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JOINT-PRESERVING OPERATIONS FOR ADVANCED AND TERMINAL STAGES OF OSTEOARTHRITIS OF THE HIP

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MEDDOCS
International

To my professors,

Ryozo Ueno, and Keiro Ono

To my wife,

For her encouragement, patience, and

understanding

Joint preserving operations for advanced and terminal stages of osteoarthritis of the hip

Abstract

The aims of Pauwels' femoral osteotomy for Osteoarthritis (**OA**) of the hip are:

1. To decrease the resultant force to regrow articular cartilage,

2) to strengthen the regrown cartilage by a long period of partial weight bearing, and

3) to improve joint congruity to maintain a long period of joint-space opening.

To accomplish these aims, the operation is combined with muscle release and pelvic side procedures such as acetabular edge resection. The results of the advanced and terminal stages of hip OA tell us that the atrophic type according to Bombelli's classification is a poor indication for joint-preserving operations because of poor results and a high rate of recurrence of OA. Residual incongruity after surgery such as a deformed femoral head produces poor results, so a hip with postoperative residual incongruity is an indication of a poor outcome. A hip classified as the non-atrophic type with postoperative complete congruity should produce a good result and be maintained for more than 10 years. Thus, relatively less invasive methods produce similar results as total hip arthroplasty. However, the range of hip flexion will not improve. A good preoperative range of hip flexion is required (more than 60°), and 1 year of postoperative partial weight bearing requires family and social supports.

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1. Preface

Many reports have claimed that the result of osteotomy is unreliable for advanced stages of hip Osteoarthritis (**OA**) [1-10]. We usually recommend that patients undergo a Total Hip Arthroplasty (**THA**) or prescribe Non-Steroidal Anti-Inflammatory Drugs (**NSAIDs**). The problems with THA, which include dislocation, infection [11], aseptic loosening, Adverse Reaction to Metal Debris (**ARMD**) [12], and periprosthetic fractures [13], are well known. The incidence of these problems is small, but they are catastrophic for the patient's life style. Most patients who experience these problems are finally treated with revision surgery, which is overwhelming and more invasive than primary THA [14]. Conservative therapies such as a brace, exercise, medications, etc. ameliorate hip pain, but cannot prevent OA progression [15-19]. Therefore, several clinicians [20-27] including us have also investigated joint-preserving operations for advanced and terminal stages of OA of the hip. Our team established these operations according to Pauwels' osteotomy [28] and reported relatively satisfactory results [29-31]. However, in Japan, in patients with advanced stages of arthritis of the hip, especially younger adults, only conservative procedures are performed, and patients are only prescribed NSAIDs. Such patients lose their best time for joint-preserving operations. Osteotomy is not only a time-saving operation (to postpone the THA procedure) [30-34], but is also a curable procedure for OA of the hip.

2. Fundamentals of the Joint-Preserving Operation

2.1 Biomechanics

Figure 1 shows the biomechanics [35] of the hip during ipsilateral leg standing. K is body weight excluding the weight of the ipsilateral leg. M is abductor muscle power to prevent lateral pelvic tilt. The hip joint is burdened by the Resultant Force (R), which is the abductor Muscle Force (M) in addition to Body Weight (K). To simplify using a lever system, for the system to be in equilibrium, $M\times l=K\times r$. And the counteracting force on the fulcrum R is M+K.

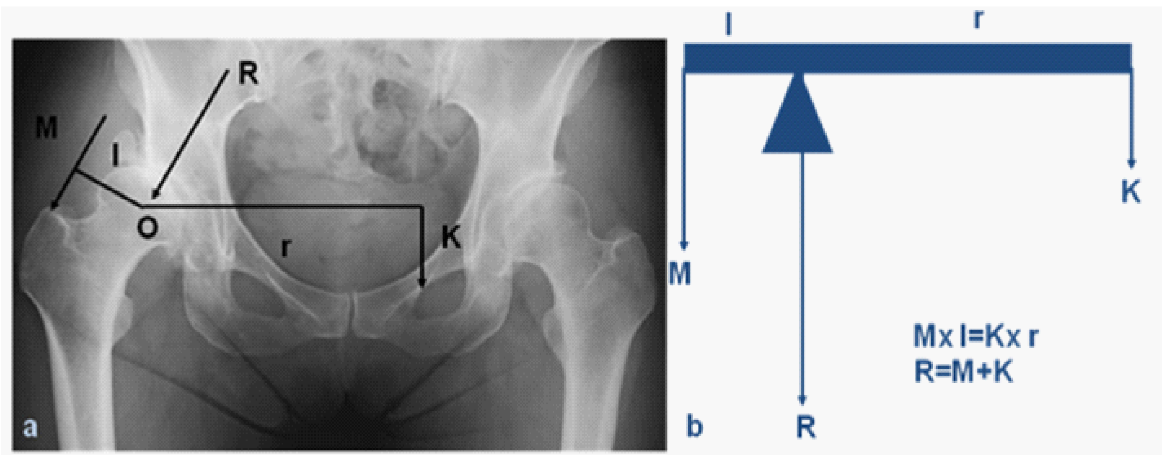


Figure 1: Simple biomechanics of the hip (a) and the lever (b).

2.2 X-Ray of the Hip

Good quality radiographs of the hip tell us much important information about the hip. An Anterior-Posterior (**AP**) X-ray film of the bilateral hip center that is collimated to the pubic symphysis is measured to show coverage of the femoral head by the acetabulum, sclerotic changes, and the joint-space width of the weight-bearing area (**Figure 8a**) (find **Figure 8 down**). Stress views (**Figure 2**), that is, an AP view of the hip with the final range of abduction (**Figure 8c**), adduction (**Figure 8e**), and the neutral position (**Figure 8d**) centered on the femoral head, tell us the operative methods. Anterior acetabular coverage of the femoral head is measured by the faux-profil view (**Figure 3a** and **Figure 3b**).

Figure 2: Actual maneuver for applying adduction stress. Keep the pelvis horizontal to the sound side. When the hip is in slight flexion, that is, over the sound leg, then, maximal adduction stress is added to the leg.

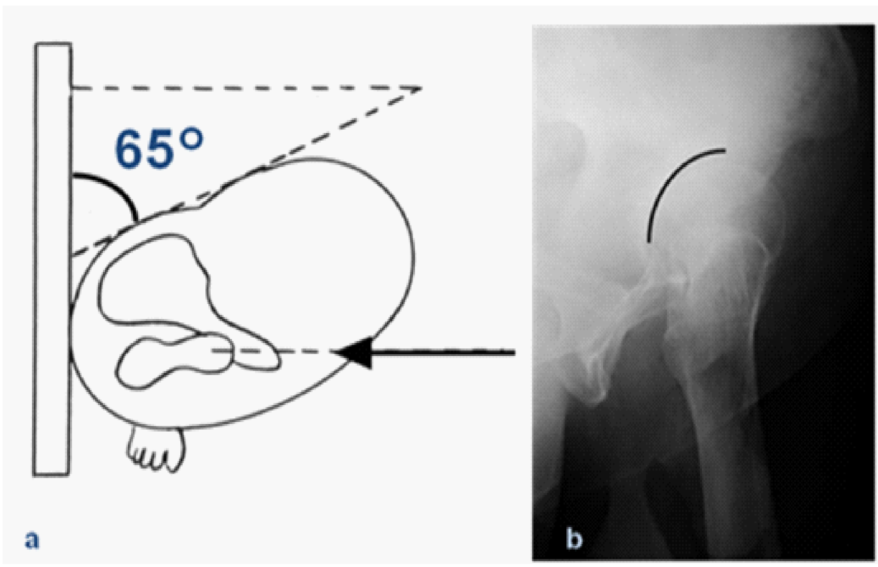


Figure 3: The position of the pelvis to take a faux-profil view of the right hip (a). The faux-profil view of the right hip (b). Curve: joint line.

2.3 Hip X-Ray Measurement

The Center-Edge (**CE**) angle ([36], **Figure 4**) and Vertical-Center-Anterior (**VCA**) angle ([37], **Figure 5a** and **Figure 5b**) are minimal requirements for investigating the acetabular coverage of the femoral head. A hip with more than 30º for both values is diagnosed as a normal hip. Less than 0º is diagnosed as severe acetabular dysplasia. Ueno et al. [30,38] developed the Lateral-Center-Medial (**LOM**) angle. **Figure 6** shows how to measure the LOM angle. More than 60º is our aim for reconstruction of the hip. The Acetabular-Head Index (**AHI**) [39] is generally used, but we are familiar with the above three indices.

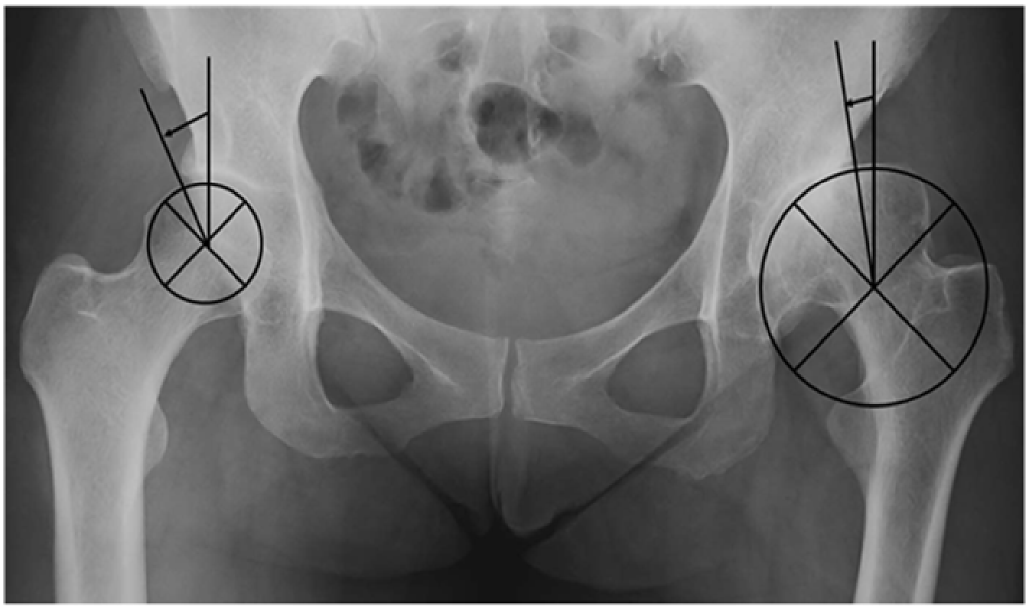


Figure 4: Measurement of the CE angle; normal femoral head (right) and the large head (left). The CE angle is defined as the angle between the vertical line from the center of the femoral head curvature and the lateral edge of the acetabulum from the center of the curvature.

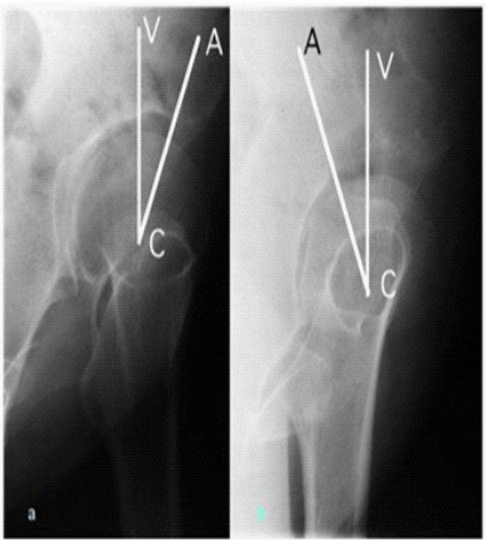


Figure 5: The VCA angle is defined as the angle between the vertical line from the center of the femoral head curvature and the anterior edge of the acetabulum. The VCA angles are 20º (a) and–20º (b).

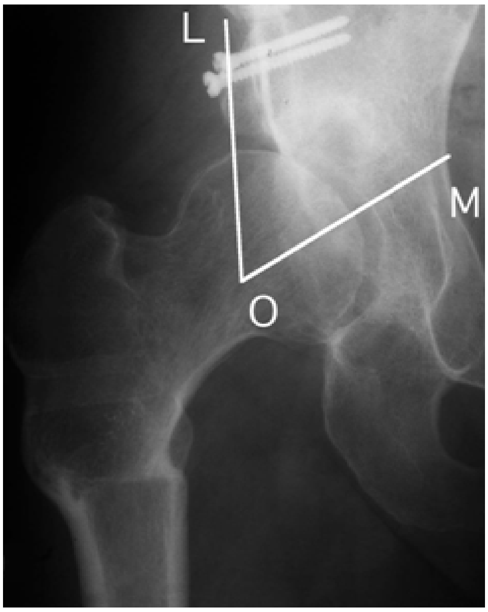


Figure 6: LOM (lateral-center-medial angle) angle is defined as the angle between the lateral edge of the weight-bearing area from the center of the femoral head curvature and the medial edge of the weight-bearing area from the center. This case included acetabuloplasty.

3. OA OF THE HIP

3.1 What is OA of the Hip?

In OA of the hip (coxarthritis), intolerable weight bearing on the joint accelerates wearing and breaking of articular cartilage. A hip X-ray reveals subchondral bone sclerotic changes, subchondral cyst formation, joint-space narrowing, and osteophyte formation; these are biophysicochemical reactions of the joint (**Table 1, Figure 7**). Because high-heel shoes have a small weight-bearing area and a high load per unit area, a dysplastic hip also shows a higher load on the weight-bearing area than a normal hip. The more dysplastic the hip, the more load focuses on the weight-bearing area at the acetabular edge. On an AP plain X-ray, triangular-shaped sclerotic changes at the lateral acetabular edge tell us to focus on weight bearing on the acetabulum. With progression of OA, the femoral head moves supero-laterally, restricting the range of motion in flexion, extension, abduction, and internal rotation. Finally, flexion-adduction-external rotation contracture occurs. Hyperlordosis of the lumbar spine and a scissors gait occur with bilateral terminal-staged hips.

OA has been classified in several studies. The Kellgren and Lawrence classification is popular (**Table 2**) [40]. The Japanese Orthopaedic Association (**JOA**) classification [41] is shown in **Table 3**. OA is divided into primary and secondary forms. Primary OA of the hip has no predisposing conditions. Secondary OA has causative diseases such as Developmental Dislocation of the Hip (**DDH**) [42], dysplastic hip, and subluxation of the hip. These diseases are not independent and usually occur together. Other causative diseases are femoral neck fracture in childhood, a vascular necrosis of the femoral head, sequelae of Legg-Perthes-Calvé disease, and femoro-acetabular impingement, which is postulated as a cause of secondary OA [43]. Primary OA is not common in Japan. DDH is classified into four groups according to whether the acetabular and femoral head are completely dislocated or partially subluxated (**Table 4, Figure 7**). Patients with "high hip dislocation" (the femoral head in the gluteal muscles) do not develop OA. However, as he or she becomes older, OA of the knee (**Figure 7b**), gluteal muscle pain, or lumbar spondylosis through scoliosis may develop.

Table 1: Radiological features of coxarthritis.

Osteophyte
Pseudocyst
Joint space narrowing
Subchondral bone sclerosis

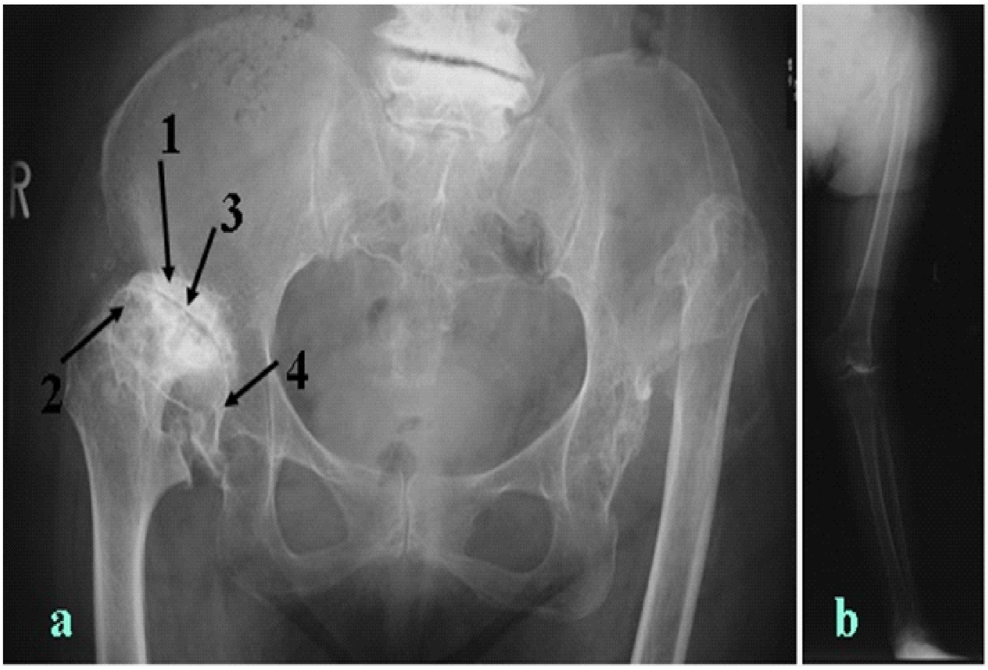


Figure 7: An AP X-ray of osteoarthritis of the hip of a 66-year-old woman, showing 1: sclerosis of the subchondral bone, 2: pseudocysts, 3: joint-space narrowing, and 4: osteophytes. Group 3 subluxation of the right hip and group 4 subluxation in her left hip classified according to Crowe (a). A gluteal dislocated hip and lateral knee osteoarthritis (b).

Table 2: Kellgren-Lawrence radiographic severity classification [40].

Severity	Class	Radiographic findings
0	Normal	No
1	probable	tiny osteophytes
2	Mild	obvious osteophytes, normal joint space
3	moderate	moderate joint-space narrowing
4	Severe	severe joint-space narrowing, sclerosis of subchondral bone

Table 3: Radiographic assessment of osteoarthritis of the hip (JOA) [41].

Grade	Radiographic Findings
Pre OA	slight incongruence, no narrowing of the joint space, possible change in trabecular alignment, developmental or acquired change of shape
Early OA	incongruence and partial narrowing of the joint space, acetabular sclerosis, mild osteophyte formation
Advanced OA	incongruence and partial attachment of the subchondral bone, acetabular subchondral sclerosis, subchondral cyst formation in the acetabulum or femoral head, osteophyte formation, acetabular bone proliferation
Terminal OA	incongruence and joint space disappearance in the weight-bearing segment, extensive subchondral sclerosis, large subchondral cyst formation, extensive osteophyte formation and double floor of the acetabulum, destruction of the acetabulum

Table 4: Crowe's classification [44].

Class	Subluxation
Group1	<50%
Group2	50-75%
Group3	75-100%
Group4	>100%

3.2 Subluxation

Subluxation is diagnosed when the femoral head enters the acetabulum deeply by abduction and the femoral head moves laterally in a neutral position (**Figure 8c** and **Figure 8d**). This condition shows that the hip is unstable. The condition is usually combined with acetabular dysplasia, and the hip may develop OA.

3.2.1 Case 1. A 56-year-old man with left hip OA

The patient complained of left hip pain for 1 year at my outpatient clinic (**Table 5)**. An X-ray of his left hip showed moderate dysplasia with joint space disappearance in the weight-bearing segment (**Figure 8a**), a CE angle of 5º, and a VCA angle of 0º (**Figure 8a** and **Figure 8b**). Stress views (**Figure 8c**, **Figure 8d** and **Figure 8e**) showed that the abduction position had good congruity and containment. I recommended that he undergo hip varus osteotomy and acetabuloplasty (Lance-Spitzy method) (**Figure 8f**). Two weeks after the operation, his hip showed superolateral migration (**Figure 8g**). During follow-up, no improvement of the subluxation was shown. Abduction stress showed good containment of the left hip (**Figure 8h** and **Figure 8i**), indicating that the primary varus osteotomy angle was insufficient (**Figure 8j**, **Figure 8k** and **Figure 8l**). Because the maximal abduction was 30º, an additional 20º of varus osteotomy was indicated (**Figure 8m**). This hip had not yet stabilized after 11 months (**Figure 8o-s**). However, in the neutral position, the hip was stable, and no deterioration of OA was found (**Figure 8n**). After osteotomy, the femoral head was stabilized, and no OA progression occurred. This case implies that hip joint stability, that is, no subluxation, is important for treatment of OA (**Table 5**).

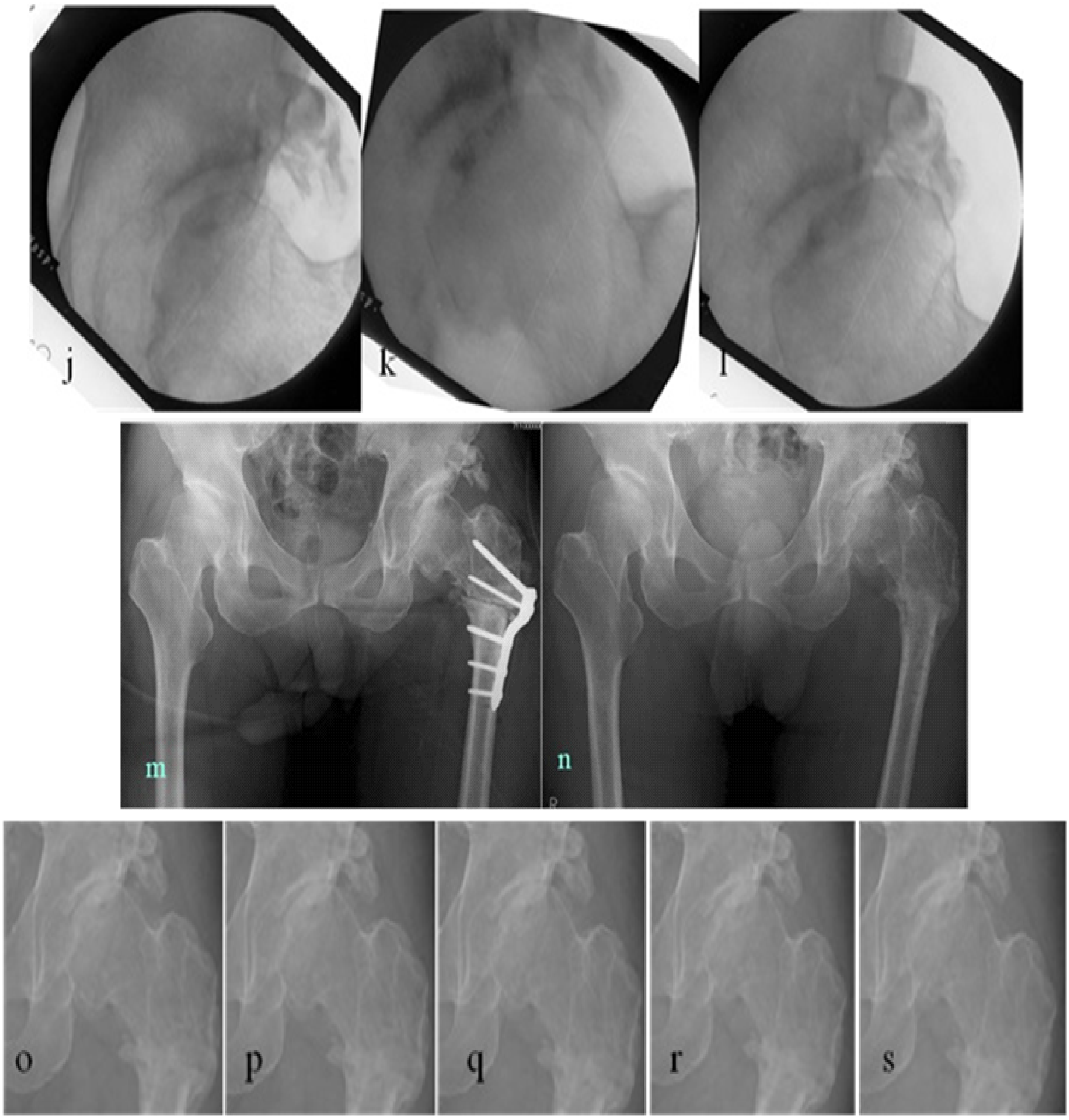


Figure 8: An AP X-ray of the hip case 1: A 56-year-old man with left hip osteoarthritis(a).The weight-bearing area is shown in the sclerotic shadow (blue curves). Faux-profil of the hip showed acetabular dysplasia, a CE angle of 5º, and a VCA angle of 0º (a,b). Stress views of the left hip: abduction (c), neutral position (d), and adduction (e). The femoral head goes inward in the abduction position (c) and goes lateral in the neutral position (d). Twenty degrees of varus osteotomy with acetabuloplasty was performed (f), but 2 weeks later, superolateral migration of the femoral head was shown (g). Stress views before reoperation: abduction (h) and neutral position (i). Congruity and containment were achieved in the abduction position. Image intensifier during reoperation showed that abduction provided good containment. Moving from abduction (j) to the neutral position (k) and adduction (l) or vice versa, a click-like sensation was felt. This hip is very unstable. Immediate postoperative X-ray (m) showed good containment and a congruous joint 11 month's later (n). At removal of the plate, image intensifier revealed instability of the joint without the click sensation. Neutral position (o) to 10º adduction position (s) with 2.5º increments (p,q,r).

Table 5: Case 1. A 56-year-old man

JOA	Preop	Postop 36 months
Pain	20	40
ROM	16	14
Gait	10	15
ADL	16	20
Sum	62	89
ROM Flex/Ext	100/0	100/0
Abd/Add	30/20	25/35

3.3 Regeneration of the Articular Cartilage

A long period of bed rest can cure hip OA. This patient (**Figure 9a**, **Figure 9b** and **Figure 9c**) was confined to bed for a year because of contralateral hip treatment. This case describes the necessity for a long period of partial weight bearing after hip osteotomy. Arthrography before and after osteotomy showed regenerating articular cartilage (**Figure 10a** and **Figure 10b**) and repair of a torn limbus (**Figure 10c** and **Figure 10d**).

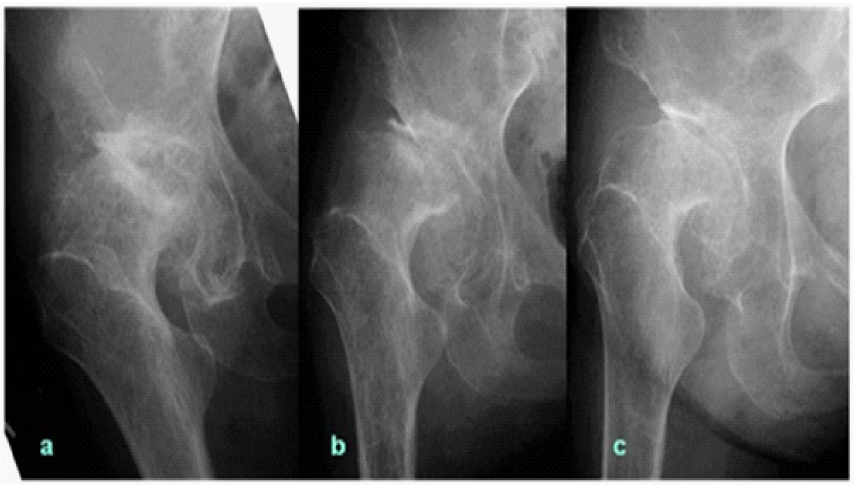


Figure 9: A 53-year-old woman with arthritis repair with rest. The contralateral side operation required her to spend a long period bed ridden and wheelchair bound. At the beginning of the bed ridden period (a), the preoperative state of the contralateral side of the hip. Ten months after the operation (b), and 30 months after the operation (c). Osteoarthritis was gradually repaired, and the joint space was open.

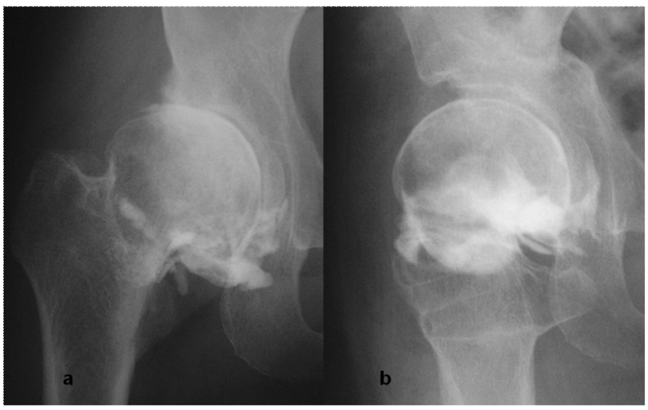


Figure 10: A 54-year-old woman. Preoperative assessment of the hip with arthrography. Articular cartilage loss in the head and acetabulum (a) and 13months postoperatively. Articular cartilage was repaired in both the acetabular and femoral sides. (b) Arthrogram of a 34-year-old woman with a torn limbus before the operation (c), and 14 months postoperatively. Valgus osteotomy and Chiari's pelvic osteotomy were performed. The torn limbus was repaired (d).

3.4 Measurement of Joint-Space Width in the Weight-Bearing Area of the Hip

We use several outcome measure batteries that measure discrete variables (**Table 6**, **Table 7** and **Table 8**) to evaluate a hip operation. Radiological assessment of OA of the hip is mostly performed with the Kellgren and Lawrence classification (**Table 2**), which is difficult to analyze statistically. To address this problem, we assessed the joint-space width at the weight-bearing segment (**Figure 11a**). As **Figure 11b** shows, when the joint-space width at the weight-bearing segment become less than 1mm, the width rarely recovers more than 1mm. The above results define joint death (end point) as the time point when the joint-space width is below 1mm; this information can be used to generate a survival curve [45,46] (**Figure 46**) (find **Figure 46** down). We analyzed the efficacy of several types of hip surgery with the same method [32,33,47].

Table 6: Merle d'Aubigné and Postel [48].

	Pain	Mobility	Ability to Walk
0	Pain is intense and permanent.	Ankylosis with poor position of the hip.	None.
1	Pain is severe even at night.	No movement; pain or slight deformity.	Only with crutches.
2	Pain is severe when walking; prevents any activity.	Flexion less than 40º.	Only with canes.
3	Pain is tolerable with limited activity.	Flexion between 40º and 60º.	With one cane, less than 1 hour; very difficult without a cane.
4	Pain is mild when walking; it disappears with rest.	Flexion between 60º and 80º; patient can reach his foot.	A long time with a cane; short time without a cane and with a limp.

5	Pain is mild and inconstant; normal activity.	Flexion between 80º and 90º; abduction of at least 15º.	Without cane but with slight limp.
6	No pain.	Flexion of more than 90º; abduction to 30º.	Normal.

Table 7: Harris Hip Score [49].

Pain (44 possible)

None or ignores it.	44
Slight, occasional, no compromise in activities.	40
Mild pain, no effect on average activities, rarely moderate pain with unusual activity, may take aspirin.	30
Moderate pain, tolerable but makes concessions to pain. Some limitations in ordinary activity or work. May require occasional pain medicine stronger than aspirin.	20
Marked pain, serious limitation in activities.	10
Totally disabled, crippled, pain in bed, bedridden.	0

Function (47 possible)

Gait (33 possible)	
Limp; None	11
Slight	8
Moderate	5
Severe	0
Support; None	11
Cane for long walks	7
Cane most of the time	5
One crutch	3
Two canes	2
Two crutches	0
Not able to walk (specify reason)	0
Distance; Unlimited	11
Six blocks	8
Two or three blocks	5
Indoor only	2
Bed and chair	0

Activities (14 possible)	
Stairs; Normally without using a railing	4
Normally using a railing	2

In any matter	1
Unable to climb stairs	0
Shoes and socks; with ease	4
with difficulty	2
unable	0
Sitting; comfortably in ordinary chair 1 hour	5
on a high chair for 30 minutes	3
unable to sit comfortably in any chair	0
Enter public transportation	1

III. Absence of deformity points (4) are given if the patient demonstrates:

A. Less than 30º fixed flexion contracture
B. Less than 10º fixed adduction
C. Less than 10º fixed internal rotation in extension
D. Limb-length discrepancy less than 3.2 centimeters

IV. Range of motion

A. Flexion 0˚-45˚X1.0; 45˚-90˚X0.6; 90˚-110˚X0.3
B. Abduction 0˚-15˚X0.8; 15˚-20˚X0.3; over 20˚X0
C. External rotation in ext. 0˚-15˚X0.4; over 15˚X0
D. Internal rotation in extension any X0
E. Adduction 0º-15º X0.2

To determine the overall rating for range of motion, multiply the sum of the index values by 0.05. Record Trendelenburg test as positive, level, or neutral.

Table 8: JOA hip score [50,51].

Pain Full; 40 points	Points
None[a]	40
Ignores[b]	35
Slight[c]	30
Moderate[d]	20
Severe[e]	10
Unbearable[f]	0

[a]No pain and/or no complaints relating to hip joint
[b]No pain. Inconstant symptoms including weary feeling or dullness
[c]No spontaneous pain. Some pain when walking (including slight pain when starting to walk or after walking for long distance)
[d]No spontaneous pain. Some pain when walking but the pain disappears quickly after a short rest
[e]Spontaneous pain. Pain is severe when attempting to walk; pain decreases after a rest
[f]Continuous pain during rest and/or at night

Range of motion Full; 20 points	Points
Flexion arc	0-12
Abduction arc	0-8

Scores are determined by multiplying 10º of motion in each arc by 1 point for flexion and 2 points for abduction.
Range of contracture should be subtracted.
Flexion of more than 120º is determined as 12 points and abduction of more than 30º as 8 points.
Either flexion or abduction is measured in the neutral position on rotation and described by its arc by passive motion.

Ability to walk Full; 20 points	Points
Normal[a]	20
Slight limp[b]	18
Mild limp[c]	15
Severe limp[d]	10
Difficult to walk[e]	5
Impossible[f]	0

[a]Able to walk long distance without limp. Able to walk fast
[b]Able to walk long distance including walking with a slight limp. Able to walk fast
[c]Able to walk 30 min or 2 km without support. Mild limp
[d]Able to walk 10-15 min or 50 m without support
[e]Able to do household activities. Difficult to do outdoor activities. Difficult to walk outdoors without bilateral support
[f]Impossible or almost impossible to walk

Activities of daily life Full; 20 points	**Normal**	**Difficult**	**Impossible**
Sitting on chair	4	2	0
Standing work (including housework) [a]	4	2	0
Squatting, standing up from sitting on the floor[b]	4	2	0
Going up and down stairs[c]	4	2	0
Getting into car or entering public transportation	4	2	0

[a]Able to continue longer than 30 min. Needs to take a rest---score as "difficult," Unable to continue longer than 5 min---score as "impossible"
[b]Support needed---score as "difficult"
[c]Handrail needed---score as "difficult"

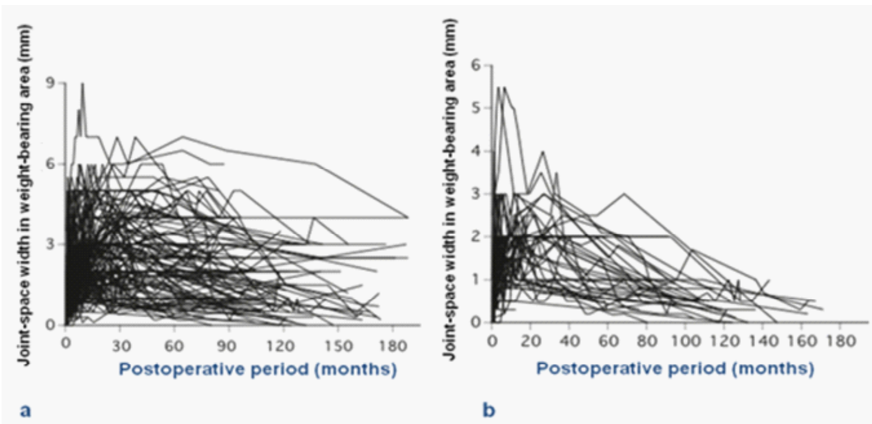


Figure 11: Radiographic course of the joint-space width in the weight-bearing segment (a) and radiographic course of the joint-space width, which becomes less than 1mm (b).

4. Joint-Preserving Operations: Theory and Indication

4.1 Theory of Joint-Preserving Operation

Joint-preserving operations require 1. Enlargement of the weight-bearing segment, 2. Reduction of the resultant force, and 3. Recovery of articular cartilage (**Table 9**).

At first, enlargement of the weight-bearing area provides improvement of joint congruity and acetabular enlargement (acetabuloplasty, Chiari's pelvic osteotomy). An enlarged weight-bearing area decreases the force per unit area. The resultant force is reduced by releasing the abductor muscle tendon, shortening the femur, and medializing the femoral head.

The formula is:

Resultant force= Abductor muscle power + Body weight. When the muscle power decreases, the resultant force decreases. Regeneration of cartilage is accelerated by a long-term period of non-weight bearing, and regenerated cartilage becomes mature with partial weight bearing. In short, osteotomy and partial weight bearing result in regeneration of cartilage, which is maintained for a long period of time by decreasing the resultant force and enlarging the weight-bearing area.

Table 9: Aim and methods of joint-preserving operation

Aim	Methods
Enlargement of weight-bearing area	Improvement of congruity Acetabuloplasty
Amelioration of resultant force	Muscle release Leg shortening, Chiari's pelvic osteotomy
Regeneration of articular cartilage	Long-term non-weight bearing

4.2 Operative Method and Theory

4.2.1 Varus osteotomy

4.2.1.1 Indication: We recommend this operation when the hip congruity becomes better in the abduction position.

4.2.1.2 Theory: The greater trochanter migrates superiorly and laterally, the abductor muscle becomes loosened, and the lever arm becomes elongated. This causes smaller abductor muscle force that can equilibrate the torque (**Figure 12a** and **Figure 12b**). The torque of both sides is in equilibrium. **Figure 12c**.

$M \times l = K \times r$ and $M' \times l' = K \times r$.

Combine:

M×l=M’×l’=K×r

Simplify:

M×l=M’×l’

Then:

1÷l’=M’÷M

Now:

l’>l.

Then:

1> l÷l’

Combine:

1> M’÷M

Then:

M>M’ --1

Using the formula:

R=M+K and R’=M’+K

Subtract K:

R—K=M and R’—K=M’

Use formula 1:

R—K>R’—K

Add K to each side:

R>R’

The resultant force also declines, and better joint congruity increases the weight-bearing segment.

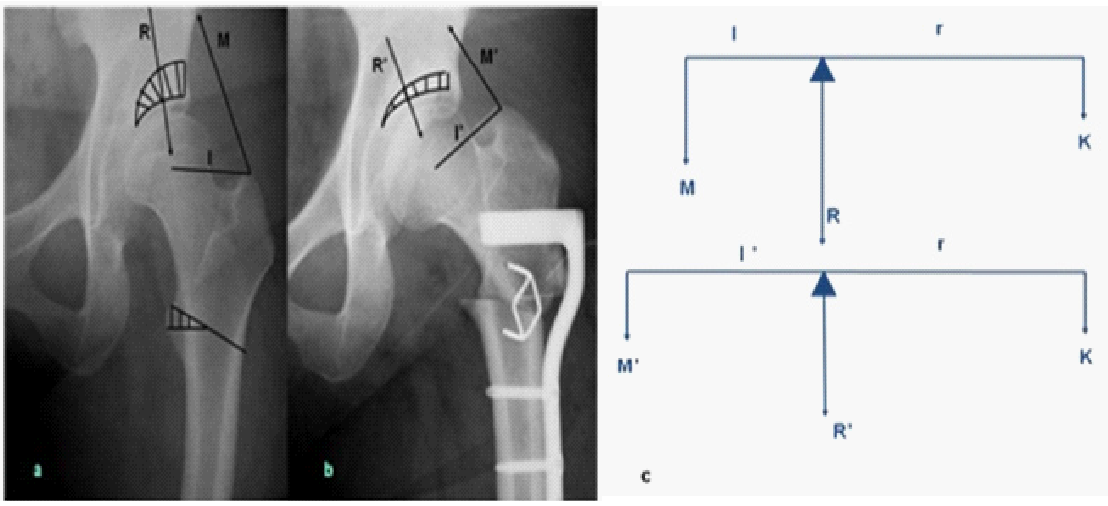


Figure 12: Theory of varus osteotomy before (a) and after surgery (b). Theory of varus osteotomy shown with a lever diagram (c). K: body weight excluding the weight-bearing leg, l: lever arm of M, l’: lever arm of M’, M: abductor muscle power for preventing pelvic tilt, M’: abductor muscle power after osteotomy, R: resultant force, R’: resultant force after osteotomy, r: lever arm of K.

4.2.2 Valgus osteotomy (Figure.13a and Figure 13b)

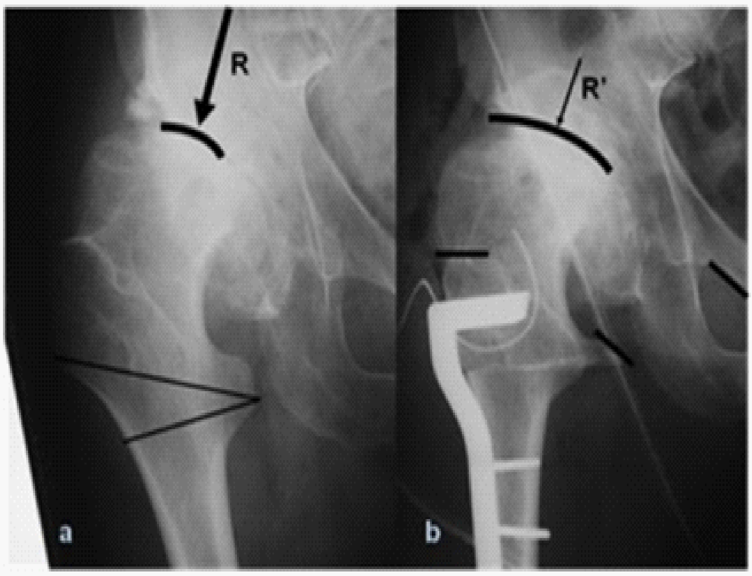


Figure 13: Theory of valgus osteotomy before (a) and after surgery (b).Curve: weight-bearing area, line: tenotomy site, triangle: osteotomy line. R: resultant force, R': resultant force after osteotomy.

4.2.2.1 Indication: The hip in the adduction position shows the best congruity.

4.2.2.2 Theory: In advanced and terminal stages of hip OA, we recommend this procedure to improve congruity and enlarge the weight-bearing area. The femur also becomes slightly internalized. A shortening osteotomy decreases muscle tension around the hip. The gluteus medius tendon is released at the greater trochanter, and then we can prevent strengthening of the gluteus medius by caudalzing the greater trochanter. Lateralization of the femoral shaft prevents medialization of the weight-bearing axis of the leg.

4.2.3 Lateralization of the greater trochanter

4.2.3.1 Indication: When the hip in the neutral position shows the best congruity, we recommend this procedure [52]. Generally, advanced and terminal stages of coxarthritis require this procedure. When both hips have OA with advanced or terminal stages, the method is indicated for the hip with the less advanced stage, and a valgus osteotomy (described later) is indicated for the contralateral hip.

4.2.3.2 Theory: Lateralization of the greater trochanter (**Figure 14**) makes the lever arm longer. When the torque of the left side (muscle power×lever arm) is constant, the torques is thesame after elongation of the left side lever arm. The muscle power becomes smaller, and the resultant force (muscle power + body weight) also decreases [52,53]. The iliopsoas muscle and the adductor longs tendon are released at the insertion and the origin, respectively.

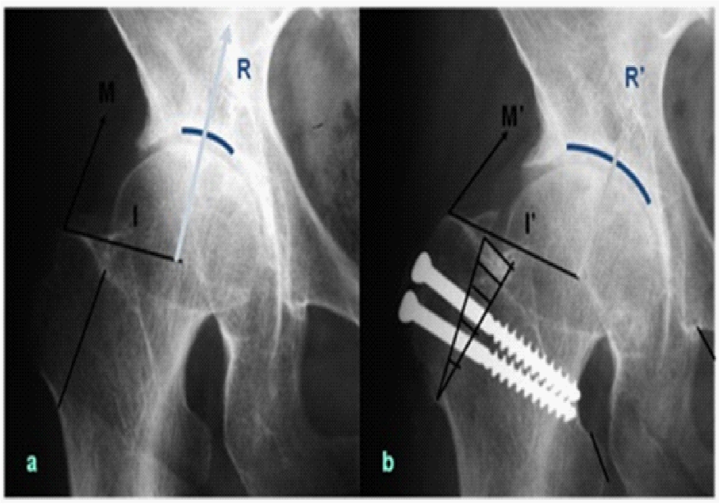


Figure 14: Theory of lateral transfer of the greater trochanter, before (a) and after (b) the operation. K: body weight excluding the weight-bearing leg, l: lever arm of M, l': lever arm of M', M: abductor muscle power for preventing pelvic tilt, M': abductor muscle power after osteotomy, R: resultant force, R': resultant force after osteotomy.

4.2.4 Chiari's pelvic osteotomy

4.2.4.1 Theory: The distal fragment of the pelvis is medially and superiorly migrated to provide better coverage of the femoral head by Chiari's pelvic osteotomy [54] (**Figure 15a** and **Figure 15b**). Moreover, shortening of the leg lowers the muscle tension, and the fulcrum is medialized (**Figure 15c** and **Figure 15d**). Then the resultant force is decreased (**Table 10)**. The medialization of the fulcrum makes the lever arm of the body weight smaller.

Figure 15c: both side torques (body weight × lever arm) are in equilibrium.

$M\times l=K\times r$

$M\times l\div K=r$--1

Figure. 15d: same as above

$M'\times l=K\times r'$

$M'\times l'\div K=r'$ ---2

Medialization of the fulcrum shows:

$r>r'$---3

Combine formulas 1, 2, and 3:

$M\times l\div K>M'\times l\div K$

Multiply by K/l on both sides

$M>M'$---4

Use the formula:

$R=M+K$, $R'=M'+K$

$R—K=M$, $R'—K=M'$

Use formula 4:

$R—K>R'—K$

Add K to both sides:

R>R'.

Varus osteotomy for subluxation of the hip also has the same effect.

The weight-bearing segment after Chiari's osteotomy, which was the joint capsule before the operation, changed to cartilaginous tissue [55].

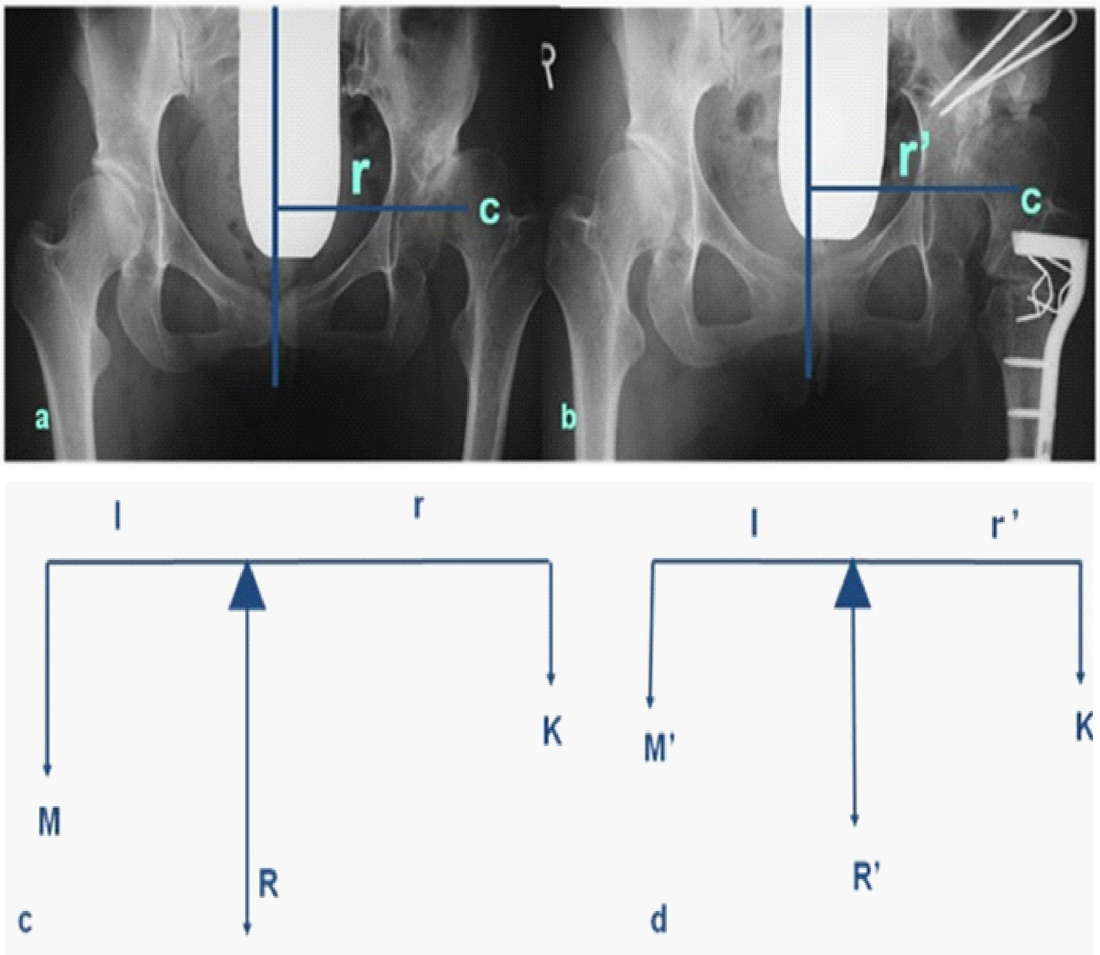


Figure 15: Theory of Chiari's pelvic osteotomy, before (a) and after (b) surgery. Lever arm illustrating Chiari's pelvic osteotomy, before (c) and after (d) surgery.K: body weight excluding the weight-bearing leg, l: lever arm of M, M: abductor muscle power for preventing pelvic tilt, M': abductor muscle power after osteotomy, R: resultant force, R': resultant force after osteotomy, r: lever arm of K, r': lever arm of K after osteotomy.

Table 10: Theory of Chari's pelvic osteotomy.

1. Supero-medialization of distal fragment
2. Leg shortening
3. Amelioration of resultant force by medialization of fulcrum

4.2.5 Muscle release

4.2.5.1 Theory: Muscle release (**Figure 16a** and **Figure 16b**) reduces the M, and then the R is decreased [56].

Muscle release makes

M>M'.

R=M+K>R'=M'+K.

This procedure is indicated for OA. The tendon of the gluteus medius and the iliopsoas muscles are released at their insertion, and the adductor longus muscle is tenotomized at its origin (**Table 11**).

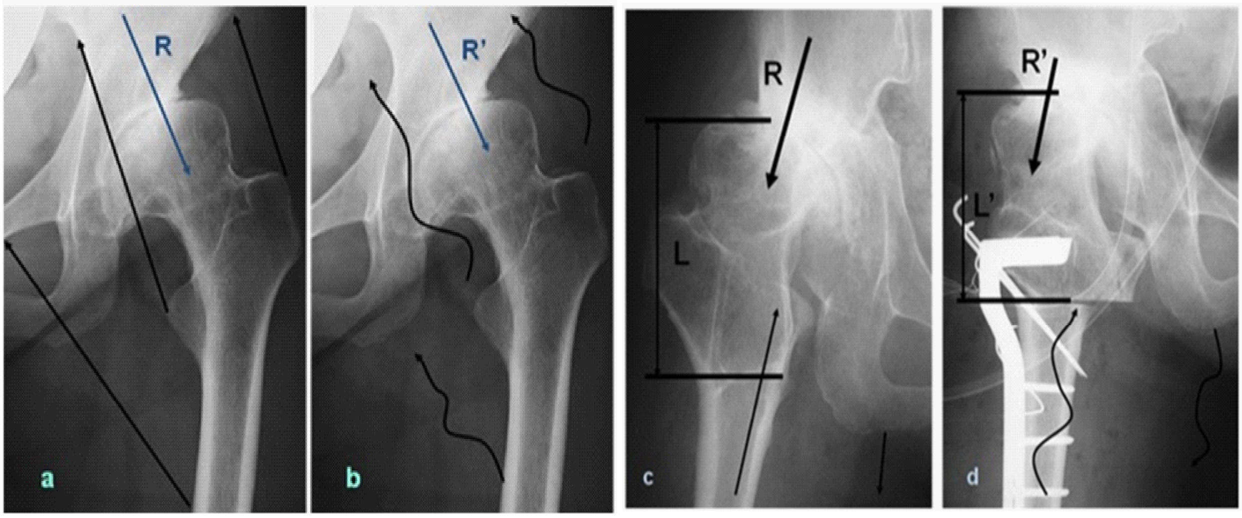


Figure 16: Theory of the muscle release (Hanging hip operation), before (a) and after (b) surgery, R: resultant force, R': resultant force after muscle release, Straight arrows: adductor longus muscle, iliopsoas muscle, and gluteus medius muscle power before muscle release (a), Wavy arrows: above muscle powers after muscle release (b). Shortening osteotomy, before (c) and after (d) surgery, L: head and neck length, L': head and neck length after osteotomy (L'<L), R: resultant force, R': resultant force after osteotomy, Straight arrows: muscle powers of quadriceps femoris muscles and hamstrings, Wavy arrows: muscle powers of quadriceps femoris muscles and hamstrings.

Table 11: Muscle release for osteoarthritis of the hip.

1. The adductor longus (all)
2. The iliopsoas(all)
3. The gluteus medius (simple valgus osteotomy) Lowering of muscle tension by the greater trochanter inferior placement

4.2.6 Shortening osteotomy

4.2.6.1 Theory: Shortening the proximal femoral length decreases muscle tension around the hip. This decreases the M, and then, R is lowered (**Figure 16c** and **Figure 16d**). Varus osteotomy and Chiari's pelvic osteotomy simultaneously shorten the limb length. However, valgus osteotomy with an osteotomy angle around 15° will lengthen the femoral length. The Hamstring muscles, rectus femoris, gluteus maximus, adductor muscles etc. are elongated, and then muscle tension will increase. Recovery of the articular cartilage will not occur as expected. Postoperative limb length elongation should be excluded **(Figure 17)**. Osteotomy planning is important to exclude femoral elongation. When this will occur, we will add 5-10 mm shortening osteotomy.

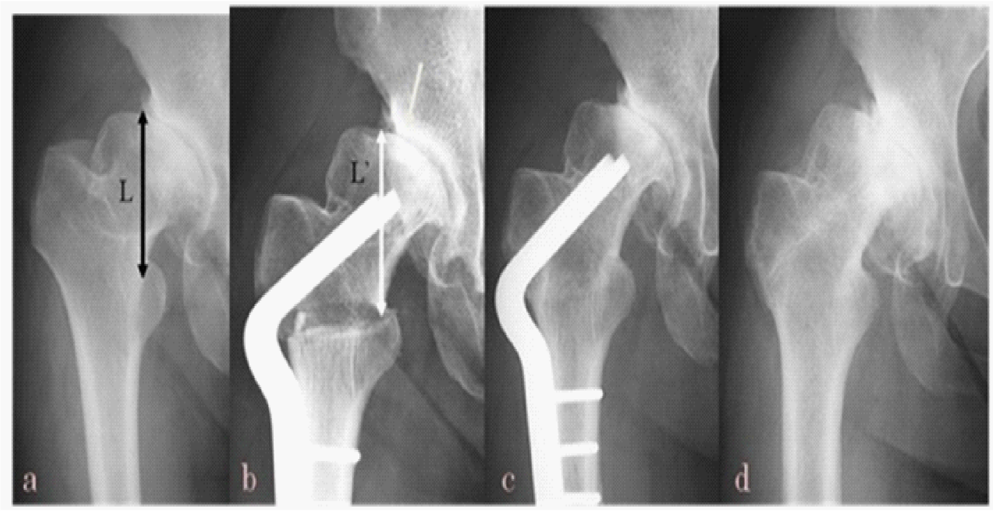


Figure 17: A 41-year-old woman. Valgus osteotomy was performed elsewhere (a). Preoperative AP X-ray: (b) 7 days postoperative, 1 year postoperative (c), and (d) 6 years after surgery. She did not experience relief of hip pain after the operation. This hip underwent postoperative limb lengthening and developed incongruity postoperatively. L: neck and head length, L': head and neck length after osteotomy (L'>L), arrow shows incongruity.

4.3 Operative Methods and Indication

Surgical indication is determined by hip X-ray at maximum abduction and adduction. We have three basic methods (**Figure 18a**); varus osteotomy (Pauwels' type I, PI), valgus osteotomy (Pauwels' type II, PII), and lateralization of the greater trochanter (Maquet's operation, Mq). When joint congruity is improved by hip abduction, we recommend varus osteotomy. When congruity is improved by hip adduction, we recommend valgus osteotomy [57,58]. When the neutral position shows the best congruity, we recommend lateralization of the greater trochanter [59] (**Table 12**). For residual partial incongruity in the superior site of the joint, we add acetabular edge resection [60-62], which is indicated for complete congruity (**Figure 18b**). This resection is indicated in both varus and valgus osteotomies. When the incongruity is shown in all weight-bearing areas or the femoral head is not round or oval, the method is contraindicated.

Finally, we recommend acetabuloplasty or Chiari`s pelvic osteotomy according to the amount of acetabular dysplasia [63,64] (**Table 13**). According to our report, hip flexion is not improved by osteotomy [33]. Hip flexion should be more than 60º before the operation. When varus osteotomy is indicated, the hip needs 15º of hip abduction to avoid adduction contracture (**Figure 18b**).

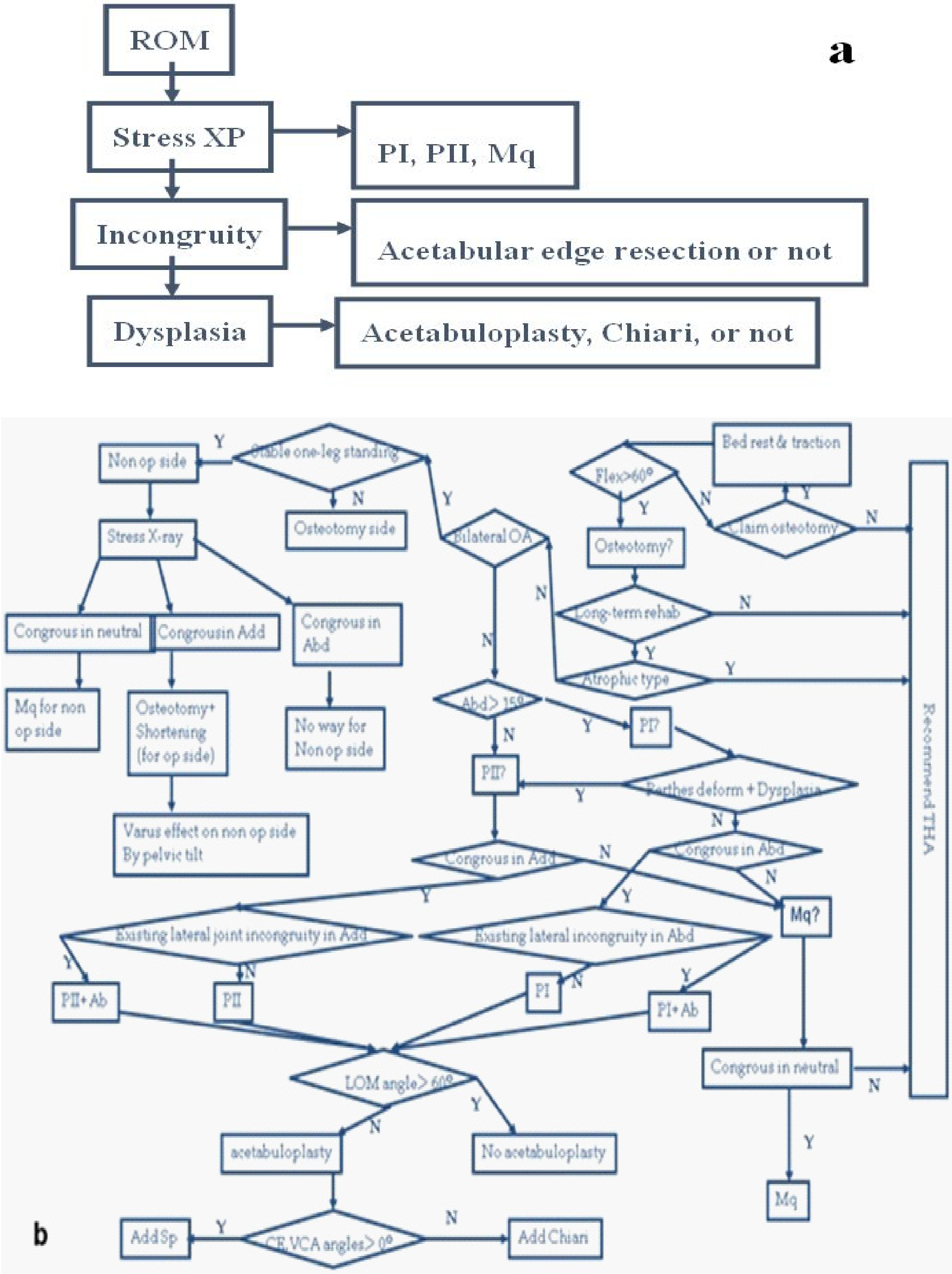


Figure 18(a): Precise algorithm of the indication (b).

Table 12: Congruity and osteotomy.

Hip position for improving congruity	Operation	Abbreviations
Abduction	Varus osteotomy	PI
Adduction	Valgus osteotomy	PII
Neutral	Lateralization of the greater trochanter	Mq

Table 13: Additional operation: enlargement of indication.

Aim	**Additional operations**
Improving congruity	Acetabular edge resection
Enlarging weight bearing area	Acetabuloplasty (Lance+Spitzy) Chiari's pelvic osteotomy

4.4 Decision Tree for Indication of Joint-Preserving Operation

When hip flexion is less than 60º, we recommend patients undergo THA. However, when a patient insists on joint preservation, he or she undergoes skin traction (Speed-Track® traction) of 1-2 kg on admission. We can recommend osteotomy when the hip flexion is more than 60º after 1week of traction in bed. One year of rest is necessary for patients with physical and economic support. Sound upper extremities are necessary, because crutch gait for a year (three-point crutch gait for 6months and a single crutch gait for another 6months) is mandatory (**Table 14**).

However, if the hip is classified as the atrophic type with Bombelli's classification [65], the prognosis is poor [47,52,66,67]. We recommend these patients undergo THA. When a patient has bilateral hip pain with advanced or terminal stages of OA of the hip, special considerations are necessary [68,69].

First, I will explain unilateral involvement. When hip abduction is more than 15º, the hip is not in the terminal stage of OA, and femoral head deformity may be minimal. We usually recommend femoral varus osteotomy. However, for a hip with a "Perthes-like" deformity of the proximal femur, such as an oval femoral head, we recommend valgus femoral osteotomy [70,71]. When congruity of hip abduction improves, varus femoral osteotomy (**PI**) is indicated (**Figure 18b**). If the patient has existing incongruity at the lateral margin of the joint, we add acetabular edge resection (**Ab**) to the varus osteotomy. If the neutral position shows the best congruity, that is, if hip adduction or abduction does not improve congruence, lateral transfer of the greater trochanter (**Mq**) is indicated (**Table 12**). Necessity of the acetabular enlargement procedure is decided by the angle of LOM (**Figure 18b**). When the LOM angle is more than 60º, no acetabuloplasty is added. When the LOM angle is less than 60º, the acetabular enlargement procedure is necessary. Acetabular enlargement is performed with two methods. Acetabuloplasty (**Sp**) is indicated when the CE and VCA angles are positive. Chiari's pelvic osteotomy is indicated when the CE and VCA angles are negative.

In general, determining the treatment plan for a patient with bilateral OA of the hip is difficult [69, 72-74]. In patients with one hip joint that cannot provide support (contralateral hip support), risk of early progression of OA in both hips may be high. When both hips are involved, we first determine their weight-bearing ability. A crutch gait for 1 year is required of the weight-bearing leg. Before the operation, a one-leg standing position is used to select the more stable leg to be the weight-bearing leg. Osteotomy is indicated for the contralateral side. Treatment for the weight-bearing leg involves three options. In stress views, if congruity is improved by hip adduction, shortening osteotomy is added to the osteotomy side to introduce pelvic lateral tilt and valgus effect on the weight-bearing hip. In the stress view of the hip X-ray, if congruity of the hip in the neutral position is the best, lateral transfer of the greater trochanter is indicated. When an abducted hip shows the best congruity, the weight-bearing hip cannot be treated, and unilateral osteotomy is indicated on the osteotomy side.

Table 14: Predisposition for joint-preserving operation.

Flexion more than 60º
Contralateral side weight-bearing leg
Long-term rehabilitation
Abduction; more than 15º in varus osteotomy

4.5 Age and Indication

We believe that there is no age limit for osteotomy. However, a long-term crutch gait demands sound upper limbs and a sound contralateral leg. Bone atrophy had progressed due to long-term partial weight bearing, which may cause a femoral neck fracture due to a fall. Severe bone atrophy after osteotomy required precise follow-up.

4.6 Predisposition for Joint-Preserving Operation

Finally, the predisposition for the indication of a joint-preserving operation is summarized as follows. Hip range of motion of 60º of flexion is necessary. When varus osteotomy is indicated, 15º of abduction is necessary. A long-term crutch gait and a sound contralateral hip are also necessary (**Table 14**). Bilateral involvement must determine the weight-bearing side. The atrophic type as classified by Bombelli is associated with a poor prognosis [33,47,66] and has no indication for a joint-preserving operation [57,59,75]. Incongruity after the operation tends to lead to long-term poor results [34,76]. Complete elimination of incongruity of the hip during the operation is mandatory. In patients with a deformed femoral head in which incomplete congruity after the operation can be predicted preoperatively, a joint-preserving operation is contraindicated.

4.7 Preoperative Autologous Blood Donation

A hip operation may require autologous blood transfusion. Femoral osteotomy is associated with an estimated 200 to 400 ml of bleeding, and homologous transfusion can be excluded with autologous blood banking. Pelvic side operation may result in blood loss of 400-600 ml, and both pelvis and femoral surgery results in blood loss of 800-1200 ml (**Table 15**). Osteotomy is expected to result in a small amount of postoperative bleeding unlike cementless THA.

Table 15: Preoperative autologous blood donation

Operation	Volume (ml)
Femoral osteotomy (FO)	None
Acetabuloplasty +FO	800
Acetabular edge resection +FO	800
Chiari's pelvic osteotomy+ FO	1200

5 Joint-Preserving Operations

5.1 Surgical Instruments for Osteotomy

In Japan, many patients suffering from hip OA are women, and the AP length of the proximal femoral shaft is small. The anteversion of the femoral neck makes contacting the posterior neck cortex easy. A shorter blade is recommended (**Figure 20a**). Goniometers for varus osteotomy (**Figure 19a**), goniometers for valgus osteotomy (**Figure 19b**), and Arbeitgemeinschaft für Osteosynthesefragen (AO, Association for the Study of Internal Fixation) Locking Compression Plate (**LCP**) pediatric hip plates (**Figure 20b** and **Figure 20c**) for varus (**Figure 20b** and **Figure 20d**) and valgus (**Figure 20c** and **Figure 20e**) osteotomies, which were originally indicated for adolescent patients under 55 kg of body weight, have recently become commercially available. This system is convenient for the operation. The AO angle blade plate for adults is too large for such patients and is likely to fracture at the insertion area **(Figure 20f)**. Files for acetabular edge resection are of two types: a pushing file and pulling file (**Figure 21c**). The pushing file cuts the inner part of the acetabulum, and the pulling file makes a shallow cut. Bone clamp and curved Cooper scissors are useful for these procedures as shown in **Figure 21a** and **Figure 21b**.

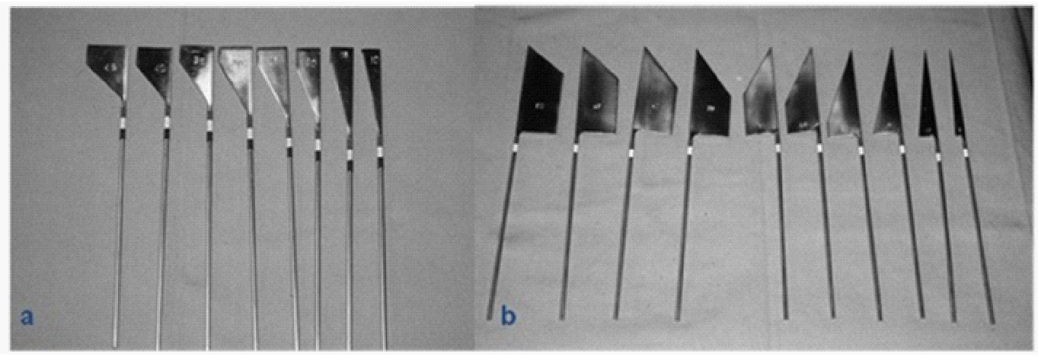
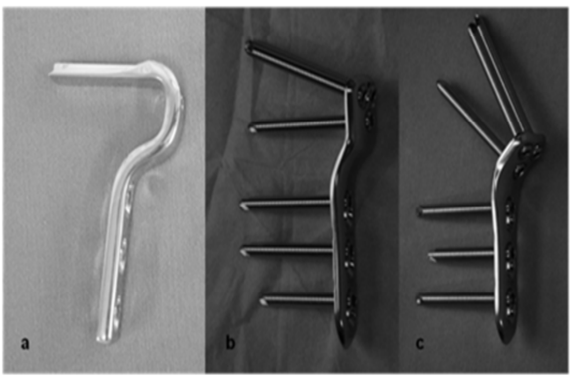


Figure 19: Goniometers for varus osteotomy (a) and valgus osteotomy (b).



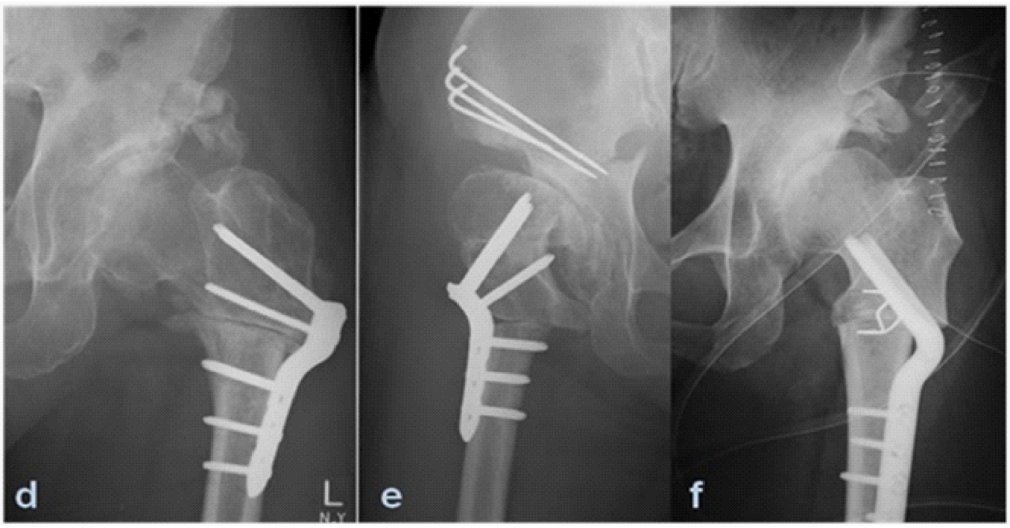


Figure 20: AO plate for young adults (a) and LCP pediatric hip plate for adolescents (b,c). X-ray of varus (d) and valgus (e) osteotomy using LCP plates. X-ray of varus osteotomy with adult AO plate (f).

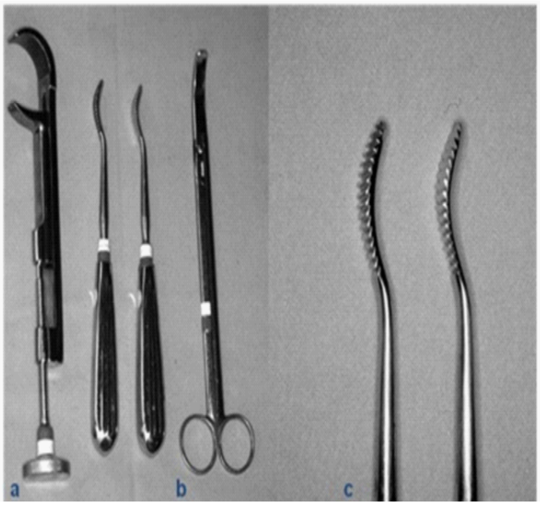


Figure 21: Bone clamp and bone files (push and pull types) for acetabular edge resection(a), long curved Cooper scissors (b), and enlarged photo of bone files (c).

5.2 In the Operating Room

5.2.1 Placement of the epidural catheter: Compared to THA, osteotomy strips off a large amount of muscle subperiosteally, which produces more motion pain than THA. For pain relief and prevention of Venous Thromboembolism (**VTE**), placement of an epidural tube is recommended.

5.2.2 Position: In the supine position, the operative site of the pelvis is placed at the edge of the operating table with mandatory horizontal setting. The operation is performed with the pelvis placed horizontally. Do not use a pillow to raise the operative side of the pelvis. If planning to take an X-ray during the operation, an X-ray film cassette is placed under the pelvis as described in **Figure 36**.

5.3 Varus Osteotomy

5.3.1 Radiography: Checking the X-ray in the abduction position improves joint congruity (**Figure 8c**, **Figure 8d** and **Figure 8e**).

5.3.2 Planning [58,77]: We plan varus osteotomy so that high placement of the greater trochanter does not occur (**Figure 22**), because otherwise limping is inevitable [78]. To avoid too much shortening of the femur, osteoplastic osteotomy (**Figure 23**) is indicated [63,78]. However, to completely eliminate instability, a high greater trochanter is indicated in some patients (**Figure 8**).

Figure 22: A high greater trochanter; the tip of the greater trochanter (upper line) is proximal to the tip of the femoral head (lower line).

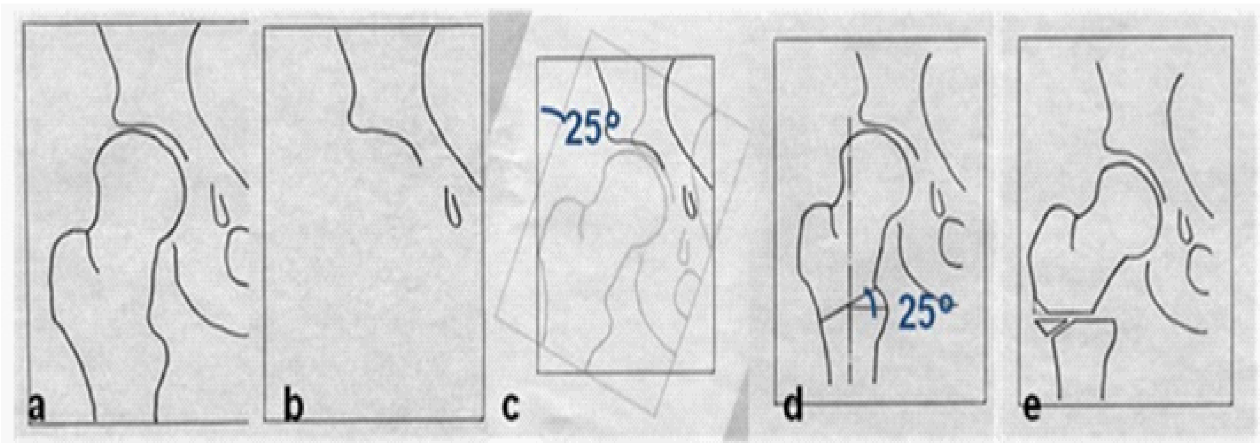


Figure 23: Planning of varus osteotomy. Drawing of the hip in the neutral position (a). In the second picture, only the acetabular was drawn (b). The second paper was overlaid on the first paper (c), rotated at the osteotomy angle (25° counterclockwise, in this case), and then the femoral head was drawn on the second paper. The preoperative hip was drawn on the first paper (d), and the postoperative hip was drawn on the second paper (e).

5.3.3 Osteotomy

5.3.3.1 Lateral approach: Osteotomy is performed through a lateral incision that begins at the proximal tip of the greater trochanter and continues distally for 15 cm (**Figure 24a** and **Figure 24b**).

5.3.3.2 Release of the iliopsoas tendon (described later)

5.3.3.3 Marking of the osteotomy angle (Figure 24c-Figure 24j)

Cutting proximally carries a risk of cutting into the proximal neck. A K-wire trial of the osteotomy guide line is good way to avoid this (**Figure 24i** and **Figure 24j**). This would create a fatigue fracture of the femoral neck (**Figure 25a** and **Figure 25b**). Cutting too distally may delay bone union.

5.3.3.4 Osteotomy: Osteotomy is performed with a bone saw by placing the saw blade vertically. The osteotomy site is cooled with saline as described in the valgus osteotomy session.

5.3.3.5 Bone fixation: (described in the valgus osteotomy session)

5.3.3.6 Wound closure: After sufficient washing with saline and introduction of a suction drain, the vastus lateralis and tensor fascia muscles, subcutaneous tissue, and skin are sutured layer by layer. A compression stocking is applied to both legs to prevent VTE.

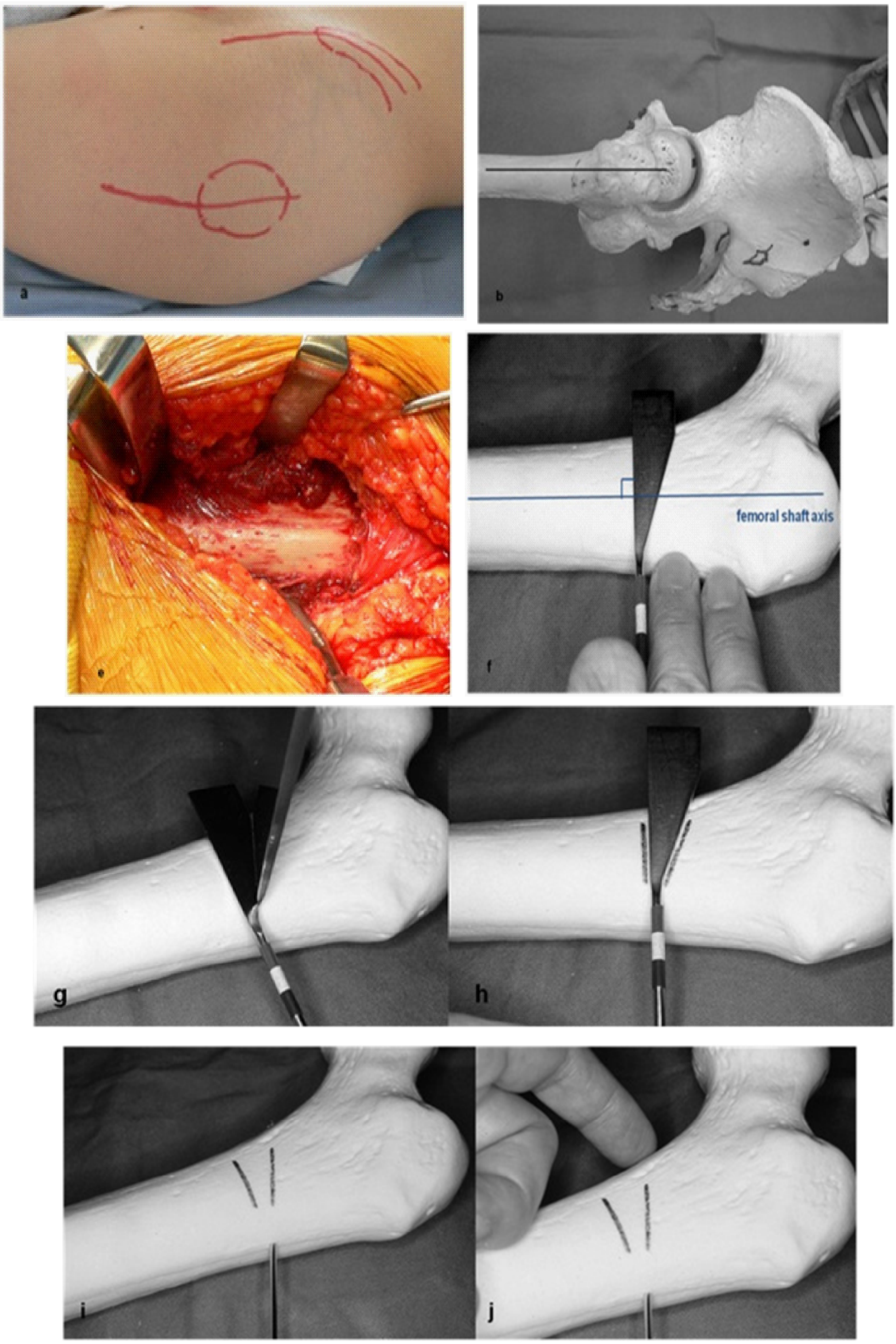


Figure 24: Lateral approach; skin incision (a,b). The vastus lateralis muscle incision was performed using the L-shaped or T-shaped approach (if the hip has contracture in external rotation).The fascia lata was incised longitudinally (c).The vastus lateralis is incised with the L-shaped approach (d) when hip internal rotation is sufficient. The L-shaped approach sometimes jeopardizes vessels and the gluteus maximus tendon if a raspatorium enters too dorsally. After subperiosteal exploration (e), a varus triangular goniometer, placed at 2 Finger Breadths (**FB**) distal from the distal tip of the greater trochanter and the base of the goniometer, is placed rectangular to the axis of the femur (f) and then sealed with a flat chisel (g). The angle of osteotomy was confirmed (h). K-wire insertion at the osteotomy line (i), touching the tip of the K-wire, and checking the alignment of the lesser trochanter and tip of the wire (j). A 5.0 LCP hip plate (100º or 110º) was used for internal fixation as described later.

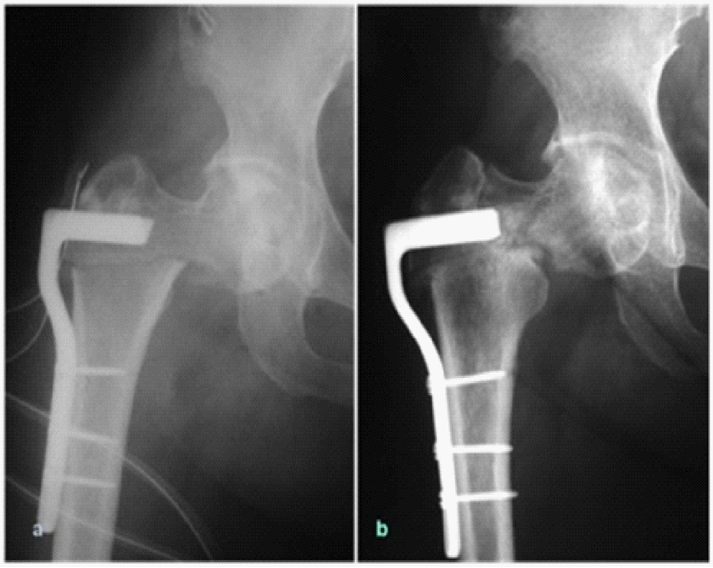


Figure 25: A 41-year-old woman. Cutting to the neck of the femur (a) resulted in a fatigue fracture at the neck 9 months after osteotomy (b).

5.4 Valgus Osteotomy

5.4.1 Radiography: In stress views (**Figure 26**), the hip in the adduction position shows the best congruity.

5.4.2 Planning: In the stress view of hip adduction, the angle between the femoral shaft and the pelvis is the osteotomy angle (α) as shown in **Figure 26a** in this condition, insufficient congruity is given, and an additional 5º of adduction is allowable (**Figure 27**).

5.4.3. Osteotomy

5.4.3.1 Adductor tenotomy

5.4.3.2 The lateral approach is the same as shown in varus osteotomy.

5.4.3.3 Release of the iliopsoas muscle tendon (described later)

5.4.3.4 Osteotomy line drawing

5.4.3.5 Osteotomy and osteosynthesis (Figure 28 and Figure 29)

5.4.3.6 The gluteus medius tenotomy (described later)

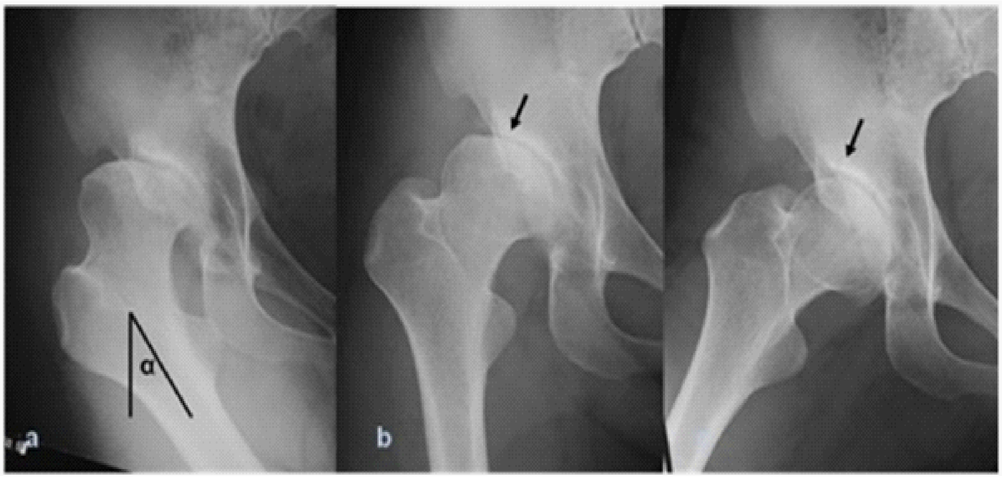


Figure 26: A 34-year-old woman. Adduction positions (a), good congruity. However, in the neutral position (b) and abduction position (c), incongruity on the lateral side was seen (arrow). α: osteotomy angle.

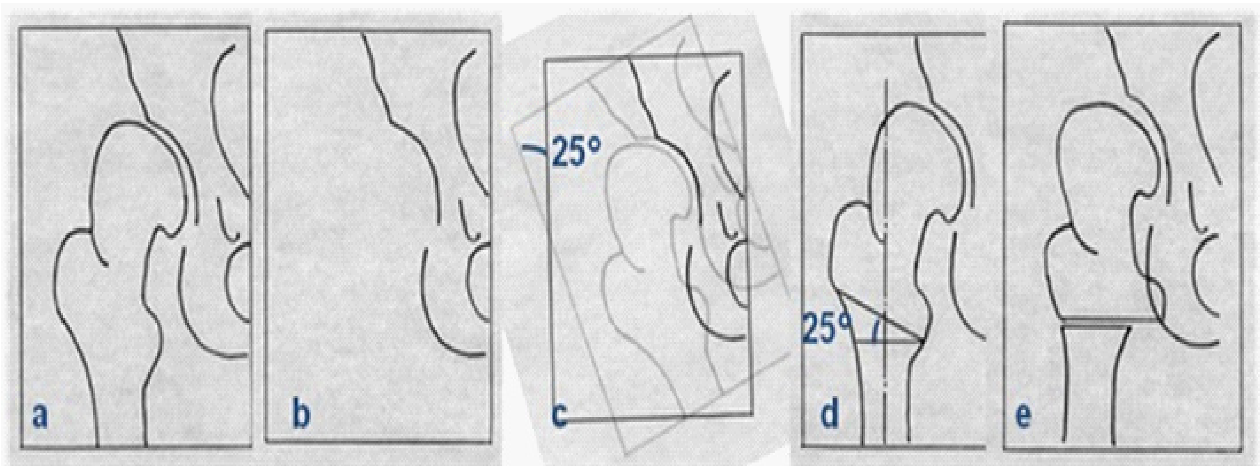


Figure 27: Planning of valgus osteotomy. Tracing X-ray film at the neutral position (a). On the second paper, tracing of only the acetabular side was done (b). The second paper was placed on the first one, and then rotated at the osteotomy angle (in this case, rotated 25º clockwise). The femoral head was traced on the second paper (c). The preoperative hip was traced on the first paper (d). At the distal end of the greater trochanter, the osteotomy line was drawn at 65º (90-25=65), crossing the femoral axis to the lesser trochanter. At the crossing point of the line and medial cortex, the line was drawn perpendicular to the femoral axis. The distal fragment (without the triangular fragment) was traced on the second paper (e).

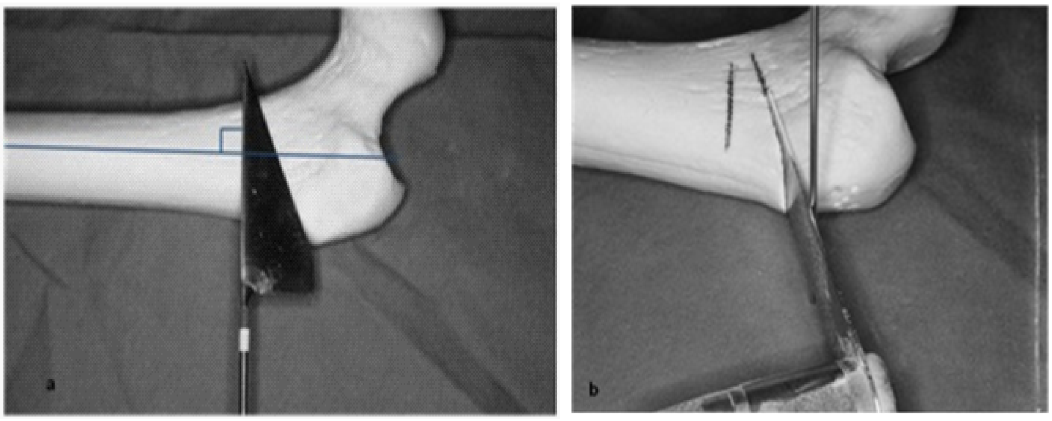


Figure 28: A triangle goniometer is applied as shown (a), the hypotenuse is placed at the distal end of the greater trochanter, and the major cathetus is rectangular to the femoral shaft axis. The osteotomy line (wedge-shape) was marked with a flat osteotome, and we checked the angle. The osteotomy angle and osteotomy direction were confirmed. The blade of the bone saw was placed perpendicularly, and the osteotomy was done with the bone saw. The osteotomy site is cooled with saline. The blade of the bone saw is perpendicular (b).

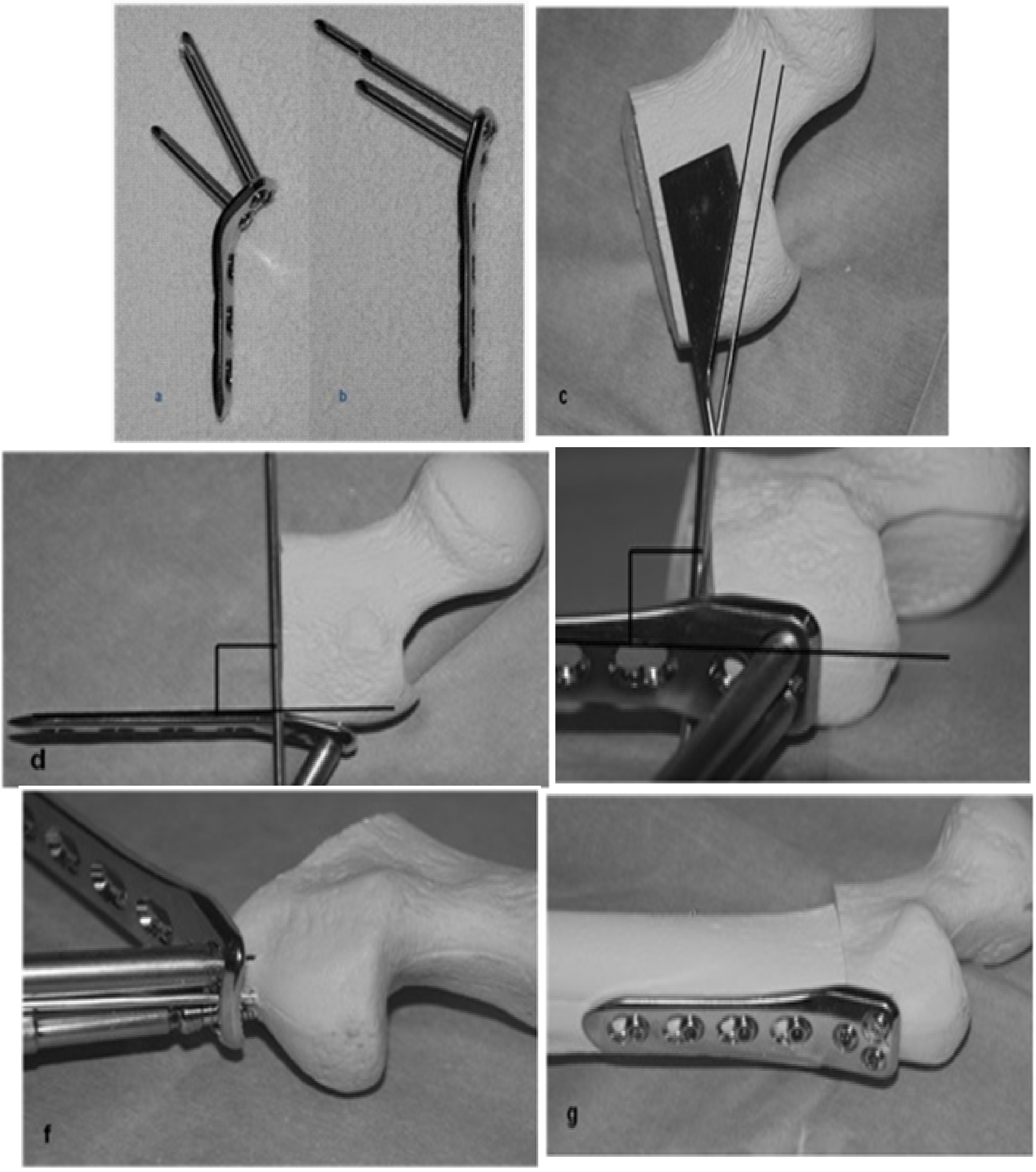


Figure 29: One FB proximal to the osteotomy plane, as mentioned in the varus osteotomy part, a 5.0 LCP pediatric hip plate for valgus osteotomy (150º (a) or 120º (b)) is applied (c). Using 120º (b) for the LCP plate, 30º of varus goniometer was applied for insertion of the locking screw (c,d). At first, a 2.0-mm K-wire was inserted proximally 30º to the horizontal plane to confirm with the image intensifier (c), despite the company instructions. Then, the drill sleeve was applied to the plate and drilled into the femoral neck (e). Then, a locking screw was applied (f). Both locking screws in the proximal holes were inserted, and the distal fragment was placed in the correct location with a bone clamp (g). Distal screws were inserted. Upon completion of osteosynthesis, the hip is moved gradually, and adduction and flexion are performed to check stability of the fixation. The safe zone is recorded. The same procedure is performed for varus osteotomy.

5.4.4 Wound closure

Same as for a varus osteotomy

5.5 Lateral Transfer of the Greater Trochanter

5.5.1 Radiography (Figure 30)

In the stress view, the hip in the neutral position shows the best congruity.

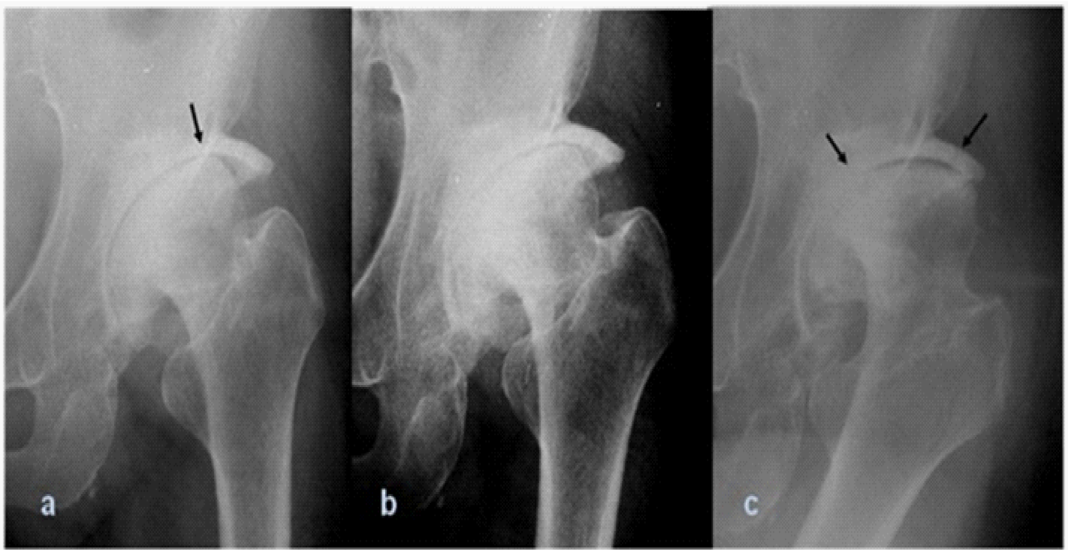


Figure 30: A 66-year-old woman. In the abduction position (a), lateral incongruity (arrow) was shown. In the neutral position (b) good congruity was shown. In the adduction position (c), medial and lateral incongruity was shown (arrows).

5.5.2 Planning (Figure 31)

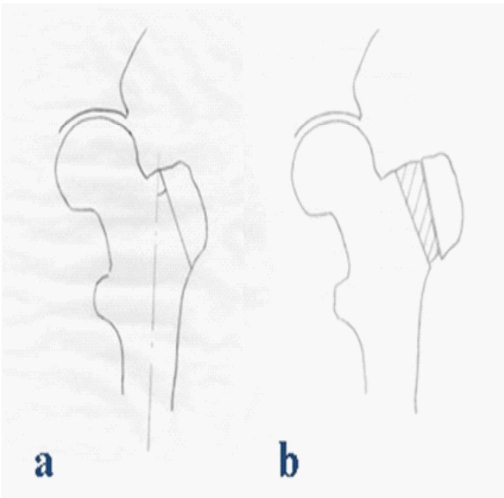


Figure 31: Planning of Maquet osteotomy. The osteotomy line for insertion of a grafted bone and the angle of the femoral axis were measured (a). The grafted bone was obtained from the iliac wing (b).

5.5.3 Operation (Figure 32)

First, the tendon of the adductor longs muscle is resected (described later). The lateral approach around the greater trochanter is performed. An AO stainless screw (**Figure 32f**) and a soft wire are used for tension band wiring (**Figure 32g**, **Figure 32h** and **Figure 32i**). If the grafted bone is placed in the wrong way, pseudoarthrosis will occur.

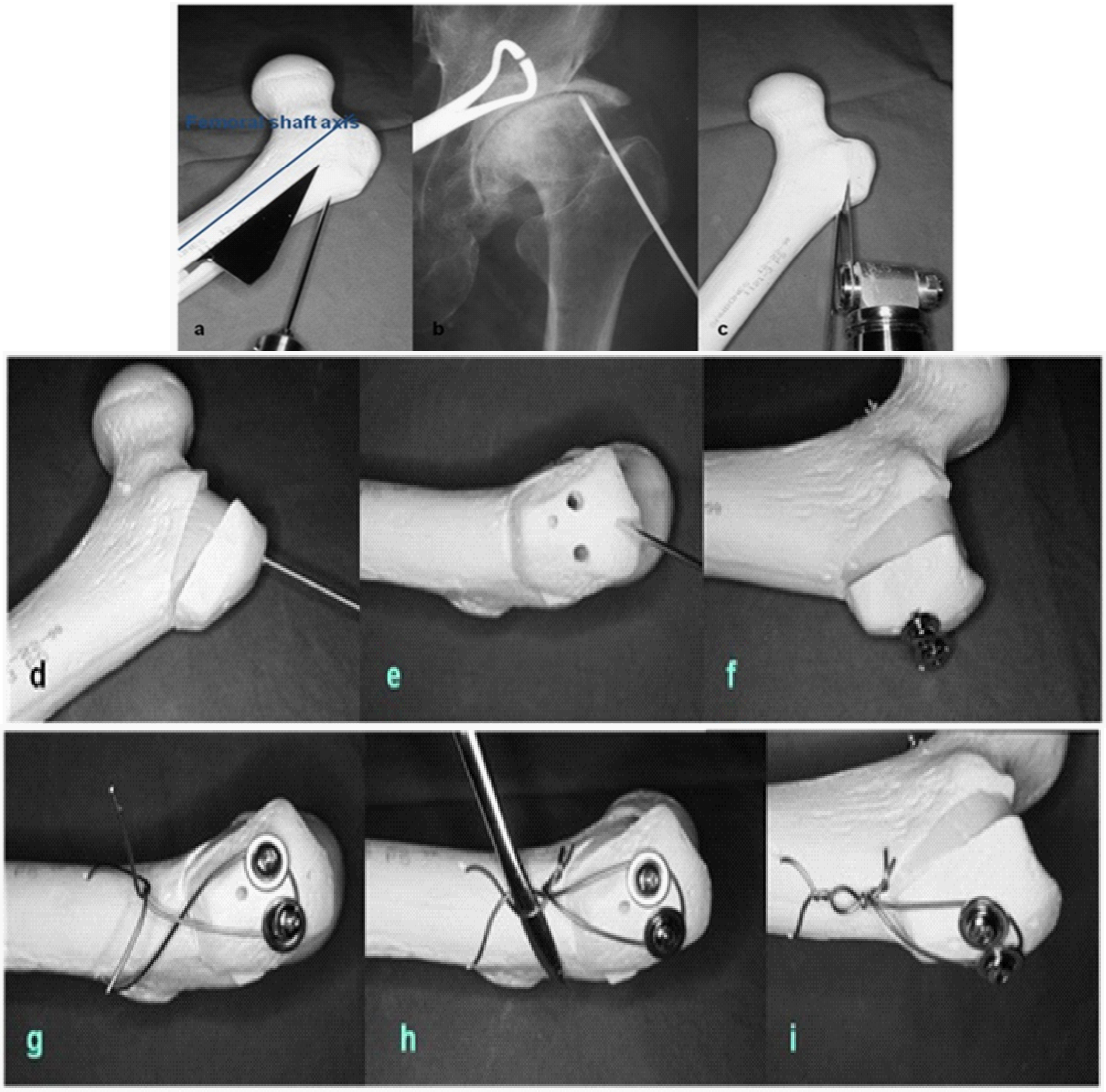


Figure 32: After a longitudinal incision is applied to the fascia lata, the vastus lateralis is transected just distal to the greater trochanter, and the femoral shaft is exposed subperiosteally. Femoral subperiosteal exposure is extended medially and distally to reach the lesser trochanter. The tendon of the iliopsoas muscle is resected at the lesser trochanter, and the greater trochanter is osteotomized. Using a triangle goniometer for valgus osteotomy, the direction of osteotomy to the greater trochanter is decided (a). A 2-mm K-wire is inserted, radiography is taken to check the direction (b), and then the greater trochanter is osteotomized perpendicularly (c). Bone grafting (d) and drilling for osteosynthesis (e) are done. The fragment of the greater trochanter is held with a towel clamp and moved laterally. Soft tissue of the proximal portion between the bone fragments is resected with an electric knife, and the greater trochanter is moved laterally. A bone graft of 3× 2 cm is obtained from the iliac wing. The graft is placed between the fragments to open the proximal greater trochanter laterally (d). For osteosynthesis, an AO cortical or cancellous bone stainless screw is inserted (f). Wire fixation (g). To enforce the fixation power, the wires were rotated together (h), and the wire fixation was completed (i).When the distal part of the greater trochanter does not contact the femoral shaft, bone union is delayed.

5.6 Combined Surgery

5.6.1 Muscle releases

5.6.1.1 The adductor longs (Figure 33)

This method is indicated for OA and for adduction contracture of a dysplastic hip.

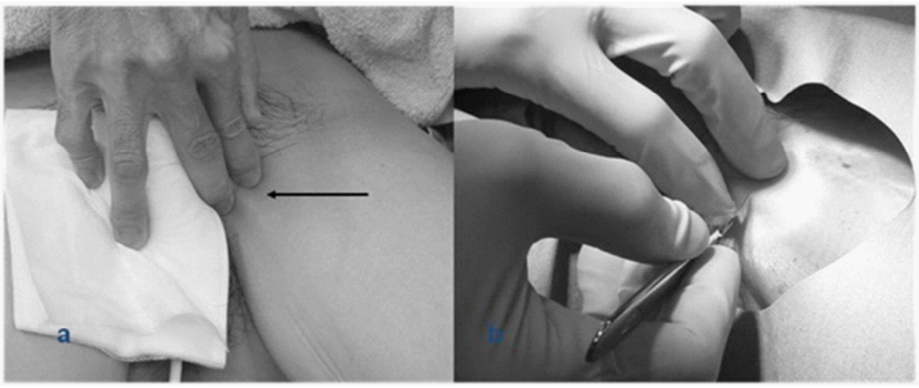


Figure 33: The Adductor longus tendon resection. Keeping the hip in the maximal abduction position, the adductor longus tendon, a tensile band is held with the index and middle fingers at the pubic bone (a), and the tendon is resected with a sickle-shaped knife (#12) (b).

5.6.1.2 The iliopsoas muscle (Figure 34)

This is for OA.

Figure 34: For the iliopsoas muscle tendon resection, the vastus lateralis muscle was exposed subperiosteally with the left index and middle fingers, touching the tendon insertion, and the tendon was then resected at the lesser trochanter. The soft tissue was retracted medially with two fingers while rotating the hip externally. At the lesser trochanter, the tendon is transected with curved scissors without direct vision. After complete release of the tendon, all parts of the lesser trochanter are palpable.

5.6.1.3 The gluteus medius muscle

For simple valgus osteotomy, the greater trochanter is placed downward. The gluteus medius muscle is pulled down, and the muscle tension is increased. The abduction part tendon of the gluteus medius muscle is transected just proximal to the greater trochanter (**Figure 35**). For a combined anterior approach (acetabuloplasty etc.), the origin of the gluteus medius muscle is subperiosteally released, and this procedure is not applicable.

Figure 35: Tenotomy of the gluteus medius muscle. For a left hip operation, the right-hand is cranial, and the tendon to be resected for the Abductor Part (**Abd**) was lifted with an elevator. IR: Muscle for internal rotation.

5.6.2 Operation for enlarged indications of osteotomy: Acetabular edge resection, acetabuloplasty, and Chiari's pelvis osteotomy are all performed by an anterior approach. First, the anterior approach will be described. An X-ray film cassette is preoperatively placed under the operative site (**Figure 36**) to take an intraoperative X-ray.

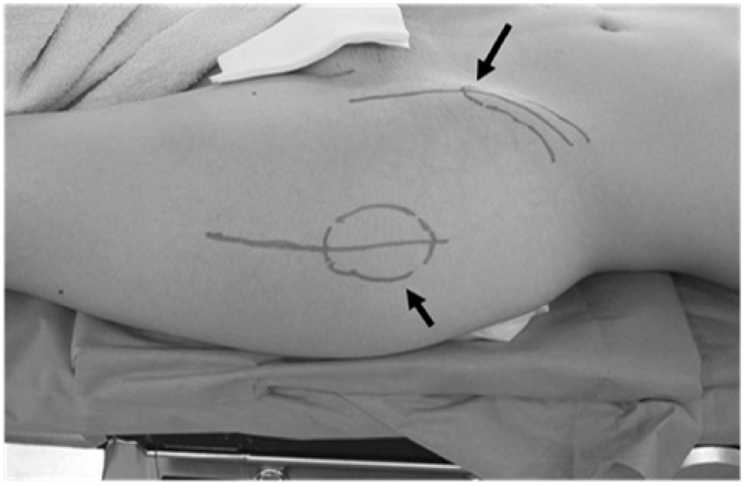


Figure 36: A film box was placed under the operated side hip. Operative position (supine), with the pelvis in the horizontal position. Skin incisions for anterior and lateral approaches are shown. Upper arrow points to the anterior superior iliac spine, and lower arrow points to the greater trochanter.

5.6.2.1 Anterior approach: The anterior approach to the hip consists of excising the tensor fascia lata muscle, the gluteus medius muscle, and other muscles subperiosteally, as well as release of the rectus femoris muscle at the origin. The procedure requires suturing of the transected muscle and re-attachment to the iliac wing. For wound stabilization, the patient needs to be on bed rest for several days. Ending bed rest too soon results in muscle activity that makes the muscle suture site stretch, causing the muscle to be pulled off from the iliac wing. The Lateral Femoral Cutaneous Nerve (**LFCN**) is across the surgical plane. Tinel-like sign and tenderness at the operative wound scar are sometimes reported [79]. Our results showed that the rate of this complaint is 30% of patients during hospitalization and after 6 months of surgery, but decreases to 20% at 1year and 15% at 1.5 years. A long-term complaint of neuritis occurs in less than 5% of patients.

5.6.2.2 Operation: Skin incision begins on the iliac crest (10 cm proximal from the Anterior Superior Iliac Spine (**ASIS**)) and extends several centimeters distally down to the mid-thigh. The LFCN is retracted medially, sharply releasing the tensor fascia lata and the gluteus medius muscle subperiosteally from the outer aspects of the iliac crest. After the above procedure, the anterior approach is accomplished (**Figure 37** and **Figure 38**).

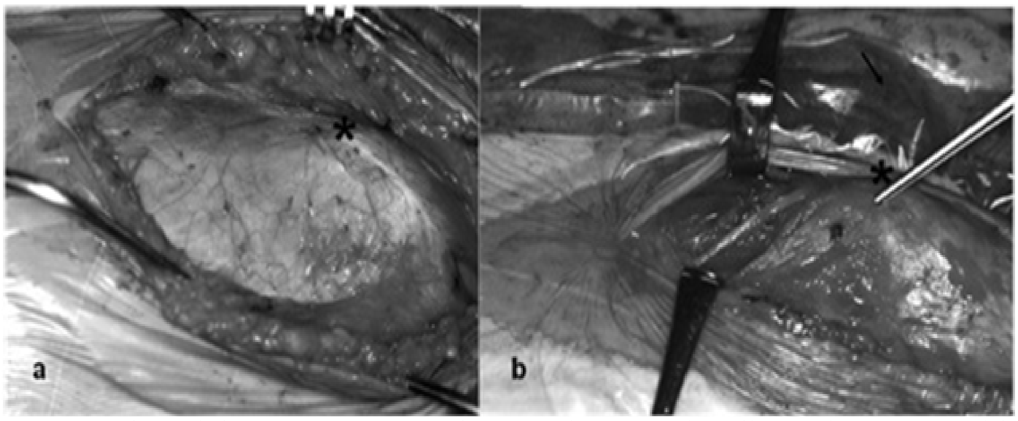


Figure 37: Exposed fascial surface (a), star: the Anterior Superior Iliac Spine (**ASIS**), identification of the Lateral Femoral Cutaneous Nerve (**LFCN**) (b), which is sometimes situated in an anomalous position. On the fascia, 1-2 cm distal to ASIS, the LFCN is across the surgical plane. The LFCN runs under the fascia. To coagulate bleeding points on the fascia without heating too deeply, the bleeding points are picked up.

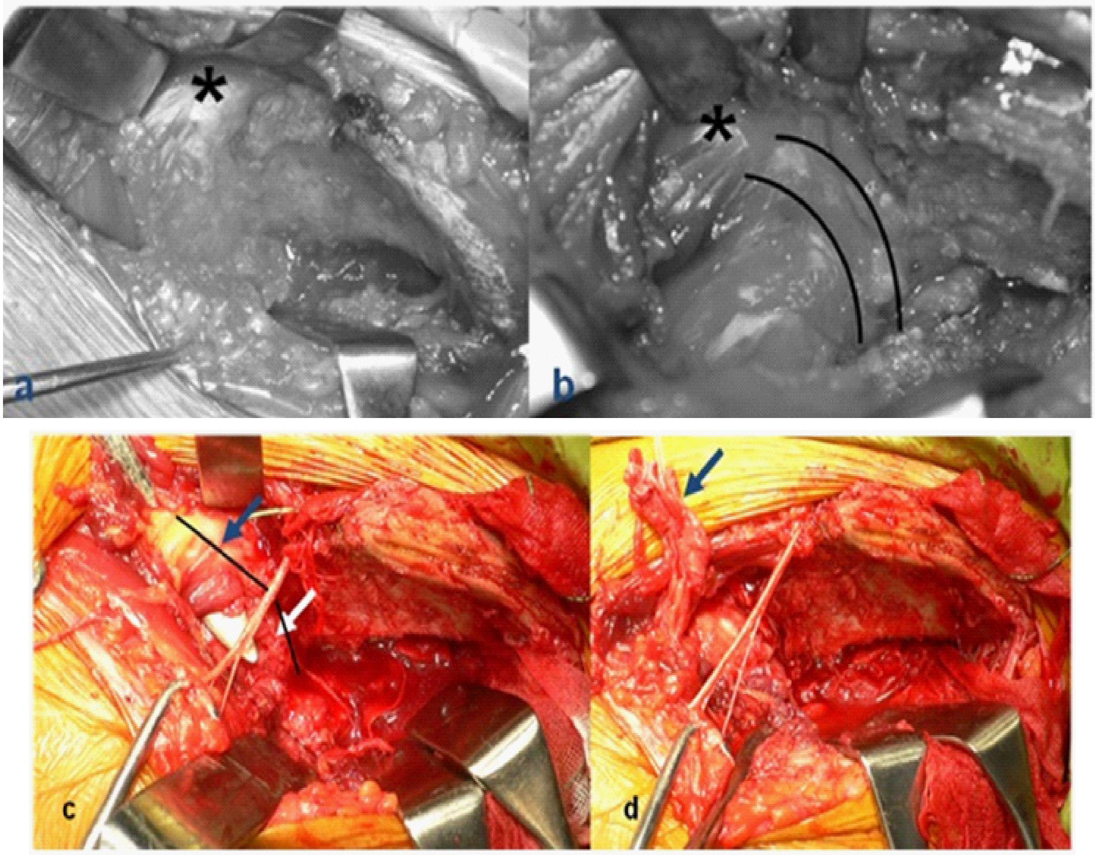


Figure 38: The medial and lateral ilium surfaces were exposed subperiosteally, and the joint capsule was exposed (a) star; the Anterior Inferior Iliac Spine (**AIIS**). The reflected head is shown by the curved line (b). Deep exposure is provided by sharp release of the sartorius origin and inguinal ligament from ASIS as a single cuff of tissue. Once the intervals between the tensor fasciae latae and the sartorius muscles are developed, fatty underlying tissue covered by a thin fascial layer is revealed. Secure the lateral circumflex vessels. Distally, approximately 10 cm from the ASIS, the ascending branches of the lateral femoral circumflex artery and vein are encountered under the thick aponeurotic fascial layer over the rectus femoris muscles. The joint capsule is exposed under the tensor fascia muscle (b). The straight head and the reflected head of the rectus femoris muscle (arrows) were exposed. Line; tenotomy line (c). The reflected head is resected subperiosteally from the iliac bone and joint capsule. Both heads are released at AIIS and transected, leaving a 3-5 mm cuff for repair and some margin for suturing (d). The distal tendon is tagged with a suture.

5.6.2.3 Wound closure: **Suction drainage is placed, and then the tissues are sutured layer by layer (Figure 39).**

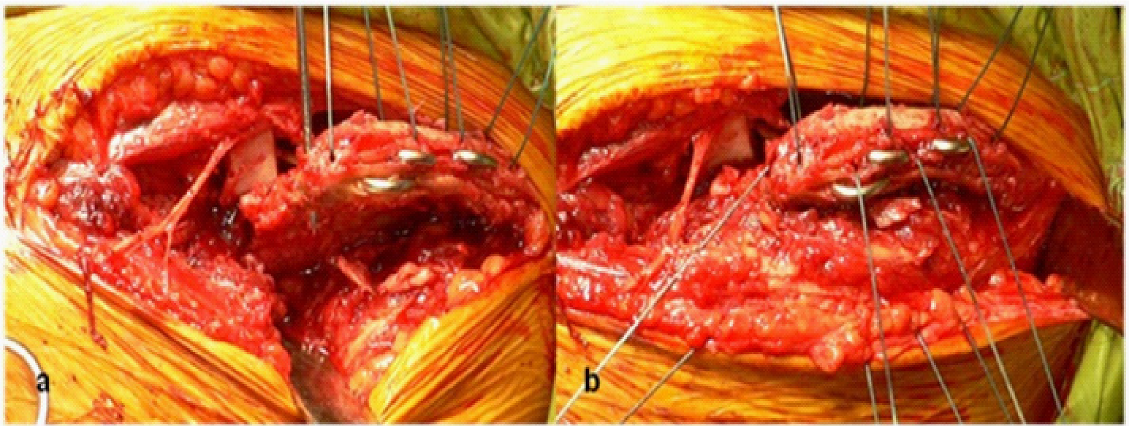
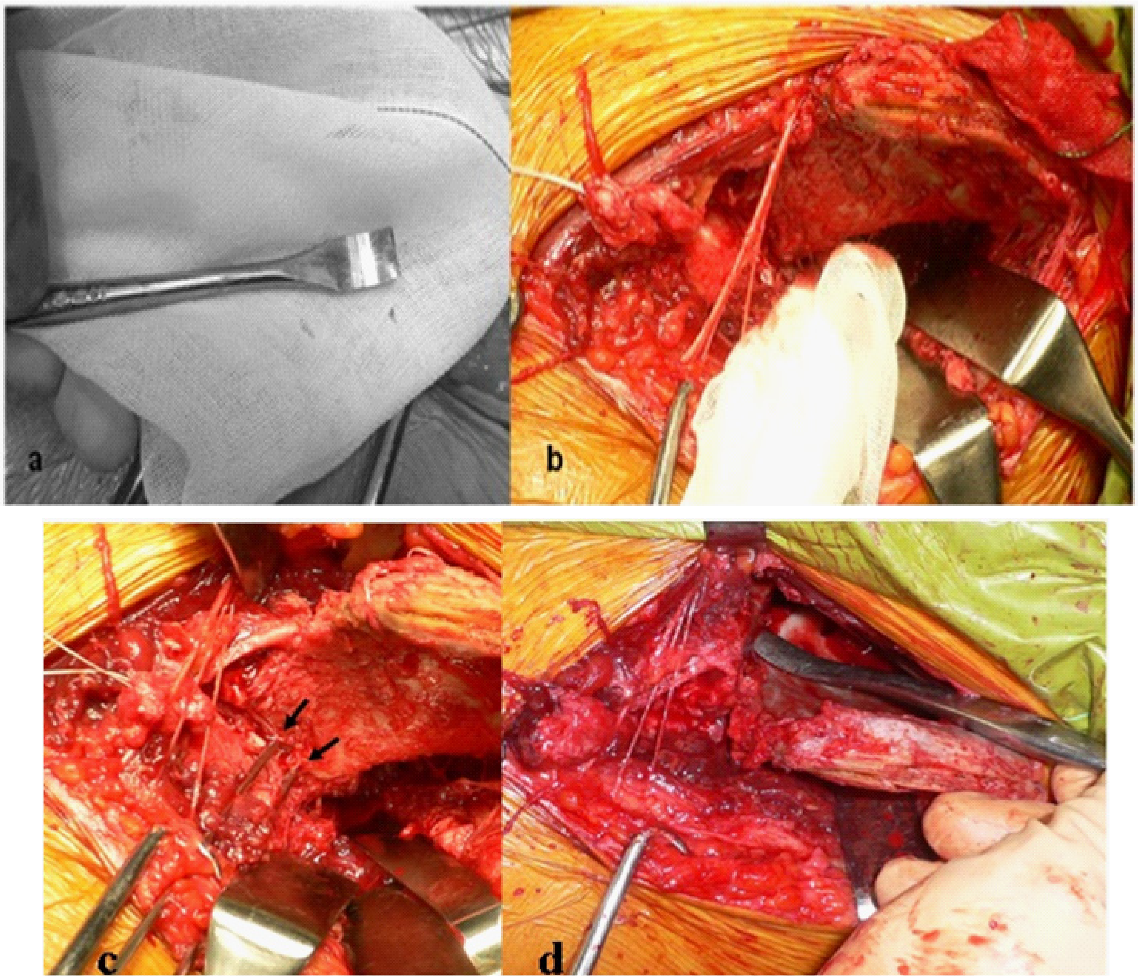


Figure 39: Reattaching the stripped periosteum and fascia to the iliac crest. Drill the iliac wing with a 2-mm K-wire and insert threads into the holes (a) (medial side). On the lateral side, threads were inserted into the drilled holes (b). At first; the direct and reflected heads of the rectus femoris are reattached to AIIS and the joint capsule. The LFCN goes through the relatively superficial muscle of the medial side, and care should be taken not to suture the nerve.

5.6.3 Chiari's pelvic osteotomy [54]: In addition to the above described anterior approach, subperiosteal exposure is extended to the greater sciatic notch as described in the legend (**Figure. 40**).



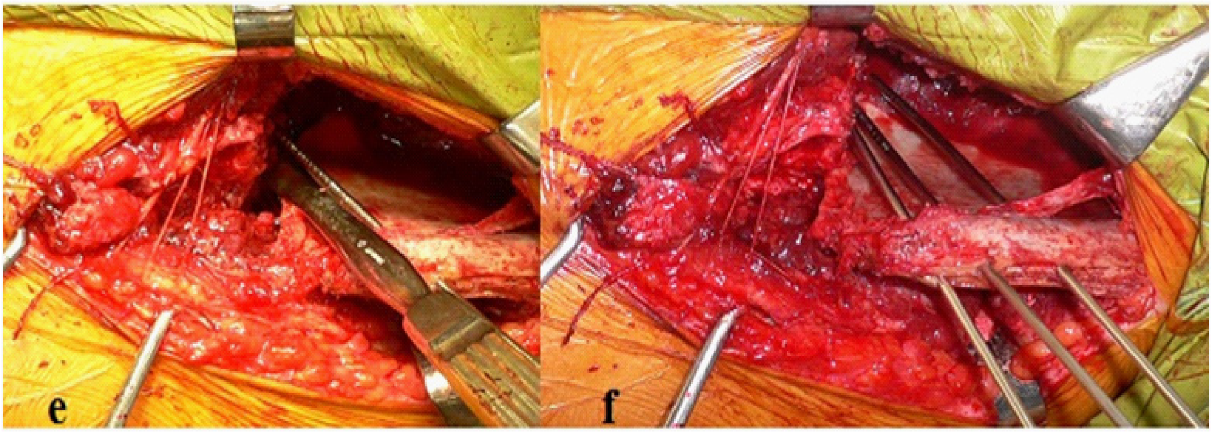


Figure 40: Using a raspatorium with gauze (a), reach the greater sciatic notch (b). At this time, a periosteal raspatorium covered with gauze is used to protect neurovascular tissue (a,b). Medial retraction in the distal portion of the exposure must be carefully undertaken, because sustained retraction or pronounced medial displacement of the iliopsoas places the femoral nerve at some risk of neuropraxic injury. An innominate bone retractor or a Hohmann retractor is placed subperiosteally to protect soft tissue. Using an innominate retractor, the pelvis is subperiosteally retracted sufficiently. The osteotomy line was confirmed with one or two 2-mm K-wires, which are then driven into the pelvis from the upper most border of the capsule superomedially at an angle of approximately 15 degrees from the horizontal (c) and do not reach the sacroiliac joint. An X-ray is taken to verify the level and angle of the osteotomy. The pelvis is osteotomized to the inner table parallel to the guide wire using a Turk saw or flat 3- to 4-cm chisel. The distal fragment is displaced medially by an elevator (lever principal). The displacement can be facilitated by an elevator inserted to the osteotomy plane (d). This instrument can be used quite effectively to move the distal fragment medially using the mechanism of a first-class lever; the fulcrum is the proximal fragment edge. The distal fragment is displaced almost 100%, and the lateral distal fragment is attached to the medial proximal fragment a little. More than 90% displacement was necessary and was fixed with a 2.4-mm K-wire (e). However, actually, the AP view of the hip X-ray shows about 50% migration. Two to three wires are recommended, and stability during flexion and abduction movement (f) is confirmed. When an anterior V-shape osseous gap between the fragments is present over the femoral head, a bone graft (resected bone from the femoral osteotomy) is added.

5.6.4 Acetabular edge resection [80]: The anterior approach is taken. After resection of the tendon of the rectus femoris (**Figure 41a**), the congruity of the hip is confirmed in the AP view of the hip as in the osteotomy angle. The hip is abducted (in varus osteotomy) or adducted (in valgus osteotomy) (**Figure 42**). During shaving, the out-coming limbus is removed. The reflected head of the rectus femoris muscle tendon is sutured to the opened joint capsule.

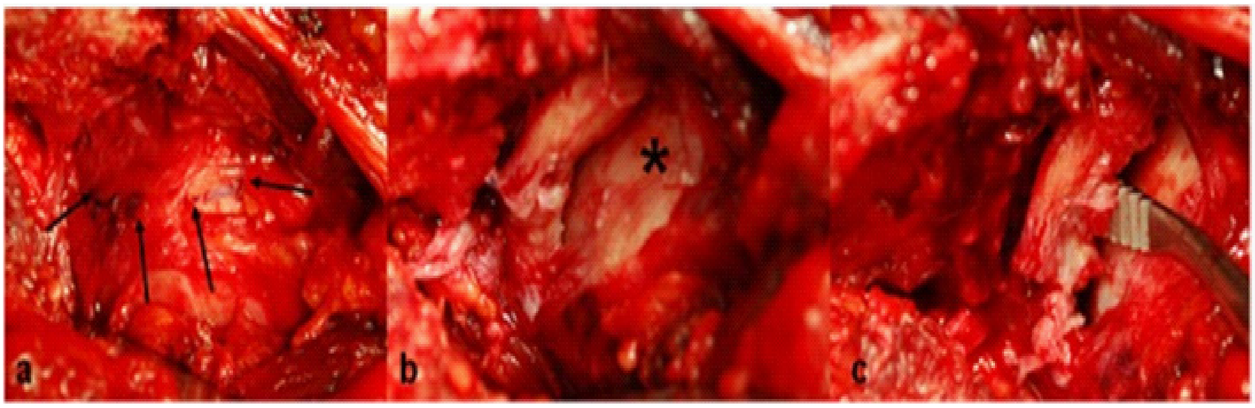


Figure 41: Capsulotomy (a) (arrow). The joint capsule is incised (3 cm long, 1cm wide). The lower extremity was pulled to confirm the joint space (b). Star: femoral head. A special bone file was used for resection of the acetabular edge (c). Pulling down the leg allows the joint space to open widely, and the acetabular edge is shaved with a file.

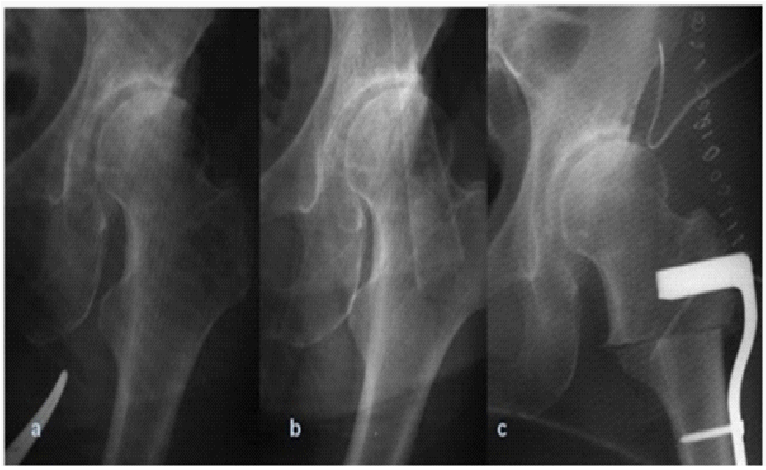


Figure 42: A 64-year-old woman. Valgus osteotomy and acetabular edge resection. Intra-operative X-ray (a) during resection (b) and immediately postoperative (c).

5.6.5 Acetabuloplasty (Lance-Spitzy method): Lately, we have adopted the Lance-Spitzy [63] method, which is a change from the Spitzy method [64]. On the lateral cortex of the ilium, several distally based flaps (0.5 × 2cm) are made (**Figure 43a**). Just proximal to the joint line, a rectangular base is fractured and placed on the joint capsule, and a slot for the new shelf 2 cm deep with an inlet of 1 × 3 cm is made using osteotomies and small curettes (**Figure 43b**). Then, according to the Spitzy method, bone grafting is performed (**Figure 43c**).

Figure 43: Lance-Spitzy method. The outer iliac cortex was cut, and the position was confirmed with a K-wire and X-ray (a). The outer cortex was fractured and placed on the capsule (b). A gutter was made on the ilium to insert the grafted bone (c). A bone fragment from the ilium was inserted in the gutter and supported the fractured outer cortex.

5.7. Rehabilitation

5.7.1 Preoperative care

5.7.1.1 Long-term care: No accelerating agents for articular cartilage regeneration are available at this time. Six months of bilateral crutch gait and another 6 months of unilateral crutch gait are mandatory (**Table 16**). Bilateral sound upper limbs and a contralateral sound lower limb are necessary. Patients with bilateral hip arthritis require special consideration (described above).

5.7.1.2 Bilateral crutch gait: To recover articular cartilage, patients should be in a bilateral crutch gait with touch-down weighting for 6 months. For varus osteotomy with the hip restoring articular cartilage, a double crutch gait is required before bone union. The reason for the requirement for touch-down gait is a need for the least force on the hip joint with the least muscle activity at touch-down walking on the total plantar surface. A non-weight-bearing gait with double crutches is required in which the patient holds the operated leg above the floor, if sufficient muscle activity to hold the leg off the floor is available. This increases the resultant force on the hip to some extent. For the above reason, touching the floor on the plantar surface with the operated side is recommended.

5.7.1.3 Preoperative skin traction: The preoperative range of hip motion is sometimes severely restricted in advanced and terminal stages of OA. Muscle spasms around the hip joint caused by inflammation restrict hip range of motion and induce hip pain. Bed rest and 1-2 kg of skin traction applied to the leg for 1-2weeks improves the range of hip motion (**Figure 44b**). When hip flexion is less than 60º, this traction is applied to determine an osteotomy indication.

5.7.2 Postoperative care: The aim of postoperative care [81] is shown in **Table 16**.

5.7.2.1 Immediate postoperative period to 1 week postoperative: Skin traction of 1-2 kg for 2weeks is applied. The operated limb is positioned in abduction for valgus osteotomy and in slight abduction for varus osteotomy. To protect the peroneal nerve, a rolled towel is placed under the popliteal fossa to elevate the fibular head (**Figure 44a**). The operated leg is not elevated to avoid hip flexion contracture. To prevent VTE, abdominal breathing and calf pumping are encouraged. A calf or foot pump and an elastic stocking to prevent VTE are also applied. After removal of the epidural tube, medication for preventing VTE is started. No active movement is allowed before bone union. At 3 days postoperative, pulley exercise starts (assist passive self-exercise) (**Figure 44b**). The long leg sits on the bed, and the operated leg is not raised to allow hip flexion with a pulley exercise. That is, when hip flexion becomes 40º with the pulley exercise, the long leg sitting on the bed should also be 40º by elevation of the head of the Gatch bed. At postoperative day 7, hip flexion should be 60º or the same as preoperative flexion. Before starting the bilateral crutch gait, patients are taught how to transition from supine to short sitting and standing. The hip with varus osteotomy usually has enough range of motion (hip flexion and adduction) to sit in a wheelchair. Sitting in a wheelchair decreases circulation in the lower limbs. Active ankle motion is encouraged to facilitate lower limb venous flow. Wheelchair sitting tends to adduct the hip position, and when transferring to or from a wheelchair, forced extensive hip flexion and adduction occur. The hip with valgus osteotomy may allow a little flexion and no adduction postoperatively. Wheelchair sitting requires the patient to be careful to not adduct the hip. The patient may touch the ground on the plantar foot with bilateral crutch gait, with weight bearing of 10-15% of body weight placed on the operated leg. No muscle exercise around the hip is recommended. The operated leg is supported by the upper limbs (**Table 17**).

Table 16: Postoperative rehabilitation aims and methods.

Aim	Methods
Maintaining preoperative hip flexion	pulley exercise
Prevention of flexion contracture	no raising of the operative leg prone position restricted sitting time
Prevention of over-flexion or adduction	prevention of stress on the osteosynthesis site
Cartilage regeneration: 1) Reduction of resultant force 2) Facilitation of cartilage regeneration	no exercise for the muscle around the hip bilateral crutch gait long-term partial weight bearing

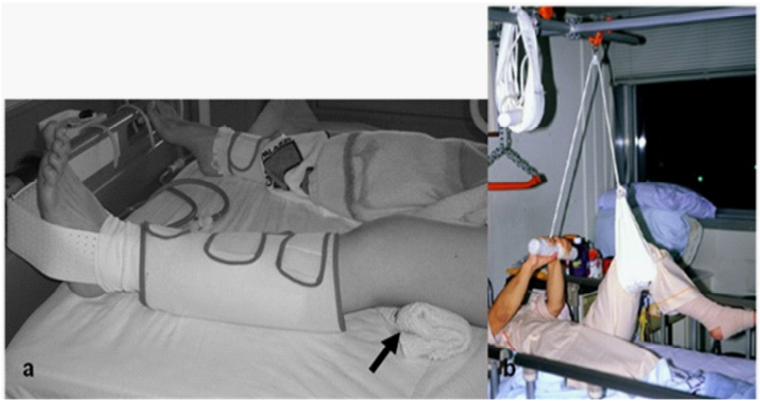


Figure 44: Postoperative skin traction (a) and protecting the peroneal nerve (arrow). Assist passive exercise with a pulley to reach the preoperative flexion angle. For valgus osteotomy patients, maintain the abduction position (b).

Table 17: Immediate postoperative period to 1week postoperative.

Bed rest
Skin traction
Prophylaxis of deep vein thrombosis: calf muscle pumping, abdominal respiration, elastic stocking or bandage (thigh to foot), air massage, medication (low molecular weight heparin or Xa inhibitor), epidural tubing
Lateral decubitus position using an abduction table or a large pillow
Pulley exercise
From bed side to side sitting and standing position without weight bearing
Refrain from muscle exercise

5.7.2.2 Two to three weeks and several months after surgery: Before bone union, in the lateral decubitus and supine position, patients should keep their hip in abduction. Hip flexion should become the preoperative flexion value. No muscle exercise is encouraged. The prone position prevents hip flexion contracture. The Thomas test can check for flexion contracture of the operated hip. If flexion contracture is found, extension exercise is recommended. Abduction should become as same as the intraoperative safe zone (**Table 18**).

Table 18: Two to 3 weeks after surgery to 1 year.

Periods	Rehab
Before bone union	Activities of daily living exercise Maintain abduction position Hip flexion, abduction ex., hip extension to be 0º Prone position and knee flexion ex. Refrain from muscle ex.
Bone union to 6months postoperative	Sit square and knee folding ex. Prone position and hip extension ex. Touch down for operated leg
After 6 months postoperative	One crutch gait Prone position Refrain from muscle ex.

5.7.2.3 After bone union: short-leg position exercise and self-roll over are allowed. Prone position to prevent flexion contracture is recommended, and the operated leg should be touch-down weight bearing. If the joint-space opening is enough (more than 2 mm) 20% weight bearing is started at 5-6 months, and weight bearing increments of 10% for 2-4 weeks is recommended. One crutch gait is started 6-7 months after surgery. Driving a car is allowed.

5.7.2.4 Six months after surgery and later: one crutch gait is encouraged for another 6 months. A prone position prevents hip flexion contracture caused by sitting for a long time. No muscle exercise around the hip joint is allowed. Patients should be checked at an outpatient clinic every month for range of motion of the hip and joint space with X-ray. Sedentary and light work is allowed.

6. Results of the Surgeries

6.1 Results of Joint-Preserving Operations for Advanced and Late Stages of Coxarthritis

In Kagawa Medical School, Osaka Teishin Hospital, and Osaka Rosai Hospital, we treated 136 hips with advanced and terminal stages of coxarthritis and 76 hips with the terminal stage of coxarthritis is [32-34] and followed up the patients for a long-term period. According to Bombelli's classification of the biologic response to OA of the hip ([65], **Table 19**), the atrophic type (**Figure 45a**) showed poor prognosis [47, 67]. We divided the hips into two groups: atrophic type and non-atrophic type (**Figure 45b**). The end point was defined as the-time after surgery at which the joint-space width of the weight-bearing segment became less than 1mm, and then Kaplan-Meier survivorship was assessed (**Figure 46**). Surgically treated hips with terminal stage OA were followed in 81% of hips (56 out of 76 hips). Preoperative and final Harris hip scores are shown in **Table 20**. For analysis with Cox's proportional hazard model [82], prognostic factors for joint space re-narrowing (less than 1 mm, recurrence of OA) were 1. Atrophic type, 2. Insufficient joint space widening 1 year after surgery. 3. Small amount of preoperative hip flexion. However, other radiological and clinical parameters had no relation to recurrence of OA. Defining the endpoint as recurrence of OA, Kaplan-Meier survivorship analysis [45] of the non-atrophic type showed that joint space was maintained after 10 years in 80%, after 15 years in 60%, and after 20 years in 20% of hips (**Figure 46**). A prognostic factor for recurrence of OA was the atrophic type. Long-term preservation of the joint space was expected for non-atrophic hips and postoperative complete joint congruity.

Table 19: Biologic responses according to Bombelli's classification.

Atrophic: no osteophyte formation, clear bone atrophy, slight subchondral sclerosis, mainly subchondral cyst formation
Non-atrophic: **Normotrophic:** intermediate manifestation between atrophic and hypertrophic types **Hypertrophic:** extensive osteophyte formation and strong subchondral sclerosis

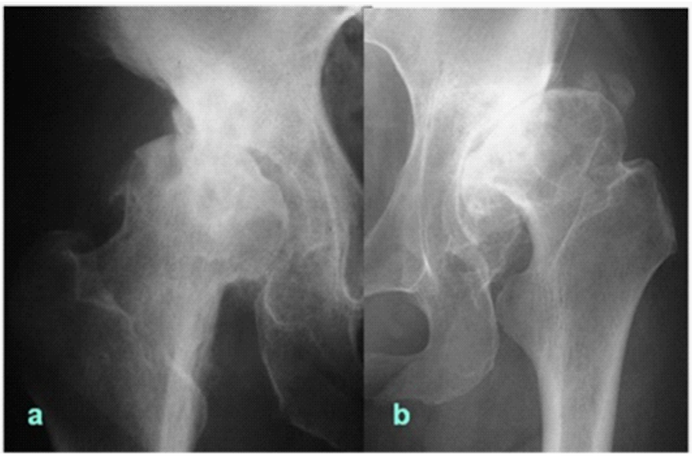


Figure 45: The hip was classified as the atrophic type (a), and a small amount of osteophyte formation and osteosclerosis were seen. Pseudocyst formation is clear. Non-atrophic type (b). Heavy osteophyte formation and dense sclerosis were seen.

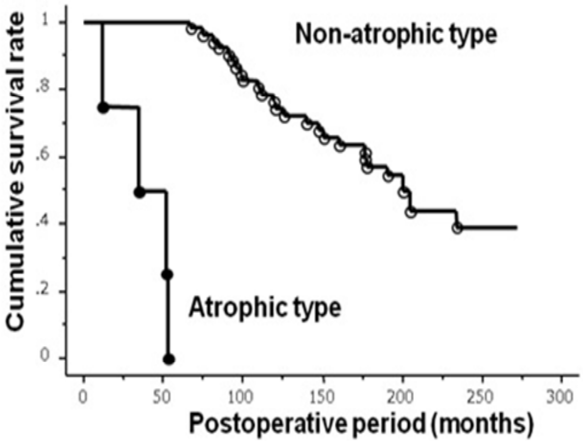


Figure 46: The result of valgus osteotomy for the terminal stage of osteoarthritis of the hip (Kaplan-Meier survivorship curve). In the atrophic type of hip, the postoperative joint space narrows rapidly. However, 40% of non-atrophic type hips maintained the space for 20 years. Adopted from [34].

Table 20: The results of valgus osteotomy for terminal-stage osteoarthritis of the hip (preoperative and final follow-up data). Adopted from [32].

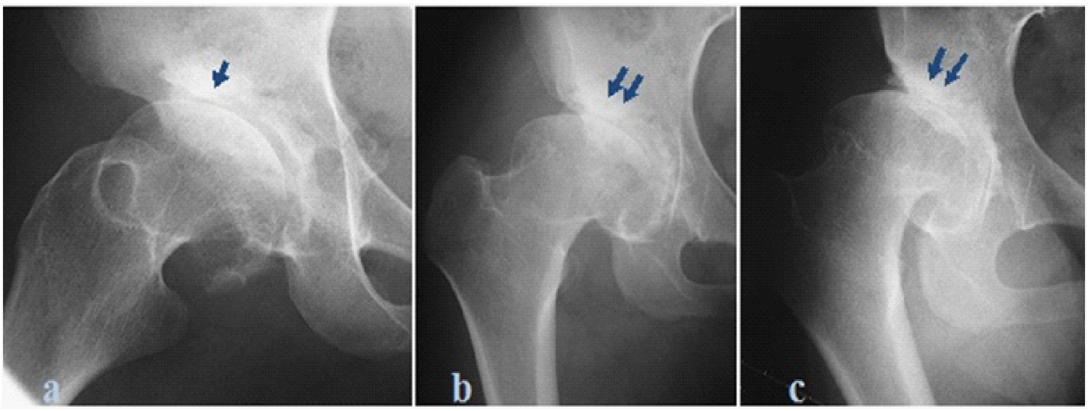
Harris Hip Score	Preop	Final (298 months in average)
Pain*	16	34
ROM	7.0	11.2
Gait*	13.6	20.5
ADL	6.5	11.1
Total*	48.3	72.8
Flex*	80.0	65.0
Abd*	12.4	20.3

Abbreviations: *p<0.01, **ADL**: Activities of Daily Living, **Total**: Harris Hip score, **Flx**: hip flexion, **Abd**: hip abduction (a) and distribution of Harris Hip score (b).

7. Case Studies

7.1 Case2. A 28-Year-Old Woman.

She complained of right hip pain, showing almost the terminal stage of OA (**Figure 47a**, **Figure 47b** and **Figure 47c**). The preoperative JOA hip score is shown in **Table 21**. Even though she was a young adult, THA would be recommended, or she would be prescribed NSAIDs and followed for years. However, the latter approach would cause her to lose a good opportunity for a joint-preserving operation. With an X-ray study, her hip in the AP view showed acetabular dysplasia (**Figure 47b**). In a dynamic view in abduction (**Figure 47a**), the hip showed better congruity in abduction than in adduction (**Figure 47c**). I recommended varus osteotomy combined with acetabular edge resection to create good congruity and acetabuloplasty for acetabular dysplasia (**Figure 47d**). The joint space opened in the 7th month postoperatively (**Figure 47e**) and was maintained for 99 months (**Figure 47f**). Her JOA score showed good results (**Table 22**), and she felt no pain during pregnancy and childbirth.



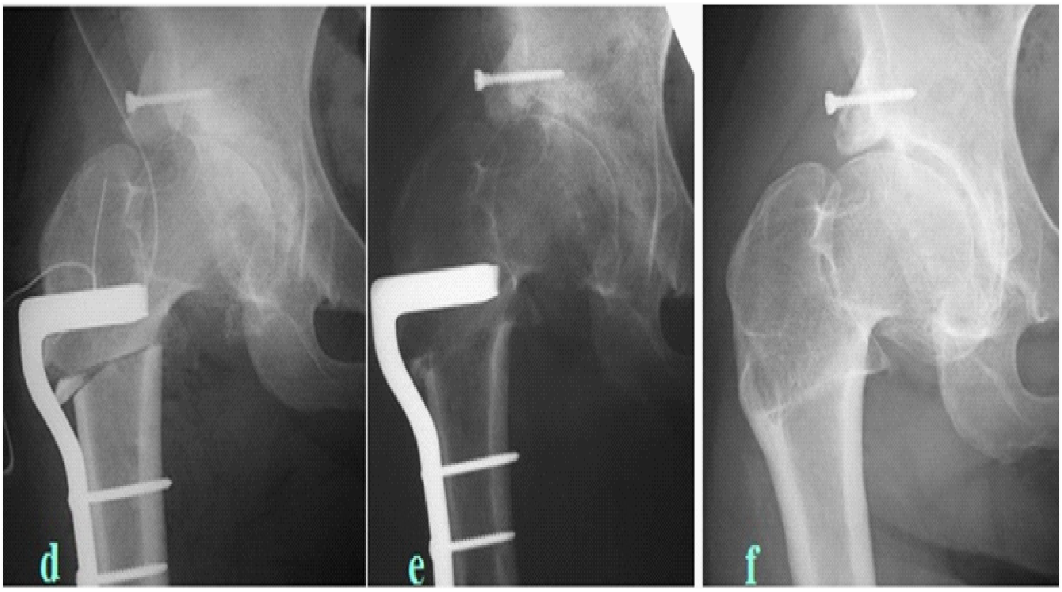


Figure 47: Case2. A 28-year-old woman. Preoperative radiograph: abduction position (a), neutral position (b), and adduction position (c). Arrow: incongruity. Immediate postoperative X-ray (d), 7 months postoperative (e), and 99 months postoperative (f).

Table 21: Case2. A 28-year-old woman, right hip OA.

JOA	Preop	Postop 99 months
Pain	20	40
ROM	14	15
Gait	10	18
ADL	18	20
Sum	62	93
ROM Flex/Ext	90/−5	90/0
Abd/Add	30/15	30/20

7.2 Case 3. A 54-Year-Old Woman with Bilateral Hip OA.

This patient underwent bilateral operations at an interval of 14 months. In the neutral position (the CE angle of the right hip was 0º, and the left was –5º. The VCA angle was 0º in the right (**Figure 48b**) and –5º in the left (**Figure 48c**). She was diagnosed with bilateral severe dysplastic hips. In a stress view of the left hip in the neutral position (**Figure 48e**) and in abduction (**Figure 48f**), both views showed incongruous joints. In adduction (**Figure 48d**), the joint space of part of the hip joint opened, and we recommended valgus osteotomy. In Chiari's pelvic osteotomy, an osteotomy line crossing the femoral head was made (**Figure 48g**), and pelvic osteotomy followed femoral osteotomy (**Figure 48h**). One year after surgery, a good congruous joint was seen (**Figure 48i**), and contralateral side osteotomy was performed. Similar to the left hip, the right hip was operated. The latest X-ray shows a good joint space (**Figure 48j**) and sufficient anterior coverage in faux-profil X-ray (**Figure 48k** and **Figure 48l**). No pain is reported (**Table 22**).

Table 22: Case3. A 54-year-old woman, bilateral hip OA.

Left hip

JOA	Preop	Postop 28 months
Pain	10	40
ROM	5	9
Gait	10	18
ADL	10	20
Sum	35	87
ROM Flex/Ext	60/-10	55/0
Abd/Add	5/30	20/10

Right hip

JOA	Preop	Postop 28 months
Pain	20	40
ROM	6	10
Gait	10	18
ADL	16	20
Sum	52	88
ROM Flex/Ext	65/10	60/0
Abd/Add	20/10	30/10

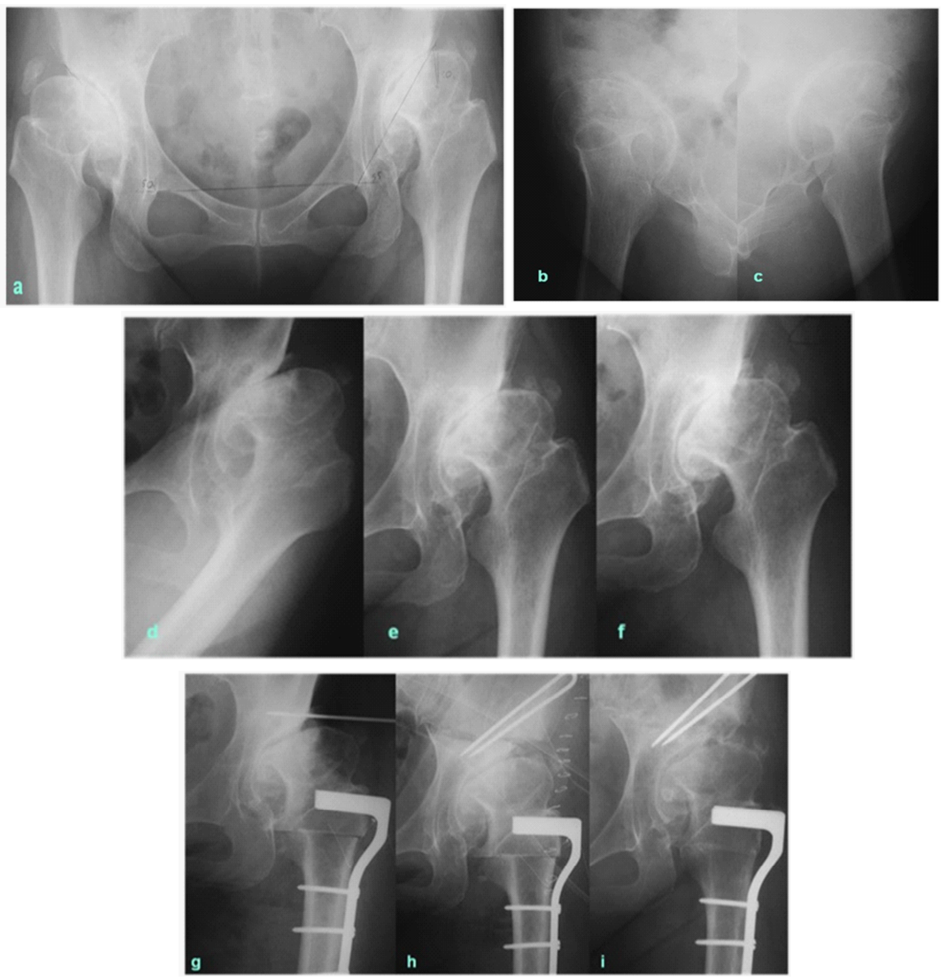


Figure 48: Case 3. A 54-year-old woman (a). Faux-profil of the right hip (b), VCA angle: −5º, and of the left hip (c), VCA angle:−5º. Stress views, adduction (d), neutral (e), and abduction positions (f) of the left hip. Note, adduction of the hip showed the best congruity. After valgus osteotomy, the height of Chiari's osteotomy was confirmed with a K-wire (g), after Chiari's osteotomy (h), and 1year after surgery (i). Right hip 3 years after, and left hip 4 years after surgery (j). Faux-profil of the right hip 3 years after surgery (k), VCA angle: 25º and of the left hip 4 years after surgery (l), VCA angle: 25º.

7.3 Case 4. A 53-Year-Old Woman with Right Hip OA.

A stress view showed a capital drop osteophyte abutting the acetabulum. Insufficient adduction was shown (**Figure 49c**). If the hip adducted sufficiently, it would have good congruity [83]. Neutral (**Figure 49b**), adduction, and abduction positions (**Figure 49a**) did not make the hip joint congruous. Reconstruction computed tomography clearly showed that the acetabular osteophyte and capital osteophyte were abutting each other (**Figure 49d**). The VCA angle was negative (**Figure 49e**), and Chiari's osteotomy was recommended. Using the anterior approach and opening the capsule with a T-shaped incision, the femoral head was dislocated, and the capital drop was excised. Sufficient adduction was available (**Figure 49f**), and superior incongruity was present. Then, acetabular edge resection was added (**Figure 49g**). Next, Chiari's pelvic osteotomy was performed (**Figure 49h**). Valgus osteotomy was planned and performed (**Figure 49i**). One year after surgery (**Figure 49j**), the joint space was opened, and 3 years and 6 months after surgery (**Figure 49k**), a stable joint was shown. Preoperative and final follow-up clinical results are shown in **Table 23**.The patient reported no pain, and an improved abduction angle was seen.

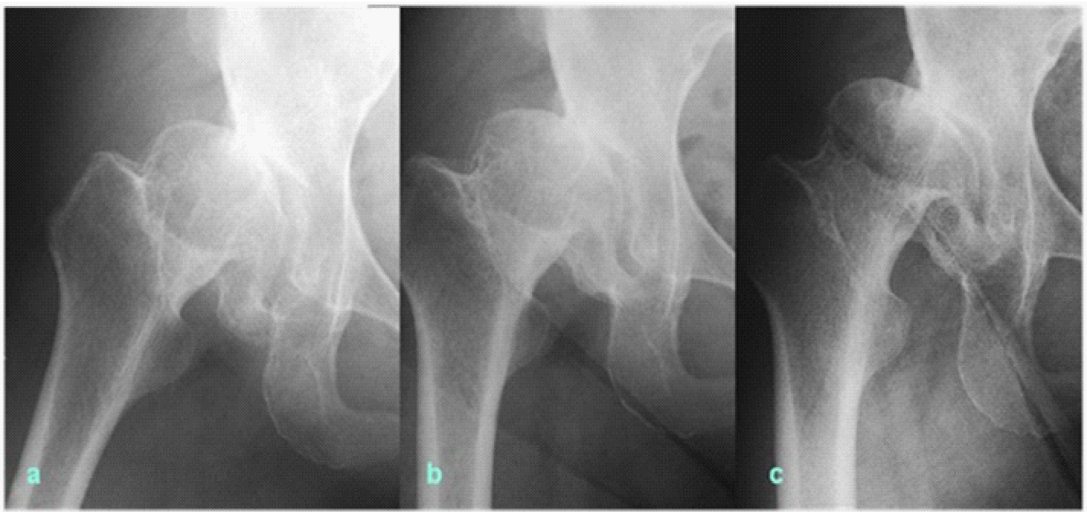


Figure 49: Case 4. A 53-year-old woman. Stress views: abduction position (a), neutral position (b), and adduction position (c). Reconstruction CT (coronal plane) (d).Faux-profil (e), VCA angle:−10º. Resection of capital drop was performed, and then, an Xray was taken in the adduction position (f). Additional resection of the acetabular edge was performed because of incongruity of the lateral acetabulum during resection of the acetabular edge (g), before Chiari's pelvic osteotomy, and also after resection of the acetabular edge (h). After Chiari's osteotomy, valgus osteotomy was performed at the angle of maximum adduction (i), 1year after surgery (j), and 3.5 years after surgery (k).

Table 23: Case 4. A 53-year-old woman, right hip OA.

JOA	Preop	Postop 55 months
Pain	20	40
ROM	9	15
Gait	10	20
ADL	18	20
Sum	57	95
ROM Flex/Ext	90/0	90/0
Abd/Add	5/15	35/20

7.4 Case 5. A 52-Year-Old Woman, Left Dislocated Hip OA Treated With Valgus Osteotomy [29].

Stress views (Figure. 50a, Figure. 50b and Figure. 50c) in the neutral position and abduction showed that the hip had incongruity. In adduction, the lateral hip joint was opened, and congruity became good. Valgus osteotomy was performed (**Figure 50d**). One year post operatively, the hip X-ray showed a good widening of the joint space (**Figure 50e**). A good joint space (**Figure 50f**) was maintained for 3.6 years. Clinical results are described in **Table 24.**

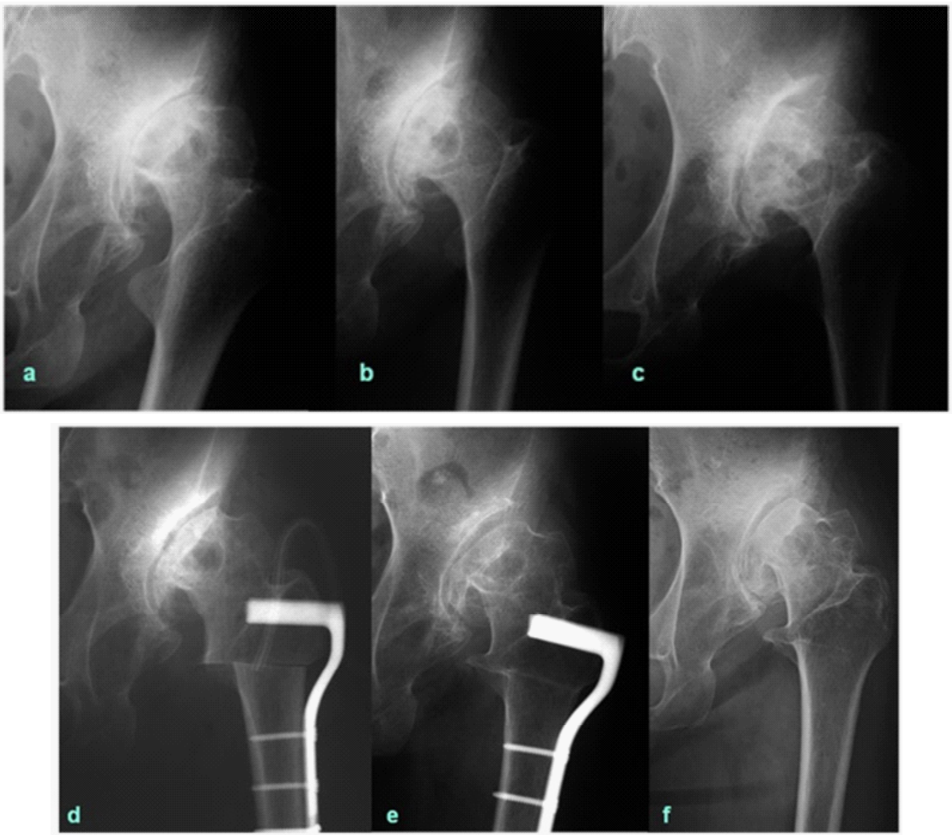


Figure 50: Case 5: A 52-year-old woman. Stress views: adduction (a), neutral (b), and abduction positions (c). Immediately after valgus osteotomy (d), 1year after surgery (e), and 164 months after surgery (f).

Table 24: Case 5. A 52-year-old woman, left hip OA.

JOA	Preop	Postop 55 months
Pain	20	40
ROM	13	15
Gait	10	18
ADL	14	16
Sum	57	89
ROM Flex/Ext	70/-0	95/0
Abd/Add	10/30	30/20

8. Conclusion

Joint-preserving operations for OA of the hip caused by a developmental dysplastic hip are not a time-saving procedure. Long-term preservation of the joint space is expected for non-atrophic hips, and complete joint congruity after surgery can be obtained.

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