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Chapter Title	Femoral Head Reduction Osteotomy for Coxa Magna and Nonspherical Femoral Head for Legg-Calvé-Perthes Disease	
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Abstract	Restoration of sphericity to the femoral head has the best prognosis after Perthes disease, typically accomplished via an osteochondroplasty or femoral head reduction osteotomy (FHRO). Three types of FHRO—Ganz, Paley, and Burian—have been developed due to the different patterns of femoral head deformity necessitating a change in the orientation of the osteotomy. The Ganz-type FHRO is made parallel to the femoral neck, while the Paley type is made perpendicular to the elongation axis of the femoral head, increasing the amount that can safely be reduced and more ideally reshaping the femoral head in cases with elongation not perpendicular to the femoral neck. The Burian FHRO, with its wedge resection, allows the advancement of the medial segment of the femoral head laterally, reducing the risk of a vascular necrosis while being easier to perform when elongation of the femoral head occurs more medially.	
Keywords (separated by " - ")	Femoral head - Necrosis - Elongation - Reduction osteotomy - Osteochondroplasty - Head - Ganz	

9

Femoral Head Reduction Osteotomy for Coxa Magna and Nonspherical Femoral Head for Legg-Calvé-Perthes Disease

Dror Paley

Femoral head sphericity is the key to joint preservation and longevity in Perthes disease. There is no controversy that a spherical femoral head has the best prognosis after Perthes disease [1, 2]. The Stulberg classification correlates well with natural history after Perthes disease [1]. Stulberg Class I and II are both spherical femoral heads. Stulberg Class III, IV, and V are all aspherical elongated femoral heads all referred to as coxa magna but also described as ellipsoid, mushroom shaped, saddle shaped, flattened, etc. Although a Class III has a better prognosis than a Class IV or V, they all lead to pain, femoroacetabular impingement, labral tears, degenerative changes to the femoral head and acetabulum, and loss of range of motion and limp. Most have symptoms as early as the teen age years, although radiographic degenerative changes may not manifest in Class III for two or three decades. The goal of containment and distraction treatment by brace/osteotomy or external fixation respectively is to prevent or reverse loss of sphericity of the femoral head. Once it is present at the end of treatment, it leads to damage to the labrum and joint cartilage. Until recently, restoring the sphericity of the femoral head was not an option. Cheilectomy [3] and valgus osteotomy [4] were considered salvage procedures which produced short term benefits. AU1

More recently, safe surgical dislocation combined with relative neck lengthening and trochanteric transfer have made it possible to improve reshaping techniques of the deformed femoral head [5, 6]. Osteochondroplasty of the anterolateral femoral head may be indicated, especially if the remainder of the femoral head is spherical and lacks degenerative changes. Unfortunately, the majority of cases of deformed femoral heads have degenerative changes corresponding to contact with the rim of the acetabulum, while the more anterolateral extruded femoral head has well preserved excellent hyaline cartilage covering it. In such cases osteochondroplasty

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would resect the healthy cartilage while preserving the degenerated cartilage. This may explain why 'cheilectomy' usually failed for Perthes disease [3].

In 2001, Reinhold Ganz from Bern, Switzerland, performed an intra-articular osteotomy of the central third of the femoral head and reduced the lateral cartilage to the medial preserved portion of the femoral head [5]. The lateral segment of the femoral head was mobilized on its vascular pedicle. The vascular pedicle to the medial femoral head was also preserved. This technique is ideal for the femoral head deformity following Perthes. As mentioned above, the lateral part of the femoral head usually has well-preserved cartilage because it never enters the acetabulum due to the enlarged femoral head. Meanwhile the adjacent cartilage that is impinging on the acetabular rim is usually damaged and is therefore ideal to be resected. The sooner this procedure is performed, the less degeneration there is to the femoral head and acetabulum. For this reason the ideal age to perform this procedure is before secondary changes occur, such as age 9–16 years. This chapter will examine the improving and evolving techniques of femoral head reduction osteotomy (FHRO) and their indications and results [7–10].

Goals of Treatment

- Convert an aspherical shaped femoral head to a spherical shaped femoral head.
- Eliminate any residual femoroacetabular impingement by osteochondroplasty.
- Reduction of coxa magna to normal sized femoral head.
- Change from coxa breva to a relatively longer femoral neck.
- Advance the overgrown greater trochanter.
- Identify and repair labral tear.
- Restore normal femoral head coverage.

Treatment Strategy

- Determine preoperatively whether the elongation of the femoral head is perpendicular to the femoral neck or not (Fig. 9.1). If perpendicular then a Ganz-type (Fig. 9.2a) FHRO is preferred, while if it is more horizontal, then the Paley type is preferred (Fig. 9.2b)
- Determine preoperatively whether this is a type A or type B (Fig. 9.3a, b). Type A requires a uniplanar reduction with parallel bone cuts, while type B requires a biplanar osteotomy with convergent bone cuts (wedge resection).
- Measure the opposite normal shaped femoral head and acetabulum and measure the ipsilateral femoral head and acetabulum.
- Determine the amount of reduction needed on AP and lateral views.
- Plan the amount of transfer needed to move the greater trochanter laterally and distally so that the tip of the greater trochanter is at the level of the center of the femoral head and is twice the radius of the femoral head away from the center of the joint.

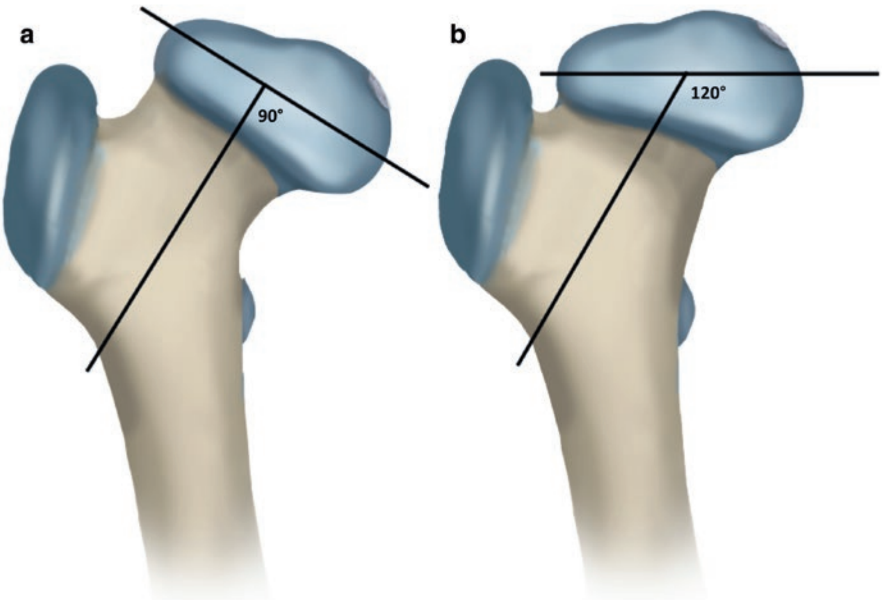


Fig. 9.1 Illustration of Type 1 elongated femoral head with elongation perpendicular to femoral neck (left) vs. Type 2 elongated femoral head with elongation not perpendicular to femoral neck. ((C) Dror Paley. Used with permission)

Surgical Details of Femoral Head Reduction Osteotomy

- Step 1: Anesthesia, positioning and draping: An epidural is placed by the anesthesia service with a catheter running up the back on the nonoperative side. A urinary catheter is inserted. The patient should be placed on their side on a beanbag on a radiolucent table in the lateral decubitus position with the operative side up. The ipsilateral arm should be appropriately padded and supported on an armrest. An axillary roll is utilized for the arm on the opposite side, and there is soft protection of boney prominences including the peroneal nerve as it crosses the fibular neck on the leg that is down. The entire operative side should be prepped and draped free from the nipple to the toes. The drapes should extend from the mid buttocks to the scrotal/labial-thigh fold. The lower limb should be completely free of the drapes. A sterile pocket should be created using drapes or a special pouch and fixed to the anterior side of the patient in line with the hip. Place a bump under the operative knee to abduct the operative hip.
- Step 2: Incision to and through fascia lata: An approximately 15-cm-long incision centered on the greater trochanter (GT) is made to and through the fascia lata (Fig. 9.4a). The fascia is separated from the gluteus maximus (GMax) muscle anteriorly to reflect this muscle posteriorly (Fig. 9.4b, c). This avoids splitting and denervating the anterior portion of this muscle.

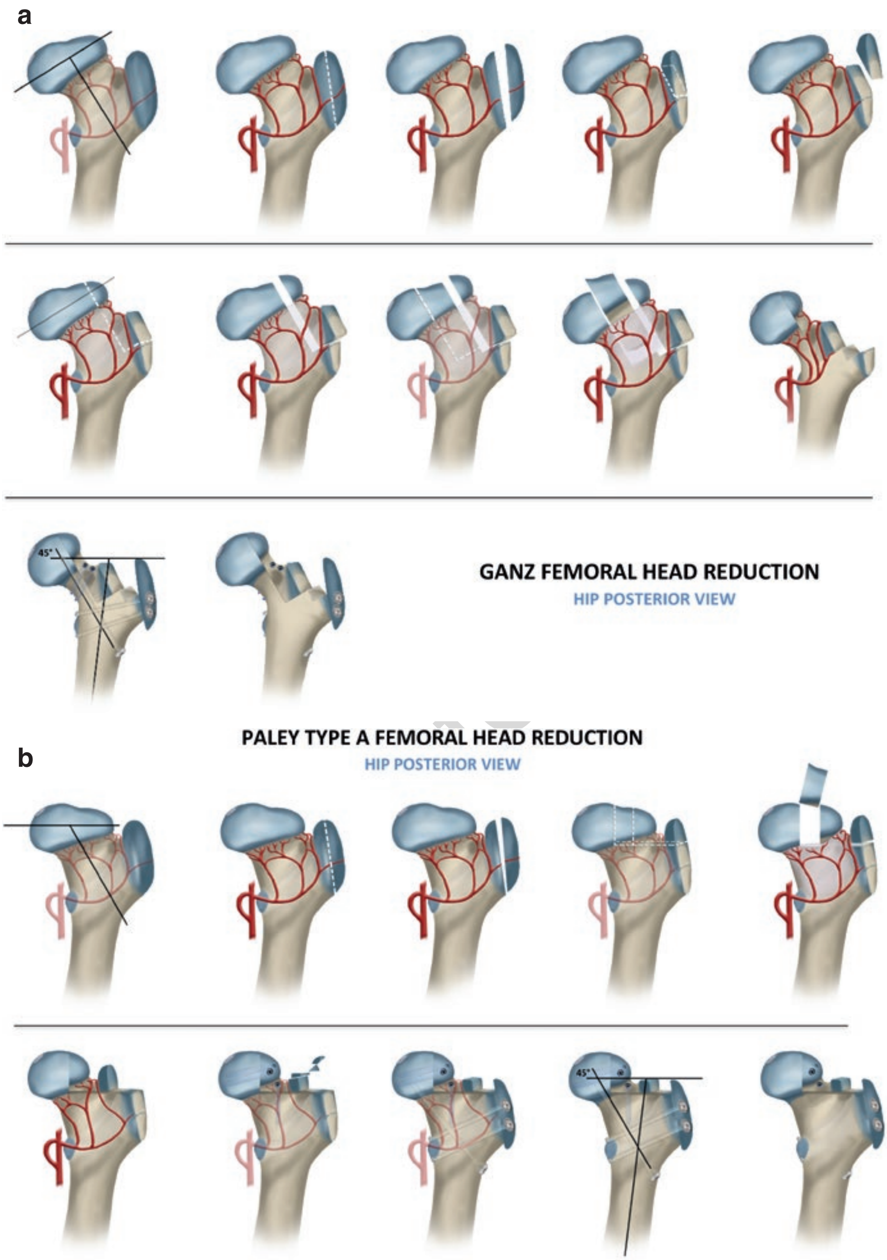


Fig. 9.2 (**a**) Ganz-type FHRO with cuts parallel to the femoral neck applied to Type 1 and femoral head elongations. (**b**) Paley-type FHRO with cuts perpendicular to the femoral head applied to Type 2 femoral head elongations. ((C) Dror Paley. Used with permission)

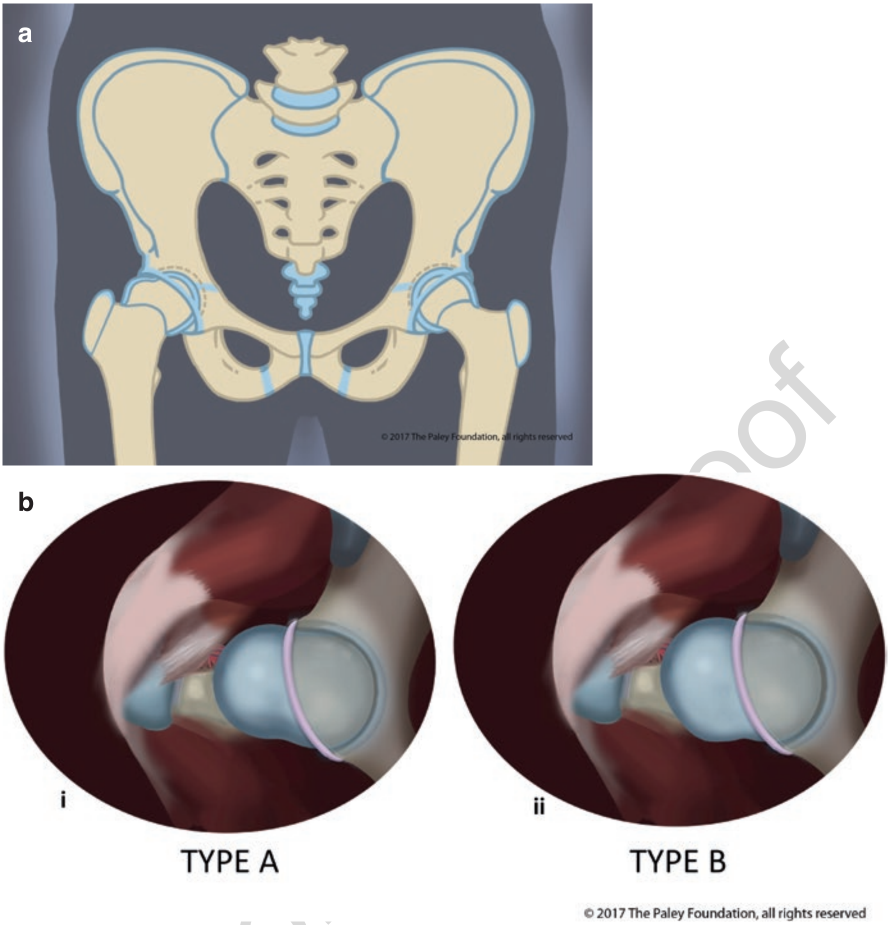


Fig. 9.3 (**a**) Illustration of saddle shaped right coxa magna, coxa breva with overgrown greater trochanter. The saddle part of the femoral head is where the femoroacetabular impingement occurs. (**b**) Superior view of (i) Type A coxa magna with lateral elongation of femoral head and (ii) Type B coxa magna with lateral elongation with anterior protrusion. ((C) Dror Paley. Used with permission)

- Step 3: Trochanteric bursa and piriformis muscle: Enter the trochanteric bursa (Fig. 9.4c) and identify the inferior edge of the piriformis tendon and the posterior edge of the gluteus medius muscle (Fig. 9.5a). The posterior border of the gluteus medius is very distinct. The terminal branch of the inferior gluteal artery (which anastomoses with the medial femoral circumflex artery) runs along the inferior border of the piriformis muscle. Also identify the junction between the gluteus maximus tendon and the posterior edge of the vastus lateralis.

- Step 4: Retract gluteus medius and minimus muscles: Identify the junction of the gluteus medius and its underlying gluteus minimus and the superior border of the piriformis muscle (Fig. 9.5b). The gluteus medius is more superficial than the deeper piriformis. The piriformis is in a more superficial layer than the gluteus minimus. The border of these three muscles is interdigitate with each other such that the posterior border of the gluteus medius slightly overlies the superior border of the piriformis which slightly overlies the posterior border of the gluteus minimus. Separate and retract distally the superior border of the piriformis from the posterior borders of the two glutei. Undermine the gluteus minimus to find the interval between this muscle and the underlying capsule. Insert a Z retractor into this interval to lift the glutei away from the capsule (Fig. 9.5c).
- Step 5: Elevate and retract the vastus lateralis: Using a cautery elevate the posterior border of the vastus lateralis off the femur. This is just anterior to the GMax tendon. Insert a Hohmann elevator to elevate this muscle (Fig. 9.5c).
- Step 6: Cauterize the posterior border of the GT: Connect a virtual line between the elevated vastus and the elevated glutei. Use a cautery to mark this line along

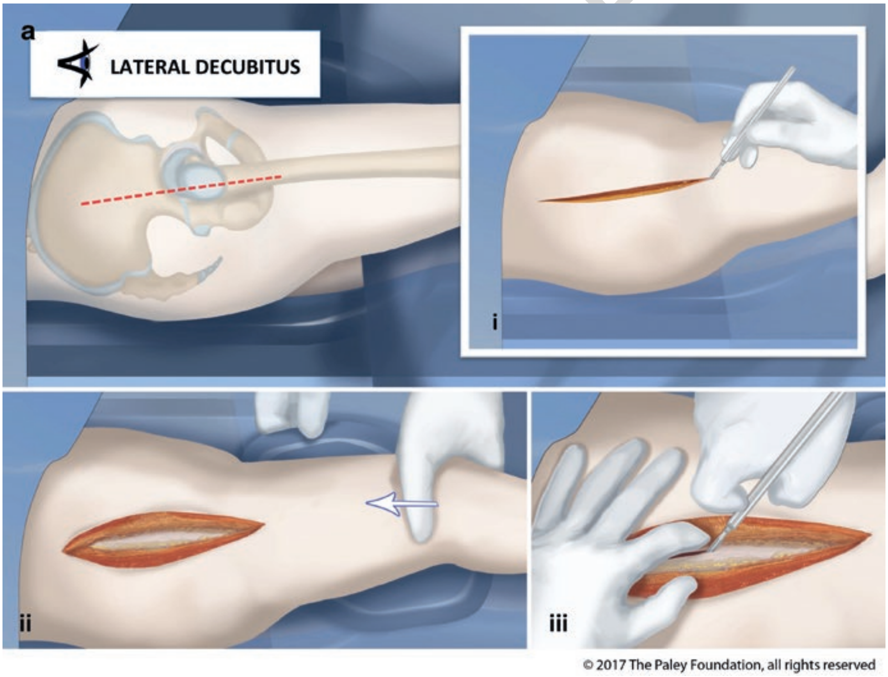
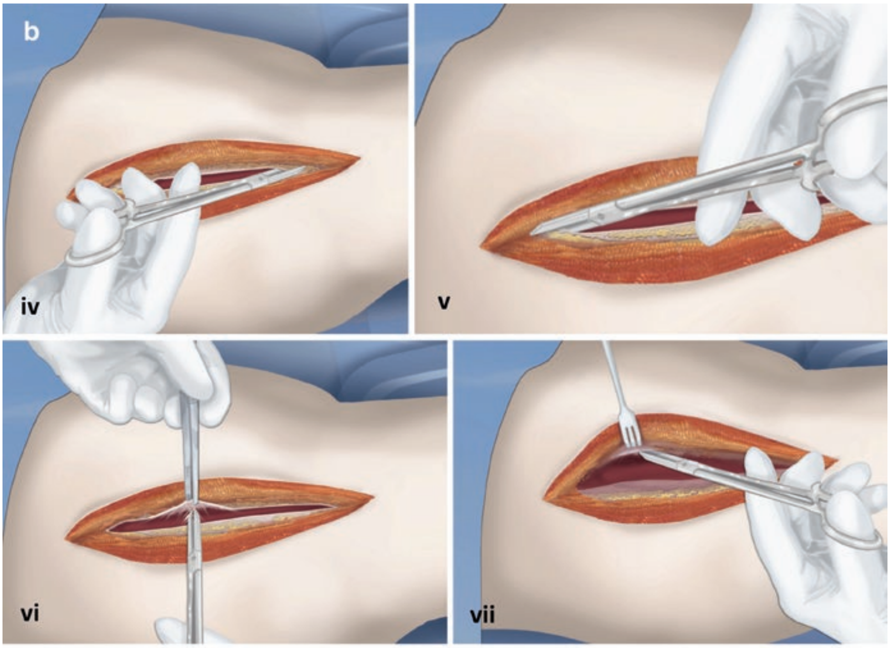
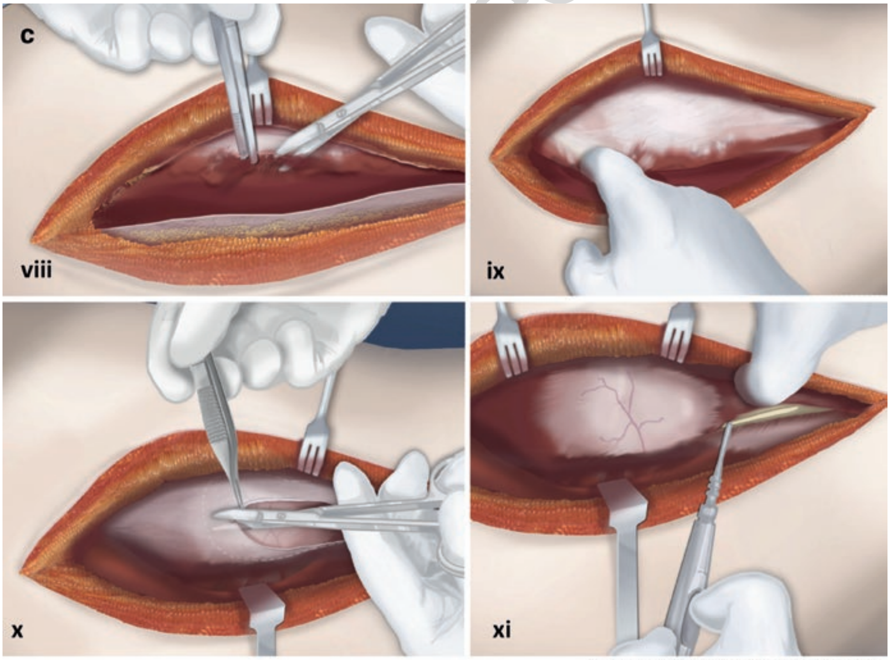


Fig. 9.4 (**a**) Lateral decubitus position with midlateral incision (i). The incision goes straight through skin, subcutaneous fat (ii), and fascia lata (iii). (**b**) The fascia is split longitudinally the entire length of the incision (iv, v) and then separated anteriorly from the underlying gluteus maximus (GMAX). (**c**) The gluteus maximus is reflected posteriorly from its anterior edge so as not to split and denervate it (viii, ix). The trochanteric bursa is opened (x) to expose the greater trochanter (xi). ((C) Dror Paley. Used with permission)





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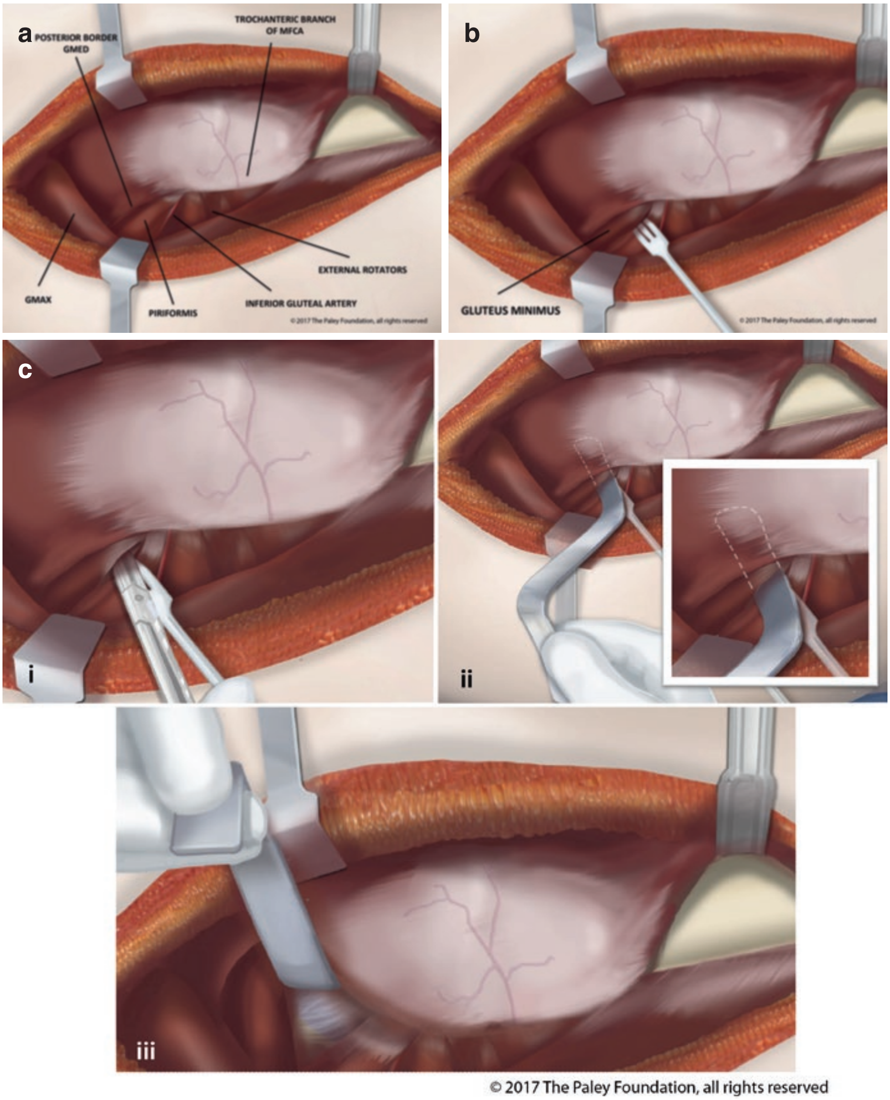


Fig. 9.5 (**a**) The posterior border of the gluteus medius (GMED) is very distinct. The inferior gluteal artery helps define the inferior border of the piriformis muscle. The trochanteric branch of the medial femoral circumflex artery (MFCA) is readily seen on the greater trochanter. The gluteus maximus tendon is seen inserting into the femur. The Vastus lateralis muscle is lifted off of the femur. (**b**) The gluteus minimus can be seen by reflecting the piriformis muscle distally. The GMED is slightly superficial to the Piriformis which is slightly superficial to the gluteus minimus. (**c**) The space under the gluteus minimus is dissected (i) so that a Z retractor can be inserted beneath it overtops the capsule (ii). The Z retractor is used to expose the underlying capsule (iii). A Hohmann elevator is lifting the Vastus Lateralis off the femur. ((C) Dror Paley. Used with permission)

the trochanteric ridge. This serves to cauterize the trochanteric vessels which are branches of the medial femoral circumflex vessels (Fig. 9.6a, b).

- Step 7: GT osteotomy: Use a saw to cut from posterior to anterior along the trochanteric ridge (Fig. 9.6c). The thickness of the lateral portion of the GT should be approximately 1.5 cm (Fig. 9.6b). The distal end of the cut should not penetrate the lateral femoral cortex to avoid subtrochanteric notching. The plane of this cut should be in line with the true lateral (maximum profile) of the GT notwithstanding the rotation at the knee.
- Step 8: Cut the soft tissues around the GT: The soft tissues around the GT should be cut with a sharp serrated curved scissors. At the proximal end, insert one leg of the scissors under the gluteal flap and the other end in the osteotomy (Fig. 9.6d). Orient the curve of the scissors concave toward the femur, to allow them to conform to the hip capsule and go around the corner anteriorly (Fig. 9.6e). Make

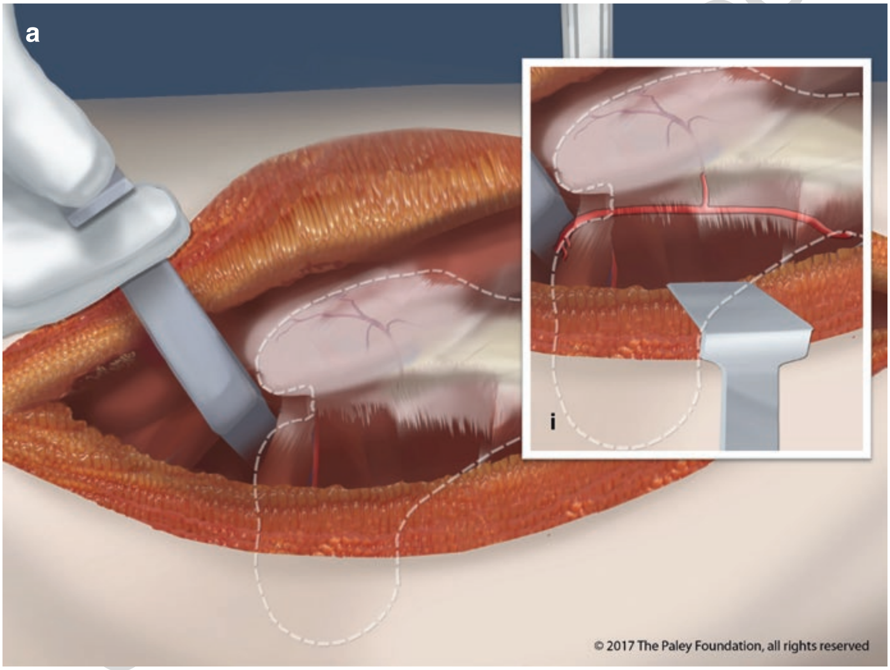
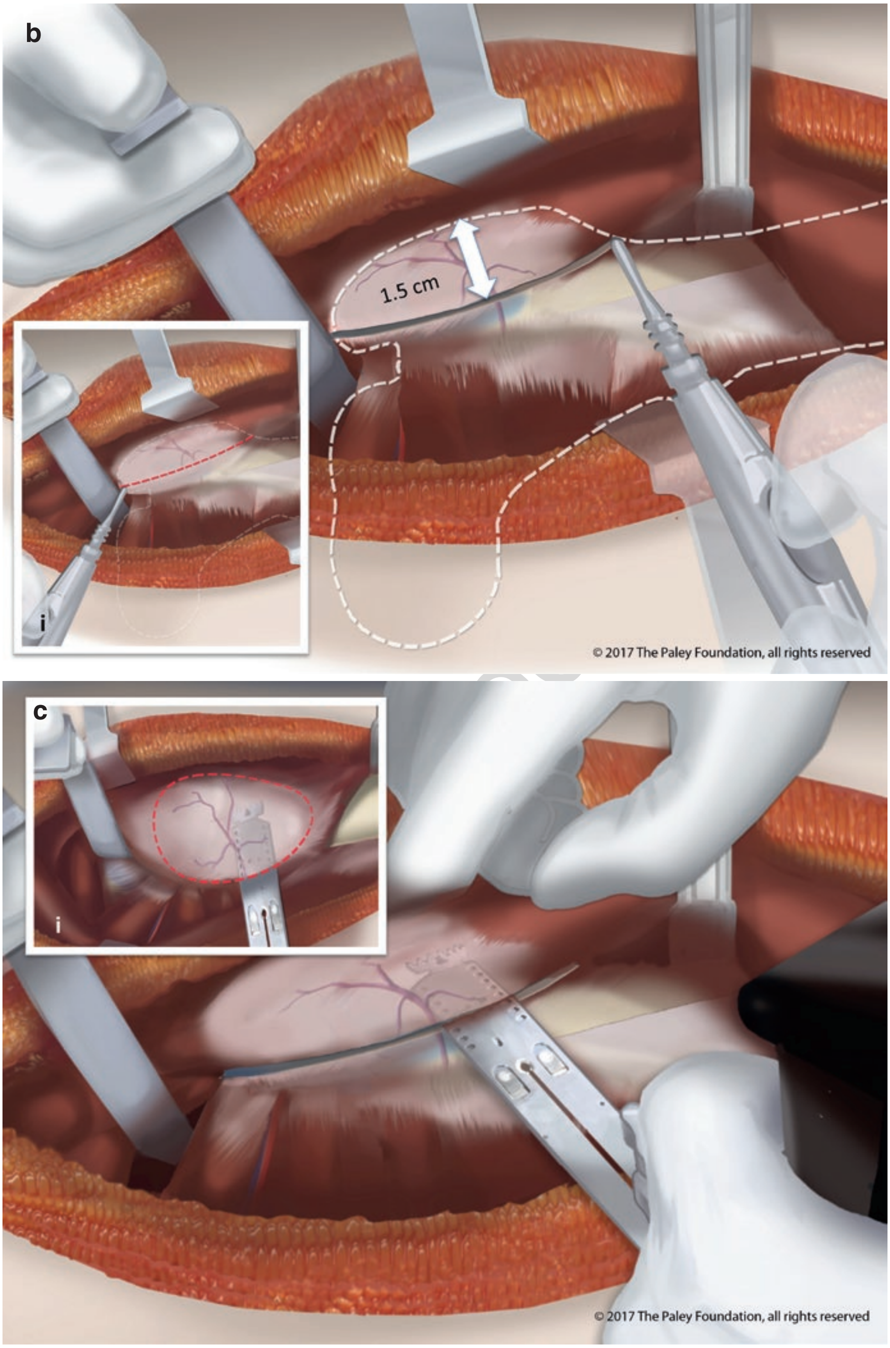


Fig. 9.6 (**a**) A lateral view of the greater trochanter is shown with the external rotator muscles inserting medial to the posterior trochanteric ridge. Underlying these running along the periosteum is the ascending branch of the MFCA (i) as it courses toward the piriformis fossa and anastomoses with the inferior gluteal artery. (**b**) The line for the trochanteric osteotomy is marked with a cautery. This line is defined along the trochanteric ridge between the insertion of the vastus lateralis distally and the Z retractor proximally. The trochanteric artery is intentionally cauterized. The thickness of the trochanteric segment is 1.5 cm. (**c**) Osteotomy of the greater trochanter is carried out with an oscillating saw. (**d**) The mobile trochanter is mobilized by cutting the soft tissues on its superior, medial, and inferior sides. At the upper end any tendinous extension from the piriformis is released. (**e**) The superomedial side of the trochanter is released. (**f**) The inferomedial side of the trochanter is released. ((C) Dror Paley. Used with permission)



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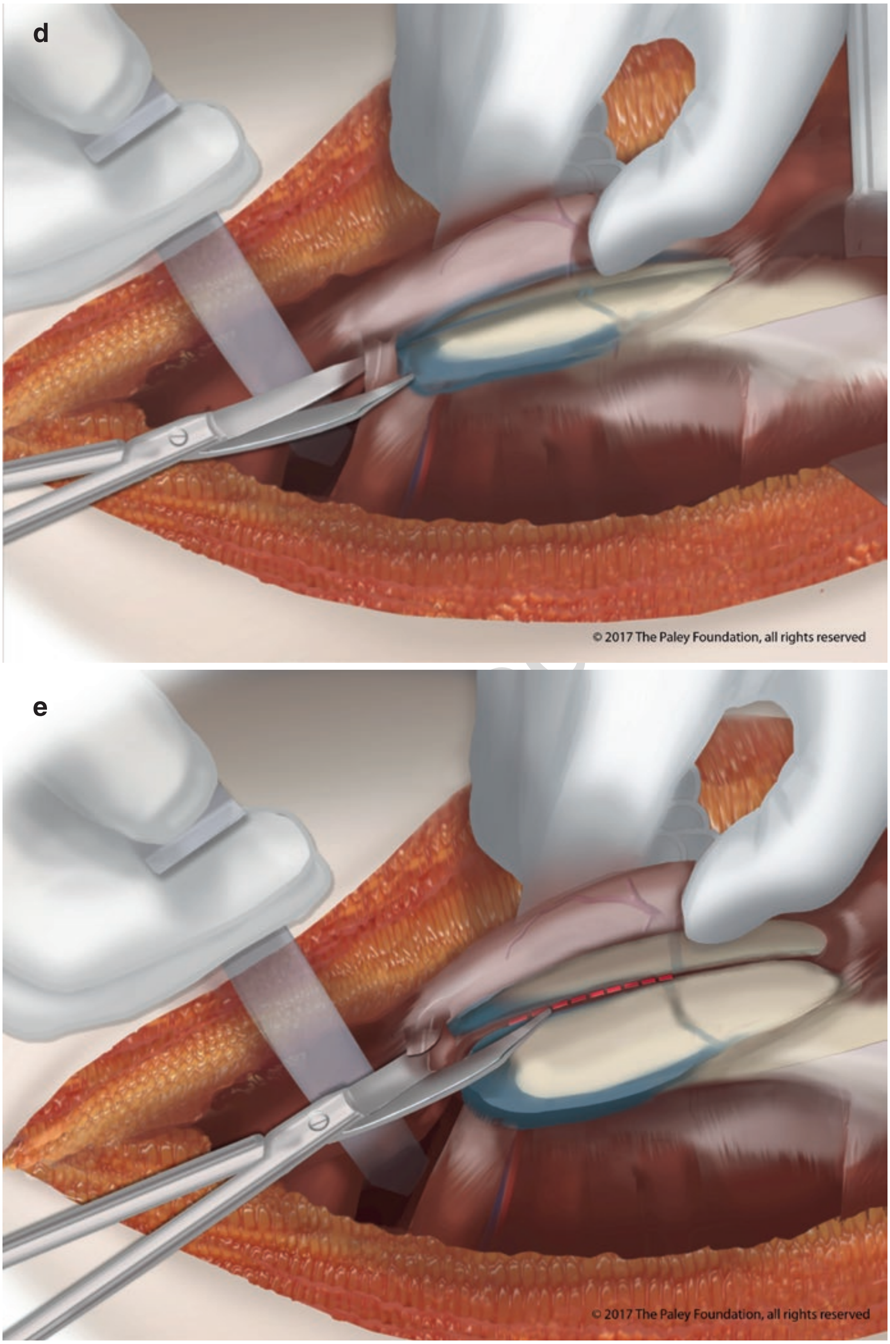

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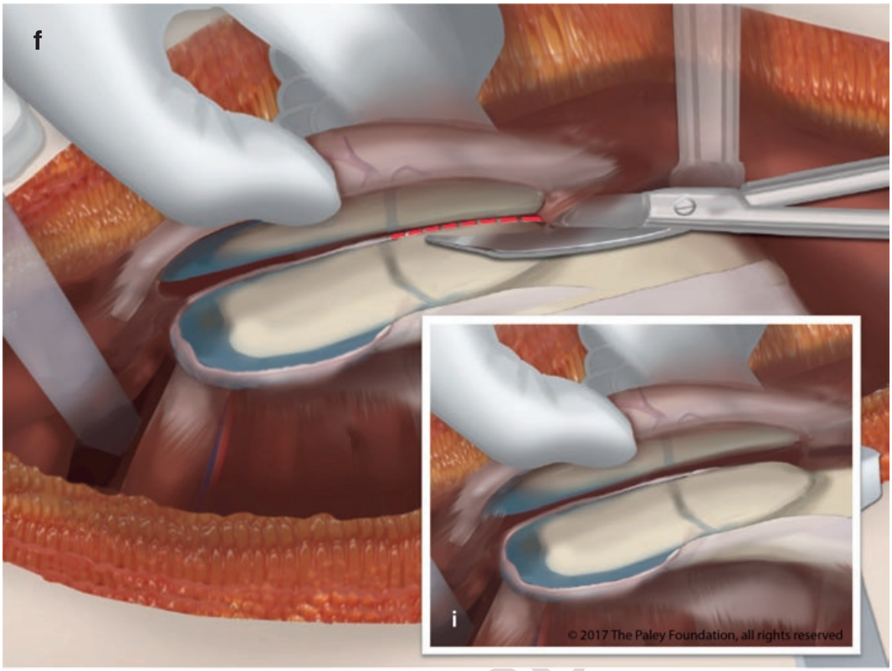


Fig. 9.6 (continued)

sure that the piriformis muscle remains posterior to the scissors. The piriformis tendon should remain connected to the stable portion of the GT with no more than a third of it still attached to the mobile GT (Fig. 9.6d). Release the part of the piriformis tendon connected to the mobile GT. Distally, do the same placing one leg of the scissors between the femur and the vastus and the other leg inside the osteotomy (Fig. 9.6f). The two cuts will converge on each other and free the GT osteotomy so it can be "flipped."

- Step 9: Insert 2 Hohmann elevators: Flex the hip and remove the bump from under the knee and allow the leg to adduct. Bluntly dissect under the muscle flap to the anterior inferior iliac spine (AIIS). Place a Hohmann elevator around the AIIS with care to stay between bone and muscle on the inside of the pelvis (Fig. 9.7a). Use a Cobb elevator to sweep the gluteus minimus muscle off of the capsule and lateral wall of the ilium. Impact a Hohmann elevator through the lateral wall of the ilium to retract the glutei proximally (Fig. 9.7b). These two elevators, which are 90 ° to each other, stay in place for the duration of the procedure.
- Step10: Z Capsulotomy: Make a Z-shaped capsulotomy. The intermediate limb of the Z (lateral to medial) is located at 11 o'clock for a left hip and 1 o'clock for a right hip with 12 o'clock being the top of the hip joint (Fig. 9.7c). Take care not to cut the labrum (Fig. 9.7d). Make one limb of the Z anterolateral and one limb

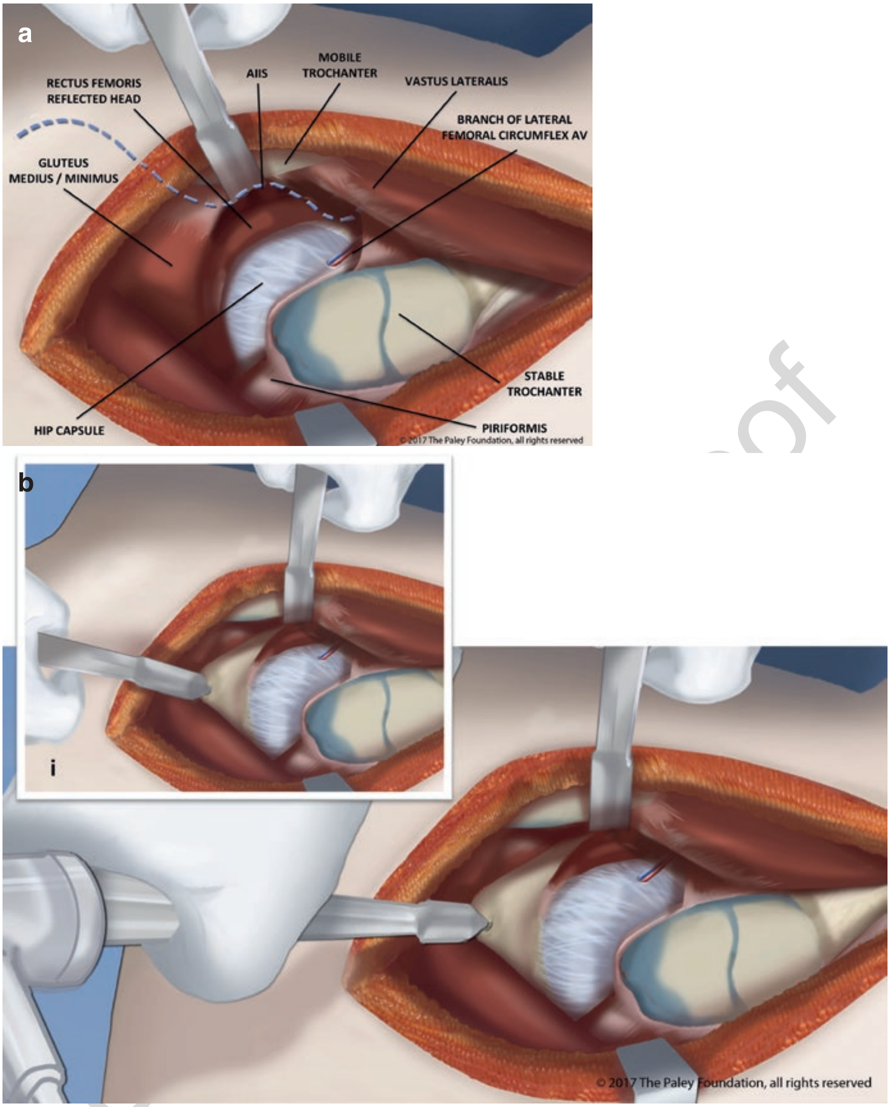
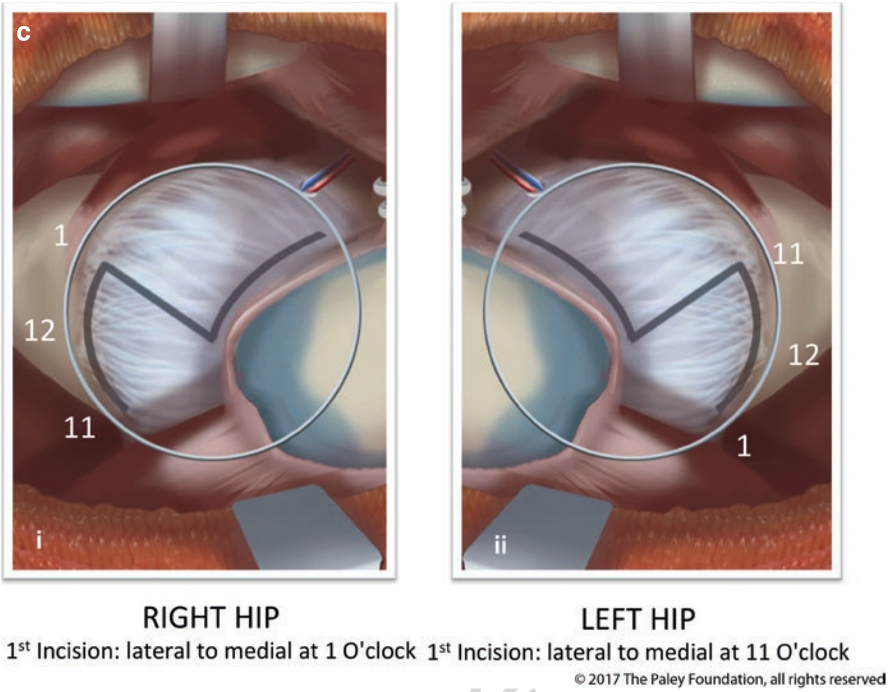
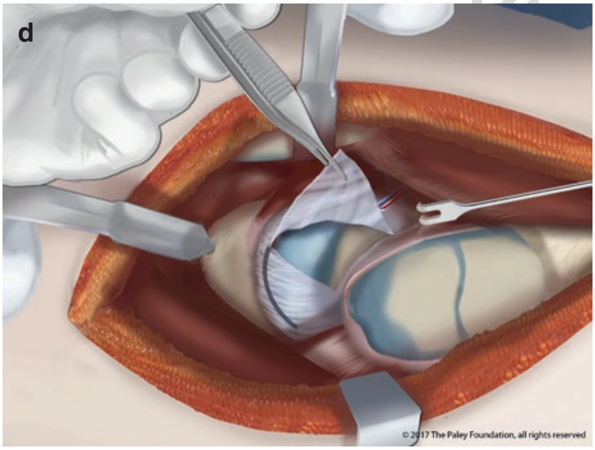


Fig. 9.7 (**a**) The hip is flexed and a Hohmann elevator is inserted around the anterior inferior iliac spine (AIIS). The branch of the lateral femoral circumflex artery should be spared if possible. (**b**) The gluteus minimus is elevated off of the capsule and lateral ilium. A Hohmann elevator is impacted into the lateral ilium to help retract the soft tissues. The two Hohmann's are 90 ° to each other and should be retracted separately with separate hands in two different directions for best exposure. (**c**) The Z-shaped capsulotomy has the distal arm lateral and the proximal arm medial. It is shown for right and left hips. (**d**) The anterior part of the capsulotomy. (**e**) After the entire capsulotomy is completed, the hip can start to be dislocated and the ligamentum teres cut with curved right angle scissors (i). ((C) Dror Paley. Used with permission)





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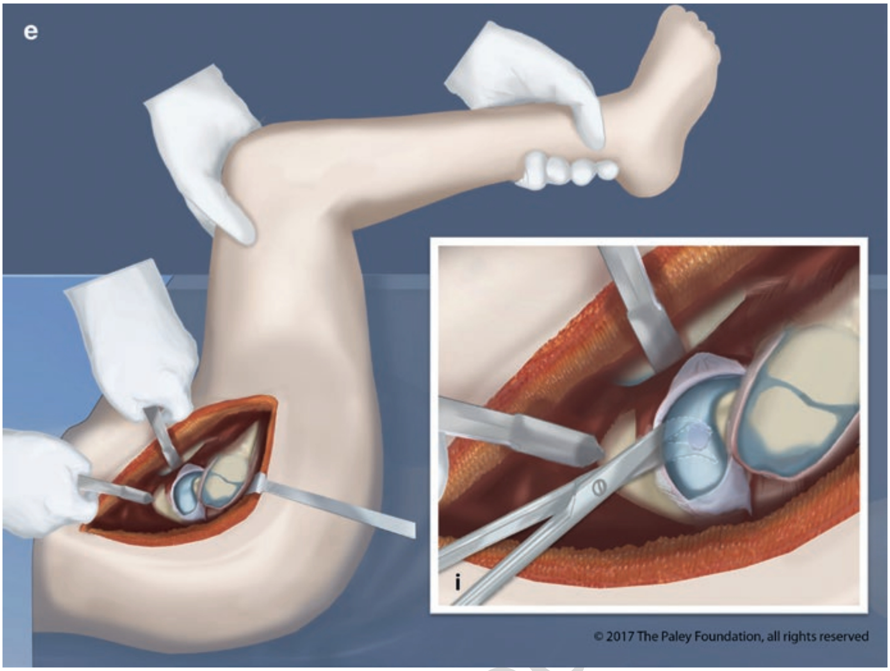


Fig. 9.7 (continued)

posterior-medial. Leave a cuff of capsule at both limbs in order to sew into and also to preserve the relationship of the capsule to the labrum.

- Step 11: Cut ligamentum teres: To be able to dislocate the hip cut the ligamentum teres with a long curved scissors (e.g., Jorgenson's) (Fig. 9.7e).
- Step 12: Dislocate the hip: Flex and externally rotate the hip to dislocate it (Fig. 9.8).
- Step 13: Resect the ligamentum teres: resect the remnant of the ligamentum both in the acetabulum and from the femoral head. Clean out the cotyloid notch from soft tissues (Fig. 9.8).
- Step 14: Inspect and repair the labrum: Inspect the labrum with a blunt hook to look for a partial or complete labral tear. If the labrum is torn resect and repair according to the pattern of the tear. Use suture anchors in the acetabular rim to anchor the labrum back to bone
- Step 15: Measure the size of the acetabulum: Use spherical acetabular sizers to measure the diameter of the acetabulum (Fig. 9.9a).

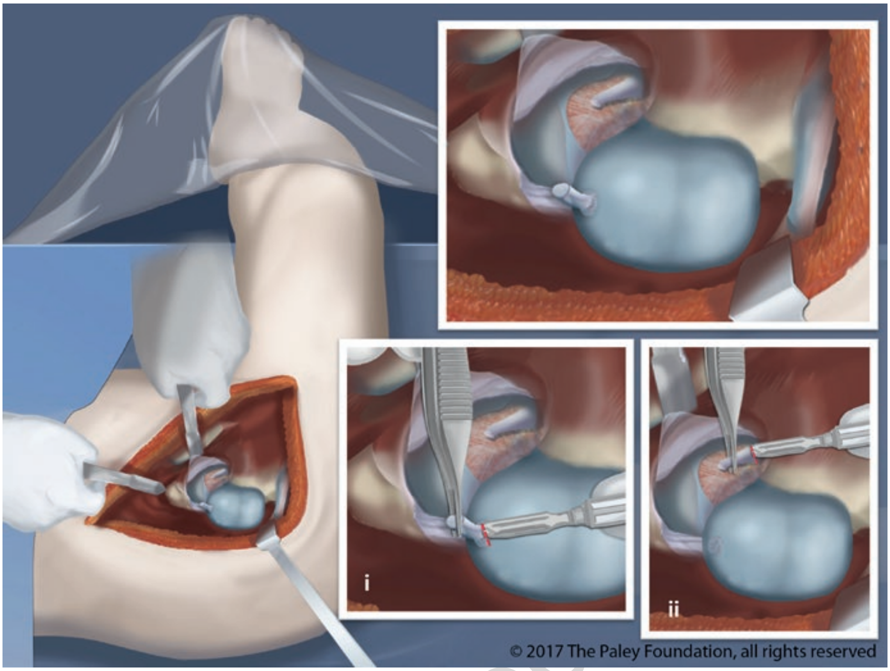


Fig. 9.8 The leg is crossed over the opposite leg and dropped into a sterile bag. The hip is now dislocated. The ligamentum teres and any pulvinar can be excised. The labrum can be probed for tears. ((C) Dror Paley. Used with permission)

- Step 16: Size the femoral head: Use femoral head spherical templates to assess the sphericity of different parts of the femoral head (Fig. 9.9b, c), starting with a template corresponding to the acetabular template. The femoral head can be sized for its curvature in different planes. Mark the medial femoral head where the sizer leaves the round. Do the same for the lateral portion of the femoral head. Using this method the femoral head can be mapped for its sphericity.
- Step 17: Retinacular flap: Reduce the hip back into joint. Do a subperiosteal dissection of the posterior femur starting at the level of the lesser trochanter and working proximally up to the level of the piriformis fossa (Fig. 9.10). The retinacular vessels are elevated with the periosteum.
- Step 18: Mark the vertical osteotomy lines: Redislocate the hip and mark the osteotomy lines. There are two osteotomy patterns: Ganz-parallel to the femoral neck and (Fig. 9.2a); Paley (Fig. 9.2b)- perpendicular to the femoral head. Furthermore there are two types of osteotomy pairings: (A) parallel cuts (Fig. 9.11a) and (B) non-parallel cuts (Fig. 9.11b). These are illustrated for the Paley type but not for the Ganz type since the former is the more common deformity pattern. For both A and B types the final diameter of the femoral head is the same and should correspond to the template diameter of the acetabulum.

- Step 19: Mark the horizontal osteotomy line: Mark this line distal enough to include the anterior part of the piriformis fossa but not too deep to narrow the femoral neck too much (Fig. 9.11a, b).
- Step 20: Make the vertical osteotomies (Figs. 9.12a–e and 9.13a–e): Use a thin saw to make the horizontal cuts first and then make the vertical cuts. Do not cut all the way to the posterior head/neck. After making most of the cut with the saw, complete the posterior part of the osteotomy with an osteotome. Crack the back of the osteotomy to avoid disrupting any retinacular vessels that may be attached.
- Step 21: Remove the intercalary segment: Remove the middle segment created by the osteotomies (Fig. 9.12e and 9.13e).
- Step 22: Mobilize the lateral segment: Mobilize the lateral segment by lifting it from anterior to posterior hinging on the retinacular flap (Fig. 9.14a). Carefully strip the retinaculum off of the neck to remain on the mobile lateral segment. This allows it to move from lateral to medial to close the defect without tethering or tearing the retinaculum (Fig. 9.14b).

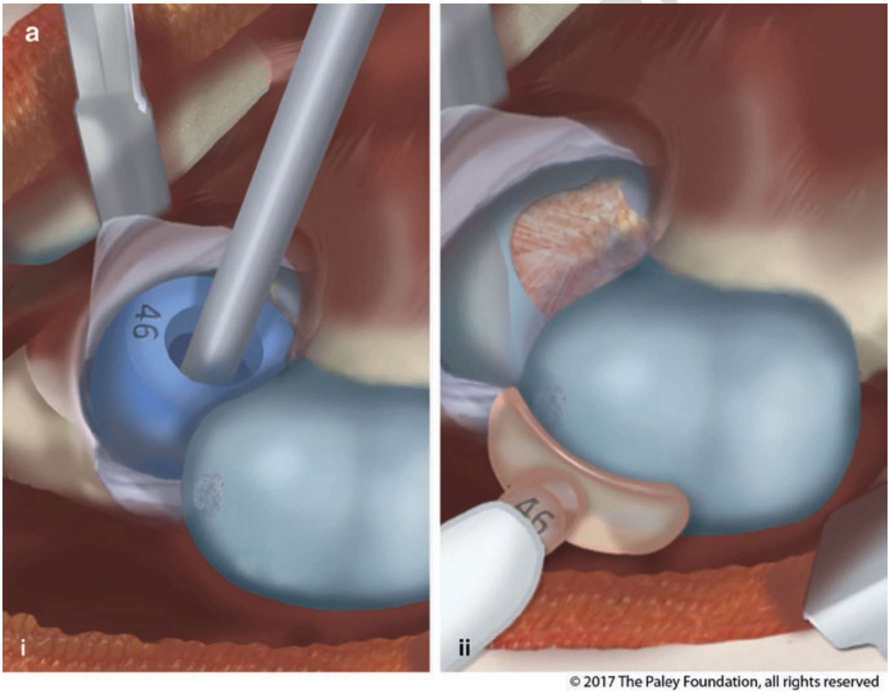
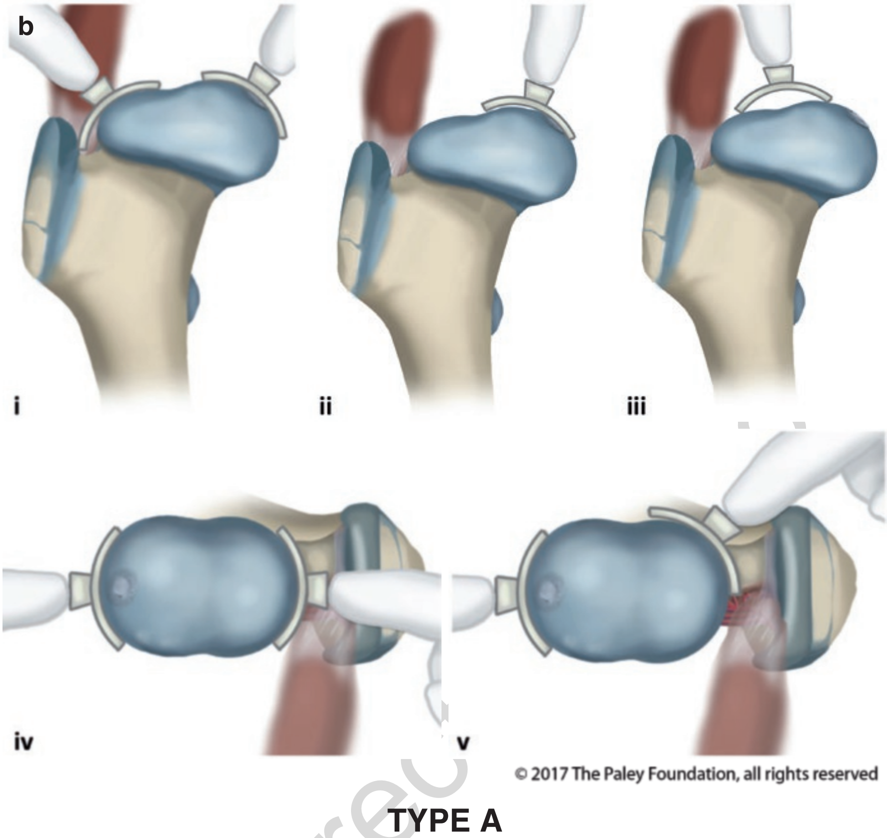


Fig. 9.9 (**a**) The acetabulum is sized (i). A femoral head template of the same size as the acetabulum (in this case 46 mm) is used to check the sphericity of the medial femoral head. (**b**) The femoral head is template along its medial and lateral sides as well as along its medial and lateral superior surfaces. It is important to note where the femoral head leaves the round. This is shown for Type A. (**c**) The same is done for a Type B case. Note the anterior bump and incongruity. ((C) Dror Paley. Used with permission)



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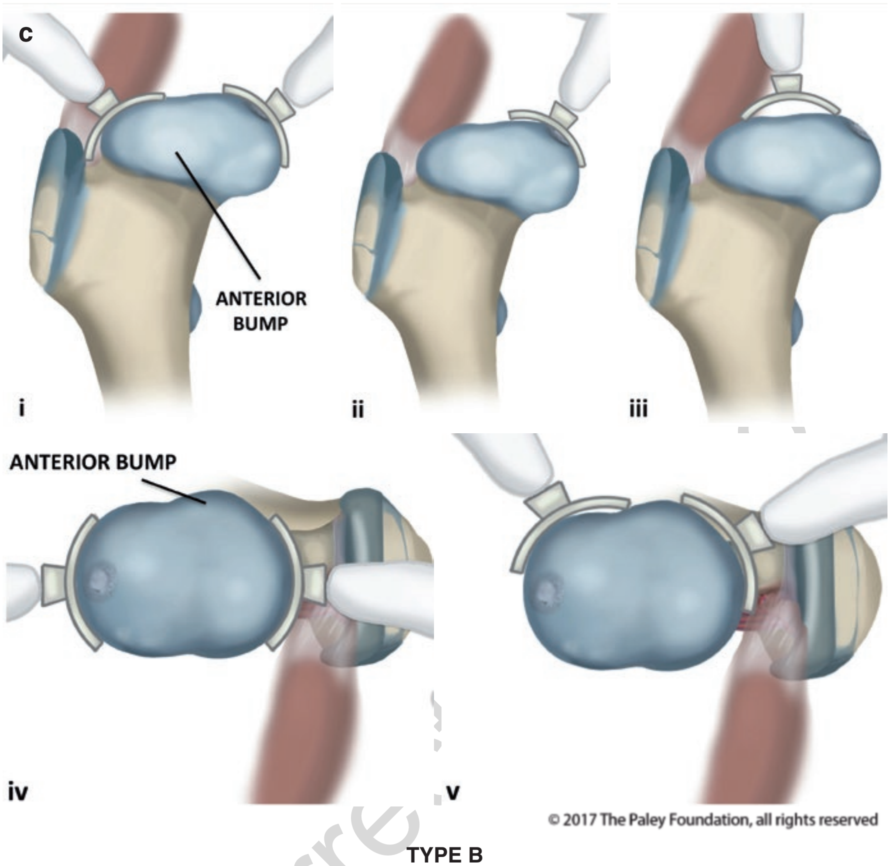

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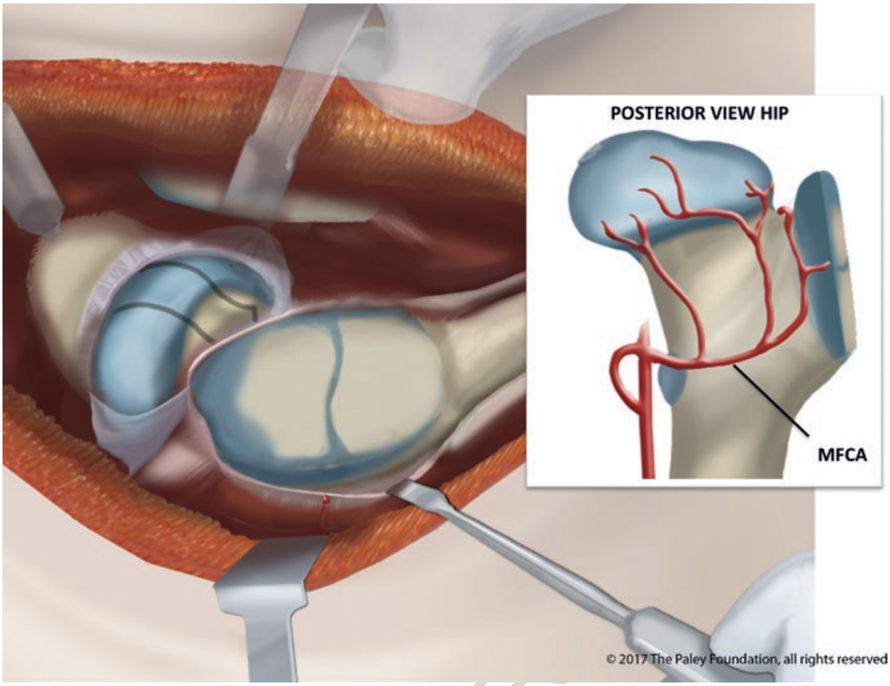


Fig. 9.10 The hip is reduced into joint again and the periosteum at the back of the femur is stripped carefully and extended proximally to help separate the retinaculum from the lateral femur. This moves the MFCA away from the lateral femur. ((C) Dror Paley. Used with permission)

- Step 23: Reduce the femoral head: Adjust the lateral segment so that the posterior congruity is as perfect as possible (Fig. 9.14b). If there is a step, make sure it is anterior.
- Step 24: Fix the femoral head with headless screws: Fix the segments with two parallel k-wires and then measure and drill over these and insert two parallel variable pitch headless screws(Fig. 9.15a). The variable pitch thread compresses the intra-articular osteotomy line.
- Step 25: Insert a third headless screw perpendicular to the osteotomy at the base of the lateral fragment: Drill a wire, cannulated drill, measure, and then insert a headless screw (Fig. 9.15b).
- Step 26: Osteochondroplasty: Perform an osteochondroplasty on any incongruous anterior aspects of the femoral head to avoid impingement and to eliminate any incongruity from the reduction.
- Step 27: Insert prophylactic screw for femoral neck: Drill a guide wire from the fovea retrograde into the femoral neck through the lateral femoral cortex. Measure and insert an antegrade cannulated screw up the femoral neck (Fig. 9.15c, d).

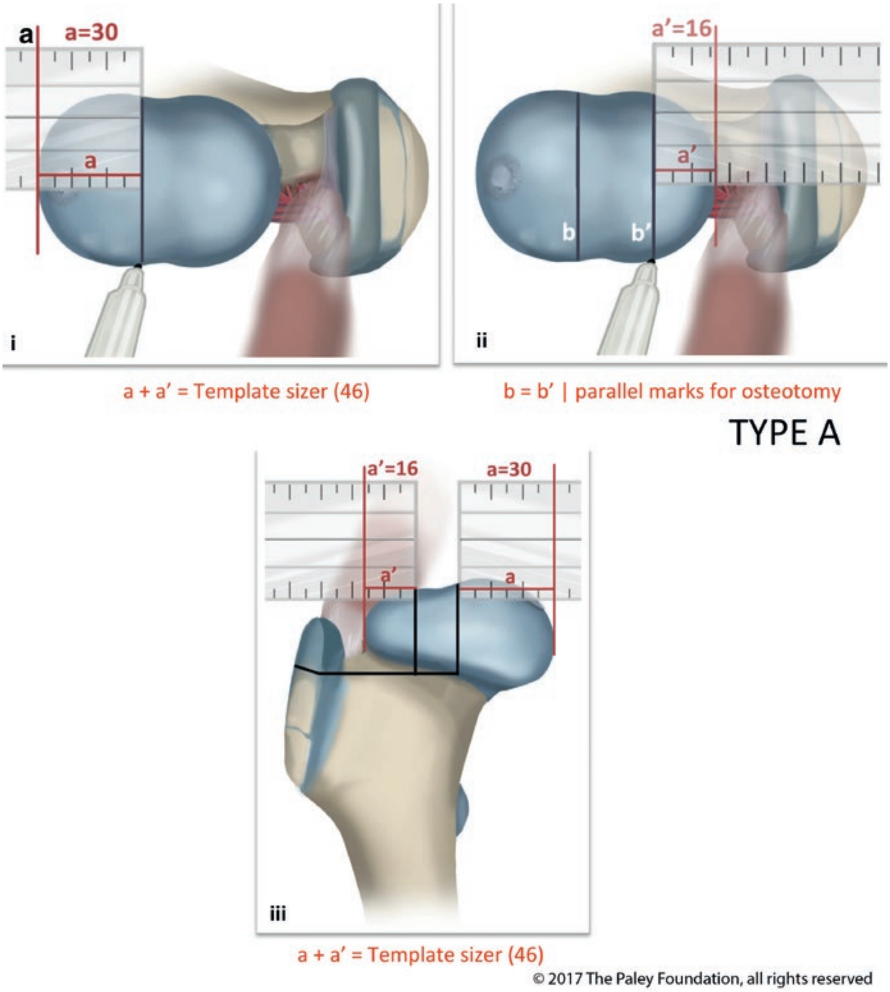
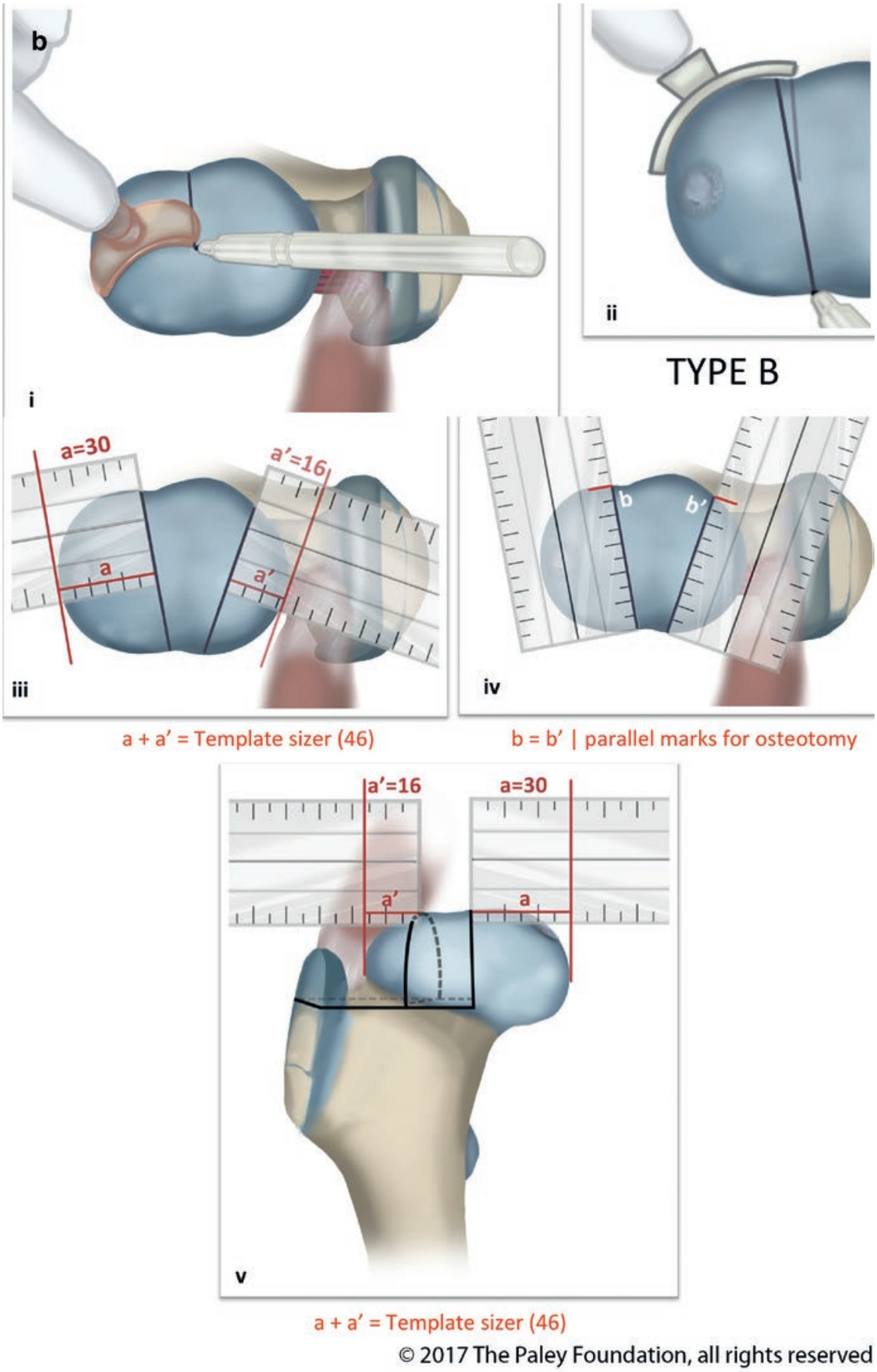


Fig. 9.11 (**a**) The femoral head is marked at the borders of where it leaves the round based on the femoral head spherical templates. Since the medial part measures 30 mm and since the total diameter of the reduced femoral head is 46 mm, then the lateral segment should be 16 mm. Since the coxa magna is Type A, the planned osteotomy lines are parallel. The baseline runs just below the ridge of the femoral head and distal to the anterior piriformis fossa. It is still superior to the most posterior piriformis fossa. The stable trochanter will be part of the lateral fragment. (**b**) For Type B the two lines are convergent posteriorly. The dimensions of the medial and lateral parts of the femoral head are the same as for Type A and add up to a 46 mm diameter femoral head. ((C) Dror Paley. Used with permission)



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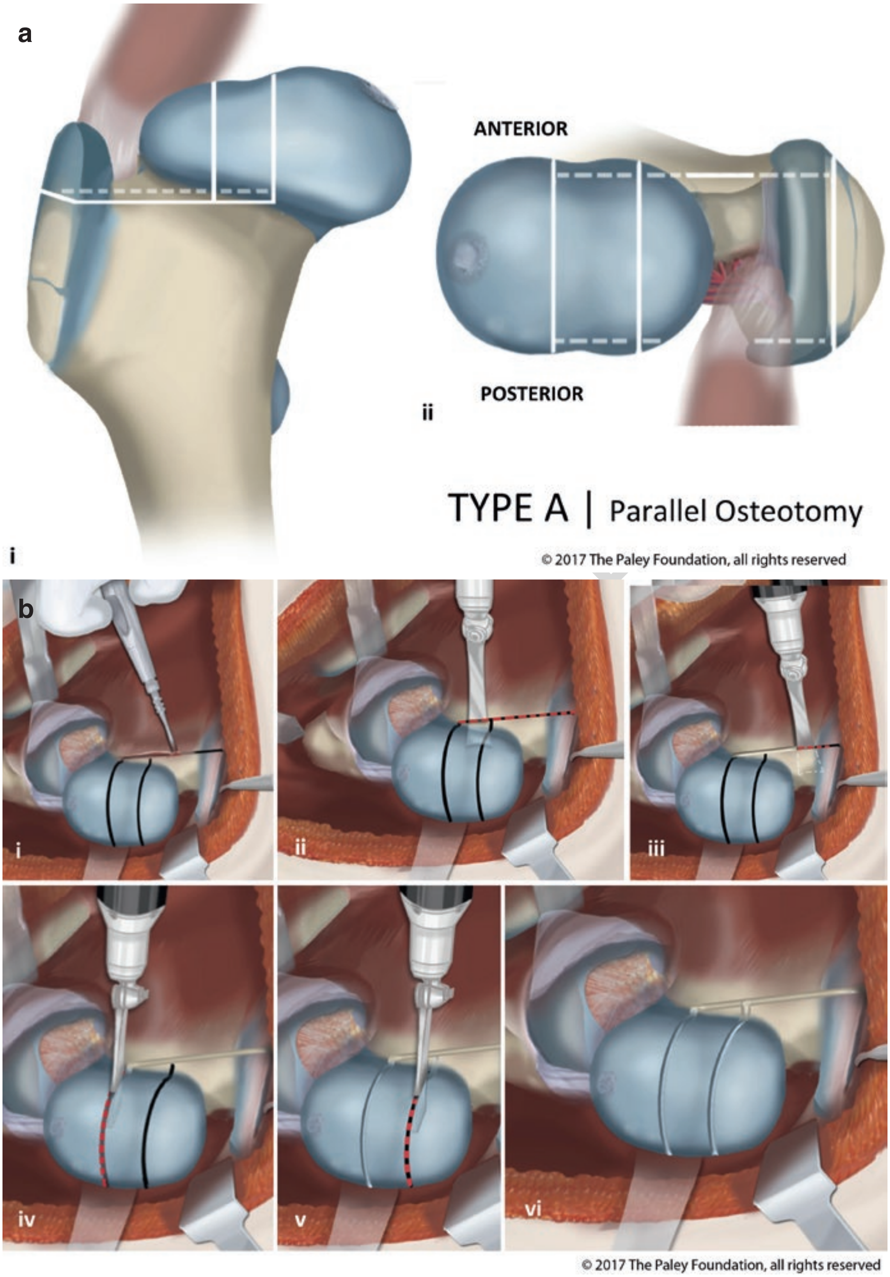
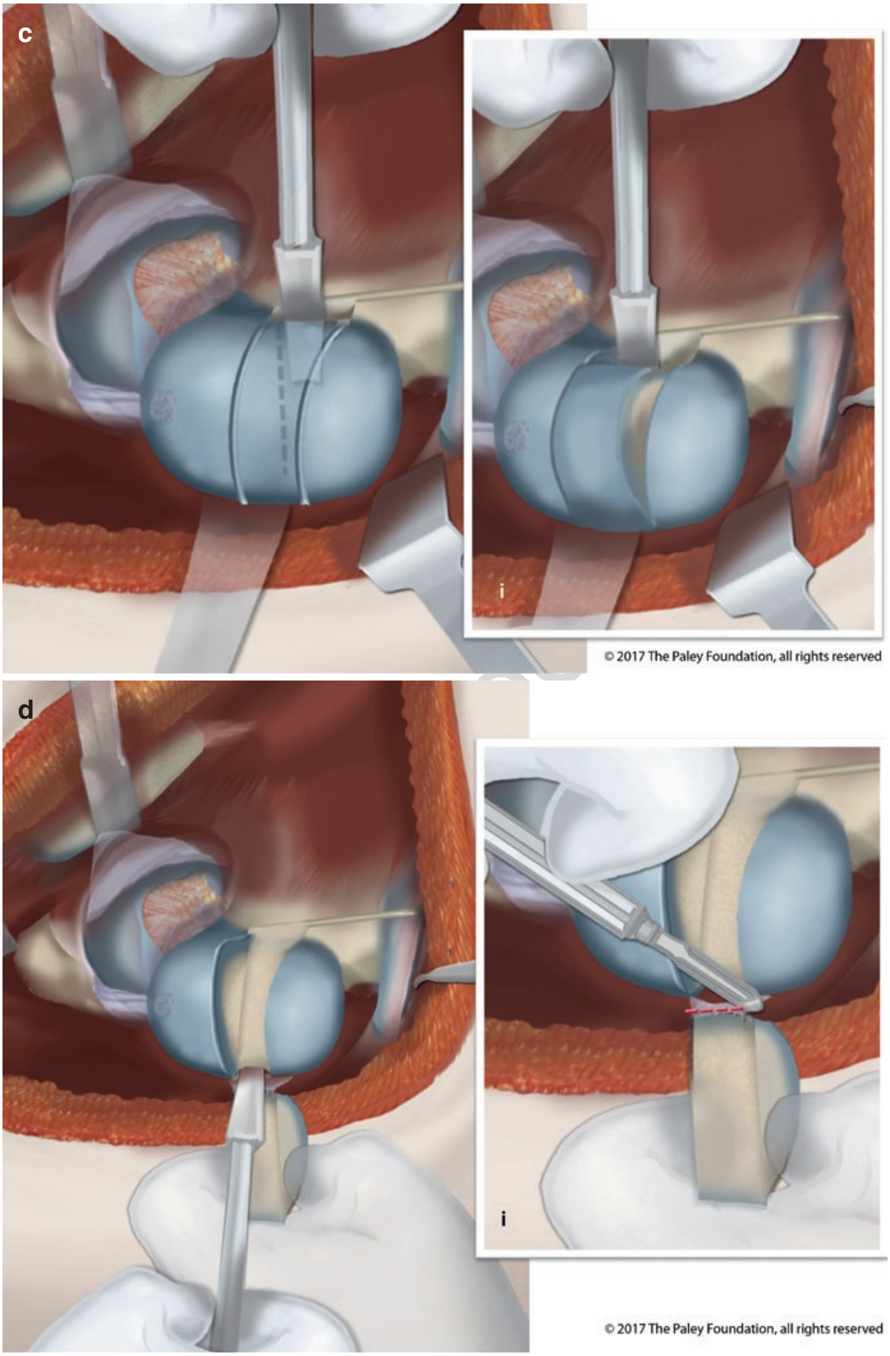


Fig. 9.12 (**a**) The osteotomy lines are outlined in white; parallel cuts. (**b**) The cautery is used to mark the anterior baseline cut (i). A very thin saw is then used to make the horizontal baseline cut (ii, iii) and then the two parallel vertical cuts (iv–vi). (**c**) An osteotome is used to complete the posterior aspect of the osteotomies and to pry out the intercalary segment (i). (**d**) The fragment is sharply dissected off of any posterior retinacular tissues. (**e**) The intercalary middle segment is removed. ((C) Dror Paley. Used with permission)



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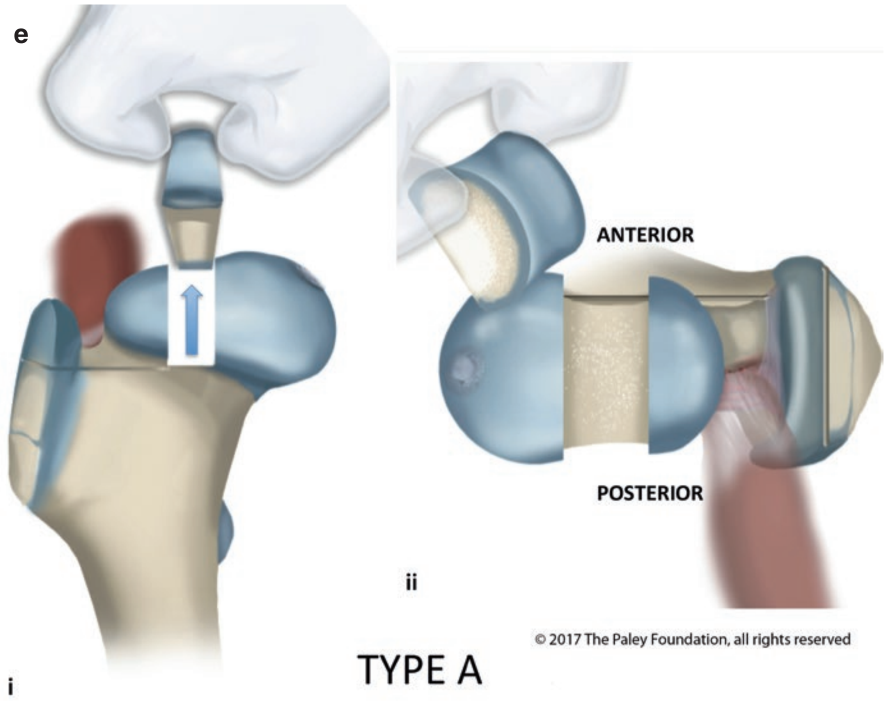


Fig. 9.12 (continued)

- Step 28: Resect the stable trochanter: Reduce the femoral head into joint. In this position, resect the stable trochanter with great care not to damage the retinacular flap (Fig. 9.16a, b).
- Step 29: Capsular repair: Repair the Z capsulotomy taking up some of the redundancy to prevent subluxation (Fig. 9.17a).
- Step 30: Transfer the mobile trochanter: Fix the mobile trochanter into place more distal and lateral than before. Aim to lower the tip of the greater trochanter to the level of the center of the femoral head. Insert two 3.2 mm drill bits and fix the trochanter at the desired level (Fig. 9.17b). Use another same length drill bit, to measure the length of each screw and then replace each drill bit with a 4.5 mm screw with washer (Fig. 9.17c).

Postoperative Care

Place the operative leg on a CPM machine in the recovery room. The patient stays on CPM for 20 hours a day for about a week. After that they use CPM half the day on and half the day off and all night long for five more weeks. When ambulating the patient uses a unilateral hip 5 ° hip abduction brace. Physical therapy is instituted allowing only passive hip abduction and flexion. No external rotation or adduction

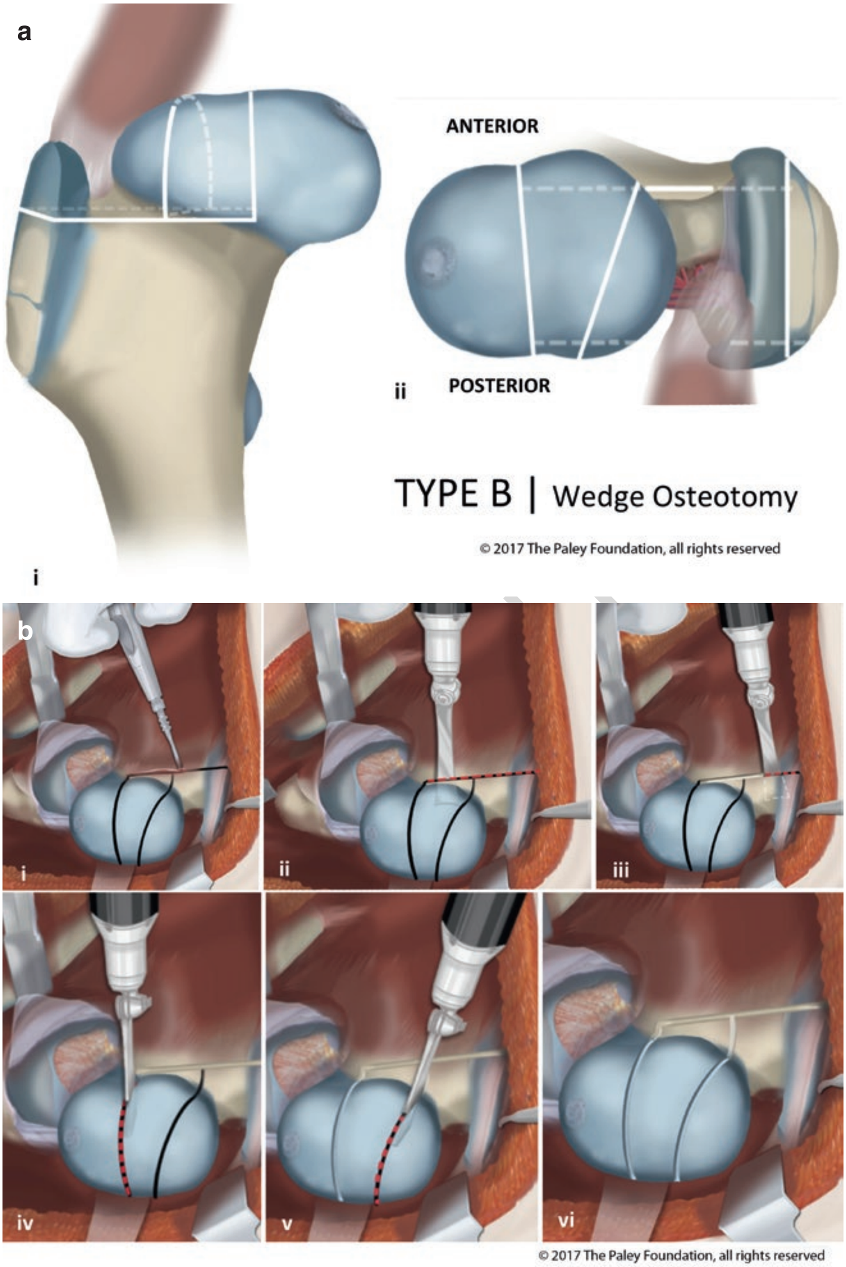
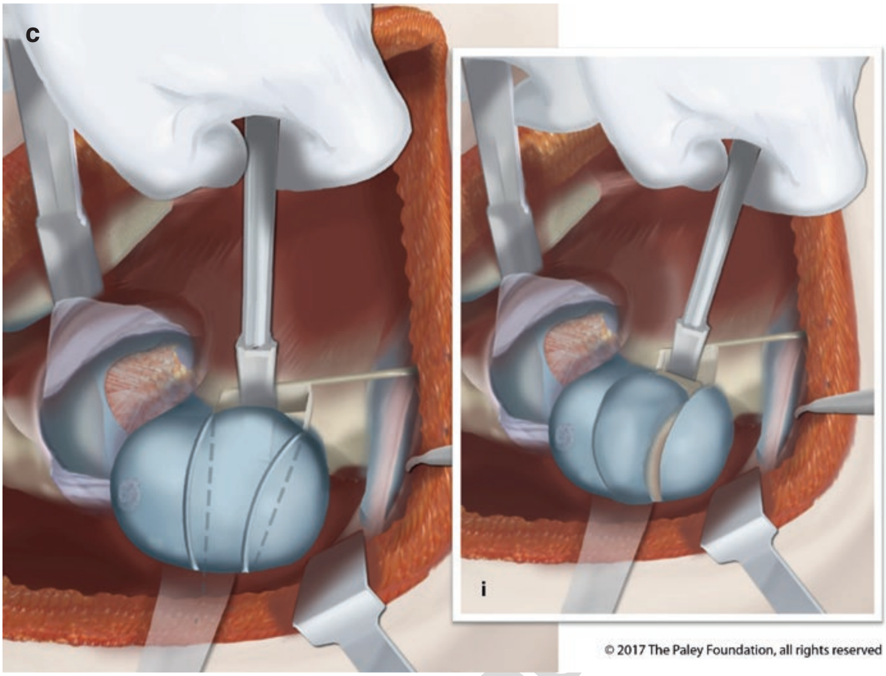
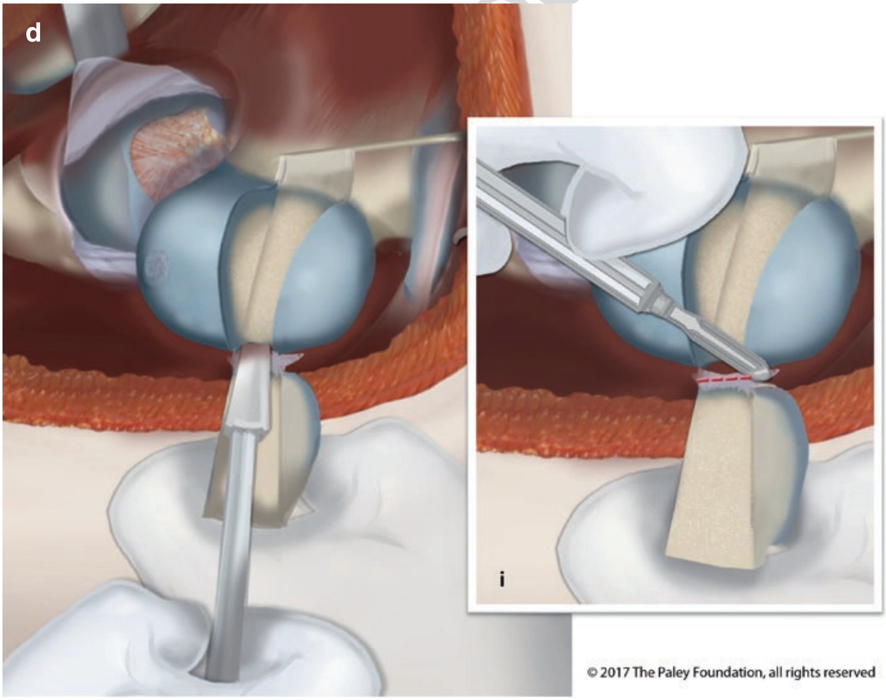


Fig. 9.13 (**a**) The osteotomy lines are outlined in white; nonparallel cuts. (**b**) The cautery is used to mark the anterior baseline cut (i). A very thin saw is then used to make the horizontal baseline cut (ii, iii) and then the two nonparallel vertical cuts (iv–vi). (**c**) An osteotome is used to complete the posterior aspect of the osteotomies and to pry out the intercalary segment (i). (**d**) The fragment is sharply dissected off of any posterior retinacular tissues. (**e**) The intercalary wedge shaped middle segment is removed. This removes the anterior bump with it. ((C) Dror Paley. Used with permission)





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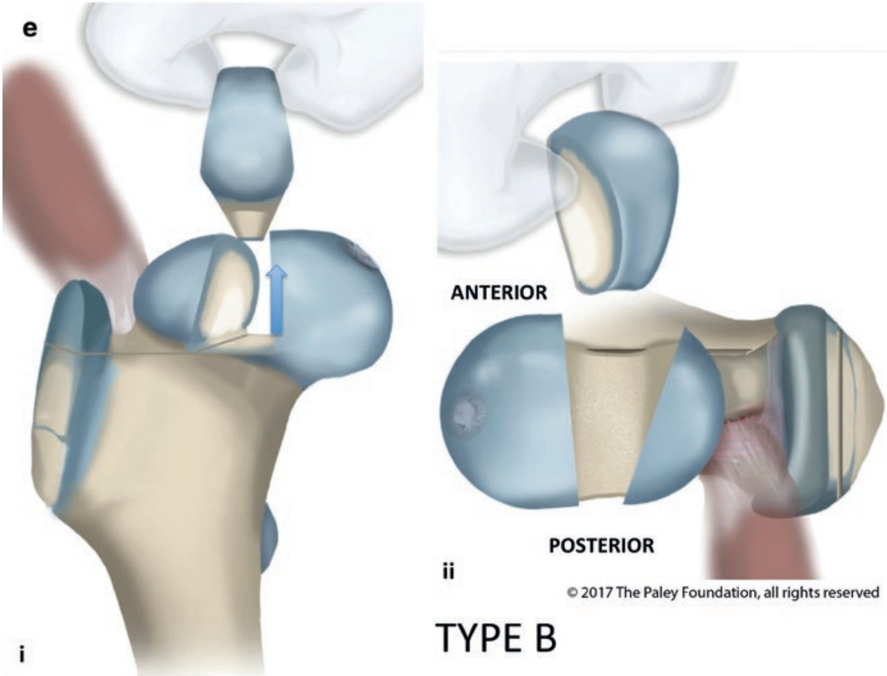


Fig. 9.13 (continued)

past the midline is permitted for 6 weeks. The patient is allowed touch down weight bearing for 12 weeks using a walker or crutches. Active assisted and active range of motion is permitted between 6 and 12 weeks. Muscle strengthening and full weight bearing without crutches begins after 12 weeks.

Postoperative Considerations

After healing of the FHRO, the hip should be assessed for the need for a periacetabular osteotomy (PAO). The need for a PAO may be obvious or subtle after the FHRO. It is not recommended to do the PAO at the time of the FHRO unless there is gross instability. In most cases the PAO is performed six or more months after the FHRO.

Leg length discrepancy can be treated by contralateral femoral epiphysiodesis in skeletally immature patients. Lengthening using an implantable lengthening rod is another option preferably after skeletal maturity.

Case Examples

Patient 1 (Fig. 9.18): An 11-year-old girl with history of left sided Perthes disease since age 6. Previously treated by range of motion but no bracing or surgery. Pre-op range of motion was 0–90 ° flexion, no internal rotation and 30 ° external rotation, abduction 10 ° with pain. She had a limp with obvious lurch to the left.

Femoral head was elongated horizontally, not perpendicular to the femoral neck. A Ganz-type FHRO was performed as one of the author's first such operations in 2007. Osteochondroplasty was also carried out. The femoral head impingement was easily seen. The cartilage outside the acetabulum was well preserved, and all of the degenerative changes corresponded to impingement with the acetabular rim. After the FHRO the reduced hip did not impinge. Her femoral head shape changed from a Stulberg class IV to Stulberg Class I after surgery. Postoperative radiographs did not deteriorate even 10 years after the original surgery. While currently a Paley type

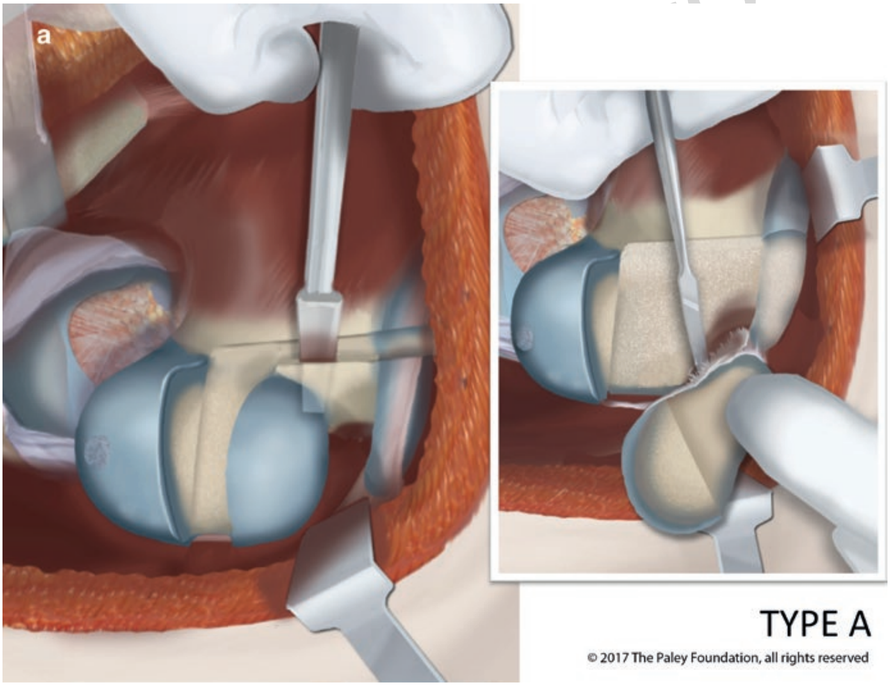
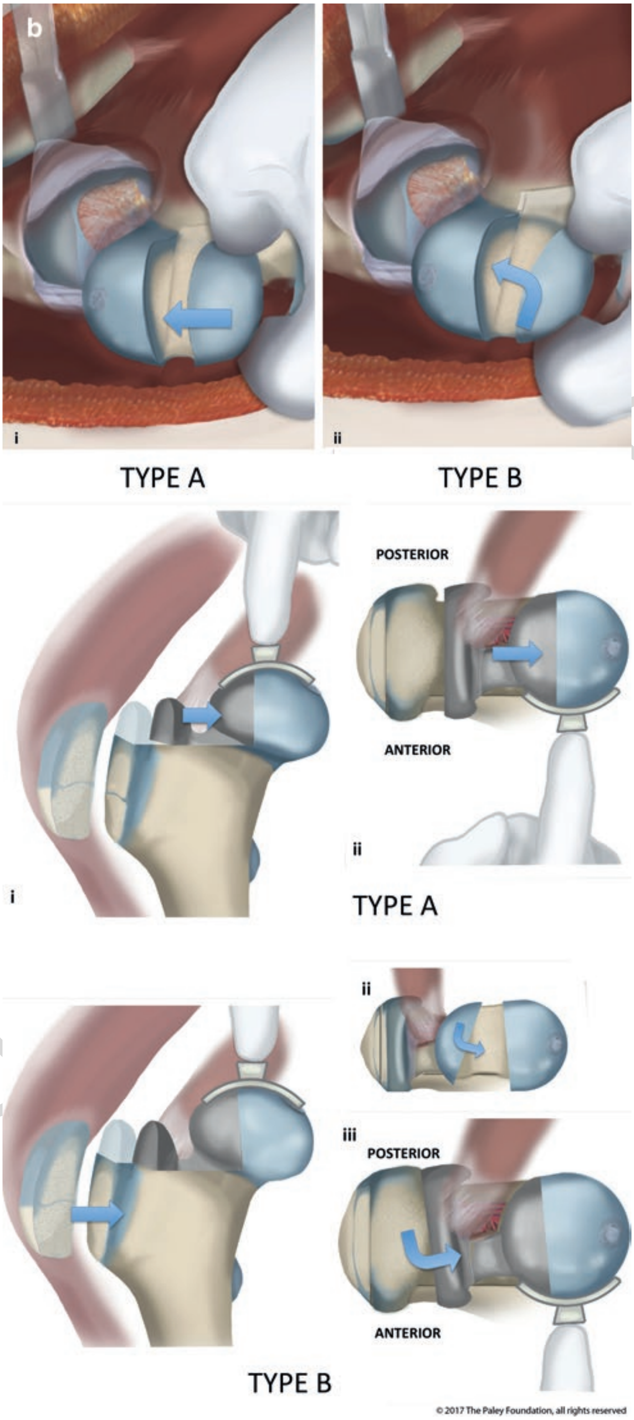


Fig. 9.14 (**a**) The lateral segment is mobilized posteriorly to connect this dissection with the original retinacular flap dissection. (**b**) The untethered lateral fragment can now be moved medially without putting tension on or tearing the retinacular flap. The trochanter moves medially with the segment which maintains the stability of the retinacular flap. This is shown for both Type A (upper) and Type B (lower). ((C) Dror Paley. Used with permission)



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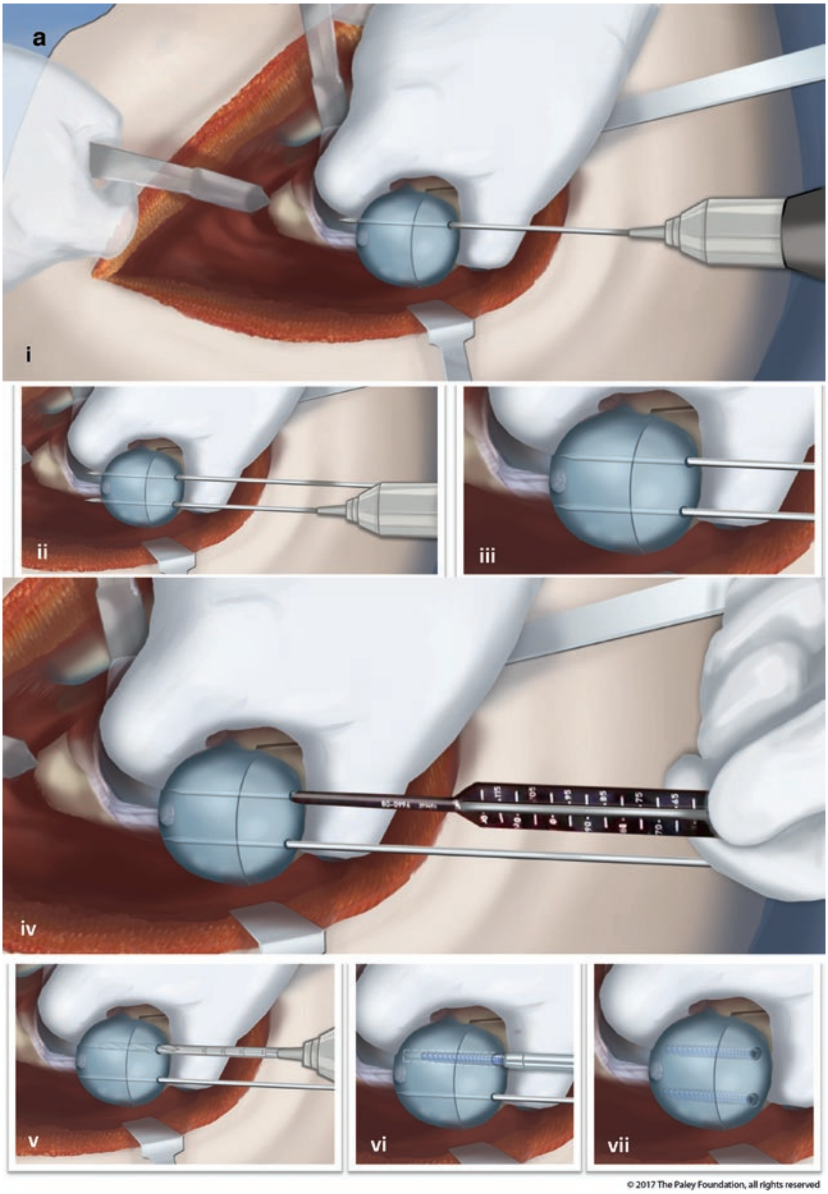
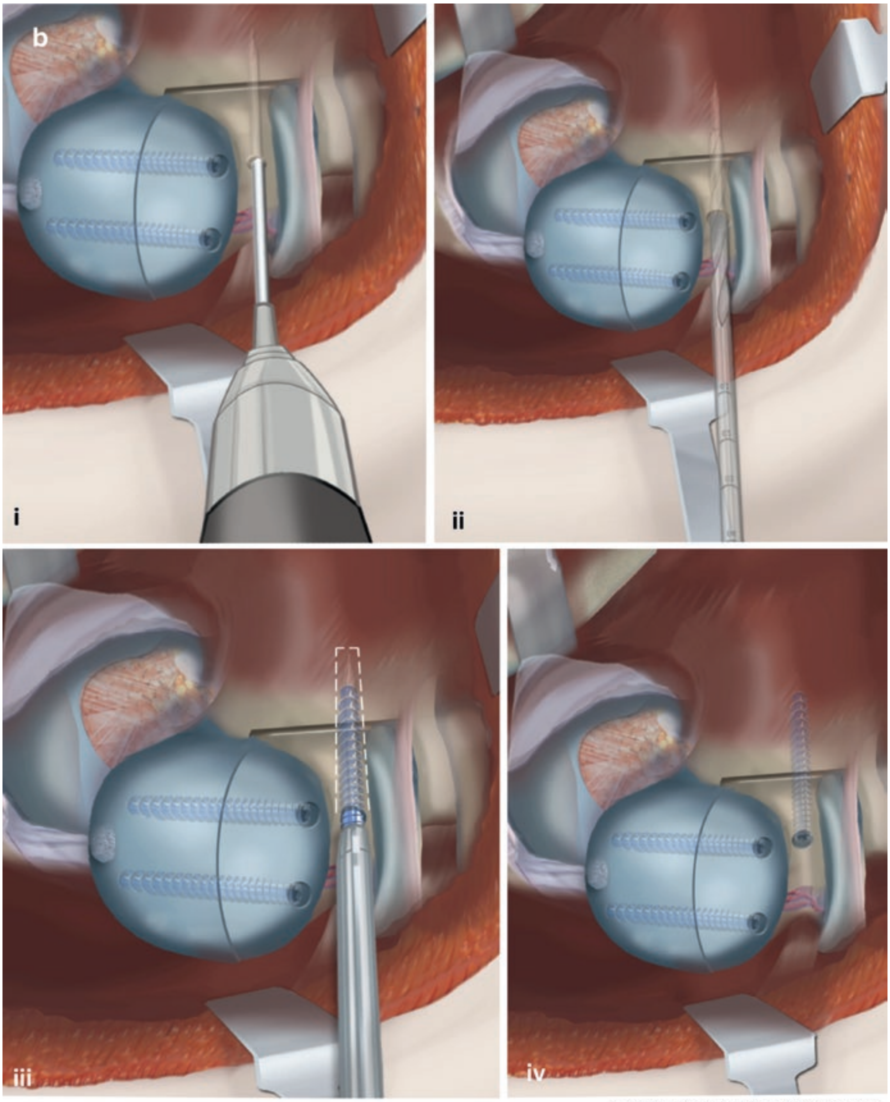


Fig. 9.15 (**a**) The lateral mobile femoral head is reduced to the stable medial femoral head. Priority should be given to matching the posterior aspects of the two parts since the anterior part can be shaved off with the osteochondroplasty method. Two wires are inserted in parallel to each other and perpendicular to the osteotomy line. After measuring and drilling, two variable pitch headless screws are inserted into the femoral head from lateral to medial. (**b**) A third headless screw is drilled and inserted perpendicular to the baseline osteotomy. (**c**) A wire is drilled from the fovea down the femoral neck and out the lateral side of the femur. A hole is drilled for a cannulated screw with a cannulated drill. (**d**) A cannulated screw is inserted to prevent fracture of the femoral neck. ((C) Dror Paley. Used with permission)



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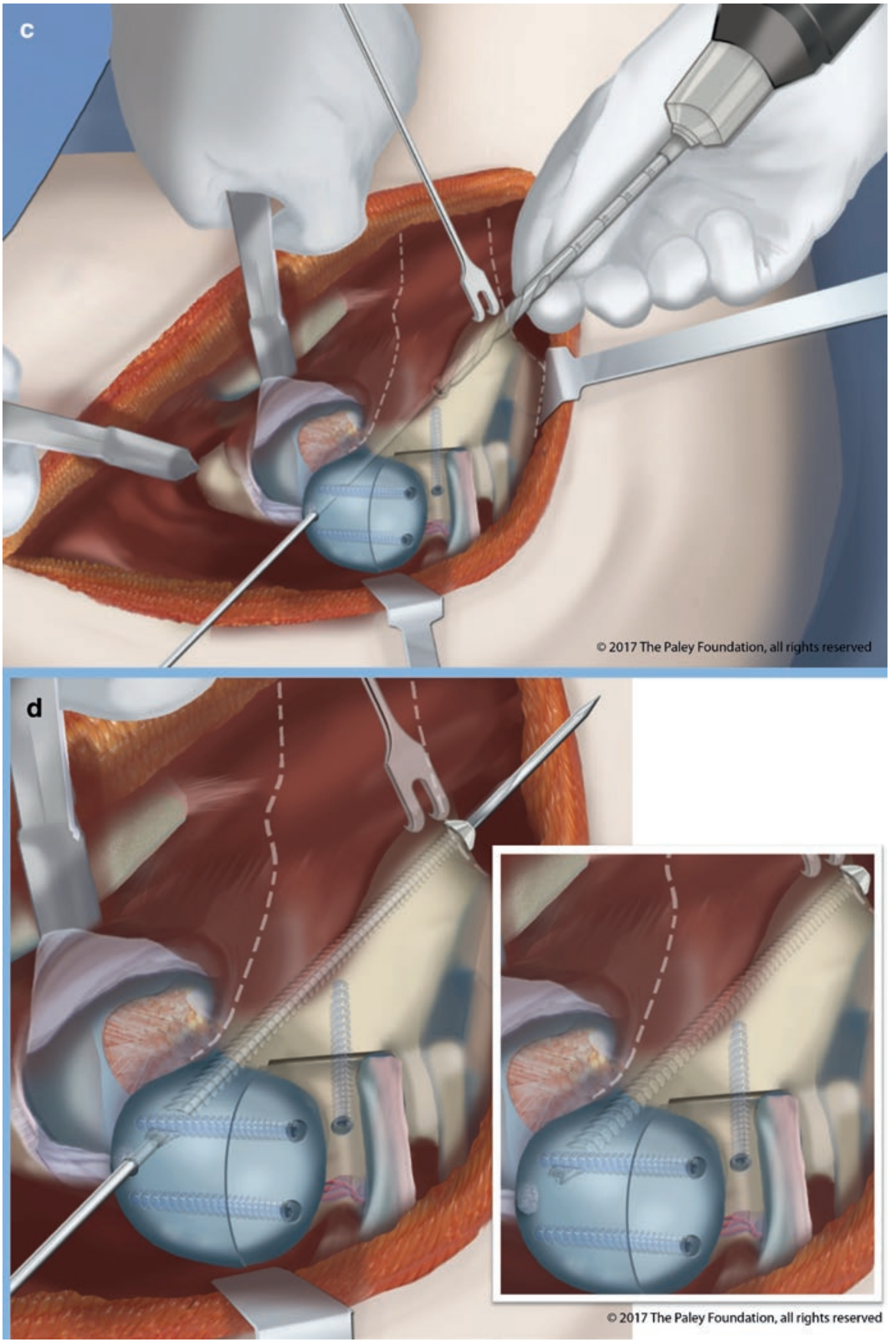

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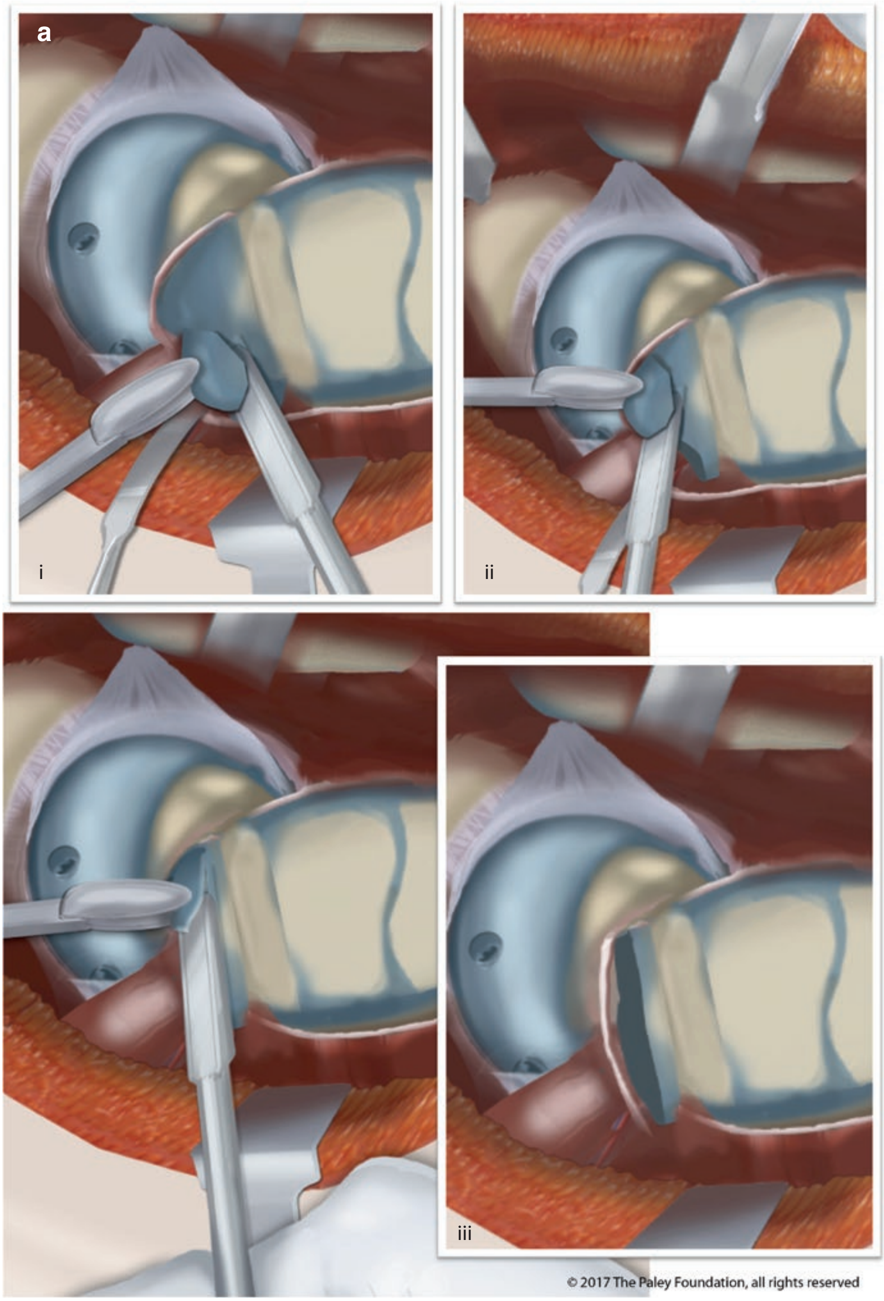
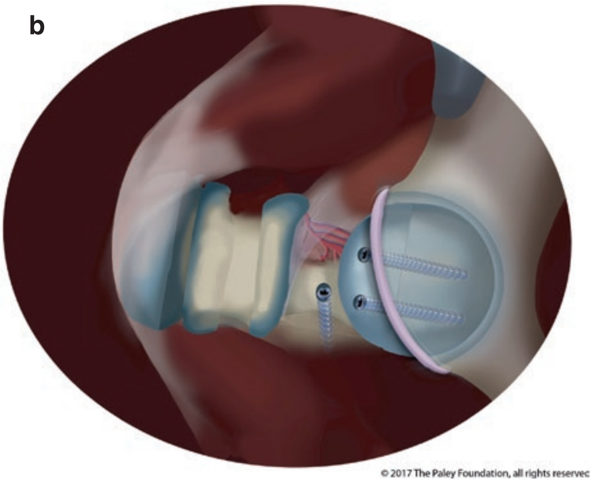


Fig. 9.16 (**a**) The femoral head is reduced into joint. The stable trochanter is excised carefully so as not to injure the retinacular vessels. (**b**) A superior view shows the femoral head mostly covered by the acetabulum after the FHRO. ((C) Dror Paley. Used with permission)



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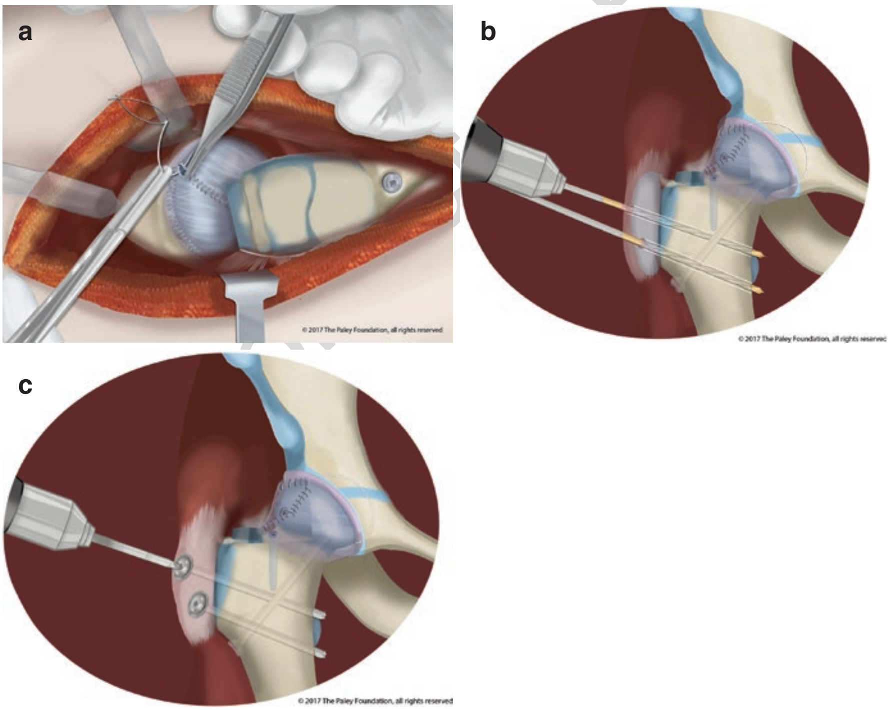


Fig. 9.17 (**a**) The capsule is closed and any redundant capsule is advanced to maintain joint stability. (**b**) The greater trochanter is advanced laterally and distally and then fixed with two 3.2 mm drill bits. The tip of the greater trochanter should be at the level of the center of the femoral head. (**c**) The drill bits are replaced with two 4.5 mm screws with washers. ((C) Dror Paley. Used with permission)

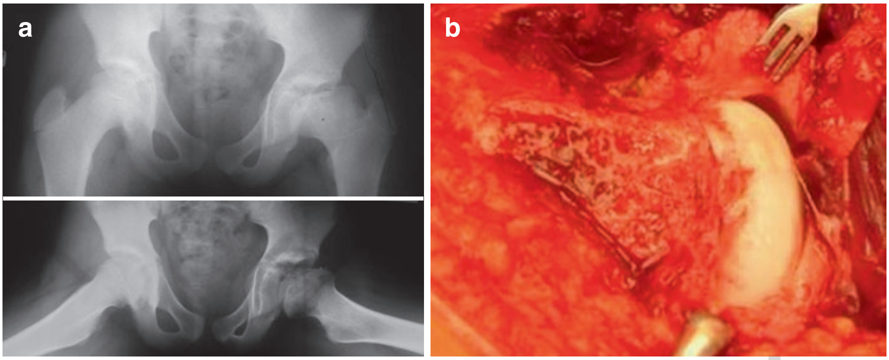
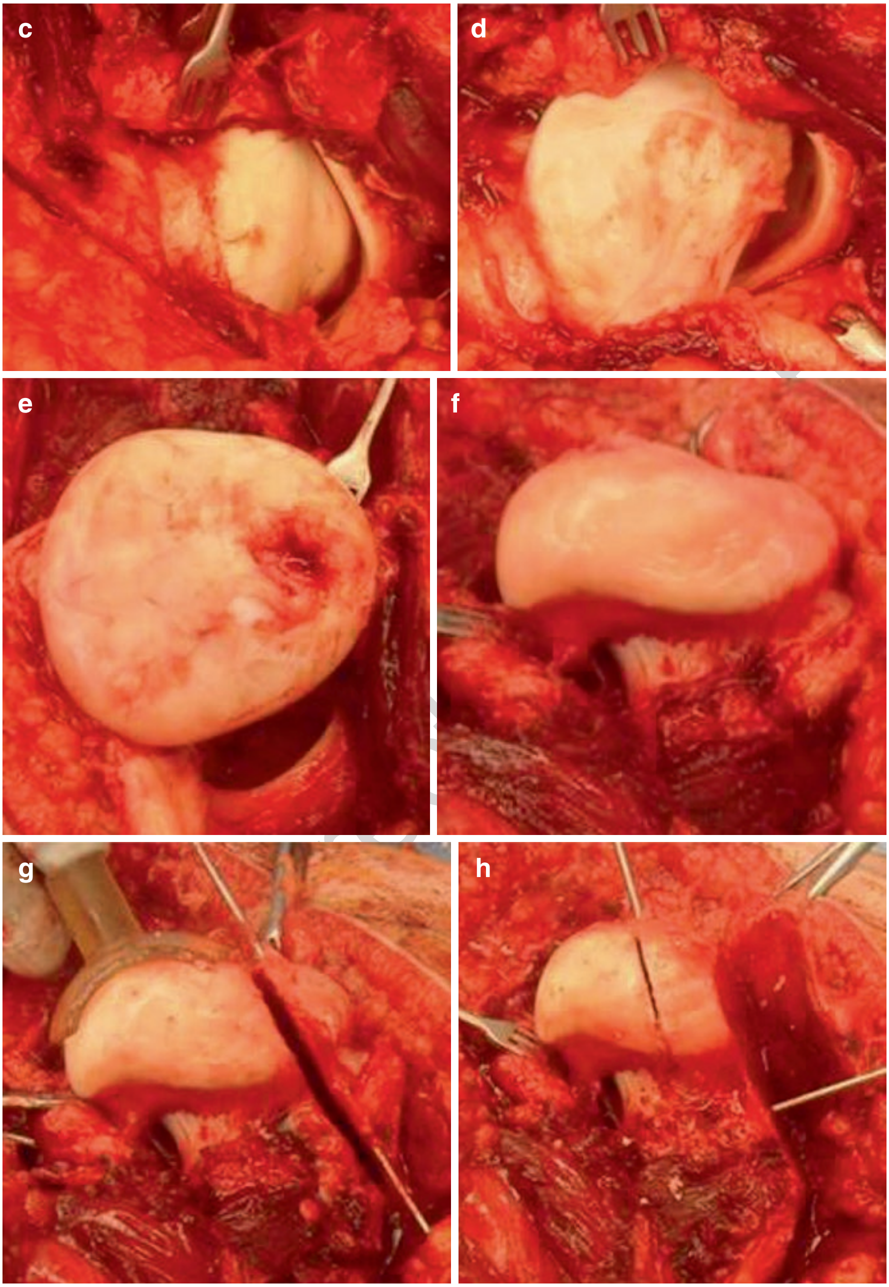


Fig. 9.18 (**a**) AP and frog lateral radiographs of pelvis of an 11-year-old girl with left coxa magna, coxa breva, coxa vara, and overgrown trochanter sequelae from previous Perthes. The elongation of the femoral head is not perpendicular to the femoral neck. (**b**) Intraoperative photograph after trochanteric osteotomy and capsulotomy but before dislocation. Note the amount of the femoral head that sits permanently outside the acetabulum. This lateral cartilage appears pristine. (**c**) Intraoperative photograph showing the indentation of the femoral head created by the labrum and acetabular rim. This produces the saddle shape. (**d**) Intraoperative photograph at time of dislocation showing that despite being only 11 years old, degenerative changes already exist in the region corresponding to the concavity of the femoral head. (**e**) Intraoperative photograph of the dislocated femoral head from a superior view. The enlarged lateral portion is too big to enter the acetabulum. (**f**) Intraoperative photograph showing anterior profile view. The femoral head has a saddle shape. The medial part is spherical. The lateral part is also round. The concave central part is misshapen and had degenerative changes. Performing a "cheilectomy" would remove the lateral part of the femoral head and leave the depressed, degenerative central part in a weight bearing location. (**g**) Intraoperative photograph showing the Ganz-type lateral osteotomy parallel to the femoral neck but at an oblique angle to the femoral head. The entire piriformis fossa is contained with the lateral segment. The femoral head template shows where the medial part leaves the round and defines where to make the medial osteotomy. (**h**) Intraoperative photograph showing two reference wires inserted to guide the medial cut (left superior wire) and the resection of the intercalary segment (right lateral wire). (**i**) Intraoperative photograph showing the resection of the intercalary segment after two parallel osteotomies (A type) also parallel to the femoral neck. Notice the narrowing of the femoral neck over a long length. (**j**) Intraoperative photograph showing advancement of the lateral mobile femoral head to the medial stable femoral head. The prominent anterolateral incongruity of the femoral head neck junction will be resected with an osteochondroplasty. (**k**) Intraoperative photograph after the reduction from a superior end on view. (**l**) Intraoperative photograph showing anterior profile view of the femoral head after the reduction and osteochondroplasty. The femoral head sphericity has been restored. (**m**) Postoperative AP pelvis radiographs after FHRO. The femoral head is well contained. The lateral portion of the femoral head sits under the dome of the acetabulum. The femoral head appears round on both AP and lateral views and would be classified as a Stulberg Class 1 femoral head. (**n**) Clinical photographs 1 year after surgery showing restoration of full and symmetric range of motion of both hips. (**o**) AP and frog lateral radiographs of the pelvis 10 years after FHRO. The joint space is well maintained. The femoral head is perfectly round. The remnant of stable trochanter was never resected and remains like an exostosis on the femoral neck. She underwent a derotation osteotomy by another surgeon 1 year prior. It is notable that the acetabulum is dysplastic although she remains completely asymptomatic. ((C) Dror Paley. Used with permission)



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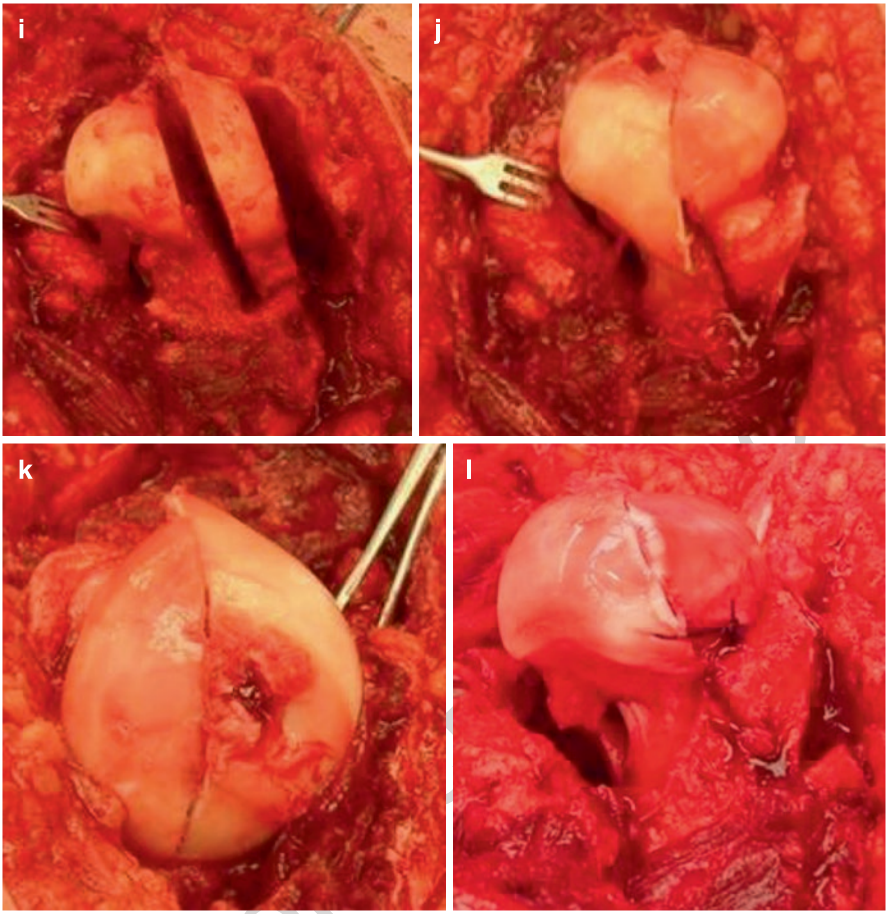

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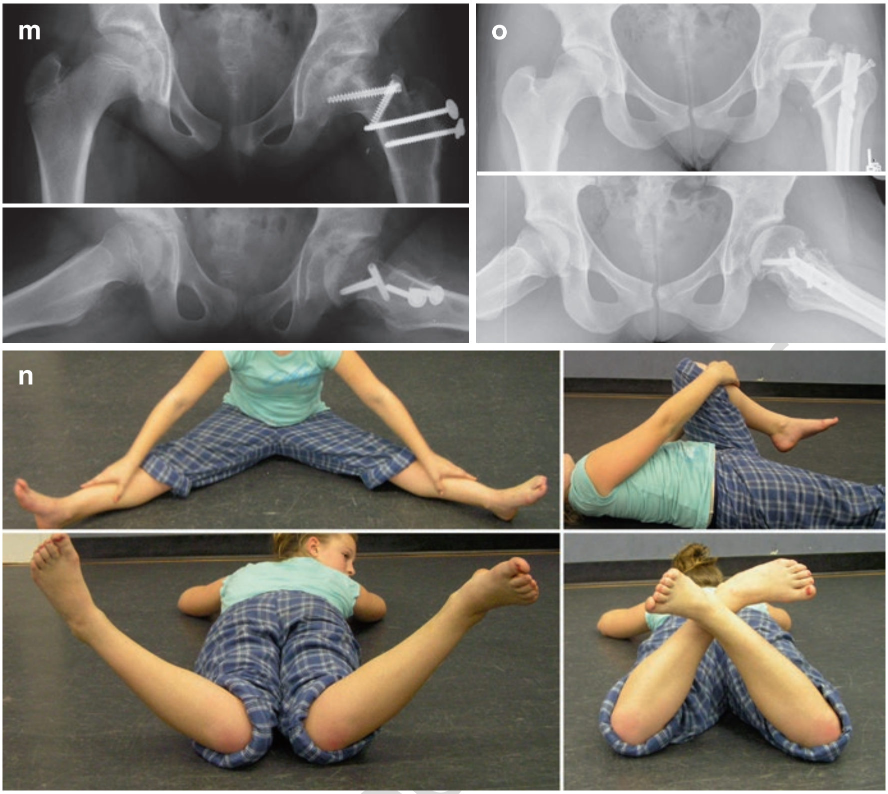

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of FHRO would be performed based on the pathoanatomy, the result from the Ganz type is excellent. She did undergo a derotation osteotomy of the femur for external femoral torsion. She has some lack of coverage that may require a PAO in the future. Arguably she should already have had one except that she is completely asymptomatic.

Patient 2 (Fig. 9.19): A 15-year-old girl with history of left-sided Perthes disease since age 8, treated nonoperatively with rest, casting, and physical therapy. She developed left hip pain a year prior to presentation. The pain was brought on by activity and prolonged sitting. She had a mild lurch to the left, which got worse as

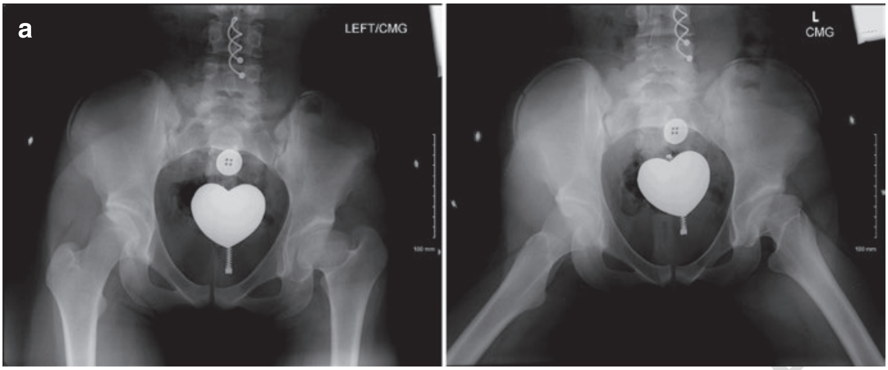
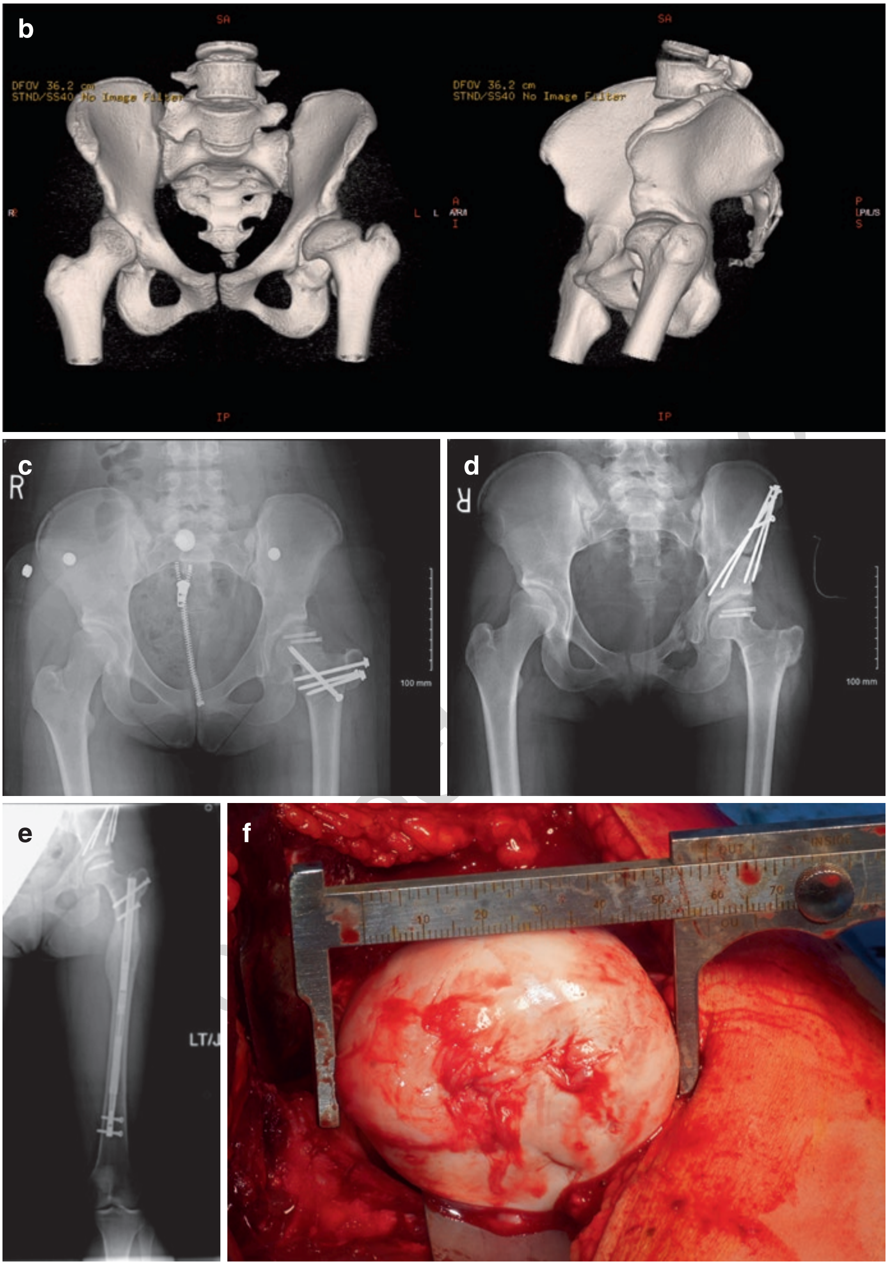


Fig. 9.19 (**a**) Preoperative AP and frog lateral radiographs of 15 year old girl with left coxa magna, coxa breva, and overgrown trochanter sequelae from previous Perthes. (**b**) 3D CT AP and lat views showing left Coxa magna and uncovered, elongated femoral head. The elongation is not perpendicular to the femoral neck. (**c**) Postoperative AP radiograph showing healed Paley-type A femoral head reduction osteotomy with level of greater trochanter restored and relative neck lengthening. The femoral head coverage is inadequate and a PAO is required. (**d**) Final AP radiograph after FHRO and Ganz-type PAO. There is excellent coverage of the femoral head. (**e**) AP femur radiograph after implantable limb lengthening to equalize limb lengths. The femoral head remains round, located, well covered, and the hip shows excellent joint space with no degeneration. (**f**) Intraoperative photograph showing superior view of femoral head after dislocation. The diameter of the femoral head is measured with a caliper. This is a Type A femoral head with minimal to no cartilage degeneration. (**g**) Intraoperative photograph showing acetabular sizer in place (blue). The profile view of the femoral head shows the saddle shape. (**h**) Intraoperative photograph showing femoral spherical template corresponding to acetabular size measured. The lateral edge of the template is where the femoral head leaves the round. A mark should be made in line with this edge. (**i**) Intraoperative photograph showing the line and a caliper measuring the width of the medial femoral head at the point where the femoral head leaves the round based on a laterally placed femoral head template. (**j**) Intraoperative photograph showing lateral part of femoral head measured for the remainder of the diameter of the femoral head after the planned reduction. This width is marked. (**k**) Intraoperative photograph showing the femoral head marked with two parallel lines for osteotomy resection of the central portion of the femoral head (A type). (**l**) Intraoperative photograph from anterior view of the femoral head showing the baseline osteotomy perpendicular to the two parallel femoral head osteotomy lines. These femoral head lines are perpendicular to the femoral head joint surface and not parallel to the femoral neck. The baseline is extends laterally to exit into the trochanteric osteotomy. (**m**) Intraoperative photograph showing the femoral head osteotomy is being made with a thin sagittal saw which is being cooled with water. (**n**) Intraoperative photograph showing the lateral fragment reduced to the medial fragment and being fixed with a headless variable pitch screw. Note that the posterior reduction is prioritized. The guidewires for the headless screws are perpendicular to the intra-articular osteotomy in order to offer maximum interfragmentary compression. (**o**) Intraoperative photograph showing the reduced femoral head. The two headless screws are buried under the cartilage. The posterior femoral head is very congruous and spherical. There is mild anterior incongruity. The lateral femoral protrudes anteriorly beyond the medial femoral head. (**p**) Intraoperative photograph showing the anterior femoral head incongruity. The spherical template rests on the posterior femoral head and demonstrates the step off relative to the anterior femoral head. (**q**) Intraoperative photograph of spherical templating of posterior femoral head at the osteotomy. (**r**) Intraoperative photographs after osteochondroplasty resection of the incongruous anterolateral part of the femoral head. ((C) Dror Paley. Used with permission)



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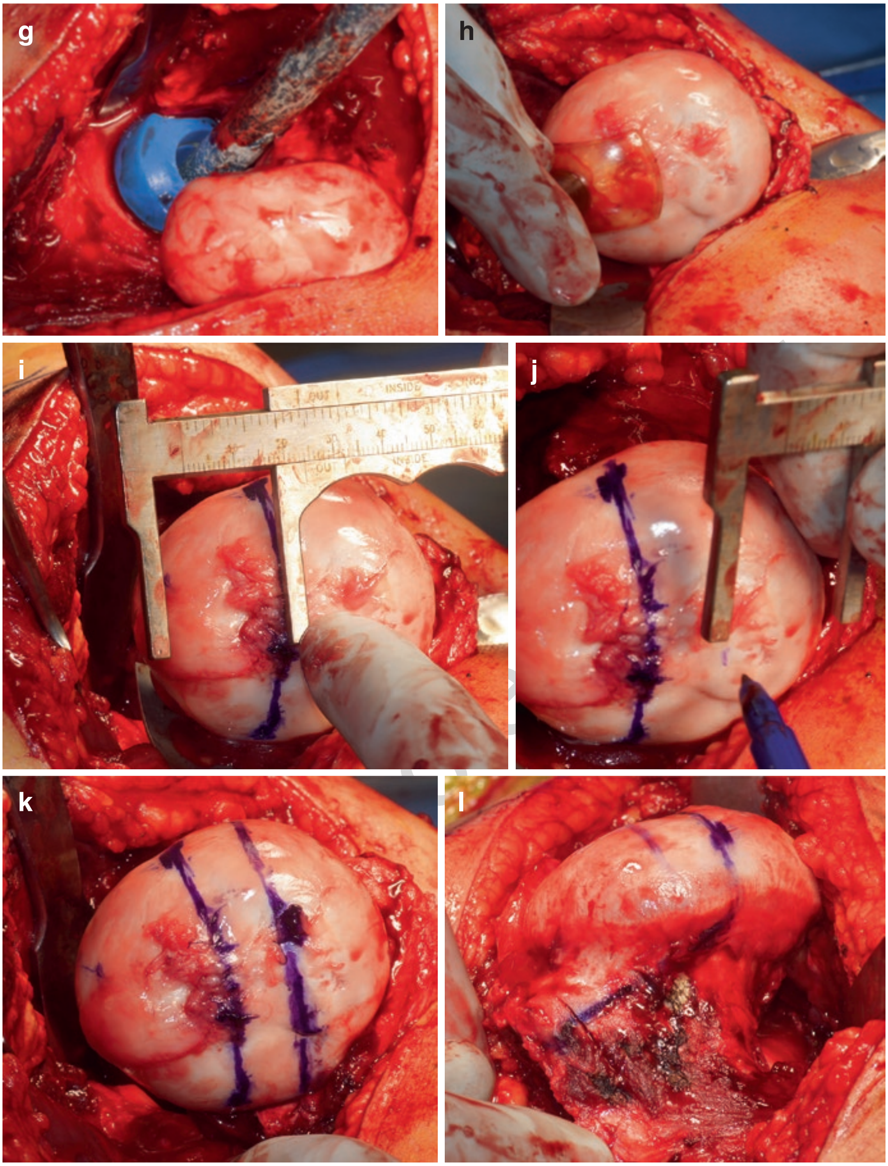

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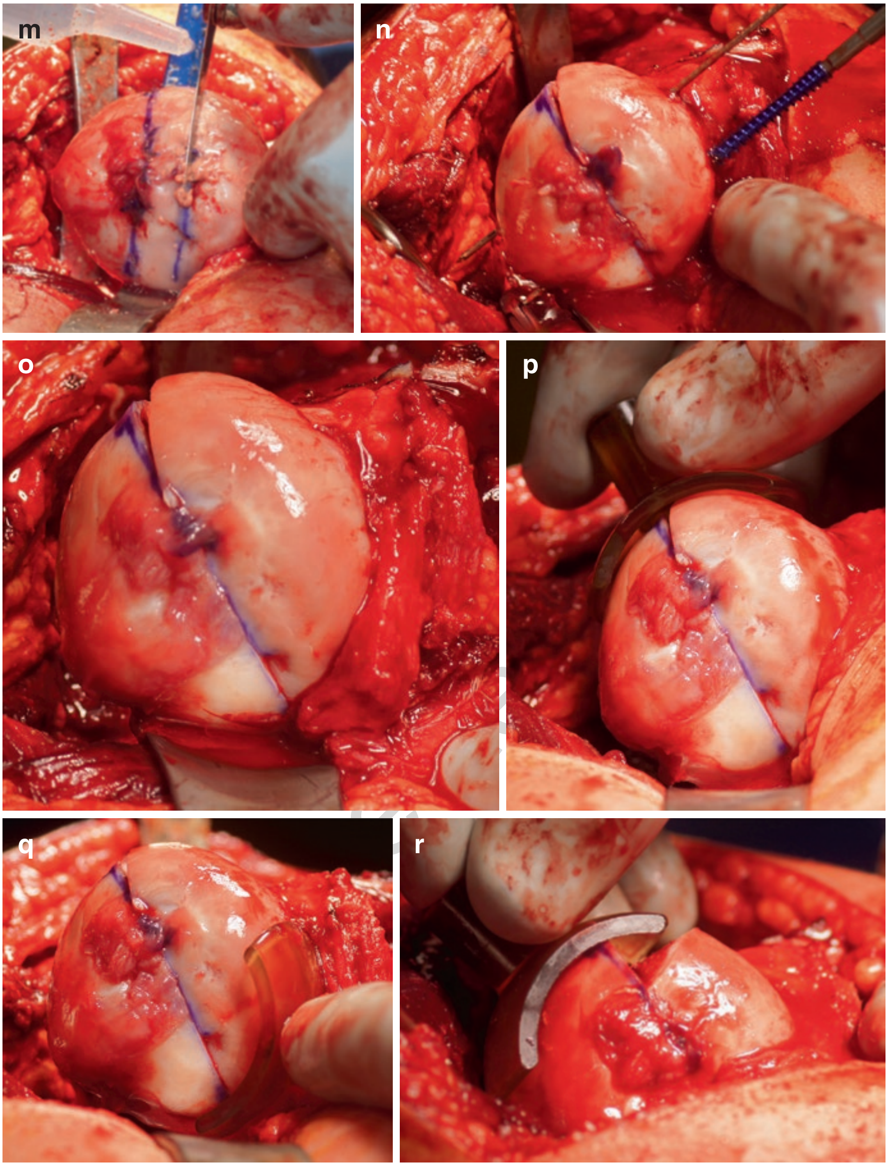


Fig. 9.19 (continued)

the day progressed. On examination she had pain on flexion with internal rotation of the hip. The hip range of motion was flexion 0–90 °, internal rotation 5 °, external rotation 45 °, adduction 20 °, and abduction 15 °.

The femoral head was elongated horizontally such that the perpendicular to this axis is not in line with the femoral neck. A Paley-type FHRO was performed. Intraoperative photographs show the step-by-step measurements confirming this was a type A. Two parallel cuts were made. An anterolateral osteochondroplasty eliminated any incongruity from the reduction. Her femoral head would be classified as a Stulberg Class III before surgery and Stulberg Class I after the FHRO. The femoral head was insufficiently covered due to previous acetabular remodeling. A PAO was performed 6 months after the FHRO. The patient currently has no limp or pin in the hip and has equal and symmetric full hip range of motion to the opposite side. Final radiographs 2 years after FHRO confirm good reduction, coverage, and joint space maintenance of the hip joint.

Patient 3 (Fig. 9.20): A 14-year-old boy with history of right-sided Perthes since age 11, treated nonoperatively by range of motion exercises. He became significantly disabled by the progressive collapse and misshapen femoral head. He had a significant antalgic lurch to the right. On examination his hip flexion was 0–90 ° with obligatory external rotation. He had 45 ° prone hip internal rotation and 10 ° prone hip external rotation. His hip abduction was 15 °. He had a leg length discrepancy.

Intraoperative photographs confirm that there is ample degeneration in the central portion but that the cartilage on the lateral rim is well preserved. The elongation of the femoral head is not perpendicular to the neck, and there is a large anterolateral bump which makes this a type B. This lends itself to a wedge resection of the anterolateral bump with nonparallel cuts restoring the femoral head sphericity. Postoperative radiographs demonstrate the transformation from a Stulberg Class V to a Stulberg Class I femoral head.

Four years after his Paley-type FHRO, he underwent lengthening with an implantable limb lengthening device to equalize his limb lengths. Ten years after the FHRO, he has no pain in his right hip and walks and runs with no limp. He has equal and full range of motion to his opposite hip. His hip abduction and external rotation movements increased significantly after surgery. His hip no longer has obligatory external rotation with flexion. He is showing no signs of any deterioration in the joint clinically or radiographically.

Pearls and Pitfalls

1. Prognosis improves with better preserved femoral and acetabular cartilage. Degenerative changes in the non-resected areas theoretically worsen the prognosis.
2. The younger the patient (age 9–16 years) often the better the outcome.
3. Preoperative planning of the size of the wedge or rectangle to be taken is essential in aiding operative execution.

4. The retinacular flap is a key component to the operation and should be performed in stages as described in the operative discussion.
5. The femoral neck screw protect against fracture of the femoral neck.
6. The capsule at the end of the reduction is capacious and should be advanced to prevent lateral subluxation.
7. Be certain the trochanter is well fixed. In older/larger patients, three screws are preferred.

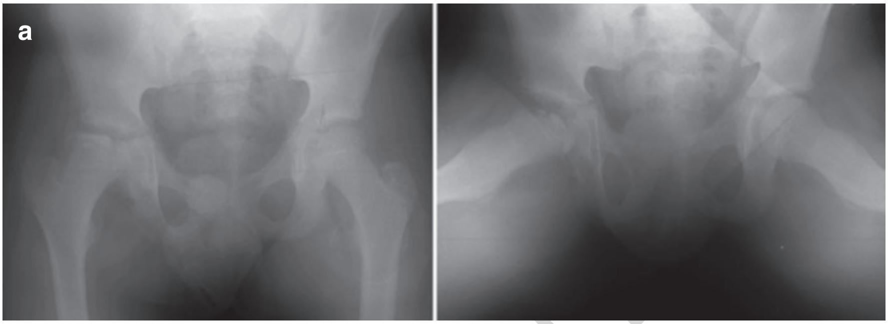
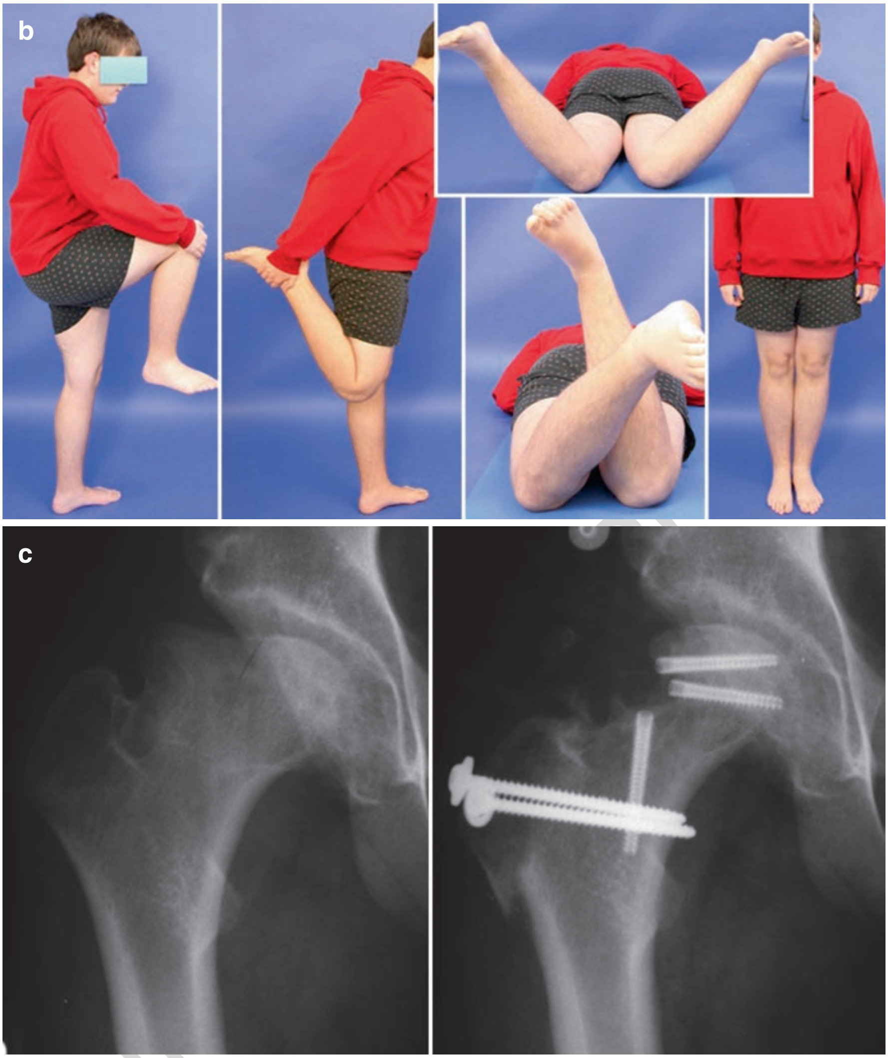


Fig. 9.20 (**a**) AP and frog lateral radiographs of the pelvis at age 11 years, showing Perthes disease affecting the right hip. There is whole head involvement and early collapse with a break in Shenton's line. There is already coxa magna with extrusion of the femoral head (proximal and lateral migration) and the greater trochanter already appears to be overgrowing and the femoral neck is already shorter than the opposite side. (**b**) Preoperative photographs showing hip range of motion. There is excellent flexion and extension but limited external rotation. There is no photograph of his hip abduction but it is limited. (**c**) Preoperative AP radiograph (left) compared to postoperative AP radiograph (right) after Paley-type FHRO. The femoral head went from a Stulberg Class 5 to a Stulberg Class 1. (**d**) Preoperative frog lateral radiograph (left) compared to postoperative frog lateral radiograph (right) after Paley-type FHRO. The femoral head went from a Stulberg Class 5 to a Stulberg Class 1. (**e**) Intraoperative photograph showing superior view of Type B femoral head. Note the large anterolateral bump. There is already significant damage to the central femoral head cartilage. Note that the lateral femoral head has excellent cartilage. (**f**) Intraoperative photograph showing superior view of the wedge shaped osteotomy resecting the anterior bump. (**g**) Intraoperative osteotomy showing superior view with the wedge removed. The wedge contains the most damaged cartilage. (**h**) Intraoperative photograph showing superior view of the osteotomy wedge closed, creating a spherical femoral head. (**i**) Intraoperative photograph from anterior view. The spherical template fits perfectly on the femoral head. Notice that the osteotomy line is perpendicular to the femoral head and not parallel to the femoral neck (Paley type). Correspondingly, the baseline osteotomy is perpendicular to the femoral head osteotomy and in line with the femoral head reduction. (**j**) Postoperative hip range of motion 10 years after FHRO surgery and 6 years after leg lengthening surgery showing excellent range of motion with improved hip abduction and external rotation. The range of motion is now symmetric to the opposite side. Note there is no lurch or Trendelenburg when in single leg stance (left). (**k**, **l**) Ten-year follow-up AP (**k**) and frog lateral (**l**) pelvis radiographs show excellent preservation of the femoral head shape and location with no evidence of any degenerative changes in the joint. Arguably, there is some relative dysplasia of the acetabulum and it would have been reasonable to do a PAO. The patient remains asymptomatic which is why he has not undergone further surgery. (**m**) Ten-year follow-up standing orthoroentgenogram demonstrating equal leg lengths and normal alignment. ((C) Dror Paley. Used with permission)



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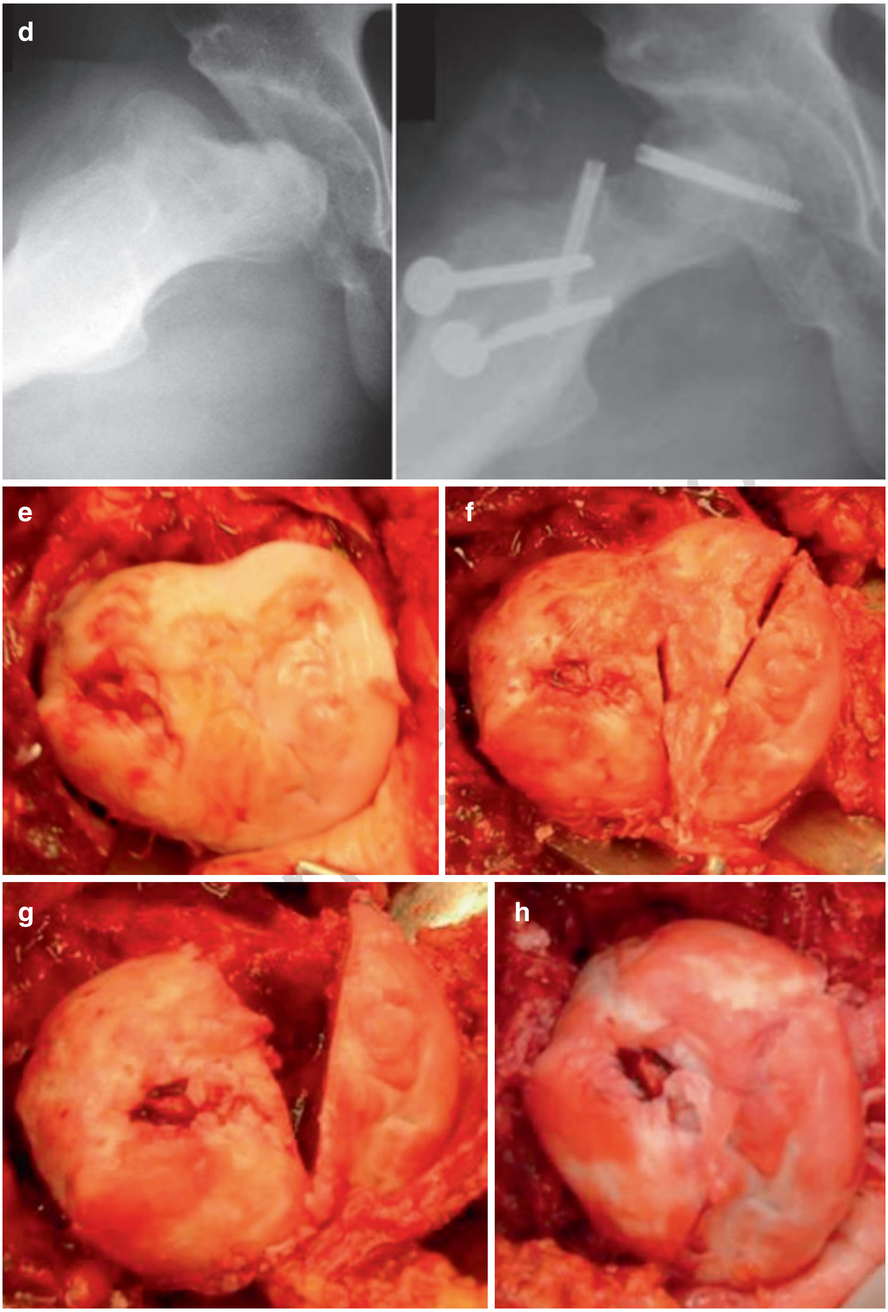

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Fig. 9.20 (continued)

8. The presence of an open physis is not a contraindication due to risk of avascular necrosis as once thought. It is important to close the physis to avoid a bifid femoral head from developing.
9. Both the Ganz and Paley types of FHRO narrow the femoral neck and run the risk of fracture. It is therefore important to use a prophylactic screw to protect the femoral neck. The Ganz type leads to a long segment of narrowed femoral neck thus increasing the lever arm on the narrowed region compared to the Paley type.

Outcome of Ganz- and Paley-Type FHRO

Ganz (2009) [5] reported the results of the first 11 patients treated with the Ganz FHRO: The patients ranged in age from 9 to 15 years. In three hips, postoperative instability was treated by a femoral varus osteotomy in two and a periacetabular osteotomy (PAO) in one to stabilize the hip. Subsequently the next three cases were treated with PAO at the time of the FHRO. Ganz et al. (2010) [11] reported on their first 14 FHROs since 2001 (presumably including the 11 patients previously mentioned). Eight hips also had a PAO at the same time as the index procedure, while three had a PAO performed at a later date. In one case a varus intertrochanteric osteotomy was performed to treat subluxation, and in another a Colonna was performed at the same time. Therefore, only 1 of their 14 cases did not have an additional procedure. None of the 14 cases developed avascular necrosis. No other details on this group were reported.

Seibenrock et al. (2014) [9] published a series of 11 hips treated by the Ganz FHRO. The Ganz osteotomy was used both in cases with elongation of the femoral head perpendicular to the femoral neck and not perpendicular to the femoral neck. The mean age was 13 years 6 months (range 7–23 years). Follow-up was a mean of 5 years (range 1–10). The mean extrusion index decreased from an average of 47–21% after FHRO. Ten of the hips were rated as Stulberg Class II in 5, Class III in 4, and Class IV in 1. The Merle d'Aubigne score did not improve from prep to postop. No hip developed AVN. Five of 11 hips had concomitant pelvic osteotomy surgery for coverage. Another five hips had a triple pelvic osteotomy an average of 2.3 years after the FHRO. There was an improvement in pain score after surgery.

Paley (2011) [8] reported on 20 cases of Ganz FHRO performed for cases with femoral head elongation perpendicular and not perpendicular to the femoral neck. The mean age was 14 years (range 10–23). Fourteen (70%) of the 20 had improved range of motion, no pain or minimal to no limp and were considered good or excellent (satisfactory) results. Six (30%) of the 20 had significant pain, limp and or stiffness and were considered fair or poor (unsatisfactory) results. The follow-up at the time of the report was 2.7 years (range 1–5). Unpublished updated follow-up on the satisfactory group has shown no deterioration with a mean follow-up of 9 years with range from 7 to 11 years. Only five cases in this study had a pelvic osteotomy, all of which were in the satisfactory group. Several appear to be uncovered and would benefit from a coverage procedure (Fig. 9.18).

Paley et al. reviewed a second series of FHRO performed between 2010 and 2016 that were no included in the first series (unpublished). There were 25 hips in 24 patients in this second series. During the time of the first series, the author did not recognize the difference between the Ganz and the Paley type of osteotomy. The Paley type of osteotomy evolved out of the Ganz type until it became evident that the two osteotomies were quite distinct and that they each had different indications. In the second series, the author recognized this distinction and applied the Ganz osteotomy selectively when the femoral head elongation was perpendicular to the femoral neck. Similarly, the Paley type of osteotomy was applied when the femoral head elongation was not perpendicular to the femoral neck. There were 19 Paley and 6 Ganz FHRO performed. The mean follow-up was 3 years (range 1–6 years). The Harris hip score improved from 57 to 84 in the Ganz group and 65 to 87 in the Paley group. Sphericity as defined as mm away from a perfect Mose circle diameter on AP/LAT view went from 12/9 mm pre-op on Ganz to 8/7 and 12/11 on Paley to 6/6. The extrusion index went from 31% pre-op in Ganz to 13.3% postop vs 34.3% pre-op in Paley to 18.7% post-op. Using the previous satisfactory and unsatisfactory result score from Paley 2011, the current results showed 4 satisfactory and 2 unsatisfactory for Ganz vs 16 satisfactory vs 3 unsatisfactory for Paley. There were two cases of AVN both in Ganz osteotomies.

These results suggest that tailoring the FHRO to always be perpendicular to the femoral head elongation axis may be preferable to always making the osteotomy parallel to the femoral neck. Critical examination of some of the author's as well as Siebenrock's [9] Ganz-type FHRO when used in cases with elongation not perpendicular to the femoral neck demonstrates less than ideal reshaping of the femoral head. Furthermore, making the osteotomy parallel to the femoral neck is more limiting in the amount that can be reduced. Osteotomy perpendicular to the femoral head elongation axis increases the amount that can be reduced safely.

A third technique of femoral head reduction osteotomy was published by Burian et al. (2013) [10]. They performed an anteromedial wedge resection of the femoral head. They dislocated the hip through an anterior approach without performing an osteotomy of the greater trochanter. They then created a wedge with its apex distal and medial in the calcar region and with its base superiorly in the femoral head. This allows them to advance the more mobile medial segment of the femoral head toward the lateral side. No relative neck lengthening or distalization of the overgrown greater trochanter is possible with this approach. This method does offer two significant advantages over the Ganz and Paley FHRO. First it avoids dissection in the region of the piriformis fossa, thus reducing the risk of avascular necrosis. Second, in cases with elongation of the femoral head in a more medial direction, which have a large overhang medially that is not well centered on the femoral neck, both the Ganz and the Paley FHRO are difficult to perform. This last situation may be the ideal indication for the Burian FHRO.

Summary

Surgical dislocation of the femoral head allows for intra-articular osteotomy of the femoral head and neck to reshape the femoral head and try and restore its sphericity. This can be accomplished by simple resection of parts of the periphery of the femoral head and neck (osteochondroplasty) or by more complex resection of intercalary parts of the femoral head and neck (femoral head reduction osteotomy). Due to the different patterns of deformity of the femoral head, the orientation of the osteotomy will change accordingly. Three types of FHRO have been developed by different surgeons, each of which has its own indications. An understanding of these indications as they relate to femoral head geometry allows the surgeon to base the choice of osteotomy on pathoanatomy.

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