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SCIENTIFIC ARTICLE

The posterior crescent sign on MRI and MR arthrography: is it a marker of hip dysplasia and instability?

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Abstract

Objective To evaluate the prevalence of the ‘posterior crescent sign’ in symptomatic patients referred for MRI/MR arthrogram of the hip and identify any correlation with imaging features of joint pathology.

Materials and methods Retrospective imaging assessment of a cohort of 1462 hips, from 1380 included MR examinations (82 bilateral) retrieved from a search of all examinations in patients 16–50 years old from June 2018 to June 2021, with median age 45.8 years (range 17.8–50.0) and 936 hips (64%) in women. Radiographic and MR findings related to hip dysplasia, femoroacetabular impingement and osteoarthritis were assessed.

Results Fifty-one hips (3.5%) were positive for the posterior crescent sign, median age of 45.8 years (range 17.8–50.0) and 29 (58%) in women. Radiographic findings included the following: mean lateral centre edge angle (LCEA) 22.2° (± 7.8°) with LCEA < 20° in 15 (31%) and LCEA 20–25° in 17 (35%) and mean acetabular index (AI) of 13.1° (± 5.8°) with AI > 13° in 22 (45%). MR findings included the following: mean anterior acetabular sector angle (AASA) 54.3° (± 9.8°), mean posterior acetabular sector angle (PASA) 92.7° (± 7.0°), labral tear at 3–4 o’clock in 20 (39%), high-grade acetabular chondral loss in 42 (83%) and ligamentum teres abnormality in 20 (39%).

Conclusion The posterior crescent sign occurs in 3.5% of symptomatic young and middle-aged adults on MR. It is associated with overt and borderline hip dysplasia and other findings of hip instability. It is also associated with osteoarthritis in some cases and should be interpreted with caution in these patients.

Keywords Hip microinstability · Hip instability · Hip laxity · Hip dysplasia

Introduction

Although historically considered a highly-constrained and inherently stable joint, the hip is more biomechanically complex and dynamic than previously assumed [1–3]. Instability contributes to the pathophysiology of hip dysplasia, which has a well-established natural history leading to osteoarthritis through excessive loading and shear stress [4]. There is now increasing recognition that minute instability of the hip is detectable and clinically significant and is postulated to lead to premature osteoarthritis [1, 5, 6], including in cases of ‘borderline’ hip dysplasia [4] and the recently-described clinical entity of hip microinstability [7], particularly in the young and athletic population. It is also identified as a complication of hip arthroscopy related primarily to capsular laxity or labral injury, potentially requiring revision or conversion to hip replacement [8].

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The accurate detection of hip instability is important, especially in symptomatic hips with both ‘borderline’ hip dysplasia and possible femoroacetabular impingement where an ‘unstable’ hip is typically managed with periacetabular osteotomy but a ‘stable’ hip is typically managed with correction of the impinging morphology [9]. The accurate diagnosis of hip microinstability allows for that condition to be optimally managed, including with appropriate hip preservation surgery. Currently, there are no objective diagnostic criteria for hip instability, with it being a composite diagnosis of clinical, imaging and intra-operative findings [10, 11]. Multiple imaging features have been proposed, mostly indirect signs such as labral hypertrophy, iliocapsularis hypertrophy or anterior joint capsule thinning [12].

The ‘posterior crescent sign’, referring to a crescent-shaped accumulation of fluid in the posteroinferior joint space on MRI (see Fig. 1) or MR arthrography (see Fig. 2), has been proposed as a diagnostic imaging feature [4, 5], even described as a ‘parameter proving hip instability’ [4]. It theoretically directly demonstrates the anterior translation of the femoral head within the acetabulum. The sign however could conceivably represent joint surface incongruity and may be a finding in normal hips. Very little primary research has investigated this finding.

The purpose of this study was to evaluate the prevalence of this sign in symptomatic adult patients referred for MR imaging of the hip and identify any correlation with imaging features of joint pathology specifically related to hip dysplasia. In addition, a novel MR imaging sequence in which the hip is imaged in the flexion, abduction and external rotation (FABER) position [12, 13] as an adjunct for the investigation of instability has been introduced, and examinations with this technique were assessed to evaluate its diagnostic role in an early cohort.

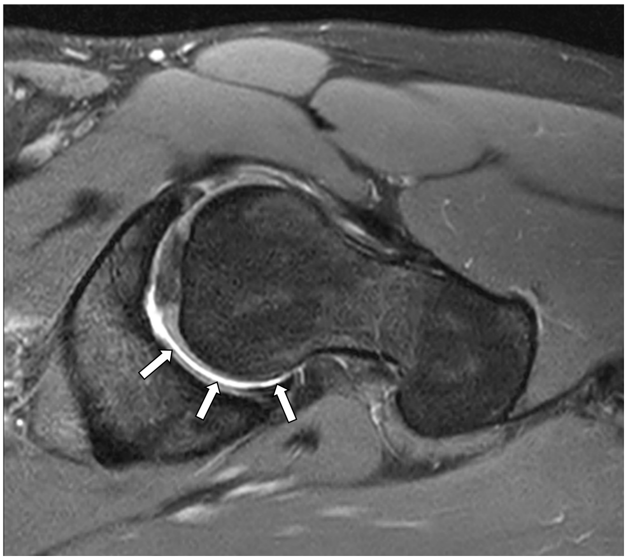

Fig. 1 Axial-oblique PD-weighted fat-suppressed (SPAIR) conventional MRI showing a posterior crescent sign (white arrows) in the hip of a 32-year-old woman

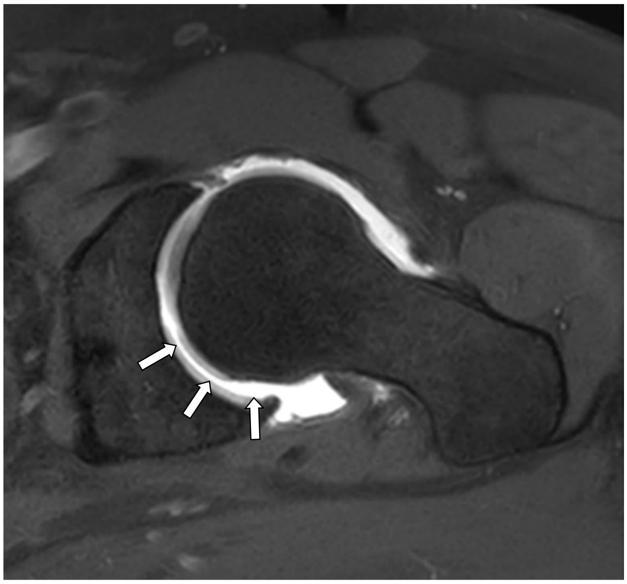

Fig. 2 Axial-oblique T1-weighted fat-suppressed (SPAIR) MR arthrogram showing a posterior crescent sign (white arrows) in the hip of a 48-year-old woman

Materials and methods

Patient cohort

An electronic search of the PACS was performed for all MRI and MR arthrogram examinations of the hip performed at Auckland Radiology Group (ARG) in Auckland, New Zealand, in patients 16 to 50 years old over the 3 years between 1st June 2018, and 30th June 2021. Limited clinical information provided in the referral was available for review; however, the patient’s clinical records beyond this were not accessed. All examinations were performed for symptoms attributed to the hip joint or the hip region, predominantly pain. A total of 1497 examinations were retrieved. One hundred seventeen (8%) were excluded for the following reasons: duplicate examinations ($n = 45$), no small field of view imaging of the hip ($n = 43$), prior periacetabular osteotomy ($n = 8$), prior arthroplasty ($n = 8$), deformity related to osseous disease including osteonecrosis with femoral head collapse, Perthes disease, slipped upper femoral epiphysis or erosive arthropathy ($n = 13$). Ethics approval for this study was granted by the national review board (New Zealand Health and Disability Ethics Committees) under Ethics Ref 21/NTB/153, 21st June 2021, which includes a waiver of the requirement for informed consent for the retrospective use of health data.

A total of 1380 MR examinations were included, derived from 1357 patients, generating a study cohort of 1462 hips (including 82 bilateral examinations and 23 patients with both hips imaged separately). A total of 1227 (83%) hips were imaged by conventional MRI (non-arthrogram), and 235 (16%) hips were imaged by MR arthrogram. Of the 1462 imaged hips, 936 (64%) were in women.

Image analysis

All MR examinations were reviewed by a single observer (AM, 3rd-year radiology resident) for the presence of the posterior crescent sign, defined as a crescent of high T2/fluid or intra-articular contrast signal in the posterior joint space at the level of the femoral head centre separating the cartilage surfaces of the femoral head and acetabulum on at least two planes. Windowing was performed to improve the differentiation of fluid/contrast signal and cartilage. All equivocal cases were reviewed together with a second author (RW, consultant radiologist with 20 years of experience in musculoskeletal radiology) and a consensus decision was reached.

All hips positive for the posterior crescent sign proceeded to a detailed retrospective hip imaging assessment to characterise the morphology and other imaging findings. Radiographs of the hip were also assessed if available within 1 year of the MR examination. The morphological parameters assessed on radiograph and MR are listed in Table 1 and were measured according to Beltran et al. [14] and Haefeli et al. [15] for iliocapsularis:rectus femoris (IC:RF) ratios. In cases where the femoral condyles were included on the MR examination, femoral torsion was measured according to Mascarenhas et al. [16] using the Reikeras technique. On a radiograph, other imaging findings assessed included the disruption of Shenton's line, posterior wall sign (considered positive if the posterior acetabular rim was projected medial to the femoral head centre), crossover sign, cam deformity of the femoral head-neck junction, osteophytes and joint space narrowing (superior joint space ≤ 2 mm). On MR, other imaging findings assessed included cranial acetabular retroversion (present or absent), cam deformity, osteophytes, high-grade chondral loss (grades 3 or 4 of modified Outerbridge classification of chondral lesions), subchondral change, labral hypertrophy (labral dimension 12 mm from base to apex at any point), labral tear (any discrete or linear high T2 signal or contrast signal within the labral substance or chondrolabral junction) and ligamentum teres abnormality (including fraying, thickening, attenuation, partial tear or complete tear). All imaging assessment was performed by a single observer (AM). To ensure accuracy, 15 hips (30%) were also assessed by a second observer (RW) for interobserver consistency analysis.

Morphologic parameters were compared to normal ranges in the published literature, included in Table 1. Upper and/or lower thresholds were selected for the categorisation of abnormal cases, also included in Table 1,

Table 1 Morphological parameters (radiographic and MR) for all cases positive for the posterior crescent sign on hip MRI/MR arthrogram ($n=51$ hips)

Modality	Morphological parameter	Results			Reference values from published literature (for comparison to normal)	
		Mean	Range	Number of abnormal hips (above/below threshold for abnormality)	Normal range	Threshold for abnormality
Radiograph ($n=49$)	LCEA (°)	22.2 (±7.8)	2.2–40.7	< 20°: 15 (31%) 20–25°: 17 (35%)	18–48 [16]	Decreased: < 20° [14]
	AI (°)	13.1 (±5.8)	1.3–26.3	> 13°: 23 (47%)	−7 to 15 [16]	Increased: > 13° [14]
MRI ($n=51$)	HASA (°)	146.9 (±12.4)	122.8–180.7	< 140°: 16 (31%)	146–190 [17]	Decreased: < 140° [14]
	AASA (°)	54.3 (±9.8)	28.3–77.7	< 50°: 16 (31%)	51–75 [17]	Decreased: < 50° [14]
	PASA (°)	92.7 (±7.0)	77.5–113.4	< 90°: 17 (33%)	90–120 [17]	Decreased: < 90° [14]
	Acetabular version (°)	19.2 (±5.6)	5.0–30.0	> 25°: 8 (16%) < 10°: 4 (8%)	7–33 [16]	Decreased: < 10° † Increased: > 25° †
	Femoral torsion (°) ($n=14$ only)	22.2 (±11.4)	5.4–43.5	> 20°: 9 (64%) < 5°: 0 (0%)	N/A	Increased: > 25° † Decreased: < 5° †
	COTAV Index (°) ($n=14$ only)	41.3 (±15.9)	15.5–64.1	> 45°: 6 (43%) < 20°: 1 (7%)	N/A	Increased: > 45° [18] Decreased: < 20° [18]
	IC:RF width ratio	1.26 (±0.31)	0.31–1.99	> 1.0: 42 (82%)	0.7–1.5 [15]	Increased: > 1.0 [15]
	IC:RF thickness ratio	1.00 (±0.32)	0.49–2.07	> 1.0: 22 (43%)	0.5–1.6 [15]	Increased: > 1.0 [15]

†Thresholds for diagnostic usage not widely published

based on thresholds reported in the literature or in common clinical usage, with the acknowledgement that there is no universal consensus in the determination or application of these thresholds [16]. Hip dysplasia is variably defined in the literature based on one or more morphological criteria: lateral centre edge angle (LCEA) < 20°, acetabular index (AI) (aka Tönnis angle) > 13°, anterior acetabular sector angle (AASA) < 50° and posterior acetabular sector angle (PASA) < 90° [14], with LCEA of 20–25° commonly used to denote 'borderline' hip dysplasia and decreased AASA and PASA angles corresponding to the undercoverage of the femoral head anteriorly and posteriorly respectively [14].

Imaging protocols

All MR examinations were performed on a 3 T MRI system, either a Siemens system including Magnetom Vida, Lumina or Skyra products (Siemens Medical Solutions, Erlangen, Germany) or a Philips Ingenia Elition (Koninklijke Philips N.V., Amsterdam, the Netherlands). All examinations were performed in the standard supine relaxed-leg position. Standard MR sequences obtained for conventional MRI included the following: coronal T1-weighted fat-suppressed sequence and T2-weighted fat-suppressed sequence through the whole pelvis (FOV 370–375 mm, slice thickness 4.0 mm); axial T1, axial T2 fat-suppressed and sagittal/coronal/axial oblique PD fat-suppressed sequences through the hip joint (FOV 160–180 mm, slice thickness 3.5 mm); and plus radial PD sequence through the hip joint (FOV 140–200 mm, slice thickness 3.0 mm). MR arthrogram examinations were performed following intra-articular injection under fluoroscopic guidance of 7–10 mL solution containing iodinated contrast agent (Iohexol 300 mg/mL as Omnipaque300; GE Healthcare, Chicago IL, USA), gadolinium-based MR contrast agent (gadodiamide 287 mg/mL as Omniscan; GE Healthcare, Chicago IL, USA) and local anaesthetic (ropivacaine hydrochloride 7.5 mg/mL as Naropin 0.75%; Aspen Pharmacare, St Leonards, Australia). Standard MR sequences obtained for MR arthrogram included the following: coronal T2 and coronal T2 fat-suppressed sequences through the whole pelvis (FOV 375 mm, slice thickness 4.0 mm); axial T1, axial T2 fat-suppressed, sagittal PD and coronal/axial oblique T1 fat-suppressed sequences through the hip joint (FOV 160–180 mm, slice thickness 3.5 mm); and plus radial PD sequence through the hip joint (FOV 140–200 mm, slice thickness 3.0 mm). In selected patients, a T1 sequence through the femoral condyles (FOV 180 mm, slice thickness 4.0 mm) was performed for the measurement of femoral torsion. All radiographs were performed by digital radiography and included an AP projection of the whole pelvis and a lateral projection of the hip.

Additional analysis

Thirty-one MR examinations included additional imaging of the hip in the FABER position, derived from 27 patients (including 4 patients with both hips imaged separately), generating a subgroup of 31 hips. All (100%) were women. These examinations were identified when encountered during a sequential review of the images of the full study cohort. Additional FABER imaging was typically performed in young female patients and more commonly when referred by surgeons with experience in hip preservation surgery or when referred with a clinical question of hip microinstability. Of these, 6 (19%) were conventional MRI (non-arthrogram), and 25 (81%) were MR arthrogram. Cases positive for the posterior crescent sign (in any hip position) proceeded to a detailed retrospective hip imaging assessment in the same manner as above.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics on Windows PC (version 26; IBM, Armonk NY, USA). Quantitative measurements are reported as mean (± standard deviation) and range, with the distribution of measurements assessed to confirm conformity to normal distribution. Normal ranges are reported as 2.5–97.5th percentile. Interobserver agreement was assessed using Cohen's kappa coefficient for categorical data and intraclass correlation coefficient for quantitative data (mean rating, absolute-agreement, two-way, mixed-effects model). Subgroup comparison of quantitative data was performed using Student's *T*-test (two-sample, two-tail *T*-test, assuming equal variances). A *p*-value of < 0.05 was considered statistically significant.

Results

Fifty-one of 1462 hips (3.5%) had a positive finding of a posterior crescent sign: 44 of 1227 (3.6%) on conventional MRI (non-arthrogram) and 7 of 235 (3.0%) on MR arthrogram. These hips were in 50 patients (one patient bilaterally), median age of 45.8 (range 17.8–50.0 years), with 29 hips (57%) in women. Of these, 49 hips (96%) had preceding radiographs for review. Morphologic parameters of all assessed hips are summarised in Table 1.

Hips positive for the posterior crescent sign exhibited a significant rate of overt or borderline hip dysplasia. Of the four criteria for diagnosing hip dysplasia (LCEA < 20°, AI > 13°, AASA < 50°, PASA < 90°), 35 hips (71%) met 1 or more criteria, 20 hips (41%) met 2 or more criteria, 12 hips (24%) met 3 or more criteria, and 4 hips (8%) met all 4 criteria. Using LCEA alone, 15 hips (31%) were overtly dysplastic (LCEA < 20°), and 17 hips (35%) were borderline dysplastic (LCEA 20–25°). All hips with a LCEA < 20° met at least one other criteria for dysplasia, indicating an abnormal LCEA did not occur in isolation. Sixteen hips (33%) on radiograph had an LCEA > 20° (considered 'non-dysplastic' by LCEA alone), but on MR had either an AASA < 50° or PASA < 90°.

An additional finding of interest is that 27 hips (55%) had a positive posterior wall sign on the radiograph, of which only 13 (48%) had a PASA < 90° on MR. This gives the posterior wall sign a sensitivity of 76.5% (95% CI: 50.1–93.2%), specificity of 56.3% (95% CI: 37.7–73.6%), positive predictive value of 48.2% (95% CI: 36.7 – 59.9%) and negative predictive value of 81.8% (95% CI: 64.4–92.8%) for the prediction of posterior wall deficiency as defined by a PASA < 90° on MRI. Additionally, 4 hips (8%) had a disrupted Shenton's line on the radiograph, 3 of which had severely reduced LCEA (range 2.2–13.8°), and the remaining one had a borderline LCEA of 20.9°.

Some hips with the posterior crescent sign showed degenerative changes (see Fig. 3). On a radiograph, 22 hips (45%) had superior joint space narrowing, 20 hips (41%) had femoral osteophytes and 14 hips (29%) had acetabular osteophytes. On MR, 27 hips (53%) had femoral osteophytes, and 17 hips (33%) had acetabular osteophytes, with 14 hips (28%) having both. On MR, 42 hips (83%) had high-grade acetabular cartilage loss of any size, and 17 hips (33%) had high-grade femoral head cartilage loss (see Table 2). A subgroup comparison of hips with the posterior crescent sign between those with high-grade acetabular chondral loss involving an area of > 20 mm ($n = 10$) and those without ($n = 41$), with no significant difference in morphological parameters between these groups ($p > 0.17$ for all). Of note, of the 22 hips with superior joint space narrowing on the radiograph, 18 of these (82%) had > 10 mm of high-grade chondral loss on the acetabular or femoral surfaces or both.

In relation to impingement morphology, 20 hips (39%) demonstrated cam deformity of the femoral head-neck junction on MR. On radiographs, 6 hips (12%) demonstrated a positive cross-over sign. Only 14 hips (28%) included MR imaging of the femoral condyles for measurement of femoral torsion and combined femoral torsion and acetabular version (COTAV) index (see Table 1).

In relation to the other soft tissue structures of the hip, 49 hips (96%) had a labral tear at any location with 20 hips (39%) having a labral tear anteriorly located at or extending into the 3–4 o'clock location. Nineteen hips (37%) had labral hypertrophy. Twenty hips (39%) had an abnormality of the ligamentum teres, with 5 hips (10%) having a complete tear.

Of the 31 hips with FABER imaging, 9 hips (29%) were positive for the posterior crescent sign in any position (standard neutral or FABER). Of these, 8 hips (89%) were positive only in the FABER position (negative in the standard neutral position) (see Fig. 4). These hips with the posterior

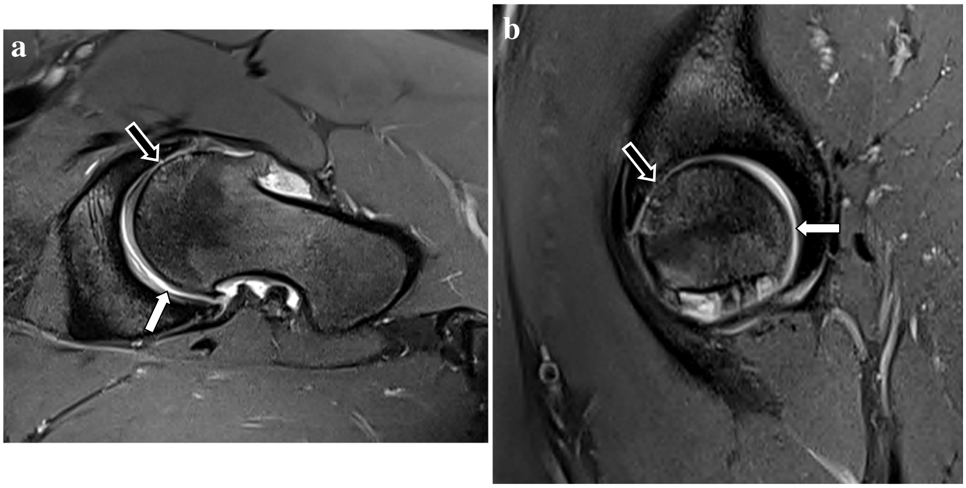

Fig. 3 PD-weighted fat-suppressed (SPAIR) conventional MRI axial-oblique (**a**) and sagittal (**b**) images showing a posterior crescent sign (white arrows) in a 24-year-old man with concomitant advanced degenerative change including high-grade chondral loss of the acetabular and femoral surfaces anterosuperiorly (white-outlined arrows) and prominent femoral head marginal osteophytes

Table 2 MR findings of chondral loss for cases positive for the posterior crescent sign on hip MRI/MR arthrogram ($n = 51$ hips)

Imaging finding		Acetabular surface	Femoral surface
Finding	Size of largest lesion		
High-grade chondral loss (grade 3 or 4)	None	9 (18%)	34 (67%)
	< 10 mm	13 (25%)	3 (6%)
	10–20 mm	19 (37%)	11 (22%)
	> 20 mm	10 (20%)	3 (6%)
Subchondral change	N/A	26 (51%)	10 (20%)

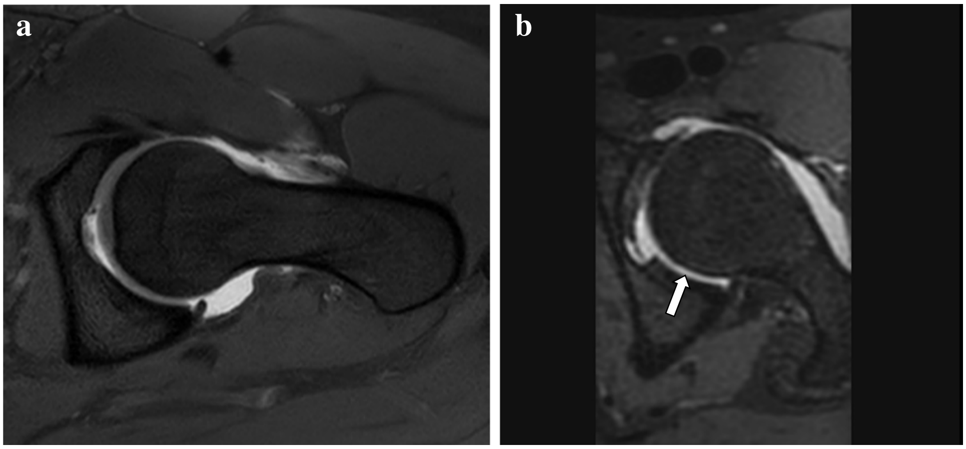

Fig. 4 T1-weighted fat-suppressed (SPAIR) MR arthrogram axial-oblique image with hip in neutral position (**a**) and axial image with hip in FABER position (**b**) in a 19-year-old woman, showing the posterior crescent sign only in the FABER position (white arrow)

crescent sign in any position were in patients with a median age of 36.5 years (range 19.6–50.0), all (100%) women. Morphologic parameters of these 9 hips included the following: mean LCEA 25.7° (± 11.4°), AI 9.3° (± 11.4°), AASA 55.0° (± 7.2°), PASA 94.7° (± 6.1°), acetabular version 19.1° (± 4.2°) and femoral torsion 21.9° (± 8.1°). Other imaging findings included the following: 4 hips (44%) had a labral tear anteriorly at 3–4 o'clock, 0 hips (0%) had labral hypertrophy, and 0 hips (0%) had an abnormality of the ligamentum teres. Only 1 hip (11%) had any findings of significant degenerative change (with < 20 mm high-grade chondral loss on both acetabular and femoral head surfaces).

Interobserver consistency of imaging findings in the 30% of cases assessed by both reviewers was satisfactory. All quantitative measurements had an intraclass correlation coefficient of > 0.87 (almost perfect agreement) and categorical findings had a kappa coefficient of > 0.70 (substantial agreement), with the exception of IC:RF thickness ratio with an intraclass correlation coefficient of 0.55. The latter is consistent with prior research indicating that IC:RF ratios have variable inter-observer reliability and are highly dependent on the slice selection on axial images [19].

Discussion

This study is the first to examine the prevalence of the posterior crescent sign in the symptomatic population undergoing MR imaging of the hip. We found the posterior crescent sign present in 3.5% of adults under 50 years of age irrespective of symptomatology or diagnostic question. This indicates that the posterior crescent sign is an uncommon, although not exceedingly rare, imaging finding and may be overlooked if not considered.

This study is the largest to date and provides the most comprehensive description of the radiographic and MR imaging features of hips with a posterior crescent sign. Only two other scientific studies have specifically assessed the posterior crescent sign: Zurmühle et al. 2021 [20], a retrospective study of pre-operative MR arthrogram in 56 dysplastic hips versus 70 hips with femoroacetabular impingement, and Sonoda and Hara 2022 [21], a retrospective study of 72 dysplastic hips without advanced radiographic osteoarthritis versus 12 control hips undergoing unrelated screening. The former study estimated the posterior crescent sign to have a sensitivity of 73% and specificity of 93% for detecting hip joint instability, concluding that the sign 'supports the possibility of instability as the predominant pathology' and has high specificity. The latter study found the prevalence of the posterior crescent sign in hips with symptomatic dysplasia group to be extremely high at 92%, versus 9% in hips with asymptomatic dysplasia and 0% in the small sample of normal controls. Both studies relied on two-dimensional radiographic measurements, primarily LCEA, for the diagnosis of dysplasia and neither assessed important soft tissue structures such as articular cartilage or the ligamentum teres.

In our cohort, the posterior crescent sign is associated with high rates of overt and borderline hip dysplasia, with 31% overtly dysplastic and 35% borderline dysplastic as determined by LCEA on radiograph alone and 73% dysplastic by broader three-dimensional morphological criteria on radiograph and MR. Whilst this study cannot determine the causality of the posterior crescent sign, the high prevalence of dysplasia in our cohort is informative. Hip joint instability is known to be an important pathophysiological process in the dysfunction and eventual development of early-onset osteoarthritis in hip dysplasia. We contend that our data is supportive of the posterior crescent sign being an indicator of hip joint instability by virtue of the high prevalence of dysplastic morphology.

Of note, it is increasingly recognised that hip dysplasia is a complex three-dimensional deformity of the acetabulum, with anterior, posterior and superolateral (or global) subtypes of dysplasia described, which are inadequately assessed on radiographic assessment and underestimated using LCEA alone [22, 23]. In our study, one-third of cases of hip dysplasia related to anterior or posterior deficiency would be missed using LCEA on a radiograph alone. This is concordant with the three-dimensional morphologic study by Nepple et al. [23] which reported rates of anterosuperior, posterosuperior and global deficiency of 30%, 34% and 36% respectively in patients with hip dysplasia managed surgically. Our study further supports the importance of a three-dimensional assessment of acetabular morphology, ideally using cross-sectional imaging, rather than relying solely on two-dimensional measurements from a frontal radiograph such as LCEA.

Furthermore, in this study, the posterior wall sign on the radiograph had a positive predictive value of only 48% for predicting posterior acetabular deficiency as defined by PASA < 90° on MR. This is concordant with findings of other morphologic studies including that of Nepple et al. [23] which concluded the posterior wall sign is not accurate. The posterior wall sign is also known to be compromised by pelvic rotation and tilt which are common on radiographs performed in clinical practice [24]. The posterior wall sign is used routinely in clinical practice for the determination of posterior acetabular deficiency. This study however suggests that the posterior wall sign should be interpreted carefully in view of its low accuracy and only on high-quality properly centred radiographs.

In our study cohort, the posterior crescent sign is associated with a high rate of labral tears at or extending into the 3–4 o'clock location, which is an otherwise uncommon configuration for labral tears which are much more commonly seen at the 12 o'clock to 3 o'clock quadrant [25]. In one study by Shibata et al. [9], hip joint instability in non-dysplastic hips was associated with a distinct pattern of chondrolabral damage at a 'straight anterior' location of the acetabulum at arthroscopy, corresponding to the 3–4 o'clock position of the labrum on imaging. These findings are concordant with the recent study by Sonoda and Hara [21] of 72 hips with dysplasia, which found that hips with a positive posterior crescent sign had a high rate of anterior labral tears (79% vs 25%, $p < 0.0001$). This phenomenon is speculated to result from biomechanical strain on the anterior hip joint in anterior hip joint instability which is the most common pattern of instability, although the precise pathophysiology of this association and whether it is more cause or effect remains unclear [26].

Although only a small subset of hips with the posterior crescent sign could be assessed for femoral torsion, these demonstrated a high rate of increased femoral antetorsion (64%) with none having decreased femoral antetorsion. Excessive femoral antetorsion, as well as increased acetabular version, are reported to be risk factors for anterior hip joint instability [7, 22, 27]. It is postulated that this configuration directs femoral head forces anteriorly and may also be associated with a posterior cam effect, leading to increased biomechanical strain on the anterior stabilisers of the hip joint including the anterior labrum, iliofemoral ligament and iliopsoas tendon, ultimately resulting in anterior translation of the femoral head. This may lead to symptoms suggesting iliopsoas impingement; however, treatment with fractional lengthening or tenotomy could exacerbate instability [28].

Abnormalities of the ligamentum teres, in the form of a complete tear, partial tear or degenerative changes such as thickening or fraying, are another finding reported to be associated with hip joint instability [29], as well as poorer outcomes following hip arthroscopy [30]. The rates of ligamentum teres abnormality in our cohort with the posterior crescent sign (39% any abnormality, 10% complete tear) are similar to rates reported in the small number of previously published studies. In patients undergoing hip arthroscopy, rates of a complete tear of up to 4% and partial tear of up to 88% in patients have been reported [31], One study by Mayes et al. [32] of 98 adults identified partial tears in 33% of ballet dancers versus 18% of matched sportspeople (non-dancers) and complete tears in 22% versus 4% respectively. There is increasing recognition that the ligamentum teres may have a role as a tertiary stabiliser of the hip joint, and tears may contribute to hip joint instability [29]. However, it is well documented that assessment of the ligamentum teres on MR is challenging, especially for the accurate diagnosis of partial tears [33, 34].

Hips with a posterior crescent sign demonstrated a high rate of degenerative change, particularly high-grade chondral loss. It is possible that advanced degenerative change is a confounding factor. High-grade chondral loss causes incongruity of the femoral and acetabular joint surfaces, which may allow decentering of the femoral head within the acetabulum and result in a 'false-positive' sign that is not indicative of instability. This possibility has been recognised in studies such as Zurmühle et al. [20] and Suter et al. [26]. Our study assesses only hips with a positive posterior crescent sign, without comparison to hips without this sign, and is therefore unable to determine any relationship between chondral loss and the finding of a posterior crescent sign. It has also been observed that the femoral head in otherwise normal hips sometimes appears flattened posteriorly and could also yield a 'false-positive' posterior crescent sign [20].

The underlying pathophysiology of the posterior crescent sign remains to be determined. It is assumed that in the absence of significant degenerative change or abnormal morphology of the posterior surface of the femoral head, the posterior crescent sign indicates subtle anterior translation of the femoral head consistent with hip joint instability. The state of the labrum in particular appears to be an important factor in both joint stability and the dynamics of fluid within the joint, as an intact labrum has been shown to have a vacuum-sealing effect which resists distraction of the femoral head and also prevents fluid accumulation in the central compartment [35]. A joint effusion or the volume of intra-articular contrast injected could conceivably also be variables in the fluid pooling which produces the posterior crescent sign; however, these factors have not been considered in any prior studies. Notably in our study, the prevalence of posterior crescent sign was essentially the same between hips imaged on conventional MRI (non-arthrogram) and MR arthrogram, suggesting that intra-articular fluid volume may not be a contributing factor.

Finally, this study is the first to report experience in assessing the posterior crescent sign on the novel technique of MRI/MR arthrogram in the FABER position. On imaging in the FABER position, 29% of hips were positive for the posterior crescent sign compared to the baseline prevalence of 3.5% on imaging in the standard neutral position; however, this is likely substantially affected by selection bias. Although the subgroup numbers are very small, it is notable that all except one hip (89%) were positive in the additional FABER position and were negative in the standard neutral position. This suggests that MR imaging in the FABER position may elicit this sign in a patient where this would otherwise be absent, although the diagnostic significance in this scenario is unclear.

This study has several methodological limitations. It is a retrospective study of imaging performed as part of a routine clinical practice, and so there is inevitably a degree of heterogeneity of imaging system, settings/parameters and acceptable image quality. However, although imaging was acquired from a range of MR systems, all were 3 T systems, and imaging was performed according to well-established institutional protocols. This study combines both conventional MRI and MR arthrogram examinations. Although these are different imaging techniques, in our cohort, the prevalence of the posterior crescent sign was the same in both groups. As an imaging-based study, it was not possible to reliably correlate with symptomatology or clinical findings, as clinical information was limited to the brief referral information on the request form.

In conclusion, the posterior crescent sign is recognisable on hip MR or MR arthrogram and is correlated with other imaging findings of hip dysplasia and hip microinstability. This supports the accepted understanding in much of the orthopaedic literature that the posterior crescent sign may be an independent finding of hip joint instability. It is also associated with osteoarthritis where it may be a 'false-positive' finding, and so should be interpreted with a high degree of caution in the setting of high-grade chondral loss.

Declarations

Ethics 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.

Conflict of interest The authors declare no competing interests.

References

1. Bolia I, Chahla J, Locks R, Briggs K, Philippon MJ. Microinstability of the hip: a previously unrecognized pathology. Muscles Ligaments Tendons J. 2016;6:354–60.
2. Safran MR, Lopomo N, Zaffagnini S, Signorelli C, Vaughn ZD, Lindsey DP, et al. In vitro analysis of peri-articular soft tissues passive constraining effect on hip kinematics and joint stability. Knee Surg Sports Traumatol Arthrosc. 2013;21:1655–63.
3. Charbonnier C, Kolo FC, Duthon VB, Magnenat-Thalmann N, Menetrey J. Assessment of congruence and impingement of the hip joint in professional ballet dancers: a motion capture study. Am J Sports Med. 2011;39:557–66.
4. Wyatt MC, Beck M. The management of the painful borderline dysplastic hip. J Hip Preserv Surg. 2018;5:105–12.
5. Safran MR. Microinstability of the hip – gaining acceptance. J Am Acad Orthop Surg. 2019;27:12–22.
6. Kalisvaart MM, Safran MR. Microinstability of the hip – it does exist: etiology, diagnosis and treatment. J Hip Preserv Surg. 2015;2:123–35.
7. Dangin A, Tardy N, Wettstein M, May O, Bonin N. Microinstability of the hip: a review. Orthop Traumatol Surg Res. 2016;102:S301–9.
8. Woodward RM, Philippon MJ. Persistent or recurrent symptoms after arthroscopic surgery for femoroacetabular impingement: a review of imaging findings. J Med Imaging Radiat Oncol. 2019;63:15–24.
9. Shibata KR, Matsuda S, Safran MR. Is there a distinct pattern to the acetabular labrum and articular cartilage damage in the non-dysplastic hip with instability? Knee Surg Sports Traumatol Arthrosc. 2017;25:84–93.
10. Safran MR, Murray IR, Andrade AJ, Aoki SK, Ayeni OR, Balakumar J, et al. Criteria for the operating room confirmation of the diagnosis of hip instability: the results of an international expert consensus conference. Arthrosc J Arthrosc Relat Surg. 2022;38:2837–49.
11. Cohen D, Jean P-O, Patel M, Aravinthan N, Simunovic N, Duong A, et al. Hip microinstability diagnosis and management: a systematic review. Knee Surg Sports Traumatol Arthrosc. https://doi.org/10.1007/s00167-022-06976-7.
12. Akiyama K, Sakai T, Koyhanagi J, Yoshikawa H, Sugamoto K. Evaluation of translation in the normal and dysplastic hip using three-dimensional magnetic resonance imaging and voxel-based registration. Osteoarthritis Cartilage. 2011;19:700–10.
13. Burke CJ, Walter WR, Gyftopoulos S, Pham H, Baron S, Gonzalez-Lomas G, et al. Real-time assessment of femoroacetabular motion using radial gradient echo magnetic resonance arthrography at 3 Tesla in routine clinical practice: a pilot study. Arthrosc J Arthrosc Relat Surg. 2019;35:2366–74.
14. Beltran LS, Rosenberg ZS, Mayo JD, Diaz de Tuesta M, Martin O, Neto LP, et al. Imaging evaluation of developmental hip dysplasia in the young adult. Am J Roentgenol. 2013;200:1077–88.

15. Haefeli PC, Steppacher SD, Babst D, Siebenrock KA, Tannast M. An increased iliocapsularis-to-rectus-femoris ratio is suggestive for instability in borderline hips. Clin Orthop. 2015;473:3725–34.
16. Mascarenhas VV, Ayeni OR, Egund N, Jurik AG, Caetano A, Castro M, et al. Imaging methodology for hip preservation: techniques, parameters, and thresholds. Semin Musculoskelet Radiol. 2019;23:197–226.
17. Anda S, Terjesen T, Kvistad KA, Svenningsen S. Acetabular angles and femoral anteversion in dysplastic hips in adults: CT investigation. J Comput Assist Tomogr. 1991;15:115–20.
18. Chadayammuri V, Garabekyan T, Bedi A, Pascual-Garrido C, Rhodes J, O'Hara J, et al. Passive hip range of motion predicts femoral torsion and acetabular version. J Bone Joint Surg Am. 2016;98:127–34.
19. Baker KB, Vesey RM, Clark B, Billington K, Woodward RM. Assessment of the iliocapsularis muscle on magnetic resonance imaging. J Med Imaging Radiat Oncol. 2022;66:920–6.
20. Zurmühle CA, Kuner V, McInnes J, Pfluger DH, Beck M. The crescent sign – a predictor of hip instability in magnetic resonance arthrography. J Hip Preserv Surg. 2021;8:164–71.
21. Sonoda K, Hara T. "Anterior-shift sign": a novel MRI finding of adult hip dysplasia. Arch Orthop Trauma Surg. 2022;142:1763–8.
22. Wilkin GP, Ibrahim MM, Smit KM, Beaulé PE. A contemporary definition of hip dysplasia and structural instability: toward a comprehensive classification for acetabular dysplasia. J Arthroplasty. 2017;32:S20–7.
23. Nepple JJ, Wells J, Ross JR, Bedi A, Schoenecker PL, Clohisy JC. Three patterns of acetabular deficiency are common in young adult patients with acetabular dysplasia. Clin Orthop. 2017;475:1037–44.
24. Tannast M, Fritsch S, Zheng G, Sibenrock KA, Steppacher SD. Which radiographic hip parameters do not have to be corrected for pelvic rotation and tilt? Clin Orthop. 2015;473:1255–66.
25. Blankenbaker DG, De Smet AA, Keene JS, Fine JP. Classification and localization of acetabular labral tears. Skeletal Radiol. 2007;36:391–7.
26. Suter A, Dietrich TJ, Maier M, Dora C, Pfirrmann CW. MR findings associated with positive distraction of the hip joint achieved by axial traction. Skeletal Radiol. 2015;44:787–95.
27. Harris JD. Hypermobile hip syndrome. Oper Tech Sports Med. 2019;27:101–18.
28. Barlow B. Iliopsoas fractional lengthening: treating a disease or a symptom? Arthrosc J Arthrosc Relat Surg. 2019;35:1441–4.
29. Cerezal L, Kassarjian A, Canga A, Dobado MC, Montero JA, Llopis E, et al. Anatomy, biomechanics, imaging, and management of ligamentum teres injuries. Radiographics. 2010;30:1637–51.
30. Perumal V, Woodley SJ, Nicholson HD, Brick MJ, Bacon CJ. Ligamentum teres lesions are associated with poorer patient outcomes in a large primary hip arthroscopy cohort of 1,935 patients. Arthrosc Sports Med Rehabil. 2022;4:e1363–72.
31. Woodward RM, Vesey RM, Bacon CJ, White SG, Brick MJ, Blankenbaker DG. Microinstability of the hip: a systemic review of the imaging findings. Skeletal Radiol. 2020;49:1903–19.
32. Mayes S, Ferris A-R, Smith P, Garnham A, Cook J. Atraumatic tears of the ligamentum teres are more frequent in professional ballet dancers than a sporting population. Skeletal Radiol. 2016;45:959–67.
33. Blankenbaker DG, De Smet AA, Keene JS, Munoz del Rio A. Imaging appearance of the normal and partially torn ligamentum teres on hip MR athrography. Am J Roentgenol. 2012;199:1093–8.
34. Shakoor D, Farahani SJ, Hafezi-Nejad N, Johnson A, Vaidya D, Khanuja HS, et al. Lesions of ligamentum teres: diagnostic performance of MRI and MR arthrography – a systematic review and meta-analysis. Am J Roentgenol. 2018;211:W52-63.
35. Field RE, Rajakulendran K. The labro-acetabular complex. J Bone Joint Surg Am. 2011;93:22–7.