Treatment of Legg-Calvé-Perthes Disease of the Hip by Joint Distraction

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Introduction

Management of Perthes disease remains controversial despite extensive literature exploring this subject. Obtaining and maintaining hip range of motion are the only principles of treatment that are universally agreed upon. Containment of the femoral head within the acetabulum is thought to have a beneficial role, especially in patients with more than 50% femoral head involvement [1]. Methods used to achieve containment include abduction bracing [2], femoral [3, 4] or innominate osteotomies [5], and shelf procedures [6, 7]. However, these methods are contraindicated when the degree of femoral head collapse and deformation prevent spherical hip motion [3]. Unloading of the hip was originally considered important in the treatment of Perthes disease [8]. Various methods, such as complete bed rest [8] and use of a Snyder sling [9], have been tried toward this end, but little evidence exists to show that these methods alter the natural history of the disease [10, 11]. The failure of unloading may be related to the misconception that non-weight bearing is equivalent to unloading. We now know that muscular forces on the non-weight bearing hip can apply one to two times the body weight. To truly remove all compressive forces from the hip, the muscular forces must be neutralized. This can be accomplished by hip joint distraction with an external fixator. Distraction of the hip also can reduce subluxation of the femoral head relative to the acetabulum.

Considering that the cartilage of the femoral head epiphysis actively proliferates into the uncovered and presumably unloaded lateral regions of the extruded femoral head [12], in 1989, I postulated that if the femoral head could be distracted back into the acetabulum, the epiphyseal cartilage might proliferate to fill the gap between the collapsed femoral head and the acetabulum. Furthermore, distraction would stretch out the contracted capsule and muscles around the hip and improved hip range of

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motion could be expected. Finally, the repair process and neo-osteogenesis of the femoral head could proceed without risking femoral head collapse. Based on this theoretical rationale, I first applied hip joint distraction as a therapeutic approach to Perthes disease in 1989. Although arthrodiatasis of the hip had been used and applied for other pathologies such as chondrolysis [13], it had not been used during the resorption phase of Perthes disease prior to this time to the author's knowledge.

Surgical Procedure (Fig. 7.1 and 7.2)

The patient is positioned supine with no bump under the hip. The pelvis should remain level and not tilted toward one side or another. The entire forequarter of the limb, from midline anterior to midline posterior and from ribs to toes, was prepped and draped free.

- Step 1: *Arthrogram of hip joint.*
  Anteroposterior (AP), AP in 30 ° flexion, AP in maximum abduction, and frog lateral fluoroscopic views are obtained with arthrographic dye in place. These are used to assess degree of medial dye pool, hinge abduction, coxa magna, and maximum flattening of the femoral head in the 30 ° flexed view.
- Step 2: *Percutaneous adductor tenotomy.*
  The hip and knee are flexed and abducted, and the adductor longus tendon is palpated at the groin and percutaneously cut with a number 15 blade. The hip and knee are then extended and abducted, and the gracilis tendon is then palpated and percutaneously cut at the groin.
- Step 3: *Psoas tendon recession.*
  Make a 3–4 cm anterior groin line incision medial to the anterior inferior iliac spine. Feel the femoral artery pulse and stay lateral to it. Identify the medial border of the sartorius muscle and dissect deep and medial to it. The femoral nerve lies on the iliopsoas muscle at its anteromedial border. The nerve is identified and retracted medially. Dissect down the medial side of the iliopsoas muscle and on the undersurface of its medial border find the psoas tendon. Cut the tendon while leaving a continuous muscle bridge of the iliacus muscle.
- Step 4: *Insert a flexion extension axis pin into the femoral head.*
  A horizontal line of the pelvis is marked on the drapes, guided by the image intensifier (line across the top of both iliac crests or bottom of both ischial tuberosities). The affected lower limb is held with the patella forward, knee in extension, and hip in 15 degrees of abduction relative to the horizontal line of the pelvis. With the image intensifier and a wire, mark a line over the diaphysis of the femur and a point over the center of the acetabulum. Draw a line from the center of the acetabulum point, perpendicular to the diaphyseal femoral line. Place the image intensifier into the lateral view. The dye in the hip joint helps identify the circumference of the femoral head. Draw a line representing the equator of the femoral head in the sagittal plane on the lateral aspect of the hip. Insert a 2.5 mm Steinmann pin into the center of the femoral head from the intersection point of the AP line with the lateral line. This pin should be perpendicular to the shaft of

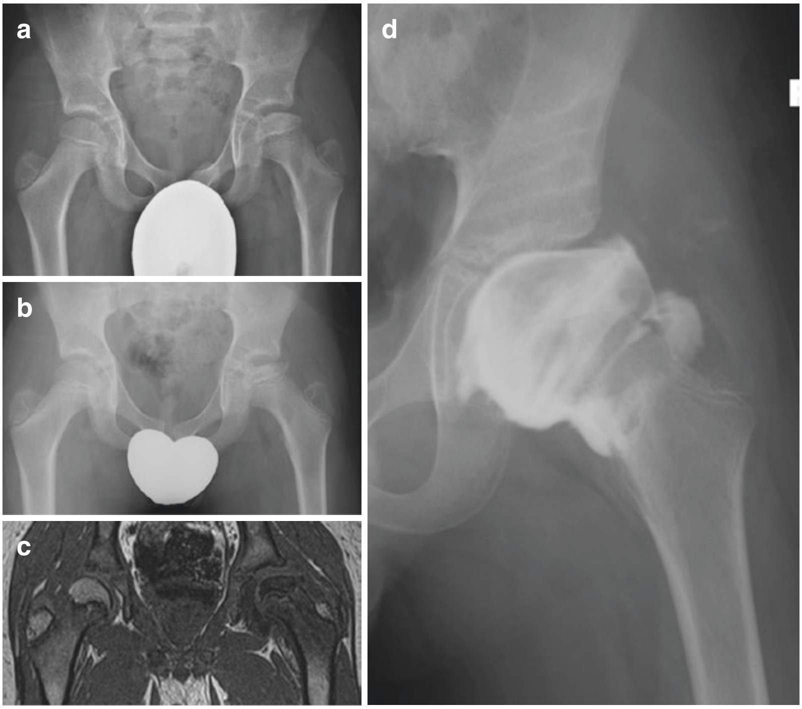
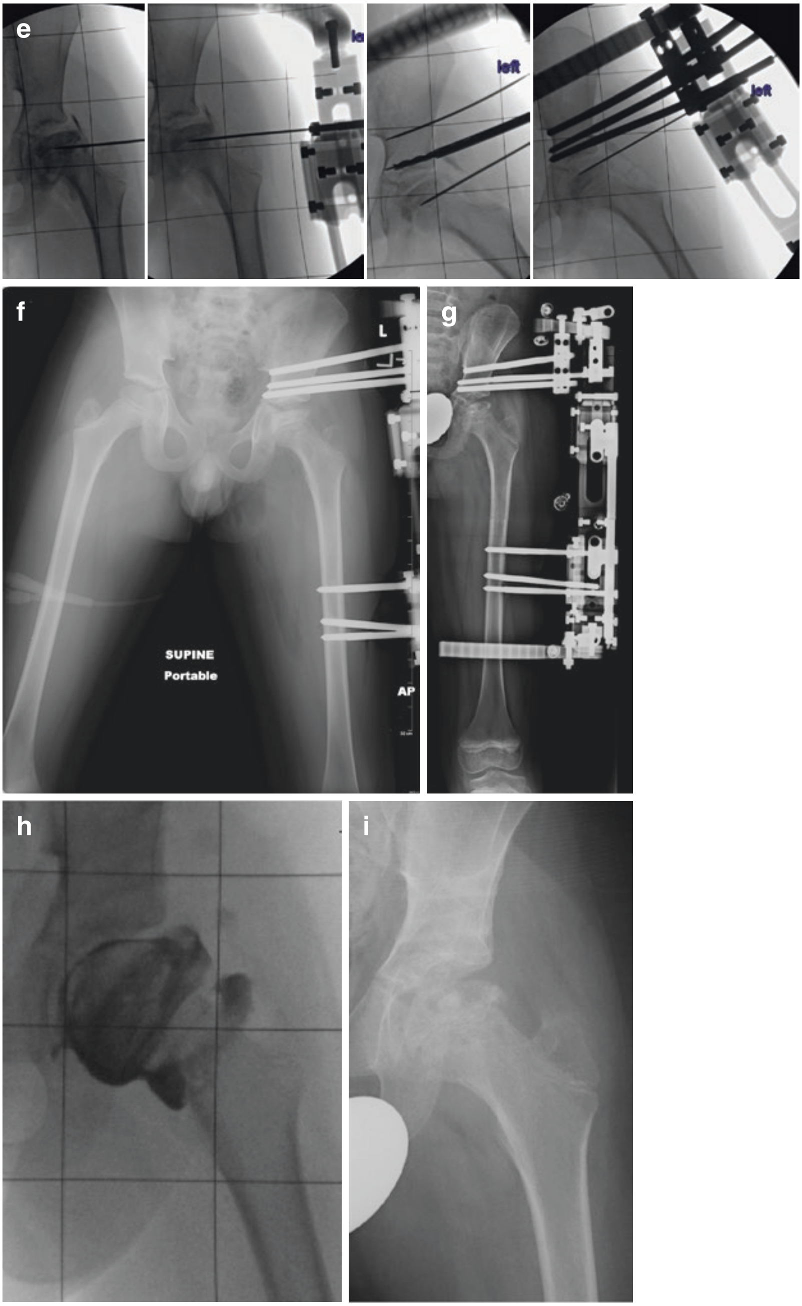


Fig. 7.1 (**a**) An 8-year and 10-month-old boy diagnosed with left-sided Perthes. There is already a slight increase in medial joint space and a small break in Shenton's line. The subchondral fracture can be seen. (**b**) Four months later the femoral head suddenly collapsed with increased pain and limitation of motion. There is more extrusion. (**c**) Pre-op MRI showing increased medial joint space, lateral extrusion and flattening of the femoral head. Note the marrow signal change in the femoral epiphysis compared to the opposite side. (**d**) Arthrogram left femoral head showing the flattening, extrusion, and medial dye pool. (**e**) Fixator placement starts with insertion of a center of rotation Steinmann pin into the femoral head (left). The pin is placed superior to the center of the head so that it ends after distraction in the center of the acetabulum. The unilateral external fixator is mounted on this pin through the cannulation in the hinge (left center). The pelvic pins are inserted at an oblique angle to the pelvis in order to abduct the hip (right center). A wire is inserted first followed by a cannulated drill bit followed by the threaded half pin. The arch is connected to the pins proximally. The hip is distracted acutely and the center of rotation pin removed and reinserted. Note that it lies in the center of the acetabulum and not the center of the femoral head which has been moved distally (right). (**f**) AP radiograph of both femurs and pelvis showing the abducted position of the left femur to the pelvis. There are four multiplanar pins in the pelvis and three in the femur. The rail is parallel to the femur shaft. The hip is overdistracted and Shenton's line is overreduced. The femoral head was moved medially and distally. (**g**) Only 2 months later the femoral head height is already increased and fills the distraction space created. Note the arch on the distal femur used to connect an anterior extension bar between the two arches. (**h**) Arthrogram of hip joint after removal of the external fixator. Note the rounding of the femoral head. (**i**) Femoral head immediately after removal. The lateral pillar is ossified, and the central portion, which has expanded, has some dead bone evident in its center (white sequestrum). (**j**) AP and frog lateral pelvis X-rays 4 years after distraction (age 13 years). The femoral head is now fully ossified. Both femoral head physes are about to close. The femoral head shape can be classified as a Stulberg Class 2. The acetabulum appears to be dysplastic due to the relative coxa magna. The patient has full range of motion of left hip and has no limp. ((C) Dror Paley. Used with Permission)



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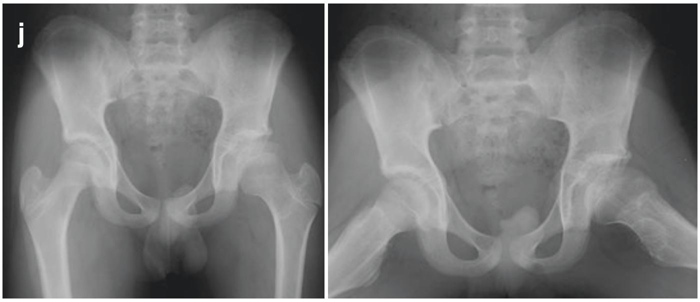

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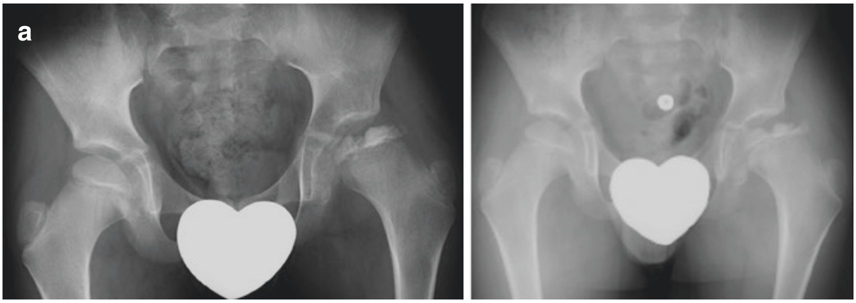
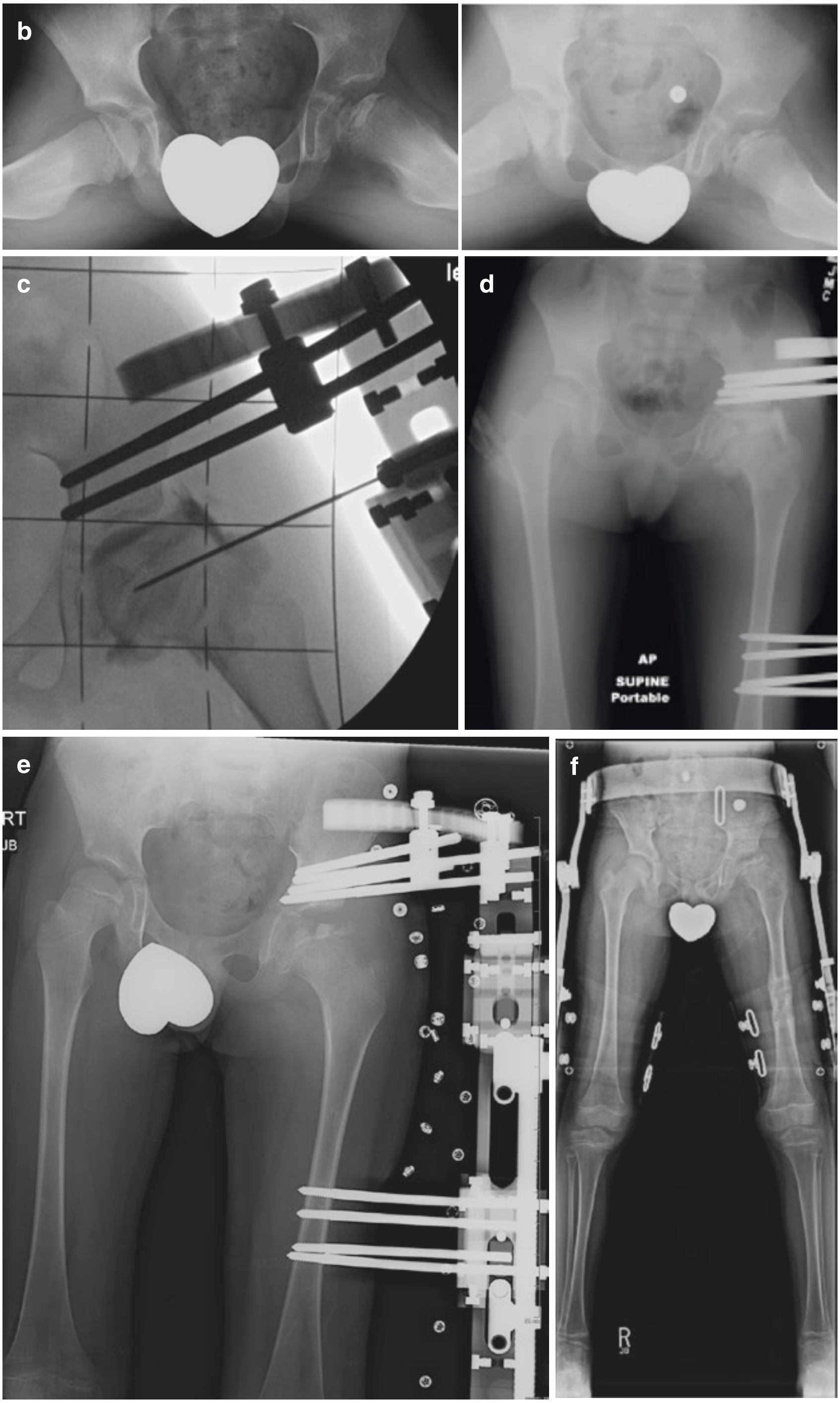


Fig. 7.2 (**a**) A 9-year-old boy with left hip Perthes. There is subluxation (break in Shenton's line and increased medial joint space) and extrusion. The epiphysis is decreased in height. (**b**) Three months later the hip is now fixed in adduction, which rapidly accelerates its deterioration. Hip motion was greatly reduced and pain increased. (**c**) Intraoperative fluoroscopic image showing hip distractor placement. Steinmann pin located at center of acetabulum. The pins in the pelvis are angled to hold the hip abducted. The flattening of the femoral head is outlined by the arthrographic dye. (**d**) Immediate postoperative AP radiographic view following application of hinged external fixation. The fixation of the hip holds it abducted relative to pelvis. Acute distraction of the joint with residual dye in the joint is seen. The femoral head has been shifted medially to eliminate the medial dye pool. There are four pins in the pelvis and four in the femur due to the larger size of the patient. Shenton's line is intentionally overcorrected. (**e**) AP radiograph of the hip 1 month after distraction already shows the rapid resorption of the femoral head. The necrotic bone is more evident due to this resorption. (**f**) Standing AP radiograph of both lower limbs in bilateral hip abduction brace a month after removal of the fixator. (**g**) AP (top) and frog lateral (bottom) radiographs 2 years after distraction (age 11 years). The femoral head is re-ossified. Shenton's line is intact. The femoral head appears enlarged and is likely ellipsoid in shape. The hip range of motion is almost the same as the opposite side with the exception of slight decrease in internal rotation. The patient has not pain or limp. (**h**) AP (left) and frog lateral (right) at age 14. The femoral head is fully ossified. The final femoral head shaped is classified as a Stulberg 2. There is no medial or superior shift. (**i**) Final hip range of motion is symmetric: upper left, abduction; upper right, flexion; lower left, internal rotation; lower right, external rotation. ((C) Dror Paley. Used with Permission)



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the femur, end in the center of the acetabulum and be in the midsaggital plane of the femoral head. Because the hip is usually proximally migrated, the center of rotation of the femoral head will be proximal to the center of the acetabulum. The axis pins should be centered on the acetabulum and is therefore more distal to the center of the femoral head.

- Step 5: *Preconstruct a hinged monolateral external fixator*

  Use one of the following: Orthofix, Biomet Zimmer, SN modular rail system (MRS), or Devise Orthopedics Drive Rail, and apply the cannulated hinge over the axis pin (please note that the Biomet Zimmer device was developed by Dr. David Feldman and the SN MRS and the Devise Drive Rail were developed by Dr. Paley). These three systems all offer the ability to distract above or below the hip hinge. The Orthofix device is limited to distracting only distal to the hinge.
- Step 6: *Insert the femoral frontal plane pins.*

  Adjust the distal clamp to the level desired on the femur (usually upper to middle third). Insert three frontal plane pins with the femur kept in the patella forward position. Leave room for lengthening on the distal fixator.
- Step 7: *Insert two pins into the anterolateral pelvis.*

  Roll the operating room table toward the opposite side so that the operative side is higher. Bring the image intensifier into the over the top position to take an oblique AP of the affected hip. Visualize a triangle in the supra-acetabular region. Drill a 1.8 mm wire into this triangle and then tap it in until a hollow sound from hitting a cortex is heard. If the wire is also in the correct alignment on the AP so that it is about 15 ° of abduction to the horizontal line of the pelvis, then advance the wire through the cortex. Use another wire to measure the length of the intraosseous part of the wire. Overdrill the wire with a 4.8 mm cannulated drill bit or in smaller children a 3.2 mm cannulated drill bit. Insert a hydroxyapatite-coated 4.5-mm- or 6-mm-diameter half pin, respectively. Repeat the same for a second pin either more proximal or more distal to the first.
- Step 8: Attach an arch to these first two pins so that the arch is in line with the rest of the fixator based on the constraints of the fixator.

  This arch will usually not be perpendicular to the pelvis due to the 15 ° abduction of the hip joint.
- Step 9: *Add two more pelvic pins.*

  Add one transverse and one oblique pin to the pelvic arch for a total of 4 pins in the pelvis. The transverse pin should be in the supra-acetabular region (most distal pelvic pin). The oblique pin should be between the transverse and the two anterior pins.
- Step 10: Test the hip motion. The hip should move easily in flexion-extension.
- Step 11: *Using the fixator distract the hip joint acutely.*

  Perform an acute distraction of the hip joint so that Shenton's line is over reduced by up to 1 cm.
- Step 12: *Reduce lateral subluxation of the hip.*

  After distraction the femur is shifted medially in the distal pin clamp by loosening the set screws and pushing in the half pins. This reduces the medial dye pool space. If the femoral head distraction is not apparent perform more distraction after reduction.

- Step 13: Ins*ert a posterolateral pin in the femoral pin clamp.*

  In the MRS and Drive Rail, a posterolateral half pin is added to the AP clamp to achieve multiplanar fixation.
- Step 14: *Add a hip extension bar.*

  Add a removable distraction rod anteriorly between the pelvic arch and the distal femoral clamp. For easier attachment, a distal femoral arch can be added to attach the hip distraction rod more anteriorly.

Postoperative Management of Distraction Treatment for Perthes Disease

Physiotherapy is initiated after surgery, with emphasis on maintaining hip flexion and extension range of motion. The therapist must clearly understand that they are not to work on hip abduction, adduction, external rotation, or internal rotation because this would stress the external fixation pin-bone interface. The patient and therapist are taught to measure the true hip motion at the hip hinge rather than doing so clinically (i.e., between the thigh and the spine) (Fig. 7.3). The patient is taught how to perform flexion-extension exercises at home, supplementing the hour of daily physical therapy. Patients are allowed 50% weight bearing, while the external fixator is in place.

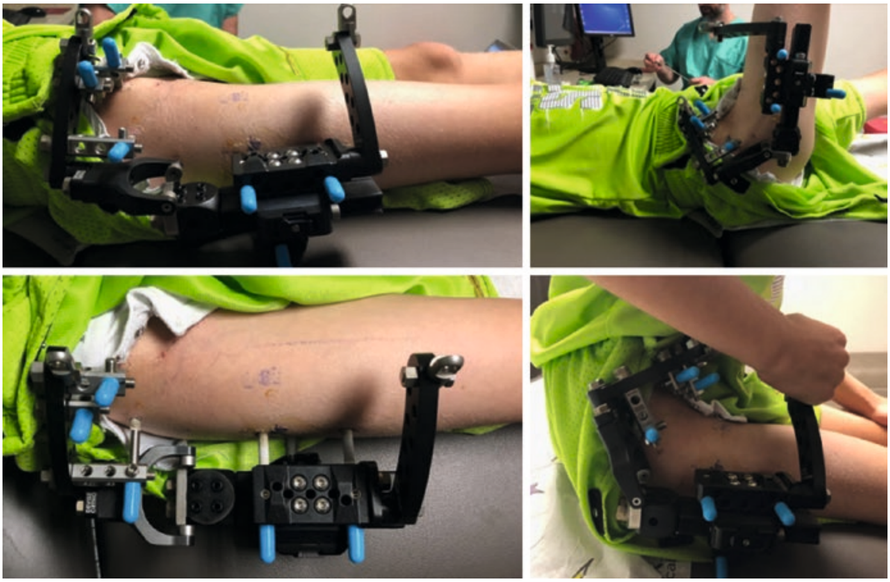

Fig. 7.3 Photographs of external fixator distraction of the hip for Perthes. The example is of a Drive Rail (Devise Orthopedics, Memphis, TN). Upper left, side view supine; lower left, front view supine; upper right, flexion of hip supine with fixator hinge flexion seen; lower right, flexion of hip sitting. ((C) Dror Paley. Used with Permission)

Physiotherapy is important for prevention and treatment of hip flexion contracture. Using the removable hip extension bar prevents this complication. The bar is removed for therapy and inserted at least half the time during the day and all night long. The fixator is left in place for 4 months in patients younger than 12 years and for 5 months in patients 12 years and older. This usually correlates with radiograph re-ossification of the lateral pillar.

Apparatus removal is performed under general anesthesia as an outpatient procedure. Because of the osteoporosis of the femoral head and neck, manipulation of the hip with the patient under anesthesia should not be performed after the removal to avoid fracture of the hip or femur. A bilateral abduction brace (pelvic band with bilateral thigh cuffs and hip hinges) set at 30 degrees of abduction per leg is applied after the removal and is used both day and night for 6 weeks. Resumption of full weight bearing begins on a gradual basis immediately after fixator removal, and full weight bearing without crutches is achieved in approximately 4 weeks after removal. After 6 weeks of full-time use, the abduction brace is used only at night for 6 months (Fig. 7.2f). Running, jumping, and participation in sports are not allowed for 1 year after treatment. Swimming, cycling, and walking are encouraged. The patient is taught a series of five stretches called the Paley Perthes exercises (Fig. 7.4). These should be performed twice daily until skeletal maturity.

Paley Perthes exercises (Fig. 7.4):

1. Wide abduction standing
2. Supine hip flexion
3. Prone internal rotation stretches
4. Prone external rotation stretches
5. Prone hyperextension of the hip

Results

Paley and Segev conducted a retrospective study of the first 16 consecutive patients (18 hips) treated by hip joint distraction between July 1989 and July 1999. Fourteen patients had Perthes disease, and two had avascular necrosis of the hip after slipped capital femoral epiphysis The patient group was comprised of four girls and 12 boys. Two patients had bilateral hip involvement and received the same treatment for both hips. One patient received repeat distraction treatment of the same hip. The mean patient age at the time of disease onset was 9.1 years (range, 6–14 years). The mean patient age at the time of surgery was 10.2 years (range, 6.5–15.6 years). All patients with Perthes disease had whole-head involvement, and the cases were classified as Catterall IV [3, 12–14] or depending on the date of initial presentation to the senior author. The two patients with slipped capital epiphysis experienced collapse of the femoral head resulting from avascular necrosis.

All patients in this series had marked proximal migration and subluxation, which are very poor prognostic factors for containment treatment. The surgical approach and treatment protocol for all patients treated by distraction included gradual

Fig. 7.4 Paley Perthes exercises: patients and parents are taught to do these exercises two to three times daily to obtain and maintain hip mobility. Standing wide abduction (left), maximum flexion (knee to chest) (top center), hip hyperextension (top right), maximum internal rotation (bottom center), maximum external rotation (bottom right). ((C) Dror Paley. Used with Permission)

distraction at half a mm per day until Shenton's line was over-reduced. The external fixator remained in place for 4 months. All the data were collected for clinical documentation in a prospective fashion by the treating author. All patients, while under general anesthesia, underwent intraoperative arthrography of the hip at the time of external fixator application and post-distraction arthrography of the hip at the time of fixator removal. Patients were examined every 6 months for the first 2 years and then annually for the remainder of the study period. Clinical observations were evaluated and recorded by the senior author at each follow-up visit and included subjective pain and activity levels, bilateral hip range of motion (flexion, fixed flexion deformity, abduction, adduction, prone internal and external rotation), knee range of motion, Trendelenburg test, clinical gait assessment, and anteroposterior plus frog leg view pelvic radiographs. The average time from surgery to most recent follow-up visit was 6.7 years (range, 3.5–13.4 years). The clinical evaluations and final follow-up radiographs were tabulated and analyzed.

Based on the total arc of hip range of motion, a clinical sphericity index was calculated to describe how close the hip motion was to being spherical. This index was calculated by dividing the total arc of motion in all three planes of motion (flexion-extension, abduction-adduction, and internal-external rotation) of the diseased hip by 270 degrees, which is the average normal total hip range of motion. The clinical sphericity index is expressed as a percentage of normal total range of motion. The hip was considered to move spherically if the index was greater than two-thirds (67%) of the normal range.

We also calculated the sphericity of the femoral head using measurements derived from pre- and post-distraction arthrograms. The ratios between the largest diameter of the femoral head divided by the lesser diameter (two times the lesser radius, perpendicular to the largest diameter and bisecting it in its middle) on the anteroposterior and lateral view arthrograms were added together and divided by 2 to calculate an index. A normal index for a spherical femoral head is 1 [15]. The closer the index is to 1, the more spherical is the head. The initial and final arthrogram ratios were compared.

The final follow-up radiographs, including those of patients who were not skeletally mature, were graded using the Stulberg [16] classification system. The following radiographic parameters were measured on the preoperative and final radiographs for the operated and normal hips: sharp acetabular angle, central edge angle, proximal migration of Shenton's line, and distance of the medial border of the femoral head from the tear drop. Closure of the proximal femoral physis on the normal side was noted and considered to be evidence of hip skeletal maturity. A premature closure of the diseased hip physis relative to the normal hip also was noted.

Fifteen patients had complained of varying degrees of pain before surgery. At final follow-up, only one patient complained of mild pain that did not require analgesics and did not interfere with daily activities. All patients returned to full school and/or work activities, including sports without limitation. All patients expressed satisfaction with the results and indicated vast improvement in their function compared with their pre-treatment abilities. Fifteen patients walked with a limp before the operation, compared with only one patient who walked with mild lurch gait at final follow-up. Fifteen patients had positive Trendelenburg sign before the operation, compared with only one with positive Trendelenburg sign at final follow-up. All patients had full ipsilateral knee range of motion before surgery and at final follow-up.

All our patients experienced marked limitation of motion on the affected side at presentation. At final follow-up, the mean flexion-extension arc of motion was 100 degrees (range, 90–130 degrees). The mean abduction-adduction arc of motion was 54 degrees (range, 25–75 degrees). The mean internal-external rotation arc of motion was 58 degrees (range, 0–90 degrees). The mean total hip arc of motion was 214 degrees (range, 115–285 degrees). The mean arc of motion for the treated hip was 79% of normal (range, 43–100%). At final follow-up, 16 of 18 hips that underwent hip joint distraction had their range of motion restored to at least two-thirds normal; two hips had a range of motion below functional range.

During distraction, early, rapid osteoporosis of the femoral head was consistently observed, revealing sclerotic dead bone. This was followed by gradual ossification of the lateral pillar, which usually was completed by 4 months. All patients except two underwent external fixator application after femoral head collapse and during the resorption phase. Two patients underwent application of the external fixator just after the initial subchondral fracture. In both of these cases, the femoral head recollapsed after fixator removal and subsequently went through a resorption phase. One of these patients underwent a second distraction treatment, and complete success was achieved the second time.

At the most recent follow-up visit, nine patients had reached skeletal maturity as judged by closure of the femoral capital epiphysis in the normal hip. Three hips showed signs of premature physeal closure on the operated side. The mean preoperative Sharp acetabular angle was 45 degrees (range, 40–50 degrees) and at final follow-up was 44 degrees (range, 35–50 degrees). The mean preoperative center edge angle was 19 degrees (range, 0–30 degrees) and increased to 24 degrees (range, 15–35 degrees) postoperatively. The difference between pre- and postoperative Sharp acetabular angles was not significant ($P = 0.094$); the increase in the center edge angle after treatment was marginally significant ($P = 0.051$).

The mean proximal migration measured as a break in Shenton's line was 7 mm (range, 0–14 mm) preoperatively and improved to 2 mm (range, 0–12 mm) at the most recent follow-up visit. This difference was statistically significant ($P = 0.002$). The average distance from the medial femoral head to the teardrop was 13 mm preoperatively (range, 8–16 mm) compared with 11 mm (range, 6–18 mm) postoperatively, which was statistically significant ($P = 0.022$). The mean radiographic sphericity index improved from 1.29 (range, 1.1–1.6) at the time of frame application to 1.17 (range, 1.0–1.59) at the time of frame removal, which was statistically significant ($P = 0.001$). The Stulberg [17] classification based on the most recent radiographs was as follows: Class I, one hip; Class II, five hips; Class III, eight hips; and Class IV, four hips.

Complications

Most patients developed minor pin tract infections, which were successfully treated with oral antibiotics. The fixator on one patient had to be removed after only 2 months because of severe pin tract infection. This patient developed recurrent stiffness and subluxation of the hip after the first removal. After the second treatment, the patient was able to maintain a mobile hip with spherical hip motion.

One patient sustained a fractured neck of the femur caused by a fall on the day of fixator removal. The fracture was treated by screw fixation and healed uneventfully.

Two patients each underwent a second application of the fixator for contralateral Perthes disease at 3 years and 3 months and at 1 year and 4 months, respectively, after the index distraction treatment. One patient underwent treatment of Perthes disease shortly after a subchondral fracture of the hip. The course of treatment by distraction was uneventful. However, after fixator removal, the femoral head proceeded to undergo resorption, collapse, and subluxation. Reapplication of the external fixator a year later, during the maximum resorption phase, led to an excellent final result.

As an addendum to this study, I decided to review the radiographs and results of as many patients that could be located in 2009. This represented a 20 year follow-up on the earliest patient. Only 13 of the total hips and 11 of the total patients could be found. All of the Stulberg 4 cases were in the follow-up group. It is interesting to note that all of the Stulberg 4 cases had evidence of degenerative changes, while none of the Stulberg 1, 2 or 3 cases did. Only two of the four Stulberg 4 cases were symptomatic, while the others were not. Femoroacetabular impingement (FAI) was present in all of the Stulberg 3 and 4 cases reviewed. We were unaware of FAI when we first conducted this study. Some of the Stulberg 3 cases were subsequently treated by femoral head reduction osteotomy. The Stulberg grade did not change at final follow-up in 2009. The result grading also did not change since the two painful Stulberg 4 cases were the same symptomatic cases in the original study. It is clear that the four Stulberg 4 cases will all require a hip replacement. It is likely that the Stulberg 3 cases will require some treatment for FAI which could include hip arthroscopy or surgical dislocation of the hip with osteochondroplasty or femoral head reduction osteotomy [17].

Discussion

The natural history of Perthes disease and avascular necrosis of the hip joint is directly related to patient age at time of disease onset and amount of femoral head involvement [18–21]. Older age and whole femoral head involvement are poor prognostic factors [22–25]. Treatment by bed rest, non-weight bearing, and abduction orthosis is of limited value and is not well tolerated [1, 2, 8, 26, 27]. Range-of-motion exercises and various forms of surgical containment have constituted the mainstay of treatment for Perthes disease [28–30] that for children older than 6 years, any method of treatment offers a better prognosis than no treatment. Containment treatment in patients older than 11 years leads to only 40% satisfactory results [12, 14] compared with an overall age-independent success rate of 70–90% [18].

Stiffness, subluxation, and femoral head collapse are considered contraindications to surgical containment treatment. Therefore, the worst cases often are not treatable with containment. Abduction bracing is a nonsurgical containment treatment method. It is fraught with problems of noncompliance, especially in older children, and can lead to hip stiffness unless prescribed in conjunction with aggressive physical therapy [27]. Varus femoral osteotomy can achieve the greatest degree of femoral head containment [3]. The resulting coxa vara deformity may not remodel and therefore may produce a long-term limp due to abductor muscle dysfunction because the abductor lever arm and muscle tension are altered [31]. A pelvic osteotomy alone for containment is more limited in its amount of coverage [32, 33]. All these methods are contraindicated if the hip is stiff, especially if it cannot abduct sufficiently; these hips are suitable for a salvage procedure.

Both varus femoral and pelvic osteotomy methods distort the anatomy and have limited ability to change the shape of an already collapsed femoral head or to reduce subluxation [28].

The distraction we describe is not limited by hip stiffness, degree of femoral head deformity, or subluxation. Although distraction is performed with the hip in 15 degrees of abduction, the primary goal is not containment. The epiphyseal cartilage of the femoral head is not primarily damaged from the loss of circulation to the femoral head. Instead, it reacts by proliferating outside the acetabulum, leading to coxa magna and lateral ossification. The cartilage also proliferates medial to the femoral head when the femoral head has migrated laterally, and superiorly [15] proliferation or ossification is not observed superior to the femoral head, where it is in contact with the acetabulum. Because the femoral head cartilage seems to have the potential to grow in the unstressed regions inside and outside the acetabulum, I postulated that if the femoral head were pulled away from the acetabulum and kept there, the epiphyseal cartilage might proliferate into the acetabulum and fill the space created by the previous collapse. The acetabulum would act as a sort of mold for the femoral head. In many ways, this is similar to the theory behind containment. Pulling the femoral head down also would reduce the apparent subluxation of the hip, especially the break in Shenton's line. In cases in which collapse has not occurred or has not progressed to maximum, dead bone may be resorbed under the protection of the distractor. If the distractor remains in place long enough, new bone formation can replace removed bone, preventing collapse after fixator removal. Herring [14] noted that once the lateral pillar has re-ossified, no further collapse is to be expected. Therefore, we chose re-ossification of the lateral pillar as a satisfactory end point for fixator removal.

The radiographic findings obtained during distraction revealed very rapid progression of osteoporosis of the femoral head and neck. The dead bone could readily be distinguished from the live bone by its white sclerotic appearance; the remainder of the femoral head and neck appeared osteoporotic. At approximately 6–8 weeks after surgery, new ossification of the lateral pillar was observed. The lateral pillar was fully reconstituted by 4 months after initiation of the distraction treatment. In children older than 12 years, this took up to 5 months.

Mose [34] and Stulberg [16] showed that femoral head sphericity and congruency with the acetabulum are directly related to the long-term prognosis. Distraction leads to improved femoral head radiographic sphericity. Our results documented an average sphericity index improvement from 1.29 before treatment to 1.17 at frame removal, indicating increased roundness of the head and improved joint congruency. These findings were corroborated by the clinical range-of-motion results. All our patients experienced improved hip range of motion with distraction treatment. The clinical sphericity index increased, on average, to 79% at last follow-up. If we can assume that when something moves like a sphere, it must be shaped like a sphere, it can be said that most of these hips demonstrated spherical three-dimensional motion.

We also observed that distraction did not change the shape of the acetabulum, as evidenced by the lack of change in Sharp angle. The position of the femoral head in the acetabulum, as judged by the center head angle, did change. In 12 of 18 cases, sustained reduction of a previously subluxed femoral head occurred, as revealed by a reduction of Shenton's line and a decrease in lateral migration distance. This, too, is consistent with improved hip biomechanics and presumably improved longevity of the hip.

Clinically, the patients were active and had little if any gait abnormality, pain, or weakness after distraction treatment. At the most recent follow-up examinations, all except one of our patients was free from pain, limp, and Trendelenburg sign. All of our patients could walk normally and took part in normal daily activities, including sports, and were happy with their outcomes. Considering that 12 of 16 patients in this study were older than 8 years and that 7 were older than 10 years, the prognosis expected with conventional treatment would not be so favorable. Our overall results with distraction were 95% satisfactory based on pain and limp. Containment of the hip by femoral osteotomy, when performed in older patients with hip subluxation, may cause an "incongruent incongruency" situation and worsen the condition of the joint [35–37].

Distraction treatment of the hip has been termed *arthrodiastasis* and has been used for stiffness of the hip after trauma, chondrolysis, slipped capital femoral epiphysis, avascular necrosis, Perthes disease, and other conditions [38, 39]. Often combined with capsulectomy and arthrolysis, it has not been used as the primary treatment for Perthes disease [38] . One study showed unsatisfactory results of such an application that included use of an Ilizarov external fixator without a hinge [40]. The authors who presented that study have since adopted the hinge distraction method reported herein for the primary treatment of Perthes disease and have achieved vastly improved results Guarniero [41] presented the results of a comparative study of two groups of patients diagnosed with Perthes disease, treated by varus femoral osteotomy or hip joint distraction. They reported consistently good results for both groups of patients and noted that the femoral head underwent remodeling faster in the patients treated by hip joint distraction.

Segev who learned this technique during his fellowship with Paley reported on 16 of his own patients with Perthes treated by distraction. The average age was 12 years, which is a much older group of patients than most and therefore would be expected to have a very poor prognosis. All patients had improved range of motion and improved pain scores. This demonstrated improved prognosis over that expected for such an older group of patients [42–44].

Minimal interference with osseous architecture and relative simplicity of hip joint distraction combined with a low complication rate renders this treatment an attractive alternative for more advanced and later-onset cases of Perthes disease. According to Stulberg et al. [17], the most important prognostic factor that affects outcome is residual deformity of the femoral head, coupled with hip joint incongruity. Class I and II spherical hips are compatible with normal longevity of the hip; Class III and IV hips with aspherical congruency usually deteriorate during the sixth decade of life; and Class V hips with incongruity usually degenerate by the fourth decade. This series did not include any cases of incongruity (Class V). Six spherical hips (Class I and II) and 12 aspherical congruity hips (Class III and IV) were included. The long-term prognosis for these patients, therefore, is relatively good, considering that 8 of 18 hips were in patients who were older than 9 years at onset of disease.

In the author's series, we proceeded with treatment once stiffness, subluxation, and collapse were evident in the presence of whole-head involvement in all except two cases in which the treatment was performed immediately after subchondral fracture occurred. The femoral head went on to re-collapse after fixator removal in both patients. One of them underwent reapplication of the fixator and a second distraction treatment without tendon release more than 1 year after the first distraction treatment; a satisfactory result was achieved. Another patient also underwent a second distraction treatment. This patient was a boy who suffered severe deep soft tissue infection of the pelvic pin sites because of poor compliance and poor personal hygiene. For the second distraction treatment, he was treated at a pediatric rehabilitation center; no subsequent difficulty occurred at the pin sites, and an excellent result was achieved after the second treatment. The final results in both of these cases were as good as those achieved by the remainder of the patients after successful one-time treatment. Because distraction does not distort the anatomy, it can be reapplied if it fails the first time. In retrospect, both of the reapplications were avoidable (too early treatment in one case and poor home hygiene in the other). Based on our results, we conclude that immediately after subchondral fracture is too early to apply treatment. Treatment should not be implemented until femoral head resorption is evident, with or without subluxation and collapse. Ideally, the best timing for distraction is 1 day before collapse would occur. Of course such timing is impossible to determine. As such, distraction should be applied during the resorption phase, preferably prior to collapse. Once collapse occurs, the femoral head is misshapen. Distraction or not the femoral head cannot be returned perfectly to its precollapse shape. Applying distraction as soon as possible after collapse gives the best chance of returning it to as close as possible to its precollapse shape.

Although we did not have a control group at our institution and because most other clinical series would have considered many of the cases in this series to be too severe for conventional containment approaches, we think it is reasonable to conclude that hip joint distraction combined with adductor tenotomy and psoas recession leads to results that are as good as or better than the results of traditional containment treatment methods for patients with Perthes disease and for patients with avascular necrosis after slipped capital femoral epiphysis. In contrast the study previously referred to by Guarniero did have a control group of patients treated by varus osteotomy. The healing of the Perthes head involvement was twice as fast in the distraction group as in the varus osteotomy group. This finding was similar to the results observed in this study. A major advantage of hip joint distraction is that it is indicated even in cases in which marked stiffness, subluxation, or deformity of the femoral head is present and is not contraindicated for older children. Distraction treatment is particularly indicated for older children with more severe at-risk and poor prognostic signs. In conclusion, distraction treatment offers many theoretical and practical advantages over conventional containment treatment approaches and is a valuable addition to the armamentarium of the orthopedic surgeon who is faced with managing the difficult problem posed by Perthes disease.

Finally, although the sphericity of the femoral head is improved with distraction, once the femoral head is larger or misshapen into a more ellipsoid or saddle shape, it will ultimately suffer from femoroacetabular impingement. This will lead to pain, labral tear, and joint degeneration. Joint distraction is therefore not the definitive treatment to prevent arthritis of the hip. It is a good alternative to femoral and pelvic osteotomies and is this author's preferred method of treatment for whole-head involvement cases during the resorption phase, which lead to subluxation and collapse of the femoral head. Once the femoral head is fully ossified, and the final shape can be determined, the only treatment that can restore sphericity to the femoral head is the femoral head reduction osteotomy [17]. Therefore, hip distraction can be considered a temporizing method to treat Perthes at an earlier stage irrespective of age and prevent fixed subluxation and more severe deformation of the femoral head. The more definitive joint preservation treatment however is femoral head reshaping by surgical hip dislocation with osteochondroplasty or femoral head reduction osteotomy.

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