



Acetabular retroversion: diagnosis and treatment

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- Acetabular retroversion (AR) consists of a malorientation of the acetabulum in the sagittal plane. AR is associated with changes in load transmission across the hip, being a risk factor for early osteoarthritis. The pathophysiological basis of AR is an anterior acetabular hyper-coverage and an overall pelvic rotation.
- The delay or the non-diagnosis of AR could have an impact in the overall management of femoroacetabular impingement (FAI). AR is a subtype of (focal) pincer deformity.
- The objective of this review was to clarify the pathophysiological, diagnosis and treatment fundamentals inherent to AR, using a current literature review.
- Radiographic evaluation is paramount in AR: the crossover, the posterior wall and ischial spine signs are classic radiographic signs of AR. However, computed tomography (CT) evaluation permits a three-dimensional characterization of the deformity, being more reliable in its recognition.
- Acetabular rim trimming (ART) and periacetabular osteotomy (PAO) are the best described surgical options for the treatment of AR.
- The clinical outcomes of both techniques are dependent on the correct characterization of existing lesions and adequate selection of patients.

Keywords: acetabular retroversion; acetabular rim trimming; femoroacetabular impingement; periacetabular osteotomy

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Introduction

Femoroacetabular impingement (FAI) consists of a set of anatomical changes both in the acetabulum and/or

proximal femur.^{1,2} FAI may be associated with chondral or labral lesions and, finally, with secondary osteoarthritis (OA).^{3,4} Dynamic joint changes could cause the characteristic lesions of FAI and other joint sequelae.^{4,5} Classically, two types of FAI are described: the cam type is characterized by a femoral head–neck junction deformity that induces labral and chondral damage at the moment of hip flexion; the pincer type is characterized by an exaggerated covering of the acetabular margins with consequent damage to the head, metaphysis or femoral neck.^{1,5} The biomechanical knowledge inherent to FAI has allowed for the extension of the definition to other causes of joint conflict, such as femoral retroversion⁶ and femoral retroversion with *coxa valga*,⁷ but has also been able to explain other deformities compatible with pincer type conflict. In this type of impingement, the hyper-coverage causes femoral lesions by impaction at the moment of maximum flexion.⁸ This excessive marginal coverage could be generalized (*coxa profunda* or *protusio acetabuli*) or focal (acetabular retroversion: AR).⁹ Changes in acetabular orientation and failure to recognize them may have implications for the final FAI treatment outcome.¹⁰ Moreover, acetabular orientation anomalies could coexist with other important deformities (femoral cam deformity, abnormal femoral version) and should always be excluded from the evaluation.

Pathoanatomy

In normal hip development, the acetabular version progressively increases until the triradiate cartilage closure. This increase is mostly due to the bone growth on the acetabular posterior wall in its supero-lateral aspect.^{11,12} AR is an abnormal opening of the acetabulum in the sagittal plane in a posterior direction, with an excessive coverage of the femoral head and metaphysis in the anterior border.¹³ Its prevalence may be increased in patients

with hip development changes. Although the risk and pathophysiological factors inherent to acetabular malorientation are unknown, AR may be present in 5 to 20% of the general population,^{10,14,15} 16 to 25% of dysplastic hips,^{16,17} 31 to 49% of patients with Legg-Calvé-Perthes disease (LCPD),^{16,18,19} and 36 to 76% of Slipped Capital Femoral Epiphysis (SCFE).^{20,21} In dysplastic hips, it is possible to find unfused secondary ossification centres named *os acetabuli* that usually increase the anterior acetabular margin and the predisposition for anterior overcoverage.^{22,23}

The clinical relevance of AR is explained by the biomechanical implications resulting from acetabular malorientation and its association with OA. Two underlying mechanisms are described: a poor posterior coverage and an excessive anterior marginal prominence.^{5,10,24,25} Additionally, anatomical modifications in the pelvic rotation (retroversion of the hemipelvis) may be at the root of AR.²⁶ In the normal hip, the highest region of contact and articular load in the acetabulum is located in the postero-superior aspect.^{27,28} The decreased area in the posterior wall, either by dysplasia or poor orientation, modifies the articular contact region, causing stress zones with subsequent early OA phenomena.^{10,15,29} The degenerative mechanisms resulting from anterior hyper-coverage are the result of a combination of labral lesions and ‘contre-coup lesions’ on the posterior wall.^{4,25,30} The load distribution occurs at specific sites and the force exerted on the acetabulum is not homogeneously distributed throughout the articular surface.³¹ The clinical impact of these changes increases when the patient stands up from a seated position where a greater load is put on the posterior wall.^{31,32} The knowledge underlying these and other changes supports the development of appropriate diagnostic and therapeutic algorithms for each specific situation.^{33,34}

Clinical presentation and physical examination

AR can be difficult to diagnose in the absence of predisposing conditions (i.e. dysplasia, SCFE) although it should always be considered in the presence of a painful hip in the young adult.^{10,35} The peculiarities of its radiographic identification and delay in the clinical-radiological correlation are associated with a delayed diagnosis and ineffective therapeutic strategies.³⁶

In the absence of a previous history of hip pathology, clinical presentation of AR is suggestive of FAI by focal or global hyper-coverage of the acetabulum.⁹ The most frequent symptom is mechanical hip pain with insidious evolution and no trauma associated. Pain in the trochanteric region with irradiation along the lateral region of the thigh is frequent and may be confused with peri-trochanteric syndrome. Pain in sitting position with relief in orthostatism

suggests a posterior hypo-coverage.³⁷ Secondary lesions of the acetabular labrum and chondral surface may also be the cause of pain.³⁸ Pain and discomfort in the buttock, thigh and lumbar region may be associated with it although they are less frequent. Exercises that require mobilization to the maximum articular range of motion can trigger and aggravate the clinical complaints.³⁵

In the physical examination, the most frequent finding is the internal rotation limitation during maximal flexion and adduction in relation to the anatomical phenomenon of anterior hyper-coverage (positive impingement sign).^{39–41} The Drehmann sign could also be present, suggesting anterior FAI.^{29,42} Limitations in the hip range of motion could be the first physical sign in the presence of early degenerative changes.⁴²

Radiological evaluation

The identification of radiographic changes in the acetabular orientation (or version) should be included in the standard assessment of hip pain in the young adult with or without risk factors.⁴² The clinical relevance of the radiological signs and changes inherent to AR is still a theme of discussion given the high incidence of these changes in asymptomatic individuals.⁴³

In addition to the classic signs of hip OA, systematic radiological examination should address the acetabular cover and the anatomical relationship between the femoral head and neck (Fig. 1a). The FAI radiographic evaluation should cover standard measures that attempt to objectify and grade possible changes found. The most frequently used radiographic incidences are the antero-posterior (AP), the Dunn and the cross-table views and the Lequesne false profile. The vertical and horizontal lines are drawn according to the pelvic anatomy and not the radiographic edge (due to a possible tilt bias).

- **Lateral centre-edge angle (Wiberg angle):** angle measured in the AP incidence formed by a vertical line and a line connecting the femoral head centre to the lateral edge of the acetabulum. This angle quantifies the acetabular coverage signalling acetabular dysplasia (< 20°) or acetabular hyper-coverage (> 30–40°) (Fig. 1b).^{32,44}
- **Acetabular index (Tönnis angle):** angle measured in the AP incidence and formed between a horizontal line and a line connecting the most medial and inferior point of the acetabular sclerotic zone to the lateral margin of the acetabular dome. Values greater than 13° suggest acetabular dysplasia and values close or inferior to 0° imply acetabular hyper-coverage (Fig. 1c).⁴⁵
- **Alpha angle (Notzli angle):** angle measured in the AP or Dunn incidence and formed between the

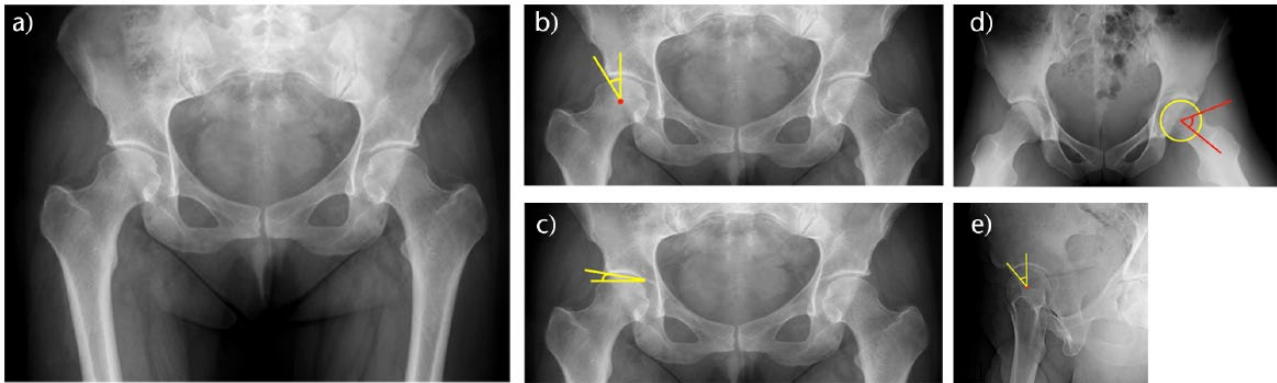


Fig. 1 (a) Radiographic evaluation of the young adult with hip pain starts with an overall evaluation of the classic pelvic antero-posterior incidence; (b) Lateral centre-edge angle (Wiberg angle); (c) Acetabular index (Tönnis angle); (d) Alpha angle (Notzli angle); (e) Anterior centre-edge angle (Lequesne angle).

femoral neck axis and a line connecting the femoral head centre to the point where the head loses sphericity. Values greater than 50° define an abnormal head–neck transition (cam deformity) that is associated with labral and chondral lesions in the maximum range of motion (Fig. 1d).⁴⁶

- **Anterior centre-edge angle (Lequesne angle):** angle measured in the false-profile view and formed between a vertical line and a line connecting the femoral head centre to the most anterior point of the acetabular margin. Values greater than 20° suggest an excessive anterior coverage and structural instability (Fig. 1e).^{1,47}

The evaluation of the relationship between the acetabulum anterior and posterior walls as well as their position in relation to the remaining pelvis could be affected by the radiographic quality and the pelvic tilt during the examination.^{48–50} However, radiographic evaluation should be the first diagnostic tool and efforts may address a reliable examination. Specific radiographic signs suggestive of AR consist of the cross-over sign, the posterior wall sign and the ischial spine sign present in the pelvic AP incidence (Fig. 2a).⁵¹

- **Cross-over sign:** present when the anterior wall of the acetabulum is more lateral than the posterior wall in an AP pelvic radiograph of the pelvis.¹³ Its presence frequently occurs in the cranial half of the overlapping acetabular walls. Identification of the posterior wall is facilitated by its location near the ischium and the anterior wall is usually more horizontal (Fig. 2b). This signal is strongly affected by the pelvic tilt and the ampoule inclination when performing the radiography.^{29,52} The sensitivity and specificity of this signal varies between 70–90% and 50–90%, respectively.^{13,53,54} The AR index is an objective value of the amount of cross-over between

both walls having revealed a strong association (values greater than 20%) with the development of early chondral lesions (Fig. 2c).^{45,49,55}

- **Posterior wall sign:** present when the posterior wall of the acetabulum is medial to the centre of the femoral head.^{10,29,56} In the normal hip, the margin of the acetabular posterior wall intersects the centre of the femoral head.⁴² Its presence reveals an anomalous acetabular version even in the absence of cross-over sign which is associated with an early progression to osteoarthritis (Fig. 2d).^{3,42}
- **Ischial spine sign:** presence of the triangular shape of the ischial spine medially to the pelvic ridge. Its presence has a sensitivity and specificity greater than 90% in the detection of AR and can be explained by the external rotation of the hemipelvis underlying AR.^{57,58} The sensitivity and specificity of this signal is relatively independent of the pelvic orientation, which makes it powerful in detecting AR.⁵⁸ The presence of this signal in association with the cross-over signal is related to the progression of degenerative changes (Fig. 2e).³

The factors affecting radiographic evaluation result in an overall high sensitivity and low specificity in the diagnosis of AR.⁵⁴ Computed tomography (CT) evaluation is a more reliable method for assessing hip anomalies (Fig. 3).^{29,38} Three-dimensional reconstructions allow the spatial and dynamic notion of acetabular and femoral deformities, allowing clarification of the cause of symptoms.^{59–61} Comparative studies between the radiographic signs and the tomographic quantification of AR highlight CT as the ideal diagnosis and preoperative planning method for AR.^{52–54} The physiological values of acetabular version range between 12° and 20° , being measured in the axial tomographic section in which the diameter of the head is greater.⁶² However, acetabular version evaluation

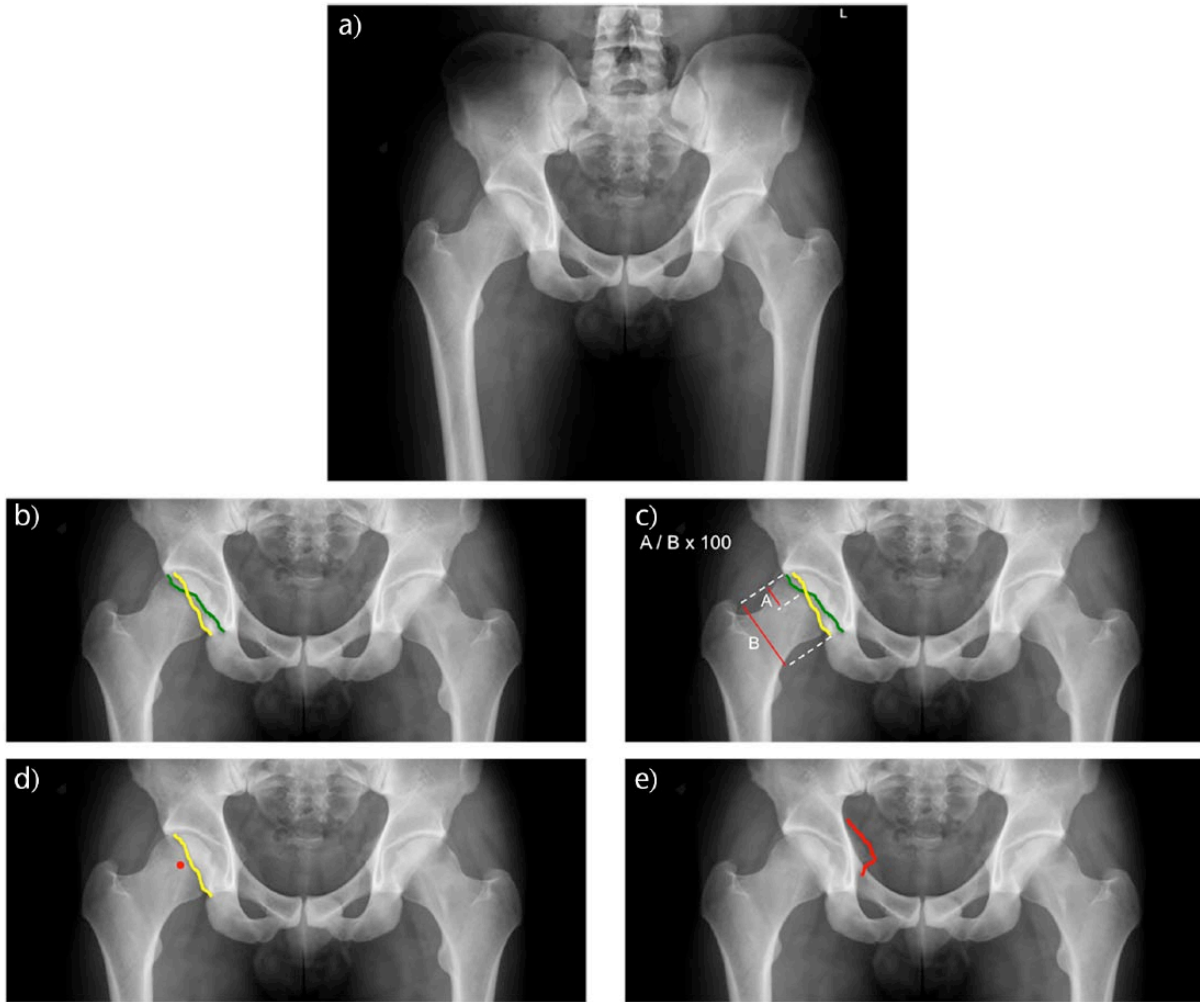


Fig. 2 (a) Specific radiographic signs suggestive of acetabular retroversion could be found in the classic pelvic antero-posterior incidence; (b) Cross-over sign; (c) the acetabular retroversion index measurement; (d) Posterior wall sign; (e) Ischial spine sign.



Fig. 3 The computed tomography axial evaluation is the most reliable method of assessing acetabular orientation. The acetabular version is an angle measured in the axial plan formed by a vertical line (perpendicular to the horizontal axis of the pelvis) and a line connecting the most anterior and posterior points of the acetabular margin.

is challenging, even with CT, since a single axial plane is not fully representative of the deformity as a whole.

The detailed evaluation of the hip involves the performance of a magnetic resonance imaging (MRI) study in order to characterize possible labral and chondral lesions and plan a therapeutic strategy (Fig. 4).³³ The main contribution of preoperative MRI is to show the extent of lesions resulting from anatomical changes previously documented with other imaging methods.²⁵ This detailed analysis as well as the development of new MRI techniques allows not only the documentation of intra-articular sequelae but also the analysis of other variables involved in the origin and progression of OA.⁶³

Treatment

FAI treatment aims to correct anatomical changes in order to relieve patients' symptoms and to avoid associated early

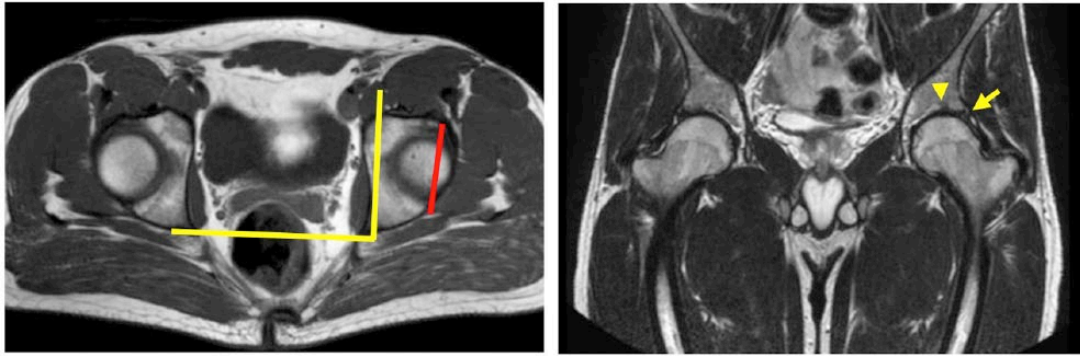


Fig. 4 The magnetic resonance imaging of the hip permits the diagnosis of labral (arrow) and chondral lesions (arrow head) and it is used to plan a therapeutic strategy.

degenerative lesions.³⁹ Preoperative planning of the symptomatic hip requires detailed anatomical assessment of the acetabulum.⁶⁴

AR must be seen as a sub-entity with specific biomechanical repercussions in the treatment of FAI. Knowledge about the mechanisms of injury may support the ideal treatment for the retroverted acetabulum with or without changes in femoral morphology. Conventionally, it is well-stated that AR presupposes an anterior hypercoverage of the femoral metaphysis, supporting the trimming of the anterior wall of the acetabulum in order to relieve the mechanism of anterior pincer lesion.^{65,66} However, AR may exist without an increase in the anterior femoral covering, and resection of the anterior wall as a form of treatment in these cases may result in an imbalance of the acetabular contact forces with potential for early degenerative changes.⁵⁴

The surgical treatment of the FAI pincer type (with or without AR) consists of acetabular rim trimming (ART) (open or arthroscopic) or acetabular re-orientation through a periacetabular osteotomy (PAO).^{56,66,67} The anatomic and morphological differences of the acetabulum in this type of impingement may have prognostic implications in a given treatment.⁶⁸ The global anatomical changes of the pelvis and their relationships with the myotendinous and periarticular structures present in AR can influence the underlying biomechanical description. Knowledge of these correlations may play a role in future therapeutic options in AR.^{17,26} The appropriate treatment for AR is still controversial due to the difficulty in clarifying the mechanisms underlying the precursor lesions of OA, although both PAO and ART have shown good results at short-term follow-up evaluation.^{56,69–73}

To date, there are only two series that directly compare two therapeutic options: PAO and ART (both with or without femoral osteochondroplasty). Peters et al³³ established the therapeutic choice based on posterior acetabular coverage and in the presence/absence of chondral lesions

(Fig. 5). Good results were verified at an average follow-up of four years in both groups, confirming the need for appropriate anatomical characterization and careful patient selection for each type of treatment. More recently, Zurmühle et al⁷⁴ described the comparison between ART (57 hips) and PAO (67 hips), with comparable results in the five-year follow-up evaluation, but with a clear reduction in survival rate in the ART group at the 10-year follow-up evaluation (23% ART vs. 79% PAO).

Periacetabular osteotomy

Modified pelvic rotation as well as decreased posterior acetabular surface and consequent increase in posterior contact stress support PAO osteotomy as the preferred treatment for AR.^{22,33,58} The study performed by Stepacher et al using MRI arthrography revealed the absence of an additional articular surface area and determined acetabular malorientation as the dominant morphological modification in AR.⁶⁸ The ART may therefore result in a decrease in joint surface area with consequent increase in load stress on the remaining acetabular surface.^{75,76}

Acetabular re-orientation through PAO was first described in the treatment of acetabular dysplasia.⁷⁷ Favourable results were described at 10-year follow-up in patients younger than 40 years, with no significant limitation of joint mobility and with incipient degenerative changes.^{33,56} Siebenrock et al demonstrated a significant functional improvement at 11-year follow-up in a group of 29 patients undergoing acetabular re-orientation osteotomy.⁷⁸ In this study, eight patients (29%) showed progression of OA, signs of over and under correction and/or requiring re-intervention. This survival rate was the same as recently described by Zurmühle et al.⁷⁴

PAO is a complex surgical technique traditionally associated with a high rate of complications, especially in the early stages of the surgical learning curve.⁷⁹ In the multi-centre study performed by Zaltz et al, a complication rate of 5.9% (12 patients) was observed in 205 operated

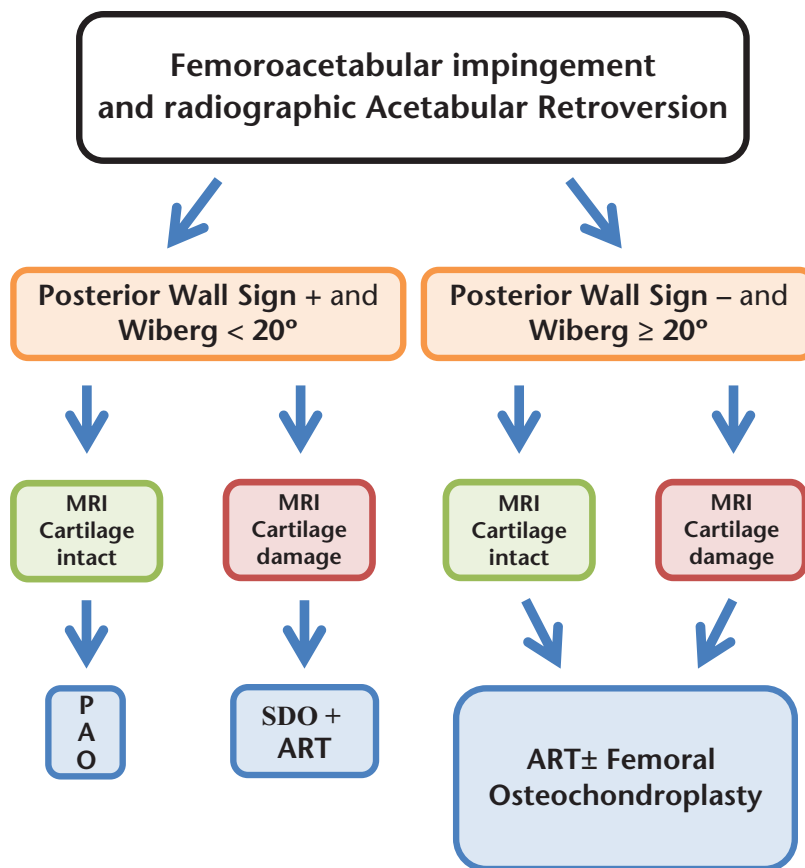


Fig. 5 Adapted algorithm for treatment of femoroacetabular impingement due to acetabular retroversion conceived by Peters et al.³³

Notes. MRI, magnetic resonance imaging; PAO, periacetabular osteotomy; ART, acetabular rim trimming; SDO, surgical dislocation and osteochondroplasty.

patients.⁸⁰ Most complications requiring re-intervention were related to structural failure of surgical fixation (five patients) and infection (two patients). The same authors confirm that, despite being dependent on a surgeon's experience, PAO is a safe procedure for correction of dysplastic hip alterations, including AR, with predictable complications and without permanent dysfunction.

Acetabular rim trimming

The pathophysiological basis supporting ART is the anterior acetabular hyper-coverage with consequent increase of the articular surface typical of pincer deformity.¹⁰ This procedure can be performed through an open approach (with or without surgical hip dislocation: SDO) or with arthroscopy.^{66,72} This strategy is indicated in young non-obese patients with no clinical signs of instability, radiographic signs of dysplasia (Wiberg angle < 20%) and significant signs of OA (Tonnis ≤ 1).^{71,72} In the presence of AR, isolated resection of the acetabular margin may be indicated in cases of significant chondral damage since acetabular re-orientation can relocate the axis load in a zone of chondral injury.³³ The finite element study of

Henak et al reveals the absence of increased contact stress resulting from AR depreciating the acetabular re-orientation to normalize the joint contact pressures.³¹

Open ART was classically conceived in the FAI group of treatments in which could be included the surgical hip dislocation described by Reinhold Ganz.⁶⁷ Although not specific to AR treatment, the first cohorts were described in 2004 by Beck et al⁸¹ and Murphy et al⁸² with a surgical survival rate (endpoint: hip arthroplasty) of 70–75% five years after surgery. Further studies, also not specific to AR, revealed better survival rates albeit with shorter follow-up times.^{70,76,83,84} In 2015, Steppacher et al⁷² described an 80% survival rate of ART through surgical hip dislocation with a 10-year follow-up time in a group of 72 patients (93 hips). To date this is the longest follow-up series published. The same study found no differences between the open and arthroscopic approaches. The same research group, however, reveals that the acetabular anatomy has a real impact on the surgical results of the FAI treatment: at 10-year follow-up, almost 50% of the hips with *protusio acetabuli* submitted to ART suffered a worsening of the degenerative changes.⁸⁵

Arthroscopic treatment allows an articular minimally invasive access and an increased visualization of joint injuries, being associated with good short and medium-term results with a low complication rate.⁷¹ However, these clinical results are described in heterogeneous series where acetabular anatomy is often not adequately characterized and with short follow-up evaluations (< 5 years).^{66,69,86–89} The series published by Hartigan et al in 2016 is the only one where arthroscopic treatment was performed to treat AR in isolation.⁷¹ In this study, in a group of 82 hips of 78 patients, good results were verified at a minimum follow-up of two years, without worsening of the articular wearing process, with a complication rate of 3.6% and only one patient requiring arthroplasty.⁷¹

Conclusion

With this review, the authors aimed to highlight the importance of a correct recognition and knowledge of the morpho-structural changes that may be present in the young adult patient with hip pain. AR is a frequent condition related to the development of OA in symptomatic patients. Its exclusion is therefore essential in this group of patients. The described conventional radiographic changes revealed a high clinical relevance. However, given the variable sensitivity and specificity described in previous studies, the CT scan is the most reliable method to diagnose AR. ART and PAO are two surgical techniques with different pathophysiological underlying philosophies and good clinical results at short and medium-term follow-up evaluations. In future, better knowledge about the pathophysiology inherent to AR may play an important role in the diagnosis and treatment of this condition.

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REFERENCES

- Ganz R, Parvizi J, Beck M, Leunig M, Notzli H, Siebenrock KA.** Femoroacetabular impingement: a cause for osteoarthritis of the hip. *Clin Orthop Relat Res* 2003;417:112–120.
- Leunig M, Beaulé PE, Ganz R.** The concept of femoroacetabular impingement: current status and future perspectives. *Clin Orthop Relat Res* 2009;467:616–622.
- Bardakos NV, Villar RN.** Predictors of progression of osteoarthritis in femoroacetabular impingement: a radiological study with a minimum of ten years follow-up. *J Bone Joint Surg Br* 2009;91:162–169.
- Beck M, Kalhor M, Leunig M, Ganz R.** Hip morphology influences the pattern of damage to the acetabular cartilage: femoroacetabular impingement as a cause of early osteoarthritis of the hip. *J Bone Joint Surg Br* 2005;87:1012–1018.
- Tibor LM, Leunig M.** The pathoanatomy and arthroscopic management of femoroacetabular impingement. *Bone Joint Res* 2012;1:245–257.
- Satpathy J, Kannan A, Owen JR, Wayne JS, Hull JR, Jiranek WA.** Hip contact stress and femoral neck retroversion: a biomechanical study to evaluate implication of femoroacetabular impingement. *J Hip Preserv Surg* 2015;2:287–294.
- Siebenrock KA, Steppacher SD, Haefeli PC, Schwab JM, Tannast M.** Valgus hip with high antetorsion causes pain through posterior extraarticular FAI. *Clin Orthop Relat Res* 2013;471:3774–3780.
- Leunig M, Ganz R.** Femoroacetabular impingement: diagnosis and management, including open surgical technique. *Oper Tech Sports Med* 2007;15:178–188.
- Hadeed MM, Cancienne JM, Gwathmey FW.** Pincer impingement. *Clin Sports Med* 2016;35:405–418.
- Giori NJ, Trousdale RT.** Acetabular retroversion is associated with osteoarthritis of the hip. *Clin Orthop Relat Res* 2003;417:263–269.
- Monazzam S, Bomar JD, Dwek JR, Hosalkar HS, Pennock AT.** Development and prevalence of femoroacetabular impingement-associated morphology in a paediatric and adolescent population: a CT study of 225 patients. *Bone Joint J* 2013;95-B:598–604.
- Hingsammer AM, Bixby S, Zurakowski D, Yen YM, Kim YJ.** How do acetabular version and femoral head coverage change with skeletal maturity? *Clin Orthop Relat Res* 2015;473:1224–1233.
- Jamali AA, Mladenov K, Meyer DC, et al.** Anteroposterior pelvic radiographs to assess acetabular retroversion: high validity of the ‘cross-over-sign’. *J Orthop Res* 2007;25:758–765.
- Li PL, Ganz R.** Morphologic features of congenital acetabular dysplasia: one in six is retroverted. *Clin Orthop Relat Res* 2003;416:245–253.
- Kim WY, Hutchinson CE, Andrew JG, Allen PD.** The relationship between acetabular retroversion and osteoarthritis of the hip. *J Bone Joint Surg Br* 2006;88:727–729.
- Ezoe M, Naito M, Inoue T.** The prevalence of acetabular retroversion among various disorders of the hip. *J Bone Joint Surg Am* 2006;88:372–379.
- Fujii M, Nakashima Y, Yamamoto T, et al.** Acetabular retroversion in developmental dysplasia of the hip. *J Bone Joint Surg Am* 2010;92:895–903.

- 18. Kawahara S, Nakashima Y, Oketani H, et al.** High prevalence of acetabular retroversion in both affected and unaffected hips after Legg–Calve–Perthes disease. *J Orthop Sci* 2012;17:226–232.
- 19. Sankar WN, Flynn JM.** The development of acetabular retroversion in children with Legg–Calve–Perthes disease. *J Pediatr Orthop* 2008;28:440–443.
- 20. Sankar WN, Brighton BK, Kim YJ, Millis MB.** Acetabular morphology in slipped capital femoral epiphysis. *J Pediatr Orthop* 2011;31:254–258.
- 21. Bauer JP, Roy DR, Thomas SS.** Acetabular retroversion in post slipped capital femoral epiphysis deformity. *J Child Orthop* 2013;7:91–94.
- 22. Martinez AE, Li SM, Ganz R, Beck M.** Os acetabuli in femoro-acetabular impingement: stress fracture or unfused secondary ossification centre of the acetabular rim? *Hip Int* 2006;16:281–286.
- 23. Hadeed MM, Cancienne JM, Gwathmey FW.** Pincer impingement. *Clin Sports Med* 2016;35:405–418.
- 24. Tonnis D, Heinecke A.** Acetabular and femoral anteversion: relationship with osteoarthritis of the hip. *J Bone Joint Surg Am* 1999;81:1747–1770.
- 25. Pffrman CW, Mengiardi B, Dora C, Kalberer F, Zanetti M, Hodler J.** Cam and pincer femoroacetabular impingement: characteristic MR arthrographic findings in 50 patients. *Radiology* 2006;240:778–785.
- 26. Tannast M, Pfannebecker P, Schwab JM, Albers CE, Siebenrock KA, Buchler L.** Pelvic morphology differs in rotation and obliquity between developmental dysplasia of the hip and retroversion. *Clin Orthop Relat Res* 2012;470:3297–3305.
- 27. Pedersen DR, Brand RA, Davy DT.** Pelvic muscle and acetabular contact forces during gait. *J Biomech* 1997;30:959–965.
- 28. Witte H, Eckstein F, Recknagel S.** A calculation of the forces acting on the human acetabulum during walking: based on in vivo force measurements, kinematic analysis and morphometry. *Acta Anat (Basel)* 1997;160:269–280.
- 29. Reynolds D, Lucas J, Klau K.** Retroversion of the acetabulum: a cause of hip pain. *J Bone Joint Surg Br* 1999;81:281–288.
- 30. Ganz R, Leunig M, Leunig-Ganz K, Harris WH.** The etiology of osteoarthritis of the hip: an integrated mechanical concept. *Clin Orthop Relat Res* 2008;466:264–272.
- 31. Henak CR, Carruth ED, Anderson AE, et al.** Finite element predictions of cartilage contact mechanics in hips with retroverted acetabula. *Osteoarthritis Cartilage* 2013;21:1522–1529.
- 32. Chagini S, Beck M, Ferguson SJ.** The effects of impingement and dysplasia on stress distributions in the hip joint during sitting and walking: a finite element analysis. *J Orthop Res* 2009;27:195–201.
- 33. Peters CL, Anderson LA, Erickson JA, Anderson AE, Weiss JA.** An algorithmic approach to surgical decision making in acetabular retroversion. *Orthopedics* 2011;34:10.
- 34. Hogervorst T, Bouma H, de Boer SF, de Vos J.** Human hip impingement morphology: an evolutionary explanation. *J Bone Joint Surg Br* 2011;93:769–776.
- 35. Clohisy JC, Knaus ER, Hunt DM, Lesher JM, Harris-Hayes M, Prather H.** Clinical presentation of patients with symptomatic anterior hip impingement. *Clin Orthop Relat Res* 2009;467:638–644.
- 36. Clohisy JC, Keeney JA, Schoenecker PL.** Preliminary assessment and treatment guidelines for hip disorders in young adults. *Clin Orthop Relat Res* 2005;441:168–179.
- 37. Tonnis D.** *Congenital dysplasia and dislocation of the hip in children and adults.* New York: Springer Berlin Heidelberg, 1984.
- 38. Jaber FM, Parvizi J.** Hip pain in young adults: femoroacetabular impingement. *J Arthroplasty* 2007;22(suppl 3):37–42.
- 39. Beaulé PE, Allen DJ, Clohisy JC, Schoenecker P, Leunig M.** The young adult with hip impingement: deciding on the optimal intervention. *J Bone Joint Surg Am* 2009;91:210–221.
- 40. Peters CL, Erickson JA.** Treatment of femoro-acetabular impingement with surgical dislocation and debridement in young adults. *J Bone Joint Surg Am* 2006;88:1735–1741.
- 41. Ratzlaff C, Simatovic J, Wong H, et al.** Reliability of hip examination tests for femoroacetabular impingement. *Arthritis Care Res (Hoboken)* 2013;65:1690–1696.
- 42. Tannast M, Siebenrock KA, Anderson SE.** Femoroacetabular impingement: radiographic diagnosis – what the radiologist should know. *AJR Am J Roentgenol* 2007;188:1540–1552.
- 43. Larson CM, Moreau-Gaudry A, Kelly BT, et al.** Are normal hips being labeled as pathologic? A CT-based method for defining normal acetabular coverage. *Clin Orthop Relat Res* 2015;473:1247–1254.
- 44. Murphy SB, Ganz R, Muller ME.** The prognosis in untreated dysplasia of the hip: a study of radiographic factors that predict the outcome. *J Bone Joint Surg Am* 1995;77:985–989.
- 45. Nehme A, Trousdale R, Tannous Z, Maalouf G, Puget J, Telmont N.** Developmental dysplasia of the hip: is acetabular retroversion a crucial factor? *Orthop Traumatol Surg Res* 2009;95:511–519.
- 46. Notzli HP, Wyss TF, Stoecklin CH, Schmid MR, Treiber K, Hodler J.** The contour of the femoral head–neck junction as a predictor for the risk of anterior impingement. *J Bone Joint Surg Br* 2002;84:556–560.
- 47. Lequesne M, de S.** False profile of the pelvis: a new radiographic incidence for the study of the hip. Its use in dysplasias and different coxopathies. *Rev Rhum Mal Osteoartic* 1961;28:643–652.
- 48. Tannast M, Zheng G, Andereg C, et al.** Tilt and rotation correction of acetabular version on pelvic radiographs. *Clin Orthop Relat Res* 2005;438:182–190.
- 49. Siebenrock KA, Kalbermatten DF, Ganz R.** Effect of pelvic tilt on acetabular retroversion: a study of pelvises from cadavers. *Clin Orthop Relat Res* 2003;407:241–248.
- 50. Tannast M, Fritsch S, Zheng G, Siebenrock KA, Steppacher SD.** Which radiographic hip parameters do not have to be corrected for pelvic rotation and tilt? *Clin Orthop Relat Res* 2015;473:1255–1266.
- 51. Werner CM, Copeland CE, Ruckstuhl T, et al.** Radiographic markers of acetabular retroversion: correlation of the cross-over sign, ischial spine sign and posterior wall sign. *Acta Orthop Belg* 2010;76:166–173.
- 52. Zaltz I, Kelly BT, Hetsroni I, Bedi A.** The crossover sign overestimates acetabular retroversion. *Clin Orthop Relat Res* 2013;471:2463–2470.
- 53. Hashemi SA, Dehghani J, Vosoughi AR.** Can the crossover sign be a reliable marker of global retroversion of the acetabulum? *Skeletal Radiol* 2017;46:17–21.
- 54. Dandachli W, Islam SU, Liu M, Richards R, Hall-Craggs M, Witt J.** Three-dimensional CT analysis to determine acetabular retroversion and the implications for the management of femoro-acetabular impingement. *J Bone Joint Surg Br* 2009;91:1031–1036.
- 55. Diaz-Ledezma C, Novack T, Marin-Pena O, Parvizi J.** The relevance of the radiological signs of acetabular retroversion among patients with femoroacetabular impingement. *Bone Joint J* 2013;95-B:893–899.
- 56. Siebenrock KA, Schoeniger R, Ganz R.** Anterior femoro-acetabular impingement due to acetabular retroversion: treatment with periacetabular osteotomy. *J Bone Joint Surg Am* 2003;85-A:278–286.

57. **Kalberer F, Sierra RJ, Madan SS, Ganz R, Leunig M.** Ischial spine projection into the pelvis: a new sign for acetabular retroversion. *Clin Orthop Relat Res* 2008;466:677–683.
58. **Kakaty DK, Fischer AF, Hosalkar HS, Siebenrock KA, Tannast M.** The ischial spine sign: does pelvic tilt and rotation matter? *Clin Orthop Relat Res* 2010;468:769–774.
59. **Tannast M, Kubiak-Langer M, Langlotz F, Puls M, Murphy SB, Siebenrock KA.** Noninvasive three-dimensional assessment of femoroacetabular impingement. *J Orthop Res* 2007;25:122–131.
60. **Perreira AC, Hunter JC, Laird T, Jamali AA.** Multilevel measurement of acetabular version using 3-D CT-generated models: implications for hip preservation surgery. *Clin Orthop Relat Res* 2011;469:552–561.
61. **Peters CL, Erickson JA, Anderson L, Anderson AA, Weiss J.** Hip-preserving surgery: understanding complex pathomorphology. *J Bone Joint Surg Am* 2009;91(suppl 6):42–58.
62. **Tallroth K, Lepisto J.** Computed tomography measurement of acetabular dimensions: normal values for correction of dysplasia. *Acta Orthop* 2006;77:598–602.
63. **Jessel RH, Zurakowski D, Zilkens C, Burstein D, Gray ML, Kim YJ.** Radiographic and patient factors associated with pre-radiographic osteoarthritis in hip dysplasia. *J Bone Joint Surg Am* 2009;91:1120–1129.
64. **Kohnlein W, Ganz R, Impellizzeri FM, Leunig M.** Acetabular morphology: implications for joint-preserving surgery. *Clin Orthop Relat Res* 2009;467:682–691.
65. **Parvizi J, Leunig M, Ganz R.** Femoroacetabular impingement. *J Am Acad Orthop Surg* 2007;15:561–570.
66. **Byrd JW, Jones KS.** Arthroscopic management of femoroacetabular impingement in athletes. *Am J Sports Med* 2011;39(suppl):7S–13S.
67. **Ganz R, Gill TJ, Gautier E, Ganz K, Krugel N, Berlemann U.** Surgical dislocation of the adult hip a technique with full access to the femoral head and acetabulum without the risk of avascular necrosis. *J Bone Joint Surg Br* 2001;83:1119–1124.
68. **Steppacher SD, Lerch TD, Gharanzadeh K, et al.** Size and shape of the lunate surface in different types of pincer impingement: theoretical implications for surgical therapy. *Osteoarthritis Cartilage* 2014;22:951–958.
69. **Palmer DH, Ganesh V, Comfort T, Tatman P.** Midterm outcomes in patients with cam femoroacetabular impingement treated arthroscopically. *Arthroscopy* 2012;28:1671–1681.
70. **Peters CL, Schabel K, Anderson L, Erickson J.** Open treatment of femoroacetabular impingement is associated with clinical improvement and low complication rate at short-term followup. *Clin Orthop Relat Res* 2010;468:504–510.
71. **Hartigan DE, Perets I, Walsh JP, Close MR, Domb BG.** Clinical outcomes of hip arthroscopy in radiographically diagnosed retroverted acetabula. *Am J Sports Med* 2016;44:2531–2536.
72. **Steppacher SD, Anwander H, Zurmühle CA, Tannast M, Siebenrock KA.** Eighty percent of patients with surgical hip dislocation for femoroacetabular impingement have a good clinical result without osteoarthritis progression at 10 years. *Clin Orthop Relat Res* 2015;473:1333–1341.
73. **Steppacher SD, Hueimmer C, Schwab JM, Tannast M, Siebenrock KA.** Surgical hip dislocation for treatment of femoroacetabular impingement: factors predicting 5-year survivorship. *Clin Orthop Relat Res* 2014;472:337–348.
74. **Zurmühle CA, Anwander H, Albers CE, et al.** Periacetabular osteotomy provides higher survivorship than rim trimming for acetabular retroversion. *Clin Orthop Relat Res* 2017;475:1138–1150.
75. **Sierra RJ.** The management of acetabular retroversion with reverse periacetabular osteotomy. *Instr Course Lect* 2013;62:305–313.
76. **Bhatia S, Lee S, Shewman E, et al.** Effects of acetabular rim trimming on hip joint contact pressures: how much is too much? *Am J Sports Med* 2015;43:2138–2145.
77. **Siebenrock KA, Leunig M, Ganz R.** Periacetabular osteotomy: the Bernese experience. *Instr Course Lect* 2001;50:239–245.
78. **Siebenrock KA, Schaller C, Tannast M, Keel M, Buchler L.** Anteverting periacetabular osteotomy for symptomatic acetabular retroversion: results at ten years. *J Bone Joint Surg Am* 2014;96:1785–1792.
79. **Peters CL, Erickson JA, Hines JL.** Early results of the Bernese periacetabular osteotomy: the learning curve at an academic medical center. *J Bone Joint Surg Am* 2006;88:1920–1926.
80. **Zaltz I, Baca G, Kim YJ, et al.** Complications associated with the periacetabular osteotomy: a prospective multicenter study. *J Bone Joint Surg Am* 2014;96:1967–1974.
81. **Beck M, Leunig M, Parvizi J, Boutier V, Wyss D, Ganz R.** Anterior femoroacetabular impingement: part II. Midterm results of surgical treatment. *Clin Orthop Relat Res* 2004;418:67–73.
82. **Murphy S, Tannast M, Kim YJ, Buly R, Millis MB.** Debridement of the adult hip for femoroacetabular impingement: indications and preliminary clinical results. *Clin Orthop Relat Res* 2004;429:178–181.
83. **Beaule PE, Le Duff MJ, Zaragoza E.** Quality of life following femoral head-neck osteochondroplasty for femoroacetabular impingement. *J Bone Joint Surg Am* 2007;89:773–779.
84. **Naal FD, Miozzari HH, Schar M, Hesper T, Notzli HP.** Midterm results of surgical hip dislocation for the treatment of femoroacetabular impingement. *Am J Sports Med* 2012;40:1501–1510.
85. **Hanke MS, Steppacher SD, Zurmühle CA, Siebenrock KA, Tannast M.** Hips with protrusio acetabuli are at increased risk for failure after femoroacetabular impingement surgery: a 10-year follow-up. *Clin Orthop Relat Res* 2016;474:2168–2180.
86. **Laude F, Sariali E, Nogier A.** Femoroacetabular impingement treatment using arthroscopy and anterior approach. *Clin Orthop Relat Res* 2009;467:747–752.
87. **Larson CM, Giveans MR, Stone RM.** Arthroscopic debridement versus refixation of the acetabular labrum associated with femoroacetabular impingement: mean 3.5-year follow-up. *Am J Sports Med* 2012;40:1015–1021.
88. **Ilizaliturri VM Jr, Joachin P, Acuna M.** Description and mid-term results of the ‘over the top’ technique for the treatment of the pincer deformity in femoroacetabular impingement. *J Hip Preserv Surg* 2015;2:369–373.
89. **Zhuo H, Wang X, Liu X, Song GY, Li Y, Feng H.** Quantitative evaluation of residual bony impingement lesions after arthroscopic treatment for isolated pincer-type femoroacetabular impingement using three-dimensional CT. *Arch Orthop Trauma Surg* 2015;135:1123–1130.