Proximal femoral osteotomies (PFO) play an important role in the treatment of numerous hip disorders in children [1–3]. The indications are not limited to dislocations or subluxations in children with neurological hip diseases. Modern imaging has confirmed the arthrogenic role of morphological femoral head or head/neck disturbances such as Legg-Calve-Perthe disease (LCP), slipped capital femoral epiphysis (SCFE), development dysplasia of the hip (DDH), osteoarthritis of the hip and congenital or acquired coxa vara [4–6]. Better understanding of the pathogenesis of these entities has renewed interest in PFO to preserve the hip, and this procedure may be performed alone or associated with other intra/extrarticular procedures.

The progression and severity of hip deformities are linked to the remaining growth potential. Biomechanical changes will gradually cause joint incongruence, which causes osteoarthritis of the hip in young adults [7–10]. The effects such as a cam-effect or "hinge" in abduction and femoroacetabular "impingement" results in progressive deterioration of the labrum and the articular cartilage, which causes
instability, limits mobility, and is the source of pain, limping and early arthritis [11–14]. Intraarticular procedures can be performed using a surgical approach with or without hip dislocation [15,16] with no risk to vascularization of the femoral head. Isolated PFO is sometimes effective in achieving correct femoroacetabular ‘containment’. Associated osteochondroplasties, labrum procedures, osteotomies for acetabular realignment, or acetabuloplasties are sometimes necessary. The negative effect of femoral ‘malalignment’ is inherent to PFO is still a major problem during hip replacements in adults [17–19].

There are two types of PFO:

- varus, valgus, flexion and extension intertrochanteric osteotomies;
- simple or double osteotomies of the greater trochanter with lengthening of the femoral neck.

### Intertrochanteric osteotomies

Preoperative planning of PFO is based on clinical and imaging results. Dynamic evaluation by dynamic X-ray views associated with arthroscopy helps determine the optimal position of the femoral head in the acetabulum and define any femoroacetabular impingement. Arthro-MRI is used to evaluate the morphology of the femoral head if it is deformed, the condition of articular cartilage and the labrum [1,2,5,11–13].

The patient’s position during surgery and closure are common to all PFO. The patient is in the lateral or dorsal position. The image intensifier is placed under the table. The incision is lateral and vertical, from the tip of the greater trochanter, 8–10 cm long. The intertrochanteric osteotomy passes by the tip of the lesser trochanter, perpendicular to the femur.

### Varus or valgus osteotomies and variations

The goal is to improve centering of the hip by realigning the femoral head and neck by reducing (varus) or increasing (valgus) the femoral neck-shaft angle. The hip should be mobile in more than 90° flexion. Abduction more than 15° is necessary for varus correction and adduction more than 15° pour valgus osteotomies. Assessment of articular range of motion should be performed under general anesthesia with or without tenotomy (adductors, psoas…).

The three most frequently used systems of internal fixation are described:

- AO angled blade plate;
- AO anterior plate;
- the LCP (locked compression plate) provides primary stability by locking screws on a plate and divergence of femoral neck screws. This internal fixation is especially adapted to osteoporotic hips in patients with neurological diseases [20–24].

### Varus osteotomies

With this technique the femoral head can be realigned, contact surfaces can be modified, pressures can be reduced on the diseased areas and the glutal muscles can be relaxed. The inconveniences are femoral shortening and a trochanteric bulge.

**Osteotomy with 90° angled blade plate.** A varus osteotomy should not result in a femoral neck-shaft angle of less than 110°. It may or may not be associated with femoral derotation, which allows the use of an angled blade plate. In neurologically diseased hips, femoral shortening relaxes the muscles and the joint. Femoral anteversion is indicated with a pin (Fig. 1a). The reference for rotation (Fig. 1b) is defined by two lateral pins: one at the tip of the greater trochanter, the other below the distal part of the plate. The reference pin (Fig. 1c) for the cutting guide is inserted below the greater trochanter then into the femoral neck and centered on the coronal and sagittal planes. For 20° varus, the pin should be at an angle of 70° (90–20°) in relation to the femoral shaft. To prevent fracture or a secondary fracture line, the entry point of the blade chisel is prepared with a drill. The chisel (Fig. 1d) is advanced under fluoroscopic guidance on the frontal and sagittal views in the femoral neck axis without fracturing the growth cartilage. It is positioned in strict profile to avoid unplanned sagittal displacement during the varus osteotomy. On the coronal plane, it is at a 110° angle in relation to the femur (Figs. 2 and 3).

The intertrochanteric osteotomy which is marked by a pin perpendicular to the femoral axis (Fig. 1e) 1.5 cm under the chisel, is performed with an oscillating saw to obtain even cuts. The distal femur is translated (Fig. 2) to avoid blocking the blade plate. The plate is then moved with the proximal fragment to the lateral side of the femur causing automatic varus correction. The trochanter rests on the femur by its internal cortex, thus preventing shortening.

Varus correction with a partial or total medial cuneiform osteotomy is defined by an intertrochanteric osteotomy line and a second oblique osteotomy line from outside to inside (Fig. 1f) parallel to the chisel of the 90° blade plate. It is obtained by a closing wedge osteotomy. There is a risk of limb shortening.

Derotation of the distal fragment can be performed. Screwing the plate stabilizes reduction. Interfragmentary screws (Fig. 13) strengthen fixation, preventing uncomfortable immobilization.

![Figure 1](image-url) Automatic varus osteotomy with a 90° angled blade plate.
Passive mobilization of the hip begins in the first weeks after surgery and weight-bearing on crutches 6 weeks post-operatively. Immobilization in a hip spica cast is limited to children with neurological hip diseases.

Immediate complications are frequent in children with neurological diseases, due to bone fragility (primary instability due to a wrong direction or movement of the blade in the neck of the femur, broken material with secondary displacement).

Secondary complications include: delayed union, non-union, fractures under the plate and periarticular osteophytes. These ossifications result in bone bridges which may cause severe stiffness and deformities.

Later complications are mainly malunion. Avascular necrosis of the femoral head may develop following a vascular injury, if a wrong direction is taken posteriorly, or from varus overcorrection.
**Locking Plate (LCP) Osteotomy.** Two techniques are possible: the first, the simplest, is a fixed angle technique, obtained with the plate by placing the guide wire then the two proximal screws parallel to the axis of the femoral neck. The angle can be calculated with the second technique: specific instruments are used to determine the position of the two proximal screws depending on the plate used. For example, for a varus correction of 25° with a 110° plate, the guide wire will be placed by adjusting the instruments to 135°. After fixation of the neck and placement of the three screws, the intertrochanteric osteotomy is performed and the proximal femoral fragment is reduced on the neck shaft with or without medialization: the plate is then attached to the femur (Fig. 4). Results are better for stability, angle correction and nearly constant union in patients with neurological hip disorders [23, 24].

**Varus osteotomy with an anterior locking plate.** Anterior placement of the plate on the proximal fragment is defined by a bone groove (Fig. 5). The angle of varus correction corresponds to the position of the plate and the femoral shaft, the two proximal holes are placed on the groove. The first bicortical screw is loosely screwed so the plate can be moved. The path of the second screw is prepared with a drill (Fig. 5a et b). The plate is temporarily twisted upwards.

The intertrochanteric osteotomy is easy to perform (Fig. 5c). Varus correction is automatic or is achieved after resection of a bone wedge by pulling the plate to the anterior surface of the femur (Fig. 5d and e). Reduction is stabilized by distal screws (Fig. 5f and g).

**Termino-lateral varus osteotomy**

This is a simple technique to obtain significant varus correction with automatic shortening of the femoral neck in dislocations and subluxations of neurological hips [25].

Once the intertrochanteric osteotomy is performed, the greater trochanter is placed in abduction. An angled (90°, 100°) blade plate is inserted into the femoral neck, into the cancellous portion of the osteotomy. Medalization of the femoral shaft is obtained, often after shortening and derotation (Fig. 6). The femoral shaft surface is placed in contact with the proximal neck which has been debrided. The plate is then screwed to the femur. The deflexion-shortening-varus correction-derotation which can be obtained with this osteotomy can reduce hips with high dislocations. Recurrence is rare and union is obtained in nearly all cases [25].

Femoral head necrosis and periarticular ossifications are the main complications of this technique. Locking plate fixation provides better stability, and avoids postoperative cast immobilization (Fig. 7) [20, 21].

**Indications.** For malalignment, subluxations and neurological dislocations of the hip, varus osteotomies are indicated when the Reimers index is more than 40%. There is a risk of recurrent dislocation due to acetabular dysplasia [26–28]. When varus correction is associated with a pelvic osteotomy, the results are better, with a stable hip without pain in more than 80% of the cases [29–31].

Termino-lateral osteotomy is only indicated in neurological subluxated or dislocated hips with the "candlestick" shaped proximal femur due to significant coxa valga.

**Varus osteotomy can play a role in severe LCP disease, in the presence of fragmentation or for early reconstruction, in cases with malalignment but without "hinge" abduction [1,2,32,33]. This is based on the principle of femoroacetabular containment. The best results are obtained when varus correction-derotation is performed during the necrotic phase, or the beginning of fragmentation [34–36], in Hering B or B/C patients and in patients above 8 years old [37, 38]. In adults, 97% of these surgically treated hips remain congruent [39].**

Varus osteotomy corrects acetabular dysplasia from DDH if alignment is good and if there is significant growth potential. Long term, these hips remain asymptomatic with good results in more than 70% of patients [40]. In significant...
Figure 5  Automatic varus correction with an anterior plate.
favor remodeling of the femoral head in young children, increase abduction and flexion of the hip and reduce pain. They reduce limping by re-tightening the gluteal medial muscle after lowering the greater trochanter.

In inherited or acquired coxa vara, the femoral head can be realigned and the Hilgenreiner Epiphysial (HE) angle which should be less than 35°, can be corrected. This angle is the essential prognostic factor for recurrence; normally it is 16° (0–25°) [44]. Because of the compression from valgus correction, ossification is stimulated, resulting in healing of the triangular ossification defect in congenital coxa vara.

Disadvantages are lengthening of the lower limb, recurrent deformity in young children, limited correction due to abductor and adductor retraction with a risk of an oblique pelvis if valgus correction is more than 40°.

Osteotomy with an AO blade plate. Anteversion guide wires (Fig. 8a) and preparation for the entry point of the blade chisel are similar to those for varus correction. The guide wire for the cutting guide is inserted into the neck of the femur along its axis (Fig. 8b). For 20° valgus with a 110° angle blade plate, the cutting guide is inserted along the axis of the femoral neck to create a 90° (110–20°) angle, thus perpendicular to the longitudinal femoral axis (Fig. 8c and d).

Partial or total lateral base wedge resection (Fig. 8d and e) equal to the angle of valgus correction is the preferred technique (Fig. 9).

Compression of the osteotomy site depends on the direction of the osteotomy lines in relation to the longitudinal axis of the femur: the proximal line is perpendicular to the distal oblique line for a 130° blade plate (Fig. 10); the proximal oblique line and the perpendicular distal line for a 90° blade plate (Fig. 11).

Osteotomy with an anterior AO plate. The limit of the anterior placement of the plate on the proximal fragment is marked by a bone groove (r) which creates the angle of valgus correction with the neck shaft, and the two proximal holes are made in this groove. The first proximal screw

Figure 6 Termino-lateral varus correction with a 90° angled blade plate.

acetabular dysplasia, the association with an acetabular osteotomy optimizes joint congruence and "containment".

Valgus osteotomies

Reserved in the past for coxa vara, this type of osteotomy is also indicated in irreducible femoroacetabular impingement in abduction. Valgus osteotomies are beneficial in LCP disease and SCFE [41–43]. They correct instability and improve congruence because they correct hinge abduction. They

Figure 7 Termino-lateral varus correction with a LCP plate [Coll. J.M. Clavert].
Proximal femoral osteotomies in children

The intertrochanteric osteotomy can easily be performed while leaving the medial cortex intact. A partial or total metaphyseal lateral base wedge, equal to valgus correction is resected from the proximal fragment. The plate is swung back along its path (r) then attached to the proximal fragment with two proximal screws (Fig. 12b). Once the intertrochanteric osteotomy has been completed, valgus correction is obtained by attaching the plate to the anterior side of the femur (Fig. 12c).

Pauwells “Y” Osteotomy [1,2,33]. This osteotomy is indicated in severe coxa vara (Fig. 13a). The lateral base intertrochanteric wedge to be resected is equivalent to the angle of varus correction (Fig. 13b): for an angle of HE = 60° it will be 44° (60° − 16° = 44°). If there is associated derotation, it will be performed before resection. The angle is marked proximally by a horizontally parallel pin under the greater trochanter to the cartilage of the inferomedial femoral neck and distally by an oblique pin in the lateral cortex aimed towards the first pin. The intersection of these two pins creates the wedge (Fig. 13c).

Once the wedge has been removed, the osteotomy is completed medially. The angle is closed by pulling the proximal fragment laterally and down, then the distal femur in abduction (Fig. 13d). A curved plate stabilizes reduction. The neck is attached to the plate with at least two screws. In small children fixation of the osteotomy is obtained by two pins reinforced with a metal tension band.

Indications. A simple valgus osteotomy is the treatment of choice in coxa vara. In children less than 8 years old, an epiphysiodesis of the greater trochanter is associated to prevent the high risk of recurrence, which depends on initial correction. An HE angle of less than 35° and a femoral neck-shaft angle of more than 130° guarantees good long-term results without recurrence [45]. This is a salvage solution in cases of articular incongruence with irreducible femoroacetabular impingement in abduction (Fig. 14). Its articular, biomechanical and analgesic benefits have been clearly confirmed in the literature [11,41,46]. It can be associated with flexion or extension of the femoral head and femoral derotation, for example in limited

is loosely screwed so the plate can be moved. The path of the second screw is prepared with a drill (Fig. 12a). The plate is temporarily swung upwards and outwards during the procedure.

Figure 8  Valgus correction with a 110° blade plate.

Figure 9  Valgus correction with wedge resection.
Figure 10  Valgus correction of a cam effect with a 130° blade plate.

osteonecrosis of the femoral head and stable, displaced PFS.

The Pauwells osteotomy is indicated in significant femoral head/neck displacement with a neck-shaft angle of less than 100°, an HE angle of more than 60° or between 45° and 60° when coxa vara is progressive and symptomatic and in pseudarthroses of the femoral neck.

**Flexion and extension osteotomies**

These osteotomies modify femoral head surface pressure by inducing flexion (backward rotation: Fig. 15a, b) or extension (forward rotation: Fig. 15c, d) of the femoral head. They improve joint congruence by excluding the diseased area (necrosis, bone sequestrum), treat femoroacetabular impingement and increase joint range of motion, with a slight risk of femoral head necrosis [1].

Significant femoral head rotation of more than 30° creates tension in the capsule and the periarticular muscles, causing joint stiffness and hip flexum. Bone shortening, tenotomies or anterior capsulotomies are necessary to prevent this [1,2]. Associated with multilevel corrections, they increase the risk of chondrolysis due to hip joint hyperpressure [47,48] and proximal femoral malalignment. The latter make future arthroplasties difficult.

**Osteotomy with a 90° angled blade plate**

The intertrochanteric osteotomy is perpendicular to the femoral diaphysis. On the sagittal plane, the plate and the femoral shaft form an angle equal to the desired rotation of the femoral head. The osteotomy leaves the medial cortex

Figure 11  Valgus correction of a cam effect with a 90° blade plate.
intact. The blade is inserted obliquely into the neck according to the planned angle of rotation. The osteotomy is then completed. The plate is pulled into place then attached to the femur. Femoral head flexion or extension is automatically obtained. The bulge of the proximal fragment caused by rotation can be a problem. It is resected and can be used as a graft for the osteotomy.

**Indications.** Flexion and extension osteotomies are indicated in limited, early stage femoral head necrosis and femoroacetabular impingement: varus or valgus correction is often associated with this procedure.

Flexion osteotomy is indicated in the presence of anterolateral impingement which is too extensive to be resected. Medial flexion-rotational osteotomy [14,49] is necessary if femoral neck-head retroversion is confirmed [6].

**Osteotomies of the greater trochanter**

The goal is to align the tip of the greater trochanter with the center of the femoral head and to restore the lever arm by modifying the position of the greater trochanter, the length of the femoral neck or both at once. The patient should be placed in the supine position on an orthopedic table. Two osteotomy techniques have been described: simple osteotomies for lowering and lateral displacement of the greater trochanter and double osteotomies combining distal and lateral transfer of the trochanter and lengthening of the femoral neck [2,3,33]. They are indicated in coxa vara in an aligned hip with no chondral deterioration. A tenotomy of the adductors and sometimes the iliac psoas is performed first to improve abduction.
Simple osteotomies for distal and lateral transfer of the greater trochanter

This procedure re-tightens the abductor muscles and restores their strength by lowering and lateral displacement of the greater trochanter. It can be associated with an osteochondroplasty of the femoral head-neck junction in the presence of a cam effect.

Technique
The periosteum of greater trochanter is released. The anterior and posterior rims of the gluteus medius muscles are identified. A dissector is slipped under this muscle to serve as a reference for the chisel. The anterior intertrochanteric line is carefully exposed to avoid injuring the circumflex vessels which arrive on the upper rim of the femoral neck. Two oblique pins are placed going from the subtrochanteric area to the superior trochanter-femoral head junction. This defines a lateral base wedge.

If the trochanter is not too high, simple lowering of the greater trochanter is obtained by resection of a wedge that leaves the superior cortex intact (Fig. 16a). Fixation of the greater trochanter to the femur is obtained with two screws with washers that should be larger than the calcar.

If the trochanter is very high, lowering of the greater trochanter is associated with lateralization. The osteotomy ascending from the greater trochanter is identical. By gradually opening the osteotomy, the superior cortex is fractured with no risk of vascular injury. Once the greater trochanter is released it is mobilized. The lateral side of the distal femur is debrided. A medial wedge with an inferior base is resected from the hypertrophic greater trochanter to connect bone surfaces and create correct contact of the greater trochanter with the superior aspect of the femoral neck (Fig. 16b). The greater trochanter is lowered then attached to the lateral side of the femur, by placing the leg in abduction. Fixation is obtained with two screws. The leg is placed in traction with the hip in abduction for 3 weeks. Weight-bearing on crutches is allowed after 3 weeks.

Figure 13  Pauwells Y osteotomy.
Figure 14  Anterior "bump" femoral head (arrow), sequella of SCFE (operative view).

Figure 15  Flexion and extension osteotomies of the femoral head.
Complications include fracture of the greater trochanter, displaced hardware, non-union and unattractive bulges due to excess lateral displacement of the greater trochanter.

**Double osteotomies for distal and lateral transfer of the greater trochanter and lengthening of the femoral neck**

The goal of these complex osteotomies is to lengthen the femoral neck with or without valgus correction, and for distal and lateral transfer of the greater trochanter. This procedure tightens the abductor muscles of the hip, reduces shortening and improves gait. Two techniques are described.

**Double opening and closing wedge intertrochanteric osteotomies** [50]

These osteotomies combine valgus correction-lengthening of the femoral neck with distal and lateral transfer of the greater trochanter [2]. Fixation is obtained with a curved locking plate and screw or a tension band on the greater trochanter.

**Double opening wedge osteotomy.** There are two parallel osteotomy lines (Fig. 17a and b): the proximal at the base of the greater trochanter and the distal line on the superior end of the femoral shaft along the axis of the inferior aspect of the femoral neck. A Steinmann pin is first inserted into the femoral neck to the center of the femoral head (Fig. 17c). The double osteotomy creates three fragments: the greater trochanter, the femoral neck and the femoral shaft. Valgus correction is obtained by using the Steinman pin as a lever. The shaft is translated laterally. The inferomedial part of the neck rests on the femoral fragment. The neck is lengthened and the greater trochanter is distally and laterally displaced. The latter is embedded and attached to the opening of the osteotomy. Bone defects are filled with a bone graft.

**Closing wedge osteotomy.** There are two parallel osteotomy lines (Fig. 18a and b): the osteotomy of the greater trochanter which is identical to that for lowering, and the intertrochanteric osteotomy, which leaves medial cortex intact. The distance between the two is defined by the angle of valgus correction (Fig. 18c). The tip of the bone wedge to be removed is defined by a pin which goes from the lateral end of the first osteotomy to the medial end of the second (Fig. 18d). A pin is placed in the axis of the femoral neck (Fig. 18e) and another below the second osteotomy (Fig. 18f). The bone wedge is resected and the medial cortex is fractured. The osteotomy is closed by pulling the pins together. When valgus correction of the neck is obtained, the femur is lateralized and the greater trochanter is lowered and temporarily attached (Fig. 18g).

**Double osteotomy for lengthening of the femoral neck with distal and lateral transfer of the greater trochanter**

This technique includes an oblique proximal osteotomy line at the base of the greater trochanter at a 130° angle in relation to a vertical line (Fig. 19a) and an intertrochanteric osteotomy parallel to the first which leaves the medial cortex intact (Fig. 19b) [51,52]. Partial resection of the hypertrophic trochanter is performed (Fig. 19c); this fragment will be used as a graft (Fig. 19e). The greater trochanter (Fig. 19d) is lowered then turned on itself by 90° so that it is in contact with the lateral side of the femoral neck which has been debrided. This manoeuvre is facilitated by abduction of the leg and fixation is obtained by two pins. For a 130° blade plate, insertion of the cutting guide into the greater trochanter and the femoral neck is guided by a reference pin which is at a 50° angle to the femoral shaft and parallel to the femoral neck anteverision reference pin. Once the intertrochanteric osteotomy is finished, the femoral shaft is pulled down and laterally. This lengthens the neck by approximately 15 mm. Stabilization is obtained by a blade plate or a locking plate with a tension band on the greater trochanter. Weight-bearing begins after 4 months.

Complications include femoral head necrosis and non-union.

**Indications.** This procedure is reserved for children above 8 years old with a Trendelenburg sign and limited abduction. Lowering of the greater trochanter is indicated in moderate coxa vara in greater trochanters that are no higher or only slightly higher than the top of the femoral head. The results of lowering-lateralization of the greater trochanter are good, with improved gait and hip mobility.
Figure 17  Double opening wedge osteotomy with distal and lateral transfer of the greater trochanter and lengthening of the femoral neck.

Figure 18  Double closing wedge osteotomy for distal and lateral transfer of the greater trochanter and lengthening of the femoral neck.
Double osteotomies are indicated in severe coxa vara in adolescents in whom the greater trochanter is at a height of by less than 90° and hypertrophied, with coxa breva and significant shortening. They also correct limb shortening, with medialization of leg alignment and relieve the lateral compartment of the knee [52–54].

Whatever the type of osteotomy, the Trendelenburg sign persists in one third of the cases: intermediate and long-term results of simple and double osteotomies are nearly identical [53–56]. Simple osteotomies of the greater trochanter are a good alternative to complex osteotomies.

Conclusion

The indications for PRO in children are mainly for children with neurological hips, malunion, deformities and coxa vara. A better understanding of the morphological disturbances, femoroacetabular impingement and their negative effects on function justifies the use of PFO to save the hip. Obtaining optimal joint congruence and correct “containment” of the growing hip is the best prevention of early arthritis. The pediatric orthopedic surgeon must be well versed in the surgical techniques of PFO. When performing PFO and anatomical normalization, the surgeon should keep in mind possible total hip arthroplasties which PFO may complicate, and the poorer results of implant survival in these cases.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References


