Skeletal Radiology
https://doi.org/10.1007/s00256-020-03516-7

REVIEW ARTICLE

Microinstability of the hip: a systematic review of the imaging findings

Rebecca M Woodward[1,2] · Renuka M Vesey[1] · Catherine J Bacon[1,3] · Steve G White[4,5] · Matthew J Brick[3] · Donna G Blankenbaker[6]

Received: 26 February 2020 / Revised: 31 May 2020 / Accepted: 10 June 2020

Abstract

Objectives To undertake a systematic review of the morphologic features associated with hip microinstability and determine whether there are suggestive or diagnostic imaging findings.

Methods Four electronic databases were searched up to September 2019 to identify original research reporting morphologic features in individuals with either a clinical diagnosis of hip microinstability (instability without overt subluxation/dislocation) or those with symptomatic laxity demonstrated on imaging (increased femoral head translation/distraction or capsular volume). Studies focussing on individuals with pre-existing hip conditions (including definite dysplasia (lateral centre edge angle < 20°), significant trauma, previous dislocation or surgery were excluded. Methodological quality was assessed by the Quality Assessment of Diagnostic Accuracy Studies 2 tool.

Results Twenty-two studies met inclusion criteria (clinical diagnosis of microinstability $n = 15$ and demonstration of laxity $n = 7$). Imaging information gathered from the studies includes radiographs ($n = 14$), MRI ($n = 6$), MR arthrography ($n = 4$), CT ($n = 1$) and intraoperative examination. Most studies exhibited design features associated with an overall high or unclear risk of bias. Some dysplastic features are associated with microinstability or laxity reference measures; however, microinstability is frequently diagnosed in those with a lateral centre edge angle > 25°. Other associated imaging findings reported include impingement morphology, anterior labral tearing, femoral head chondral injury, ligamentum teres tears and capsular attenuation.

Conclusions The current literature does not provide strong evidence for imaging features diagnostic of microinstability. In the appropriate clinical context, dysplastic morphology, anterior labral tears and ligamentum teres tears may be suggestive of this condition although further research is needed to confirm this.

PROSPERO registration CRD42019122406

Keywords Hip microinstability · Hip instability · Hip laxity · Transient hip subluxation

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00256-020-03516-7) contains supplementary material, which is available to authorized users.

✉ Renuka M Vesey
rmah239@aucklanduni.ac.nz

1 Faculty of Medical and Health Sciences, University of Auckland, 85 Park Road, Grafton, Auckland 1023, New Zealand

2 Auckland Radiology Group, Auckland, New Zealand

3 Orthosports North Harbour Ltd., Millennium Institute of Sport & Health, Auckland, New Zealand

4 Active Living and Rehabilitation: Aotearoa New Zealand, Health and Rehabilitation Research Institute, Faculty of Health and Environmental Sciences, Auckland University of Technology, Auckland, New Zealand

5 Department of Physiotherapy, School of Clinical Sciences, Faculty of Health and Environmental Sciences, Auckland University of Technology, Auckland, New Zealand

6 University of Wisconsin School of Medicine and Public Health, Madison, WI, USA

Published online: 25 June 2020

Introduction

With the evolution of hip arthroscopy, new perspectives on the assessment and treatment of hip pathology have developed resulting in a greater awareness of hip instability as a potential cause for pain and dysfunction [1–6]. There is a spectrum of hip instability, ranging from dislocation to microinstability. Microinstability has been defined as extraphysiologic hip motion that causes pain [6], with the presence of pain differentiating it from laxity. For the purpose of this review, the term microinstability has been used broadly to include instability without overt subluxation or dislocation, and/or increased laxity in symptomatic individuals. Microinstability is increasingly being recognised by clinicians as a cause of hip pain in young adults; however, it is still a controversial entity and objective criteria for the diagnosis are lacking [7].

The aetiology of microinstability of the hip is multifactorial [1]. Contributing factors include abnormal osseous morphology, generalised hyperlaxity, capsular laxity and traumatic and iatrogenic injury [1–5]. Reduced bony coverage in hip dysplasia is associated with increased femoral head (FH) translation [8–10] and premature development of osteoarthritis (OA) [11]. A broad spectrum of alterations in morphology and stability is present in dysplasia [12] and the changes predisposing to microinstability may be subtle [12, 13]. Femoroacetabular impingement (FAI) morphology [14–16] and extreme range of motion activities [17–19] may lead to impingement, subluxation and capsulolabral damage.

Labral and capsular damage result in increased FH translation and abnormal joint kinematics [20–23]. It is proposed that the FH translation initiates a cycle of damage which is further exacerbated by pain and muscle weakness [4]. Focal capsular injury can be related to acute traumatic subluxation/dislocation, previous hip surgery or repetitive microtrauma [1, 4, 24]. Microtrauma may cause atraumatic instability in athletes, particularly in sports which involve repetitive hip loading with axial rotation such as ballet, gymnastics, figure skating, football, martial arts and golf [4, 5, 25]. Cyclic stretching of the anterior hip capsule has been demonstrated to increase hip rotation and FH translation [26].

Although the examination findings may be suggestive of microinstability, it is difficult to confirm this diagnosis preoperatively [27]. Diagnosis can be confirmed at surgery with the ease of hip distraction, visualisation of capsular thinning or capsular redundancy on manual probing [24, 28]. However, there is a need to differentiate between microinstability and impingement preoperatively as although the two conditions often coexist [29], treatment options differ [30]. Targeted physical therapy and capsular plication may improve hip stability [7, 31, 32] while unrepaired capsulotomy, rim trimming, labral resection and ligamentum teres (LT) debridement can exacerbate the instability [7, 33–36].

The purpose of this systematic review is to document any morphological findings suggestive or diagnostic of microinstability in individuals without pre-existing hip conditions, significant trauma, previous dislocation or surgery.

Methods

Search strategy and selection criteria

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement [37] with protocol registered on PROSPERO (CRD42019122406). The authors searched for literature relating to or describing instability of the hip in PubMed, MEDLINE (Ovid), Embase (1980-present) and CINAHL Plus databases from inception through to 31 December 2018; the search was then repeated on 29 September 2019. Studies were limited to original peer-reviewed research articles written in English, involving live human subjects aged 13–64 years. Keywords included “hip” with any of the following terms in the title/abstract: “instability”, “microinstability” OR “subluxation”, with the aim of identifying adolescents and adults with transient subluxation of the hip. Studies were excluded if the subjects with suspected microinstability had traumatic or syndromic instability; pre-existing hip conditions such as definite hip dysplasia (as defined by a lateral centre edge angle (LCEA) of < 20°), Perthes disease, slipped capital femoral epiphysis and arthritis; and neurological conditions, neuromuscular disorders and previous hip surgery. Additionally, case reports involving a single participant were excluded.

Following the searches, duplicates were first removed and then titles and abstracts were assessed by two authors (RW and RV) independently based on the above criteria. Any disagreement was settled by discussion and consensus in consultation with the senior author (DB). Full texts of the remaining studies were then scrutinised carefully to identify studies which included clinical diagnosis of microinstability (as defined by the authors) or demonstration of increased FH translation/distraction or capsular volume in symptomatic individuals, and morphologic features. Morphology considered in this review included that demonstrated by any imaging modality or intraoperative findings which would be visible on imaging studies. On-topic papers found by hand-searching reference lists were also included.

Data extraction

Each study was thoroughly reviewed, and the following data were extracted: author, study design, number of participants (and hips), demographics, imaging methods and study findings (related to the review question).

Risk of bias

The identified studies were assessed using the Quality Assessment of Diagnostic Accuracy Studies 2 (QUADAS-2) tool [38] for bias by two authors (CB and SW) who rated them independently prior to agreement of bias and applicability ratings by consensus. This tool helps to determine the "quality" of a study by determining both the risk of bias across four domains (patient selection, index test, reference standard, flow and timing) and any "concern" regarding the applicability of study to the research question. Case series that included no descriptive statistics were not included in the risk of bias assessment. Judgements were made relating to each study's ability to address the systematic review question from a diagnostic framework, irrespective of the primary study aims. In this case, this ability meant the strength of evidence provided by the study to associate specific imaging findings and anatomical or pathological features with microinstability of the hip. For this, the diagnosis or demonstration of instability was regarded as the reference standard, and specific radiological findings, including morphologic indices or observations of pathology in combination or isolation, as the indices. To be judged as fully applicable to the reference question, studies were required to determine the relationship between the specific imaging findings and instability in subjects with clinical hip symptoms. Studies which examined only those subjects with clinically and/or surgically confirmed diagnoses of microinstability were considered separately. The criteria used by the authors for determining the level of potential bias (low, high or unclear) and applicability judgements using the QUADAS-2 tool are detailed in Appendix A in the Supplementary information.

Results

Search results

The initial search showed 2441 studies which could be included (Fig. 1). After removing duplicates and screening study titles and abstracts, 2339 studies were excluded. Another 83 studies were excluded after reviewing the full text. This resulted in 19 eligible studies with three additional studies added due to citation tracking, making the total 22 for qualitative synthesis.

Study characteristics

The majority of studies (77%, $n = 16$) included subjects undergoing hip arthroscopy or orthopaedic examination [7, 28, 39–52]. Two studies were of radiology patients being assessed for hip pain [53, 54]. The remaining four studies recruited ballet dancers, analysed as a single group [55, 56] or compared with non-dancer controls [17, 18].

A clinical diagnosis of microinstability was made in 15 of the 22 studies; the number of subjects ranged from 2 to 82 and all subjects were symptomatic except in the study by Roderiguez et al. [55] (Table 1). Microinstability was more common or pronounced in women [7, 28, 39, 41, 45, 48, 49, 51, 53, 56]. Variable diagnostic criteria for microinstability were employed: a single physical examination finding ($n = 3$) [41, 42, 55]; multiple examination findings ($n = 3$) [43, 44, 52]; intraoperative confirmation ($n = 8$) [7, 28, 45, 46, 49–51, 57]; criteria was not reported ($n = 1$) [48] (Appendix B in the Supplementary information). Only seven of these 15 studies directly evaluated the relationship between instability and morphologic features as the primary objective [7, 28, 41, 45, 49, 50, 52] and in three of these studies, radiological parameters were used to allocate participants to study groups [28, 45, 52]. In three studies, indirect indicators of instability such as LT tears [46, 57] and labral hypertrophy [42] were primarily assessed. The remaining studies which did not include a clinical diagnosis ($n = 7$) reported the relationship between structural features and FH translation [17, 18, 56], FH traction [39, 47, 53] or capsular volume [54].

Imaging information gathered from the studies includes radiographs ($n = 14$) [7, 28, 39, 41, 44–46, 48, 50–52, 54, 56, 57], MRI ($n = 6$) [17, 18, 41, 43, 44, 54], MR arthrography ($n = 2$) [49, 54], traction MR arthrography ($n = 2$) [47, 53], CT ($n = 1$) [42] and intraoperative examination ($n = 7$) [28, 42, 43, 45–47, 52] (Table 1). The most commonly described features were dysplastic and impingement morphology, chondrolabral and LT pathology and capsular attenuation.

Risk of bias

A total of 20 studies were assessed using the QUADAS-2 tool (see Table 2), the remaining two [43, 44] being case reports which did not provide any descriptive statistics that allowed the accuracy of imaging findings compared with the reference standard to be determined. Most studies ($n = 13$) [7, 17, 18, 40, 41, 45, 46, 48, 49, 51, 52, 55, 56] were judged to have high risk of bias across at least two of the four domains (patient selection, index test, reference standard, flow and timing) evaluated with the QUADAS-2 tool. Selection bias and applicability concern were often rated as high due to inadequate reporting of participant selection into the study, particularly for control groups, and due to comparison of groups potentially at either extreme of the diagnostic continuum (e.g. in cohort subgroup analyses or case-control designs). Another common inadequacy, reflected in the assessment of bias for the index test(s) (imaging findings) or reference standard (diagnosis of instability), was a lack of information about the procedure used to determine either measure. Studies commonly failed to report objective assessment criteria, design features

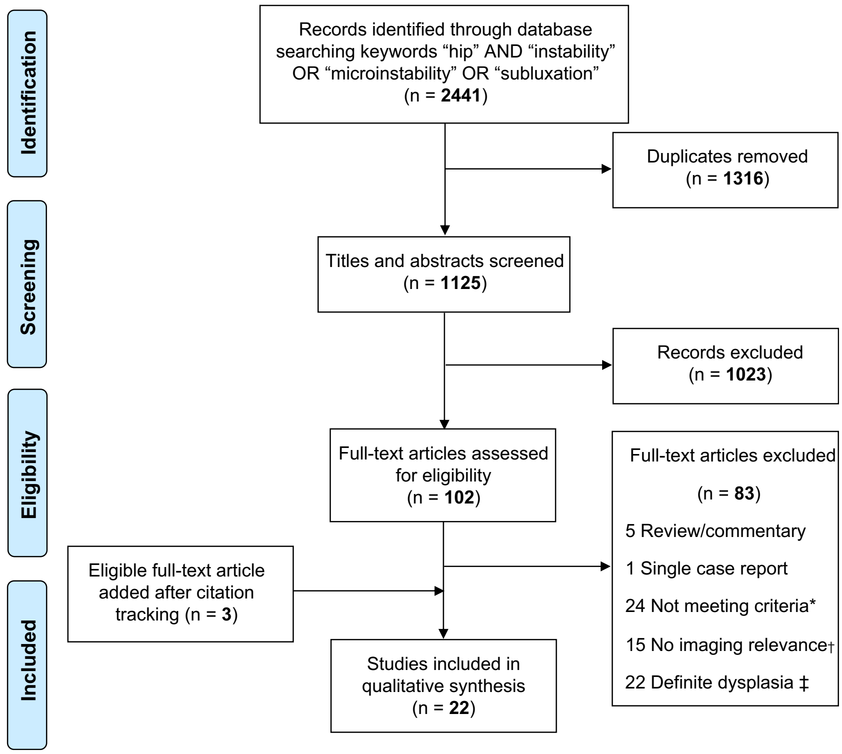

Fig. 1 PRISMA flow diagram for search results and study selection. Single asterisk (*) means did not include clinical instability or femoral head translation, single dagger (†) indicates no morphological features linked to microinstability of the hip and double dagger (‡) means as defined by a lateral centre angle < 20°

such as independent rating by multiple observers or blinding of measurement of indices to diagnostic reference or vice versa.

Dysplastic morphology

Of the 22 studies included, three stated dysplastic subjects were excluded [7, 39, 48]. In studies identifying dysplasia, the radiographic LCEA was the most commonly reported parameter utilised and was often the sole criterion for labelling subjects as dysplastic [28, 42, 46, 50, 52]. Where the LCEA or Wiberg centre edge angle (WCEA) was reported, often the method of measurement was not clearly stated [7, 42, 46, 51, 52, 57]. The LCEA cut-off values for dysplasia also varied from LCEA < 25° [28, 42, 46], < 20° [50, 52] and < 18° [39, 48] with some studies identifying a borderline category (LCEA 20–25°) [28, 52]. Several studies also utilised an increased Tonnis angle, also known as acetabular index, in combination with a LCEA < 25° to identify dysplasia [7, 39, 48].

In the reviewed studies, the clinical diagnosis of microinstability was not confined to those with a LCEA < 25° [7, 28, 41, 45, 51]. In Shibata et al. [28], 21% (12/57) of subjects with clinical instability had an LCEA < 25° while in Kalisvaart et al. [7], 29% (9/31) had dysplasia defined by an LCEA < 25° and acetabular index > 10. In Suter et al. [53], although subjects with positive joint space distraction had significantly smaller LCEA than the control group, their mean LCEA was 34.6°. In five studies, no association was demonstrated between the LCEA and instability measures [7, 28, 39, 54, 57]. Findings were mixed for other dysplastic morphology parameters. Significant increases in acetabular index were present in those with full-thickness LT tears [46] but no significant relationship was demonstrated between instability measures and acetabular index [7, 46, 54, 56]. Dysplastic features such as a smaller overall transverse centre edge angle (CEA) and increased neck shaft angle were associated with positive joint distraction [53].

Only one study in the review directly examined the relationship of laxity/instability and acetabular version [53]. No significant difference in acetabular version (assessed on MR arthrography at three levels) was demonstrated between those with positive joint distraction and no distraction [42, 53].

Impingement

In several studies, lack of impingement morphology was one of the criteria for the diagnosis of microinstability [45, 52]. Concavity at the lateral FH neck junction on AP pelvis radiograph, termed the cliff sign, was present in the majority of subjects with microinstability [50]. In contrast, other studies demonstrated significant relationships between an increased alpha angle and positive hip distraction [53], increased stiffness [39] and laxity inferred by a positive dial test [55]. No relationship has been shown between alpha angle and capsular volume [54] or labral hypertrophy [42].

FH subluxation occurred in ballet dancers in the splits position, inferring impingement-induced instability at extreme ROM [17, 18, 56]. In Mitchell et al. [56], the mean lateral

Table 1 Summary of included studies

Author	Study design	Study population hips n; sex n; age mean (SD or range)	Modality of assessment of morphological parameters	Relevant results
Abrams et al. 2017	Case-control	Individuals with hip pain - Instability $n = 5$; 5 F; 30.8 (14.0) years - Comparison FAI $n = 12$; 3 F + 9 M; 34.5 (12.2) years	XR and intraoperative synovial biopsy	- Synovitis or inflammatory infiltrate present in both instability and FAI groups but less inflammation in more distractible joints ($p = 0.005$) - No difference in mean LCEA (SD) between instability group (28.6 (4.8)) and FAI group (30.9 (6.2)) ($p = 0.474$)
Bellabarba et al. 1998	Single group comparison	Individuals with painful coxa saltans $n = 5$; 4 F + 1 M; [25–36] years - Sx side - Asx side	XR and fluoroscopy	- Audible pop, subluxation of FH and vacuum phenomenon at fluoroscopy on gentle traction of Sx side but not Asx side - 4/5 had generalised laxity - All had slightly lower CEA and higher Sharps angle on Sx side vs. Asx side
Blakely et al. 2010	Case-control and single group means within case series	Individuals with groin pain and suspected hip instability $n = 11$; 6 F + 4 M; 31 (21–47) years - Comparison - Asx side	XR and dynamic MRI 1.5 T	- Describes laxity, capsular attenuation and thinning of iliofemoral ligament at lateral attachment on MRI - No significant translation demonstrated with increasing external rotation - Mean CEA 33.4 (23.3–50.6)
Bruce et al. 2002	Case reports	Individuals with hip pain and osteochondral injury after minor trauma $n = 3$; 1 F + 2 M; [28–45] years	XR, scintigraphy, CT, MRI for 1 and intraoperative assessment for the other 2	- Pattern of injuries consistent with transient subluxation - Increased radioisotope uptake at iliofemoral ligament attachment sites - Anterior labral tear in patients with mild dysplasia - 2/3 had osteochondral injuries
Cerezal et al. 2015	Cohort group analysis	Individuals with hip pain who were treated arthroscopically within 1 month of a traction MRA $n = 184$; 76 F + 108 M; 32.6 (19–53) years	Traction MRA 1.5 T and intraoperative assessment of LT	- Mean distraction increased with full-thickness LT tear ($p = 0.001$) - Traction MRA high sensitivity and specificity for full-thickness tears; moderate sensitivity and high specificity for partial-thickness tears - More false positives and negatives with LT degeneration
Chahla et al. 2016	Cohort subgroup analysis	Individuals undergoing primary hip arthroscopic surgery for the treatment of FAI - Normal LT $n = 233$; 92 F + 141 M; 33 (12) years - Full-thickness LT $n = 33$; 22 F + 11 M; 39 (22) years	XR and intraoperative assessment of LT and chondrolabral damage	- Laxity more frequent in those with full-thickness LT tear (27%) than intact LT (9%; $p = 0.007$) - Full-thickness LT tear also 3× more likely to be F ($p = 0.004$); more common with a CEA < 25 ($p = 0.001$); more common with mean AI ($p = 0.009$); 3.1× more likely to have FH cartilage defect ($p = 0.013$) - Number of acetabular chondral defects, presence and size of labral lesions similar between groups
Duthon et al. 2013	Case-control	- Ballet dancers $n = 39$; 20 F; 26 (18–39) years - Active healthy age-matched controls $n = 28$; 14 F; 27 (20–34) years	MRI supine 1.5 T and MRI in the forward splits position-dancers only	- Dancers had mean FH subluxation of 2.05 mm in splits - Only one dancer had FAI (cam) morphology - Dancers slightly lower NSA than controls ($p = 0.003$) - Cartilage lesions twice as frequent and severe in dancers (75%; 29/39) than controls (28%; 8/28; $p = 0.037$) - No significant difference in acetabular depth/version, AA and femoral neck version - Incidence of labral lesions comparable (85% (33/39) vs. 85% (24/28); $p = 1$) - No correlation with dancers' pain and range of motion or bony morphology
Frank et al. 2016	Cohort group analysis	Individuals with clinical FAI	XR and MRA 1.5 T	

Table 1 (continued)

Author	Study design	Study population hips *n*; sex *n*; age mean (SD or range)	Modality of assessment of morphological parameters	Relevant results
		$n = 97$; 53 F + 44 M; 32.21 (8.99) years		- Males have larger total capsular, FH and true capsular volumes compared with females (each $p < 0.01$) - No significant relationship between capsular volume and AA > 50, WCEA < 25 and AI > 10 or < 0
Kalisvaart et al. 2017	Single group nested	Individuals treated for microinstability $n = 31$; 31 F; 27 (14–49) years note: 6 patients had prior arthroscopy	XR	- Only 32% had Beighton score of ≥ 2 or more - Only 29% dysplastic (XR LCEA 18–25, AI > 10) - Median LCEA 28 (18–37)
Kapron et al. 2018	Cohort group analysis	Individuals undergoing primary hip arthroscopic surgery for the treatment of FAI $n = 101$; 61 F + 40 M; F 30 (10) years M 35(11) years	XR and intraoperative assessment of labrum	- On univariable regression, AA, Beighton score, hamstring flexibility and sex were correlated with force required to distraction at arthroscopy. - However, on multivariable regression, only sex was correlated with force ($p = 0.001$) with males requiring greater force. - LCEA and presence of labral tear were not correlated with stiffness to distraction.
Kapron et al. 2019	Cohort group analysis	Individuals undergoing primary hip arthroscopic surgery for the treatment of FAI - Plication $n = 21$; 21 F; 35 (11) years - No plication $n = 79$; 39 F + 40 M; 34 (13) years	XR and intraoperative assessment of chondrolabral damage	- Over 90% cohort had chondrolabral damage between 12:30 and 2:30. - Severe cartilage ($p = 0.022$) and labral damage ($p = 0.046$) increased with radiographic cam deformity but was not related to radiographic measures of acetabular coverage. - 21/100 had capsular plication for instability. - Comparing the plication group with the remainder—LCEA mean was 22 plication vs. 27 other ($p = 0.004$); LCEA median was 21 vs. 28; range 10–33 vs. 11–44. - Femoral cartilage damage similar: 2/21 vs. 8/79 - Chondrolabral junction anterior labral at 3–4 o'clock: 5/21 vs. 17/79 - Chondrolabral junction anterior cartilage at 3–3.5 o'clock: 12/21 vs. 57/79 - No increase in isolated chondral damage in plication group
Kaya et al. 2016	Cohort group analysis	Individuals undergoing primary hip arthroscopic surgery $n = 100$; 66 F + 34 M; 47.2 (18–76) years - FAI ($n = 54$) - Laxity ($n = 20$) - Dysplasia ($n = 10$) - BD ($n = 16$)	XR used to assign to subgroups and intraoperative assessment of chondrolabral damage	- Pattern of articular cartilage damage differed depending whether in FAI, laxity, BD (LCEA 20–25) or dysplasia (LCEA < 20) group - Anterosuperior and middle superior acetabulum most frequently involved in all groups - Dysplasia also frequently posterosuperior - Laxity and dysplasia groups had fewer FH cartilage lesions than FAI and BD. - Laxity group primarily had partial-thickness cartilage damage while FAI, dysplasia and BD cartilage lesions were predominantly full thickness.
Kolo et al. 2013	Case-control	- Professional ballet dancers $n = 59$; 30 F; 24.6 (18–39) years - Asx non-dancers $n = 28$; 14 F; 27.1 (20–34) years	MRI supine 1.5 T and MRI in forward splits position-dancers only	- Dancers had mean FH subluxation of 2.05 mm in splits. - Only one dancer had FAI (cam) morphology. - Cartilage lesions > 5 mm more frequent in dancers (29%; 17/59) than non-dancers (7%; 2/28; $p = 0.026$) - Labral tears not significantly different between the groups (47% (28/59) vs. 29% (8/28); $p = 0.095$)

Table 1 (continued)

Author	Study design	Study population hips n; sex n; age mean (SD or range)	Modality of assessment of morphological parameters	Relevant results
				- Herniation pits more common in dancers and present in region of bony contact in splits ($p = 0.002$)
Magerkurth et al. 2013	Cohort group analysis	Individuals assessed for capsular laxity at arthroscopy with preoperative MRA - Positive for laxity $n = 17$; 12 F + 5 M; 30 (15–55) years - Negative for laxity $n = 10$; 5 F + 5 M; 39 (19–61) years	MRA 3 T	- Laxity group had thinner anterior capsule (2.5 mm vs. 3.3 mm; $p = 0.0043$) and wider anterior recess width (mean 5.8 mm vs. 3.6 mm; $p < 0.0001$). - No difference in thickness of zona orbicularis between groups - No significant difference in volume of contrast injected for each group - No correlation between width of recess and amount of contrast used
Martin et al. 2012	Single group nested	Individuals with FAI, labral tears and full-thickness LT tear at arthroscopy $n = 20$; 13 F + 7 M; 41.3, 22–61 (12.6) years	XR	- All had laxity at dynamic testing during arthroscopy. - On follow-up, 5/9 patients had subjective instability with "inferior acetabular insufficiency" but no pattern of increased NSA, low LCEA or abnormal AI demonstrated.
Mitchell et al. 2016	Single group correlational	Professional ballet dancers $n = 47$; 26 F + 21 M; 23.8 (5.4) years	XR in splits position	- 42/47 ballet dancers FH translated laterally on radiograph in splits. Mean subluxation 1.41 mm ($p = 0.035$). - Moderate negative correlation between subluxation distance and NSA ($r = -0.332$; $p = 0.022$) - Strong positive correlation with splits HCP and AA on Dunn view ($r = 0.461$; $p = 0.001$); - 17/47 had vacuum phenomenon, present in more F than M ($p = 0.026$). - Females- moderate negative correlation with subluxation distance and NSA but no significant correlation with splits HCP and radiographic parameters of FAI or dysplasia - Males- splits HCP increased with decreased WCEA, ACEA, AI and FH extrusion index but no significant correlation between subluxation distance and these parameters
Nwachukwu et al. 2019	Case-control nested	Individuals undergoing primary hip arthroscopic surgery for the treatment of FAI. - Labral hypertrophy $n = 39$; 29 F:10 M; 30.6 (10.8) years - Age, sex and BMI matched-controls $n = 39$; 29 F:10 M; 30.7 (10.4) years	XR, CT and intraoperative assessment of labral hypertrophy	- Those with labral hypertrophy (width > 4 mm) had increased internal rotation of hip in flexion compared with controls ($p = 0.004$). - Labral hypertrophy group had smaller LCEA ($p < 0.001$) and larger AI ($p < 0.04$) than the control group but were not dysplastic (mean LCEA 27.6, AI mean 6.61). - No difference in CT measurements between groups for AA, femoral NSA, acetabular version and femoral version
Oh et al. 2007	Case reports	Individuals with history suggestive of hip subluxation after minor trauma $n = 2$; 2 M; 29 and 35 years	MRI (case 1 only) and intraoperative assessment	- Case 1: MRI T2 hyperintensity around LT. At arthroscopy, partial-thickness LT tear, anterior labral tear and osteochondral lesion of acetabulum - Case 2: At arthroscopy, partial avulsion of the LT at femoral attachment with adjacent FH osteochondral lesion
Packer et al. 2018	Cohort group analysis	Individuals undergoing primary hip arthroscopic surgery 47 F + 49 M - Microinstability	XR	- 89% of patients with microinstability had a cliff sign, compared with 27% of patients without instability ($p < 0.0001$).

Table 1 (continued)

Author	Study design	Study population hips n; sex n; age mean (SD or range)	Modality of assessment of morphological parameters	Relevant results
		$n = 44$; 31.4 (10.9) years - No microinstability $n = 52$; 35.9 (12.9) years		- 74% of patients with a cliff sign had microinstability, while only 12% of patients without a cliff sign had instability ($p < 0.0001$). - Cliff sign sensitivity 89% and specificity 73% - All the young women (< 32 years) with a cliff sign were diagnosed with microinstability.
Rodriguez et al. 2019	Single group	Asymptomatic professional ballet dancers $n = 82$; 44 F + 38 M; 28.6 (17–42) years	Ultrasound	- Positive dial test bilaterally in 59 dancers - Association of isolated cam and positive dial test on the right ($p < 0.001$)
Shibata et al. 2017	Cohort group analysis	Individuals undergoing primary hip arthroscopy for FAI and/or instability - Instability alone $n = 45$; 41 F + 4 M; 26.3 (8.9) years - Instability BD $n = 12$; 12 F; 33.2 (9.4) years - Pincer FAI $n = 100$; 78 F + 19 M; 32.1 (10.5) years - Cam FAI $n = 54$; 15 F + 38 M; 30 (10.7) years - Combined FAI $n = 269$; 84 F + 162 M; 31.8 (9.8) years	XR and intraoperative assessment of chondrolabral damage	- Instability only: 42.2% chondral/labral lesions straight anterior (2–4:00) significantly more than all 3 FAI groups; 15.6% anterior to lateral (3–11:00) significantly less than all 3 FAI groups; 11.1% lateral (1–11:00) significantly more than pincer and combined; - All instability alone patients with anterior lesions had chondrolabral separation type tear. - Instability BD group- no statistically significant pattern of labral-chondral damage - Mean width of acetabular rim cartilage lesion in instability alone (2.9 mm) significantly narrower than in the FAI groups $p < 0.001$ and less severe
Suter et al. 2015	Case-control nested in cohort	Individuals with hip pain referred for MRA - Hips with positive distraction $n = 50$; 36 F + 14 M; 41.2 (20.6–68.3) years - Hips without distraction matched by age and gender $n = 50$; 36 F + 14 M; 41.0 (21.3–71.2) years	Traction MRA	- Patients with positive joint space distraction had on MRA higher NSA (134.1 vs. 131.6°; $p < 0.05$), smaller LCEA (34.6 vs. 38.1, $p < 0.05$), smaller overall transverse CEA (153.6 vs. 161.4, $p < 0.001$), higher AA (59.2 vs. 53.5, $p < 0.01$) and a thicker LT (5.4 mm vs. 4.7 mm, $p < 0.05$) - No significant differences in acetabular version, extrusion index, capsular thickness, tearing of LT or labral tears at 10:00, 12:00 and 2:00 - No abnormality in iliopsoas

SD standard deviation; *FAI* femoracetabular impingement; *LCEA* lateral centre edge angle; *XR* X-ray; *Sx* symptomatic; *Asx* asymptomatic; *MRI* magnetic resonance imaging; *LT* ligamentum teres; *MRA* magnetic resonance angiography; *FH* femoral head; *NSA* neck shaft angle; *AA* alpha angle; *WCEA* Wibergs centre edge angle; *CEA* centre edge angle; *ACEA* anterior centre edge angle; *AI* acetabular index or Tonnis angle

translation of the FH on splits radiograph compared with standing AP pelvis was 1.41 mm; FH subluxation distance in the splits position increased with decreased neck shaft angle ($p = 0.022$) but not with radiographic parameters of FAI or dysplasia.

Chondrolabral pathology

Chondral and labral pathology was described in those with clinical instability [28, 43, 44, 48, 52] in relation to LT tearing [46] and distraction of the joint on traction MR arthrography [53]. In cohorts undergoing arthroscopy for FAI, the acetabular chondral pathology was frequently near the chondrolabral junction [28, 48] and was predominantly anterosuperior in distribution [28, 48, 52]. In Shibata et al. [28], subjects with a normal LCEA, whose primary clinical diagnosis was microinstability, had more anterior chondral and labral damage (particularly straight anterior 3 to 4 o'clock) than any of the FAI groups [28]. Increased anterior labral tearing in microinstability compared with FAI was not reported in the other included studies although it is noted that Suter et al. [53] did not evaluate the labrum at 3 or 4 o'clock.

An increase in the proportion of partial thickness rather than full-thickness acetabular chondral lesions is reported in

Table 2 Risk of bias assessment for studies using the Quality Assessment of Diagnostic Accuracy Studies 2 tool

	Index/indices	Reference	Selection bias	Selection applicability concern	Index bias	Index applicability concern	Reference bias	Reference applicability concern	Patient flow bias
Abrams et al. 2017	LCEA; AA	Preoperative criteria and surgical confirmation	H	L	H	L	H	L	L
Bellabarba et al. 1998	LCEA; Sharp's angle	Subluxation audible pop and vacuum phenomenon on gentle longitudinal traction	H	L	H	L	U	L	H
Blakely et al. 2010	Iliofemoral ligament pathology, subluxation with dynamic MRI; LCEA, AA, NSA	Recoil test: lack of recoil from drop to external rotation and hip pain with abduction/extension and external rotation force	H	L	H	L	H	L	L
Cerezal et al. 2015	LT tear	Joint distraction (fixed force)	U	L	U	L	U	U	U
Chahla et al. 2016	LT tear	Capsular laxity at probing	H	L	U	L	H	L	L
Duthon et al. 2013	MR measures: femoral NSA and anteversion, acetabular depth and version; AA; chondrolabral lesions and herniation pits	FH translation in dancers	H	H	U	L	H	H	H
Frank et al. 2016	WCEA; AA; AI	MR hip capsular volume	U	L	L	L	H	U	U
Kalisvaart et al. 2017	LCEA, AI	Preoperative criteria and surgical confirmation	H	L	H	L	U	L	L
Kapron et al. 2018	LCEA, AA, labral tear	Joint distraction (force and displacement)	U	L	U	L	U	L	L
Kapron et al. 2019	LCEA, AA, AI, head-neck offset; chondrolabral damage: size, location, severity	Clinical instability treated with capsular plication for (criteria not stated)	U	L	U	L	H	H	L
Kaya et al. 2016	Surgically observed cartilage lesion patterns	Clinical diagnosis of laxity	L	L	U	L	U	L	L
Kolo et al. 2013	Range MR measures: acetabular depth and version; AA; chondrolabral lesions; herniation pits	FH translation in dancers	H	H	U	H	H	H	H
Magerkurth et al. 2013	Range MR measures: capsule thickness; zona orbicularis thickness; anterior and posterior joint recess width; synovitis of joint recess; capsule discontinuity; angle between ischium and femoral neck	Preoperative examination and surgical confirmation	H	L	L	L	H	L	L
Martin et al. 2012	Range XR measures: NSA, LCEA, AI, inferior acetabular insufficiency	LT tear with laxity	H	L	H	L	H	L	H
Mitchell et al. 2016	WCEA; AA; NSA; AI; ACEA; FH extrusion index; hip centre position	Hip subluxation distance (standing to splits: change in hip centre position)	H	U	U	L	U	H	L
	Labral hypertrophy intraoperatively	Increased internal rotation	H	U	U	L	H	H	L

Table 2 (continued)

	Index/indices	Reference	Selection bias	Selection applicability concern	Index bias	Index applicability concern	Reference bias	Reference applicability concern	Patient flow bias
Nwachukwu et al. 2018									
Packer et al. 2018	XR: cliff sign; reverse AA; cliff/femoral neck cobb angle; cliff/femoral shaft cobb angle; cliff length/FH diameter ratio	Preoperative criteria and surgical confirmation	L	L	L	L	H	U	L
Rodriguez et al. 2019	Cam morphology on ultrasound	Hip dial test	H	U	U	L	H	H	L
Shibata et al. 2017	LCEA and intraoperative assessment of chondrolabral damage	Preoperative criteria and surgical confirmation	H	L	U	L	U	L	L
Suter et al. 2015	Range MR measures: NSA, LCEA, ACEA, extrusion index of FH, acetabular depth, AA, acetabular version, LT, capsule thickness, iliopsoas size, labral tearing	Joint distraction (fixed force)	H	L	U	L	U	L	L

LCEA lateral centre edge angle; *AA* alpha angle; *H* high; *L* low; *MRI* magnetic resonance imaging; *NSA* neck shaft angle; *LT* ligamentum teres; *U* unclear; *MR* magnetic resonance; *FH* femoral head; *WCEA* Wibergs centre edge angle; *AI* acetabular index or Tonnis angle; *XR* X-ray; *ACEA* anterior centre edge angle; *CT* computed tomography

the microinstability groups compared with those with FAI [28, 52] and dysplasia [52]. In one study, the acetabular rim chondral damage was narrower in the instability alone group and associated with tearing at the chondrolabral junction, differing from the intrasubstance tearing present in FAI [28].

Conflicting findings are reported for an association between laxity and FH chondral damage. Although full-thickness LT tears were associated with capsular laxity and more frequent FH chondral lesions in one study [46], Kaya et al. [52] detected fewer FH cartilage lesions in the laxity group. The proportion of subjects with FH cartilage damage was similar in those treated with capsular plication compared with the rest of the surgical cohort in Kapron et al. [48] ($n = 2/21$ vs. 8/79).

Duthon et al. [18] and Kolo et al. [17] compared supine MRI findings of professional ballet dancers and healthy non-dancing controls. Both found cartilage lesions were more frequent and severe in dancers compared with the controls; however, the incidence of labral pathology in the two groups was comparable [17, 18], see Table 1.

In two small case reports [43, 44], the subjects had a pattern of injuries consistent with transient subluxation after minor trauma such as tripping or twisting injuries; four out of five subjects had labral tears, three were anterior and one more extensive; three out of five had osteochondral injuries, and two involved the FH.

Ligamentum teres

The incidence of complete LT tears at arthroscopy was 1.5% (33/2213) in Chahla et al. and 3.8% (7/1084) in Cerezal et al. but partial tears varied between 13.6% (25/184) in Cerezal et al. and 88% (1947/2213) in Chahla et al. [46, 47]. Tearing of the LT was associated with laxity, indicated by increased distraction on traction MR arthrography [47], capsular probing at arthroscopy [46] and dynamic evaluation at arthroscopy [40]. Additionally, LT tears were present in subjects with suspected subluxation after minor trauma [43]. Cerezal et al. [47] stated the degree of distraction on traction MR arthrography increased significantly with partial and complete LT tear compared with an intact ligament ($p = 0.001$) while Suter et al. [53] reported thickening of the LT in the group with positive distraction on traction MR arthrography ($p < 0.05$), and no complete tears were identified [53].

Capsule

The capsule thickness was assessed on MRI [41], MR arthrography [49] and traction MR arthrography [53] with varying findings. Both Blakely et al. [41] and Magerkurth et al. [49] report thinning of the lateral aspect of the anterior capsule in subjects with clinical microinstability. Blakely et al. [41] assessed the capsule on MRI with increasing external rotation and described capsular attenuation, thinning of the iliofemoral ligament at its lateral attachment and undulation suggesting laxity; however, no objective measures of capsular thickness were reported. Magerkurth et al. [49] recorded the minimal thickness just lateral to the zona orbicularis on MR arthrography as well as the maximal width of the anterior and posterior joint recesses lateral to the zona orbicularis at the level of the FH [49]. Laxity was associated with thinning of the lateral part of the anterior capsule (< 3 mm) and widening of the anterior joint recess (> 5 mm), although there was a lack of standardisation to the degree of capsular distension [49]. Suter et al. [53] measured the thickness at the midpoint of the superior and inferior bands on distraction MR arthrography and did not demonstrate capsular thinning in those with positive hip distraction.

Fig. 2 A 32-year-old woman with dysplasia presents with left hip pain. **a** AP radiograph demonstrates moderate reduction in the superolateral femoral head coverage bilaterally and superolateral subluxation of the femoral head on the left with disruption of Shenton's line (arrow). **b** Axial oblique fat-supressed PD MR image suggests subtle anterior shift of the femoral head is present with a posterior crescent of fluid (arrows)

Discussion

A large number of imaging features have been proposed to suggest a diagnosis of hip microinstability [3, 4, 58]. This is the first study to systematically examine the evidence supporting a relationship between a clinical diagnosis of microinstability and specific imaging findings. It has identified several possible relationships between morphological features and microinstability which warrant further investigation.

In most of the reviewed studies, the evaluation of bony morphology was limited, with an emphasis on the radiographic parameters. There was a heavy reliance on the LCEA, to identify dysplasia [7, 28, 40, 42, 46, 50, 52] and limited information about other dysplastic features. The LCEA does not give an indication of the anterior or posterior coverage of the FH or congruency of the FH and acetabulum and thus may underestimate dysplasia [12, 13, 30, 59, 60]. In dysplasia, the risk of instability can be classified as primarily anterior, posterior or global/lateral but this requires 3D assessment of bony morphology [12]. Although the LCEA is reduced in the global subtype of dysplasia, it may be normal in those with anterior or posterior instability [12]. Overall, there is insufficient evidence in identified studies to determine if the presence of microinstability in individuals with a normal LCEA solely reflects the impact of soft tissue factors on hip stability or whether there is a contribution from osseous deficiency which has not been documented. It is important to note that while there is an association between laxity and dysplastic features such as a decreased LCEA and increased neck shaft angle [53], the clinical diagnosis of microinstability is not limited to those with an increased global laxity score [7] or those classified as dysplastic [7, 28, 41, 45, 51].

Although increased femoral antetorsion may contribute to anterior instability, particularly in combination with increased acetabular anteversion [3, 12, 58, 61], this review fails to clarify the relationship between microinstability and acetabular or femoral version. Acetabular retroversion or cam morphology is thought to contribute to posterior instability [2, 16, 62]. In this review, cam morphology was associated with increased FH distraction [53] and was common in ballet dancers with a positive dial test [55] supporting an association with increased laxity. Included studies demonstrating FH translation in the splits [17, 18, 56] support impingement-induced capsulolabral damage at extreme ROM even without cam morphology. However, no clear relationship between impingement and a clinical diagnosis of microinstability was demonstrated.

The cliff sign described by Packer et al. [50] identified subjects who instead of cam morphology had relative concavity in the contour of the FH laterally. These authors correlated this finding with the clinical diagnosis of microinstability [50]. The applicability of this finding to the wider population is unclear. Although capsular laxity has been proposed as a

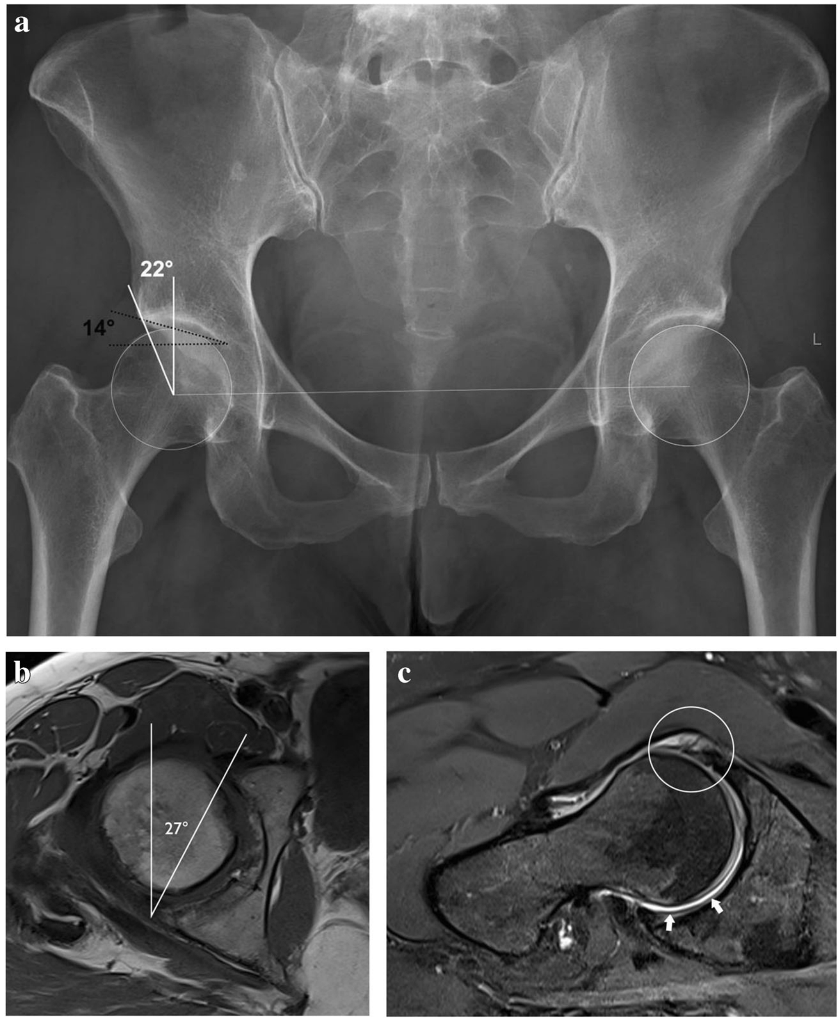

Fig. 3 A 45-year-old woman with right hip pain and clinical microinstability. **a** AP radiograph shows no overt femoral head subluxation. There is a borderline reduction in the right LCEA (22° shown in white), and acetabular index is increased (14° shown in black). **b** Axial T1-weighted MR image shows decreased anterior coverage of the femoral head with 27° acetabular anteversion. **c** Axial oblique fat-suppressed PD image shows fluid separating the joint surfaces posteriorly, termed the posterior crescent sign (arrows) indicating subtle anterior femoral head shift and complex anterior labral tearing (circle)

possible explanation for clinical findings suggestive of FAI in the absence of impingement morphology [63], microinstability should not become a default diagnosis. Some authors have suggested that indicators of FH migration such as a break in Shenton's line (Fig. 2) and a positive crescent sign (Fig. 3) prove hip instability [30]; however, none of the included studies evaluated these parameters.

The pattern of chondrolabral injury has been proposed as a way of differentiating whether the dominant pathomechanics are impingement or instability [64]. Laterally hinged flaps are postulated to develop due to outwardly directed shear forces caused by FH subluxation in dysplasia [64–66]. No single pattern of chondrolabral injury emerged in the review. Inside out chondral flaps were not described though several studies reported an inside out chondrolabral shearing injury with an anterior distribution [28, 44] rather than the typical anterior superior distribution in FAI [28, 48, 52]. Although the evidence for an association with microinstability in this review is mixed [46, 48, 52], a relationship between focal FH chondral damage and transient subluxation or microinstability is plausible (Fig. 4).

The role of the LT is incompletely understood but there is increasing acceptance of its contribution to the stability of the hip [67]. This is supported by the review studies where instability was associated with LT thickening [53] and LT tears [40, 44, 46, 47]. Traumatic rupture of the LT, a recognised cause of pain [68], most frequently occurs after major trauma but may also be present after minor trauma such twisting injuries [68] as seen in Oh et al. [43]. Complete LT tears are uncommon in subjects undergoing arthroscopy and are more common in women, those with a lower CEA and capsular laxity [46]. The ligament may have a more important role only in those who have risk factors for instability such as generalised hypermobility, osseous deficiency or capsular laxity (Fig. 5). Alternatively it is possible that atraumatic LT pathology is a consequence rather than a cause of microinstability as LT hypertrophy and tearing are often present in hip dysplasia [69], gymnasts [70] and ballet dancers [71] and may be asymptomatic [71].

Capsular thinning, labral hypertrophy and hypertrophy of anterior periarticular muscle have also been proposed as indicators of joint instability [72–74]. In this review, focal anterior

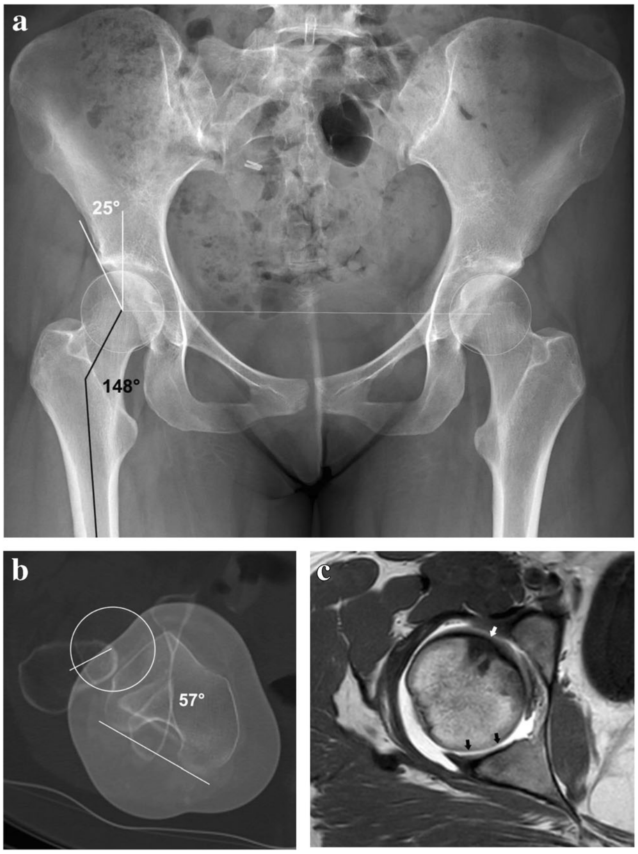

Fig. 4 A 21-year-old woman with ongoing right groin pain and an intermittent sensation of clicking and giving way after jarring right hip while running. **a** AP radiograph shows no femoral head subluxation; however, there are features which suggest an increased risk of instability. The femoral neck shaft angle is increased (148° shown in black) and the acetabulum appears to have a reduced volume, although the LCEA is within the normal range (25° shown in white). **b** CT image with the femoral head, distal neck and femoral condyles superimposed demonstrates markedly increased femoral antetorsion (57°). **c** An axial T1 MR arthrogram image shows reduced anterior coverage, focal subchondral sclerosis with intact overlying cartilage (white arrow) in keeping with a subacute traumatic bone injury and slight decentering of the femoral head with a posterior crescent of fluid (black arrows) consistent with anterior microinstability

capsular redundancy was described at arthroscopy [46], but there was no strong evidence for capsular thinning visible on MR imaging [49, 53]. In Nwachukwu et al. [49], labral hypertrophy was associated with a smaller LCEA and increased acetabular index; however, there was no direct relationship with microinstability [53]. The only study in the review to evaluate the periarticular muscles reported no increase in the thickness of iliopsoas in those with positive hip distraction [53].

Both iliopsoas impingement [75, 76] and microinstability [28] have been associated with isolated anterior labral tearing. Dynamic overload of the hip flexors and abductors stabilising the hip in those with instability is thought to predispose the subject to iliopsoas tightness, tendinitis and painful internal snapping [1, 5, 25] as presented by Bellabarba et al. [51].

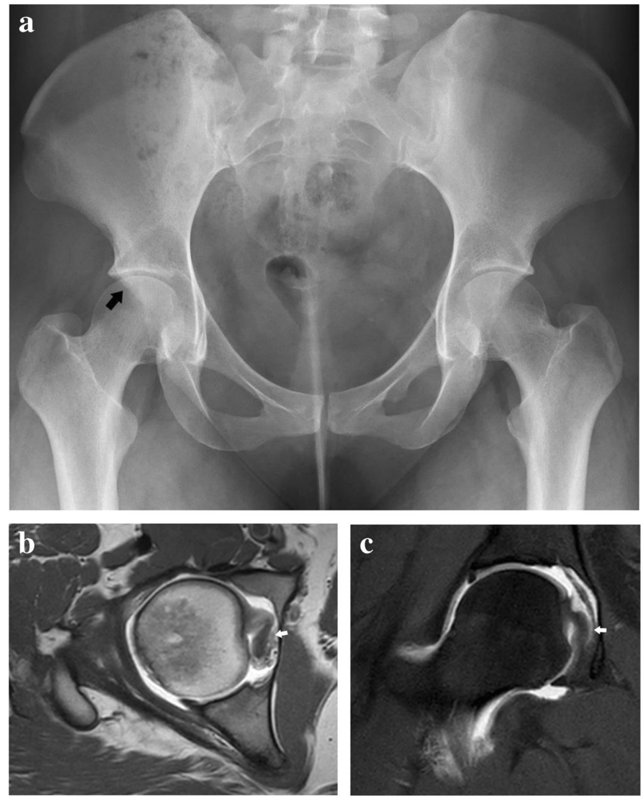

Fig. 5 A 27-year-old woman with right hip pain after tripping has an increased Beighton's generalised hypermobility score. **a** AP radiograph of the pelvis shows cranial acetabular retroversion (arrow) but no femoral head migration or reduced osseous coverage. **b** Axial T1 and **c** coronal fat-suppressed T1 MR arthrogram images show a thickened and elongated LT (arrows). A high-grade ligamentum teres injury was confirmed intraoperatively

When iliopsoas impingement is suspected, it is important for radiologists to document whether there are factors suggestive of microinstability as surgical iliopsoas lengthening can result in muscle weakness [77] and atrophy [78] potentially further compromising hip stability [79–81].

The majority of studies included in this review have an overall unclear or high risk of bias. None were designed as diagnostic accuracy studies. Thus, our critique should not be viewed as flaws in the original studies, but indicators of how confident we can be in interpreting the evidence in a way that lends weight to the review question. The lack of a clear diagnostic standard made it difficult to determine either whether the diagnostic reference was able to correctly classify the condition, or if it was applicable to the review research question. Hip symptoms were an essential feature of this review, hence ratings of high applicability concern for asymptomatic dancers [17, 18, 55], even when subluxation was demonstrated in extreme range of motion [17, 18]. The information gained from the surgical case series is limited by the influence of morphology on surgical selection and the use of FAI morphology or dysplastic features to assign subjects to subgroups [28, 52]. Studies differentiating participants based on objective measures of longitudinal traction are impacted less by confounding variables and generate useful objective data; however, it is noted that longitudinal traction may not directly equate with anterior or rotational instability.

There are several limitations of the review process that the authors acknowledge. The lack of universally accepted diagnostic criteria for microinstability required broad search criteria. This was a major limitation as many heterogeneous studies with variable diagnostic criteria were identified, hindered our ability to make study comparisons or draw definitive conclusions. Case reports which could not be evaluated with the QADAS tool were of limited value and in retrospect could have been excluded. It is possible that other pertinent studies exist. The cut-off LCEA < 20° in the review was chosen to exclude studies focussing on symptomatic dysplasia. Although this possibly resulted in the exclusion of relevant studies, the population of interest in this review is those without definite dysplasia in whom symptoms caused by subtle instability may be difficult to differentiate from impingement.

Symptoms and clinical findings of microinstability may be subtle or nonspecific [3, 4]; thus, the workup generally follows the standard imaging algorithm for the assessment of a young adult with hip pain. This begins with well-centred AP pelvis and lateral hip radiographs (cross-table lateral or 45° Dunn view) followed by a dedicated MRI of the hip [59, 82]. MR is the cross-sectional imaging method of choice as it provides information about the labrum, cartilage, LT and periarticular structures as well as allowing 3D characterisation of the bony morphology [83, 84]. The young adult hip is frequently evaluated with 3.0-Tesla MR imaging is frequently utilised for evaluation of the young adult hip because the increased signal to noise ratio enables high-resolution imaging [59]. In addition to small field of view hip sequences with an optimised high-resolution protocol, a fluid-sensitive fat-suppressed sequence of the entire pelvis should be considered to identify any other cause of pain [85]. An axial sequence through the femoral condyles is necessary for measurement of the femoral version [59, 82]. Direct arthrography has been shown to have a higher sensitivity and accuracy for the detection of labral and cartilage pathology than conventional MRI at 1.5 Tesla [86–88]. The superiority of arthrography is less clear at 3.0 Tesla [89, 90] and high-resolution conventional MR imaging is replacing MR arthrography at many centres. Direct 3.0-Tesla MR arthrography is the authors preferred method (RW, MB) as in our experience, the distension of the joint allows better evaluation of the intra-articular structures and the injection of local anaesthetic can be useful to confirm an intra-articular pain generator [91]. CT may be requested by the hip surgeon for further characterisation of bone morphology [92]. CT arthrography can be useful for the detection of intra-articular pathology in patients who are unable to undergo MR imaging [93].

Microinstability is a clinical diagnosis that radiologists should be aware of. This review describes imaging findings reported to be associated with, but not diagnostic of, microinstability. There is an overlap between symptomatic dysplasia and microinstability but the LCEA is frequently normal, highlighting the importance of 3D assessment and thorough documentation of all dysplastic morphology. The review provides some support for the suggestion that an anterior distribution of chondrolabral injury, particularly isolated straight anterior labral tears, may differentiate microinstability from FAI. LT tears may also be associated with instability and should be documented. There is insufficient evidence to suggest a link between microinstability and hypertrophy of the labrum or periarticular muscles, or capsular thinning visible on MRI. A consensus on the definition and diagnostic criteria for microinstability is necessary to enable future exploration of this clinical entity. Further research is needed to clarify the significance of FH migration on static imaging, the contribution of reduced acetabular coverage and increased femoral version to instability. As FH translation is sub physiologic and dynamic, subluxation may not be evident on static imaging; thus, dynamic MRI [94] and ultrasound [95] imaging of microinstability should be further evaluated.

In conclusion, this review has demonstrated that the current literature does not provide strong evidence for imaging features diagnostic of microinstability. In the appropriate clinical context, dysplastic morphology, anterior labral tears and LT tears may be suggestive of this condition although further research is needed to confirm this.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Harris JD, Slikker W, Abrams GD, Nho SJ. Atraumatic instability and surgical technique. Hip Arthrosc Hip Joint Preservation Surg. 2015:1001–14.
2. Canham CD, Yen Y, Giordano BD. Does femoroacetabular impingement cause hip instability? A systematic review. Arthroscopy. 2016;32(1):203–8.
3. Dangin A, Tardy N, Wettstein M, May O, Bonin N. Microinstability of the hip: a review. Orthop Traumatol: Surg & Res. 2016;102(8):S301–9.
4. Safran MR. Microinstability of the hip-gaining acceptance. JAAOS-J Am Acad Orthop Surg. 2019;27(1):12–22.
5. Shindle MK, Ranawat AS, Kelly BT. Diagnosis and management of traumatic and atraumatic hip instability in the athletic patient. Clin Sports Med. 2006;25(2):309–26 **ix**.
6. Shu B, Safran MR. Hip instability: anatomic and clinical considerations of traumatic and atraumatic instability. Clin Sports Med. 2011;30(2):349–67.

7. Kalisvaart MM, Safran MR. Hip instability treated with arthroscopic capsular plication. Knee Surg Sports Traumatol Arthrosc. 2017;25(1):24–30.
8. Akiyama K, Sakai T, Koyanagi J, Yoshikawa H, Sugamoto K. Evaluation of translation in the normal and dysplastic hip using three-dimensional magnetic resonance imaging and voxel-based registration. Osteoarthr Cartil. 2011;19(6):700–10.
9. Akiyama K, Sakai T, Koyanagi J, Yoshikawa H, Sugamoto K. In vivo hip joint contact distribution and bony impingement in normal and dysplastic human hips. J Orthop Res. 2013;31(10):1611–9.
10. Sato T, Tanino H, Nishida Y, Ito H, Matsuno T, Banks SA. Dynamic femoral head translations in dysplastic hips. Clin Biomech. 2017;46:40–5.
11. Jacobsen S, Sonne-Holm S, Soballe K, Gebuhr P, Lund B. Hip dysplasia and osteoarthrosis: a survey of 4151 subjects from the Osteoarthrosis Substudy of the Copenhagen City Heart Study. Acta Orthop. 2005;76(2):149–58.
12. 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 Arthroplast. 2017;32(9):S20–7.
13. Kraeutler MJ, Garabekyan T, Pascual-Garrido C, Mei-Dan O. Hip instability: a review of hip dysplasia and other contributing factors. Muscles Ligaments Tendons J. 2016;6(3):343.
14. Mayer SW, Abdo JCM, Hill MK, Kestel LA, Pan Z, Novais EN. Femoroacetabular impingement is associated with sports-related posterior hip instability in adolescents: a matched-cohort study. Am J Sports Med. 2016;44(9):2299–303.
15. Wassilew GI, Janz V, Heller MO, Tohtz S, Rogalla P, Hein P, et al. Real time visualization of femoroacetabular impingement and subluxation using 320-slice computed tomography. J Orthop Res. 2013;31(2):275–81.
16. Steppacher SD, Albers CE, Siebenrock KA, Tannast M, Ganz R. Femoroacetabular impingement predisposes to traumatic posterior hip dislocation. Clin Orthop Relat Res. 2013;471(6):1937–43.
17. Kolo FC, Charbonnier C, Pfirrmann CW, Duc SR, Lubbeke A, Duthon VB, et al. Extreme hip motion in professional ballet dancers: dynamic and morphological evaluation based on magnetic resonance imaging. Skelet Radiol. 2013;42(5):689–98.
18. Duthon VB, Charbonnier C, Kolo FC, Magnenat-Thalmann N, Becker CD, Bouvet C, et al. Correlation of clinical and magnetic resonance imaging findings in hips of elite female ballet dancers. Arthroscopy. 2013;29(3):411–9.
19. Charbonnier C, Kolo FC, Duthon VB, Magnenat-Thalmann N, Becker CD, Hoffmeyer P, et al. Assessment of congruence and impingement of the hip joint in professional ballet dancers: a motion capture study. Am J Sports Med. 2011;39(3):557–66.
20. Han S, Alexander JW, Thomas VS, Choi J, Harris JD, Doherty DB, et al. Does capsular laxity lead to microinstability of the native hip? Am J Sports Med. 2018;46(6):1315–23.
21. Crawford MJ, Dy CJ, Alexander JW, Thompson M, Schroder SJ, Vega CE, et al. The 2007 Frank Stinchfield Award: the biomechanics of the hip labrum and the stability of the hip. Clin Orthop Relat Res. 2007;465:16–22.
22. Myers CA, Register BC, Lertwanich P, Ejnisman L, Pennington WW, Giphart JE, et al. Role of the acetabular labrum and the iliofemoral ligament in hip stability: an in vitro biplane fluoroscopy study. Am J Sports Med. 2011;39(Supplement 1):85–91.
23. Wuerz TH, Song SH, Grzybowski JS, Martin HD, Mather RC III, Salata MJ, et al. Capsulotomy size affects hip joint kinematic stability. Arthroscopy. 2016;32(8):1571–80.
24. Domb BG, Philippon MJ, Giordano BD. Arthroscopic capsulotomy, capsular repair, and capsular plication of the hip: relation to atraumatic instability. Arthroscopy. 2013;29(1):162–73.
25. Smith MV, Sekiya JK. Hip instability. Sports Med Arthrosc Rev. 2010;18(2):108–12.
26. Johannsen AM, Behn AW, Shibata K, Ejnisman L, Thio T, Safran MR. The role of anterior capsular laxity in hip microinstability: a novel biomechanical model. Am J Sports Med. 2019;47(5):1151–8.
27. Hoppe DJ, Truntzer JN, Shapiro LM, Abrams GD, Safran MR. Diagnostic accuracy of 3 physical examination tests in the assessment of hip microinstability. Orthopaedic Journal of Sports Medicine. 2017;5(11):2325967117740121.
28. 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 Surgery, Sports Traumatology. Arthroscopy. 2017;25(1):84–93.
29. Matsuda DK, Wolff AB, Nho SJ, Salvo JP Jr, Christoforetti JJ, Kivlan BR, et al. Hip dysplasia: prevalence, associated findings, and procedures from large multicenter arthroscopy study group. Arthroscopy. 2018;34(2):444–53.
30. Wyatt MC, Beck M. The management of the painful borderline dysplastic hip. J Hip Preser Surg. 2018;5(2):105–12.
31. Harris JD, Gerrie BJ, Lintner DM, Varner KE, McCulloch PC. Microinstability of the hip and the splits radiograph. Orthopedics. 2016;39(1):e169–75.
32. Kuroda D, Maeyama A, Naito M, Moriyama S, Yoshimura I, Nakamura Y, et al. Dynamic hip stability, strength and pain before and after hip abductor strengthening exercises for patients with dysplastic hips. Isokinetics Exerc Sci. 2013;21(2):95–100.
33. Homma Y, Baba T, Kobayashi H, Murphy CG, Kaneko K. The importance of the soft tissue stabilizers of the hip: three cases of rapid onset osteoarthritis following hip arthroscopy. J Orthop Sci. 2017;22(4):795–801.
34. Yeung M, Kowalczuk M, Simunovic N, Ayeni OR. Hip arthroscopy in the setting of hip dysplasia: a systematic review. Bone Joint Res. 2016;5(6):225–31.
35. Duplantier NL, McCulloch PC, Nho SJ, Mather RC III, Lewis BD, Harris JD. Hip dislocation or subluxation after hip arthroscopy: a systematic review. Arthroscopy. 2016;32(7):1428–34.
36. Mei-Dan O, McConkey MO, Brick M. Catastrophic failure of hip arthroscopy due to iatrogenic instability: can partial division of the ligamentum teres and iliofemoral ligament cause subluxation? Arthroscopy. 2012;28(3):440–5.
37. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev. 2015;4(1):1.
38. Whiting PF, Rutjes AW, Westwood ME, Mallett S, Deeks JJ, Reitsma JB, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. Ann Intern Med. 2011;155(8):529–36.
39. Kapron AL, Karns M, Aoki SK, Adeyemi TF, Baillargeon EA, Hartley MK, et al. Patient-specific parameters associated with traction stiffness in primary and revision hip arthroscopy. Orthop J of Sports Med. 2018;6(11):2325967118807707.
40. Martin RL, Palmer I, Martin HD. Ligamentum teres: a functional description and potential clinical relevance. Knee Surg Sports Traumatol Arthrosc. 2012;20(6):1209–14.
41. Blakey CM, Field MH, Singh PJ, Tayar R, Field RE. Secondary capsular laxity of the hip. Hip Int. 2010;20(4):497–504.
42. Nwachukwu BU, Gaudiani MA, Marsh NA, Ranawat AS. Labral hypertrophy correlates with borderline hip dysplasia and microinstability in femoroacetabular impingement: a matched case-control analysis. HIP Int. 2019;29(2):198–203.
43. Oh K, Pandher D, Lee S. Arthroscopic management of acute painful hip following occult subluxation: evidence-based case report. Knee Surg Sports Traumatol Arthrosc. 2007;15(11):1370–4.

44. Bruce W, Higgs RJ, Munidasa D, Hunjan JS, Van Der Wall H. Acute osteochondral injuries of the hip. Clin Nucl Med. 2002;27(8):547–9.
45. Abrams GD, Luria A, Sampson J, Madding RA, Robinson WH, Safran MR, et al. Decreased synovial inflammation in atraumatic hip microinstability compared with femoroacetabular impingement. Arthroscopy. 2017;33(3):553–8.
46. Chahla J, Soares EA, Devitt BM, Peixoto LP, Goljan P, Briggs KK, et al. Ligamentum teres tears and femoroacetabular impingement: prevalence and preoperative findings. Arthroscopy. 2016;32(7): 1293–7.
47. Cerezal L, Arnaiz J, Canga A, Piedra T, Altónaga JR, Munafo R, et al. Emerging topics on the hip: ligamentum teres and hip microinstability. Eur J Radiol. 2012;81(12):3745–54.
48. Kapron AL, Aoki SK, Weiss JA, Krych AJ, Maak TG. Isolated focal cartilage and labral defects in patients with femoroacetabular impingement syndrome may represent new, unique injury patterns. Knee Surg Sports Traumatol Arthrosc. 2019;27(10):3057–65.
49. Magerkurth O, Jacobson JA, Morag Y, Caoili E, Fessell D, Sekiya JK. Capsular laxity of the hip: findings at magnetic resonance arthrography. Arthroscopy. 2013;29(10):1615–22.
50. Packer JD, Cowan JB, Rebolledo BJ, Shibata KR, Riley GM, Finlay AK, et al. The cliff sign: a new radiographic sign of hip instability. Orthop J Sports Med. 2018;6(11):2325967118807176.
51. Bellabarba C, Sheinkop MB, Kuo KN. Idiopathic hip instability: an unrecognized cause of Coxa Saltans in the adult. Clin Orthop Relat Res. 1998;355:261–71.
52. Kaya M, Suzuki T, Emori M, Yamashita T. Hip morphology influences the pattern of articular cartilage damage. Knee Surg Sports Traumatol Arthrosc. 2016;24(6).
53. 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(6):787–95.
54. Frank JM, Lee S, McCormick FM, Jordan M, Austell B, Slikker W, et al. Quantification and correlation of hip capsular volume to demographic and radiographic predictors. Knee Surg Sports Traumatol Arthrosc. 2016;24(6):2009–15.
55. Rodriguez M, Bolia IK, Philippon MD, Briggs KK, Philippon MJ. Hip screening of a professional ballet company using ultrasound-assisted physical examination diagnosing the at-risk hip. J Dance Med Sci. 2019;23(2):51–7.
56. Mitchell RJ, Gerrie BJ, McCulloch PC, Murphy AJ, Varner KE, Lintner DM, et al. Radiographic evidence of hip microinstability in elite ballet. Arthroscopy. 2016;32(6):1038–1044.e1.
57. Martin HD, Hatem MA, Kivlan BR, Martin RL. Function of the ligamentum teres in limiting hip rotation: a cadaveric study. Arthroscopy. 2014;30(9):1085–91.
58. Harris JD. Hypermobile hip syndrome. Operative Tech Sports Med. 2019;27(3):108–18.
59. Mascarenhas VV, Ayeni OR, Egund N, Jurik AG, Caetano A, Castro M, et al. Imaging methodology for hip preservation: techniques, parameters, and thresholds. Semin in Musculoskelet Radiol. 2019;23(03):226 Thieme Medical Publishers.
60. 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 Relat Res. 2017;475(4):1037–44.
61. Siebenrock KA, Steppacher SD, Haefeli PC, Schwab JM, Tannast M. Valgus hip with high antetorsion causes pain through posterior extraarticular FAI. Clin Orthop Relat Res. 2013;471(12):3774–80.
62. Krych AJ, Thompson M, Larson CM, Byrd JW, Kelly BT. Is posterior hip instability associated with cam and pincer deformity? Clin Orthop Relat Res. 2012;470(12):3390–7.
63. Ranawat AS, McClincy M, Sekiya JK. Anterior dislocation of the hip after arthroscopy in a patient with capsular laxity of the hip: a case report. JBJS. 2009;91(1):192–7.
64. Kraeutler MJ, Goodrich JA, Fioravanti MJ, Garabekyan T, Mei-Dan O. The “outside-in” lesion of hip impingement and the “inside-out” lesion of hip dysplasia: two distinct patterns of acetabular chondral injury. Am J Sports Med. 2019;47(12):2978–84.
65. Schmaranzer F, Todorski IAS, Lerch TD, Schwab J, Cullmann-Bastian J, Tannast M. Intra-articular lesions: imaging and surgical correlation. Semin Musculoskelet Radiol. 2017;21(05):506 Thieme Medical Publishers.
66. Ross JR, Zaltz I, Nepple JJ, Schoenecker PL, Clohisy JC. Arthroscopic disease classification and interventions as an adjunct in the treatment of acetabular dysplasia. Am J Sports Med. 2011;39(1_suppl):72–8.
67. O’Donnell JM, Devitt BM, Arora M. The role of the ligamentum teres in the adult hip: redundant or relevant? A review. J Hip Preserve Surg. 2018;5(1):15–22.
68. Byrd JT, Jones KS. Traumatic rupture of the ligamentum teres as a source of hip pain. Arthroscopy. 2004;20(4):385–91.
69. Kawaguchi AT, Otsuka NY, Delgado ED, Genant HK, Lang P. Magnetic resonance arthrography in children with developmental hip dysplasia. Clin Orthop Relat Res. 1976–2007;2000(374):235–46.
70. Papavasiliou A, Siatras T, Bintoudi A, Milosis D, Lallas V, Sykaras E, et al. The gymnasts’ hip and groin: a magnetic resonance imaging study in asymptomatic elite athletes. Skelet Radiol. 2014;43(8): 1071–7.
71. Mayes S, Ferris A, Smith P, Garnham A, Cook J. Atraumatic tears of the ligamentum teres are more frequent in professional ballet dancers than a sporting population. Skelet Radiol. 2016;45(7): 959–67.
72. 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 Relat Res. 2015;473(12): 3725–34.
73. Devitt BM, Smith BN, Stapf R, Tacey M, O’Donnell JM. Generalized joint hypermobility is predictive of hip capsular thickness. Orthop J Sports Med. 2017;5(4):2325967117701882.
74. Leunig M, Podeszwa D, Beck M, Werlen S, Ganz R. Magnetic resonance arthrography of labral disorders in hips with dysplasia and impingement. Clin Orthop Relat Res. 1976–2007;2004(418): 74–80.
75. Domb BG, Shindle MK, McArthur B, Voos JE, Magennis EM, Kelly BT. Iliopsoas impingement: a newly identified cause of labral pathology in the hip. HSS J. 2011;7(2):145–50.
76. Blankenbaker DG, Tuite MJ, Keene JS, AMd R. Labral injuries due to iliopsoas impingement: can they be diagnosed on MR arthrography? Am J Roentgenol. 2012;199(4):894–900.
77. Brandenburg JB, Kapron AL, Wylie JD, Wilkinson BG, Maak TG, Gonzalez CD, et al. The functional and structural outcomes of arthroscopic iliopsoas release. Am J Sports Med. 2016;44(5):1286–91.
78. Walczak BE, Blankenbaker DG, Tuite MR, Keene JS. Magnetic resonance imaging appearance of the hip musculature after arthroscopic labral-level iliopsoas tenotomies. Orthop J Sports Med. 2017;5(5):2325967117707498.
79. Fabricant PD, Bedi A, Torre KDL, Kelly BT. Clinical outcomes after arthroscopic psoas lengthening: the effect of femoral version. Arthroscopy. 2012;28(7):965–71.
80. Harris JD. Editorial commentary: caveat flexor—to release or not to release the iliopsoas, that is the question. J Arthrosc Relat Surg. 2018;34(6):1851–5.
81. Barlow B. Editorial commentary: iliopsoas fractional lengthening: treating a disease or a symptom? Arthroscopy. 2019;34(7):2102–4.
82. Sutter R, Pfirrmann CW. Update on femoroacetabular impingement: what is new, and how should we assess it? Semin Musculoskelet Radiol. 2017;21(5):518–28 Thieme Medical Publishers.

83. Beltran LS, Rosenberg ZS, Mayo JD, De Tuesta MD, Martin O, Neto LP, et al. Imaging evaluation of developmental hip dysplasia in the young adult. AJR Am J Roentgenol. 2013;200(5):1077–88.
84. Schmaranzer F, Cerezal L, Llopis E. Conventional and arthrographic magnetic resonance techniques for hip evaluation: what the radiologist should know. Semin Musculoskelet Radiol. 2019;23(3):227–51 Thieme Medical Publishers.
85. Agten CA, Sutter R, Buck FM, Pfirrmann CW. Hip imaging in athletes: sports imaging series. Radiology. 2016;280(2):351–69.
86. Smith TO, Hilton G, Toms AP, Donell ST, Hing CB. The diagnostic accuracy of acetabular labral tears using magnetic resonance imaging and magnetic resonance arthrography: a meta-analysis. Eur Radiol. 2011;21(4):863–74.
87. Sutter R, Zubler V, Hoffmann A, Mamisch-Saupe N, Dora C, Kalberer F, et al. Hip MRI: how useful is intraarticular contrast material for evaluating surgically proven lesions of the labrum and articular cartilage? AJR Am J Roentgenol. 2014;202(1):160–9.
88. Naraghi A, White LM. MRI of labral and chondral lesions of the hip. AJR Am J Roentgenol. 2015;205(3):479–90.
89. Tian CY, Wang JQ, Zheng ZZ, Ren AH. 3.0 T conventional hip MR and hip MR arthrography for the acetabular labral tears confirmed by arthroscopy. Eur Radiol. 2014;83(10):1822–7.
90. Magee T. Comparison of 3.0-T MR vs 3.0-T MR arthrography of the hip for detection of acetabular labral tears and chondral defects in the same patient population. Br J Radiol. 2015;88(1053):20140817.
91. Kheterpal AB, Bunnell KM, Husseini JS, Chang CY, Martin SD, Zoga AC, et al. Value of response to anesthetic injection during hip MR arthrography to differentiate between intra-and extra-articular pathology. Skelet Radiol. 2020;49(4):555–61.
92. Mascarenhas VV, Caetano A. Imaging the young adult hip in the future. Ann Joint. 2018;3:47.
93. Klaan B, Wuennemann F, Kintzelé L, Gersing AS, Weber MA. MR and CT arthrography in cartilage imaging: indications and implementation. Radiologe. 2019;59(8):710–21.
94. 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. Arthroscopy. 2019;35(8):2366–74.
95. d'Hemecourt PA, Sugimoto D, McKee-Proctor M, Zwicker RL, Jackson SS, Novais EN, et al. Can dynamic ultrasonography of the hip reliably assess anterior femoral head translation? Clin Orthop Relat Res. 2019;477(5):1086–98.