spine and continuing backward, parallel to the attachment of the joint capsule, or the reflected head of the rectus femoris muscle, about a quarter of an inch above (1 cm). Perform the osteotomy by direct visualization until the level of the sciatic notch. Then the tip of the osteotome will be buried in bone and reach for the ilio-ischial limb of the triradiate cartilage at the midportion, about halfway to the center of the posterior edge of the acetabulum and the anterior margin of the sciatic notch. Complete the cut using fluoroscope visualization.
15. Perform the osteotomy of the inner aspect of the ilium parallel to the outer cut, at a lower level and with a lesser degree of curvature. This is the most difficult step of the entire procedure. The surgeon must be careful to avoid extending the osteotomy to the sciatic notch, to the acetabulum, or through to the triradiate cartilage.
16. Complete the osteotomy, dividing the cancellous bone between the two osteotomized walls by inserting a curved osteotome. Carry this procedure out manually without a mallet. Then release the portion of the ilium distal to the osteotomy. If the defect is mainly anterior and the acetabular roof needs to be displaced directly downward to cover the femoral head on its anterior portion, the osteotomies of both walls may be performed at exactly the same level. If it is necessary to cover the femoral head more laterally, the osteotomy of the inner aspect of the ilium must be performed forward, toward the iliopubic junction, allowing the acetabular roof to tilt laterally. The flexibility of the triradiate cartilage permits rotation of the acetabular roof outwards and laterally to cover the femoral head if considerable anteversion is present.
17. By downward pressure, lower the antero-lateral edge of the acetabulum to close the anatomical defect and to retract the femoral head into the acetabulum.
18. Remove a triangular piece of full-thickness ilium from the iliac crest
19. Press firmly the graft at the space created by the osteotomy to maintain the fragments in the correct position. Internal fixation is not necessary.
20. Reattach the apophysis and the muscles using sutures.

21. Stitch the deep fascia, avoiding injury to the lateral femoral cutaneous nerve.
22. Suture the subcutaneous tissue and close the wound subcuticularly.
23. Apply a spica cast.
24. Take an antero-posterior radiograph to evaluate the coverage of the femoral head and the positioning of the bone graft.

The Pemberton osteotomy may be performed during an open reduction for DDH to improve stability or the hip and to treat acetabular dysplasia. The authors prefer the Pemberton osteotomy in children under 18 months of age with a capacious acetabulum and a high acetabular index. Prior to performing the Pemberton osteotomy, the femoral head must be concentrically reduced.

Postoperative Care

The cast is removed after 6 weeks and radiographs are taken. If the radiographs show satisfactory union, weightbearing with crutches is permitted for an additional 2 or 3 weeks. Afterwards, the crutches can be dispensed with and no further protection is necessary.

Complications

- Stiffness immediately after surgery[385]
- Chondrolysis[94]
- Growth disturbance or arrest when the cut extends into the triradiate cartilage)
- Avascular necrosis of the femoral head[385]
- Redislocation[450]
- Coxa plana[450]

Results

Pemberton[450,451] published the results of 8 years of follow-up of osteotomies performed on 64 hips in 46 patients younger than 4 years of age. All showed good results. He operated on 25 hips in 24 patients of between 4 and 7 years of age and rated 21 as having good and 4 as having fair results. From 7 to 12 years of age, 21 patients (26 hips) were treated, and their results were rated as good in 12, fair in 6, and poor in 3. He concluded that this method can correct the defect in the anterior portion of the acetabulum and can obtain a spherical head, which fits snugly into a well-formed acetabulum. Vedantan et al. [610] made a retrospective analysis of the results of this osteotomy for the treatment of dysplasia in 16 hips of 14 patients older than 7 years of age. They concluded that the procedure is effective and safe, demonstrating improvement in the acetabular index, the center-edge angle, and the Severin classification. Slomczykowski et al.[526] used physical examination and two-dimensional and three-dimensional CT scanning of the acetabulae in 18 pigs, 4 sheep, and 15 human models to determine the acetabular volume. A comparison between the acetabulae before and after Pemberton osteotomies in three patients with dysplasia and two patients with dislocated hips was also made. They concluded that there were no statistical differences between the results obtained utilizing the three methods and that the Pemberton osteotomy increases the volume of the acetabulum. Faciszewski et al.[148] reported the results of treatment with the Pemberton osteotomy of 52 residual hip dysplasias in 42 patients whose average age at the time of surgery was 4 years. They found that the Severin classification could be extended to younger patients because "they had the same distribution of marginal values" as Severin gave for patients who were 6 to 13 years old. Preoperatively, 6 hips were rated as Severin class IIB, 22 as class III, 9 as class IV, and 15 as class IVB. The average duration of follow-up after the Pemberton osteotomy was 10 years, and they rated 42 hips as class IA, 2 as class IB, 5 as class IIA, two as class IIB, and one as class III. They concluded that the Pemberton osteotomy is a safe and effective procedure for the treatment of residual dysplasia. Kessier et al.[306] performed 26 Pemberton osteotomies using patellar allograft wedges. They reported that this provides good correction of the acetabular dysplasia and that graft stability often eliminates the need of spica casting postoperatively, even for patients undergoing bilateral procedures. Nishiyama et al.[426] performed 56 Pemberton procedures in 49 patients and reported complications in 2 patients. In one case, the reduction of the acetabular dysplasia was considered excessive and the femoral head dislocated inferiorly. In the other case, too much pressure was considered to be placed on the femoral head and AVN developed. McKay[385] reported four cases with necrosis of the femoral head after the Pemberton procedure.

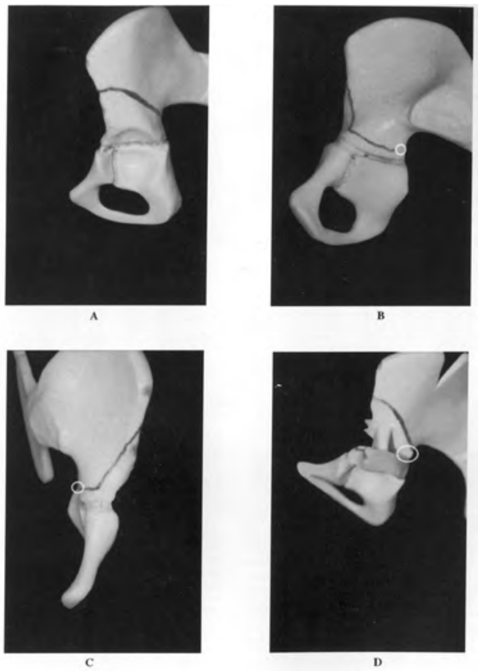
Dega Acetabuloplasty[120–124]

Wiktor Dega designed his operative technique to correct, in a one-stage procedure, "all abnormalities of the dysplastic acetabulum."[120–124] The procedure involves an opening osteotomy of the dome of the acetabulum, in which the lateral surface of the acetabulum is bent downward to correct the acetabulum (dysplasia). This procedure differs from the Pemberton osteotomy, which hinges the osteotomy at the triradiate cartilage. The Dega procedure bends the bone to contour an acetabulum. The graft of the Dega procedure is placed from lateral to medial, whereas the graft in the Pemberton osteotomy is placed from anterior to posterior. The Pemberton osteotomy offers anterior acetabular coverage of the femoral head; however, the Dega procedure can cover additionally the superolateral part of the femoral head by adjusting the placement of the graft. (The Dega procedure has been modified in neuromuscular hip dysplasia to allow posterior acetabular coverage of the femoral head by placing the osteotomy and the graft more posteriorly.)

The authors' goal in performing this operation is to reconstruct a capacious acetabulum to the contour of a concentrically reduced femoral head and to achieve a center-edge angle of at least 20° and an acetabulum index of 20–25° on the postoperative radiograph.

Indications

- In patients between 3 and 5 years of age
- Dislocated hip: congenital or paralytic
- Capacious type of acetabular dysplasia



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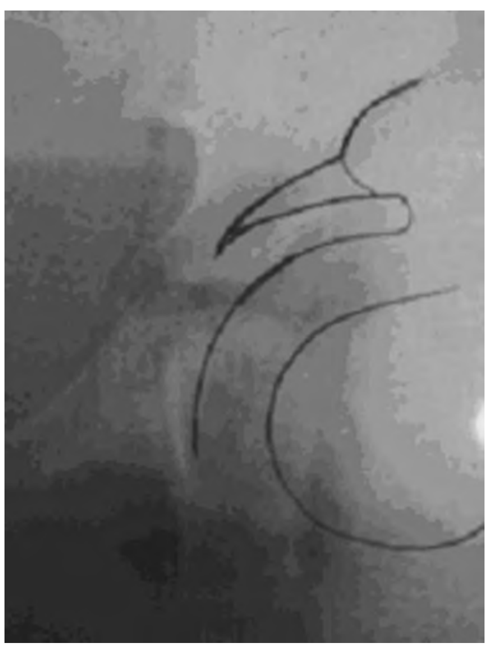

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Figure 9-2 Dega procedure for reconstruction of a capacious acetabulum. **A.** Schematic drawing of the Dega osteotomy (from Jozwiak M, Marciniak W, Piontek T, Pietrzak SJ: Dega's transiliac osteotomy in the treatment of spastic hip subluxation and dislocation in cerebral palsy, Pediatr Orthop B: 9(4):257–64, p 259, 2000). **B.** Model of the Dega osteotomy. **C.** Radiograph of the Dega osteotomy.

Procedure

1. Place the patient on the operating table in a supine position with a sandbag behind the chest.
2. Prepare the lower limb, pelvis, and lower part of the chest sterile and draped as usual for a hip surgical procedure.
3. Perform an antero-lateral (originally described) or "bikini" approach in order to obtain a good exposure of the lateral aspect of the ilium.
4. Separate the sartorius, the tensor fascia lata muscles, and the gluteal attachments subperiosteally from the outer aspect of the ilium.
5. Insert retractors into the sciatic notch from each side to protect the gluteal vessels and the sciatic nerve.
6. Insert osteotomes (usually 1 or 1.5 cm wide) from the lateral wall of the ilium, just above the anterior inferior iliac spine, guided toward the triradiate cartilage medially and downward. Perform the cut under image intensifier control. The medio-posterior cortical corner must remain intact; this part represents the rotation center, at which point the acetabular roof is switched into lateral and anterior.
7. Pull down the osteotomes to lever down the entire acetabular roof over the femoral head to contour the roof in the shape of the femoral head. (The acetabular roof will often bend to the desired contour.) Do not fracture the roof of the acetabulum, which can easily be done in older patients.
8. Prepare an allogenic, lyophilized, or autogenic bone wedge to fit into the osteotomy gap to keep the acetabulum correctly in place. The bone graft is packed firmly into the gap, and it is not necessary to insert pins to fix the graft. The graft is directed from laterally to medially.
9. Take a radiograph to evaluate the new acetabular position.
10. Close the wound.
11. Apply a hip spica cast with the hip at 25° of flexion, 20° of abduction, and neutral rotation.

If open reduction is necessary, the femoral head is reduced into the acetabulum before the Dega procedure is performed. If a varus derotation osteotomy of the femur is necessary, the femoral procedure is performed through a separate lateral incision (see sections on open reduction (chapter 6) and femoral osteotomies (chapter 10)). [**Au: Where are those sections?**] In Dega's original article, this procedure was performed by an antero-lateral approach and an oblique intertrochanteric femoral osteotomy was made subperiosteally. The subperiosteal osteotomy permitted correction of the femoral torsion and shortening.

Postoperative care

The patient returns for cast care after 1 week and returns after a further 3 to 5 weeks for cast removal. The total length of casting varies from 4 to 6 weeks, depending on the patient's age. Walking with the help of crutches is initiated with progressive weightbearing.

Complications

- Redislocation
- Late subluxation
- Avascular necrosis (Dega observed avascular changes in 28 percent of his cases after 6 months, mostly in older children)[120–124]

Results

Dega reported the results of 172 of 398 patients operated on between 1953 and 1955, based on movement, gait, pain, and fatigue.[120–124] He developed a 1–10-point scale to rate his cases: 10 was considered excellent; 8 to 9, good; 5 to 7, fair; and 5 or less, poor. The follow-up ranged from 2 to 4 years and the age of the patients at the time of surgery ranged from 3 to 12 years. He concluded that the border age between good and bad results was 6 years, because 84 percent were excellent or good under 6 years of age and 94 percent were excellent between 3 and 5 years of age. On the other hand, only 23 percent were classified as satisfactory if the surgery was carried out after the age of 6 years.

Reichel and Hein[478] published the results of 51 patients with 70 hip surgeries utilizing this procedure between 1973 and 1984. The mean age of the patients at the time of the surgery was 2.9 years (range 8 months to 8 years) and the mean follow-up was 15.2 years (range 10 to 19 years) after the Dega procedure. All patients in their study had idiopathic developmental dysplasia of the hip. Sixty-two of the patients had been treated previously nonoperatively, 8 children had undergone an open reduction, and 5 had had an intertrochanteric osteotomy. Preoperatively, avascular necrosis was present in 24.3 percent of the joints. In 61 hips, the Dega procedure was performed combined with a derotational varus osteotomy. Redislocation did not occur in any patients, but in children over 7 years of age, persistent incongruous joints resulted. For this reason, they now prefer to perform the triple pelvic osteotomy of Tönnis for these patients. The rate of avascular necrosis originated by this surgery was 5.7 percent, and they observed that the duration of the subluxation or dislocation and the type and time of closed reduction had more significant influence on the rate of the avascular necrosis than the operative method. Based on the Severin criteria, their clinical outcome was classified as class A, very good, 46 hips (65.7 percent); classes B and C, good, 10 hips (14.3 percent); class D, fair, 8 hips (11.4 percent); and classes E, F, and G, poor, 6 hips (8.8 percent).

Chapter Ten

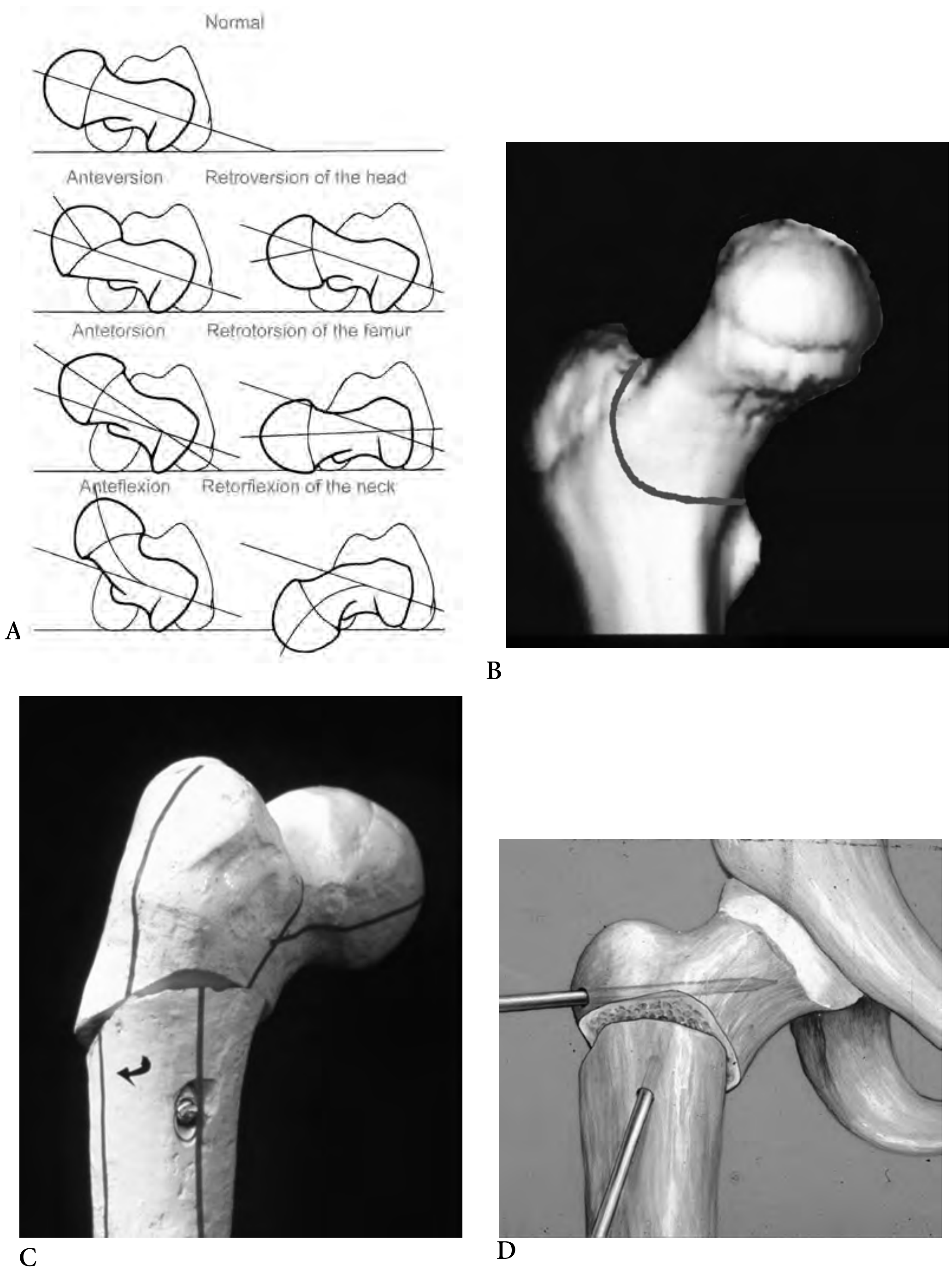
Femoral Osteotomies

The treatment of dislocated and dysplastic hips by a proximal femoral osteotomy (intertrochanteric or subtrochanteric) proposes a means of repositioning the femoral head into the acetabulum.[72,80,187,284,448,505,506,532] The principles of proximal femoral osteotomy are to change the stress within the hip, alter the relationship between the femoral head and the acetabulum, alter the direction and the length of the femoral neck axis, causing changes at the lever arm of the hip abductor muscles, and elevate (or depress) the greater trochanter. The articular cartilage of the femoral head from its lateral margin to the fovea is available for weightbearing. A varus proximal femoral osteotomy increases the articular cartilage surface of the femoral head available for weightbearing, and a valgus osteotomy decreases it.

Tönnis[593] defined the nomenclature of the femoral head and neck deformities. If the abnormal angulation is between the femoral head and the femoral neck, *anteversion or retroversion of the head* is used. The angle of torsion between the distal-posterior aspect of femoral condyles to the femoral neck is referred to as increased *antetorsion or retrotorsion of the femur* (normal antetorsion is about 12°). Angulation within the femoral neck is either *anteflexion or retroflexion* of the neck of the femur.

Intertrochanteric and subtrochanteric proximal femoral osteotomies are utilized frequently to correct anteversion, reposition the femoral head in the acetabulum, and correct an abnormal neck shaft angle. However, the relationship of the level of the tip of the greater trochanter to the level of the center of the femoral head is changed. Deformities in the femoral head, femoral neck, and greater trochanter may reduce the effectiveness of a proximal femoral osteotomy. If the femoral head is deformed and adequate motion of the hip cannot be obtained or if the osteotomy results in an incongruent joint, full correction by a proximal femoral osteotomy may not be desirable. In some cases in which the greater trochanter has an abnormal position or the femoral neck is abnormal, additional operative procedures may be required (see Trochanteric Procedures in chapter 11).

Both intertrochanteric and subtrochanteric proximal femoral osteotomies reposition the level of the greater trochanter in relation to the center of the femoral head. Normally the level of the tip of the greater trochanter is at or just below the level of the center of the femoral head. A valgus osteotomy will lengthen the abductor muscles of the hip and a varus osteotomy will shorten them. Be cautious of performing a varus osteotomy in adolescents, because destabilization of the abductor muscles can result in a permanent Trendelenburg gait. Also, a valgus osteotomy may increase the pressure across the hip joint and


Normal
Anteversion
Retroversion of the head
Antetorsion
Retrotorsion of the femur
Anteflexion
Retroflexion of the neck
A
B
C
D

E

F

Figure 10-1 **A.** Tönnis nomenclature of femoral head and neck deformities (modified from Tönnis D, Legal H, Graf R: Congenital Dysplasia and Dislocation of the Hip in Children and Adults, p 4, Fig 1.7, Berlin, Springer-Verlag, 1987). **B.** CT with schematic drawing of the Nishio helical dome osteotomy (Nischio 1984). **C.** Model of the oblique femoral osteotomy of MacEwen and Shands. **D.** Schematic drawing of the oblique femoral osteotomy. **E.** Model demonstrating how the oblique osteotomy corrects anteversion and valgus. **F.** Radiograph of the oblique femoral osteotomy.

possibly compress the cartilage. McLauchlan (Stracathra approach) reported a soft-tissue procedure in which the insertion of the gluteus medius and minimus muscles is elevated from the anterior one-third of the greater trochanter along with the origin of the vastus lateralis muscle. This results in continuity of the abductor muscles and the vastus lateralis muscle. After the proximal femoral osteotomy, the muscles may slide along the greater trochanter and be reattached within their appropriate lengths.[388]

VARUS OSTEOTOMY OF THE PROXIMAL FEMUR

Correction of a Valgus Deformity

A varus osteotomy can be utilized to correct a valgus deformity of the proximal femur. Adequate abduction of the hip is required; otherwise the lower limb may be placed inappropriately in a nonfunctional position. If the femoral head is spherical, there are no contractures of the hip, and the relationship of the femoral neck to the greater trochanter is normal, a varus osteotomy can offer full correction. If a soft-tissue contracture prevents correction and the femoral head is spherical, release of the contracture may be necessary; however, therapy can often correct a contracture in children.

The authors prefer a preoperative radiograph with the limb abducted until the proximal femur is in the corrected position (the center of the femoral head is at the level of the proximal tip of the greater trochanter). If there is no deformity of the distal femur, an osteotomy just above the level of the lesser trochanter will correct both the mechanical and anatomical axis of the femur.[443] Translation of the distal segment of the osteotomy may be necessary in circumstances in which the CORA is not at the level of the osteotomy. For example, if the varus osteotomy is distal to the CORA, the distal segment must be angulated to correct the valgus deformity and translated medially to correct the mechanical and anatomical axis of the femur.[443]

Correction of Mild Acetabular Dysplasia

A varus osteotomy can be utilized to treat mild acetabular dysplasia. The varus osteotomy changes the intra-articular stresses and muscle forces. The acetabulum responds to this change in the femoral orientation until about 2 years of age, then the capacity of remodeling decreases and cannot be prognosticated after the age of 4 to 6 years.[300,505,534] In the authors' opinion, a varus osteotomy is too unpredictable in correcting dysplasia in cases with only acetabular dysplasia and no proximal femoral deformity; therefore, we prefer an acetabular procedure in these cases (see chapter 7).

In hips with mild acetabular dysplasia, the authors' goal in performing a femoral varus osteotomy is to correct the anteversion of the proximal femur to 15°, to create a neck-shaft angle of 110° in children less than 5 years of age, or 115° in children over 5 years, and/or to shorten the femoral shaft to reduce pressure on the femoral head during an open reduction (refer to the section on open reduction, chapter 6).

Prerequisites

- Concentric relationship between the femoral head and the acetabulum (may be verified radiographically when the lower limb is positioned in abduction and internal rotation)
- Minimal arch of motion: 90° flexion and 10° rotation (ideal arch of motion of abduction-adduction is 50–60° and internal/external rotation of 50–60°)
- Proximal femur deformity such as anteversion or coxa vara
- Image intensifier radiography (fluoroscopy)

Indications

- Instability of the hip
- Delay of normal development of the acetabulum due to femoral anteversion, valgus deviation, or both

Contraindications

- Limited range of motion
- Normal proximal femur
- Avascular necrosis of the femoral head
- Osteophyte impingement

Advantages

- Easy procedure

Disadvantages

- Shortening of the lower limb

Preoperative care

- Radiographs: antero-posterior views in neutral position, in abduction to determine the degree of varus deformity, and in internal rotation to determine the degree of derotation.
- Determine the degree of femoral anteversion (radiographs, CT, sonography, etc.).
- Arthrogram in younger children is helpful in establishing the degree of concentricity of reduction.

The best site to perform the osteotomy is at the intertrochanteric level, just above the lesser trochanter and the insertion of the iliopsoas and gluteus maximus muscles. The lesser trochanter will be displaced anteriorly, decreasing the lateral rotatory force and conserving the medial rotatory force. Also, it permits easy correction of the valgus deformity of the proximal femur and rapid healing because of the extensive surface of bone contact. If the osteotomy is performed at the subtrochanteric level, the distal fragment of the femur may rotate laterally and create a pathologic retroversion of the lesser trochanter, which rotates the thigh more externally due to the action of the iliopsoas muscle.

Nishio developed a helical dome (arced) osteotomy that is performed at the base of the femoral neck along the posterior intertrochanteric ridge. Through this osteotomy, a varus or valgus correction can be achieved. The osteotomy prevents proximal displacement of the greater trochanter as is observed with an intertrochanteric or subtrochanteric osteotomy. This osteotomy is helpful in cases in which the femoral neck requires correction; however, the greater trochanter must be positioned appropriately.

Differences in the type of bony fixation depend upon the choice of the orthopaedic surgeon. The osteosynthesis can be carried out employing crossed Kirschner wires, Steinmann pins, Coventry plates, AO blade plates, and various hip lag screws with side plates. The authors prefer rigid fixation with a hip screw with side plate.

PROCEDURES

Oblique Osteotomy of MacEwen and Shands[365,366]

1. Place the patient on an operating table in a supine position.
2. Prepare sterile and drape the lower limb.
3. Perform a 7–10-cm lateral skin incision, beginning at the tip of the greater trochanter and extending distally parallel to the femoral axis.

4. Divide the subcutaneous tissue and the fascia lata in line with the skin incision.
5. Expose to the greater trochanter and the antero-lateral region of the proximal femur, avoiding injury of the trochanteric physis.
6. Divide the vastus lateralis muscle at its origin from the inferior margin of the greater trochanter, extending distally on the postero-lateral aspect of the femur.
7. Incise and elevate the periosteum to expose the proximal femur.
8. Place the thigh in abduction and internal rotation to reduce the femoral head concentrically into the acetabulum. Check the accuracy of the reduction attained by radiography or fluoroscopy.
9. Pass a threaded Steinmann pin from the lateral aspect of the proximal femur, just below the apophysis of the greater trochanter, along the femoral neck towards the calcar.
10. Drill holes in the proximal femur following an oblique line from the antero-superior to the postero-inferior aspect of the femur.
11. Complete the osteotomy using a sharp osteotome.
12. Based on the preoperative calculation determined by the d'Aubigne and Vaillant graph, rotate the limb externally to obtain varus angle of the femoral neck. If necessary, rotation may be corrected at this time.
13. Hold the proximal pin perpendicular to the femur and parallel to the floor to maintain the reduction. The affected lower limb should be placed parallel to the contra-lateral limb and the foot should point straight up towards the ceiling.
14. Insert a Steinmann pin from the anterior aspect of the proximal end of the distal femur fragment into the posterior part of the proximal fragment.
15. Take an antero-posterior radiograph to assure the reduction, the correction of deformity, and the osteosynthesis.
16. Cut off the anterior pin just below the level of the skin.
17. Apply a hip spica cast. The lateral pin is incorporated into the cast to maintain the proper angle of the femoral neck angle.

Postoperative care

The patient returns after 2 weeks for cast care and again during the sixth week for radiographs. If the osteotomy has healed, the lateral pin is removed. The spica cast is maintained for a total of 8 weeks. Active exercises are then encouraged and crutch walking is initiated. Complete weightbearing is allowed after bone union, about the twelfth week.

Varus Osteotomy with Rigid Internal Fixation

Procedure

1. Place the patient in a supine position on a standard orthopaedic table with a sandbag under the flank to elevate the pelvis and the thigh on the side of the intended surgery.

2. Prepare sterile the pelvis and the affected lower limb, and drape as usual.
3. Perform a straight skin incision on the lateral side of the thigh from the tip of the greater trochanter to the proximal third of the femoral shaft, or an oblique incision beginning more posterior proximally and extending laterally to the upper third of the femoral shaft.
4. Incise the subcutaneous tissue and the fascia lata in a straight line.
5. Make a transverse incision on the proximal attachment of the vastus lateralis muscle and extend it distally along the postero-lateral side of the femur.
6. Elevate and anteriorly retract the vastus lateralis muscle to expose the proximal femoral shaft.
7. Subperiosteally elevate the intertrochanteric area, especially at the level of the lesser trochanter. Place Hohmann retractors beside both sides of the femur.
8. Apply the internal fixation after performing the osteotomy according to the specifications in the manufacturer guidelines.
9. Reattach the vastus lateralis muscle over the implant to its original site.
10. Stitch the fascia lata.
11. Close the subcutaneous tissue and the skin as usual.
12. Take antero-posterior and lateral radiographs of the operated limb.

Postoperative care

If the proximal femur osteotomy is performed during an open reduction of the hip, a spica cast is used to maintain the hip reduction (refer to the section on open reduction of the dislocated hip, chapter 6). If the osteotomy is performed to correct proximal femoral dysplasia and the internal fixation is secure, no cast is generally necessary. Weightbearing is discouraged until the osteotomy heals, which is usually in 6 to 8 weeks in most children.

Complications

- Infection
- Loss of correction
- Distal supracondylar fractures due to disuse osteoporosis from the cast immobilization
- Proximal femoral epiphyseal slip[332]

Results

Kasser et al.[300] reported the results of 44 varus osteotomies in 34 patients. The ages of the patients ranged from 1 year and 6 months to 13 years and 2 months at the time of the surgery, and the follow-up ranged from 5 to 22 years (average 10.3 years). Based on the Severin classification, the results were excellent in 8 hips (18 percent), good in 13 (30 percent), fair in 2 (5 percent), and failure in 22 (48 percent). They observed that the age of the patients and the presence or absence of AVN at the time of the surgery are the most significant predictors of success or failure of the treatment. In children under 4 years of age who have no avascular necrosis, good results are expected and acetabular improvement should persist until the age of 8 years.

Valgus Osteotomy[69]

Proximal femoral osteotomies are performed to center the femoral head into the acetabulum and improve stability and coverage. These principles are traditionally established in the treatment of DDH. The valgus osteotomy was used in the past for the treatment of coxa vara. Since 1976, Bombelli[46] has used this operation for the treatment of intermediate stages of osteoarthritis of the hip to reduce the forces at the lateral margin of the femoral head and the acetabulum and to produce good contact at the medial aspect of the femoral head, which is congruently round within the acetabulum.

A valgus osteotomy to obtain full correction of a varus deformity requires adequate preoperative abduction of the hip. If the femoral head is spherical, there are no deformities of the femoral neck or greater trochanter, and there are no contractures, correction can usually be anticipated. To correct the mechanical and anatomical axis of the femur fully, the distal segment of the osteotomy must be angulated (to correct the varus deformity) and translated unless the osteotomy is at the level of the CORA. Intertrochanteric and subtrochanteric valgus osteotomies often require translation laterally because the osteotomy is distal to the CORA.[443] If the femoral head is deformed and adequate adduction of the hip cannot be obtained, or if the necessary hip adduction results in an incongruent joint, full correction may not be desirable. The authors prefer a preoperative radiograph with the limb adducted until the proximal femur is positioned in the corrected position (the center of the femoral head is at the level of the proximal tip of the greater trochanter).

Indications

- Coxa vara
- Sequela of osteoarthritis of the hip
- Irreversible deformed hips in later stages of osteoarthritis or avascular necrosis of the femoral head
- Special cases of DDH with oval femoral heads
- Malunion of a fracture of the femoral neck[69]

Advantages

- Place the round surface of the femoral head into the acetabulum
- Improve the abductor lever arm[68]

Disadvantages

- Makes the femoral neck more vertical, altering the forces that pass through the knee

- In a capacious acetabulum, a valgus femoral osteotomy may result in subluxation of the hip

Prerequisites

- Careful clinical examination under general anesthesia to ensure congruency of the hip
- Arthrography to visualize the contour of the cartilaginous femoral head and its relationship with the acetabulum (take images in neutral, abduction, adduction, and flexion positions)

Procedure

1. Place the patient on an orthopaedic table in a supine position.
2. Prepare sterile the pelvis and the affected lower limb and drape as usual.
3. Perform a lateral oblique incision from the posterior aspect of the greater trochanter and following the femoral axis distally.
4. Incise the subcutaneous tissue and the fascia lata along the same line as the skin incision.
5. Release the inferior margin of the gluteus medius muscle from its attachment to the femur.
6. Perform a "T"-shaped incision at the origin of the vastus lateralis and subperiosteally elevate this muscle from the upper femur.
7. Insert retractors to expose the proximal femur.
8. Insert a guide wire from the lateral aspect of the femur, just below the trochanteric growth plate, through the femoral neck. This guide wire should be placed parallel to the anterior aspect and proximal to the inferior margin of the femoral neck.
9. Pass the reamer of the hip screw over the guide wire.
10. Insert a suitable screw into the femoral neck.
11. Place the leg in the position of realignment, as indicated by the arthrographic study, to recuperate the congruity of the joint.
12. Perform the first osteotomy cut just below the hip screw with an oscillating saw positioned at right angles to the femur in the frontal and sagittal planes.
13. Place the lower limb back in the neutral position and perform the second osteotomy cut at right angles to the femoral shaft and to the floor.
14. Remove the wedge of bone.
15. Apply the plate to the hip screw and abduct the leg.
16. Apply the plate and hold it to the distal femur fragment using a holding clamp.
17. Insert the locking nut and the screws to fix the plate to the distal femur segment.
18. Stitch the vastus lateralis.
19. Close the fascia and the wound in layers as usual.

Postoperative care

Hip range of motion is encouraged and crutch walking with partial weightbearing is permitted until the osteotomy is consolidated, usually by the sixth or eight week after surgery. If the femur is osteopenic or fixation weak, a spica cast may be applied until bone union.

Femoral Shortening and Derotational Osteotomy

During an open hip reduction procedure, some patients require correction of femoral anteversion to provide better centering and coverage of the femoral head by the acetabulum. If the dislocation is irreducible or difficult to achieve and the femoral head is pressed into the acetabulum, femoral shortening facilitates reduction and decompresses the hip (refer to the section on open reduction of the dislocated hip, chapter 6).

Ombredanne[435] combined the shortening of the femur with open reduction of the hip joint and a shelf procedure to the acetabulum. Stojimirovic[316] detached the iliopsoas muscle from the lesser trochanter and combined correction of the femoral anteversion with the femoral shortening. Klisic and Jankovic[316,317] performed open reduction and added medial transposition of the iliopsoas muscle, correction of the increased neck-shaft angle of the femur, and osteotomy of the iliac bone to the Ombredanne-Stojimirovic operation[435] for the treatment of DDH in older children. Bassett et al. [24] evaluated the results of psoas muscle tenotomy and lengthening by MRI, dynamometry, and gait analysis and cautioned against complete psoas tenotomy at the level of the lesser trochanter. Even lengthening of the psoas tendon during open reduction may cause atrophy of the psoas muscle. Open reduction with a femoral osteotomy to correct anteversion and a femoral shortening to reduce hip pressure are used by many surgeons to treatment of older children with DDH.[176]

Indications

- High dislocation
- To facilitate the reduction of the femoral head
- To avoid increasing pressure on the femoral head after reduction

Contraindications

- Limited range of motion

Advantages

- Easy procedure
- Avoids the use of preoperative traction
- Does not increase significantly the length of the operation

Disadvantages

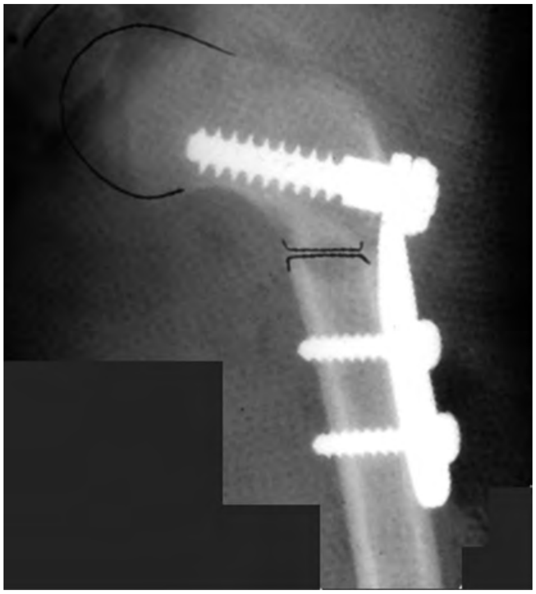
- Additional scars on the skin
- Additional surgery to remove the plate if necessary

Determination of femoral shortening

1. Preoperatively on an antero-posterior radiograph, measure the distance between the floor of the acetabulum and the inferior border of the femoral head.
2. During the surgery, reduce the femoral head into the acetabulum and measure the overlap of the femur segments after the femoral osteotomy.

Procedure

1. Place the patient on an operating table in a supine position.
2. Prepare sterile and drape the lower limb.
3. Perform a 7–10-cm lateral skin incision beginning at the tip of the greater trochanter and extending distally parallel to the femoral axis.
4. Divide the subcutaneous tissue and the fascia lata in line with the skin incision.
5. Expose the antero-lateral region of the proximal femur distal to the greater trochanter. (Do not damage the physis of the greater trochanter.)
6. Divide the vastus lateralis muscle at its origin from the inferior margin of the greater trochanter, extending the cut distally on the postero-lateral aspect of the femur.
7. Incise and elevate the periosteum to expose the proximal metaphysis of the femur.
8. Mark a longitudinal line on the anterior surface of the femoral shaft to avoid loosening rotation after the osteotomy and resection, or insert two threaded Steinmann pins, one in the proximal femoral segment and the other in the distal segment. If only shortening osteotomy is required, the pins should be inserted parallel to each other. If a derotational osteotomy is indicated, the angle between both pins should correspond to the desired correction.
9. Make two parallel and transverse osteotomy cuts, the first just below the lesser trochanter and the second distal to it according to the previous measurements, or overlapping the femoral fragments.
10. The authors prefer to insert the two proximal screws of the four-hole plate before completing the two-level osteotomies at their medial side. Then, when the osteotomies are completed, the shortening is done by resection of a segment of the femur, and if necessary, correction of the rotation is performed. (Varus can be added to the osteotomy to facilitate the reduction in selected cases.)
11. Place a bone clamp to fix the plate to the distal fragment and check the length and alignment of the femur.
12. Insert the last two screws to fix the plate to the distal fragment of the femur.
13. Close the wound.



A

B

Figure 10-2 Femoral shortening osteotomy to achieve reduction of a dislocated hip. **A.** Radiograph demonstrating femoral shortening to achieve a safer open reduction. **B.** Radiograph of internal fixation that secured an open reduction and femoral shortening. Notice that the fixation has been internalized into the femur as the child matured. If internal fixation is used in young children, its removal may facilitate reconstructive procedures in adolescence or adulthood.

Results

Klisic and Jankovic[316,317] reported their results in the treatment of 51 children with 67 congenital dislocations treated between 1963 and 1967. The age of the patients at the time of surgery varied from 5 to 15 years (average 8 years). The minimum follow-up in 60 hips of 47 children was 5 years. Their results were excellent in 2 hips (3 percent), good in 36 hips (60 percent), fair in 18 hips (30 percent), and poor in 4 hips (7 percent). Klisic et al.[317] again reported their results in 1988 involving 189 patients (225 hips) treated between 1963 and 1977. Age at surgery ranged from 7 to 15 years and follow-up ranged from 1 to 24 years (average 5 years). They sent questionnaires to all 225 patients and answers were received from 144 hips, allowing subjective assessment from 9 to 24 years postoperatively (mean of

13 years). The patients were treated with a combined operation: Chiari pelvic osteotomy was performed in 99 hips, Salter innominate osteotomy in 89, and Pemberton iliac osteotomy in 37. The patients' average age at surgery was 10 years in Chiari osteotomies, 9.3 years in Pemberton osteotomies, and 8.8 years in Salter innominate osteotomies. Based on the Severin classification, the hips treated by Chiari osteotomy most frequently showed group II results. In patients treated by Salter innominate osteotomy, group III results were most frequent. Most treated with the Pemberton osteotomy had group IV results. However, late subjective results were significantly better after combined operation with Pemberton osteotomy. They advised older children with a very shallow acetabulum and flattened roof to have a Chiari-type osteotomy. In cases with radiographs showing a moderately dysplastic acetabular roof, especially in younger patients, a Salter- or Pemberton-type iliac osteotomy may promote better outcome.

Preuss and Caldeira[469] reported the results of DDH treated by open reduction and femur varus and shortening osteotomy in 7 patients (11 hips). The patients' ages averaged 2.5 years (range 2 to 4 years). The results by radiographic evaluation considered 18 percent excellent, 64 percent good, and 18 percent regular. There was no AVN, redislocations, or persistent subluxation.

Wenger et al.[650] published their observations on the treatment of 15 patients, 20 hips, carrying out combined derotational femoral shortening osteotomy. The patients' ages at the time of surgery ranged from 5 to 23 months and the minimum follow-up was 2 years. Based on the Severin classification, they reported 15 excellent or good results and 5 fair or poor. They concluded that femoral shortening could be used occasionally to accomplish reduction in developmental dysplasia of the hip in patients younger than 2 years of age.

The authors routinely use femoral shortening to facilitate open reduction of DDH in children with increased pressure upon the femoral head after a trial reduction or to correct excessive anteversion. (See section on open reduction, chapter 6). In young children, the internal fixation for the femoral shortening osteotomy may require removal after healing; otherwise, continued growth of the femur may incorporate the fixation within the diaphysis and make removal as an adult very difficult.

Chapter Eleven

Avascular Necrosis of the Proximal Femur

Avascular necrosis (AVN) of the femoral head is perhaps the most feared complication in the treatment of DDH. Delay in diagnosis or failure in conservative treatment can be resolved usually by operative correction, but severe necrosis causes limitations that will endure for the remainder of the patient's life.

Avascular necrosis and *ischemic necrosis* are terms used by different authors to define the same affliction. Thomas et al.[579,580] consider that AVN refers to the total absence of blood supply, and ischemic necrosis only a partial absence. Thus, according to this definition, *ischemic* is more appropriately applied to DDH where the blood supply is partially affected. In this book, the authors will use the term *avascular necrosis* to include ischemic necrosis. In DDH, avascular necrosis is transient and aseptic, and it is prejudicial only to specific vessels of the femoral head. The authors believe the ischemia occurs as the femoral head is reduced into the acetabulum and involves the vessels that supply the bony epiphysis and physeal area of the proximal femur. Since the proximal femur grows slowly, the effects of the ischemia may not be observed for months or years.

Excessive abduction (more than about 65°) of the hip and *compression* of the femoral head into the acetabulum in the postoperative spica cast are probably the most common causes of AVN. When the hip is widely abducted, the medial circumflex artery is compressed between the adductors and pectineus muscles and the iliopsoas tendon. If the hip is extremely abducted, the medial circumflex artery is compressed between the iliopsoas tendon and the pubic ramus. The postero-superior branches of this artery may be compressed by the impingement of the acetabular ring on the greater trochanteric fossa. In extreme abduction, flexion, and internal rotation, this artery is stretched.[431] The iliopsoas tendon may compress the posterior inferior branches of the medial circumflex artery as they pass toward the lesser trochanter. Compression of the femoral head into the acetabulum probably causes pressure necrosis; however, it is difficult to evaluate these forces. In the process of reducing a dislocated hip, the surgeon should be as gentle as possible and try to relieve all excessive pressure from the femoral head.

Two anatomic areas are affected by the ischemic process: the ossific nucleus of the femoral head and the proximal capital femoral physis (epiphyseal growth cartilage).[49] AVN must be considered if radiographic variations of growth or formation are observed in the proximal femur after reduction. During the first year of life, the appearance of a dense line (Harris growth line) across the proximal femoral metaphysis on antero-posterior radiographs is predictive of femoral growth. When growth is normal, this line is defined as having a smooth inverted "L" form. With AVN, alterations in the form of this line can be seen within 6 months after reduction of the hip joint, and can also predict the type of the metaphyseal growth disturbance and the location and amount of the physeal closure. For better judgment and prediction of damage to the hip joint by AVN; acetabular dysplasia, deformity of the femoral head, neck length, femoral neck-shaft angle, overgrowth of the greater trochanter, and limb-length discrepancy need to be evaluated.

To identify the presence of AVN, Salter et al.[564] described the criteria as follows:

1. Failure of appearance of the ossific nucleus during the year after reduction
2. Failure of appearance of the ossific nucleus a year or more after reduction
3. Broadening of the femoral neck during the year after reduction
4. Increased radiographic density followed by fragmentation
5. Residual deformity after reossification is complete

The incidence of AVN varies according to the method of treatment, and it is not observed in the untreated dislocated hip.[49,434,564] The percentage of hips that develop AVN increases with the higher level of the dislocation, the method of reduction, and the position of immobilization in a cast or orthosis. Tachdjian[565] considered the occurrence of avascular necrosis of the hip following treatment of DDH to be iatrogenic. Although AVN usually occurs following reduction of a dislocated hip, some authors have described rare cases of AVN following treatment in the noninvolved side.[104,200,251] Probably treatment of the involved hip caused iatrogenic damage in the normal side. In the past decade, the incidence of necrosis has decreased from 73 percent to near 10 percent[105,349,378,496] owing to early diagnosis, the use of traction before reduction, gentle manipulation during reduction, and immobilization that avoids extreme positions such as wide abduction ("frog-leg position"), flexion, and internal rotation. In general, the occurrence of AVN of the femoral head is not related specifically to the age of the patient or the duration of immobilization. However, there appears to be a higher incidence of severe necrosis in young infants who undergo closed reduction and casting prior to the formation of the ossific nucleus of the femoral head.

Avascular necrosis following Pavlik harness treatment currently shows a rate from 0 to 9 percent,[372,571,582] and with the use of abduction pants, AVN of the femoral head was not observed.[410] Following nonoperative treatment (closed reduction) of DDH, AVN is reported at a rate of about 8 percent (range 0–75 percent. It may occur in the affected or contralateral normal hip.[54,81,89,153,175,305,316,317,380,428,476,485,528] Gage and Winter[175] observed in their series that traction, gentle manipulation, and avoidance of the extreme abduction position in the treatment of DDH decreased the incidence of AVN from 34.8 percent to 4.5 percent. Kalamchi and MacEwen[296] observed more severe forms of AVN in cases whose initial treatment started before 6 months of age. Another study[565] of 276 patients showed fewer cases of AVN when prereduction traction was used. This article reported a 14 percent AVN occurrence in infants younger than 3 months of age, reducing to 6 percent between 6 and 12 months of age, and increasing again in children between 24 and 36 months of age.

The initial use of traction in diminishing the incidence of AVN caused by closed reduction is under discussion by some authors,[89,267] especially Kahle,[294] who reported excellent results without using early traction in the treatment of his patients. The evidence of the relationship of different degrees of abduction of the hip and AVN was reported in a study on 222 hips in 173 patients.[163] All lower limbs were held at 90° of flexion. The patients were divided into two groups. In the first group the hips were abducted 90°, and in the second group the abduction was no more than 60°. The incidence of AVN in the first group was 17 percent, but it was only 9 percent in the second group. They did not observe differences between the groups in relation to partial AVN, and the results of the less-than-60° group were similar to other reports on traction with the hips in extension. Another study by Smith et al.[528] evaluated computed tomographic scans of 53 children with 68 dislocated hips treated by closed reduction and spica casts. They measured acetabular indices and anteversion, hip-abduction angle, femoral displacement from a modified Shenton line drawn from the pubic rami, and lateral and posterior displacement of the femur from the acetabulum. They observed that the variables were not predictive of the outcome of persistent dysplasia of the hip, but the subsequent development of AVN was statistically connected with hip abduction angles over 55°, with 20 percent of the hips subsequently developing ischemic necrosis. A study by Stanton et al.[546] based on closed reduction showed no correlation between appearance of AVN and degree of abduction in plaster, but in their series the average abduction was 54°, maintaining the position of immobilization within the safe zone of Ramsey.

The incidence of AVN after open reduction is about 12 percent. It generally ranges from 0–60 percent,[89,141,153,316,317,342,376,380,394,395,428,485,566,580,665] but treatment variations make the cause of necrosis difficult to determine. Different surgical approaches have different rates of necrosis. Simons[523] recommends abandoning the use of the antero-medial approach because of the significant incidence of AVN of the femoral head in all studied cases. Morcuende et al.,[413] reviewing the long-term outcome of 73 patients, with 93 hips, treated by open reduction through an antero-medial approach, observed high incidence of growth disturbances of the femoral head in cases of high hip dislocations operated on after 24 months of age. They reported 66 excellent and good results (71 percent), 24 fair results (26 percent), and 3 poor results (3 percent). Fifty-three hips (57 percent) did not have AVN. Tönnis[586] collected studies from different hospitals, and associating these with his personal cases, published the rate of ischemic necrosis in open reductions related to different operative approaches. For the antero-lateral approach, the rate was 8.2 percent; for the inguinal approach, it was 9.6 percent; and for Ludloff's operation, it was 16.7 percent. When open reduction was combined with femur-shortening osteotomy, the incidence was 5.5 percent; when associated with Salter osteotomy, it increased to 10.3 percent; and with concomitant varus osteotomy, it rose to 22.2 percent. Similar results were reported by Simons[523] in relation to the postero-medial approach and agree that the antero-lateral approach showed a lower incidence of AVN.

Hsieh and Huang[268] reported a retrospective study of 32 patients with 34 dislocated hips that had failed in a primary open reduction and had a repeated open reduction associated with other procedures for dysplasia. The patients' ages at the time of the second surgery ranged from 1.5 to 16.5 years, and the interval between the primary open reduction and the second operation ranged from 3 days to 10 years. They observed AVN of the femoral head in approximately half of the hips before the secondary treatment, and the most common cause of the failure of the initial treatment was technical errors, such as the persistence of a tight inferior capsule or the transverse acetabular ligament blockage of congruent reduction. They concluded, based on McKay criteria, that 18 hips in 32 patients achieved excellent or good results after the secondary procedure.

CLASSIFICATIONS OF AVN OF THE FEMORAL HEAD

The classifications of AVN are based on different degrees of severity in necrosis of the femoral head, predicting its natural history, and proposing the most adequate treatment.

Classification of Tönnis and Kuhlman (1968)[592]

Grade I: Mildest degree of alteration. The ossific center shows a rough contour and its structure is slightly granular and irregular.

Grade IIa: Perceptible alterations in structure without fragmentation.

b: the femoral head shows small lateral notches on its surface (punched-out defects).

Grade III: Ossific nucleus identified only by small fragments or as a flat strip.

Grade IV: Significant involvement of the physis and metaphysis affecting the growth of the femur. Alterations are also perceptible in the neck and epiphyseal cartilage of the femoral head.

Classification of Bucholz and Ogden (1978)[52]

Type I: Caused by extracapsular occlusion of the main circumflex artery; is characterized by either delay in appearance or fragmentation of the ossific nucleus and mottling of the cartilage model.

Type II: Caused by occlusion of the posterior superior branches of the medial circumflex artery; is characterized by damage to the lateral portion of the capital physis, provoking premature fusion of the supero-lateral aspect of the growth plate. On radiographs, changes in the lateral aspect of the metaphysis, physis, and epiphysis are seen initially, followed by lateral ossification, lateral physeal irregularity, and bone bridging across the physis, lateral notching of the epiphysis, and lateral metaphyseal defect. In the lateral views, the defects are posteriorly or centrally located in the femoral neck. This type is subclassified into the following groups:

Type IIa: Involvement of the lateral portion of the growth plate.

Type IIb: Associated with damage to the lateral portion of the physis; there is a central involvement of the ossific nucleus.

Type III: The entire proximal portion of the femur is involved by this severe ischemia, including the metaphysis, physis, and epiphysis. The capital physis closes prematurely, the femoral head is flattened and deformed, and the hip joint becomes incongruous. The greater trochanter grows normally, resulting in a relative overgrowth, altering the lever arm of abduction.

Type IV: Caused by the occlusion of the posterior inferior medial circumflex vessels, resulting in a short varus femoral neck (coxa brevis) and coxa magna.

Classification of Kalamchi and MacEwen (1980)[296]

Group I: Characterized by delay in the appearance or mottled aspect of the ossific nucleus.

Group II: The lateral aspect of the physis of the femoral head (ischemic portion) is damaged. It is described as "tethered" and is provoked by immobilization in wide abduction. On the radiographs, lateral ossification, lateral physeal irregularity, and bridging can be seen. A lateral defect of the physis or metaphysis (notching) is also present.

Group III: Characterized by damage to the central physis. On antero-posterior radiograph, it appears as a large central metaphyseal defect.

Group IV: The entire femoral head and physis are damaged, developing an early femoral head deformity, flattening, and coxa magna.

The outcome and prognosis based on Bucholz and Ogden[52] and Kalamchi and MacEwen classifications are as follows:[296]

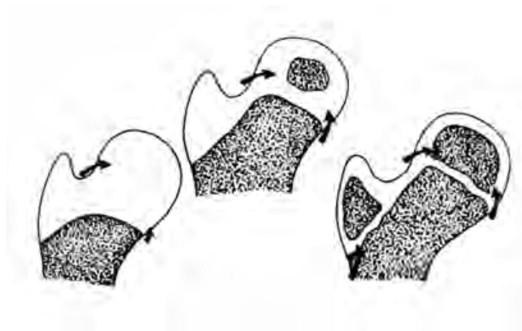
Type I/Group I: With revascularization, the femoral head initially may be flattened, but it commonly recuperates its spherical shape. The hip joint usually retains its regular shape. The prognosis is good and hip function is complete.

Type II/Group II: The femoral neck ends short, the femoral shaft angle increases, and a valgus deformity of the neck and the head is usual. For this reason, deficient coverage of the femoral head by the acetabulum may occur in adolescence. The greater trochanter grows normally, resulting in a relative overgrowth, but only on rare occasions does this cause abductor weakness.

Type III/Group III: The outcome of this lesion is a short femoral neck without much change in the neck shaft angle, overgrowth of the greater trochanter, and limb-length discrepancy. Evident deformation of the femoral head and neck is always permanent.

Group IV: The neck shaft angle may decrease, becoming varus, and the greater trochanter overgrowth results in abductor weakness. Acetabular development is also insufficient and leg length inequality commonly occurs.

A



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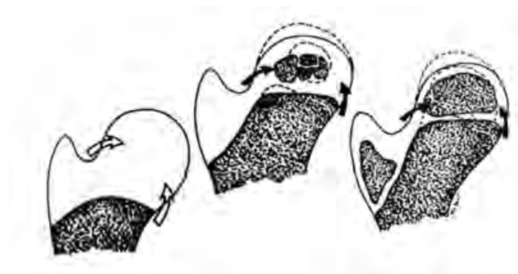

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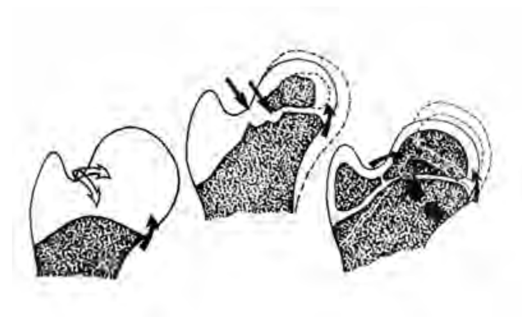

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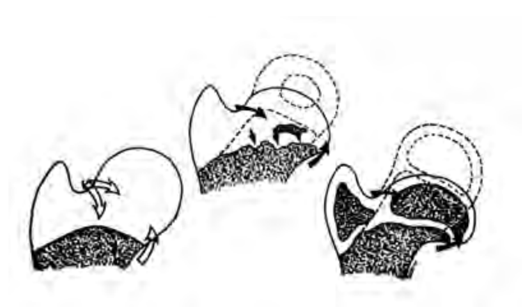
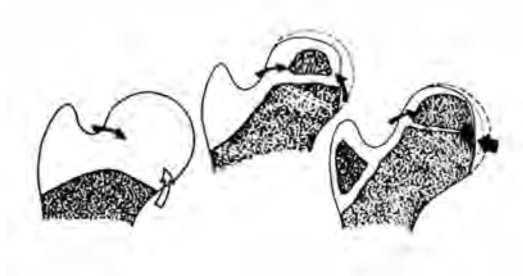
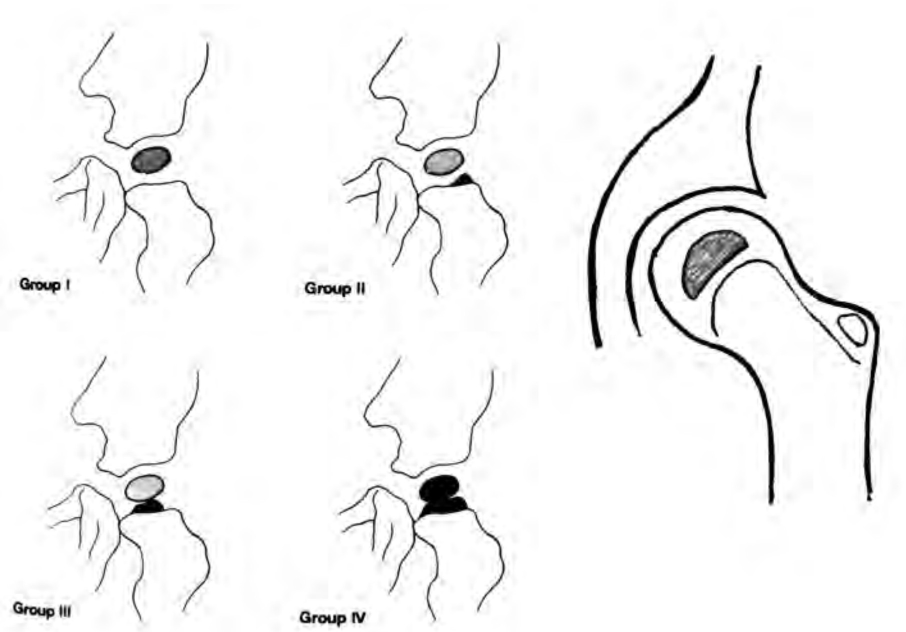




E

Figure 11-1 Schematic drawings of the classification of AVN by Bucholz and Ogden (1978) (modified from Tachdjian MO, ed: Congenital Dislocation of the Hip, p 83, Fig 3.33, New York, Churchill Livingstone, 1982). **A.** Normal growth. **B.** Type I. **C.** Type II. **D.** Type III. **E.** Type IV.



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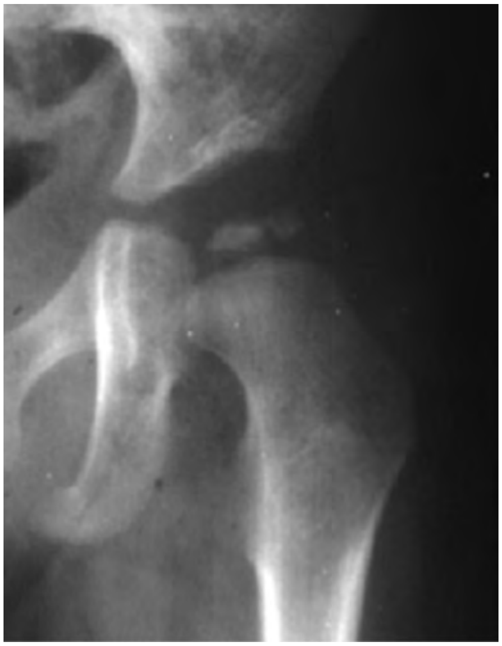

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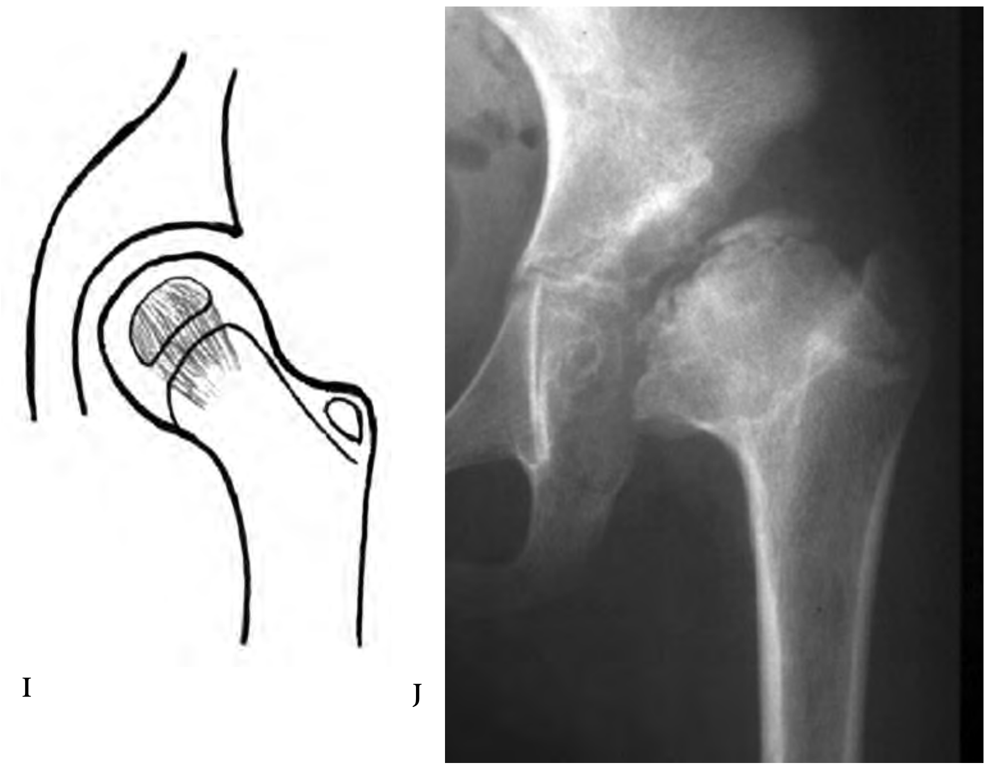


I J

Figure 11-2 **A.** Schematic drawing of the classification of AVN by Kalamchi and MacEwen (from Kalamchi A, MacEwen GD: Avascular necrosis following treatment of congenital dislocation of the hip, J Bone Joint Surg Am 62(6): 876–88, p 884, Fig 8, 1980). **B.** Schematic drawing of group I AVN. **C.** Radiograph of group I AVN. **D.** Schematic drawing of group II AVN. **E.** Radiograph of group II AVN. **F.** MRI of group II AVN. **G.** Schematic drawing of group III AVN. **H.** Radiograph of group III AVN. **I.** Schematic drawing of group IV AVN. **J.** Radiograph of group IV AVN.

Treatment of AVN

The authors prefer to use the Kalamchi and MacEwen[296] classification to determine treatment in their patients. Treatment of the four classification groups is described in the following paragraphs.

In group I patients, radiographs show delay in appearance or fragmentation of the ossific nucleus and mottling of the cartilage model. Since most hips reossify rapidly without deformity, observation only is required. If flattening or subluxation of the femoral head begins, an abduction brace is recommended to contain the hip and prevent subluxation.

In group II patients, due to damage of the lateral portion of the physis (isthmus) and involvement of the ossific nucleus; radiographs show a short valgus and externally rotated femoral neck; relative overgrowth of the greater trochanter; and acetabular dysplasia. Clinically, the patient develops a leg-length discrepancy. The treatment consists of observation of whether a mild coxa valga develops. If it does and there is no acetabular dysplasia and good femoral head coverage, continue observation. In a few cases, the progressive coxa valga has been prevented by an epiphysiodesis of the medial portion of the physis of the femoral head. If coxa valga is associated with insufficient acetabular coverage, an arthrogram is indicated to evaluate the relationship of the femoral head and the acetabulum. If the coxa valga is severe, a varus osteotomy with a medial proximal femoral epiphysiodesis is performed. Overgrowth of the greater trochanter is treated with apophysiodesis in younger children, and with older children distal and lateral transfer of the greater trochanter or double osteotomy of Wagner[628] and Hasler/Morscher.[243] To reposition the femoral head into the acetabulum and correct the acetabular dysplasia, pelvic osteotomies as described by Salter may be performed in younger children,[20] and for older children triple pelvic osteotomies are recommended. Limb-length discrepancy, when less than 2 cm, does not require treatment. When the discrepancy is between 2 and 5 cm, a shoe lift may be used until a distal femoral epiphysiodesis on the contralateral side is performed to equalize length. Severe limb-length discrepancies may require a limb-lengthening procedure.

In group III and IV patients, when severe trochanteric overgrowth occurs, trochanteric apophysiodesis can be considered in patients up to 4 years of age, but for patients over 10 to 12 years of age, distal and lateral greater trochanter transfer may be considered. Acetabular dysplasia is often severe in these types of AVN, which require reconstruction with pelvic osteotomies (see discussion of pelvic osteotomies in chapter 12). The limb-length discrepancy is treated as described above for group II.

TROCHANTERIC PROCEDURES

The anatomic relationship among the femoral head, the greater trochanter, and the abductor muscles in a hip joint is extremely important to produce pelvic-femoral stability for a normal and balanced gait. Wagner[626,629] reported that the tip of the greater trochanter is leveled or is slightly distal to the center of the femoral head, and the distance between them is two to two-and-one-half times the radius of the femoral head. The articulo-trochanteric distance[304] normally measures 10–25 mm. This value is positive when the tip of the greater trochanter is distal to the center of the femoral head, neutral if both are at the same level, and negative when the tip of the greater trochanter is proximal to the center of the femoral head. Gage and Cary[174] evaluated the articulo-trochanteric distance and concluded that the term *trochanteric overgrowth* is a misnomer and suggested the *relative trochanteric overgrowth* instead. In hips with AVN, retardation of growth in the capital femoral epiphysis and normal growth of the greater trochanter cause the relative overgrowth of the trochanter.

The height and lateral position (lateralization) of the greater trochanter determine the lever arm of the abductor muscle complex.[448] If a relative overgrowth occurs, the length of the lever arm is decreased and the gluteus medius and minimus muscles become shortened. Trendelenburg's sign becomes positive, and the patient walks with a gluteus medius lurch. For this reason, some operative procedures have been designed to recuperate the length of the lever arm and its relationship with the proximal end of the femur. Osteotomies of the greater trochanter are considered when there is an abnormal relationship between the axis of the femoral neck (measured by the neck shaft angle) and the axis (or lever arm) between the tip of the greater trochanter and the center of the femoral head (measured as the medial proximal femoral angle). The neck shaft angle is measured on an antero-posterior radiograph at the intersection of a line drawn from the center of the femoral head to the center of the femoral neck and a line drawn through the femoral diaphysis. The normal neck shaft angle averages 135°. The medial proximal femoral angle is measured on an antero-posterior radiograph at the intersection of a line drawn from the tip of the greater trochanter to the center of the femoral head and a line parallel to the shaft of the femur. The normal medial proximal femoral angle averages 90°. The commonly utilized procedures are (1) greater trochanter apophysis arrest (apophysiodesis), (2) distal and lateral transfer of greater trochanter, (3) lateral transfer of the greater trochanter to lengthen the lever arm of hip abductors, and (4) double intertrochanteric osteotomy of Wagner.

Greater Trochanteric Apophyseal Arrest (Apophysiodesis)

Langenskiöld and Selenius[336] described this technique to prevent severe greater trochanter overgrowth. This procedure is useful in children under 4 years of age and may be helpful up to 7 years of age. It is inadequate in older children because approximately half the growth of the greater trochanter occurs by appositional bone growth at its cephalic cartilaginous part, which is not affected by an apophysiodesis. Gage and Cary[174] determined that a trochanteric growth plate arrest (apophysiodesis) achieved a 42.3 percent reduction in anticipated remaining growth. They suggest that a greater trochanteric apophyseal growth plate arrest is effective in children under age 5 in slowing the relative overgrowth; however, continued appositional growth may not maintain the status quo in hips with AVN of Kalamchi groups 2, 3, and 4.

Indications

Premature growth arrest of the capital femoral physis

Children under 7 years of age

Contraindications

Children over 7 years of age.

Advantages

Easy procedure

Disadvantages

Does not lateralize the greater trochanter

Does not change the neck-shaft angle if coxa vara is present (the coxa vara needs treatment by valgus osteotomy)

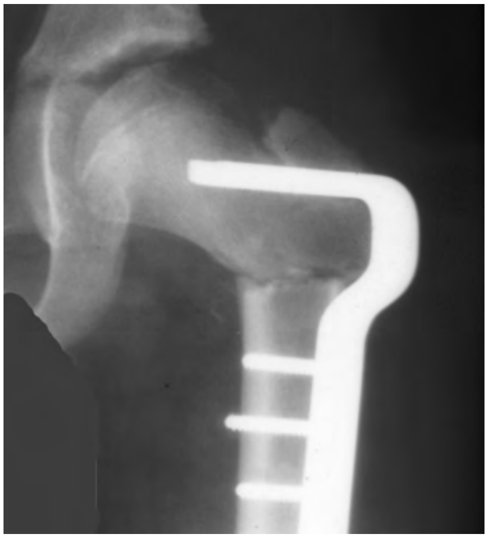


Figure 11-3 Greater trochanteric apophyseal arrest (apophysiodesis) by the Langenskiöld and Salenius method: radiograph of a greater trochanteric apophyseal arrest and a derotational femoral osteotomy. The internal fixation secures both the apophyseal arrest and the osteotomy.

Procedure

1. Place the patient in a supine position with a sandbag under the affected hip.
2. Prepare sterile and drape the pelvis and the lower limb.
3. Perform a 5–7-cm long transverse or longitudinal incision to approach the apophysis of the greater trochanter.
4. Divide the subcutaneous tissue in line with the skin incision.
5. Make a longitudinal incision in the fascia of the tensor fascia lata muscle.
6. Anteriorly retract the tensor fascia muscle.
7. Detach the vastus lateralis muscle at its origin and elevate it extraperiosteally.
8. Introduce a Keith needle or a smooth Kirschner wire into the soft growth plate of the greater trochanteric apophysis. Take an antero-posterior radiograph or use an image intensifier to evaluate the position of the needle or Kirschner wire at the growth plate.
9. Divide the periosteum in an "H"-shaped incision, with the horizontal portion made longitudinally (approximately 2 cm long and 1.5 cm wide for a bigger child and 1.2 cm long and 0.6 cm wide for a smaller child).
10. Elevate the periosteum.
11. Frequently this procedure is performed utilizing osteotomes to remove a rectangular piece of bone in such a manner that the growth plate stays in its proximal third. This rectangular piece of bone is approximately 1.5 cm long, 1.2 cm wide, and 0.5 cm deep for a bigger child and 1 cm long, 0.5 cm wide, and 0.4 cm deep for

a smaller child. Care must be taken to avoid resecting a large piece of bone and loosening the greater trochanter and entering the trochanteric fossa, and damaging the femoral head blood supply.

11a. Rotate the piece of bone 180° and replace it in the defect previously produced in the greater trochanteric physis.

Or

11b. Utilize curettes or a drill to destroy the growth plate in the same dimensions as described above for small and big children.

12. Close the periosteum.
13. Reattach the vastus lateralis muscle.
14. Close the fascia, the subcuticular tissue, and the wound.
15. Immobilization of the patient is usually not necessary.

Postoperative care

Postoperatively, walking is allowed with a three-point crutch gait for about 3 to 4 weeks. Activities are restricted until radiographs demonstrate healing of the osteotomies.

Distal and Lateral Transfer of the Greater Trochanter

Jani[288] described this operation in 1969 to improve gait. He considered that lateralization of the greater trochanter is more important than its distal transfer.

The procedure is utilized in cases in which the neck shaft angle is normal and the greater trochanter is overgrown. These cases have a disassociation between the moment arms from the tip of the greater trochanter to the rotation of the hip at the center of the femoral head and the moment arm of the femur to the rotation of the hip. By transfer of the greater trochanter distally and laterally, the pull of the abductor muscle (force) and length of the moment arm (distance from the tip of the greater trochanter to the center of the femoral head) can be restored.

Indications

- Adolescent or young adult with a positive Trendelenburg sign
- Normal neck shaft angle
- Overgrowth of the greater trochanter (the tip of the greater trochanter is above the center of the femoral head, i.e., at the level of the hip joint line)

Contraindications

- Degenerative hip joint changes
- Stiffness of the hip joint
- Deficient gluteus medius and minimus muscles

Advantages

- Relatively easy procedure

Disadvantages

- Possible increase in articular pressure that may cause chondrolysis

Prerequisites

- Age less than 8 years.
- Concentric hip joint.
- Femoral neck-shaft angle of at least 110°.
- Femoral anteversion of less than 40°.
- Hip motion in an extension position with an arch of abduction/adduction at least 45°. The strength of the gluteus medius and minimus muscles must be at least a fair grade.
- Image intensifier radiography.

Procedure

1. Place the patient on the operating table in a supine position with a sandbag under the affected limb to bring the greater trochanter forward, thus facilitating its exposure.
2. Prepare sterile and drape the affected lower limb.
3. Perform a straight lateral incision from the tip of the greater trochanter and extend distally approximately 8 to 10 cm. Some surgeons prefer a transverse incision centered 2 to 3 cm below the tip of the greater trochanter.
4. Incise the subcutaneous tissue longitudinally.
5. Split the fascia lata muscle longitudinally at its postero-lateral border.
6. Detach the vastus lateralis muscle from the abductor tubercle by a "U"-shaped incision and elevate it subperiosteally from the femoral shaft for approximately 5 to 8 cm.
7. Identify the margin of the gluteus medius superiorly and introduce a retractor pointing toward the trochanteric fossa. A second retractor is placed beneath the posterior edge of the greater trochanter.
8. Insert a smooth Kirschner wire through the abductor tubercle pointing slightly superior to the trochanteric fossa to orient the plane of the trochanteric osteotomy. Use an image intensifier to evaluate the position of the Kirschner wire.
9. Use a 2.5–3.0-cm wide osteotome or an oscillating saw to perform an oblique osteotomy of the greater trochanteric. This osteotomy is completed by gentle leverage proximally using a broad osteotome. Care must be taken to avoid injuring the retinacula vessels at the trochanteric fossa.
10. Lift the trochanteric fragment supero-laterally with a bone clamp.

11. Release soft-tissue adhesions between the joint capsule and the medial margin of the greater trochanteric to mobilize it by traction distally and laterally. Take great care to avoid damaging the retinacula vessels and fracturing the greater trochanteric fragment.
12. Prepare a flattened surface on the proximal end of the femoral shaft using an osteotome to receive the trochanteric fragment.
13. Remove a segment of the greater trochanter on its medial aspect to facilitate attachment to the receptor site at the femoral shaft.
14. Abduct the leg and hold the trochanter in the desired position (1 to 2 cm distally and slightly posteriorly to position the tip of the greater trochanter leveled with the center of the femoral head when the leg is in the neutral position).
15. Temporarily fix the trochanter with two threaded Kirschner wires and, by using image intensifier, verify that the new position of the greater trochanter is correct. Then insert two lag screws (with washers) pointing to the calcar to achieve strong compression; if necessary, a tension band may be employed to strengthen the fixation. Some surgeons utilize two threaded and heavy pins placed parallel to each other, pointing medially and upwards.
16. Test the stability of the osteosynthesis by moving the lower limb and take radiographs to confirm the position of the trochanter.
17. Suture the vastus lateralis muscle to the tendon insertion of the gluteus medius and minimus muscles.
18. Close the fascia lata and the wound.
19. Place the patient in a split Russell's traction with the hips at 35–40° of abduction or abduction in a spica cast pending stability of fixation.

Postoperative care

Active abduction exercises are encouraged (adduction and excessive flexion of the hip should be avoided). Sitting is not permitted for 3 weeks to avoid loosening the fixation. On or about third day, partial weightbearing with the aid of crutches is allowed. In the sixth postoperative week, the use of one crutch on the contralateral side is allowed. This is maintained until the hip abductor muscles are normal or the Trendelenburg sign is negative. Usually, the osteotomy heals in 3 months. The screws may be removed 3 to 6 months postoperatively and the affected limb should be protected by the use of crutches for 3 weeks.

Complications

- Infection
- Thromboembolism (if combined with pelvic or intertrochanteric osteotomy)
- Loss of the fixation (fracture of the thin cortical bone of the trochanter)
- Nonunion
- Insufficient advancement

- Excessive lateralization
- Trochanteric bursitis
- Prominence of the greater trochanter

Results

Givon et al.[196] reported the results of seven patients (nine hips) with coxa brevis (vara) and AVN secondary to DDH, which were treated by distal transfer of the greater trochanter. Good results were achieved in 89 percent of their patients, according to a 5-year follow-up study. They reviewed the same patients 12 years after surgery, and, based on the Mayo Clinic hip score, 71 percent maintained their improvement in gait but 67 percent decreased their hip score because of the appearance or advance of osteoarthritis. They concluded that distal transfer of the greater trochanter is beneficial in improvement of gait but may increase osteoarthritis. Bar-On et al.[20] published the clinical and radiographic outcomes of 25 patients with AVN of the femoral head following previous treatment of DDH. Fifteen of the patients were treated with innominate pelvic osteotomy and were classified into three groups: A, B, and C. Group A consisted of seven patients whose surgery was performed 1 to 3 years after the ischemic insult. Group B consisted of eight patients whose surgery was performed 5 to 10 years after AVN. Group C consisted of the remaining 10 patients who did not have pelvic osteotomy. The minimum follow-up was 10 years from the ischemic insult, and, based on a modified Severin grading, the patients from group A showed better radiographic outcomes, less pain, and better gait and required fewer additional procedures for limb length inequality than group B. After a distal and lateral transfer of the greater trochanter, Macnicol and Makris[370] observed an increase in hip abduction, correction of a positive Trendelenburg gait, relief of pain, and reduction of limping in their patients. They reported two factors that increased the incidence of poor results: first, a primary condition affecting the hip joint such as septic arthritis and DDH; and second, the number of surgeries performed before trochanteric transfer. Anwar et al.[10] published their preference for distal transfer only based on their conclusion that lateral shift of the greater trochanter does not interfere with limp or the Trendelenburg sign after medial displacement pelvic osteotomy. Porat et al.[462] reported 15 patients who limped and had early fatigue during walking with AVN that were treated by distal and lateral transfer of the greater trochanter. The limp appeared at the age of 9 to 10 years; however, at this age no limited walking capacity was noted. Disability developed at about 12 years of age. Nine patients also had more than a 3-cm leg-length discrepancy that was treated by a contralateral epiphysiodesis. In seven patients the trochanteric and epiphysiodesis procedures were performed simultaneously without serious complications. At maturity the limp was eliminated and walking distance improved.

Lateral Advancement of the Greater Trochanter[566,628]

Indications

- Foreshortened femoral neck, which narrows the distance between the trochanter and the center of the femoral head

- Tip of the greater trochanter at its normal level: distal transfer not necessary

Advantages

- Easy procedure
- Increases the lever arm of the hip abductors

Disadvantages

- Needs a separate incision to take the bone graft from the ilium

Procedure

The surgical approach is the same as that previously described for distal and lateral advance of the greater trochanter. Follow steps 1 to 11. Then:

12. Laterally shift the greater trochanter segment, filling the cleft between the trochanteric fragment and the femoral shaft with an autogenous cancellous bone previously taken from the iliac bone by a separate incision.
13. Fix the greater trochanter and the bone graft to the femoral shaft using two wide-threaded cancellous screws placed perpendicularly to the osteotomized lateral aspect of the femur.
14. Add a taut tension band of heavy wire suture, which extends from both trochanteric screws, to a small cortical screw inserted 5–6 cm distally on the external aspect of the femoral shaft. (This wire tension band is used to counteract the pull of the hip abductor muscle.)
15. Reattach the vastus lateralis muscle at the insertion of the gluteus medius muscle.
16. Close the fascia lata muscle and the wound.

Postoperative care

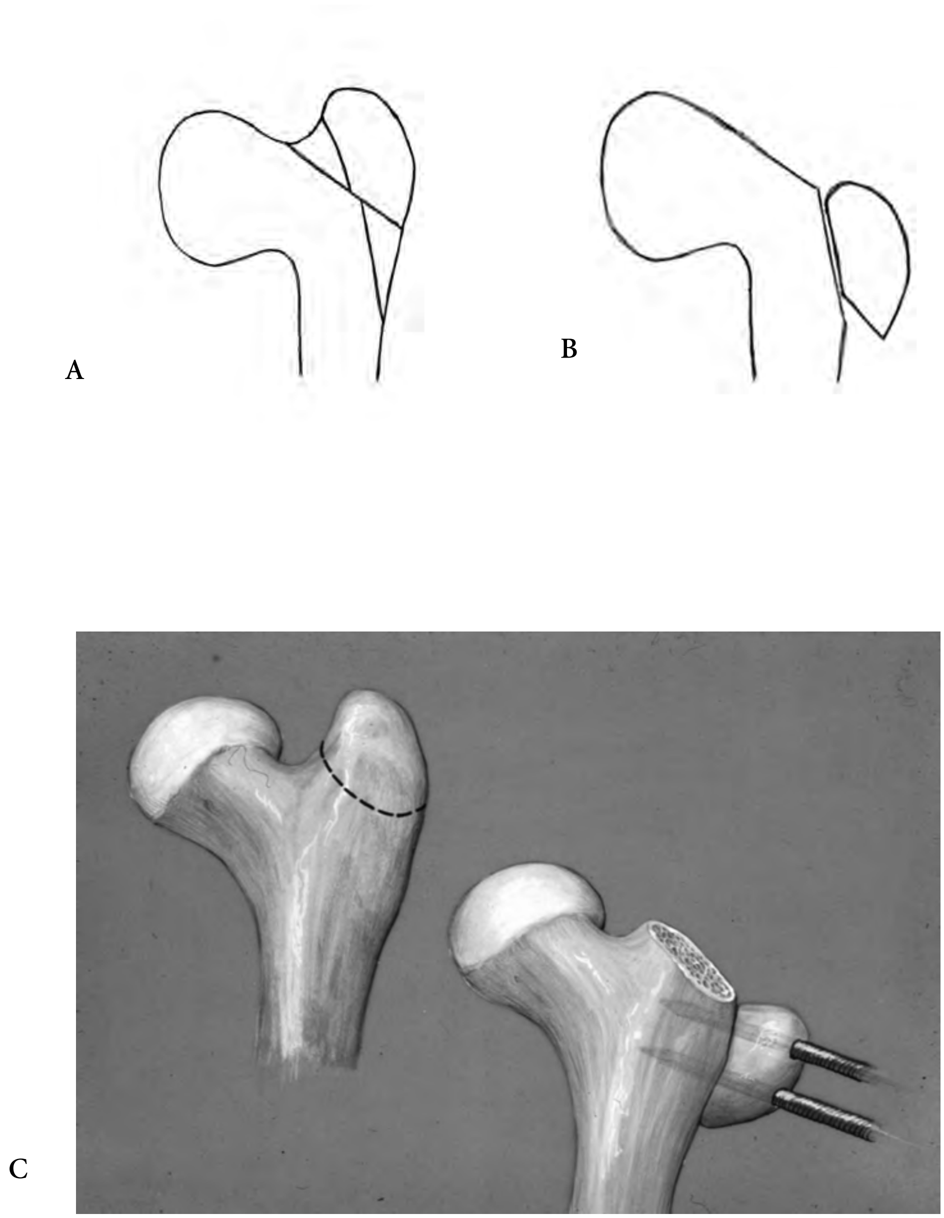
Postoperative patient care is similar to that described for distal and lateral transfer of the greater trochanter.

Double Intertrochanteric Osteotomy of Wagner[624,625,628,629]

This operation, designed by Wagner,[628] consists of two horizontal and parallel osteotomies to elongate the femoral neck, recover the neck-shaft angle, and remove the greater trochanter laterally and distally. The goals of this procedure are to restore the neck shaft angle to 135°, level the tip of the greater trochanter to the center of the femoral head, and restore the length of the femoral neck.

Advantages

- Transfers the greater trochanter laterally and distally and elongates the femoral neck.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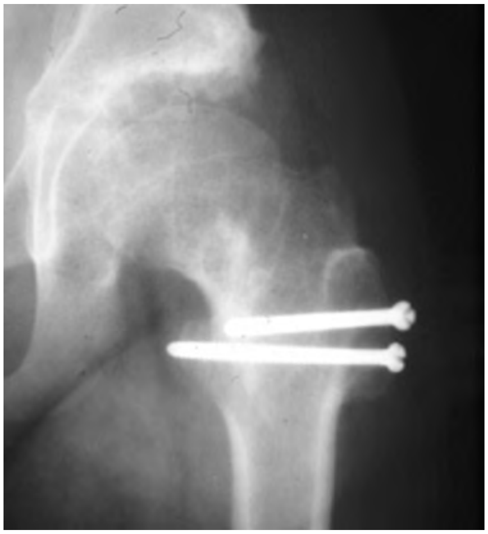


D

Figure 11-4 Distal and lateral transfer of the greater trochanter. **A–C.** Schematic drawings of a distal and lateral transfer of the greater trochanter. **D.** Radiograph of a distal and lateral transfer of the greater trochanter.

Disadvantages

- Difficult procedure

Prerequisites

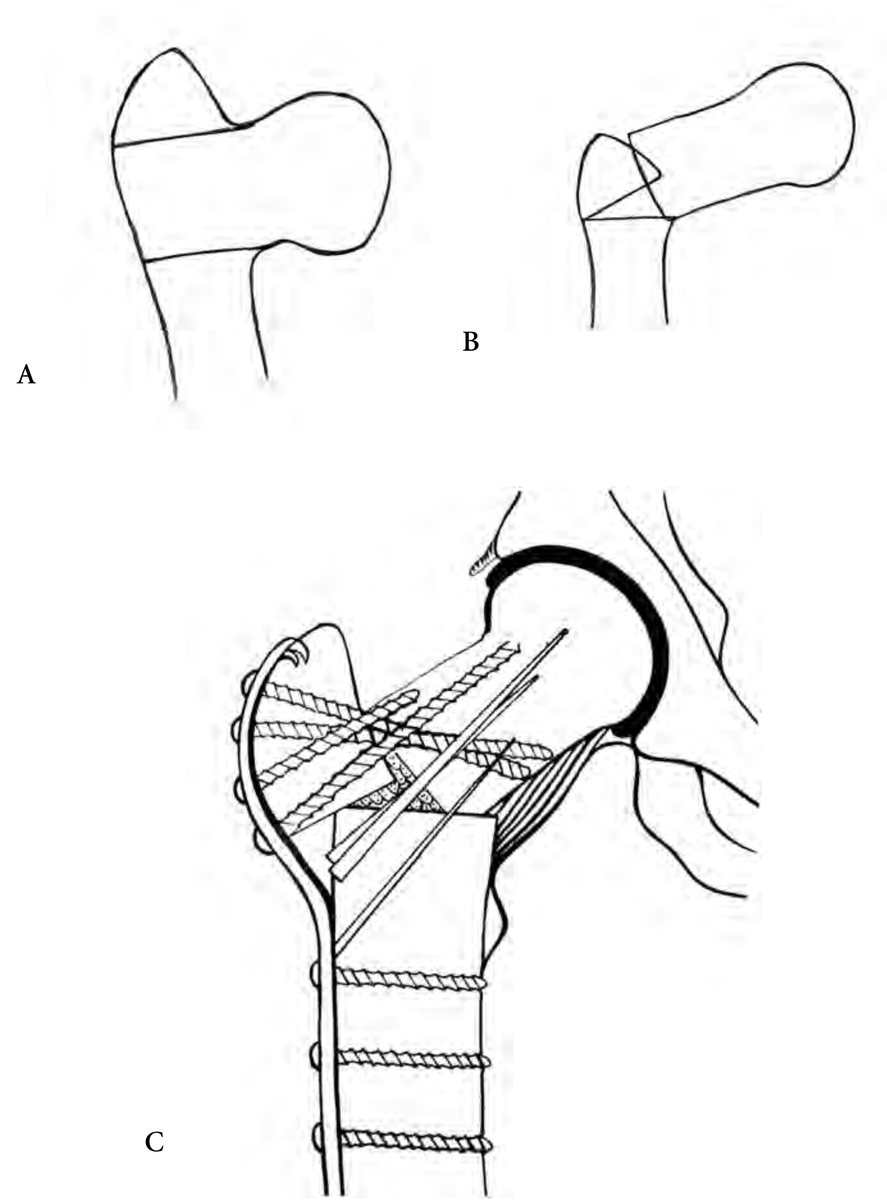
- Image-intensifier radiograph

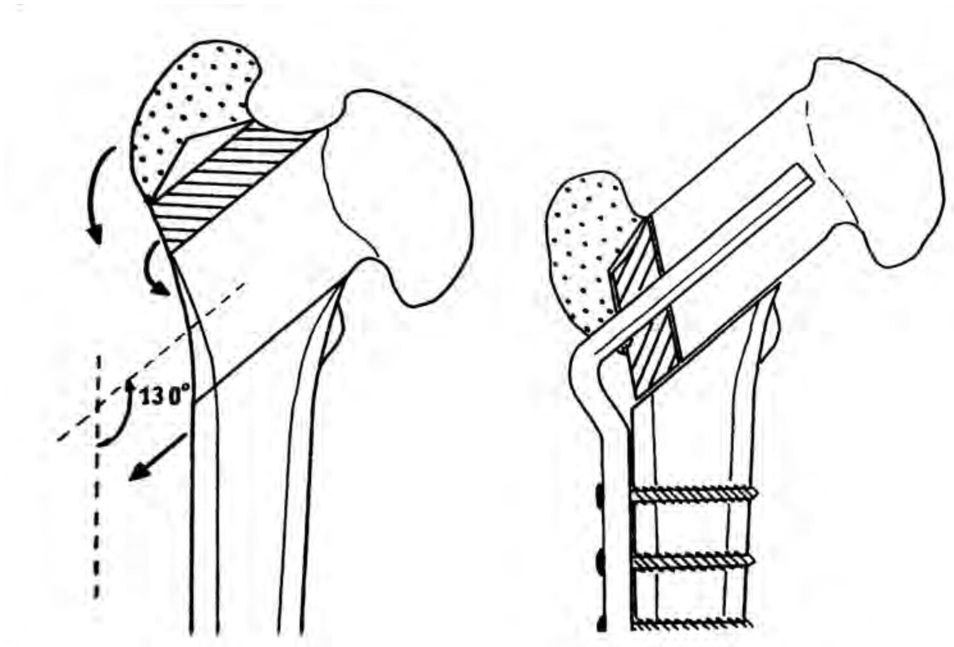
Procedure

Follow steps 1 to 11 as described in the distal and lateral transfer of the greater trochanter section. Then:

12. Insert a threaded Steinmann pin into the center of the femoral head. This pin must stop close to the capital femoral physis.
13. Determine the level of the two osteotomies using the image intensifier. The first osteotomy should be at the base of the greater trochanter and the second should be immediately distal to the base of the femoral neck
14. Mark the levels of the osteotomies by inserting smooth Kirschner wires into the bone.
15. Insert a threaded Steinmann pin into the midportion of the greater trochanter.
16. Perform the two horizontal and parallel osteotomies under image intensifier control. Stop the osteotomies just before the medial cortex of the femur. Complete the osteotomies by provoking a greenstick fracture. Care must be taken to avoid injuring the retinacula vessels and the vessels in the trochanteric fossa. These osteotomies produce three fragments: the greater trochanter, the head and neck, and the femoral shaft fragments.

17. Proximally retract the greater trochanter fragment to provide better exposure.
18. Push the femoral neck fragment downward and medially.
19. Laterally pull the distal femoral fragment to produce a buttress to the infero-medial corner of the femoral neck with the proximal end of the femoral shaft.
20. Using three smooth Kirschner wires, temporarily fix the head and neck and the femoral shaft fragments.





D

Figure 11-5 **A–C.** Schematic drawings of the double intertrochanteric osteotomy of Wagner. **D.** Schematic drawing of the Morscher osteotomy (from Hasler CC, Morscher EW: Femoral neck lengthening osteotomy after growth disturbance of the proximal femur, J Pediatr Orthop B 8(4): 271–75, p 272, Fig 2, 1999).

21. Transfer the greater trochanter distally and laterally and fix it to the femoral neck with the threaded Steinmann pin previously inserted in its midportion. Correct the neck shaft angle. The tip of the trochanter should be aligned with the center of the femoral head.
22. Take radiographs to make sure that the three fragments are in the desired position. Notice: the neck shaft angle should be 135°, the tip of the greater trochanter should be leveled to the center of the femoral head, and the length of the femoral neck should be restored (2.5 times the radius of the femoral head).
23. Perform the osteosynthesis utilizing 90–30° AO right-angle plate and multiple screws, hip screw, and side plate, or a molded semitubular plate prepared at its proximal end as a hook to fix the trochanter (cut the plate at its first screw hole; the bifurcated limbs are sharpened and bent inward to form hooks).[564,566]
24. Pack the spaces between the fragments with autogenous cancellous bone. These bone grafts are obtained from the ilium through a separate incision.
25. Reattach the vastus lateralis muscle at the insertion of the gluteus medius muscle.
26. Close the fascia lata muscle and the wound.
27. Place the patient in a split Russell's traction or make a spica cast in 35–40° of abduction.

Postoperative care

The patient rests in bed with split Russell traction or spica cast for 3 weeks. Active exercises are stimulated 3 or 4 days postoperatively after removing the hip spica cast. Partial weightbearing with the help of crutches or with a three-point crutch is permitted after 3 weeks. Full weightbearing is allowed after bone healing, which usually occurs within 3 months.

Morscher Intertrochanteric Osteotomy to Lengthen the Femoral Neck[243]

This osteotomy is indicated in hips in which the neck shaft angle is normal, the femoral neck is short, and the greater trochanter is relatively overgrown. With this osteotomy the neck shaft angle is unchanged; however, the femoral neck length is restored and the tip of the greater trochanter is leveled to the center of the femoral head (Fig. 11-5D).

Advantages

- The femoral neck is lengthened
- Distalization of the greater trochanter
- The neck shaft angle is not changed

Preoperative planning

- Three osteotomies are planned with an angle of 130° with respect to the lateral cortex of the femur
- A hip blade plate is utilized
- A bony bridge of 2 cm or more should be left between the most distal osteotomy to avoid breakout of the implant.
- The blade of the implant should just reach the base of the femoral head and fill 50–70 percent of the diameter in the axial view.

Procedure

1. The patient is placed supine on the operative table.
2. A straight skin incision is made for the tip of the greater trochanter about 12 cm distally.
3. Dissection is carried down to the femur.
4. A K-wire is placed on the flat surface of the femoral neck to determine anteversion.
5. A K-wire is inserted in the femoral neck parallel to the anteversion with an angle of 50° to the femoral shaft.
6. The seating chisel is driven into the femoral neck parallel to the K-wire.
7. At each level of the anticipated osteotomies, K-wires are placed parallel to the seating chisel.
8. The first osteotomy is at the base of the greater trochanter.

9. The second osteotomy is at the upper border of the femoral neck.
10. A bony disc of 1–1.5 cm thick is resected and preserved.
11. The third osteotomy is at the lower border of the femoral neck
12. After the seating chisel is removed, the blade of the 130° plate is put through the bony disk and into the femoral neck.
13. The femoral shaft is lateralized and secured with screws to the plate. This maneuver lengthens the femoral neck.
14. The greater trochanter is distalized until its tip is at the level of the center of the femoral head.
15. Tension band wiring fixes the greater trochanter to the femur.
16. The wound is closed.

Postoperative

The patient is mobilized on two crutches with partial weightbearing until consolidation is confirmed by radiographs at follow-up (usually 6 to 12 weeks).

Chapter Twelve

Osteotomies, Arthrodesis, and Total Hip Arthroplasty for Salvage

SHELF OPERATION

The shelf operation was designed to enlarge a dysplastic acetabulum by extending the acetabular roof laterally, posteriorly, and anteriorly with the addition of bone grafts directly over the capsule of the uncovered femoral head. The weightbearing forces are directed through the femoral head to the capsule (interposing tissue) onto the shelf (the ilium). Dickson[130,131] in 1924 was the first to use the term “shelf” to describe this operative procedure. Albee[3] performed the technique in two cases of paralytic dislocations of the hip, reporting good results, and Fairbank[149] was the first to carry out a successful shelf operation for DDH. This operation has been utilized by many surgeons[189,192,217,328] in an attempt to treat the different types of subluxations and dislocations. Modifications to facilitate the positioning of the bone graft and the stability of the femoral head inside the acetabulum have been described.[131,186,190,193,359,422,541]

Even though the initial results of the shelf procedures are good, the authors believe the capsule (interposing tissue between the femoral head and ilium) will not be able to withstand the long-term hip wear. Therefore, we consider the shelf operation to be a salvage procedure. Whenever possible, reconstructive procedures that redirect the acetabulum with its hyaline cartilage may be preferable to the shelf procedure in selected patients.

Prerequisites

- Absence of significant degenerative bone changes in the hip joint
- At least 50 percent of the femoral head must be covered by the dysplastic acetabulum in a weightbearing position

Indications

- To improve acetabular dysplasia
- To increase the weightbearing area of the hip joint
- To prevent lateral and upward migration of the femoral head
- Can be performed at any age from 1 year to younger adults (better applied to adolescents)

Contraindications

- In frank dislocation of the hip
- When the CE angle is less than 0°

Advantages

- Safe procedure
- Stabilizes the hip
- Prevents supero-lateral migration of the femoral head
- Decreases pressure forces across the hip joint
- Does not interfere in the blood supply of the femoral head
- Does not disturb the articular cartilage of the acetabulum or the femoral head
- Does not require internal fixation
- Does not provoke obstetrical problems
- Is an extra-articular procedure
- Minimal chance of jeopardizing the sciatic nerve
- Bilateral procedure can be performed at the same time
- Can be associated with other procedures (femoral, Salter, Steel, or Chiari osteotomies)

Disadvantages

- Is not appropriate for posterior acetabular deficiency
- Cast is required for 6 weeks
- Does not provide medialization of the femoral head
- The femoral head is covered by fibrocartilage (fibrocapsule converts into fibrocartilage)
- Does not medialize the acetabulum (the center of gravity across the hip remains lateral)
- Can absorb the graft if it is carried out during the first few years of life

Procedure

1. Place patient in a supine position with a sandbag under the chest and prepare and drape as usual for a hip surgical procedure.
2. Perform an antero-lateral or bikini incision in order to obtain good exposure of the lateral wall of the ilium (see Innominate Osteotomy of Salter in chapter 8).
3. Expose the iliac crest.
4. Widen the gap between the sartorius medially and the tensor fascia lata laterally.
5. Isolate, protect, and retract the lateral femoral cutaneous nerve.

6. Split the ilium apophysis vertically with a scalpel and expose subperiosteally both walls of the ilium. The authors prefer to make an osteotomy just below the cartilaginous iliac apophysis from the outer side and to displace the apophysis medially.
7. Isolate and detach the reflected head of the rectus femoris muscle from the capsule and tag it with a suture for later reattachment. Clear the capsule from the adherent abductor muscles.
8. Separate the capsule from the outer aspect of the ilium with a blunt periosteal elevator. Gently peel distally to thin the thick capsule. Do not perforate the capsule. Some surgeons suggest opening the capsule,[660] but others[328] utilize a blunt probe, such as a hemostat, to identify the joint line. Continue splitting the capsule in half, distally, parallel to the femoral head, utilizing scissors, to provide a pocket in which the bone graft can be inserted.
9. Create a slot at the level of the thinned capsule just above the femoral head.
10. Outline a flap of bone with drill holes on the lateral side of the ilium.
11. The bone flap must be placed into the slot that has been created, pointing upwards and under the reflected head of the rectus femoris muscle, directly into the split capsule. Some surgeons[369] turn down the bone flap using a curved osteotome, bending it distally over the uncovered femoral head and suturing it in place with a single absorbable suture. At this time, care must be taken to avoid breaking the bone flap. The bone should be extended anteriorly and laterally and should be sufficient to form a CE angle of about 30°. Do not create a shelf that limits the abduction touching the greater trochanter.
12. Remove more cancellous bone from the outer aspect of the ilium to form a thick buttress on the lateral wall of the ilium.
13. Take an antero-posterior radiogram to confirm the position and extension of the created shelf.
14. Close the wound in layers as usual.
15. Apply a hip spica cast.

Postoperative Care

The total time in the spica cast is 6 weeks. The patient is followed during the first week for cast care and radiograms. The patient returns after a further 5 weeks for cast removal. Walking with the help of crutches is allowed when the range of movement of the affected hip is 90° of flexion and the knee flexion on the operated side is 90°. Progressive weightbearing is allowed 3 months after surgery.

Complications

- Infection
- Bone graft resorption
- Upward displacement of the shelf

Figure 12-1 Schematic drawing of a shelf procedure as described by Wilson (from Wilson JC Jr: Surgical treatment of the dysplastic acetabulum in adolescence, Clin Orthop 98: 137–45, p 140, Fig 10, 1974).

- Meralgia paraesthetica in the adolescent and young adult due to damage to the lateral femoral cutaneous nerve

Shelf Procedure as Described by Wilson

Wilson[660] described this procedure with some modifications, which are listed below:

1. Place the patient is placed in the supine position in preparation for the surgery; otherwise the approach is the same as described above.
2. The medial and lateral aspects of the ilium are exposed subperiosteally. Originally, the approach described was by the Smith-Petersen incision.
3. Detach the straight head of the rectus femoris muscle, tag with suture, and reflect distally.
4. Expose widely the capsule in its anterior, lateral, and posterior aspects.
5. Release and elevate the capsule from the lateral wall of the ilium distally as far as possible to the lateral margin of the acetabulum.
6. Make a small aperture in the capsule to identify the hip joint.
7. Perform a partial capsulectomy to thin the thickened capsule.
8. Locate the femoral head. Mark, with drill holes on the lateral wall of the ilium, a 2.5–3-cm area immediately superior and slightly anterior to the femoral head.
9. Use a curved osteotome to turn down this piece of bone, which becomes the first layer of the shelf, and suture it to the capsule using chromic catgut.

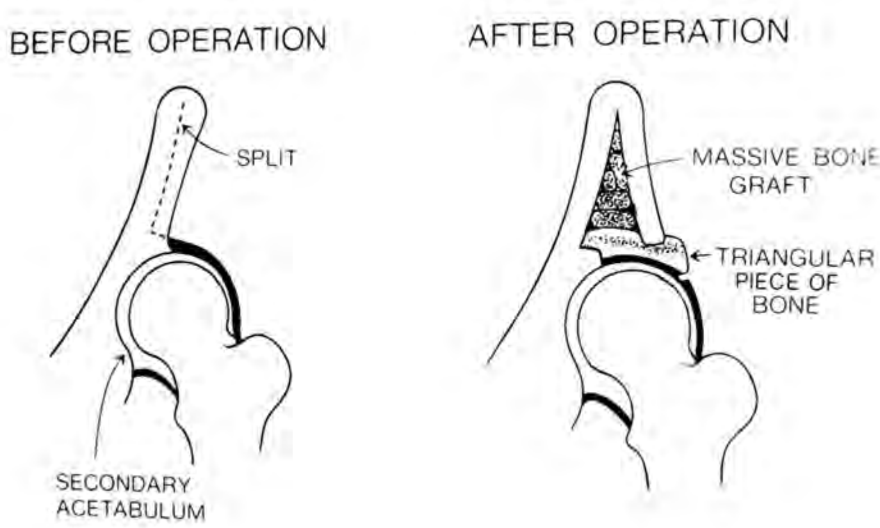


Figure 12-2 Schematic drawing of the Saito tectoplasty technique, in which a triangular piece of bone graft is placed over the femoral head and the external cortex of the ilium is split away from the inner cortex. The gap between the outer and inner cortex of the ilium is filled with bone graft (from Saito S, Takaoka K, Ono K: Tectoplasty for painful dislocation or subluxation of the hip. Long-term evaluation of a new acetabuloplasty, J Bone Joint Surg Br 68(1): 55–60, p 56, Fig 5, 1986. Copyright © the British Editorial Society of Bone and Joint Surgery. Reproduced with permission).

10. In the region of the anterior superior iliac spine, mark the outline of a wedge-shaped graft with drill holes. Resect the triangular bone graft from the ilium and place it in the previously prepared defect through the cancellous bone of the ilium to the inner cortex. Reinforce the shelf with additional chip grafts on each side of the triangular graft from the ilium.
11. Fix the wedge-shaped graft to the inner wall of the ilium with a Steinmann pin.
12. Cut off the Steinmann pin just below the skin.
13. Close the wound in layers.
14. Install a bilateral skeletal traction by inserting the traction pin through the tibia.

Postoperative care

After 4 weeks the skeletal traction is discontinued and a one-and-one-half spica cast is applied and maintained for another 8 weeks. Afterwards, hydrotherapy is prescribed and partial weightbearing with crutches is permitted for an additional 6 weeks.

Tectoplasty Procedure as Described by Saito et al.

Saito et al.[490] reported another kind of modification, described as *tectoplasty.*

1. The approach is similar to that described above.
2. Detach and reflect the sartorius and the straight head of the rectus femoris muscles at their origins.
3. Expose subperiosteally both the lateral and the medial surfaces of the ilium.
4. Expose widely the hip joint capsule from above to the acetabular rim and resect the reflect head of the rectus femoris muscle.
5. Insert a Kirschner wire just above the joint capsule as a guide to the level of the acetabuloplasty. Take a radiograph to confirm the correct position of the wire.
6. Locate the femoral head, and, by the use of small drill holes, outline on the lateral aspect of the ilium a rectangular flap of bone based proximally.
7. Resect a triangular wedge-shaped bone including the anterior superior iliac spine.
8. Cut around the wedges with an osteotome. Preserve the proximal hinge of the flap when separating it from the medial cortex of the ilium with an osteotome, bending it outwards gently.
9. Insert the triangular bone graft to make a floor for the triangle of bone. It is important and helpful to make a gutter in the cortex of this bone graft to adjust to the lower edge of the hinge flap.
10. Fill the space formed by the inner cortex of the ilium, the flap of bone that was hinged outwards, and the floor formed by the bone graft from the anterior superior iliac spine, with cancellous bone from the iliac crest. Macnicol[370] reported that some surgeons prefer to use cancellous bone graft alone to fill this space formed by the hinged flap of bone and the medial cortex of the ilium because the graft can easily be remodeled to the shape of the extra-articular femoral head.
11. Close the wound as usual.
12. Apply a hip spica cast with the thigh at 30° of abduction.

Postoperative care

The patient returns in the third postoperative week for cast removal. Active movements in bed are permitted for the next 3 weeks, followed by walking with the aid of crutches after about 6 to 8 weeks.

Slotted Acetabular Augmentation of Staheli[541]

Slotted acetabular augmentation is a shelf procedure that was designed to increase the load-bearing area and the stability of the hip joint. Staheli developed the procedure as a "simple method of creating a congruous acetabular extension in which the size and position of the augmentation can be easily and accurately controlled."[541]

Indication

- Deficient acetabulum that cannot be corrected by redirectional pelvic osteotomy

Contraindications

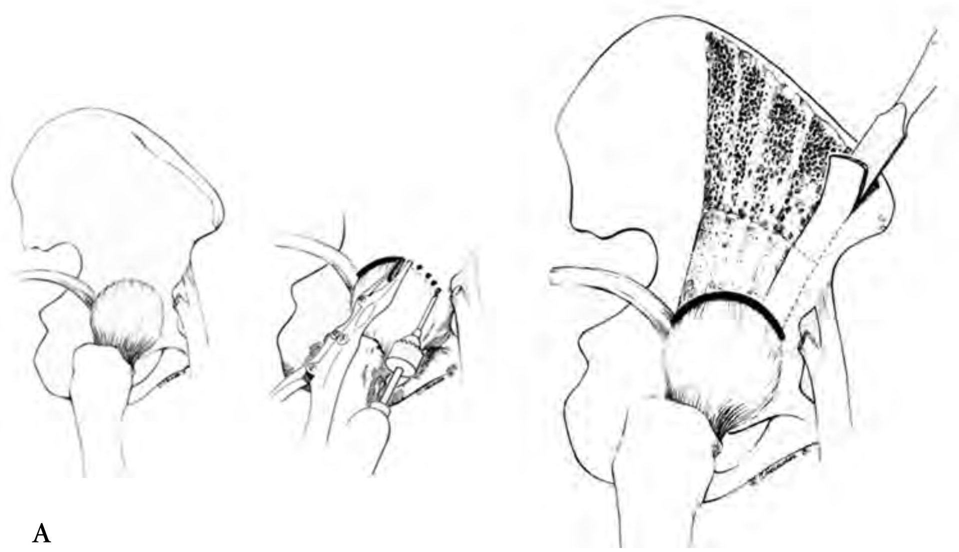
- Hip joint that requires open reduction and supplementary stability
- Dysplastic hips with spherical congruity that are more appropriate for treatment by a redirectional osteotomy

Requisites

- Antero-posterior pelvic radiographs in standing and supine positions in abduction and internal rotation. (If the joint demonstrates congruity in the abduction internal rotation view, the best recommendation for this case may be femoral or pelvic redirectional osteotomy.)

Preoperative analysis

- To determine the center-edge (CE) angle on the standing antero-posterior radiogram.
- To calculate the additional width necessary to extend the acetabulum on the standing antero-posterior view on the side of the dysplastic joint by drawing a normal CE angle of about 35°. The difference between the real and the desired 35° of CE angle corresponds to the width of the augmentation necessary to cover adequately the femoral head.



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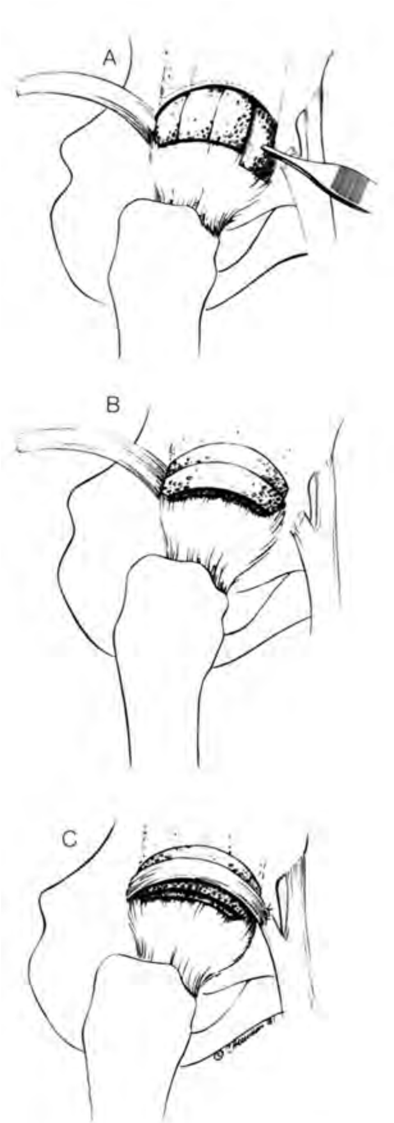

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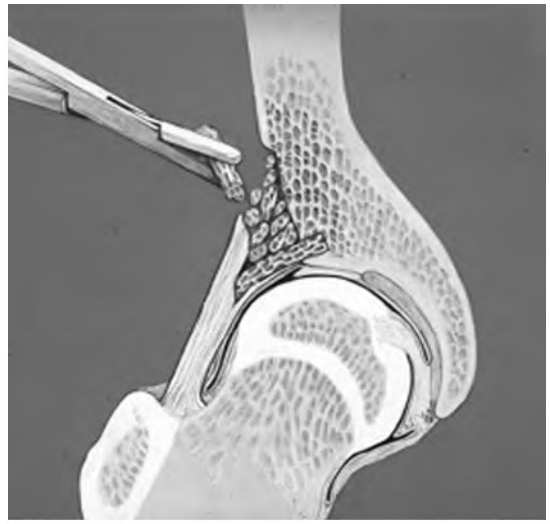

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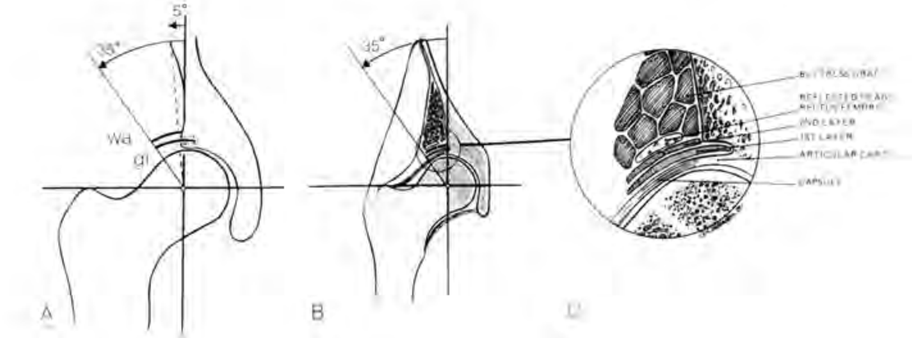
Figure 12-3 **A–C.** Schematic drawings of the Staheli shelf technique. The width of the augmentation is determined on a frontal pelvis radiograph drawing a center-edge angle of 35° (from Staheli LT: Slotted acetabular augmentation, J Pediatr Orthop 1(3): 321–27, p 322, Fig 156, 1981). **D, E.** Schematic drawing of the modification by Kumar (from Kumar SJ, MacEwen GD, Jaykumar AS: Triple osteotomy of the innominate bone for the treatment of congenital hip dysplasia, J Pediatr Orthop 6(4): 393–98, p 396, Fig 3, 1986).



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Procedure

1. Place the patient on the operating table in a semiprone position with a sandbag behind the hip.
2. Prepare the lower limb as usual to allow free movement during the surgical procedure.
3. Make a bikini incision 2–3 cm below and parallel to the iliac crest.
4. Expose the hip joint by a standard iliofemoral approach.
5. Divide the tendon of the reflected head of the rectus femoris muscle anteriorly and retract posteriorly.
6. Make a small incision in the capsule to measure its thickness. This can also be done by palpation. The capsule must be thinned, and in the absence of the rectus femoris muscle, capsular flaps may be made and left attached on their anterior and posterior sides to stabilize the bone grafts.
7. The slot must be placed exactly at the acetabular margin. Staheli describes this as the most critical part of the procedure and suggests placing a probe into the joint to palpate the acetabular rim.
8. Introduce a drill onto the selected site and take an antero-posterior radiograph to confirm the correctness of the position.
9. Make a slot by drilling a series of holes accompanying the acetabular margin. With a small rongeur, create a 5-mm-wide and 10-mm-deep slot. The length is determined by the necessity of coverage. If the head of the femur is anteverted, the slot should extend anteriorly; if the acetabulum is deficient in its posterior aspect, the slot should extend posteriorly.
10. Take strips of cortical and cancellous bone from the lateral wall of the ilium. These strips of bone should be as long as possible, from the iliac crest to the superior margin of the slot, to allow rapid fusion of the graft to the ilium.
11. Measure the depth of the slot and add the width of the desired augmentation calculated from the preoperative radiograph.
12. Select strips 1 mm high and 1 cm wide, with appropriate length of cancellous bone, and apply them radially from the slot, with the concave side down to produce a congruous extension of the acetabulum.
13. Place longer cancellous strips parallel to the acetabular margin to produce the second layer. The strips chosen for this layer may be thicker (2 mm), particularly the most lateral one, to produce a well-defined lateral margin of the augmentation.
14. To avoid blocking hip flexion, do not extend the augmentation too anteriorly.
15. Reattach the reflected head of the rectus femoris tendon in its original position over the two layers of strips to stabilize them. If the rectus femoris tendon is not available, utilize a capsular flap as described above. The reflected head of the rectus femoris muscle or the capsular flaps will be incorporated in the bone shelf.
16. Cut the remaining bone graft into small pieces and apply over the initial layers.
17. Reattach the abductor muscles.

18. Take an antero-posterior radiograph to verify the position and the width of the shelf.
19. Close the wound as usual.
20. Apply a single spica cast with the hip at 15° of abduction, 20° of flexion, and neutral rotation.

Postoperative care

The cast is maintained for 6 weeks, after which it is removed and crutch walking is allowed with partial (one-fifth) body-weight-bearing on the operated side until the graft is incorporated. Periodic radiographs are taken to determine when to begin weaning from the crutches, usually at about 3 to 4 months postoperatively.

The authors use the Staheli technique and maintain the patient in a one-and-one-half spica cast for 6 weeks, followed by walking with the aid of crutches for 6 to 8 weeks.

Results of Shelf Procedures

Macnicol,[369] Wainwright,[630] and Summers et al.[555] report that the shelf procedure is a safe and simple operation. The patients are usually pleased with the results and loss of joint space or stiffness does not occur. However, they also observe a slight limp after surgery, and if the patients limp before the operation they rarely stop limping postoperatively. Pain is usually relieved after surgery. Wainwright[630] operated on 20 hips: 3 in adults and 17 in adolescents. The 17 adolescents' ages ranged from 9 to 18 years and the follow-up period was from 5 to 20 years (average 9 years). The results achieved in the adolescent group were 13 good, 2 fair, and 2 poor. Summers et al.[555] operated on 24 patients, 27 hips. The mean age at the time of surgery was 14 years and 9 months and the mean follow-up was 16 years and 8 months. They reported 16 good results (80 percent) in 20 patients operated on between 3 and 20 years of age and two good results (29 percent) in 7 patients operated on after 21 years of age. Saito et al.[490] showed the results of their tectoplasty performed on 34 hips. They evaluated 27 hips after an average follow-up of 12 years. These patients were 35 years old on average, and 78 percent were considered as having a satisfactory result without pain. Klaue et al.[312,313] examined 13 patients, with 14 shelf procedures. All of them had subluxation due to residual dysplasia. The mean age at surgery was 20.8 years (range 15 to 34 years) with follow-up of 2 to 11 years (mean 6.1 years). They analyzed antero-posterior pelvic radiographs to measure the center-edge angle of Wiberg and utilized CT scanning to evaluate the surface apposition of the acetabulum against the femoral head. They observed that the shelf procedure provides very deficient coverage over the postero-lateral quadrant of the femoral head.

PELVIC OSTEOTOMY OF CHIARI[77,78]

In 1950 Chiari[75–78] designed a medial displacement osteotomy of the pelvis for the treatment of residual subluxation. The basic concept is to construct a congruent bony buttress just above the intact hip joint without the necessity of bone grafting, by medialization of the distal fragment of the pelvis. The hip capsule is the interposing weightbearing surface between the femoral head and the buttress.

Initially, the Chiari osteotomy was considered useful in young children; however, recently this procedure has been reserved for severe dysplasia in which a reconstructive procedure is impossible. The authors use the Chiari procedure in the most severe hips of lateralized and false acetabular types of acetabular dysplasia. Also the osteotomy distorts the shape of the pelvis, which may compromise the possibility of a vaginal childbirth and necessitate a Ciceronian delivery.

Prerequisites

- Functional range of hip motion
- Previous correction of valgus inclination and/or femur anteversion required
- Level of the femoral head not be so high that the osteotomy will extend into the sacroiliac joint

Indications

- For all types of congenital subluxations in which a reconstructive procedure cannot be performed
- Older children (4 to 6 years), adolescents, and adults
- Untreated congenital dysplasias or lateralized types of residual dysplasias after previous conservative treatment
- Coxa magna, femoral head uncovered more than 30 percent
- Incongruous joint that makes acetabuloplasty contraindicated
- Irreducible lateral subluxation
- Hip pain (arthritis)
- Hip instability (femoral anteversion or valgus)
- Dysplastic hips with osteoarthritis (including severe cases)
- Paralytic or spastic hips with dislocation

Contraindications

- Severe osteoarthritis
- Reducible lateral subluxation (consider a reconstructive procedure)
- Stiffness
- Shallow acetabulum (consider a reconstructive procedure)

Advantages

- Enlarges the capacity of the newly formed acetabulum
- Shifts the hip joint medially
- Increases the load-bearing surface on the femoral head

- Is an extra-articular procedure
- Does not disturb the acetabular roof
- Shortens the medial arm of the hip abductor lever system, diminishing the load on the femoral head[96]
- Forms a strong, deep, and live bony acetabular roof

Disadvantages

- Creates a fibrocartilaginous coverage of the femoral head
- Postoperative narrowing of the pelvis may interfere with vaginal delivery (more frequently with bilateral procedures)
- Shortening of the lower limb may occur
- Risk of sciatic nerve paresis
- Risk of stiff joint
- Flexion deformity of the hip (posterior slipping of the distal fragment due to a straight-line osteotomy)
- Anterior superior iliac spine becomes prominent (straight-line osteotomy)
- May adversely affect the biomechanics of the contralateral hip[480]
- Defect between the osteotomized fragment and the ischium if major correction is performed

Prerequisites

- Image intensifier (helpful)
- If bilateral, blood transfusion is needed

Procedure

1. Place the patient on an orthopaedic traction table, with the affected lower limb in slight abduction and external rotation. (The authors prefer the lower limb free to allow full motion during the surgery.)
2. Prepare and drape the skin.
3. Perform a skin bikini incision as in the Salter osteotomy or the ilio-femoral (Smith-Petersen) approach. This ilio-femoral approach is recommended for larger or obese patients.
4. Expose the iliac crest.
5. Widen the gap between the sartorius medially and the tensor fascia lata laterally. The sartorius muscle can be detached from the anterior superior iliac spine. Its free end is marked with a suture for later reattachment and reflected distally and medially.
6. Isolate, protect, and retract the lateral femoral cutaneous nerve.

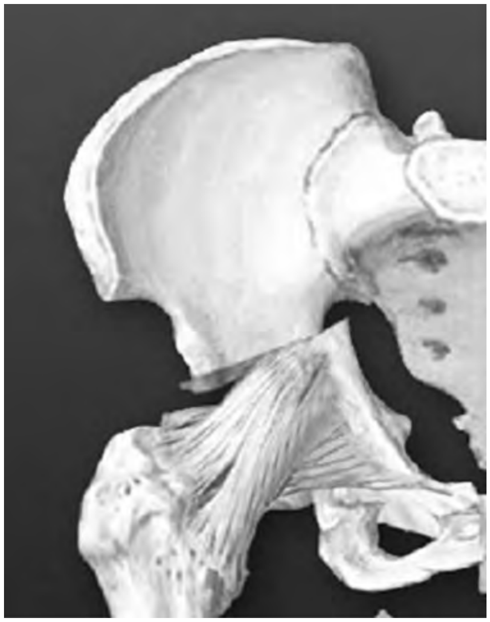
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Figure 12-4 Chiari procedure. **A.** Schematic drawing (from Dr. G. Dean MacEwen). **B.** Radiograph of the Chiari procedure. The osteotomy starts just above the capsule and is directed 15° upwards to allow medial displacement of the distal fragment of the ilium. The osteotomy displaces the fulcrum of the hip joint and shortens the medial arm of the hip abductor lever system, decreasing the load on the femoral head. **C.** Radiograph of a dysplastic hip with a lateralized type of acetabulum that is painful. **D.** Radiograph of the hip after the Chiari procedure.

7. Split the ilium apophysis vertically with a scalpel and expose subperiosteally both the inner and outer walls of the ilium downward to the greater sciatic notch. (The authors prefer to make an osteotomy just below the cartilaginous iliac apophysis from the outer iliac wall and to displace the apophysis medially. This helps prevent a growth disturbance of the iliac apophysis.)
8. Dissect and elevate the capsule from the outer aspect of the ilium and from the rectus muscle and its reflected tendon. The capsule is usually thickened and adherent; care must be taken to avoid opening or damaging it at the site of its latter interposition.
9. Place the osteotome between the insertion of the capsule and the reflected head of the rectus femoris muscle.
10. Check the position of the osteotome by image intensifier. Some authors use a Steinmann pin to locate the correct site of the osteotomy. The cut must be made higher if the femoral head is subluxed superiorly into a false acetabulum.
11. Make an osteotomy at an angle of 10–15° medially and upward in a curved line, beginning inferiorly at the anterior inferior iliac spine anteriorly and finishing at the lower part of the sciatic notch posteriorly. This curved osteotomy should follow the shape of the femoral head and may be marked by drill holes on the outer aspect of the ilium. Then it is performed using narrow osteotomes positioned side by side and advancing from the lateral side to the medial side of the ilium. The posterior cut (1 or 2 cm) of the ilium is made using a Gigli saw. The Gigli saw can be used to make the entire osteotomy. Care must be taken to avoid entering the hip or sacroiliac joints.
12. Open the cut gently using a laminar spreader to make sure that the distal fragment of the ilium is loosened.
13. Abduct the affected hip as an assistant applies counterpressure from the contralateral side of the pelvis. This maneuver causes the lower segment to displace medially 50–80 percent of the width of the ilium, covering the femoral head. Forced maneuvers may provoke greenstick fracture or superior or posterior displacement of the segment, which can damage the sciatic nerve.
14. Fix the osteotomy using two threaded Steinmann pins or lag screws, placed from the iliac crest to the distal fragment, avoiding penetration of the hip joint.
15. Test the hip joint mobility, particularly flexion, which can be limited by the anterior projection of bone formed by the displacement of the ilium.
16. Close the deep fascia and the iliac apophysis and reattach the sartorius muscle.
17. Close the subcuticular tissue and the skin as usual.
18. A hip spica cast is not necessary.
19. Take an antero-posterior radiograph to evaluate the femoral coverage, the displacement and position of the distal fragment, and the Steinmann pins.

Medial displacement must be sufficiently extensive to cover and to support the femoral head. If this does not occur, the contact area between the femoral head and the socket is too small, and consequently pressure over a small contact area on the head provokes degenerative osteoarthritis. The authors add bone graft between iliac osteotomy when the required displacement to cover the femoral head is inadequate.

Postoperative Care

The application of antibiotics and thromboembolism prophylaxis are recommended. Bilateral split Russell traction is applied for 1 or 2 weeks and active movements in the traction are encouraged. Walking with the aid of crutches is allowed after 2 weeks and weightbearing is permitted at 12 weeks. (Chiari advocates the use of a spica cast at 20–30° of abduction, extension, and neutral rotation for 3 weeks.)

Complications

- Greenstick fracture of the ilium
- Inadequate (insufficient or excessive) displacement
- Osteotomy too low
- Infection
- Palsy of the sciatic nerve
- Palsy of the femoral nerve
- Partial peroneal paresis[408]
- Thigh numbness
- Dislocation of the hip
- Thromboembolism
- Stiffness of the hip
- Extension contracture
- Flexion contracture (from shrinkage of the sartorius and tensor fascia lata muscles at their attachment; may be treated by resection of the scars)
- Ossifying myositis of the gluteus minimus muscle
- Intra-operative damage of the capsule will destroy the interposition tissue, provoking limitation of mobility or stiffness
- Inappropriate level of the osteotomy: if too high, will not provide a good coverage and bone resorption may occur; if too low, will damage the interposed capsule
- Inappropriate direction of the osteotomy: if directed more than 15–20 upwards, the cut can damage the sacroiliac joint; if performed by descending medially, the medial displacement will be impeded and the femoral head will not be supported properly. "The ideal osteotomy line for most of the cases will be horizontal or slightly ascending."[77]

Results of the Chiari Osteotomy

After a follow-up varying from 2 to 8 years, Chiari in 1974[77] reported his first 200 cases, showing two-thirds with excellent or good results. The age at the time of surgery of the great majority of these patients was more than 16 years. Mitchell,[408] in the same year, published his results of 40 Chiari osteotomies performed from 1966 to 1972, classifying pain and technical achievement. Twenty-eight hips were pain-free and demonstrated good technical procedure, 7 hips were pain-free but technical errors were present, 3 hips produced slight pain but the technical result was considered good, and 1 hip was classified as a positive technical error and presented severe pain. In the last case, an arthrodesis was performed. When only pain was considered as a symptom, 35 hips had no pain, 3 had slight pain, and 1 had severe pain. Volpon et al.[615] performed 27 Chiari osteotomies in 25 patients. They evaluated the femoral head coverage by the CE Wiberg angle and compared the acetabular sclerosis before surgery and at follow-up. They obtained good results in most patients. Reynolds[483] showed 29 good results in 32 "properly selected" patients and concluded that this osteotomy retards the progression of degenerative changes. Calvert et al.[60] published their studies on 45 patients, 49 hips treated by Chiari pelvic osteotomy between 1965 and 1974. The average age at review was 33.9 years (range 18 to 54 tears) and the average period of follow-up was 14 years (range 10 to 19 years). The primary diagnosis was acetabular dysplasia in 7 hips and congenital dislocation in 42 hips. They evaluated the hips and based their results on the Harris and Iowa hip scores and observed that a young age at the time of surgery was associated with a higher final hip score. A painless hip and the absence of degenerative changes on the radiograph at the time of operation were associated with a significantly higher Harris hip score. They also noticed no correlation between the final hip score and the percentage of subluxation, the medial shift, and the angle or height of the osteotomy. Betz et al.[37] published the results of a series of Chiari osteotomies from the A. I. duPont Institute. Between 1966 and 1981, a Chiari osteotomy was performed on 24 patients age 10 to 23 years at the time of surgery. Follow-up was from 3 to 20 years. Twelve patients had DDH; 6, poliomyelitis; 3, cerebral palsy; 1, sequelae of multiple epiphyseal dysplasia; 1, osteonecrosis; and one, osteomyelitis. They achieved good and excellent results in 21 patients (91.6 percent) and recommend medial bone grafting if it is necessary to displace the osteotomy more than 50 percent to cover the femoral head. Rejholec et al.[480] reported the long-term results of 104 Chiari osteotomies (18 years of follow-up). Forty-eight percent of patients complained of persistent hip pain, and 15 percent complained of pain in the lumbo-sacral spine. Limitation of hip movement occurred in 41 percent, the Trendelenburg sign was present in 74 percent, shortening over 1 cm occurred in 77 percent of cases, and delivery by caesarean section occurred in 36 percent. They concluded that the main indication for this procedure is grave instability of the hip joint. For valgus hips, this operation should only be carried out after 14 years of age.

Lack et al.[331] reported the late results of 100 Chiari osteotomies for osteoarthritis secondary to hip dysplasia. Eighty-two patients were reviewed and 18 items of information were obtained by questionnaire. All patients were over 30 years of age at the time of surgery, and follow-up averaged 15.5 years. The results were 75 percent good, 9 percent fair, and 16 percent poor. The worst results came from the patients who were 44 years of age or older at the time of their operation. Twenty hips had undergone secondary total hip replacement. They concluded that this procedure is an alternative to early hip replacement in hips with osteoarthritis secondary to hip dysplasia.

Klaue et al.[312] published a radiological assessment of Chiari osteotomy using conventional radiographs and three-dimensional reconstruction from CT scans. They examined

16 patients with 19 Chiari osteotomies carried out for subluxation due to residual dysplasia. The patients' ages at surgery ranged from 11 to 51 years (average 24.3 years) and follow-up was from 3 to 12 years (average 6 to 8 years). The center-edge angle of Wiberg was measured on antero-posterior radiographs, and coverage of the femoral head by the acetabulum was evaluated by CT scan. Their study concluded that improvement of the CE angle of Wiberg (usually greater than normal) does not show the real covering of the femoral head, which may be insufficiently covered on its postero-lateral quadrant.

DOME PELVIC OSTEOTOMY OF KAWAMURA[301,302]

Kawamura in 1958 modified the Chiari procedure to improve the results in patients with hip dysplasia by creating a dome-shaped osteotomy to cover and support the femoral head.[301,302] The dome-shaped osteotomy contoured to the shape of the femoral head. He utilized the lateral approach to the pelvis, made a greater trochanter osteotomy for better exposition of the lateral wall of the ilium, and used a special oscillating saw to perform the osteotomy. This approach also permits a valgus or varus proximal femoral osteotomy and distal and lateral transfer of the greater trochanter.

Advantages

- Constructs a strong nonabsorbable roof at the moment of surgery
- Recuperates the normal biomechanics of the hip by redirecting the gluteus medius muscle to the vertical line, improving the lever arm of abduction
- Reduces the load over the newly constructed hip joint due to medialization of the femoral head

Disadvantages

- Postoperative narrowing of the pelvis
- Leg shortening
- Fibrocartilage coverage of the femoral head
- Risk of injuring the sciatic nerve

Indications and Contraindications

- Similar to those for Chiari osteotomy

Procedure

1. Place the patient on an operating table in a lateral position with the affected hip upwards. Prepare and drape the hip.
2. Perform an infero-posterior skin incision from the anterior superior iliac spine to the greater trochanter, continuing posteriorly to a point that corresponds to the sciatic notch. Tachdjian[302] began the skin incision at the middle third of the iliac crest and exposed the inner wall of the ilium by splitting the iliac apophysis.

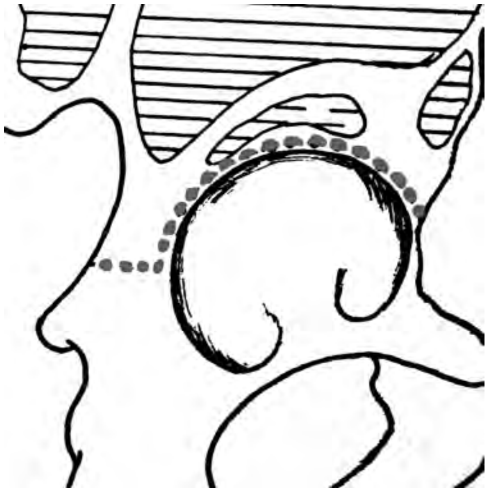


Figure 12-5 Schematic drawing showing the Kawamura osteotomy (red line) that creates a dome-shape bone shelf over the femoral head. (modified from Kawamura B, Hosono S, Yokogushi K: Dome osteotomy of the pelvis, in Congenital Dislocation of the Hip, edited by Tachdjian MO, 609–29, p 610, Fig 33.1, New York, Churchill Livingstone, 1982).

3. Divide the subcutaneous tissue and the deep fascia along the same line as the skin incision.
4. Widen the gap between the gluteus medius and the tensor fasciae femoris muscles by blunt dissection.
5. Detach the vastus lateralis from the abductor tubercle and elevate it subperiosteally from the femoral shaft approximately 5 cm.
6. Retract laterally the gluteus medius muscle.
7. Mark the correct level on the femur for the trochanter osteotomy using a smooth Kirschner wire under image intensifier control.
8. Make the trochanter osteotomy with an oscillating electric saw, cutting in a supero-medial direction. This kind of cut gives good exposure and allows the displacement and reattachment to the femur more distally and laterally.
9. Reflect the greater trochanter, with its attached muscles, proximally.
10. Expose the superior aspect of the hip capsule and the adjacent iliac bone.
11. Expose, detach, and excise the reflected head of the rectus femoris muscle from the acetabulum. The direct head of the rectus femoris muscle should be sectioned from the anterior inferior iliac spine, marked with a suture, and reflected distally.
12. Divide the periosteum along the acetabular rim and elevate it approximately 1 cm from the lateral aspect of the ilium. The entire acetabular rim should be visible from the anterior to the posterior edges and the sciatic notch, permitting a safe pelvic osteotomy.
13. Elevate the periosteum of the inner wall of the ilium from the greater sciatic notch to the anterior inferior iliac spine.
14. Elevate the periosteum of the anterior edge of the ilium from the anterior superior iliac spine to the ileopectineal eminence. Kawamura incises and elevates 3 to 5 cm

of the periosteum from the front to the arcuate line and from the sciatic notch to the arcuate line. This step is necessary to complete detachment above the line of osteotomy, allowing medial displacement of the acetabulum.

15. Place retractors subperiosteally in the sciatic notch, from the lateral and medial sides of the ilium, to protect the vessels and the sciatic nerve.
16. Locate the level of the osteotomy just above the hypertrophied joint capsule. Mark with a Kirschner wire and confirm by image intensifier. If the capsule is too thick, some of it may be thinned.
17. Make multiple drill holes from the external wall of the ilium, outlining the dome osteotomy line, parallel to the femoral head contour. These drill holes must be pointed upward 15° in a lateral, medial direction.
18. Complete the osteotomy using a small osteotome. Kawamura utilizes a drill-type saw specially designed for this procedure.
19. Abduct the hip and push the femoral head inwards to shift the distal fragment of the ilium medially. To carry the proximal fragment of the ilium over the femoral head, it should be pulled outwards by bone hook and periosteal elevators. At the symphysis pubis, the fragments hinge more than at the sacroiliac joint.
20. Pull the lower limb distally to widen the space between the femoral head and the newly constructed acetabular roof. The inferior aspect of the superior fragment should be reshaped into a dome and smoothed with a rasp, thus avoiding a rough surface, which may create susceptibility to osteoarthritis.
21. Fix the fragments with two threaded Steinmann pins or cancellous screws.
22. Take an antero-posterior radiograph to evaluate the femoral head coverage and the osteosynthesis.
23. Reattach and fix the greater trochanter in the desired position with two screws.
24. Close the wound as usual.

Postoperative Care

Postoperative care is similar to that for the Chiari procedure. The hip is immobilized in 20° flexion and 30° abduction in a spica cast for 3 weeks. Walking with the aid of crutches with partial weightbearing is allowed at 6 weeks, and full weightbearing is permitted at 12 weeks.

Results

Kawamura[301] reported the results of 36 unilateral cases with a follow-up of over 5 years. The patients' ages ranged from 3 to 25 years. Nineteen patients were operated on with the trapezoid osteotomy technique, and the other seventeen cases had the improved technique with drillings. No significant difference between the two techniques was perceived in the results. Fourteen patients were classified as excellent, 15 as good, 5 as fair, and 2 as poor. The reason observed for fewer excellent results in older age groups was the presence of preosteoarthritic or early osteoarthritic changes in the patients' hips.

Anwar et al.[10] published the results of 101 Kawamura dome osteotomies with simultaneous distal transfer of the greater trochanter carried out on 91 patients from 1978 to 1986. All patients showed osteoarthritis secondary to hip dysplasia. The age at the time of surgery ranged from 15 to 55 years (average 30 years), and the mean follow-up was 8.3 years (range 5 to 14 years). Ninety-one hips had good acetabular remodeling and did not show any progression of osteoarthritis. The other 10 hips showed progression of osteoarthritis, and 6 of them underwent a total hip replacement. They reported 92 percent excellent or good results based on the Merle d'Aubigne score. They concluded that age of 40 years or more at the time of surgery, valgus deformity of the proximal femur, advanced stage of osteoarthritis, and postoperative limping (associated or not with a positive Trendelenburg sign) are factors significantly related with poor results.

OPERATIVE HIP DISLOCATION BY GANZ ET AL.[177]

Operative dislocation of the young adult hip is rarely indicated; however, treatment of impingement of the femoral head-neck area against the rim of the acetabulum and labral tears may require complete or partial dislocation of the hip. The vascularity of the femoral head must not be injured; otherwise iatrogenic AVN will occur. Trueta and Harrison[603] showed that the majority of the blood supply to the femoral head is from the medial femoral circumflex artery and very little or none is from the lateral femoral circumflex artery. Articles[107,517] confirm the importance of preserving the vascularity of the lateral femoral circumflex artery in operative dislocations of the hip. Desmond Dall[113] described an approach to the hip by an osteotomy of the anterior part of the greater trochanter that maintains the continuity of the tendon junction between the anterior half of the gluteus medius muscle and the vastus lateralis muscle and preserves intact the insertion of the gluteus minimus muscle to the anterior surface of the trochanter. Ganz et al.[177] described a "trochanteric flip" osteotomy, similar to the approach of Dall, which preserves the vascularity of the femoral head and allows access for an anterior hip dislocation.

Procedure

1. Place the patient in a lateral decubitus position. Prepare and drape the entire extremity.
2. Make a Kocher-Langenbeck incision over the lateral aspect of the proximal femur; the cephalic end is curved posterior.
3. Internally rotate the leg and identify the posterior border of the gluteus medius muscle.
4. Make an incision from the postero-superior edge of the greater trochanter extending distally to the posterior border of the ridge of the vastus lateralis muscle.
5. Do not attempt to mobilize the gluteus medius muscle or to visualize the tendon of the piriformis muscle.

6. Make a trochanteric osteotomy with a maximal thickness of about 1.5 cm along the posterior border of the ridge of the vastus lateralis muscle. The osteotomy should end just anterior to the posterior insertion of the gluteus medius muscle (this protects medial femoral circumflex artery.)
7. Mobilize the greater trochanteric fragment anteriorly.
8. Release the most posterior fibers of the of the gluteus medius tendon from the trochanter.
9. With the leg flexed and externally rotated, elevate the vastus lateralis and intermedius from the lateral and anterior area of the femur.
10. Separate the inferior border of the gluteus minimus tendon from the relaxed piriformis muscle and underlying capsule.
11. Preserve the anastomosis between the inferior gluteal artery and the medial femoral circumflex artery.
12. Retract the entire flap, including the gluteus minimus muscle, anteriorly and superiorly to expose the antero-superior and the postero-superior capsule. With the femur flexed and externally rotated, perform a Z-shaped capsulotomy. Make the long axis of the capsular incision along the long axis of the femoral neck, being cautious not to injury the lateral retinacular vessels. Make the antero-inferior part of the capsular incision while remaining anterior to the lesser trochanter, avoiding injury to the medial femoral circumflex artery. Make the supero-posterior part of the capsular incision parallel to the acetabular labrum to the retracted tendon of the piriformis muscle.
13. Dislocate the hip by flexion and external rotation of the leg.
14. Perform the operative repair within the hip.
15. The vascular supply to the femoral head can be tested by Doppler flowmetry or by observation of bleeding at the periphery for the femoral head.
16. Reduce the hip by manual traction of the flexed knee and internal rotation of the leg.
17. Repair the capsule, but not tightly.
18. Reattach the greater trochanteric osteotomy by screws or wire.
19. Close the operative wound.

Outcome

Ganz et al.[177] reported his experience in using this technique in 213 hips over a 7-year period. No hips developed AVN. Kim and Millis reported their experience at the Specialty Day Meeting (February 26, 2005, Washington, DC) with this approach at the Children's Hospital in Boston from July 2001 to November 2004. Eighty-nine hips in 85 children underwent a "safe" hip dislocation. Twenty-nine hips in 26 patients were treated for femoro-acetabular impingements. Three hips developed AVN after associated osteotomies in the subcapital femoral neck and intertrochanteric areas.

ARTHROSCOPY OF THE HIP BY BOWEN[50,502]

Arthroscopy of the hip is helpful in removing intra-articular loose bodies, debriding and repairing labral lesions, and resecting abnormal impingement of bone and cartilage from the femoral head-neck area.[144,169,198,246,276,277,412] Arthroscopic examination of the hip can be considered as two compartments.[55,279] The central compartment includes the articular cartilage (femur and acetabulum), acetabular fossa, and ligamentum teres. The peripheral compartment includes the nonweightbearing cartilage of the femoral head, the femoral neck, capsule/synovia, and intrinsic ligaments. Visualization of the central compartment requires traction to separate the femoral head from the acetabulum by about 6 mm and allow space for the introduction of the scope. Traction can usually be achieved by skin traction from a fracture table or by an external fixator spanning from the femur to the acetabulum. Arthroscopy of the peripheral compartment can be performed without traction by positioning the hip, thereby freeing the capsule at the desired area for scope introduction.[132]

Bowen recommends that the patient be positioned supine on a fracture table and the entire leg/hip be draped freely. The fracture table should be set up to allow skin traction at the ankle as well as free movement of the leg. Traction from the fracture table is typical; however, a monolateral external fixation is available if addition distraction is required. (In children, Bowen uses a monolateral external fixation for traction because of the fear of a physeal separation in the leg from fracture table traction.) A mobile image intensifier is positioned above the hip and is withdrawn when not utilized. An arthrogram is performed to facilitate the placement of the arthroscope. Occasionally, hip arthroscopy cannot achieve the desired goals and operative exposure will be necessary; therefore, concurrent permission for arthroscopy and/or operative exposure should be requested so that treatment may proceed if arthroscopy is inadequate.

Procedure

1. Position the patient supine on the fracture table. Set up the table for free motion of the leg/hip as well as for skin/ankle traction (a pubic post is positioned for countertraction).
2. Prepare and drape freely the entire leg and hip area.
3. Introduce a 21-gauge spinal needle from an antero-lateral portal and perform arthrography of the hip (see Arthrography of the Hip Joint in chapter 3).
4. For central compartment visualization, apply traction is until the hip joint is distracted approximately 6 mm to 1 cm (table traction or by external fixation)

4B. For peripheral compartment visualization see 5B.

5. Introduce a 5-mm arthroscope with a 30° angular lens under image intensification through an antero-lateral portal just lateral to the sartorius muscle. Special attention must be paid to the introduction of the arthroscopic trocar, directing the tip beneath the lateral acetabular labrum, through the capsule, and into the distracted space in the hip joint (be careful not to injury the labrum or articular surface).

6. The hip capsule may be penetrated only once; multiple punctures allow irrigation solution to escape into the soft tissue about the hip.
7. Irrigate the joint with lactated Ringer's solution (or other desired irrigation arthroscopic fluid).
8. If bleeding occurs, epinephrine may be added to the irrigate (caution: calculate appropriate dosage).
9. Evaluate the joint; multiple-angled lenses may be necessary.
10. Removal of a loose body or repair of a labral tear, etc. may require additional portals. Prepare additional portals in a similar manner as for arthroscope insertion, above.
11. At the end of the arthroscopy, remove the scope and close the small incisions by sutures.

5B. Flex the hip (without traction) to make the anterior capsule lax.
6B. Place the arthroscope into the anterior aspect of the hip as with steps 5–9.
7B. Additional portals may be placed in a similar manner.
8B. Areas of femoral neck that cause femoro-acetabular impingement may be debrided and labral tears repaired.[132]
9B. Fluoroscopic (image intensifier) confirmation of bone debridement is helpful.

Outcome

The outcome of arthroscopic treatment is not extensively reported; however, arthroscopy offers the advantage of not dislocating the hip and possibly reduces probability of AVN. In the author's experience,[50,502] removal of osteo-chondral loose bodies have been very successful. Labral tears may be difficult to repair. Removal of bone from the femoral neck that impinges against the acetabulum has been problematic if metaphyseal bleeding obstructs visibility. The author has had two complications[502] from hip arthroscopy, which were temporary pudendal nerve dysesthesias with full recovery possibly from the traction; however, there is potential for many severe complications.[499]

PELVIC SUPPORT OSTEOTOMY AND FEMORAL LENGTHENING

A pelvic support osteotomy (PSO) and distal femoral lengthening may be an acceptable solution to alleviate pain for young adults[67,280,443] or adolescents with high-dislocated hips. This procedure consists of a subtrochanteric osteotomy to achieve adduction of proximal segment of the femur. The effect of this osteotomy is to place the proximal femur under the pelvis for support. In addition, abductor muscles are lengthened and their leverage with the greater trochanter moves distally and laterally. A second osteotomy can be performed in the distal femur to treat a limb-length discrepancy and align the mechanical axis of the limb. The purpose of the pelvic support osteotomy is to improve function of the affected extremity, remove pain, correct a limb-length discrepancy, and reduce Trendelenburg gait.[443]

In adolescents or young adults with untreated high congenital dislocation of the hip there are many orthopaedic problems, which may include pain, limp, hip instability, weakness of the abductor muscles, limb-length inequality, joint arthrosis, stiffness, and limitation of daily activities. The goal of treatment is to achieve a painless, stable, and functional hip. There are four treatment alternatives that may achieve this goal: excision of the femoral head and neck, arthrodesis, joint replacement, and pelvic support osteotomies. Resection of the femoral head and neck is seldom indicated in DDH and has a very high rate of morbidity (Girdlestone procedure).[25] This operation is seldom performed and is almost a historical procedure. Arthrodesis provides a stable, pain-free hip; however, it may have an adverse effect on other joints, as in the lower back, contralateral hip, and knees.[58,539]

Hip arthrodesis is contraindicated in bilateral hip disease. The experience of total hip arthroplasty in young adults with a congenital dislocation of the hip has a high incidence of early failure.[36,134] Long-term follow-up of a group treated with a cemented Charnley arthroplasty gave a failure rate of over 40 percent at 25 years due to aseptic loosening.[31] This group also had a revision rate 3.3 times greater than normal and 10 times higher for infection.

The pelvic support osteotomy was first performed for DDH by Bouvier in 1838.[139] Modifications have been described by Kirmisson, Lorenz,[357] Schanz,[173,501] Milch,[398–402] and Hass.[244] Walter Blount used a plate and screws to internally fix the osteotomy.[42] In arthritic hips, the femoral head and neck can be resected.[399]

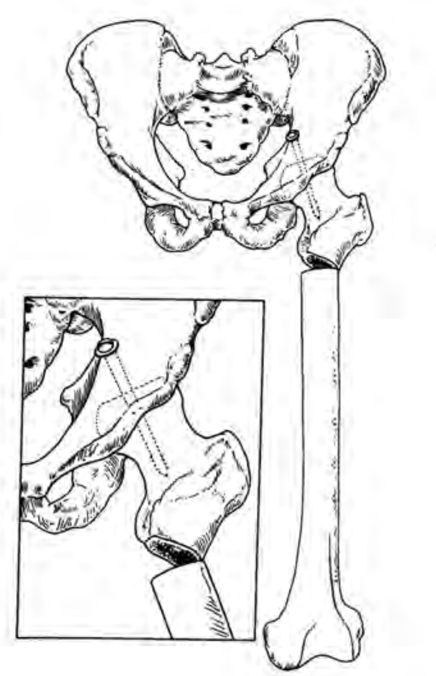
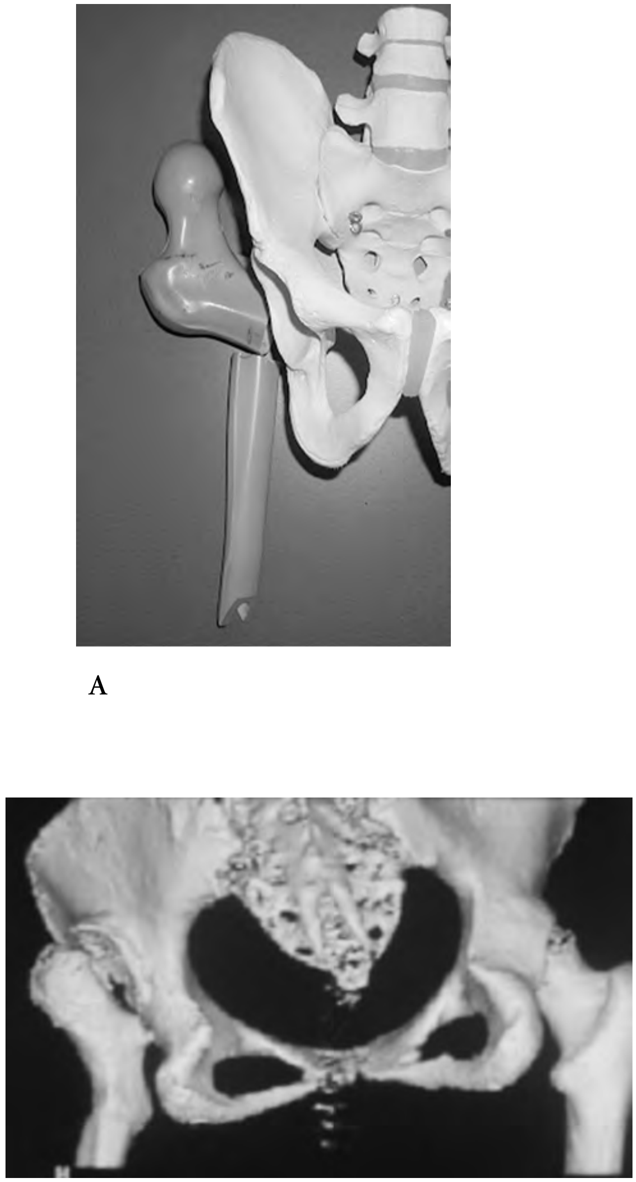


Figure 12-6 Schematic drawing of the Schanz osteotomy.



A

B

Figure 12-7 **A.** Model of a Lorenz osteotomy (from Dr. M. Inan). **B.** Three-dimensional CT of the Lorenz osteotomy (medial displacement of the femoral shaft).

Figure 12-8 Milch osteotomy (resection of the femoral head). **A.** Preoperative radiograph of a high dislocated painful hip from DDH. **B.** Postoperative radiograph following a Milch osteotomy. Notice the resection of the arthritic dislocated femoral head. **C.** MRI showing the Milch osteotomy (from Dr. M. Inan).

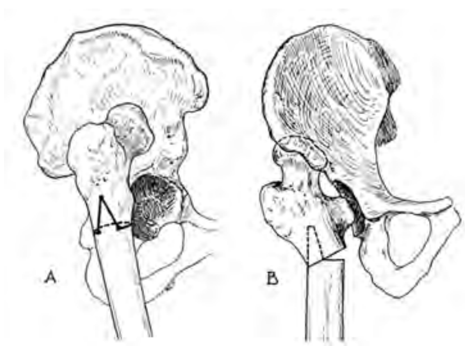


Figure 12-9 Schematic drawing of the Hass osteotomy (from Hass J: A subtrochanteric osteotomy for pelvic support, J Bone Joint Surg 25A: 281–91, p 283, Fig 2).

These procedures were able to treat the hip instability but not the limb-length discrepancy and mechanical axis of the limb until Ilizarov modified the pelvic support osteotomy by adding a distal femoral lengthening. Catagni[67] and Paley[443] have advocated extensive preoperative planning with a hybrid Ilizarov technique. Recently, Muharram Inan described a unilateral fixator technique to facilitate patient mobility (personal communication).

Indications

- Older than 13 years of age
- Unilateral or bilateral high hip dislocation
- Pain in the hip/groin area
- Low back pain related to postural lordosis or/and scoliosis

Pelvic Support Operation, Ilizarov Technique[67,280,443]

Preoperative planning

1. *Level of the proximal osteotomy:* The level of the proximal osteotomy is determined from an antero-posterior radiograph of the pelvis with the involved limb in maximum adduction. The osteotomy of the proximal femur should be at the level of the ischial tuberosity.
2. *Correction of the proximal femoral valgus, rotation, and extension:* Determine proximal femoral valgus correction of the femoral osteotomy by taking antero-posterior radiographs of the patient standing on the affected leg. Calculate the difference between the femoral shaft longitudinal axis and the perpendicular line of the pelvis (A°). The valgus angle of the pelvic support osteotomy should be A° plus 15° of overcorrection. At the proximal osteotomy, the femur should be extended by the amount of flexion contracture of hip plus 5° and internally rotated 10–15° to achieve stability of the hip during single-leg stance.
3. *Planning of distal femoral osteotomy:* The proximal axis line is the line perpendicular to the horizontal line of the pelvis, passing through the apex of the proximal femoral osteotomy. The distal axis line is the mechanical axis line of the distal femur. The center of rotation angulation (CORA) is the level of distal femoral osteotomy. The distal femoral osteotomy is performed at the CORA level. The femur is lengthened first without angular correction. After the lengthening has been achieved, a gradual varus angulation of the distal osteotomy is performed by using the hinges in the external fixator until a normal mechanical axis is achieved.

Pelvic Support Osteotomy, Ilizarov Technique[280]

1. Place the patient, under general anesthesia, supine on a fracture table.

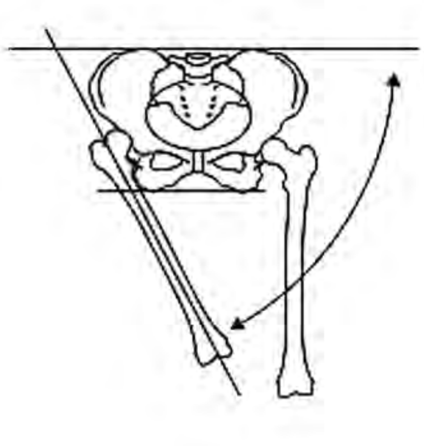


Figure 12-10 Drawing of an antero-posterior radiograph of the pelvis with the hip in maximum abduction. The proximal osteotomy of the femur is at the ischial tuberosity level.

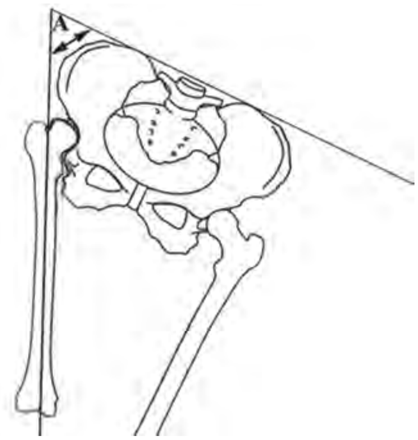


Figure 12-11 Schematic drawing demonstrating the amount of standing adduction (A°). The valgus angulation of the proximal femoral osteotomy should be A° plus 15°.

2. Insert a 5–6-mm half-pin laterally under image intensifier from the greater trochanter with the precalculated angle (A° + 15°).
3. Insert a second half-pin 15 cm distally from the first half-pin and perpendicular to the distal femoral shaft.
4. Attach an Ilizarov external fixator arch to each half-pin and add one or two half-pins to each arch.
5. Perform the proximal osteotomy at the precalculated level in the femur through a 3-cm transverse incision between the two arches. Closure of soft tissue with this transverse incision after the adduction osteotomy is easier than in a longitudinal incision.
6. Achieve valgus angulation is by bringing the arches parallel. Fifteen degrees of internal rotation and extension should be added in addition to adduction to obtain optimal support.
7. Connect the arches with rods while they are holding the corrected position.
8. Insert a 1.8-mm K-wire distally into the femur at the level of superior pole of the patella from lateral to medial direction and parallel to knee joint line.
9. Attach tensioned K-wire to the ring and add two half-pins, one posteromedial and one posterolateral, in the supracondylar region of the femur.
11. Connect the distal rings to the arch with hinges and rods.
12. The level of the hinges must be centered on the distal osteotomy site.

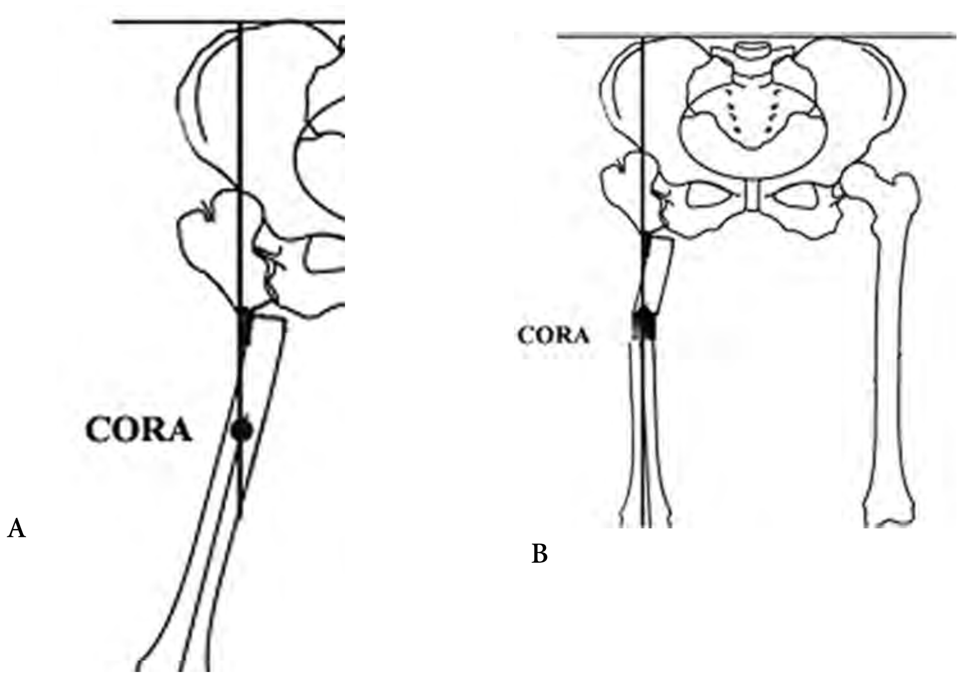


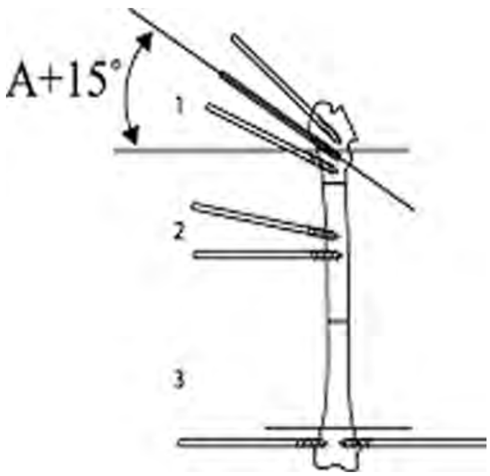
Figure 12-12 **A.** Calculation of CORA point by using proximal and distal axis lines for determining distal osteotomy level. **B.** The final mechanical axis is perpendicular to the horizontal line of the pelvis and normal lateral distal femoral angle of 87° should be obtained.

13. Perform a transverse distal osteotomy, supracondylar or diaphyseal, between the arch and the distal ring. (Caution: Both locations have disadvantages. Knee joint stiffness occurs frequently after a supracondylar osteotomy, and delayed bone consolidation after a diaphyseal osteotomy.)

Unilateral Fixator Technique for the Pelvic Support Osteotomy (M. Inan, personal communication)

Preoperative planning

1. *Level of the proximal femoral osteotomy:* The level of the osteotomy in the proximal femur is at the contact point of the femur to the pelvis as the hip is fully adducted. The contact point can be acetabular, subacetabular, or ischium. For example, the contact point of femur can be at the level of acetabulum in a patient who has a highly dislocated hip, and at the ischial tuberosity level for a subluxated hip.



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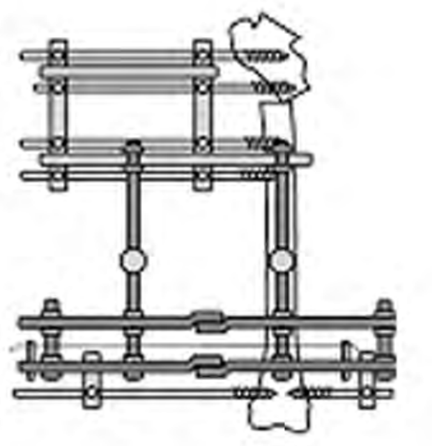

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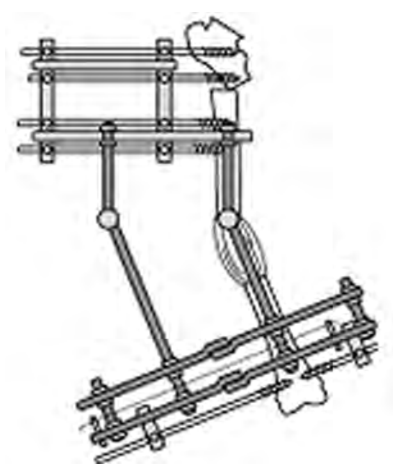


C

Figure 12-13 Ilizarov technique for pelvic support osteotomy. **A.** Schematic drawing showing placement of the pins at the planned angles in the femur. **B.** Schematic drawing shows the external fixator application. **C.** Schematic drawing showing the correction of the mechanical axis of the femur through the distal femoral osteotomy.

2. *Level of the distal femoral osteotomy:* The distal femoral osteotomy is to be performed near the midpoint between the proximal femoral osteotomy and the knee joint line.

3. *Determination of the angle of the osteotomies:* The angle of the proximal femoral osteotomy is determined as the degrees of maximum hip adduction plus 15°. The angle of the distal osteotomy of the femur is formed by a line parallel to the shaft of the femur below the proximal osteotomy and a line of the mid-diaphysis of the distal femur. (The line of the mid-diaphysis of the distal femur is 87° to the distal femoral condyles of the knee.)

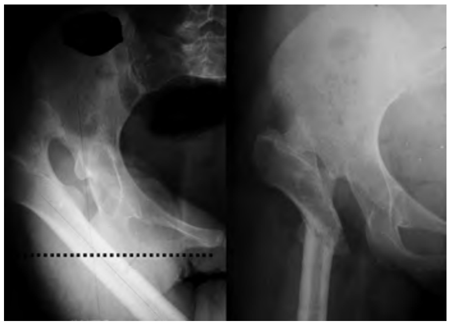


Figure 12-14 Radiographs demonstrating that the level of the osteotomy in the proximal femur is at the contact point of the femur to the pelvis as the hip is fully adducted.

Surgical Technique of Inan

Order of the procedure

First all monolateral half pins are placed at the levels and positions determined during the preoperative planning. Second, the proximal femoral osteotomy is performed and secured by an external fixator (monolateral rail type). After this step, the pelvic support component of the operation is established. Third, the distal femoral osteotomy is performed and the mechanical axis of the femur is corrected acutely by an additional clamp to the external fixator (set the rail fixator to lengthen through the distal osteotomy).

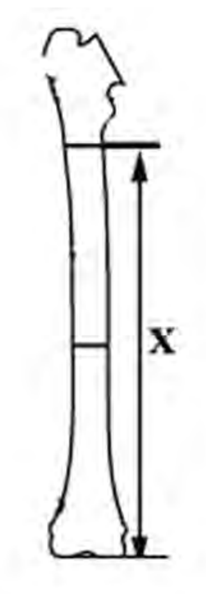


Figure 12-15 Schematic drawing showing the level of the distal femoral osteotomy, which should be performed near the midpoint between the knee and the proximal femoral osteotomy.

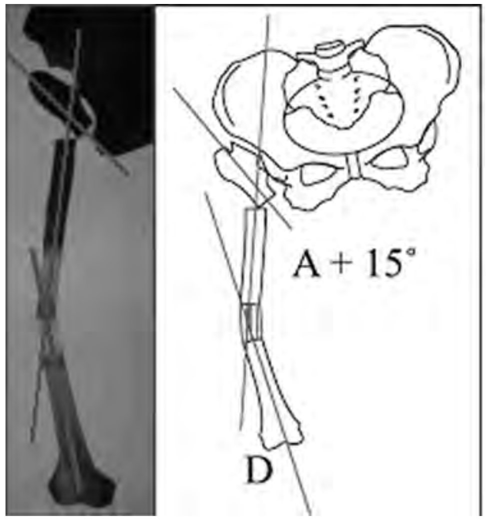


Figure 12-16 Schematic drawing showing the angle of the proximal femoral osteotomy to be the maximum adduction of the hip (A) + 15° and the angle of the distal femoral osteotomy to correct the mechanical axis (D).

Postoperatively the femur is lengthened through the distal femoral osteotomy until the limb length is corrected.

1. Insert the first pin (5–6-mm half-pin), under image intensifier, as described above with the Ilizarov technique.
2. Insert the second pin about 15 cm distally and with 15° of internal rotation relative to the first pin.
3. Insert the third pin into the distal femoral metaphysis according to preoperative planning angle (D). Determine the angle and the level of pins by the radiographs.
4. Insert the fourth pin into the proximal femur distal to the first pin and establish the appropriate distance between the pins by using the fixator clamp. Position this fourth pin posteriorly relative to the first pin to obtain 15° of extension of the proximal femoral osteotomy site.
5. Apply additional pins by using the fixator clamp as a guide at the middle femoral and distal femoral levels.
6. Perform the proximal femoral osteotomy with a transverse incision between the first and second pins.
7. Then bring the proximal mono-lateral fixator clamp parallel to the middle clamp to achieve extension, internal rotation, and adduction of the proximal femur through the proximal femoral osteotomy.

8. Attach clamps to the mono-lateral fixator body, which stabilizes the proximal femoral osteotomy in the desired position for the pelvic support osteotomy to heal.
9. Use a longitudinal lateral incision for the distal femoral osteotomy. Following the distal osteotomy, achieve an acute varus correction by bringing the middle and distal clamps parallel.
10. Attach the distal clamp to the fixator.
11. Determine bone contact at the distal femoral osteotomy site with the image intensifier.
12. Soft-tissue releases around the pin sites may be required to prevent excessive skin tension.

Postoperatively, limb lengthening can be carried out through the distal femoral osteotomy to achieve lower limb equality.

Postoperative

Physical therapy and partial weightbearing with crutches are begun postoperatively. Following a recovery period of 7 to 10 days postoperatively, gradual lengthening is started from the distal osteotomy site at a rate of 0.25 mm four times a daily (total maximum daily lengthening of 1 mm). In the Ilizarov technique, after the lengthening is near to completion, a gradual varus angulation of the distal osteotomy is performed using the hinges until a normal mechanical axis is achieved. For the unilateral fixator technique, a full-leg AP radiograph is taken when distraction is ended. If there is a mechanical axis deviation, correction can be achieved by adjusting the fixator.

Outcomes

The major goal of the procedure, which is to achieve a painless, stable hip and a negative Trendelenburg sign, can be obtained in 50–82 percent of patients.[67,319,375] Pain relief can be achieved in arthritic hips after the pelvic support femoral osteotomy and resection of femoral head in 75–80 percent of hips. Functional abduction obtained on the surgical treated side aids perineal hygiene and sexual function in women.[375]

Valgus deformity of the proximal femoral created by the pelvic support osteotomy may add significantly to the surgical difficulty of later arthroplasty (total hip replacement) but probably does not affect long-term outcomes.[519] This valgus deformity may need to be corrected by an osteotomy before joint arthroplasty.[531]

Complications

Pin-tract infection is more common in the proximal pin sites than in the distal pins and can be treated with local pin site care and oral/parenteral antibiotics, Occasionally pins must be removed to prevent extensive osteomyelitis. Delayed consolidation may be seen following lengthening procedure from a diaphyseal osteotomy and is treated by slowing

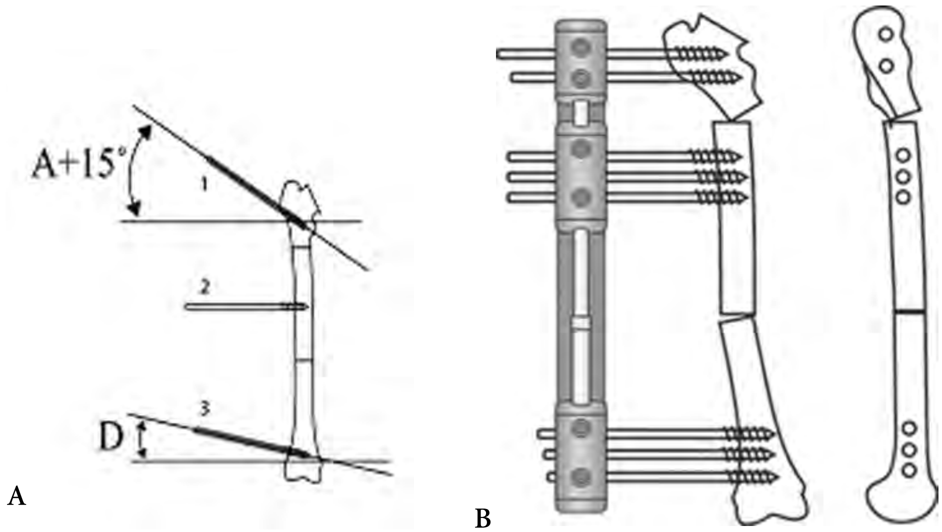


Figure 12-17 Unilateral fixation technique. **A.** Schematic drawing showing the inserted reference pin and the position of the second pin before the proximal osteotomy. **B.** Schematic drawing after osteotomies and application of the monolateral fixator.

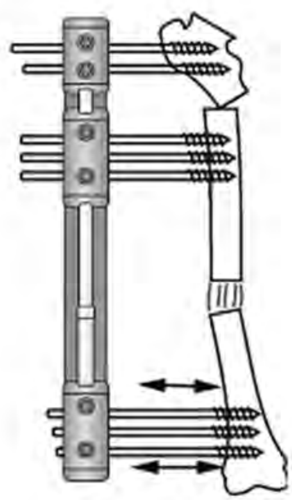


Figure 12-18 Schematic drawing shows varus angulation of the osteotomy of the distal femur by using hinges to correct mechanical axis. Correction of mechanical axis is achieved by pulling or pushing the distal pins before tightening the clamp of the monolateral fixator.

the distraction rate. Premature consolidation is rarely a problem and can be treated by manipulation of the osteotomy site under anesthesia.

Knee stiffness is a common problem. To avoid a permanent contracture, range-of-motion therapy is crucial. In general, biarticular muscles should be stretched 30 times per session and uniarticular muscles should be stretched 10 to 15 times per session. A progressive loss of the valgus angulation of the proximal osteotomy can lead to a lack of pelvic support and a persistent Trendelenburg gait. In the preoperative planning, a slightly increased valgus is desired to reduce the risk of loss of correction during lengthening. The position of the proximal femur must be monitored during the lengthening and consolidation phases to ensure a proper position. A fracture of the femur can occur during the lengthening or more commonly after removal of an external fixator. To reduce the risk of a fracture after removal of the fixator, a cast or brace can be used for 3 months after the removal of an external fixator. A fracture may require reapplication of the external fixator to prevent malunion.

TOTAL HIP ARTHROPLASTY

Hip arthroplasty in adolescents or young adults who have hip arthrosis from dysplasia is an operative procedure to relieve pain and increase functional ability. However, there are conflicting reports on long-term outcomes. Many series report rather poor results, especially with high rates of loosening.[71,134,531] Schotard and Porter reported the long-term follow-up of a group treated with a cemented Charnley arthroplasty, which gave a failure rate of over 40 percent at 25 years due to aseptic loosening.[531] This group also had a revision rate 3.3 times greater than normal and a 10 times higher rate of infection. In addition, the abnormal anatomy of the femur and acetabulum, which includes increased anteversion, a narrowing medullary canal of the femur, acetabular deficiency particularly at the superior aspect, increases intraoperatively the risk of iatrogenic complications.[184,194] For these reasons, some orthopaedists consider a total hip arthroplasty a poor choice of treatment in younger patients. Some recent studies have reported good long-term outcomes and low complication rates in adults.[232,239,452] The improved outcomes have been attributed to the procedures being performed by specialized surgeons or to technological development of total arthroplasty systems.[63]

Indications

Severe pain

Limitation of hip motion

Contraindications

Open triradiate cartilage in growing children

Active infection

Operative Considerations

Templates may be used for preoperative planning to estimate appropriate size of the femoral stem and acetabular cup. The placement of the acetabular cup is important. Hartofilakidis[240] classified the congenital dislocated hip into three types: type I is dysplastic, type II has a low dislocation, and type III has a high dislocation. Most authors[390] recommend placement of the acetabular component in the true acetabulum with or without cement because of equalization of limb shortening and improvement of abductor muscle function. The shallow dysplastic acetabulum may, however, require a very small-sized acetabular component and the use of a thin polyethylene liner. This is major limitation of this prosthesis, especially in young and active patients with CDH.[282] Femoral head autograft or allograft can be used for increasing superior coverage of the acetabular component.[318,537] In the cases with a high dislocation, femoral shortening is recommended to allow the acetabular component to be placed in the normal anatomical location. Placing the acetabular component in the anatomical location may prevent excessive compressive loads across the hip joint.[73]

The required femoral component is often smaller than normal to contour to the narrow femoral canal in hips with DDH. Techniques for femoral component stabilization differ including those with or without bone cement. The stem of the femoral component may need to be straight and the position of the femoral stem is to be in neutral or slight anteversion in relation to the axis of the knee joint. Severe femoral anteversion as observed in some hips with DDH may be corrected with a modular component or with a derotational osteotomy of the femur. However, maintenance of torsional stability of the femoral stem can be a problem after femoral shortening or osteotomy, and augmentative techniques using plate fixation, wire circulage, and bone grafting may be necessary.

Postoperative Rehabilitation Program

There is no universally accepted standard for rehabilitation treatment of patients with DDH following total hip arthroplasty. However, several common items are accepted. In the early postoperative period, adduction of the hip is avoided to prevent dislocation of the acetabular and femoral components. The hip can be positioned in abduction by using a hip abduction pillow. Isometric exercise of the quadriceps and gluteal muscles is started postoperatively, usually in the first postoperative day. Gait training begins with assistance to prevent injury. If the total hip arthroplasty components are cementless or if a femoral osteotomy is performed, limited weightbearing is often recommended for 6 to 8 weeks. With cemented components, early weightbearing to tolerance is often permitted.

Complications of Total Hip Arthroplasty

1. Intra-operative:
   - Fracture in the proximal part of femur
   - Femoral shaft perforations
   - Neurovascular injuries

2. Early complications:
   - Dislocations
   - Hemorrhage
   - Periprosthetic fracture
   - Superficial or deep soft-tissue infection
   - Thrombophlebitis
   - Pulmonary embolism
3. Late complications:
   - Aseptic or septic loosening
   - Nonunion of femoral osteotomy
   - Periprosthetic fracture

Rorabeck and Bourne[486] reported the outcomes of 180 total hip replacements in 148 women and 32 men with hip dysplasia. Dysplastic acetabulae were treated in 140 hips, low dislocations in 17 hips, and high dislocations in 23 hips. The average at total hip replacement was 46 years and the mean follow-up was 8.5 years. All acetabular components were cementless, and all sockets were relocated to the true anatomical position. Femoral stems were placed cementless in 141 hips, and 39 stems were cemented. Most femoral stems were bi-body, which allowed compensation for the femoral shortening, excessive anteversion, and the posterior position of the greater trochanter. In cases requiring femoral shortening they recommend strut allograft to enhance torsional stability. The surgeon should attempt to place the acetabular cup in the location of the true acetabulum. In the dysplastic acetabulum, the anatomical location can be obtained by reaming to the anatomical position. If good cup fixation can be obtained, a cementless cup without bulk allograft is recommended. If coverage is less than 50 percent, bulk allograft is recommended. They reported a common need for a 36- or 40-mm acetabular component, which necessitates a 22-mm femoral head component. They concluded that cementless femoral stems had 97 percent survivorship and gave excellent results.

HIP ARTHRODESIS

The goals of hip arthrodesis are to provide a stable joint and complete pain relief. The authors are unaware of a specific operative technique for hip arthrodesis in patients with DDH; however, techniques developed to treat other conditions have been adapted. The authors perform a hip arthrodesis by removing the articular cartilage of the femoral head and acetabulum (internal fusion), placing internal fixation across the femoral head and acetabulum, applying bone graft around and across the hip joint (a muscle pedicle grafts works well), and maintaining postoperative spica casting until fusion.

There are many reported techniques to achieve hip arthrodesis. In 1884, Heusner[253] achieved successful arthrodesis of the hip in a patient with a congenital dislocation of the hip, and according to Murrell et al.,[420] La Grange in 1892 performed a hip arthrodesis on a

16-year-old girl with hip dislocation and arthritis. In 1938, Watson-Jones[638] added internal fixation (Smith-Petersen nail) in an attempt to maintain the hip position and decrease the time for healing in a cast. In recent years, many other types of internal fixation, including include screws, plates, and rods, have been used successfully.[13,19,127,386,504,549,550]

Bone grafting facilitates fusion; multiple techniques for bone grafting have been developed.[70,117,550] Intra-articular grafts include cortical struts from the fibula and tibia allografts. Bridging grafts may be mortised into slots across the hip. These grafts may be vascularized by a muscle-bone pedicle from the ilium or femur. On-lay grafts of cancellous bone are often used around the hip to increase the potential for arthrodesis. Extra-articular hip arthrodesis can be achieved from the femur to the ischium.

Aladar Farkas[152] from Budapest developed an ingenious modification of hip arthrodesis technique to protect the hip during the early stage of healing. He fused the hip in 17 cases by adding a subtrochanteric osteotomy to the routine technique of articular surface debridement of the hip and acetabulum. The subtrochanteric osteotomy relieves the movement forces across the hip and allows the hip to fuse before the subtrochanteric osteotomy heals. The authors have found the Farkas modification to be very helpful.

Indications in Adults with Sequelae of DDH

- Arthritis following DDH
- Avascular necrosis resulting in arthritis
- Painful hip dislocation
- After septic hip arthroplasty

Contraindications

- Bilateral hip pathology
- Active infection in the hip
- Severe osteoporosis

Operative Considerations

The position of the hip following arthrodesis is flexion of 15–20° and neutral abduction, adduction, or rotation.[299]

Techniques to accomplish an arthrodesis for arthritis following DDH in which the hip is reduced or subluxated are similar to techniques used in other conditions, such as infection and tuberculosis arthritis.[70,418,581]

The authors are unaware of a specific arthrodesis technique described to treat a high congenital dislocated hip.

Chandler Technique for Hip Arthrodesis[70]

Through a vertical incision, the lateral aspect of the proximal femur, the femoral neck, and acetabulum is exposed. The articular surfaces of the femoral head and acetabulum are removed. "Heavy grafts of cancellous bone are reflected from the antero-lateral and postero-lateral aspects of the greater trochanter. The periosteal and muscular attachments of these grafts are not disturbed. The trochanteric graft is turned end to end and shaped for maximum contact" across the hip joint to obtain the arthrodesis.[70]

Stone Technique for Hip Arthrodesis[550]

After the articular cartilage has been removed from the femoral head and acetabulum, a superior-based long vertical iliac bone flap is elevated and the dislocated femoral head is reduced beneath the flap. Additional graft may be added to enhance the fusion.

Davis Muscle-Pedicle Graft Technique for Hip Arthrodesis[117]

After the articular cartilage has been removed from the femoral head and acetabulum, a slot is prepared that extends from the acetabulum to the femoral head. A vascularized muscle-pedicle bone graft is harvested from the superior rim of the anterior crest of the ilium (iliac wing) and secured into the slot with screws.

Schneider Cobra Plate Technique for Hip Arthrodesis[420,504]

This technique was developed in 1966 for stabilization of the arthrodesed hip. A subtrochanteric osteotomy may be performed with or without pelvic osteotomy.

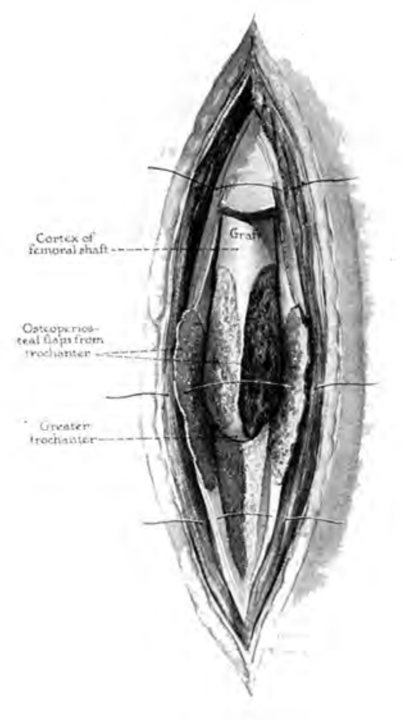


Figure 12-19 Schematic drawing of the Chandler technique for hip arthrodesis. Bone graft was obtained from the anterior and posterior areas of the greater trochanter to facilitate the hip fusion (from Chandler FA: Hip-fusion operation, J Bone Joint Surg 15: 947–52, p 950, Fig 4, 1933).

Hip Fusion and Subtrochanteric Osteotomy[581]

Outcomes of hip fusion

When the hip is fused in the optimum position, and when the spine, the contralateral hip, and the knee are mobile, good patient function is to be expected.[299] Often young adult patients readily adapt themselves to an arthrodesed hip. Sponseller et al. reported patients who had an arthrodesis with at least 20 years' follow-up (mean of 38 years).[539] Seventy-eight percent of the patients were satisfied with the outcome and 11 percent were dissatisfied. Occasional back pain was present in 57 percent of the patients. Ipsilateral knee pain was present in 45 percent, and contralateral knee pain in 26 percent. The hip arthrodesis had been converted into a total hip replacement in 13 percent. Most patients were described as uncomfortable with prolonged sitting, and as having limitation in sports; how-

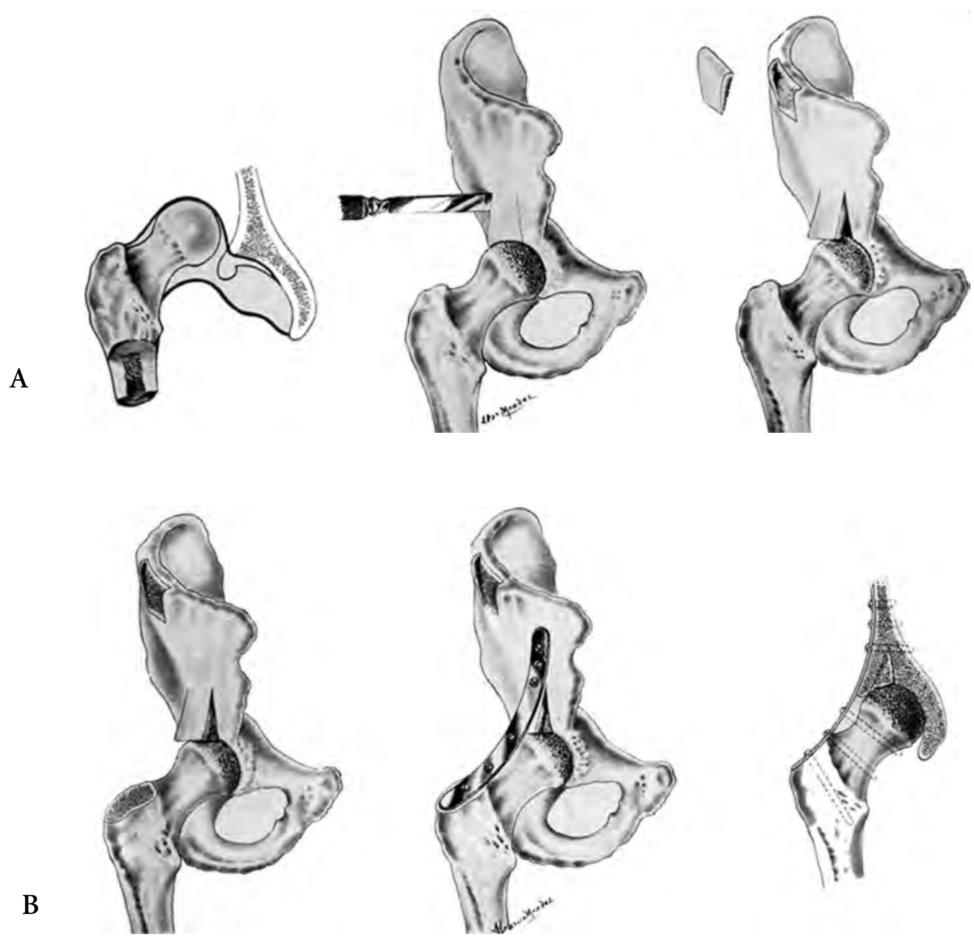


Figure 12-20 **A, B.** Schematic drawing of the Stone technique for hip arthrodesis (from Stone MM: Arthrodesis of the hip, J Bone Joint Surg 38A: 1346–52, p 1346, Fig 1).

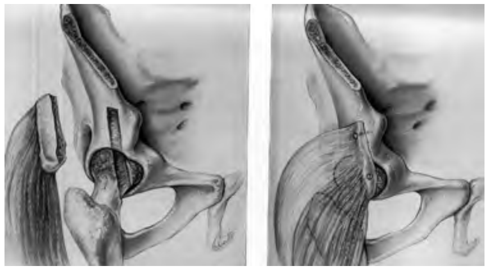


Figure 12-21 Schematic drawing of the Davis muscle-pedicle graft technique for hip arthrodesis (from Davis JB: The muscle-pedicle bone graft in hip fusion, J Bone Joint Surg 36-A: 790–99, p 791, Figs 2, 3, 1954).

ever, they considered their overall activity level to be average for their age group. The authors recommend a hip arthrodesis rather than a total hip arthroplasty in young patients with mono-articular hip disease.

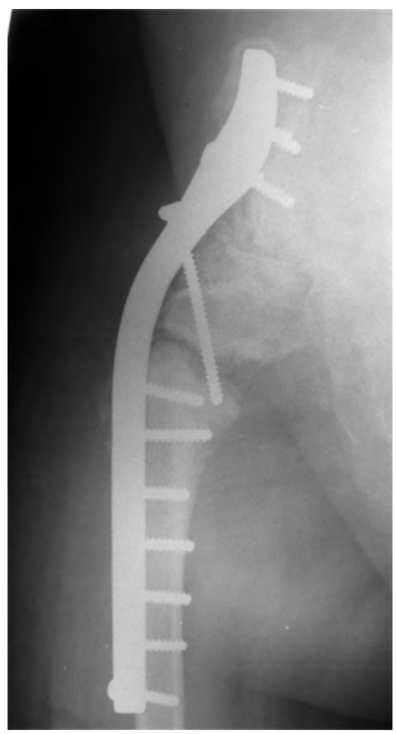


Figure 12-22 Radiograph demonstrating the Schneider Cobra plate technique for hip arthrodesis.

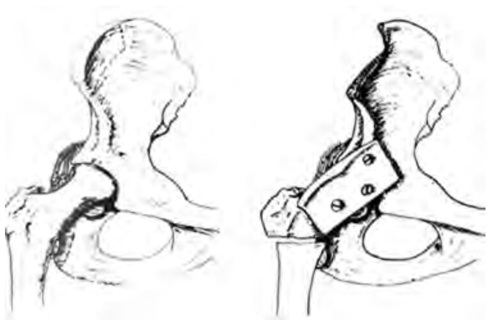
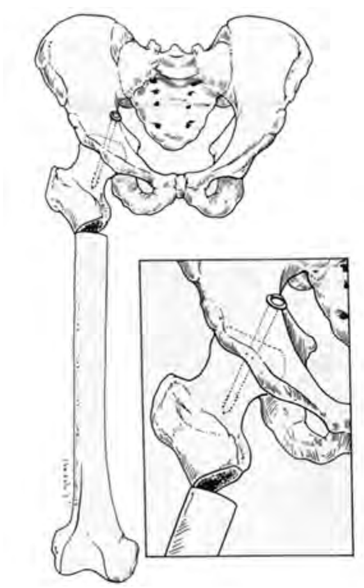


Figure 12-23 Schematic drawing of the Thompson technique of hip fusion with a subtrochanteric osteotomy (from Thompson F: Hip fusion and subtrochanteric osteotomy, J Bone Joint Surg 38-A, p 15, Fig 3, 1956).



A

B

C

Figure 12-24 A, B. Schematic drawing and radiograph of a technique of hip fusion with screw internal fixation and subtrochanteric osteotomy (from Mowery et al, Simple method of hip arthrodesis, J Pediatry Orthop 6, p 10, Fig 6, 1986). **C.** Radiograph of a technique of hip fusion with an external fixator.

Hip arthrodesis may have an adverse effect on adjacent joints such as in the lower back, contralateral hip, and knees.[58,539] Gore et al.[201] performed gait analysis in patients with a unilateral hip arthrodesis. The arthrodesis increased rotation of the pelvis, increased motion in the contralateral hip, and increased flexion of the ipsilateral knee. Gress et al.[208] reported 11 patients with a hip arthrodesis and with more than 10 years' follow-up. All patients had varying degrees of back pain, and 63.6 percent had evidence of degenerative arthritis in the contralateral hip. Degenerative arthritis was observed in 68 percent of the ipsilateral knees and in 60 percent of the contralateral knees.

Complications of hip fusion

- Nonunion
- Adjacent joint problems are most frequently complications after hip arthrodesis. Spinal problems after hip arthrodesis are common.[299] Eighty-four percent of the patients had back pain. Also, sclerosis of the sacroiliac joint was present in 70 percent of patients.
- Laxity of the medial collateral and anterior cruciate ligaments is another frequent finding related to hip arthrodesis.[171] The varus and valgus angulation of the knee are correlated with position of the fused hip. More than 10° of adduction of the hip is associated with greater valgus angulation of the knee; less than 10° of the abduction is associated with varus angulation.
- Early degenerative changes can develop at the contralateral hip. However, according to Sponseller et al.,[539] arthrodesis at a young age was not associated with degenerative changes.
- It should be remembered that arthrodesis may not end treatment, because conversation of an arthrodesed hip to a total hip arthroplasty may be performed in patients who have intractable pain in the lower back, knee, or contralateral hip.

In the authors' practice, hip arthrodesis has been an acceptable treatment for young adults with intractable hip pain and with severe mono-articular degenerative hip arthritis following DDH. However, currently few patients accept the restrictions of a hip arthrodesis, and most prefer instead a total hip arthroplasty.

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