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Review article

Residual acetabular dysplasia in congenital hip dysplasia

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ABSTRACT

Residual hip dysplasia may exist despite appropriate treatment of congenital hip dysplasia (CHD). The abnormalities chiefly affect the acetabulum and can lead to premature osteoarthritis. Although the main cause is delayed treatment of CHD, primary lesions are also possible and may be worsened by the initial treatment itself. Residual hip dysplasia must be detected during the follow-up of patients with CHD. The antero-posterior radiograph of the pelvis is the main diagnostic tool. However, the importance of non-ossified anatomical structures requires additional investigations such as arthrography and magnetic resonance imaging. The risk of premature osteoarthritis is difficult to predict based only on the imaging-study findings. Hip dysplasia is best treated before 5 years of age. The work-up at this age should allow determination of the best treatment. Surgery is required but should not be performed unnecessarily. The decision rests on the absence of improvement in the radiographic criteria and on the findings from additional imaging studies. The usual treatment is Salter's osteotomy, during which excessive anterior displacement should be avoided. At adolescence, the information provided by radiography in the coronal plane should be completed by a three-dimensional evaluation of the acetabulum and an assessment of the quality of the labrum. The shelf procedure has been proven to relieve pain and to significantly postpone the need for hip arthroplasty, when performed early, before the development of visible osteoarthritis, and on a congruent hip. Chiari's osteotomy has a role to play in complex dysplasia affecting both the acetabulum and the femur. Periacetabular osteotomy is getting more used thanks to cooperation between paediatric and adult orthopaedic surgeons. This osteotomy provides optimal correction in all three dimensions.

1. Introduction

Hip dysplasia is the most common reason for hip osteoarthritis in young individuals and is present in over 50% of patients who require total hip arthroplasty (THA) before 50 years of age. This structural abnormality affects the femur, the acetabulum, or both and is due to a developmental disorder of the joint. Hip dysplasia may be primary or secondary to treatments. Seringe defined residual hip dysplasia (RHD) as hip dysplasia present after appropriate treatment of congenital hip dislocation (CHD) [1]. RHD has been reported in 2% to 20% of treated hips overall and in 2.7% of hips in recent cohort studies.

RHD results in mechanical hip dysfunction that accelerates cartilage wear, thereby leading to premature osteoarthritis. The treatment goal is to delay the development of osteoarthritis. The risk of osteoarthritis must therefore be evaluated and careful thought given to choosing a treatment approach that will have the least impact possible on the performance of arthroplasty for the definitive treatment of hip osteoarthritis.

In this article, we will not discuss iatrogenic femoral lesions, which have an early impact on the prognosis; primary dysplasia in patients with no known history of CHD; or dysplasia secondary to other conditions (e.g., infection or neurological disorders). A persistently eccentric femoral head is viewed as a form of treatment failure rather than as RHD. Consequently, we will focus on residual acetabular dysplasia (RAD).

We will discuss the following five questions:

- How can RAD be defined relative to normal hip growth?
- What are the causes of RAD?
- Which investigations should be performed to evaluate and monitor RAD?
- How can the consequences of RAD in the medium and long terms be evaluated?
- Which treatments are appropriate in each age group?

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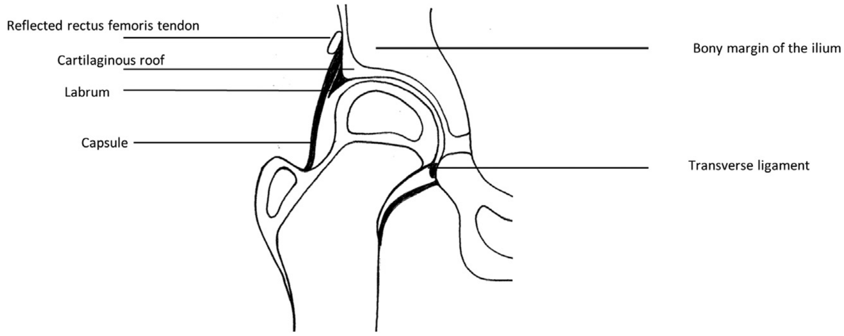

Fig. 1. Coronal view of a growing hip.

This work is based on recently published data, and therefore is dependent on their limitations (heterogeneous cohorts and limited follow-up duration), combined with reflections based on the experience of the authors.

2. How can residual acetabular dysplasia (RAD) be defined relative to normal hip growth?

2.1. Normal growth

The acetabulum develops at the junction of the cartilage anlages of the ilium, ischium, and pubic bone, which are connected by the triradiate cartilage.

The periphery of the acetabulum plays a key role in the development and evaluation of RAD. It is composed of three entities, whose definitions are controversial. We suggest that the following should be distinguished:

- the bony roof visible on standard radiographs;
- the cartilaginous roof, i.e., the non-ossified component composed of chondro-epiphyseal growth cartilage and its fibrocartilaginous rim, known as the *labrum* which persists in adulthood. The cartilaginous roof is nearly circular but is open distally, where it is in continuity with the transverse ligament. It is in contact with the intra-articular aspect of the joint capsule [2] (Fig. 1). At birth, the cartilaginous roof accounts for half the surface area of the acetabulum.

Ossification of the peripheral growth cartilage becomes complete at 12 years of age through three secondary ossification centres develop, one for each of the three bones that make up the acetabulum.

The labrum grows under the influence of mechanical forces generated by the growth of the bone [3].

Harmonious development of the hip requires that the femoral head be spherical, centred, and stable within a sufficiently deep acetabular cavity that is properly oriented. In addition, an efficient blood supply is needed.

According to Wolff's law, the reciprocal modelling of the femoral head and acetabulum in contact with each other produces the normal hip morphology.

2.2. Description of acetabular dysplasia

Acetabular dysplasia involves the bone, capsule, and ligaments [4], with the following abnormalities:

- excessively shallow acetabulum;
- verticalization of the acetabulum compared to the normal antero-inferior orientation;
- variable modification in acetabular anteversion: although the initial dislocation always occurs in the postero-superior direction, insufficient antero-superior coverage is the rule; it should be noted, however, that acetabular retroversion is seen in 18% of cases [5];
- in some cases, eccentric position of the femoral head, which rests on the lateral rim of the acetabulum;
- distortion of the cartilaginous roof and labrum; the labrum may be everted, crushed, or inverted; it gradually becomes hypertrophic and may develop tears, chiefly in its lateral and anterior parts;
- loss of femoral head sphericity;
- abnormal orientation of the proximal femoral metaphysis;
- instability with distension of the capsule and ligaments (Fig. 2).

Fig. 2. Residual acetabular dysplasia and coxa vara.

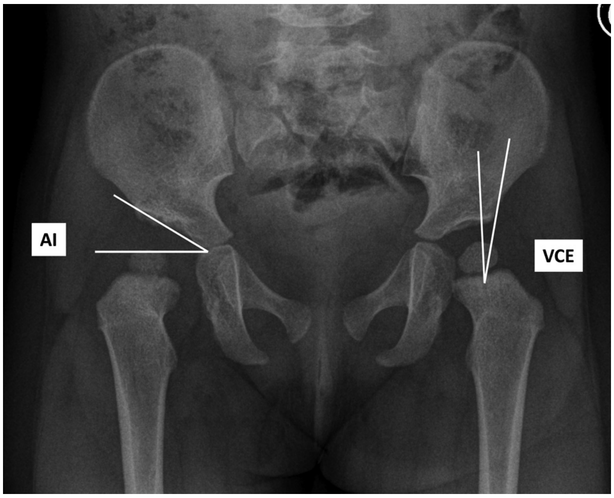

Fig. 3. Measurement of the vertical centre edge (VCE) angle and acetabular index (AI).

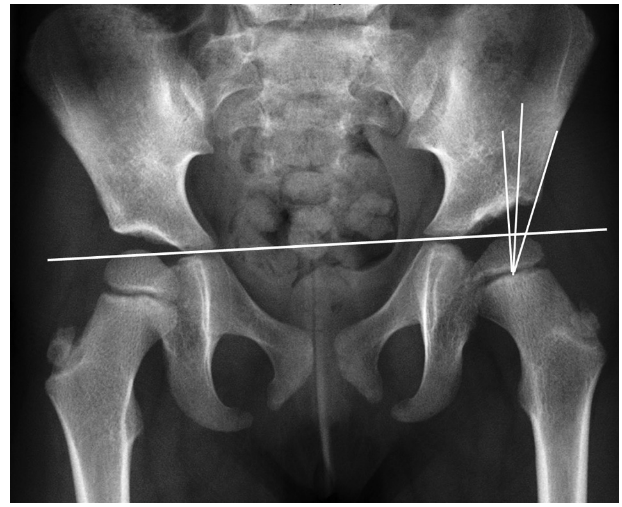

Fig. 4. VCE angle 11° according to Kim and 27° according to Shin.

2.3. Radiological definitions

RAD has been described on radiographs of the pelvis. The radiographic parameters are angles based on bony landmarks. The large proportion of cartilage in children therefore decreases measurement accuracy. The position of the child can also cause variations in all the parameters [6]. With increasing age, measurement accuracy and reproducibility improve, and the normal values gradually become more similar to those in adults.

- The vertical centre edge (VCE) angle or angle of lateral coverage is formed by a vertical line drawn through the centre of the femoral head, which is in the middle of the upper border of the metaphysis, and a line drawn from this point to the lateral brim of the acetabular roof. This angle increases gradually as ossification of the acetabular roof progresses. The VCE angle depends on the acetabulum and femoral head concentricity. It is normally greater than 20° at 4 years of age and equal to 25°–30° in adolescence.
- The acetabular index (AI) evaluates the slope of the acetabulum and is the angle formed by the horizontal line running through the most distal point of the iliac ossification centre (tri radiate cartilages line) and the lateral rim of the bony roof. The AI is not affected by femoral head centring. It decreases as ossification progresses until 4 years of age then remains stable. The normal value is 17° ± 5° (Fig. 3).
- In 2000, Kim suggested a modification of these measurements that uses the linear area of sclerosis known as the acetabular sourcil. The morphology, length, and orientation of the sourcil provide qualitative information on the dysplasia. According to Kim et al., the lateral end of the sourcil corresponds to the middle portion of the bony roof and the most lateral bony margin to its antero-lateral portion [7]. However, in a recent case-control study Shin et al. showed that the lateral margin of the bony acetabular roof produced better reproducibility compared to the lateral end of the sourcil, whose use may result in overdiagnosis of RAD and, consequently, in unnecessary surgical procedures [8] (Fig. 4).
- The acetabular angle described by Sharp in 1961 and reappraised by Tönnis measures the angle of infero-lateral inclination of the acetabulum. The same controversy exists about the best lateral landmark and the normal value, which is less than 38° according to Sharp and less than 41° according to Wenger [9].
- The shape of the acetabulum in its horizontal dimension and its surface area can be evaluated using Hefti's technique provided the anterior and posterior borders are visible [10], which occurs near the achievement of skeletal maturity (Fig. 5).
- Loss of femoral head centring is measured by the Reimers index as a percentage relative to the acetabulum and by the centre head distance discrepancy (CHDD) relative to the centre of the pelvis, normalised for the contralateral value [7] (Figs. 6 and 7).

3. What are the causes of residual acetabular dysplasia (RAD)?

The treatment of hip dysplasia consists in creating the conditions required for the joint to resume normal growth, often with a catch-up period. After reduction and stabilisation, the hip goes through a period of residual dysplasia, which normally improves rapidly, after 6 months to 2 years depending on the severity of the dislocation and the promptness of the treatment [9]. When this improvement does not occur, due either to excessively severe initial lesions or to delayed or excessively aggressive treatment, residual dysplasia persists.

Three causes may be combined:

- primary dysplasia, which initially promotes instability;
- dysplasia secondary to delayed or imperfect re-centring or stabilisation;
- and iatrogenic lesions.

The respective contributions of each of these three causes cannot be determined.

3.1. Primary dysplasia

The initial shape of the acetabulum is difficult to evaluate but probably plays a role in residual dysplasia. The high frequency of dysplasia of the contralateral hip supports this possibility.

Antenatal compression with inversion of the cartilaginous roof adversely affects the growth of this structure until adolescence. These lesions develop during the last three months of pregnancy and are all the more severe that they occur earlier [11].

In addition to postero-superior compression by the femoral head, pressure from the ilio-psoas tendon on the antero-superior portion of the joint capsule and cartilage may contribute to the development of dysplasia at this site.

Wolff's law also explains that dysplasia predominates at the antero-superior part of the acetabulum, whereas the displacement

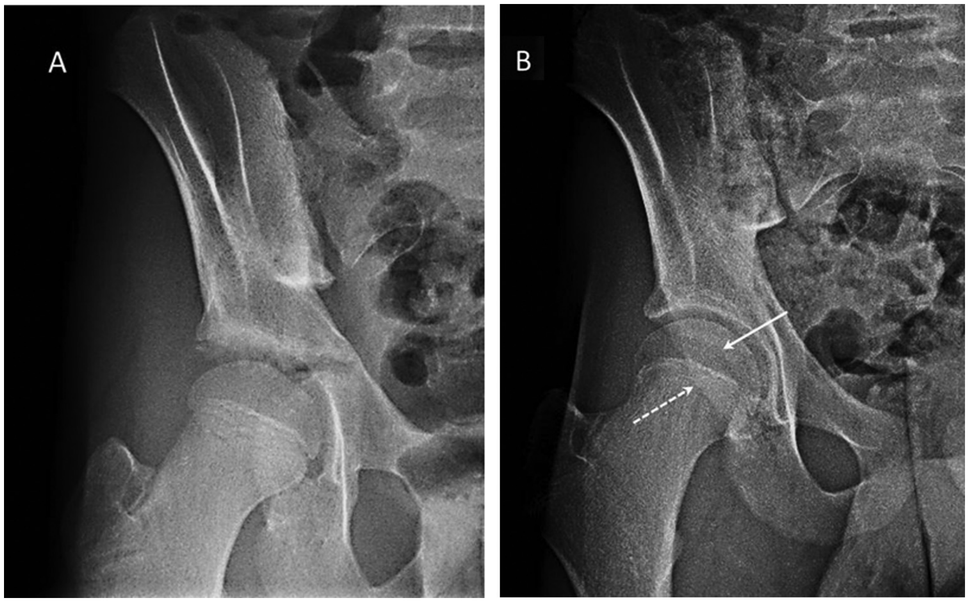

Fig. 5. At 12 years of age (A) the secondary ossification centre of the acetabulum becomes visible. At 15 years of age (B) the acetabular roof is ossified, and its anterior margin (solid arrow) and posterior margin (dotted-line arrow) are clearly visible.

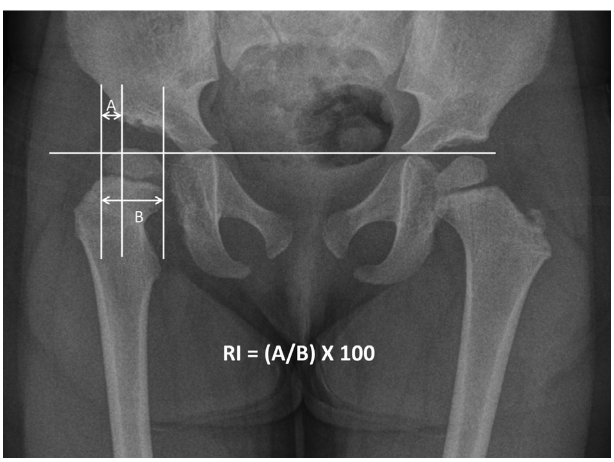

Fig. 6. Reimers index.

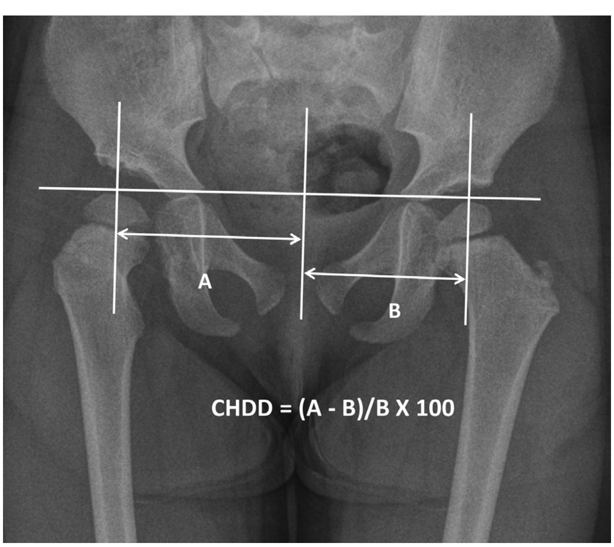

Fig. 7. Centre head distance discrepancy (CHDD).

of the femoral head occurs in the postero-superior direction: the absence of anterior pressure temporarily inhibits the growth of the anterior part of the acetabulum, as shown in experimental studies by Delgado-Baeza [12].

3.2. Delayed treatment

The main cause of residual dysplasia is delayed treatment, which is due to delayed diagnosis. The institution of early screening for developmental hip dysplasia has been associated with a decrease in the frequency of residual dysplasia from over 20% to less than 3% of treated hips.

Appropriate treatment before 4 months of age usually ensures normal hip development, with no visible residual dysplasia, due to normalisation of the loads applied to the cartilaginous roof.

After 4 months of age, any delay in treatment initiation increases the risk of residual dysplasia. After 36 months of age, and perhaps even after 18 months of age, residual dysplasia is almost consistently present [13]. Consequently, many teams perform an acetabular osteotomy at the time of reduction if the treatment is delayed. This strategy was validated by a case-control study reported by Carsi in 2016 [14].

3.3. Iatrogenic lesions

Forced reduction manoeuvres, notably in abduction, increase the loads placed on the acetabular roof and labrum, particularly if the femoral head is eccentric [11].

MRI studies after reduction have shown that the cartilaginous roof can remain inverted or crushed and that this increases the risk of impaired lateral acetabular growth [15].

4. Which investigations should be performed to evaluate and monitor residual acetabular dysplasia (RAD)?

The following signs should be looked for during the physical examination:

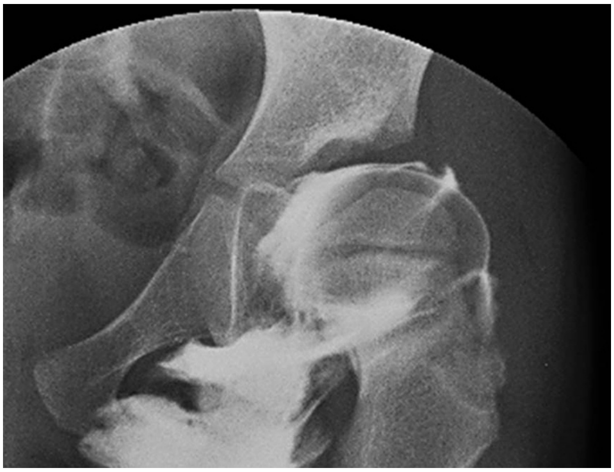

Fig. 8. Arthrography showing dynamic loss of femoral head centring and deformability of the labrum.

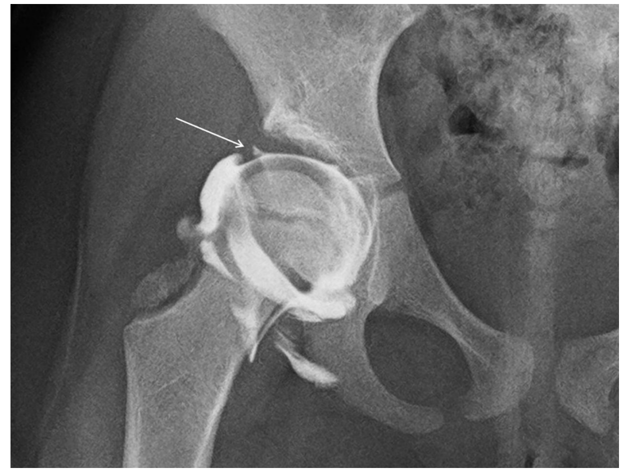

Fig. 9. Lesion of the labral insertion visible by arthrography (white arrow).

- a limp, which is present only in severe forms with instability or in adolescents with incipient osteoarthritis, combined with mechanical pain in the groin or lateral thigh;
- a decrease in the range of hip abduction;
- an imbalance in hip rotations;
- leg length discrepancy.

However, residual dysplasia is often clinically silent. It follows that investigations are needed for screening, evaluation, and monitoring of residual hip dysplasia.

4.1. Radiography

The antero-posterior radiograph of the pelvis is the key diagnostic tool.

The parameters used and the sources of inaccuracy in their measurement are discussed above.

Other useful views may include the following:

- an abduction view to assess the reducibility of an eccentrically positioned femoral head;
- a weight-bearing faux profil view, in adolescents, to assess anterior coverage by measuring the vertical-centre-anterior (VCA) angle (normally > 25°).

In addition to the absolute values of the radiographic parameters, their changes over time are important to assess by routinely obtaining radiographs after 1, 2, 4, and 6 years.

4.2. Additional imaging studies

When the diagnosis is suspected, additional imaging studies can be obtained to guide the treatment decisions.

Arthrography provides information on the stability and reducibility of the hip; the shape of the femoral head; and the shape, position, and pliability of the labrum. It allows a dynamic evaluation but requires anaesthesia. Moreover, the two components of the acetabular roof cannot be individualised [16] (Figs. 8 and 9).

MRI has been the focus of several studies published over the last ten years. The child must be sedated during image acquisition. The three components of the acetabular margin can be differentiated and measured. The VCE angle, acetabular index, and Reimers index can be measured with better reproducibility compared to radiographs, and the equivalent parameters for the cartilaginous component can be determined, although care must be taken to identify the border of the growth cartilage, without the labrum. Section planes located more or less anteriorly or posteriorly can be selected, and three-dimensional (3D) reformations can be obtained.

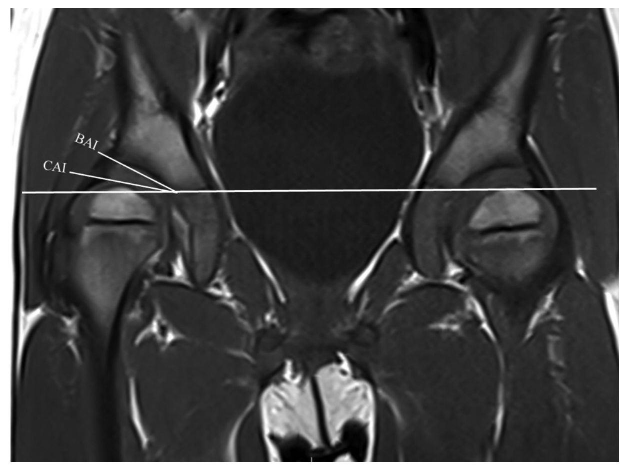

Fig. 10. MRI showing divergent dysplasia with BAI = 30, CAI = 11, and CAI^2/BAI = 4.

A bone acetabular index (BAI) and a cartilage acetabular index (CAI) have been described. In the normal hip, the CAI is smaller than the BAI by about 15° on average [17]. The BAI decreases from 20° to 15° with advancing age, whereas the CAI remains unchanged at 5° [18]. The CAI^2/BAI ratio was studied by Merckaert, who suggested that the value should not exceed 5 in the normal hip. This ratio is a simple and reproducible parameter for assessing the growth potential of the acetabular margin [19] (Fig. 10).

In addition to these quantitative parameters, MRI provides qualitative information:

- abnormalities of the cartilage roof seen as high signal on T2 sequences may be visible and are of adverse prognostic significance [20];
- the dGEMRIC (delayed Gadolinium Enhanced MRI of Cartilage) sequence ensures the early detection of cartilage lesions that may progress to osteoarthritis [9];
- MR-arthrography improves the visibility of labral lesions [21].

Computed tomography (CT) is often recommended in adolescents and young adults to allow surgical planning by providing a 3D assessment. We believe that the radiation exposure associated with CT is excessive when weighed against the expected benefit, and we suggest that CT may be best reserved for unusual situations or for research studies to which the patient has provided informed consent.

5. How can the consequences of residual dysplasia in the medium and long terms be evaluated?

Dysplasia results in a smaller surface area of contact between the femoral head and the acetabulum, which translates into increased loads per unit of surface area and, therefore, to premature cartilage wear. Hip instability and lesions to the labrum, notably its anterior portion, worsen this premature ageing of the cartilage [22].

In the medium term, dysplasia may cause limping and pain, which are sufficient to consider treatment.

The difficulty lies in assessing the severity of the dysplasia in asymptomatic patients. The challenge is to predict the time to development of osteoarthritis of sufficient severity to require hip arthroplasty. This time interval depends on many factors including:

- morphology of the hip;
- genetics;
- body weight;
- level of physical activity;
- nutrition

Among these factors, only hip morphology can be evaluated and treated by the surgeon. The other factors should be brought to the attention of the patient or parents so that preventive interventions can be instituted. The time of osteoarthritis development cannot be determined with precision. We will simply state the points for which a consensus exists and that can help to make surgical decisions in the two age groups most commonly involved.

5.1. Children 3 to 5 years of age

The issue of residual dysplasia frequently arises at this age, for the following reasons:

- several years have elapsed since the end of the treatment for CHD, and the hip is therefore expected to have recovered a normal morphology;
- several radiographs have been obtained during monitoring, allowing an assessment of the changes over time;
- the child is about to start school.

Any residual dysplasia is best corrected before 5 years of age as the outcomes are then better than with later intervention [23].

Any of the following decisions should be taken:

- stop the close monitoring if the hip is normal, and plan an evaluation of growth in adolescence;
- consider treatment after obtaining additional investigations; or
- continue to monitor the patient annually.

How can the decision to perform surgery be made without risking unnecessary procedures?

What are the cut-off values establishing that the dysplasia will not correct spontaneously?

The physical examination is of little help, since the child is asymptomatic, except in the very rare cases of complete treatment failure.

5.1.1. Radiography

The results of studies of hip parameter cut-off values are consistent with the 1976 study by Tönnis. Li [24] compared the changes in the AI, VCE angle, and Reimers index over the years that followed hip reduction to the hip outcomes. They performed a ROC curve analysis to estimate the best cut-offs. Performance was best for the AI, whose cut-off was $\leq 25^\circ$ 2 to 4 years after reduction. The VCE angle and Reimers index had less predictive power; the cut-offs were $<20^\circ$ and $>27\%$, respectively. Absence of change in the AI over several years was of adverse prognostic significance.

Fig. 11. Salter's osteotomy in a 5-year-old.

Fig. 12. Salter's osteotomy, outcome after 10 years.

Given these data, we believe a finer assessment should be obtained by performing arthrography, MRI, or both.

5.1.2. Arthrography

We consider that persistent instability of several millimetres is a major argument in favour of surgical treatment, as it impairs acetabular growth and promotes damage to the labrum. When instability exists, the contrast pools medially in the dislocated position and supero-laterally in the reduced position.

5.1.3. MRI

Measurement of the cartilage parameters predicts the expected angles in adulthood. Comparing the BAI and CAI values allows the differentiation of harmonious and divergent dysplasia. In harmonious dysplasia, the BAI and CAI are both increased and the prognosis is reserved. In divergent dysplasia, the BAI is too high but the CAI is normal, indicating that spontaneous improvement will

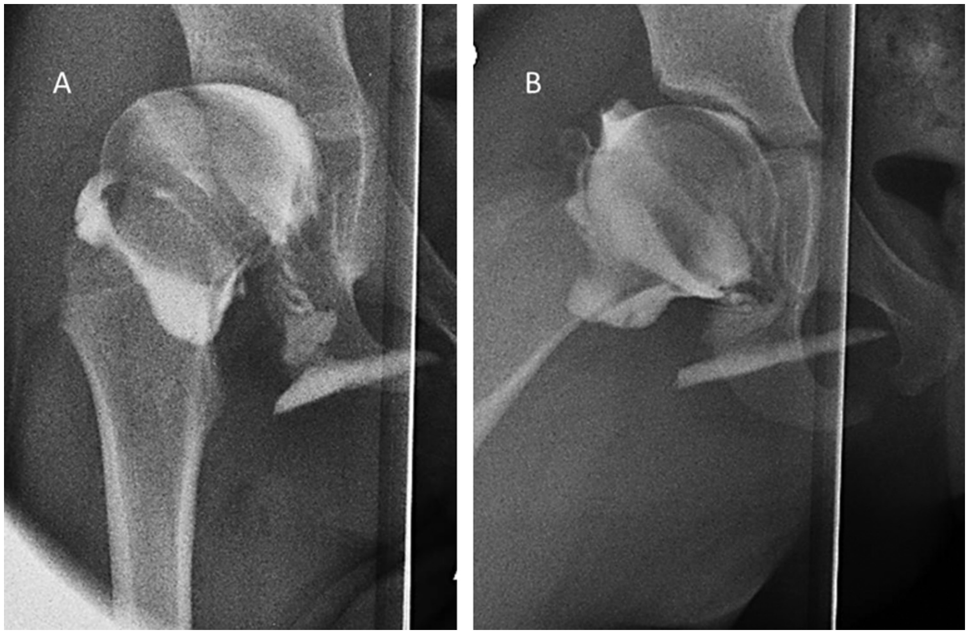

Fig. 13. Unstable dysplastic hip. A: neutral position; B: abduction. Note the absence of superior contrast-agent pooling when the hip is reduced. The acetabular roof cannot be lowered, and acetabular redirection is therefore the better option.

probably occur [25]. A CAI²/BAI ratio above 5 may indicate a need for surgery [19]. Finally, the detection of high-signal foci within the cartilage on T2-weighted images indicates a poor prognosis [20], as does persistent labral inversion [15].

In practice, we consider that the hip is normal if the bone coverage increases over time and the radiograph at 4 years of age shows the following:

- AI < 25°;
- VCE > 20°;
- Reimers index < 27%.

When these criteria are not met, further imaging studies should be obtained. We suggest arthrography to look for instability and MRI. If these investigations show any of the following:

- significant instability, or
- harmonious dysplasia with a CAI²/BAI ratio > 5, or
- an abnormality in the cartilaginous roof,
- then surgical correction is indicated.

If the investigations show all of the following:

- stable hip, and
- divergent dysplasia with CAI²/BAI < 5, and
- a normal cartilaginous roof.

Then the radiological monitoring of the improvements in bony roof growth should be continued.

5.2. Adolescents

Symptoms may develop in patients with severe dysplasia. Another possibility is that the monitoring radiographs show that the hip is no longer improving, due to growth failure of the secondary acetabular ossification centre.

The radiographic parameters are similar to those in adults. The VCE angle remains the most widely used parameter.

Terjesen [26] reported that the proportion of patients with osteoarthritis at 45 years of age was:

- 80% for hips with an eccentric femoral head,
- 22% for hips whose VCE angle was between 10° and 20°, and
- 5% for hips whose VCE angle was greater than 20°.

However, all the available studies indicate that the course can be unpredictable due to 3D morphological considerations and to labral lesions not visible on standard radiographs.

5.3. In conclusion

- A dysplastic hip that causes pain must be treated.
- If the femoral head is in an eccentric position, there is a risk of rapid progression to osteoarthritis.
- If the VCE angle is less than 20° or the AI is above 25°, further imaging studies must be obtained.

Additional investigations are needed:

- to assess the 3D morphology in order to prevent antero-medial impingement, and
- to rule out a labral lesion.

MRI provides answers to these questions and avoids the radiation exposure associated with CT.

Routine arthrography has been suggested to rule out a labral lesion. In addition, arthroscopy can help to guide the treatment decisions.

6. Which treatments are appropriate in each age group?

The treatment is surgical. The goal is to achieve optimal function without impeding future hip arthroplasty.

Fig. 14. Pemberton's osteotomy (Courtesy of P. Mary).

6.1. In children aged 3 to 5 years

The two options are re-direction and morphological modification of the acetabulum. A consensus exists about the benefits of Salter's osteotomy to re-orient the acetabulum. A supra-acetabular bicortical cut is made, after which the flexibility of the pubic symphysis allows the acetabulum to be tilted to the desired position. If the tilt is insufficient, a triple pelvic osteotomy can be performed with the same objective. Salter's osteotomy is well standardised and the complications are rare. In addition, long-term data are available. In most cases, near-normal radiographic parameters and clinical growth are obtained [27,28] (Figs. 11 and 12).

The coverage gain predominates antero-laterally, where labral lesions may exist and coverage is inadequate. Nonetheless, in the long term, acetabular retroversion exists for 24% of hips after Salter's osteotomy and up to 60% after triple pelvic osteotomy [29,30]. Acetabular retroversion may promote anterior impingement, which is a risk factor for progression to osteoarthritis. Consequently, a careful pre-operative assessment of acetabular anteversion on the MRI scan is imperative, and excessive anterior coverage must be avoided by tilting the acetabulum as far laterally as possible.

The Dega osteotomy modifies the shape of the acetabulum. A single cortex is cut, and no internal fixation is necessary. The acetabular roof moves downwards and laterally, using the triradiate cartilage as a hinge. Priority can be given to either anterior or posterior coverage [30]. This alternative is controversial in children with residual dysplasia. In most cases treated using the Dega osteotomy, the femoral head is in an eccentric position, and the hip is reduced during the same surgical stage. Indeed, the Dega osteotomy seems most relevant in cases with true instability, which is well corrected by the superior closure effect on the acetabulum [31]. If the hip is dysplastic but stable and congruent, lowering the roof is theoretically not feasible, supporting the usefulness of pre-operative arthrography [32] (Fig. 13).

Pemberton's osteotomy is similar to the Dega osteotomy, as the increase in coverage occurs only at the antero-lateral portion of the acetabulum (Fig. 14).

6.2. Adolescents

Selection of the best treatment is difficult. The objective is dual:

- to relieve the pain, and
- to significantly delay arthroplasty.

The impact of major conservative surgery on the development of adolescents must be taken into consideration.

Factors that influence the choice of the procedure include congruency of the hip, reducibility of the dislocation, the presence of osteoarthritis, the presence of labral lesions, and the morphology of the femur. Femoral osteotomy may be required if the femoral head is eccentric. If the labrum must be sutured, arthrotomy or arthroscopy may be necessary.

Available procedures for the acetabulum are as follows:

- shelf arthroplasty,
- Chiari's osteotomy, and
- redirection peri-acetabular osteotomies.

6.2.1. Shelf arthroplasty

This relatively demanding but simple technique provides lateral coverage and either anterior or posterior coverage as desired. The femoral head is covered by bare bone, with no cartilage. Interposition of the joint capsule provides the interface. This procedure is rarely indicated when the femoral head is not properly centred. In a cohort study by Terjesen with a 30-year follow-up, 35% of patients were free of pain and 65% had not had further surgery. Factors of adverse prognostic significance include a VCE angle below 10°, evidence of avascular necrosis, and established osteoarthritis. Patients with a longer pre-operative history of pain have a shorter post-operative pain-free interval [26]. Berton has emphasised the need to look for labral lesions, as failure to treat these is a poor prognostic factor [33]. The recent literature review by Willemsen confirms the reliability of the shelf procedure in properly selected patients [34] (Fig. 15).

Fig. 15. A et B. Before and after the shelf procedure (Courtesy of J. Langlais).

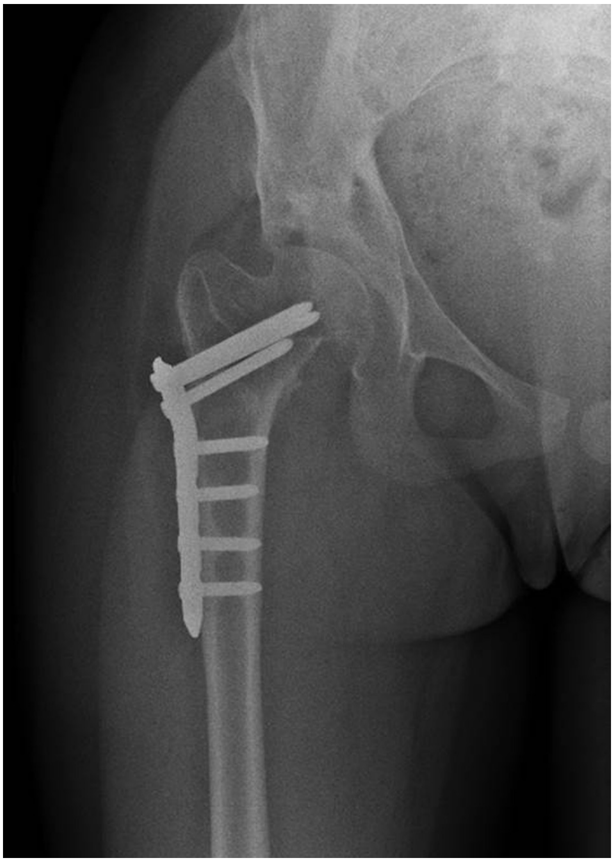

Fig. 16. Combined Chiari's osteotomy and valgus femoral osteotomy (same patient as in Fig. 2).

6.2.2. Chiari's osteotomy

Chiari's osteotomy is a salvage procedure for hips with an eccentrically positioned femoral head and is not, in principle, indicated for patients with RAD strictly speaking. In a cohort study by Uchiyama, in which some patients also underwent femoral osteotomy, fewer than half the patients did not require hip arthroplasty within the 20 years following the osteotomy [35] (Fig. 16).

6.2.3. Re-orientation osteotomy

Osteotomies designed to redirect the acetabulum are the only osteotomies that place authentic joint cartilage over the femoral head. There is widespread agreement that Salter's osteotomy is not indicated at this age, since the pubic symphysis is no longer sufficiently flexible. The osteotomies described by Le Cœur, Carlioz, Tönnis, and Ganz are performed increasingly near the acetabulum. Each of these techniques has its limitations, technical requirements, and complications. In a study of 58 hips treated using the Tönnis osteotomy, Farsetti found good outcomes in 83% of hips, with no arthroplasty after 12 years of follow-up [36].

Peri-acetabular osteotomy (PAO), which was developed by Ganz in Bern [37], has gained popularity in some adult orthopaedic surgery departments. This method seems optimal for restoring near-normal radiographic parameters but is technically difficult and should be reserved for patients whose hip growth is nearly complete. PAO is not yet widely used in France. The large studies reported to date were usually in single-surgeon cohorts. The learning curve is steep. The 20-year survival rate (without arthroplasty) is 60% [38,39]. Factors associated with failure are age older than 25 years, pre-operative lack of joint congruence, and greater than Tönnis grade 2 osteoarthritis. The complication rate is 6% for highly experienced surgeons overall but is 19% in patients with a history of surgery on the same hip [39–41]. PAO does not make subsequent arthroplasty more difficult, and may even be a facilitating factor as it avoids the use of grafts to increase the bone stock. Intra-articular procedures can be performed during the same stage, such as routine arthroscopy [33] and labral re-attachment or grafting [42] (Figs. 17 and 18).

The dysplasia does not always predominate anteriorly. The group in Bern has reported that a sixth of the hips exhibit acetabular retroversion. This finding supports the need for a pre-operative 3D assessment, which can be performed by radiologically evaluating the anterior and posterior margins as described by Hefti [10] or by performing MRI or CT. When the acetabulum is retroverted, the PAO should be inversed to avoid antero-lateral impingement [39,43,44].

7. Conclusion

Residual hip dysplasia raises complex issues, some of which remain unresolved. The evaluation is driven by the changes that occur with growth, which require prolonged follow-up. The goal of efficiently delaying arthroplasty is ambitious. Whether it is achieved is difficult to say given the absence of prospective cohort studies with large sample sizes and over 20 years of follow-up. To do no harm therefore becomes the priority.

In small children, the pre-operative work-up must include at least an MRI scan and, if possible, an arthrogram to avoid unnecessary surgery. Salter's osteotomy produces satisfactory long-term results provided excessive correction does not promote anterior

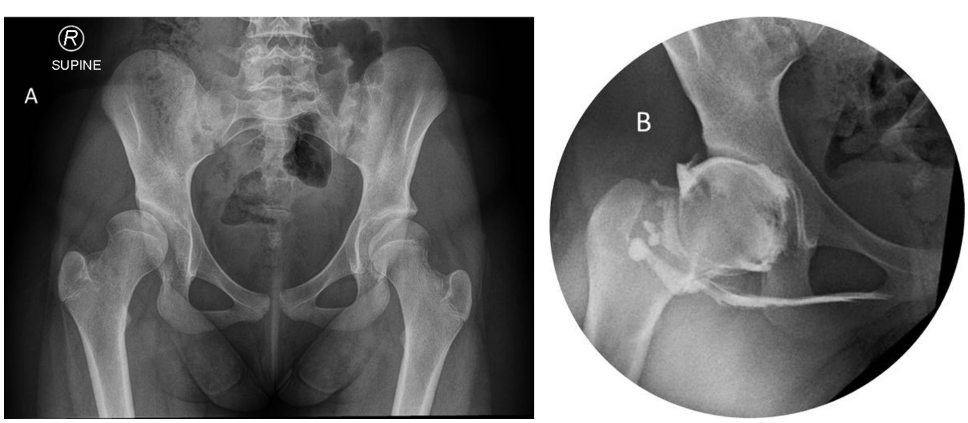

Fig. 17. A: The right hip is painful, dysplastic, uncentred, and reducible. Note the sub-chondral geode in the femoral head. B: Arthrography: the hip is reducible in abduction, the labrum is intact, and the geode is non-communicating. Peri-acetabular osteotomy was recommended.

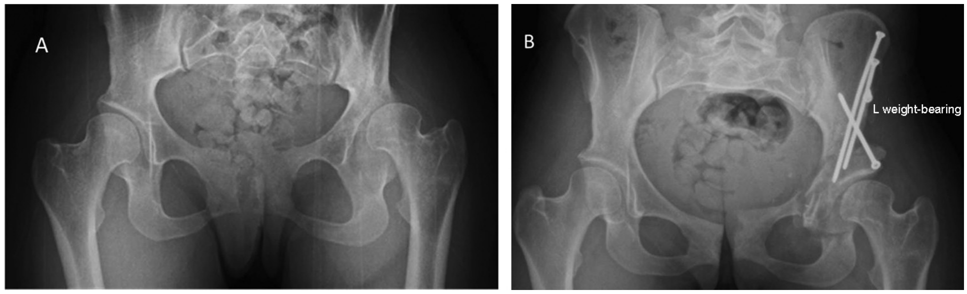

Fig. 18. A et B: Before and after peri-acetabular osteotomy of the left hip.

impingement. The Dega osteotomy is an alternative whose indications remain to be clarified.

In adolescents, the presence of hip pain requires prompt treatment. In the event of established osteoarthritis, conservative surgery may provide temporary pain relief, and its potential benefits should be weighed against those of early hip arthroplasty, particularly in patients who also have femoral abnormalities. In patients with symptoms but no osteoarthritis, the shelf procedure is reliable, and PAO performed as close as possible to the acetabulum is a rational alternative whose indications should be determined with caution.

The development of these techniques is necessarily slow, since their indications are rare, making them difficult to teach comparatively to arthroplasties, whose simplicity and reliability are improving at a brisk pace.

Close collaboration is required between the paediatric orthopaedic surgeons who monitor and know the patients and the adult orthopaedic surgeons who will provide them with long-term follow-up. Only adult orthopaedic surgeons can compare the expected outcomes of conservative surgery to those of arthroplasty.

Advances in imaging techniques now provide information on the cartilage and labrum. Unrecognized lesions of these structures probably explain certain unexpected treatment failures. On the other hand, the absence of cartilaginous and labral lesions may explain the favourable outcomes of some patients.

Artificial intelligence will gradually help to increase the accuracy of anatomical corrections by adjusting them to a detailed pre-operative evaluation: surgical planning software (Hip2Norm), intra-operative 3D imaging, and custom-made cutting guides are examples of the use of artificial intelligence.

Disclosure of interest

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B. de Courtivron contributed to write the manuscript.

K. Brulefert contributed to write the manuscript and to obtain sources of information.

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References

[1] Mladenov K, Dora C, Wicart P, Seringe R. Natural history of hips with borderline acetabular index and acetabular dysplasia in infants. J Pediatr Orthop 2002;22:607–12.

[2] Clavert JM. Développement embryonnaire des membres et orthopédie. Cahiers d'enseignement de la SOFCOT. Conférences d'enseignement. Expansion scientifique française, Paris VI; 1991. p. 15–28.

[3] Nogier A. Lésions du labrum et du complexe acétabulaire périphérique stabilisateur (CAPS): synthèse de la littérature. Rev Chir Orthop 2010;96–8S:277–86.

[4] Seringe R. La hanche dysplasique du nouveau-né et du nourrisson. Cahiers d'enseignement de la SOFCOT. Conférences d'enseignement. Expansion scientifique française, Paris; 1991. p. 59–72.

[5] Fujii M, Nakashima Y, Yamamoto T, Mawatari T, Motomura G, Matsushita A, et al. Acetabular retroversion in hip developmental dysplasia of the hip. J Bone Joint Surg Am 2010;92:895–903.

[6] Portinaro NMA, Murray DW, Bhullar TPS. Errors in measurement of acetabular index. J Pediatr Orthop 1995;15:780–4.

[7] Kim HT, Kim JI, Yoo CI. Diagnosing childhood acetabular dysplasia using the lateral margin of the sourcil. J Pediatr Orthop 2000;20:709–17.

[8] Shin CH, Yang E, Lim C, Yoo WJ, Choi IO, Cho TJ. Which acetabular landmarks are the most useful for measuring the acetabular index and center-edge angle in developmental dysplasia of the hip? A comparison of two methods. Clin Orthop Relat Res 2020;478:2120–31.

[9] Wenger D, Siversson C, Dahlberg LE, Tiderius CJ. Residual hip dysplasia at 1 year after treatment for neonatal hip instability is not related to degenerative joint disease in young adulthood: a 21-year follow-up study including dGEMRIC. Osteoarthritis Cartil 2016;24:436–42.

[10] Hefti F. Spherical assessment of the hip on standard AP radiographs: a simple method for the measurement of the contact area between acetabulum and femoral head and of acetabular orientation. J Pediatr Orthop 1995;15:797–805.

[11] Seringe R, Bonnet JC, Katti E. Pathogeny and natural history of congenital dislocation of the hip. Orthop Traumatol Surg Res 2014;100:59–67.

[12] Delgado-Baeza E, Albinana-Cilveti J, Miralles-Flores C. Why does pelvic deformity occur in experimental dislocation of the growing hip? J Pediatr Orthop 1992;12:376–83.

[13] Zhang Z, Li H, Li H, Zhang Z. Timing for closed reduction procedure for developmental dysplasia of the hip and its failure analysis. BMC Musculoskelet Disord 2020;21:613.

[14] Carsi B, Clarke N. Acetabuloplasties at open reduction prevent acetabular dysplasia in intentionally delayed developmental dysplasia of the hip: a case-control study. Clin Orthop Relat Res 2016;474:1180–8.

[15] Liu J, Zhou W, Li L, Zhang L, Li Q, Wang E. The fate of inverted limbus in children with developmental dysplasia of the hip: clinical observation. J Orthop Res 2021;39:1433–40.

[16] Zamzam MM, Kremli MK, Khoshhal KI, Abak AA, Bakarman KA, Alsiddiky AM, et al. Acetabular cartilaginous angle. A new method for predicting acetabular development developmental dysplasia of the hip in children between 2 and 18 months of age. J Pediatr Orthop 2008;28:518–23.

[17] Douira-Khomsi W, Smida M, Louati H, Hassine LB, Bouchoucha S, Saied W, et al. Magnetic resonance evaluation of acetabular residual dysplasia in developmental dysplasia of the hip: a preliminary study of 27 patients. J Pediatr Orthop 2010;30:37–43.

[18] Huber H, Mainard-Simard L, Lascombes P, Renaud F, Jean-Baptiste M, Journeau P. Normal values of bony, cartilaginous and labral coverage of the infant hip in MR imaging. J Pediatr Orthop 2014;34:674–8.

[19] Merckaert SR, Pierzchala K, Bregou A, Zambelli PY. Residual hip dysplasia in children: osseous and cartilaginous acetabular angles to guide further treatment-a pilot study. J Orthop Surg Res 2019;14:379.

[20] Wakabayashi K, Wada I, Horiuchi O, Mizutani J, Tsuchiya D, Otsuka T. MRI findings in residual hip dysplasia. J Pediatr Orthop 2011;31:381–7.

[21] Zlatkin MB, Pevsner D, Sanders TG, Hancock CR, Ceballos CE, Herrera MF. Acetabular labral tears and cartilage lesions of the hip: indirect MR arthrographic correlation with arthroscopy–a preliminary study. AJR Am J Roentgenol 2010;194:709–14.

[22] Stelzeneder D, Mamisch TC, Kress I, Domayer SE, Werlen S, Bixby SD, et al. Patterns of joint damage seen on MRI in early hip osteoarthritis due to structural hip deformities. Osteoarthr Cartil 2012;20:661–9.
[23] Blamoutier A, Carlioz H. L'ostéotomie innominée de Salter dans le traitement de la luxation congénitale de la hanche. Résultats à plus de 10 ans de recul de 43 ostéotomies. Rev Chir Orthop 1990;76:403–10.
[24] Li YQ, Guop YM, Zhou LM, Liu Y, Chen WD, Canavese F, et al. Acetabular index is the best predictor of late residual acetabular dysplasia after closed reduction in developmental dysplasia of the hip. Int Orthop 2018;42:631–40.
[25] Walbron P, Müller F, Mainard-Simard L, Luc A, Journeau P. Bone maturation of MRI residual developmental dysplasia of the hip with discrepancy between osseous and cartilaginous acetabular index. J Pediatr Ortho B 2019;28:419–23.
[26] Terjesen T. Residual hip dysplasia as a risk factor for osteoarthritis in 45 years follow-up of late-detected hip dislocation. J Child Orthop 2011;5:425–31.
[27] Morin C, Bisogno J, Kulkarni S, Morel G. Treatment of late-presenting developmental dislocation of the hip by progressive orthopaedic reduction and innominate osteotomy. Our results with more than 30 years of follow-up. J Child Orthop 2011;5:252–60.
[28] Thomas S, Wedge J, Salter R. Outcome at forty-five years after open reduction and innominate osteotomy for late-presenting developmental dislocation of the hip. J Bone Joint Surg 2007;89:2341–50.
[29] Dora C, Mascard E, Mladenov K, Seringe R. Retroversion of the acetabular dome after Salter and triple pelvic osteotomy for congenital dislocation of the hip. J Pediatr Orthop B 2002;11:34–40.
[30] Klein C, Fontanarosa A, Khouri N, Bellity J, Padovani JP, Glorion C, et al. Couverture excessive antérieure et latérale après triple ostéotomie pelvienne chez l'enfant pour dysplasie secondaire à une luxation congénitale de la hanche: fréquence, caractéristiques et conséquences cliniques à moyen terme. Rev Chir Orthop 2018;104:271–5.
[31] Al-Ghamdi A, Rendon JS, Al-Faya F, Saran N, Benaroh T, Hamdy R. Dega osteotomy for the correction of acetabular dysplasia of the hip: a radiographic review of 21 cases. J Pediatr Orthop 2012;32:113–20.
[32] Rampal V, Klein C, Arellano E, Boubakeur Y, Seringe R, Glorion C, et al. Outcomes of modified Dega acetabuloplasty in acetabular dysplasia related to developmental dislocation of the hip. Orthop Traumatol Surg Res 2014;100:203–7.
[33] Berton C, Bocquet D, Krantz N, Cotten A, Migaud H, Girard J. Shelf arthroplasties long-term outcome: influence of labral tears. A prospective study at a minimal 16 years' follow-up. Orthop Traumatol Surg Res 2010;96:753–9.
[34] Willemsen K, Doelman C, Sam A, Seevinck P, Sakkers R, Weinans H, et al. Long-term outcomes of the hip shelf arthroplasty in adolescents and adults with residual hip dysplasia: a systematic review. Acta Orthop 2020;91:383–9.
[35] Uchiyama K, Moriya M, Fukushima K, Yamamoto T, Takahira N, Takaso M. Clinical results and prognostic factors for outcomes of valgus femoral osteotomy combined with Chiari pelvic osteotomy for osteoarthritis of the hip. JB JS Open Access 2017;2:e0006.
[36] Farsetti P, Caterini R, De Maio F, Potenza V, Efremov K, Ippolito E. Tönnis pelvic osteotomy for the management of late residual acetabular dysplasia: mid-term to long-term follow-up study of 54 patients. J Pediatr Orthop B 2019;28:202–6.
[37] Ganz R, Klaue K, Vinh TS, Mast JW. A new periacetabular osteotomy for the treatment of hip dysplasias. Technique and preliminary results. Clin Orthop Relat Res 2004;418:3–8.
[38] Steppacher SD, Tannast M, Ganz R, Siebenrock KA. Mean 20-year follow-up of Bernese periacetabular osteotomy. Clin Orthop Relat Res 2008;466:1633–44.
[39] Zaltz I, Baca G, Kim YJ, Schoenecker P, Trousdale R, Sierra R, et al. Complications associated with the periacetabular osteotomy: a prospective multicenter study. J Bone Joint Surg Am 2014;96:1967–74.
[40] Polkowski GG, Novais EN, Kim YJ, Millis MB, Schoenecker PL, Clohisy JC. Does previous reconstructive surgery influence functional improvement and deformity correction after periacetabular osteotomy? Clin Orthop Relat Res 2012;470:516–24.
[41] Millis M, McClincy M. Periacetabular osteotomy to treat residual dysplasia in adolescents and young adults: indications, complications, results. J Child Orthop 2018;12:349–57.
[42] Maldonado DR, LaReau JM, Lall AJ, Battaglia MR, Mohr MR, Domb BG. Concomitant arthroscopy with labral reconstruction and periacetabular osteotomy for hip dysplasia. Arthroscopy Techn 2018;7:e1141–7.
[43] Tawrani DP, Feldman DS, Sala DA. Not all dysplasias are the same: preoperative CT version study and the need for reverse Bernese periacetabular osteotomy. J Pediatr Orthop 2017;37:47–52.
[44] Jawish R, Najdi H, Krayan A. Periacetabular triple osteotomy of the pelvis in older children: computed tomography scan analysis of acetabular retroversion and anterior overcoverage of the hip, preventing femoral acetabular impingement. J Pediatr Orthop B 2018;27:257–63.