Joint Distraction for Special Conditions

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12.1 Treatment of Perthes Disease of the Hip by Joint Distraction

12.1.1 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 (Kamhi and MacEwen 1975). Methods used to achieve containment include abduction bracing (Meehan et al. 1992), femoral (Axer et al. 1980; Lloyd-Roberts et al. 1976) or innominate osteotomies (Salter 1966), and shelf procedures (Willett et al. 1992; Daly et al. 1999). However, these methods are contraindicated when the degree of femoral head collapse and deformation prevent spherical hip motion (Lloyd-Roberts et al. 1976). Unloading of the hip was originally considered important in the treatment of Perthes disease (Eaton 1967). Various methods, such as complete bed rest (Eaton 1967) and use of a Snyder sling (Snyder 1947), have been tried toward this end, but little evidence exists to show that these methods alter the natural history of the disease (Evans 1958; Evans and Lloyd-Roberts 1958). The failure of unloading may be related to the misconception that non-weight bearing is equivalent to

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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 (Catterall 1971). We 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 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, Paley first applied hip joint distraction as a therapeutic approach to Perthes disease in 1989. Although arthrodiastasis of the hip had been used and applied for other pathologies such as chondrolysis (Herring et al. 1992), it had not been used during the resorption phase of Perthes disease prior to this time to the author's knowledge.

12.1.2 Surgical Procedure (Fig. 12.1)

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 and frog leg views are obtained with arthrographic dye in place.

Step 2: Percutaneous adductor tenotomy of adductor longus and gracilis tendons.

Step 3: Psoas tenotomy

Make a 3–4 cm anterior groin line incision. 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 is identified and retracted medially. The nerve lies on the medial anterior aspect of the iliopsoas muscle. Dissect down the medial side of this muscle, and on the undersurface of its medial side can be found the psoas tendon. Cut the tendon while leaving a continuous muscle bridge.

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° of abduction relative to the horizontal line of the pelvis. With the image intensifier and a wire, mark a line over the shaft 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 shaft of the 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. 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. These pins should be perpendicular to the shaft of the femur, end in the center of the acetabulum, and be in the midsagittal 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 (e.g., Orthofix, EBI, or the SN modular rail system (MRS)) and apply the cannulated hinge over the axis pin.

Step 6: Insert the femoral frontal plane pins.

Adjust the distal clamp to the level desired on the femur. Insert two 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 to the opposite side and place the image intensifier over the affect supra-acetabular region. When a triangle is visualized over the acetabulum, the correct plane for the pin is seen. 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 in the correct plane, then level the table and 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 half-pin. Repeat the same for a 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 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. 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: Perform an acute distraction of the hip joint so that Shenton line is over reduced.

Step 12: Reduce any lateral subluxation of the hip. This is achieved by loosening the fixation of the distal frontal plane pins and pushing the femur medially to reduce the femoral head deeper into the acetabulum.

Step 13: Insert one or two more distal femoral pins in a delta configuration to the frontal plane pins.

Step 14: Add an arch to the distal femur clamp.

Step 15: Add a removable distraction rod anteriorly between the pelvic arch and the distal femoral arch to prevent flexion contracture by keeping the hip extended especially at night.

12.1.3 Postoperative Management of Distraction Treatment for Perthes Disease

Physiotherapy is initiated immediately to work on hip flexion-extension, with emphasis on maintaining hip extension with prone exercises. 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). 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.

Flexion contracture of the hip commonly develops. Physiotherapy is important for prevention and treatment of contractures. If a severe degree of flexion contracture occurs, distraction of the hip joint is compromised. Using the removable hip extension bar prevents this complication. The apparatus 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° of abduction per leg is applied after the removal and was 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 is achieved in approximately 4 weeks. After 6 weeks of full-time use, the abduction splint is used only at night for 6 months. 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 I call the Perthes exercises. These should be performed twice daily until skeletal maturity.

Perthes Exercises

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

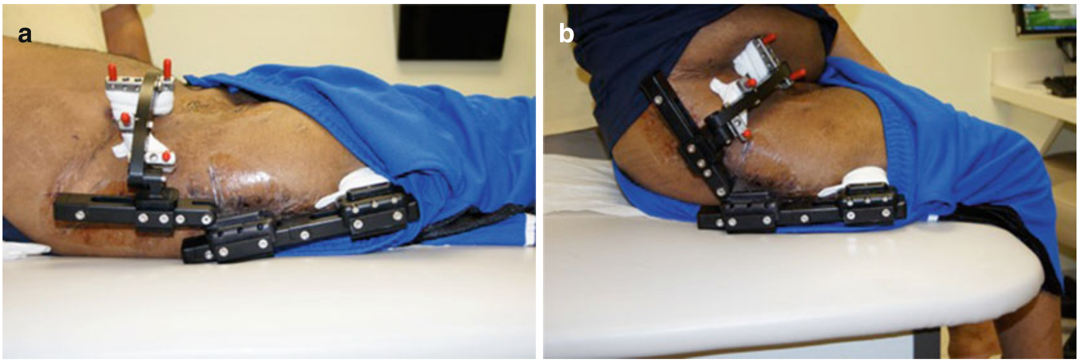

Fig. 12.1 Hip hinge distraction external fixator (Smith and Nephew Modular Rail System) supine (**a**) and sitting (**b**)

12.1.4 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 (Catterall 1971; Lloyd-Roberts et al. 1976; Herring et al. 1992; Salter and Thompson 1984) 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.

The treatment protocol used in all these cases was based on previous experience with hip distraction for chondrolysis and hip dislocation and the successful treatment of the first patient in this series in 1989 (Fig. 12.2). Containment surgery by osteotomy was contraindicated for this 11-year-old patient who presented with a very stiff, subluxed, and deformed hip that had previously been treated by bracing for 1 year. Distraction was proposed to reduce the hip, which had marked proximal migration and subluxation. This patient was considered to have a very poor prognosis before treatment. The striking success of the distraction treatment in this difficult case encouraged us to offer distraction treatment as an alternative therapy for patients who subsequently presented with Perthes disease. Conventional treatment options, such as pelvic and femoral osteotomy and shelf procedures, were discussed with all patients and were offered as surgical management options when patients met the criteria for these procedures. The surgical approach and treatment protocol for all patients treated by distraction was identical to those used for the index patient, and all documentation was conducted in the same way at the same time intervals. Although this study is retrospective in that no formal study was organized or planned in advance, all the data were collected for clinical documentation in a prospective fashion by the treating author. These data were later reviewed for this retrospective study.

The families of all patients who were offered the distraction treatment were first given the phone numbers of one or two previously treated patients so that they could contact them. Families made their decision to proceed with distraction or containment surgical treatment based on their conversations with previous patients and based on information provided by the surgeon regarding conventional treatment. Because of our success in the treatment of Perthes disease, the distraction regimen was additionally applied to all cases of avascular necrosis resulting from

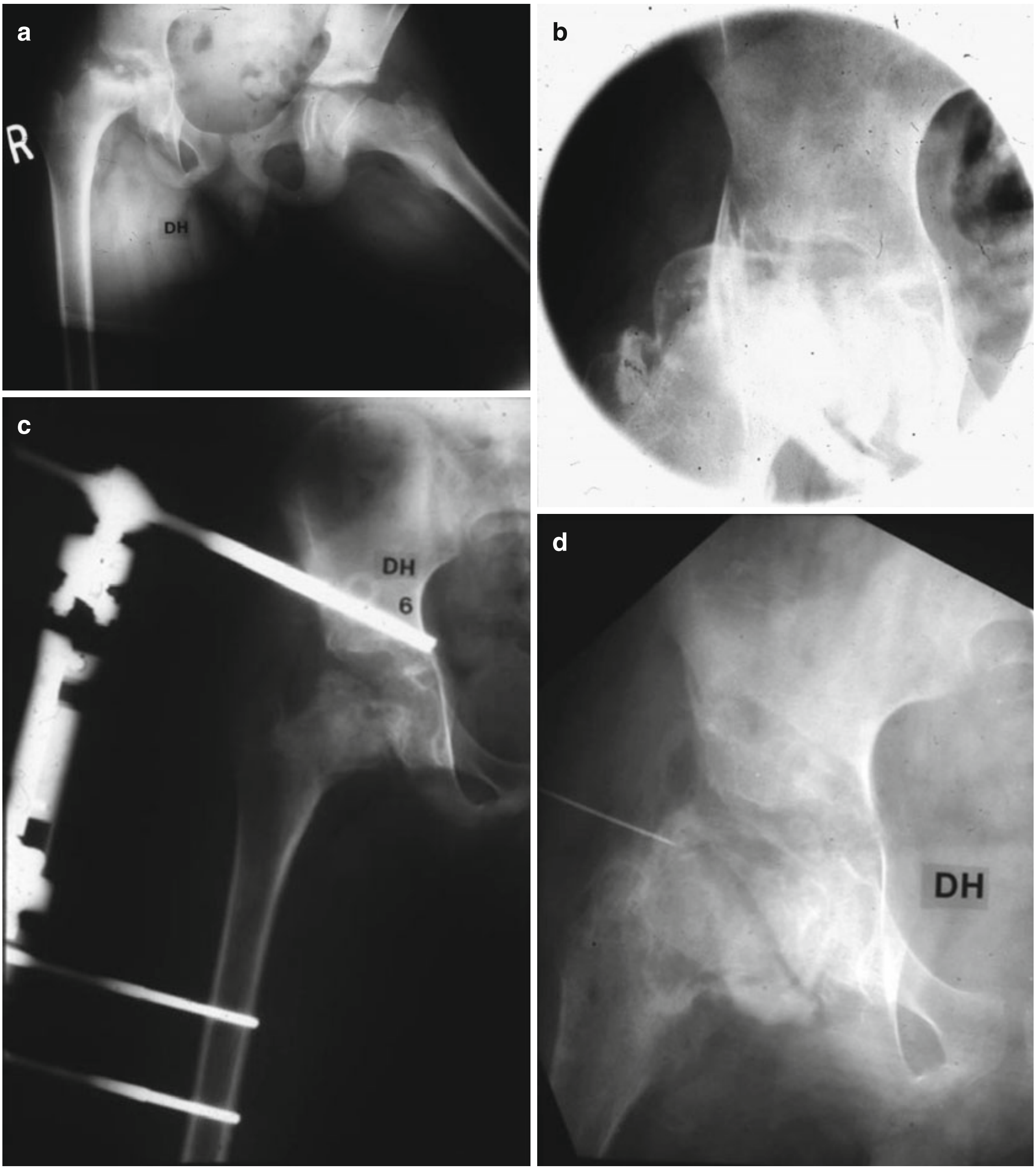

Fig. 12.2 (**a**) An 11-year-old boy with Perthes with fixed flexion-adduction contracture. There is a break in Shenton line with proximal and lateral migration of the femoral head; (**b**) intraoperative arthrogram showing femoral head flattening; (**c**) reduction of the femoral head by application of hinge distraction external fixator with hip in 15° of abduction; (**d**) arthrogram at time of removal of apparatus. The femoral head is rounder; (**e**) follow-up radiograph 22 months after surgery; (**f**) hip abduction 22 months after distraction; hip external (**g**) and internal (**h**) rotation 22 months after distraction; hip abduction 10 years after distraction (**i**, **j**); hip external (**k**) and internal (**l**) rotation 22 months after distraction; AP (**m**) and frog lateral (**n**) pelvis x-rays 10 years after distraction; flexion 10 years after distraction (**o**)

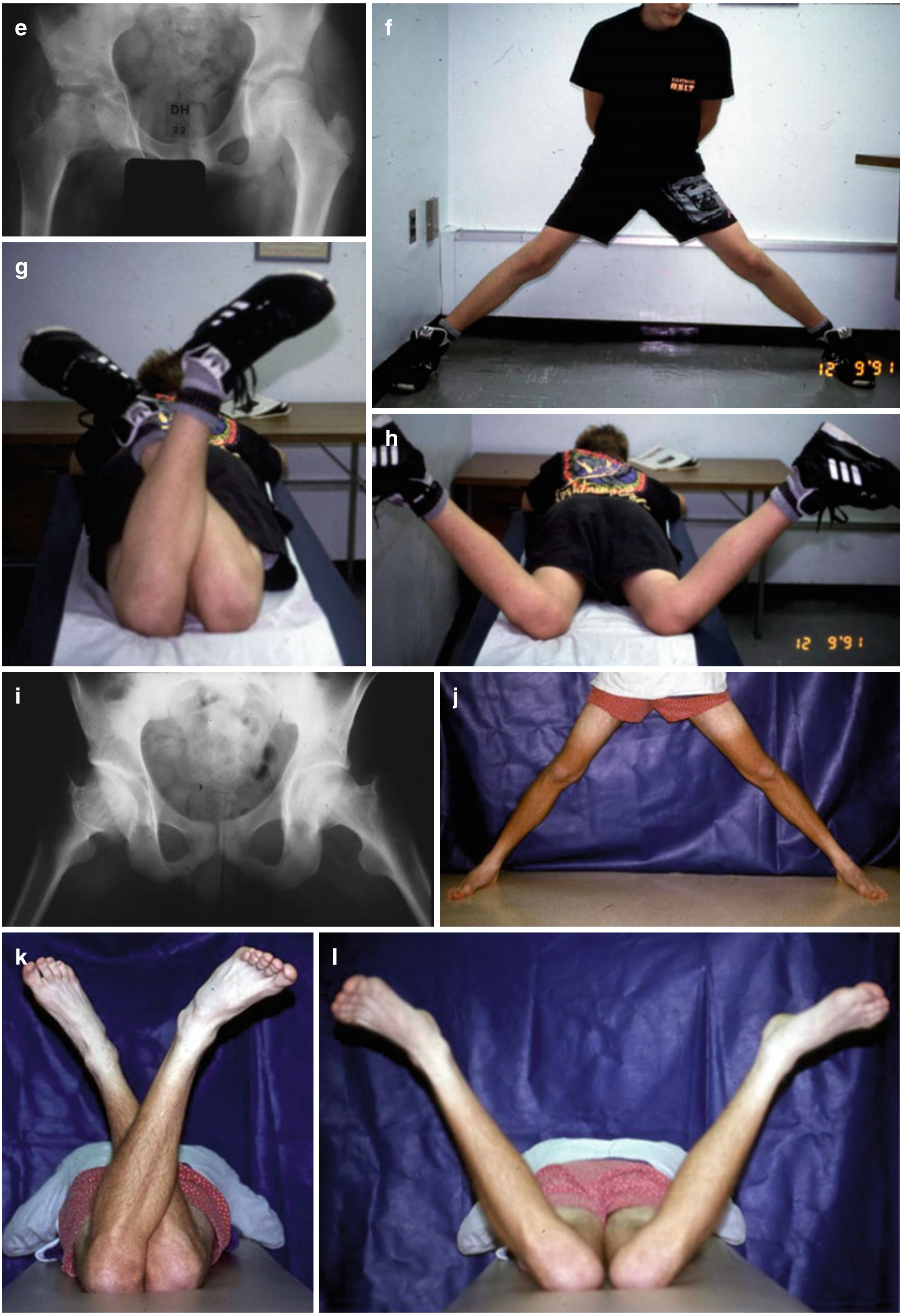

Fig. 12.2 (continued)

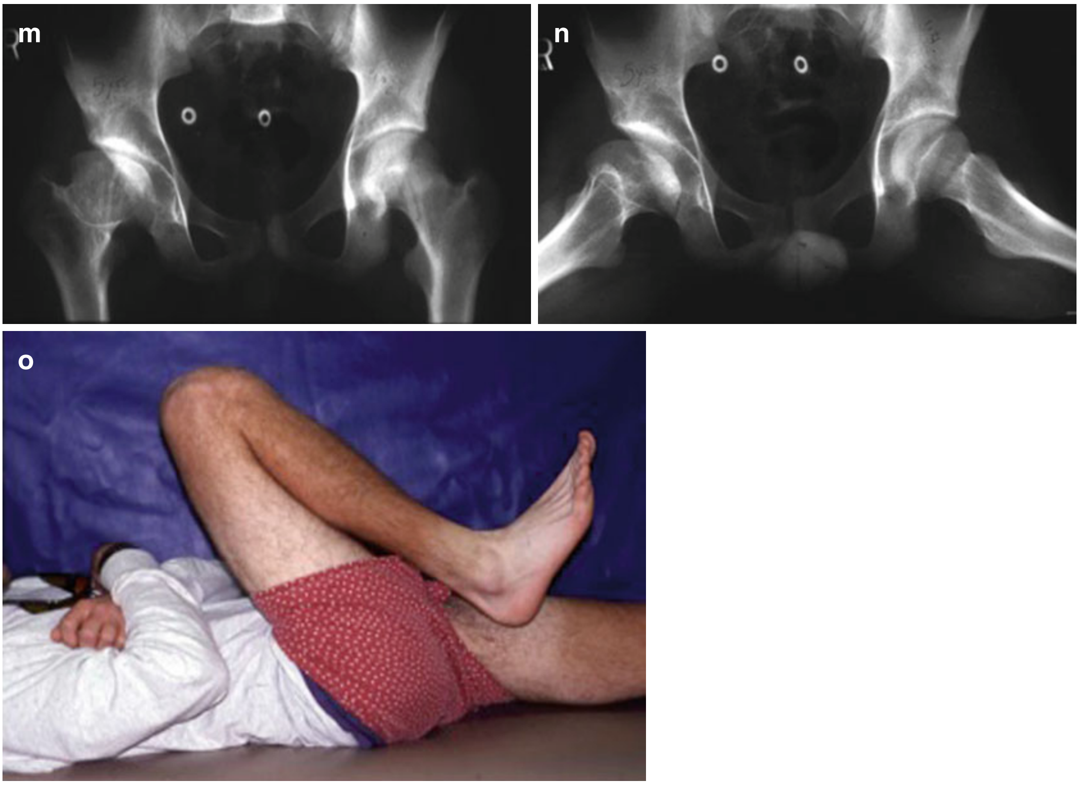

Fig. 12.2 (continued)

slipped capital femoral epiphysis treated during the same time period. To date, all these patients have chosen distraction treatment.

External fixation was in use at our institution for hip joint distraction and distraction of other joints for various indications; the use of the technique to treat Perthes disease was therefore not considered experimental. During the study period, internal review board approval was not required by our institution for the application of hip distraction to cases of Perthes disease or avascular necrosis of the hip. Furthermore, because no formal prospective study was being conducted, this study is considered retrospective. Internal review board approval was obtained to conduct this retrospective study.

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°, 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 1.1 (Bennett et al. 2002). The closer the index is to 1.1, 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 et al. (1981) 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 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 pretreatment 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° (range, 90–130°). The mean abduction-adduction arc of motion was 54° (range, 25–75°). The mean internal-external rotation arc of motion was 58° (range, 0–90°). The mean total hip arc of motion was 214° (range, 115–285°). 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 re-collapsed 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° (range, 40–50°) and at final follow-up was 44° (range, 35–50°). The mean preoperative center-edge angle was 19° (range, 0–30°) and increased to 24° (range, 15–35°) 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 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 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 (unpublished study).

12.1.5 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. Femero-acetabular 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 are being considered for 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 (Paley 2011).

12.1.6 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 (Gower and Johnston 1971; McAndrew and Weinstein 1984; Yrjonen 1999; Ippolito et al. 1985). Older age and whole femoral head involvement are poor prognostic factors (Ippolito et al. 1987; Norlin et al. 1991; Mazda et al. 1999; Eyre-brook 1936). Treatment by bed rest, non-weight bearing, and abduction orthosis is of limited value and is not well tolerated (Kamhi and MacEwen 1975; Meehan et al. 1992; Eaton 1967; Martinez et al. 1992). Range-of-motion exercises and various forms of surgical containment have constituted the mainstay of treatment for Perthes disease (Lack et al. 1989; Bankes et al. 2000; Klisic 1983) 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 (Catterall 1971; Salter and Thompson 1984) compared with an overall age-independent success rate of 70–90 % (Gower and Johnston 1971).

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 (Martinez et al. 1992). Varus femoral osteotomy can achieve the greatest degree of femoral head containment (Lloyd-Roberts et al. 1976). 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 (Noonan et al. 2001). A pelvic osteotomy alone for containment is more limited in its amount of coverage (Rowe et al. 2006; Lee et al. 2009). 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 (Lack et al. 1989).

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° 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 (Bennett et al. 2002). 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, we 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 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 (Salter and Thompson 1984) 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 (1980) and Stulberg et al. (1981) 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 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 (Lloyd-Roberts 1955; Cooperman and Stulberg 1986; Salter 1980).

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 (Canadell et al. 1993; Aldegheri et al. 1994a). Often combined with capsulectomy and arthrolysis, it has not been used as the primary treatment for Perthes disease (Canadell et al. 1993). One study showed unsatisfactory results of such an application that included use of an Ilizarov external fixator without a hinge (Kocaoglu et al. 1999). 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 (Guarniero 2006) 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 from Paley reported on 16 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 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 (Segev 2004, 2008; Segev et al. 2004).

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., 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 eight of 18 hips were in patients who were older than 9 years at onset of disease.

In this 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 (patient 5) 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 it is too early to apply treatment. Treatment should not be implemented until femoral head resorption is evident, with or without subluxation and collapse.

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.

12.2 Distraction Arthroplasty of the Ankle

12.2.1 Introduction

A growing number of patients are developing ankle arthritis from various causes. Many patients are seeking alternative treatment options to arthrodesis or total joint replacement. Most patients prefer to preserve their natural ankle joint and ankle motion. Although research into cartilage regeneration and repair is promising, it is too preliminary to offer a viable clinical option for the ankle at this time.

Joint distraction with external fixation has evolved as an alternative to arthrodesis and/or joint replacement. The technique of joint distraction uses the principle of ligamentotaxis to restore the normal joint space, afford less joint loading, and provide an environment in which the joint cartilage can recover. The first reported joint distractions of the knee and elbow were performed in 1975 and of the ankle in 1978 (Volkov and Oganesian 1975; Judet and Judet 1978). Aldegheri et al. (1994), from Verona, Italy, coined the term *arthrodiastasis* in 1979 to describe joint distraction (arthro [joint], dia [through], and tasis [to stretch out]).

Indications for ankle joint distraction are congruent joint surface, pain, joint mobility, and moderate to severe arthritis. The indications may be stretched to include avascular necrosis of the talus. The success of the clinical outcomes varies with respect to the presenting diagnosis.

12.2.2 Existing Method and Results

Van Roermund and colleagues have written extensively about ankle distraction for the treatment of arthritis of the ankle (van Roermund et al. 2002; Marijnissen et al. 2001a, b, 2002, 2003; van Roermund and Lafeber 1999; van Valburg et al. 1995, 1999). Their hypothesis for ankle distraction treatment is that the mechanical stress (weight-bearing forces) on the cartilage is removed to allow for restoration. Weight bearing in the fixator also allows for continued intra-articular intermittent fluid pressure and increased synovial fluid, providing further cartilage restoration. Maintaining the patient within the fixator for 3 months also allows for reduction in the subchondral bone density to increase the resiliency of the joint. These changes will allow the osteoarthritic cartilage to show reparative activity.

The indications cited by van Roermund and colleagues are posttraumatic ankle osteoarthritis with or without equinus contracture in patients who are 20–70 years old and have semi-mobile ankle joints. Their protocol involves application of the Ilizarov device (a two-ring construct) to the tibia with two 1.5-mm Kirschner wires per ring attached via four threaded rods to a U-shaped foot ring (closed distally). A talar wire to prevent distraction of the subtalar joint, two crossing calcaneal olive wires, and one medial olive wire through the metatarsals are fixed to the foot ring. Distraction is performed at a rate of 0.5 mm two times per day for 5 days to achieve a total distraction of 5 mm. This distraction is maintained for 3 months, during which full weight bearing is allowed. The device is not hinged.

The authors (van Roermund et al. 2002; Marijnissen et al. 2001a, b, 2002, 2003; van Roermund and Lafeber 1999; van Valburg et al. 1995, 1999) report that 70 % of their patients showed significant clinical improvement, including decrease in pain and increase in function (results for 50 patients with 2–8 years of follow-up). Joint mobility was sustained with the distraction treatment but was markedly restricted (50 % of normal range). Most notable was the timing of the clinical improvement, with only one-half of the clinical improvement occurring within the first year after the procedure. A slight increase in joint mobility, significant widening of the joint space, and diminished subchondral sclerosis were progressively observed during the 5 years after the procedure. The authors also performed a prospective controlled study which showed that joint distraction led to a statistically significant better clinical outcome than did arthroscopic débridement of the ankle joint alone (Marijnissen et al. 2001a, 2002, 2003). In summary, van Roermund and colleagues (van Roermund et al. 2002; Marijnissen et al. 2003) showed that static ankle distraction alone without range-of-motion exercises yields a positive clinical effect in 70 % of cases.

12.2.3 Paley's Method

Unlike the Dutch group, Paley chose to build the ankle distractor with an anatomically located hinge which allows the patient to perform range-of-motion exercises throughout the entire distraction treatment. In addition, he combined adjunctive procedures to increase range of motion, eliminate impingement, improve stability, and improve joint orientation. This method is referred to as Paley's method and includes hinged ankle joint distraction, allowing joint range-of-motion exercises during treatment; correction of osseous alignment using osteotomy; surgical treatment of muscle/joint contractures by soft tissue releases; and treatment of joint impingement by resection of osteophytes and osteochondroplasty.

12.2.4 Paley Method Technique

12.2.4.1 Adjunctive Procedures

Blocking Osteophyte Resection

If dorsiflexion is limited by anterior distal tibial or talar neck osteophytes, the osteophytes should be resected. An anterior incision is made lateral to the tibialis anterior tendon. The tibialis anterior tendon is retracted medial and the neurovascular bundle lateral. The ankle joint is entered through the posterior sheath of the tibialis anterior tendon. The anterior distal tibia is then resected and the neck of the talus deepened.

The extent of the resection is checked using fluoroscopy. If plantar flexion is limited by posterior ankle osteophytes, they should be resected through a posterolateral incision (i.e., Gallie approach) to gain access to the posterior ankle capsule. To prevent recurrence of these osteophytes, bone wax may be pressed into the cancellous bone. We use nonsteroidal anti-inflammatory drugs (NSAIDs) (e.g., indomethacin, naproxen) postoperatively to inhibit bone formation for 6 weeks. However, NSAIDs are not used if an osteotomy is performed concomitantly (Dahners and Mullis 2004).

Equinus Contracture Release

Equinus contracture can be released by performing either isolated anterior or posterior gastrocnemius recession (i.e., Baumann or Strayer, respectively), gastrocnemius-soleus recession (i.e., modified Vulpius procedure), or Achilles tendon lengthening (Lamm et al. 2005; Paley 2005; Herzenberg et al. 2007). We prefer the isolated gastrocnemius recession or gastrocnemius-soleus recession to maintain triceps surae muscle strength. Operating on the triceps surae structures is not enough to correct the equinus. A posterior capsular release may also be required to restore the ankle joint motion. Acute correction of equinus contractures should be combined with tarsal tunnel decompression to prevent stretch and acute entrapment (Lamm et al. 2007). Both the tarsal tunnel decompression and the posterior ankle capsular release can be accomplished through a posteromedial longitudinal incision. The posterior osteophytes can also be resected through a posteromedial incision. When acute release is not sufficient to reduce the equinus, the residual equinus can be corrected using gradual distraction (Fig. 12.3).

Ankle Joint Realignment

Ankle joint malalignment due to deformities such as valgus and recurvatum may be the cause of ankle joint degeneration (Paley 2005). To increase the longevity of the ankle joint cartilage, reorientation procedures, such as supramalleolar osteotomy, realign the ankle joint plafond. If the tibia-fibula relationship (ankle Shenton line) is incongruent, an isolated tibial lengthening with or without deformity correction or a fibular shortening or lengthening might be necessary to accurately restore the normal ankle anatomy. Fixed subtalar joint compensatory contracture, if present, should be addressed at the time of realignment and distraction. Subtalar contractures can be acutely reduced through a release or gradually corrected with the use of an external fixator. It is important to accurately assess compensatory deformities before surgical intervention (Paley 2005; Lamm and Paley 2004). Correction of ankle alignment is usually done using a supramalleolar osteotomy. This can be carried out acutely and fixed internally while the distraction is performed with external fixation. An alternative is to perform acute or gradual distal tibial realignment and ankle distraction with the same external fixator.

12.2.4.2 Application of Hinged External Fixation for Ankle Joint Distraction (Figs. 12.4 and 12.5)

Step 1—Apply a two-ring fixation block (orthogonal to the tibial axis) to the tibia by using wire(s) and half-pin(s). The tibial external fixation construct should be applied an ample distance proximal to the ankle joint to ensure ease of hinge application. Insert a temporary center-of-rotation wire through the Inman ankle axis of rotation

Fig. 12.3 (**a**) A 45-year-old woman with Ollier's disease status post osteotomies and ankle arthritis. She has equinus deformity of the ankle. (**b**) Lateral radiograph shows anterior ankle osteophytes blocking dorsiflexion. (**c**) After resection of osteophytes and application of a hinged external fixation ankle joint distraction device. (**d**) Lateral radiograph after distraction and correction of ankle joint contracture. (**e**) Anteroposterior and lateral radiographs after removal of the external fixator obtained at 3-year follow-up. (**f**) Lateral view obtained at 3-year follow-up shows recurrence of ankle osteophytes and a plantigrade foot position. The patient has no pain. (**g**) Final clinical photo at 3-year follow-up. The foot is plantigrade

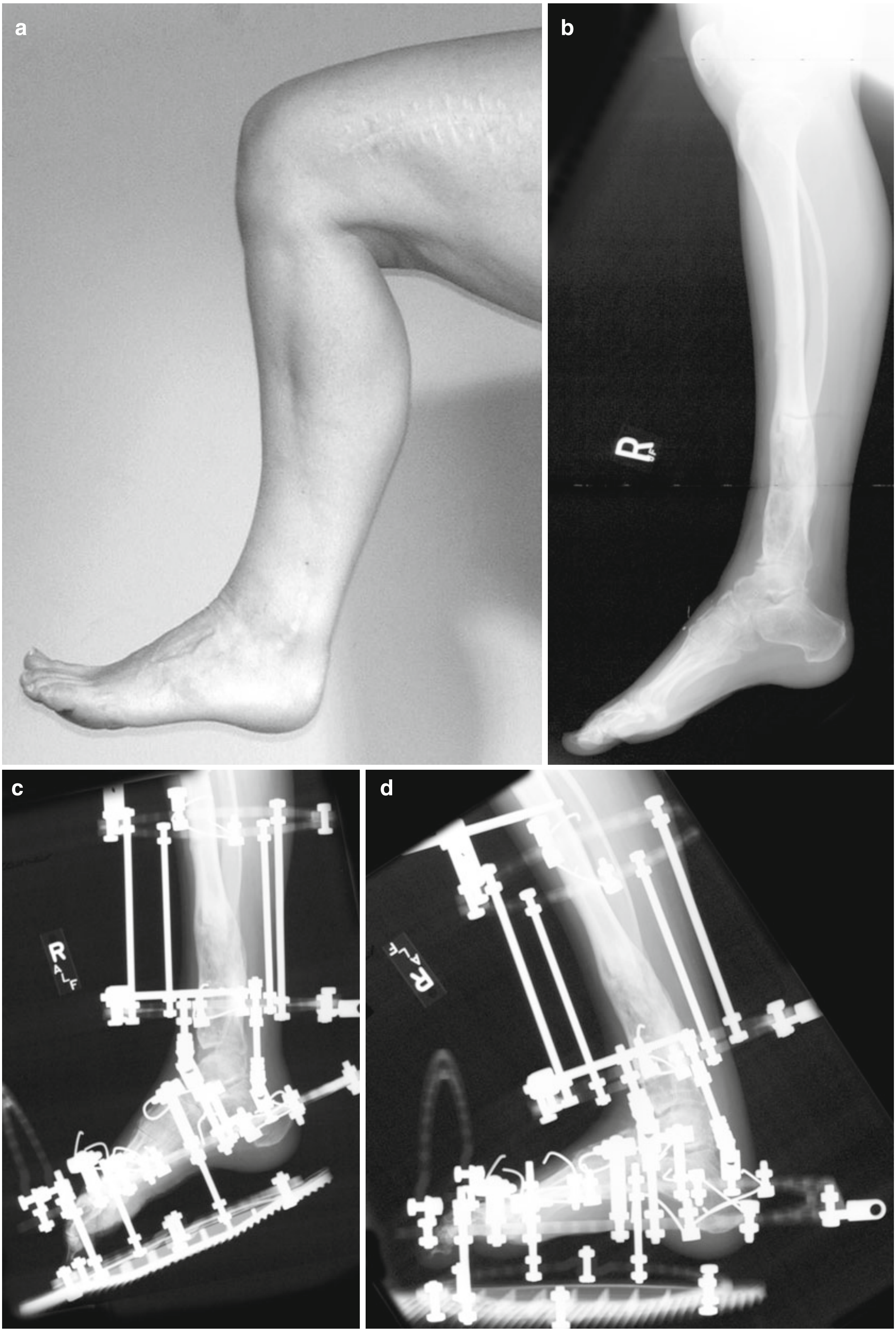
a
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Fig. 12.3 (continued)

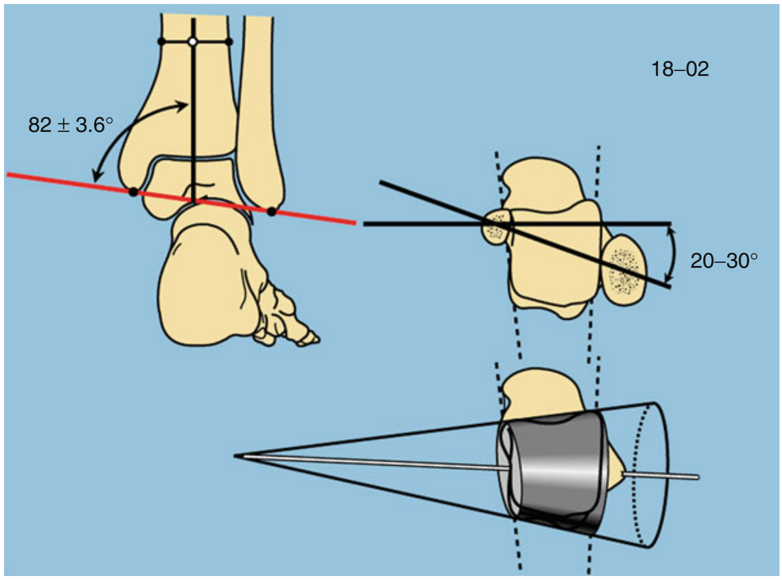

Fig. 12.4 Inman's ankle joint axis illustrated in multiple planes (Reproduced with permission from Paley (2005))

(start from the tip of lateral malleolus to the tip of medial malleolus) (Paley 2005). Then cut this wire short to allow space for hinge adjustment.

Step 2—Mount a closed U-shaped foot ring parallel to the sole of the foot by using two crossed calcaneal wires and two midfoot wires. Then insert two talar smooth wires, one medial to lateral through the talar neck and the other from anteromedial in the neck of the talus to posterolateral to the Achilles tendon. The position of the wires should be monitored with fluoroscopy to make sure they do not enter the subtalar or ankle joints. Mount these two wires to the foot ring and tension them.

Step 3—Attach medial and lateral threaded rods from the tibial to the foot ring making sure the universal hinge align/intersect the ankle axis wire. The universal hinges joint should be centered with the ankle axis wire. The medial hinge is positioned more proximal and anterior than the lateral hinge.

Step 4—Add a posterior distraction rod, which can be removed by the patient for ankle range-of-motion exercises.

I prefer to simultaneously distract both the subtalar and ankle joints acutely. This is accomplished by applying distraction between the tibial and foot fixation before inserting the two talar wires. In addition, after insertion of the two talar wires, 2 mm of acute ankle distraction is performed and checked with the use of fluoroscopy to ensure symmetrical and accurate ankle distraction. The patient starts distraction at a rate of 1 mm per day on postoperative day 1 for a total of 5 days. The goal is to achieve 8–10 mm of symmetrical ankle joint distraction. The external fixation device is maintained for 3 months while allowing weight bearing as tolerated. The patient removes the posterior distraction rod to perform daily ankle range-of-motion exercises and attends physical therapy three times a week.

12.2.5 **Author's Results** (Paley and Lamm 2005; Paley et al. 2008)

Paley and Lamm reported on 32 patients who underwent this ankle joint distraction technique

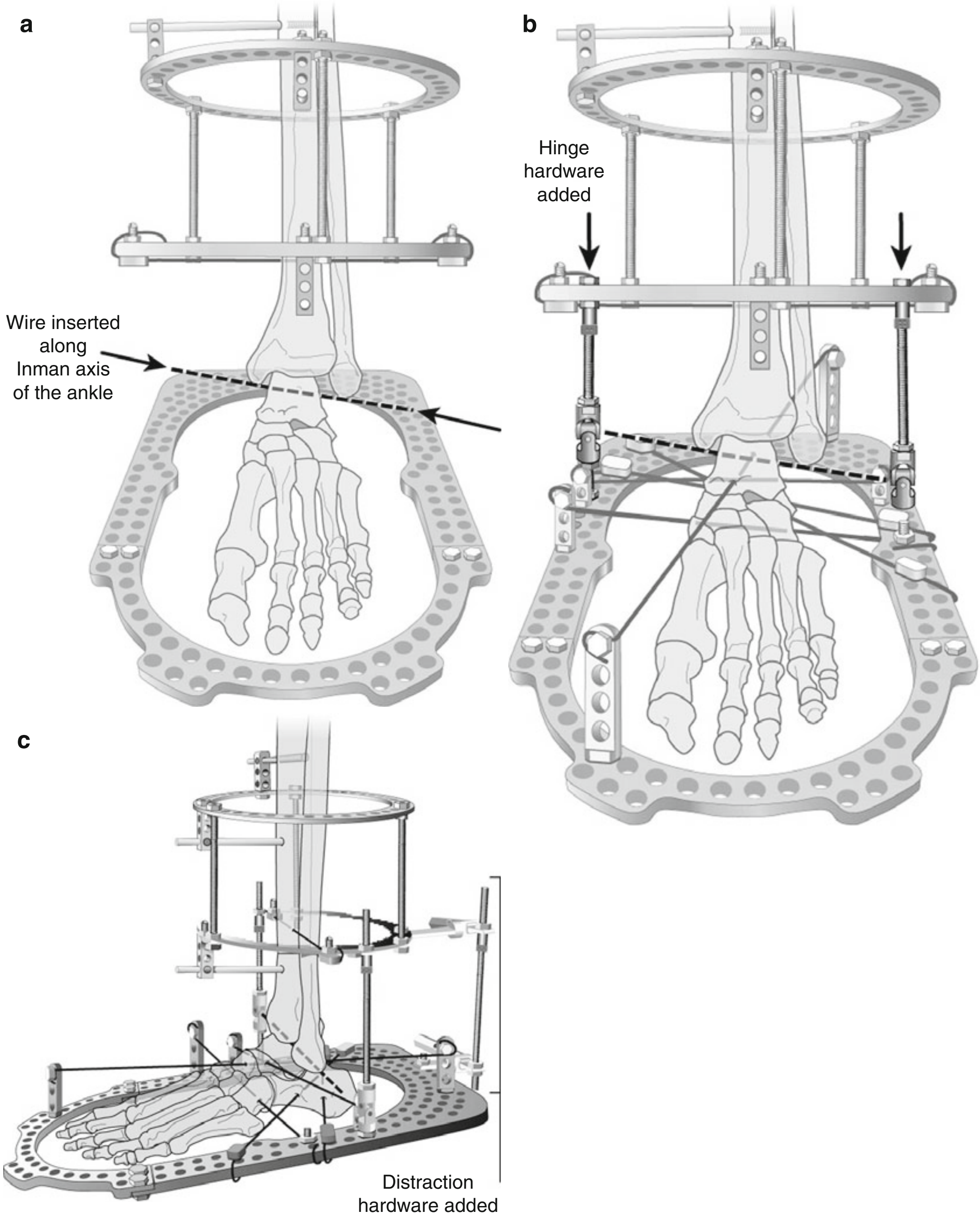

Fig. 12.5 (**a**) Two-ring block of fixation is placed on the tibia by using a wire and three half-pins perpendicular to the tibia bisection in both the transverse and sagittal planes. A center-of-rotation wire is placed through the Inman axis of the ankle (tip of medial malleolus to tip of lateral malleolus). This is a reference wire (*dotted line*) which is cut short and utilized for positioning the medial and lateral ankle hinges. (**b**) The foot ring is mounted parallel to the sole of the foot. Note the foot ring is closed/completed by attaching a half ring to the distal end of the U-shaped foot ring. Fixation of the foot ring is achieved with two crossed wires in the calcaneus, two talar neck wires, and one wire across the midfoot. Universal hinges are placed to intersect the Inman's ankle axis wire. Once aligned the universal hinges are then mounted to the foot ring. Note the medial hinge is more proximal than the lateral hinge. (**c**) A posterior distraction rod is placed and can be removed by the patient for ankle range-of-motion exercises. Note the medial hinge is more anterior than the lateral hinge

and found 78 % of patients had maintained their ankle range of motion and have none to occasional moderate pain that can be managed generally with NSAIDs alone. Only one has required an ankle fusion, and only one has been converted to an ankle joint replacement. The longevity of these results and the higher percent of good or excellent results when compared with other studies suggest that combining adjunctive procedures and articulation with ankle distraction improves the results of this procedure.

12.2.6 Discussion

The reason ankle distraction leads to lasting pain relief when treating ankle joint osteoarthritis is still speculative. It is possible that distraction permits cartilage repair to occur in a protected low-pressure environment. Salter et al. (1980) showed that cartilage repair (fibrocartilage) occurs within a cartilage defect. Fibrocartilage formation is the body's attempt to restore a normal joint surface. Pain from osteoarthritis may be related to the effect of hydrostatic pressure on subchondral bone cyst, whereby the synovial fluid from the joint enters through a cartilage defect (channel) and increases the fluid and thus the pressure within the subchondral bone cyst (van Valburg et al. 1995). Distraction might allow for the formation of fibrocartilage, which adequately seals these channels to the subchondral bone cyst and therefore eliminates the increased fluid (pressure) and the pain. In addition, joint distraction of the hip in cases of Perthes disease has been shown to stimulate epiphyseal cartilage to grow (Paley 2005).

Radiographs obtained after the external fixation is removed show that the joint distraction space of the ankle is not maintained. However, this radiographic finding does not seem to negatively impact the clinical result. Cartilage repair (i.e., fibrocartilage) has occurred although it is not enough to increase the radiographic measured joint space post-distraction but merely seal the cartilage cracks and defects.

Our results showed that the total arc of ankle joint motion was only slightly reduced by the treatment of hinged ankle distraction. This finding is significant in that our technique of hinged distraction did not create any additional ankle joint stiffness. Most notable is that the arch of ankle joint motion was harnessed into a functional range to our goal of 10° of dorsiflexion and at least 15° of plantar flexion. Therefore, if patients have very little ankle motion preoperatively, it is unlikely to become increased by this procedure.

The patients who underwent hinged ankle joint distraction using the protocol detailed above had promising long-term results. Seventy-eight percent (14 of 18 patients) had only occasional moderate to mild pain. Our mean Foot and Ankle Follow-Up Questionnaire ankle distraction score of 71 points is comparable to a recent ankle fusion study in which the score was 74 points (Colman and Pomeroy 2007). Most notably, only one of our patients required conversion to ankle arthroplasty and only one of our patients required an ankle fusion.

As for the longevity of our aforementioned hinged ankle joint distraction treatment protocol, our longest follow-up patient that was tractable was 13 years. That patient is still functioning well with occasional NSAIDs and without further surgery. After 5 years post-distraction treatment, the benefit decreases as shown by our data (Foot and Ankle Follow-Up Questionnaire score was 79 points for the patients with 5 years or less follow-up and 52 points for patients greater than 5 years follow-up). Therefore, the benefit of the distraction treatment decreases after 5 years.

Although 44 % of the patients who underwent treatment at our center could not be located or refused to be included in the study, we think the 56 % who took the questionnaire were representative of the group. Seventy-nine percent have maintained their ankle range of motion and have none to mild pain that can be managed without pain medication or with NSAIDs alone. Only one has required an ankle fusion, and only one has been converted to an ankle joint replacement. The longevity of these results and the higher percent of good or excellent results when compared with other studies (van Roermund et al. 2002; Marijnissen et al. 2003; Marijnissen et al. 2002;

van Valburg et al. 1995, 1999) suggest that combining adjunctive procedures and articulation with ankle distraction improves the results of this procedure.

Conclusions

Ankle joint distraction is a viable alternative to ankle arthrodesis or ankle replacement. A congruent, painful, mobile, and arthritic ankle joint treated with this technique can achieve good results. The à la carte approach (blocking osteophyte resection, muscle/joint contracture release, and osseous ankle realignment procedures) presented in this article is as important for a successful outcome as is the hinged ankle joint distraction technique itself.

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