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Hip preservation

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- Classical indications for hip preserving surgery are: femoro-acetabular impingement (FAI) (intra- and extra-articular), hip dysplasia, slipped capital femoral epiphysis, residual deformities after Perthes disease, avascular necrosis of the femoral head.
- Pre-operative evaluation of the pathomorphology is crucial for surgical planning including radiographs as the basic modality and magnetic resonance imaging (MRI) and/or computed tomography (CT) to evaluate further intra-articular lesions and osseous deformities.
- Two main mechanisms of intra-articular impingement have been described:
  (1) Inclusion type FAI ('cam type').
  (2) Impaction type FAI ('pincer type').
- Either arthroscopic or open treatment can be performed depending on the severity of deformity.
- Slipped capital femoral epiphysis often results in a cam-like deformity of the hip. In acute cases a subcapital re-alignment (modified Dunn procedure) of the femoral epiphysis is an effective therapy.
- Perthes disease can lead to complex femoro-acetabular deformity which predisposes to impingement with/without joint incongruency and requires a comprehensive diagnostic workup for surgical planning.
- Developmental dysplasia of the hip results in a static overload of the acetabular rim and early osteoarthritis. Surgical correction by means of periacetabular osteotomy offers good long-term results.

Keywords: femoro-acetabular impingement; hip arthroscopy; hip dysplasia; periacetabular osteotomy; surgical hip dislocation

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Over the past two decades, substantial increases in the knowledge of pre-arthritic conditions of the hip joint, including developmental dysplasia of the hip, femoro-acetabular impingement, slipped capital femoral epiphysis, residual deformities after Perthes disease, avascular necrosis of the femoral head, together with the development of new surgical approaches and procedures, have revolutionized the field of hip-preserving surgery.

Pre-operative workup

Conventional radiographs remain the basis of the diagnostic workup in patients eligible for joint-preserving hip surgery. These should include supine anteroposterior (AP) pelvic views to assess radiographic joint degeneration, coverage and version of the acetabulum and gross anatomy of the pelvis.[1] An axial view is needed to detect cam deformities which are typically located anterosuperiorly.[1] In the absence of severe joint space narrowing, magnetic resonance imaging (MRI) of the hip should be performed in all patients evaluated for joint-preserving surgery. At first, fluid-sensitive images with a large field of view should be obtained to screen for associated inflammatory or neoplastic conditions surrounding the hip joint.[2] Fast axial images of the pelvis and the distal femoral condyles should be acquired to assess femoral torsion.[3] Then dedicated high-resolution images of the hip at field strengths of 1.5 T or 3 T in the coronal, axial-oblique/axial and sagittal orientations should be performed to assess intra-articular lesions.[4] Acquisition of radial images is essential to provide a circumferential assessment of the femoral head neck junction.[5,6] Although promising results have been demonstrated for non-contrast MRI of the hip at 3 T, direct MR arthrography is still the current diagnostic gold-standard in the detection of chondrolabral lesions.[7–9] MR arthrograms provide crucial prognostic information as extensive cartilage defects, acetabular cysts and osteophyte formations indicate a higher risk for failure of femoro-acetabular impingement (FAI) surgery in the long-term.[10] Injection of intra-articular contrast agent further enables application of leg traction to achieve joint distraction and has shown promising early results to improve the visualization of intra-articular lesions.[11–14]

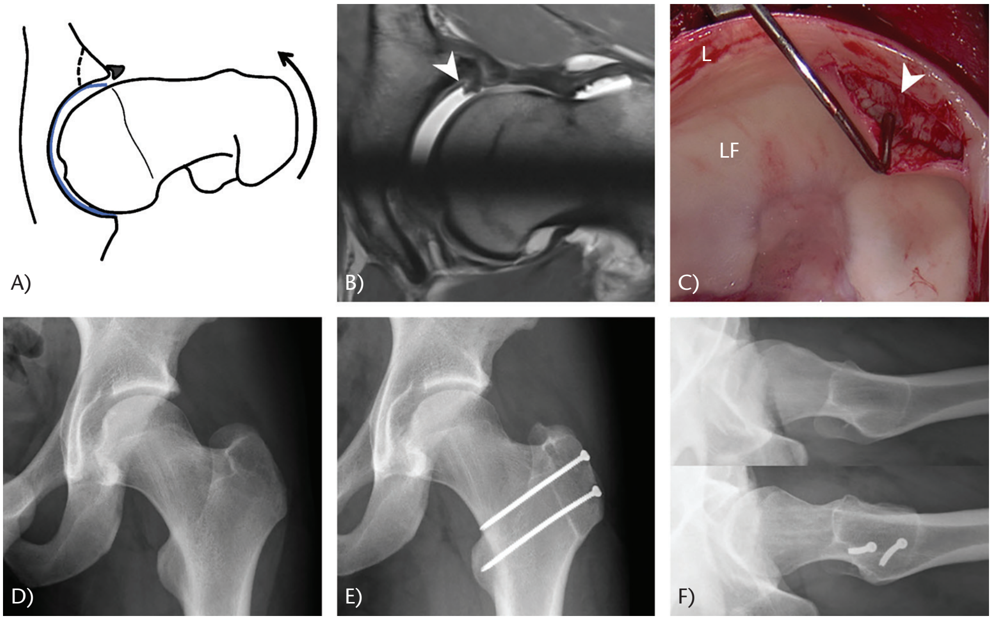

Fig. 1 (A) Schematic drawing, (B) direct MR arthrography with traction at 3T of a 27-year-old man with mixed FAI who underwent (B) surgical hip dislocation. (A–C) Dynamic abutment leads to an 'outside-in lesion' shearing of the chondrolabral complex. (A) In severe cases this can lead to a fatigue fracture of the osseous rim (dashed line). (B) Radial PD-w image shows contrast agent undermining the delaminated cartilage from the labral-chondral transition zone towards the joint cavity. (C) The surgical probe is advanced beneath the delaminated cartilage (arrowhead). (D–F) conventional X-rays: Pre-operative AP X-ray (D) showing slight 'pistol-grip' deformity and on the cross-table view (F: upper image) the cam deformity is clearly visible. (E and F: lower image) post-operative X-rays after surgical hip dislocation and femoral osteochondroplasty.

Note. MR, magnetic resonance; FAI, femoro-acetabular impingement; PD-w, proton density weighted; AP, anteroposterior; L, labrum; LF, lunate facies. Images A–C reprinted with permission from Schmaranzer et al.[4]

In addition, new biochemical cartilage MRI techniques such as delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) or T2* imaging offer the ability to evaluate chondral defects more accurately before surgical therapy.[15,16] 3D CT scans enable exact visualization of the bony deformities, and specific software for dynamic range of motion simulation can be very effective to identify the dominant osseous deformity and plan surgical correction.[17] This is especially true for surgical planning in cases with suspected extra-articular FAI.[18] 3D MRI has great potential to replace 3D CT for rendering of 3D models of the hip joint and further analysis for a non-invasive improved surgical decision-making in these mostly young patients.[19–21]

Femoro-acetabular impingement (FAI)

The concept of FAI was first described in 2003.[22] It was defined as a condition of abnormal femoral abutment against the acetabular rim arising as a result of abnormal morphological features involving the proximal femur and/or the acetabulum.[22]

Two main mechanisms of intra-articular impingement have been described:[1] inclusion type FAI ('cam type') in which the aspherical femoral head protrudes into the acetabulum and induces shear forces which lead to the typical carpet-like delamination of cartilage and detachment of the labrum (Fig. 1);[2] impaction type FAI ('pincer type') in which the femoral head abuts against an excessively prominent acetabulum leading to cartilage thinning and degenerative labrum tears (Fig. 2).[4,22–24]

The asphericity at the femoral head neck junction reflects a pattern of distinct osseous variants. Most frequently (~ 80% cases) an 'idiopathic' cam type deformity can be found which typically arises from an excessively lateral extension of the epiphysis.[25] Less frequently a slip-like morphology resembling sequelae of slipped capital femoral epiphysis (SCFE) or post-slip morphologies are observed.[25,26] The cam deformity is typically located anterosuperiorly. The head-neck sphericity can be quantified with the alpha angle (Fig. 3) A normal alpha angle is less than 50°, and an alpha angle exceeding 50° classically defines a cam type morphology.[27] Evidence for a threshold of > 60° is mounting due to previously published data, showing that an alpha angle exceeding 60° is associated with clinical symptoms and the development of incident osteoarthritis.[28,29] During flexion, internal rotation and adduction, the eccentric part of the femoral-neck junction slides into the anterosuperior acetabulum. The first structure to fail is the chondrolabral transition zone due to the induced shear stress. Chondrolabral separation reflects the

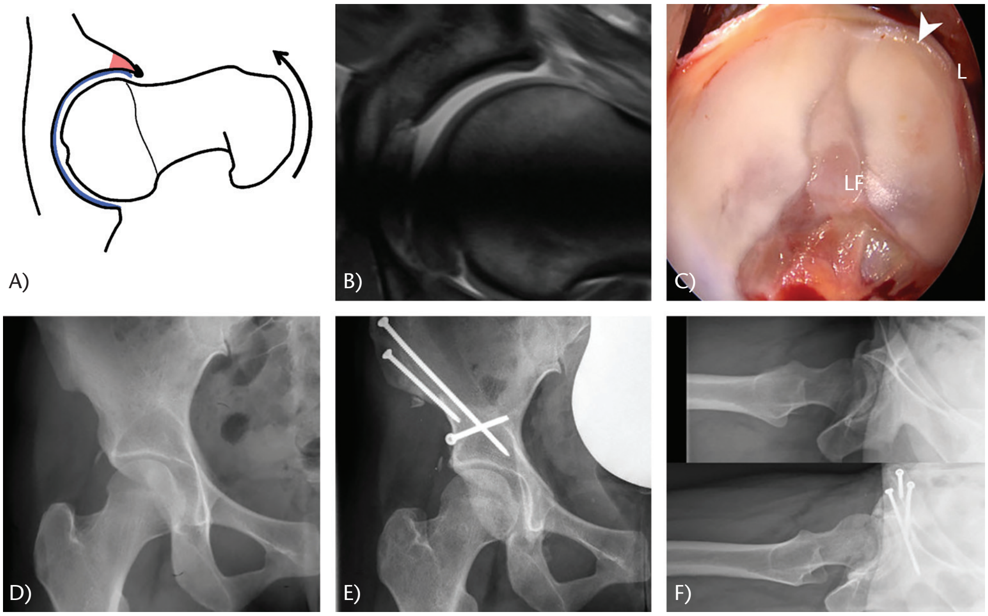

Fig. 2 (A) Schematic drawing, (B) direct MR arthrography with traction at 3T of a 26-year-old female with impaction type FAI due to severe acetabular retroversion who underwent (E) anteverting PAO. (A–C) Early dynamic abutment due to overgrowth of the anterior acetabular wall (in red) leads to impaction against the chondrolabral complex and typically a narrow and circumferential strip with labral damage and degenerative tearing within the labrum visible on (B) the radial PD-w image. (C) Correlating intra-operative image (arrowhead) in a different patient who underwent surgical hip dislocation in case of acetabular retroversion. (D–F) conventional X-rays: pre-operative AP X-ray (D) showing acetabular retroversion with positive cross-over sign, ischial spine and positive posterior wall sign. Cross-table view (F: upper image) no additional cam deformity is visible. (E and F: lower image) post-operative X-rays after anteverting periacetabular osteotomy.

Note. MR, magnetic resonance; FAI, femoro-acetabular impingement; PAO, periacetabular osteotomy; PD-w, proton density weighted; AP, anteroposterior; L, labrum; LF, lunate facies.

precursor lesion, which progresses to acetabular cartilage delamination and avulsion of the labrum from the acetabular rim. Even fatigue fractures of the rim can occur and are referred to as 'os acetabuli'.[4] Damage secondary to inclusion FAI is typically focal but pronounced (Fig. 1).[4,24]

Either arthroscopic or open treatment by means of a surgical hip dislocation (SHD) with recreation of the femoral head-neck offset can be performed.[30–33] For open treatment of the cam deformity, hemispherical plastic templates are used to intra-operatively identify the location and extent of the cam deformity. The femoral head-neck offset is restored using chisels and a high-speed burr. Intra-operative dynamic evaluation of hip range of motion (ROM) determines the extent of the surgical correction. The torn labrum is trimmed to stable substance and re-attached. To achieve a good clinical outcome, labrum preservation or reconstruction of the labrum should be achieved whenever possible.[34,35] Autologous fascia lata or ligamentum teres grafts can be used for labral reconstruction.[36–39]

In hips with impaction type morphology, acetabular over-coverage restricts the impingement-free range of motion. Different pathomorphologies of over-coverage can be defined: [1] localized as an anterior osseous acetabular prominence (e.g. with anterosuperior acetabular retroversion or osteophytes),[40] or [2] generalized over-coverage of the entire acetabulum (e.g. protrusio acetabuli representing the most severe form of pincer impingement) or severe acetabular retroversion.[41]

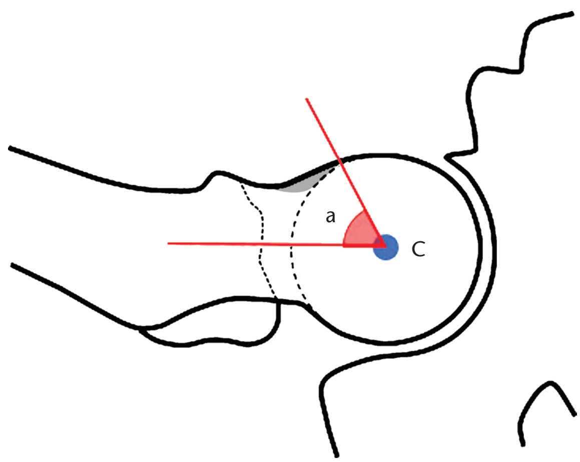

Fig. 3 Alpha angle: angle formed by the femoral head-neck axis (a) and line through the centre of the femoral head (C) and the point where the anterior head-neck contour exceeds the head radius.

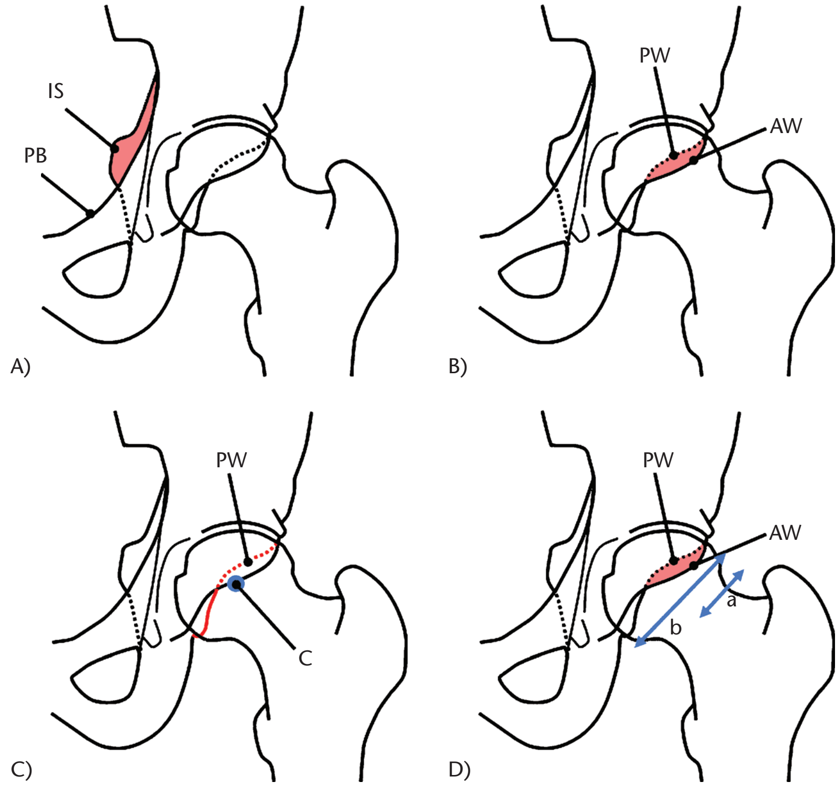

Fig. 4 (A) 'Ischial spine sign': positive if the ischial spine (IS) is projected medially to the pelvic brim (PB). (B) 'Cross-over' sign: positive if the anterior wall (AW) crosses the posterior wall (PW). (C) Posterior wall sign: positive if the posterior wall (PW) runs medially to the centre (C) of the femoral head. (D) Retroversion index: percentage of the retroverted acetabular opening (a) divided by the entire opening (b).

To measure the acetabular coverage the lateral centre-edge (LCE) angle is the most important angle. An LCE angle of less than 23° is defined as dysplastic, an angle exceeding 33° is considered as an acetabular over-coverage, and an angle exceeding 39° is considered as a severe acetabular over-coverage.[41] The acetabular index (AI) is used to measure the inclination of the acetabular roof. An AI of > 14° is defined as dysplastic and an AI of ≤ 2° is considered as an acetabular over-coverage, and an AI < –8° is considered as a severe acetabular over-coverage.[41]

In hips with acetabular over-coverage, cartilage damage is usually restricted to a narrow and circumferential strip with labral damage usually co-located, and typically presents as ossification and degenerative tearing within the labrum (Fig. 2).[4,24]

Either arthroscopic or open acetabular rim trimming is performed until impingement-free ROM is achieved followed by re-attachment of the labrum.[30–32]

There is mounting evidence that severe acetabular retroversion represents a rotational abnormality of the entire hemipelvis rather than a prominent overgrowth of the anterior acetabular wall.[42–46] Further, it has been shown that the outer margin of the acetabulum rim and size of the lunate surface are essentially normal in retroverted acetabula.[45] Therefore cases with substantial acetabular retroversion present with a combination of radiographic findings: a positive cross-over sign (with a retroversion index exceeding 30%), a positive posterior wall sign, and a positive ischial spine sign (Fig. 4). Long-term outcome data supports acetabular re-orientation by means of an anteverting PAO (periacetabular osteotomy) over acetabular rim trimming.[47–49] In contrast to the re-orientation in DDH, an internal rotation of the acetabular fragment is performed to achieve a rotational correction of the acetabulum.[50]

For arthroscopic treatment of FAI less favourable outcomes have been reported for patients of older age groups (> 45 years), female sex, with elevated BMI, osteoarthritic changes, decreased joint space (< 2 mm), chondral defects, increased LCE angle, and labral debridement compared with labral repair.[51] Comparable predictive factors associated with decreased long-term survivorship are reportedly associated with over- or under-treatment of the acetabular rim, age > 40 years, and elevated BMI (> 30 kg/m²) for patients undergoing surgical hip dislocation.[31,32]

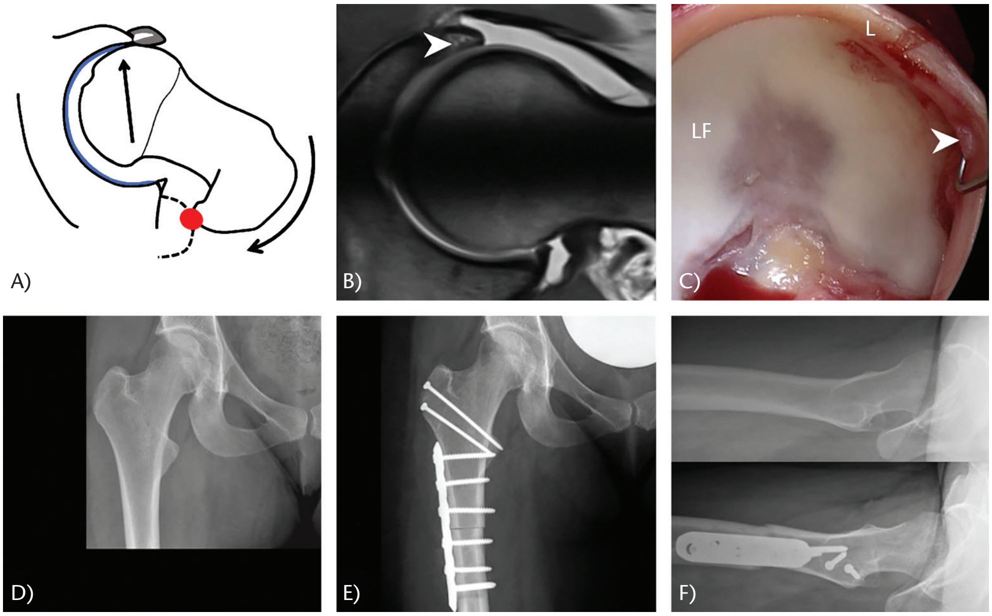

Fig. 5 (A) Schematic drawing, (B) direct MR arthrography at 3T of a 23-year-old female with a posterior, extra-articular impingement due to increased femoral torsion who underwent (B) surgical hip dislocation and an additional de-rotational osteotomy. (A) The dynamic posterior abutment leads to an anterior leverage mechanism and causes a dynamic overload of the anterior chondrolabral complex. (B) Radial PD-w image shows a hypertrophied labrum with hyper-intense signal alterations corresponding to an intra-substance tear. (C) The surgical probe is advanced within the labrum and the adjacent acetabular cartilage is thinned. (D–F) conventional X-rays: pre-operative AP X-ray (D) showing the typical morphology of a coxa valga antetorta and on the cross-table view (F: upper image) a slight cam deformity is visible. (E and F: lower image) post-operative X-rays after surgical hip dislocation, subtrochanteric de-rotational osteotomy and femoral osteochondroplasty.

Note. MR, magnetic resonance; PD-w, proton density weighted; AP, anteroposterior; L, labrum; LF, lunate facies.
Images A–C reprinted with permission from Schmaranzer et al.[4]

Extra-articular impingement

Recently, extra-articular hip impingement has been recognized as an additional but less frequent cause of impingement. Extra-articular impingement can occur anteriorly or posteriorly. Anterior, 'subspine' impingement is typically located between the anterior iliac inferior spine (AIIS) and the intertrochanteric region of the proximal femur.[52] This condition can be caused by low femoral torsion (even without concomitant cam or pincer morphologies),[53] severe acetabular retroversion or after avulsion fractures of the AIIS. This has been described using CT-based 3D reconstructions of the pelvis and femur and is probably underestimated. The use of intra-articular corticosteroid injections can help to differentiate between anterior intra- and extra-articular hip impingement. Because clinical diagnosis is difficult, the use of CT-based 3D reconstructions of the pelvis and femur and dynamic simulation of hip impingement for diagnosis and pre-operative planning in these cases is helpful.[18] This is particularly due to the fact that most patients show combined intra- and extra-articular impingement.[53]

Surgical treatment for these hips is performed arthroscopically or by means of a surgical hip dislocation for cam resection and resection of the intertrochanteric region and/or resection of the anterior iliac inferior spine. We use intra-operative dynamic evaluation of hip ROM for testing of impingement-free motion. In cases with persisting anterior FAI after the aforementioned resection, a rotational femoral osteotomy to increase femoral torsion should be considered if an internal rotation of at least 30° in 90° flexion is not present.[54]

Posteriorly, ischiofemoral impingement is typically located between the ischial tuberosity and the lesser trochanter.[18] Excessive high femoral torsion (> 35 degrees) combined with a valgus deformity (neck-shaft angle > 139°) predisposes to this conflict in extension with or without external rotation in the hip joint. The posterior osseous abutment supposedly leads to a levering mechanism and de-centralization or dynamic hip instability (Fig. 5).[2] Consequently the femoral head subluxates anteriorly and leads to an inside-out avulsion of the acetabular labrum and tearing of the labral body.[4] Clinical diagnosis is established by a positive posterior impingement test or the FABER test. Especially in the presence of a cam deformity and in the presence of acetabular overcoverage it can be challenging to diagnose ischiofemoral impingement. CT-based 3D reconstructions of the pelvis and femur followed by a dynamic simulation of hip impingement considerably facilitate surgical decision-making in patients with suspected posterior extra-articular FAI.[18]

The causal treatment for this condition represents a proximal femoral de-rotational osteotomy.[54] In our institution, this procedure typically is combined with a SHD for an anterior cam resection and for intra-operative dynamic evaluation of hip ROM. A de-rotational osteotomy will increase the range of external rotation while impairing the range of internal rotation. Thus, a concomitant anterior cam resection is performed on a nearly regular basis in these hips (Fig. 5).

Slipped capital femoral epiphysis (SCFE)

SCFE is the most common adolescent hip disorder.[55] The association between deformities from SCFE and the development of FAI and early osteoarthritis of the hip has been shown in multiple studies.[56–58] It is suspected that multiple factors lead to a weakened physis no longer restraining the forces acting upon the epiphysis, resulting in a slip of the epiphysis over the metaphysis in a postero-inferior direction.[55] Historically, in situ pinning had the lowest risk for avascular necrosis and became the treatment of choice in many institutions. The downside of in situ fixation is that even large deformations are left uncorrected overall resulting in an abutment of the anterior metaphyseal flare against the acetabular rim, causing chondrolabral damage[59–61] and exposing young patients to the risk of early hip dysfunction.[62] In many centres severe or unstable SCFE is nowadays treated open using surgical hip dislocation with development of a retinacular soft tissue flap to perform a subcapital re-alignment of the slipped epiphysis, the so-called 'modified Dunn' procedure.[63] The femoral head is stepwise mobilized respectively and separated from the femoral epiphysis. The callus formation of the metaphysis is resected and the epiphyseal scar is cleaned. The epiphysis is then manually reduced on the metaphyseal stump and fixed with anterograde Kirschner wires.[63] Of the hips, 93% presented with no progression of osteoarthritis, good clinical scores and no subsequent total hip arthroplasty (THA) at 10-year follow-up[64] following a modified Dunn procedure. Different rates of avascular necrosis (AVN) are reported for the modified Dunn procedure in the literature with low rates of 4–6%[65,66] or high rates of up to 26%.[67] In contrast to the modified Dunn procedure, devastating long-term results were shown for in situ pinning with almost 75% of hips demonstrating degenerative changes on X-rays or requiring conversion to THA in a series with a mean follow-up of 23 years.[62]

Residual deformities after Perthes disease

As the result of an abnormal development of the growth plate, Legg-Calvé-Perthes disease (LCPD) results typically in an aspherical, mushroom-shaped femoral head.[68] In flexion and internal rotation the aspherical portion of the head-neck junction may protrude into the acetabulum and create shear forces perpendicular to the acetabular cartilage,[24] resulting in cartilage avulsion from the labrum and/or abrasions on the acetabular cartilage. To restore ROM the surgical treatment of choice is resection of the aspherical portion of the head.[68] A high-riding trochanter is another typical deformity in LCPD, causing extra-articular impingement between the greater trochanter and the supra-acetabular region and impairment of abductor strength.[68,69] Relative femoral neck lengthening[70] is necessary to improve the lever arm and restore abductor function.[71] In cases in which the deformed and enlarged femoral head is not contained by the acetabulum, intra-articular impingement between the femoral head and the acetabulum, also referred to as 'hinged abduction', results in levering out of the head in abduction.[72,73] Via a surgical hip dislocation, a semi-circumferential femoral osteochondroplasty can be safely performed. A further femoral head reduction osteotomy can be considered in selective cases if containment of the femoral head cannot be achieved with femoral osteochondroplasty alone.[74] As a result of a premature fusion of the tri-radiate cartilage, the acetabulum becomes dysplastic concomitant with severe femoral head deformities[75,76] presenting with an increased radius, a decreased depth and a more vertically orientated acetabular roof.[75,77] Overall this results in joint instability leading to acetabular rim overload and concurrent chondrolabral lesions[78] requiring a periacetabular osteotomy to manage the dysplastic component of these hips.[68]

Avascular necrosis (AVN) of the femoral head

AVN typically leads to femoral head collapse and subsequent rapid progression of osteoarthritis. Mainly young and active patients in the third and fourth decades of life are affected.[79] Apart from idiopathic aetiologies, osteonecrosis of the femoral head occurs secondary to corticosteroid use, alcohol abuse, sickle cell disease, radiation, and cytotoxic agents.[80] There is no consensus on the optimal surgical treatment for this challenging condition according to a recent systematic review of the literature.[79] Depending on the localization, extension and stage of the osteonecrosis, multiple therapeutic options are available such as rotational osteotomies, bone grafting, core decompression and varus/flexion femoral osteotomy aiming to preserve the joint in these mostly young and active

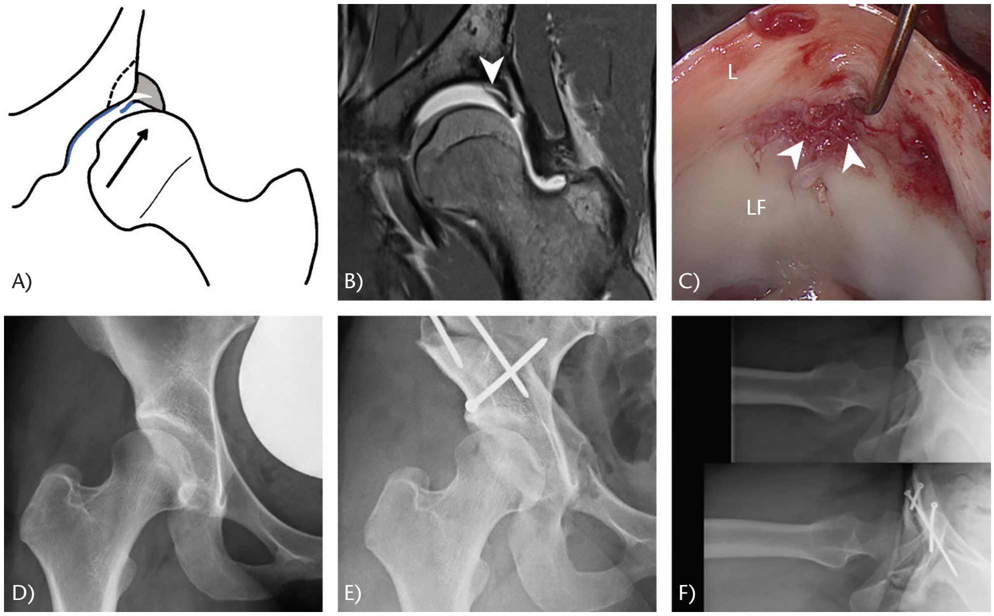

Fig. 6 (A) Schematic drawing, (B) direct MR arthrography with traction at 3T of a 17-year-old woman with hip dysplasia who underwent (B) surgical hip dislocation and subsequent periacetabular osteotomy. (A–C) Static axial overload leads to 'inside-out lesion' of the chondrolabral complex. (A) In severe cases this can lead to a fatigue fracture of the osseous rim (dashed line). (B) Coronal PD-w image and (C) intra-operative image shows a cartilage sleeve which extends from centrally into the chondrolabral transition zone and the hypertrophied labrum. (D–F) conventional X-rays of a 23-year-old woman: pre-operative AP X-ray (D: showing hip dysplasia with LCE angle of 17° and acetabular index of 14°. On the cross-table view (F: upper image) a concomitant cam deformity is apparent. (E and F: lower image) post-operative X-rays after periacetabular osteotomy and femoral osteochondroplasty.

Note. MR, magnetic resonance; PD-w, proton density weighted; AP, anteroposterior; LCE, lateral centre-edge; L, labrum; LF, lunate facies.
Images A–C reprinted with permission from Schmaranzer et al.[4]

patients.[79] Combined surgical dislocation with flexion/varus osteotomy and direct treatment of the necrosis with subchondral drilling or cartilage repair followed by curettage of the necrotic lesion has shown promising early results in hips with advanced AVN.[81] If joint preservation is not possible THA should be performed.[79,80]

Developmental dysplasia of the hip (DDH)

Acetabular under-coverage (development dysplasia of the hip) produces a different pathomechanism leading to degenerative hip arthritis and is defined by a lateral centre-edge angle of less than 22°.[41] Further prognostic values are an acetabular index > 14° and a femoral head extrusion index > 27%. Typically, the entire innominate bone is internally rotated.[46] Different studies have shown that dysplastic hips have a decrease in size of the lunate surface[45,82] compared with normal hips and increased contact pressures (e.g. 23% increased pressure in mid-stance phase of gait).[82] An up to four times increased load to the labrum results in a reactive labral hypertrophy.[83–85] The labrum is torn along with a part of the adjacent cartilage due to subluxation of the femoral head that tears the labrum from the acetabular rim together with a sleeve of cartilage (Fig. 6). Furthermore, progressive thinning of the acetabular cartilage occurs finally resulting in full-thickness defects at the peripheral acetabular rim due to static overload.[86] This chondrolabral damage is typically located superiorly.[87]

Surgical treatment of acetabular under-coverage aims to re-orientate the acetabulum to normalize joint contact pressure by optimizing the femoral containment and prevention of subluxation.[82,88] Different studies have shown that joint contact pressure can be reduced through acetabular re-orientation.[89,90]

Various acetabular osteotomies have been described. At our institution the Bernese periacetabular osteotomy (PAO) (Fig. 6) is the standard of care.[91] This approach gives the advantage of enabling the surgeon to perform corrections in a large tri-dimensional fashion, producing an inherent stability of the acetabular fragment due to the polygonal cuts and furthermore the preservation of the posterior column. Patients can proceed with partial weight-bearing directly after the surgery. Furthermore, the birth canal is not affected. If needed, femoral osteochondroplasty is performed additionally if an internal rotation of less than 30° in 90° flexion is apparent after the acetabular re-orientation.

As these patients are often very young at the time of surgery, long-term follow-up and identification of factors associated with osteoarthritis progression, poor clinical outcome, and conversion THA will help to improve patient selection. Recently a study presented 30-year follow-up results.[92] Advanced age > 40 years, a pre-operative Merle d'Aubigné-Postel score < 15 points, a pre-operative Harris Hip Score < 70 points, pre-operative limp, presence of positive anterior impingement test, presence of positive posterior impingement test, a pre-operative internal rotation of < 20°, a pre-operative Tönnis Grade > 1, a post-operative anterior coverage > 27%, and a post-operative acetabular retroversion are associated with inferior survivorship at long-term follow-up.[92] Furthermore, a proper acetabular re-orientation with correction of the femoral head-neck offset improves survivorship in the long-term.[93] Therefore, pre-operative radiographic and clinical evaluation should include assessment of a frequently present asphericity of the femoral head.[92]

Conclusions

Typical indications for hip-preserving surgery are: femoroacetabular impingement (intra- and extra-articular), hip dysplasia, slipped capital femoral epiphysis, residual deformities after Perthes disease, and avascular necrosis of the femoral head. To offer an adequate pathomorphology-driven treatment the pre-operative evaluation is crucial. Thus, a wide spectrum of treatment modalities can therefore be used to correct the underlying pathology.

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