Original Clinical Article

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Obstacles to reduction in infantile developmental dysplasia of the hip

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Abstract

Purpose Identification of anatomical structures that block reduction in developmental dysplasia of the hip (DDH) is important for the management of this challenging condition. Obstacles to reduction seen on arthrogram are well-known. However, despite the increasing use of MRI in the assessment of adequacy of reduction in DDH, the interpretation of MRI patho-anatomy is ill-defined with a lack of relevant literature to guide clinicians.

Method This is a retrospective analysis of the MRI of patients with DDH treated by closed reduction over a five-year period (between 2009 and 2014). Neuromuscular and genetic disorders were excluded. Each MRI was analysed by two orthopaedic surgeons and a paediatric musculoskeletal radiologist to identify the ligamentum teres, pulvinar, transverse acetabular ligament (TAL), capsule, labrum and acetabular roof cartilage hypertrophy. Inter- and intraobserver reliability was calculated. The minimum follow-up was 12 months.

Results A total of 29 patients (38 hips) underwent closed reduction for treatment of DDH. Eight hips showed persistent subluxation on post-operative MRI. Only three of these eight hips showed an abnormality on arthrogram. The pulvinar was frequently interpreted as 'abnormal' on MRI. The main obstacles identified on MRI were the ligamentum teres (15.8%), labrum (13.1%) and acetabular roof cartilage hypertrophy (13.2%). The inter-rater reliability was good for TAL, capsule and pulvinar; moderate for ligamentum teres and labrum; and poor for hypertrophied cartilage.

Conclusion The labrum, ligamentum teres and acetabular roof cartilage hypertrophy are the most important structures seen on MRI preventing complete reduction of DDH. Focused interpretation of these structures may assist in the management of DDH.

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Introduction

The pathological structures that may be present in cases of infantile developmental dysplasia of the hip (DDH) have been well-described. They include thickened ligamentum teres, transverse acetabular ligament (TAL) and capsule, pulvinar, thickened or infolded labrum ('limbus') and acetabular roof cartilage hypertrophy ('neolimbus').[1] Arthrography has long been considered the benchmark for determining both the quality of reduction of the femoral head into the acetabulum in infantile DDH and the presence of pathological structures.

MRI is used increasingly to assess the adequacy of hip reduction following surgical management of infantile DDH. This non-invasive imaging modality has a number of advantages over conventional arthrography, including assessment of soft-tissue and bony structures in 3D, often without additional anaesthesia and without radiation exposure.[2] However, the interpretation of post-reduction MRI can be challenging as there is minimal literature describing the patho-anatomy on MRI that can be encountered in infantile DDH.

The primary aim of this study was to identify and describe pathological structures seen on post-procedure MRI in patients with infantile DDH who have undergone closed reduction and correlate MRI findings with arthrogram findings. The secondary aim was to determine the inter- and intra-rater reliability in identifying pathological structures on MRI scan.

Materials and methods

Approval for the study protocol was granted by the Research Ethics Committee (HREC/13/WCHN/631A).

The study setting was a tertiary referral paediatric centre treating all cases of late-diagnosed DDH (diagnosed at more than three months of age) and DDH cases that have failed initial brace treatment. A retrospective medical imaging and chart review of patients with DDH treated by closed reduction over a five-year period (between 2009 and 2014) was conducted. Patients were included if they had undergone examination under anaesthetic with arthrogram, followed by closed reduction for DDH with a post-procedure MRI to check the position of the femoral head, within 48 hours of arthrogram. Patients with neuromuscular, skeletal diseases or genetic disorders were excluded.

All MRI and plain radiograph images were reviewed using the digital picture archiving and communication system. Arthrogram images were printed on conventional film. A medial dye pool on arthrogram was defined as > 7 mm.[3,4] As fluoroscopy images are not calibrated, any obvious large dye pool was included, and for equivocal cases, the size of the dye pool was calculated by defining it as a percentage compared with the ossified femoral head, then measuring the ossified femoral head on the calibrated pre-operative digital radiograph image.

Retrospective analysis of arthrograms was initially independently performed by a paediatric radiologist (AG) and a paediatric orthopaedic surgeon (KS), with consensus achieved before interpretation of the MRI relative to the existing 'gold standard' of arthrography. The presence of the following obstacles on arthrogram was documented: medial dye pool > or < 7 mm;[4] ligamentum teres; inverted labrum; and capsular constriction.

All MRI scans were performed on a single digital scanner (1.5T Philips Ingenia Medical System; Philips, Best, The Netherlands). The rapid sequence MRI protocol included acquisition of the following images: T2 axial; T1 axial with fat suppression; T2 coronal; T1 coronal; and coronal multiecho fast field echo spin. General anaesthesia (GA) or sedation was not used, with scanning scheduled soon after a feed when the baby was settled.

MRI images were analysed by a paediatric orthopaedic surgeon (KS), an orthopaedic surgeon (PS) and a paediatric radiologist (AG). The reduction on MRI was classified as concentric or non-concentric according to the position of the ossific nucleus on the transverse and coronal plane scans in relation to an imaginary line drawn through the tri-radiate cartilage.[5] In the case of a non-concentric reduction, the subluxation was defined as loss of concentricity of the femoral head within the acetabulum in either a lateral or posterior position. In cases where no ossific nucleus was present, the centre of the cartilaginous femoral head was drawn and used as the landmark.

We analysed potential intra-articular obstacles on MRI. The presence of the following anatomical structures were documented: ligamentum teres; pulvinar; transverse acetabular ligament (TAL); infolded capsule (into the articulation); thickened or infolded labrum ('limbus'); and acetabular roof cartilage hypertrophy ('neolimbus').[1]

Findings were further categorised into definite or possible obstacles to concentric reduction. As there is no definition in the literature as to what constitutes an obstacle on MRI, a definite obstacle was defined as an anatomical structure which was considered by the reviewer to be severe enough to explain a non-concentric reduction. A possible obstacle was an anatomical structure, which the reviewer considered pathological (bigger than the 'normal' contralateral side or bigger than what would be expected in a normal hip), but not directly responsible for a non-concentric reduction. MRI pictures were re-analysed by the same observers exactly three months after the first analysis for intra-rater variability.

In certain cases, a repeat MRI in the follow-up period was performed, at the surgeon's discretion, to ensure the femoral head was 'docking' in the acetabulum.

Final follow-up radiographs were analysed for teardrop development, acetabular index and the International Hip Dysplasia Institute (IHDI) grade[6] in cases with follow-up greater than 24 months.

The Kappa statistic was used to calculate inter- and intraobserver reliability. This was defined as follows: > 90% excellent; 80% to 90% good; 70% to 80% moderate; and < 70% poor.

Results

In total, 39 hips (30 patients) underwent closed reduction for DDH. One patient/one hip was excluded because the quality of the MRI was insufficient for detailed interpretation. Of the remaining 38 hips (29 patients), only four were male. Median follow-up was 28 months (12 to 66), median age was nine months (2 to 27). A total of 11 patients (14 hips) had failed previous brace treatment (median age at closed reduction four months (2 to 10)), one patient (bilateral early DDH) had an attempt of closed reduction which failed. A total of 17 patients

(22 hips) were late-diagnosed DDH (diagnosis over the age of three months) and underwent closed reduction under anaesthesia as their initial treatment (start of first treatment median age 9.75 months (5 to 27)). All patients had undergone percutaneous adductor tenotomy in association with closed reduction, in order to improve the safe zone.[7] Psoas tenotomy was not performed for any patient. Following reduction, all patients were placed in a spica cast with the hips in approximately 100° of flexion and abduction in the middle of the safe zone. The cast was completed to the ankle bilaterally for younger patients, and in certain older patients was above the knee on the non-affected side at the discretion of the treating surgeon.

Correlation with intra-operative arthrogram

Medial pooling (six hips) on arthrogram was correlated with non-concentric reduction on MRI and was attributed to MRI findings of a thickened ligamentum teres/TAL (five hips) and hypertrophied cartilage/labrum (three hips). Five hips showed other anatomical structures presenting an obstacle on arthrogram (ligamentum teres, labrum, pulvinar) with the MRI confirming definite obstacles for four of these: ligamentum teres with or without pathological labrum (three cases) and isolated pathological labrum (one case). A statistical correlation was not possible because of the small sample size.

Concentric reduction on MRI

Concentric reduction on MRI was observed in 18 hips of the 38 closed reductions, in both axial and coronal planes (Fig. 1). Of these 18 hips, 15 hips had a good clinical and radiological outcome with a median acetabular index at final follow-up of 22° (12° to 30°). Two hips with a concentric reduction subsequently underwent Salter osteotomy after a further 24 months of follow-up. One of these hips showed retrospectively a thickened labrum and an infolded capsule on the early post-procedure MRI and the second hip had an excessively large pulvinar.

Non-concentric reduction in a single plane on MRI

Non-concentric reduction in a single plane on MRI was observed in ten hips. Of these hips, six were suspicious on the arthrogram (questionable medial dye pool > 7 mm) and the MRI confirmed non-concentric reduction in four. Five hips showed lateral subluxation and/or posterior subluxation in five hips. In no cases did the appearance of the post-procedure MRI cause the treating surgeon to change the treatment plan as the surgeon expected the

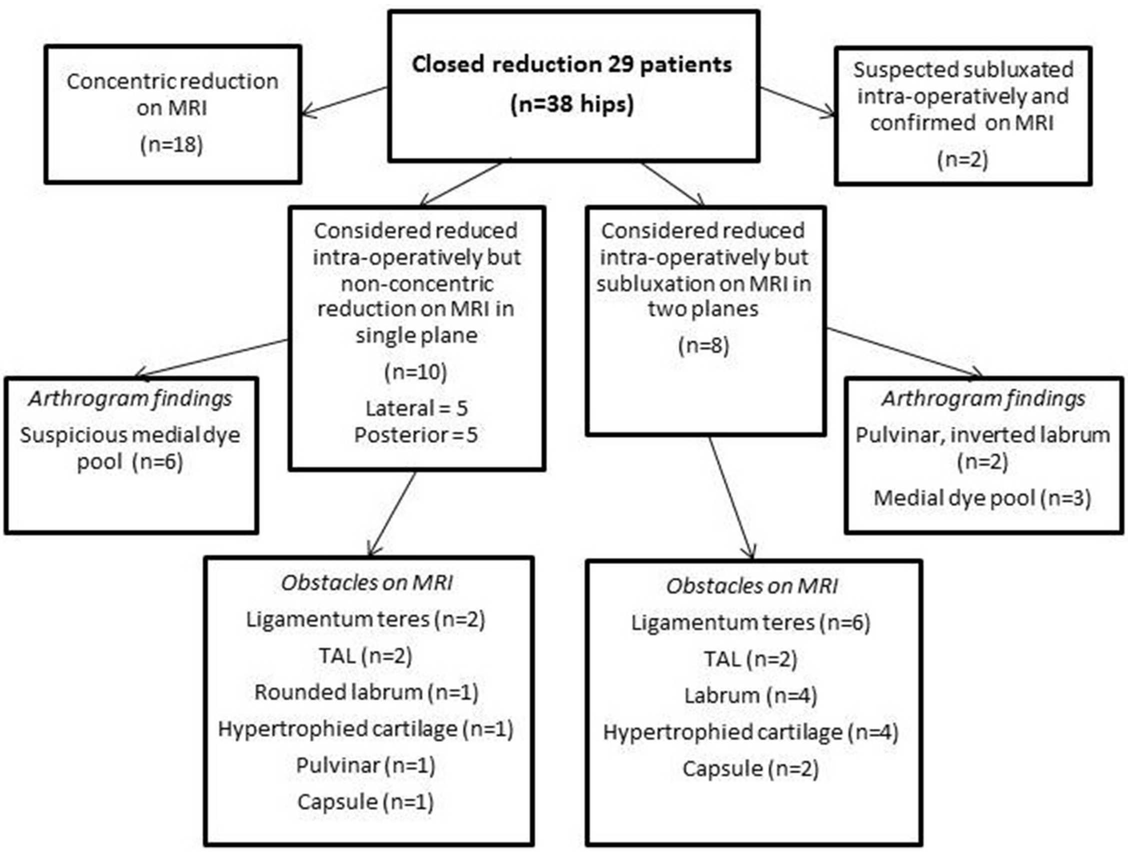

Fig. 1 Flow chart of arthrography and MRI findings for hips identified as non-concentric or subluxated on post-reduction MRI (TAL, transverse acetabular ligament).

hip to improve in docking position with time. Anatomical possible obstacles on MRI were present in nine of these ten hips: ligamentum teres (two hips); rounded labrum (two hips); TAL (two hips); hypertrophied roof cartilage (one hip); capsule (one hip); and pulvinar (one hip). One patient did not show an anatomical block on the arthrogram or a discernable obstacle in the MRI. This hip was found to be subluxated on plain radiographs at 12 months after closed reduction. One patient with a thickened ligamentum teres developed severe avascular necrosis (AVN) (Kalamchi Grade III)[8] and new supero-lateral re-subluxation on radiographs at 15 months after closed reduction.

Incomplete reduction on MRI

Incomplete reduction on MRI was observed in eight hips with a persistent subluxated position in both planes (Fig. 1). Only two of the eight hips showed an abnormal anatomical structure in the arthrogram (pulvinar, inverted labrum) and three had medial pooling on arthrogram. In these subluxated hips, the contributory possible blocks to reduction seen on MRI were labrum (four hips), ligamentum teres (six hips), capsule (two hips), excessive pulvinar (two hips), TAL (two hips) and hypertrophied cartilage (four hips). The definite obstacles (mainly responsible) for subluxation were labrum (two hips), ligamentum teres (two hips), infolded posterior joint capsule (one hip) and hypertrophied cartilage (three hips). These definite obstacles are presented in Table 1. None of these hips subsequently developed a mature acetabulum, defined by the presence of the teardrop, in the 24 months of follow-up after further treatment. Along with the abnormal development of the teardrop, a higher acetabular index was seen (median 30° at age 24 to 30 months). Five hips showed IHDI grade I and two hips showed grade III at 24-month follow-up (one hip < 24 months of follow-up). Lateral subluxation had a worse outcome than posterior subluxation, with AVN in two hips or persistent lateral subluxation in one hip and need for open hip reduction in one hip (median 12 months post-operatively).

Subluxation on arthrogram and confirmation of persistent dislocation on MRI

Subluxation on arthrogram and confirmation of persistent dislocation on MRI was observed in two hips.

A summary of the results is presented in Tables 1 and 2.

The results of inter- and intraobserver reliability for the potential obstacles to concentric reduction are shown in Table 3. The inter- and intraobserver reliability was good for the TAL, pulvinar and capsule, moderate for the labrum and ligamentum teres and poor for hypertrophied acetabular roof cartilage.

Discussion

To our knowledge, this is the first study analysing anatomical structures associated with non-concentric reduction in DDH patients undergoing post-reduction MRI scans. Our results suggest that the labrum, ligamentum teres and the hypertrophic cartilage of the acetabular roof are the most important structures preventing a complete reduction in DDH (in at least 13% of the hips).

Our study has several limitations. It is a retrospective study and understandably there was no control group. In unilateral cases, the contralateral side could be used as an internal control, although care must be taken with this approach as varying degrees of dysplasia may occur coincidentally on the contralateral side when a single hip is dislocated.[9] The quality of our MRI appeared to improve with increasing use of rapid sequence MRI and with refinement of the medical imaging protocol (including patient preparation). This observation was unable to be quantified. We were also unable to conclude which structures may resolve with time. Greater numbers, repeated MRI and longer follow-up may eventually answer this question. Finally, although the iliopsoas tendon is described in the literature as an extra-articular obstacle to reduction, this study focused on structures found to be obstacles within the hip joint articulation. While the iliopsoas was not specifically analysed, it is interesting to note that it was not an obvious obstacle to reduction in any of the reviewed hips and an hourglass constriction in the capsule was not seen on any arthrogram. The reviewed arthrogram images were all with the hip in the maximally reduced position. It is therefore possible that iliopsoas is only seen to be pathological with the hip in an extended position and is not a true obstacle to reduction with the hip in flexion and abduction, but this is speculative.

Hypertrophied cartilage of the acetabular roof was rarely an isolated obstacle to reduction, but often seen in addition to other structure(s). The two hips with markedly hypertrophied roof cartilage as the only MRI obstacle to reduction were diagnosed prior to the age of three months and failed both brace treatment and closed reduction. Both cases ultimately underwent open reduction and the operative reports describe thickened acetabular roof cartilage. Our findings support other studies that suggest the presence of hypertrophied cartilage is not only a morphological change seen with persistent instability but also a predictor for irreducibility and a bad outcome.[10-12] An ultrasound finding of hypertrophied acetabular roof cartilage (thickness of 5 mm to 7 mm) has been described in cases of irreducible neonatal DDH when compared with healthy hips (thickness of 2 mm).[13] Further study is required to quantify the magnitude of hypertrophy seen on MRI that is associated with treatment difficulties and poor outcomes. When present, the morphological and histological changes in the cartilaginous component

Table 1. Characteristics of patients with subluxated hip/s on post-reduction MRI scan and analysis of anatomical obstacles to reduction seen on MRI.

Hips	Sex	Diagnosis	Side	Age CR (mths)	Failed splint treatment	Main direction of subluxation	Labrum	Ligamentum teres	Capsule	Pulvinar	TAL	HC	Consequence of MRI	Outcome (age 12 to 48 mths)
P11	F	Late Unilateral	R	16.4	No	Posterior	No	No	No	No	No	**Yes**	Resolution of obstacles in 2nd MRI	Ongoing observation
P22	F	Late Unilateral	L	5.4	No	Posterior	**Yes**	Yes	No	Yes	Yes	Yes		Poor femoral head coverage
P25	F	Late Unilateral	L	19.1	No	Posterior	**Yes**	Yes	No	Yes	No	**Yes**	Repeat MRI at 3 wks: improvement	Salter osteotomy (age 30 mths)
P27	F	Early Bilateral	R	3	Yes, 2 mths	Lateral	No	**Yes**	No	No	No	Yes	Early repeat CR with improved positioning	AVN, ongoing observation
P30	F	Late Unilateral	L	16.0	No	Lateral	**Yes**	Yes	Yes	No	No	No	Repeat MRI at 3 wks, then proceeded directly to open reduction	Salter OT (age 17 mths)
P32	F	Late Unilateral	L	17	No	Lateral	No	**Yes**	No	No	No	No	Repeat MRI at 3 wks demonstrated redundant ligamentum teres	AVN, persistent subluxation, observation
P35	M	Early Bilateral	L	2	Yes, 2 mths	Lateral	No	No	**Yes**	No	No	Yes	Early repeat CR	Residual dysplasia (age 24 mths)
P39	M	Early Bilateral	L	4.1	Yes, 3 mths	Lateral	No	No	No	No	No	**Yes**	Early repeat CR	Open hip reduction (age 12 mths)

Bold indicates anatomical structure considered to be mainly responsible for unsuccessful reduction

M, male; F, female; CR, closed reduction; TAL, transverse acetabular ligament; HC, hypertrophied cartilage of the acetabular roof; AVN, avascular necrosis; OT, osteotomy

Table 2. Radiological findings at final follow-up for hips that were subluxated on post-reduction MRI.

Case	Arthrogram findings	Femoro-acetabular distance on arthrogram(mm)*	Femoro-acetabular distance on MRI (mm)*	Initial IHDI grade	IHDI grade at 30 mths	Acetabular index at 30 mths	Teardrop shape at 30 mths
P11	No abnormality	< 7	3.5	3	1	20	Open V
P22	Pulvinar	< 7	7.6	3	3	31	NV
P25	Medial pooling	> 7	4.2	3	1	32	NV (after Salter osteotomy - visible after 6 mths)
P27	Medial pooling	> 7	8.0	X†	3	38	Narrow V
P30	No abnormality	> 7	8.0	4	1	23	Crossed V
P32	No abnormality	> 7	8.0	3	1	28	Open V
P35	No abnormality	< 7	6.5	X	–§	–	–
P39	No abnormality	< 7	7.8	X	–	–	–

*Femoro-acetabular distance was the smallest measured distance from the cartilaginous portion of the femoral head to the cartilaginous acetabulum

†X, no pre-reduction radiograph performed (young patients)

§ follow-up < 30 months

NV, not visible; IHDI, International Hip Dysplasia Institute

Table 3. Inter- and intraobserver reliability for obstacles to reduction identified on post-reduction MRI.

Structure	Hips* (n = 38 hips) Obstacles to reduction		Reliability†		
	Possible	Definite	Intra-rater	Inter-rater 1 (authors KS/AG)	Inter-rater 2 (authors PS/AG)
Pulvinar	12 (31.5)	2 (5.2)	94.29 (0.87)	87.10 (0.69)	62.5 (< 0.40)
Ligamentum teres	9 (23.7)	6 (15.8)	88.57 (0.77)	80.65 (0.62)	42.68 (< 0.30)
Labrum	8 (21.05)	5 (13.1)	80 (0.50)	78.13 (0.44)	37.50 (< 0.30)
Acetabular roof cartilage hypertrophy	7 (18.4)	5 (13.2)	71.43 (0.38)	70.97 (0.28)	72 (0.38)
Transverse acetabular ligament	6 (15.8)	4 (10.5)	91.43 (0.62)	90.32 (0.62)	87.50 (0.70)
Capsule	4 (10.5)	3 (7.8)	91.43 (0.62)	90.32 (0.62)	87.50 (0.70)

*values are presented as n (%)

†values are presented as % (kappa)

of the superior acetabulum may contribute to ongoing instability.[14] Instability and difficult reductions are likely to occur in the presence of femoroacetabular mismatch, where there is deformity of the femoral head and acetabular dysplasia.[15,16] This is difficult to measure but was seen in a number of our cases, where the acetabulum was almost convex, with reduced volume, and associated with a small, flattened femoral head (Fig. 2).

In 37% of the hips that remained subluxated after closed reduction, the labrum was interpreted as inverted and acting as a main obstacle in the post-operative MRI. In only one case was the pathological labrum seen in retrospect on the arthrogram and in no case was the pathological labrum identified intra-operatively by the surgeon performing the arthrogram. All of these patients had a late diagnosis of DDH. None of these hips developed a mature acetabulum within the first four years of age. The acetabular index was increased and the teardrop delayed or even absent. All four patients underwent later pelvic osteotomy to address residual acetabular dysplasia with acetabular index greater than 30°. Controversy exists regarding the potential for soft-tissue interposition to resolve with time.[17-22] It has been suggested that an inverted labrum may resolve with time, if it is not large, and fibrous changes at the acetabular floor are not advanced.[18] In the study by Hattori et al,[20] the inverted labrum disappeared in 71% of patients by the age of five years.

The results of our study suggest that when persistent subluxation in association with an inverted labrum is identified on post-reduction MRI in a child with late-diagnosed DDH, this should be addressed in order to achieve ongoing optimal acetabular development and perhaps minimise later surgeries. 'Docking' of the femoral head into the acetabulum following closed reduction in these cases did not occur, even though the hips were appropriately immobilised and positioned. We hypothesise that the dense fibrous labrum was incapable of resolution in these cases and continued to 'push' the femoral head out of the acetabulum. It is, of course, not easy to surgically address a pathological labrum without damaging this structure, and early diagnosis and treatment of DDH remains the best option to minimise such complications.[19]

The arthrogram has historically been a valuable tool during closed reduction of DDH and a reduction with a widening of the hip joint < 7 mm is said to be satisfactory.[3,4] However, the performance of an arthrogram can be difficult in a true dislocated hip, especially after previous invasive procedures around the hip and interpretation of this 2D imaging modality can pose difficulties. MRI offers an alternative tool and allows ongoing surveillance, particularly when the child is immobilised and does not require anaesthesia.[23] It also protects the child from ionising radiation. Medial pooling > 7 mm on arthrogram correlated with non-concentric reduction on post-procedure MRI scan. In

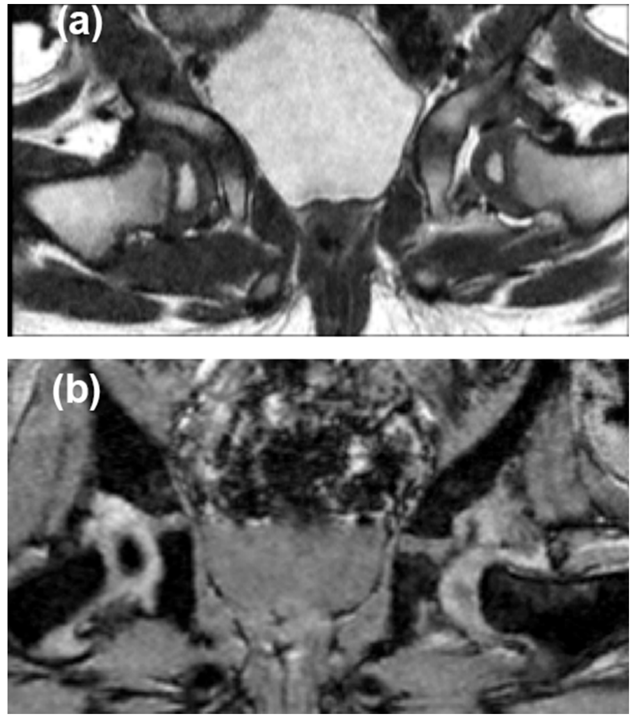

Fig. 2 MRI of six-month-old girl after closed reduction showing femoro-acetabular mismatch and hypertrophied transverse acetabular ligament.

six hips that demonstrated medial pooling at the time of closed reduction, the post-procedure MRI identified at least one obstacle to concentric reduction. The structures identified on our retrospective review of five arthrograms included infolded labrum (one case), enlarged ligamentum teres (three cases) and pulvinar (one case). In other cases, there was only a suspicion. The interpretation of obstacles in the arthrogram was therefore less sensitive than MRI.[18] This limitation of arthrogram, in addition to its invasive nature[24] and requirement for general anaesthesia, may lead clinicians to establish MRI as their preferred tool for select cases. In our institution, repeat rapid sequence MRI in spica cast at the end of cast treatment, in conjunction with a standard clinical examination out of cast, has replaced repeat examination under anaesthetic and arthrograms for most cases. This has reduced our anaesthesia and operating theatre requirements. However, the dynamic nature of arthrography, unavailable with MRI, means that the arthrogram is likely to continue to play an important role in the management of DDH.

Currently, there is no consensus on how to define an adequate concentric reduction on MRI. Kawaguchi et al[25] considered that the same limits as in arthrograms could be used.[4] While this question lies beyond the scope of our study, visualisation of the femoral head in both the coronal and axial planes is important to establish that a concentric reduction has been achieved.[23] A simple visualisation of the capital femoral epiphysis in contact with the posterior

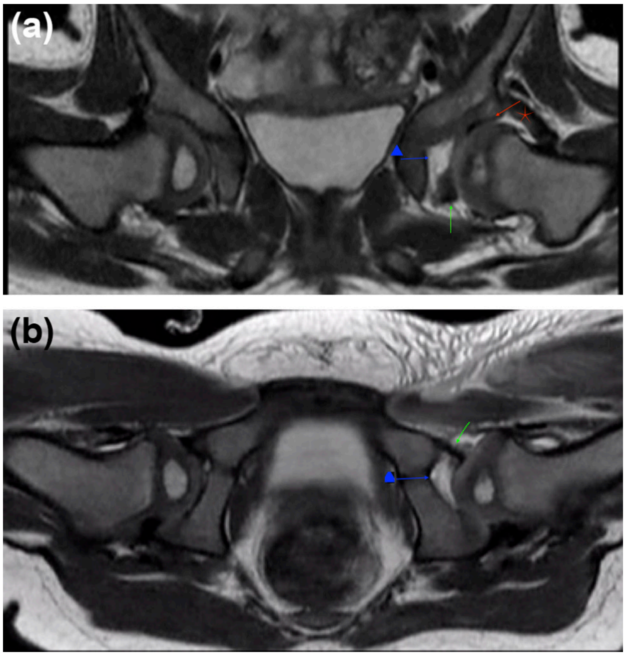

Fig. 3 Five-month-old girl with post-operative MRI after closed reduction: inverted labrum (arrow with star), hypertrophied transverse acetabular ligament (simple arrow), prominent pulvinar (arrow with triangle).

Fig. 4 Anteroposterior radiograph of the pelvis: 28 months after closed reduction without development of teardrop.

margin of the acetabulum[5,26,27] may not be sufficient. Lateral subluxation of the capital femoral epiphysis seems to be the most sensitive indicator of persistent subluxation on MRI.[28] The femoral head is less likely to subsequently reduce into the acetabulum from the lateral position. Obstacles which prevent a concentric reduction in the coronal plane such as the labrum appear less likely to resolve than obstacles preventing concentric reduction in the transverse plane. Further evidence of this phenomenon is provided by Duffy et al,[28] who reported spontaneous resolution at one year of all but 10% of the 58% of cases that showed initial post-procedure subluxation in the transverse plane. In our study, lateral subluxation was more difficult to manage, as evidenced in five cases of lateral subluxation which needed a revision closed reduction and one required open reduction. In one case of lateral subluxation, the hypertrophied TAL and inverted labrum, in addition to the enlarged pulvinar, were interpreted as blocks to concentric reduction (Fig. 3). At the 28-month follow-up, the teardrop did not develop (Fig. 4). In two of the subluxated hips, severe AVN developed. The results of this study suggest lateral subluxation on MRI should not be accepted and provides further evidence that anatomical structures such as inverted labrum or thickened ligamentum teres may not resolve, whereas the enlarged pulvinar may resolve if the hip is well immobilised and the hip shows a concentric reduction. Our findings suggest that the pulvinar is not a sole obstacle to reduction, but may be seen in addition to other obstacles. In the case of a concentric reduction, the femoral head appears to have the ability to push down the fibro-fatty tissue of the pulvinar (mostly fat).

Teardrop development on radiographs is a good marker for a successful concentric reduction of the femoral head and development of the acetabulum.[29,30] In our study, nine hips showed a V-shaped teardrop after closed reduction as a sign of residual acetabular dysplasia.[30] Of these, one-third had a possible obstacle in the post-operative MRI: thickened labrum/and or hypertrophied cartilage (two hips) and thickened ligamentum teres (one hip). All of these hips had a borderline increased acetabular index at the age of 30 months and are being observed for a possible later reconstructive procedure.[31] Our indications for surgery are commonly the absence of the teardrop, acetabular angle > 30° at the age of three years and/or signs of non-concentric position of the femoral head in the acetabulum.

Our study demonstrates the challenges of interpreting complex imaging, even for specialist surgeons and radiologists. The capsule and TAL were reliably identified by an adult orthopedic surgeon specialising in hip surgery but the ligamentum teres (reliability of 43%) and labrum (38%) were more difficult to interpret for an orthopaedic surgeon not specialising in paediatric orthopaedic surgery. There is a learning curve for interpretation of MRI of the infant hip after closed reduction and scans should always be reviewed by someone with familiarity and expertise in this area.

Rapid sequence non-GA MRI is a reproducible method of identifying pathological structures following closed reduction for DDH. It is a useful adjunct to the management of the DDH patient and provides information to improve our understanding of the patho-anatomy of this condition. In our series of late-treated DDH, lateral subluxation on post-reduction MRI, particularly in association with an inverted labrum, did not resolve spontaneously and was associated with a worse outcome. The pulvinar resolved in cases where concentric reduction was achieved. The TAL was the structure most reliably identified and, although often hypertrophied, it rarely acted as the main block to reduction. Hypertrophy of the acetabular roof cartilage was associated with severe DDH and its presence should alert the surgeon to potential treatment difficulties.

Focused interpretation of these structures on MRI may facilitate better management of DDH.

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COMPLIANCE WITH ETHICAL STANDARDS

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ETHICAL STATEMENT

Ethical Approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent: For this retrospective type of study formal consent is not required.

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