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Review article

Novelties in slipped capital femoral epiphysis imaging: A narrative review

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A B S T R A C T

Rationale and objectives: Imaging plays a key role in Slipped Capital Femoral Epiphysis diagnosis and severity assessment. In the last two decades, signs and measurements emerged in literature showed potential to help in SCFE diagnosis and tailoring treatment. The purpose of this review is to collect and discuss new imaging signs, measurements, and techniques according to investigations published after 2000 to improve SCFE diagnosis.
Material and methods: The PubMed, Scopus, and Science Direct databases were used to search for relevant articles related to imaging in SCFE diagnosis from January 2000 to March 2023. Article selection and review was performed by two board-certified radiologists). Article quality assessment were conducted by authors using QUADAS-2 and SANRA evaluation tools.
Results: The research resulted in a total of 2577 articles. After duplicates removal and abstract analysis, 28 articles were finally selected for full-text analysis. Seventeen articles were focused on Radiographs, 6 on CT, 1 on both Radiographs and CT, 4 on MRI. No study focused on ultrasound was selected.
Conclusions: Use of modified Klein's line and S-sign may improve radiographs accuracy in daily routine. Lucency sign may help in early diagnosis on radiographs. Preoperative CT may be useful in planning a tailored treatment predicting SCFE severity and instability. MRI is the most accurate modality to diagnose SCFE at early stage. Nevertheless, it cannot be used to predict the risk of contralateral SCFE. Risk prediction can be assessed with radiographs, using a new rapid mOBS. Further investigation and validation of these sign is needed.

1. Introduction

Slipped Capital Femoral Epiphysis (SCFE) consist in a posterior and medial slippage of the femoral head during growth, due to failure of the bone plate [1].

In most cases, SCFE occurs in adolescents aged from 8 to 15 years (mean age 12.8 years) with a reported prevalence of 10.8 per 100000 and a male-to-female ratio of 2/1.4 [1]. SCFE is bilateral in 18–63% of cases [2]. Patients with unilateral slippage have a 10–30% risk of contralateral slippage in the first 18 months [3].

Clinically, SFCE has an insidious clinical presentation with progressive limping and hip pain. Untreated, SCFE may lead to severe disability [1].

SCFE is defined as "unstable" when associated with pain and functional impairment. Unstable SCFE should be treated within 48–72 h from onset of symptoms to avoid early osteoarthritis [4].

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Abbreviations

SCFE	Slipped Capital Femoral Epiphysis
US	Ultrasound
CT	Computer Tomography
MRI	Magnetic Resonance
RDA	Riccardo De Angelis
GN	Giulia Negro
PS	Paolo Simoni
MPAG	Maria Pilar Aparisi Gomez
SI	Samia Ikhlef
AP	Antero-posterior
FL	Frog-lateral
mOBS	modified Oxford Bone Score

Imaging plays a key role in SCFE diagnosis. Radiographs are the first-line method used to diagnose SCFE by using Klein's line and Southwick's angle [5,6]. However, their reported accuracy and reproducibility is limited (Klein's line sensitivity of 68,3% and specificity of 89% - Southwick's angle sensitivity 71% and specificity 89%) [5–8]. Ultrasound (US) may raise suspicion of SCFE in pediatric patients with painful hip, but findings are often non-specific, mainly consisting with fluid effusion and synovitis [9,10]. More recently, the use of Magnetic Resonance (MR) and Computer Tomography (CT) have showed a great potential in SCFE early diagnosis and severity assessment respectively. However, their use is still limited in clinical settings due to CT irradiation and MR costs and availability [11].

In the last two decades, a large variety of new imaging signs and measurements emerged in literature who showed potential to help radiologist in SCFE diagnosis and to help tailoring treatment [12].

Therefore, the purpose of this narrative systematic review is to collect and discuss new imaging signs, measurements, and techniques according to investigations published after 2000 to improve SCFE diagnosis.

2. Material and methods

2.1. Search strategy

The PubMed, Scopus, and Science Direct databases were used to search for relevant articles related to imaging in SCFE diagnosis from January 2000 to March 2023.

The literature search was determined using PICO strategy as described below [13].

Population: Pediatric and adolescent population (8–19 years) diagnosed with SCFE.

Intervention: Imaging techniques in SCFE diagnosis.

Comparison: Accuracy, reproducibility, and contribution to research of different imaging techniques in SCFE diagnosis (Radiographs, Ultrasound, Computer Tomography, Magnetic Resonance).

Outcome: New approaches, signs, measurements, and techniques proposed in imaging in SCFE diagnosis in the last two decades.

The search strings for each database are provided in Annexe 1.

2.2. Article selection

Article selection and review was performed by two board-certified radiologists, one with 3 years of expertise in musculoskeletal and the other with three years of expertise in pediatric radiology respectively (RDA, GN). In case of lack of agreement, a third radiologist, with seventeen years of experience in musculoskeletal radiology and eight years in pediatric radiology, not implied in the selection, could be solicited to reach a consensus (PS).

2.3. Inclusion criteria

Articles were selected for full text analysis based on their title, abstract and keywords.

The main scope of the study indicated in the title and abstract had to be the SCFE assessment based on imaging features.

Articles that met all the following criteria were considered for full-text reading:

- Original articles
- Articles primarily assessing imaging modalities in the SCFE diagnosis were selected (if this criterion was not clearly indicated in the abstract, a targeted search of the full text was performed).
- The article had to be accepted for publication in a peer-reviewed journal listed on PubMed, Scopus, ScienceDirect or Embase at the time of the search.

2.4. Exclusion criteria

The following articles were considered not eligible:

- Single case reports, review articles, editorials, letters to the editor, commentaries and opinion articles were excluded
- Articles including data published even partially in other research were considered duplicates and discarded and only the original article were included.
- Article written in other language than English was discarded.

2.5. Data extraction and analysis

Extraction and analysis of the data focused on relevant findings and main conclusion of every article. Data was summarized (RDA) in a Word Worksheet. For each study we indicated the year of publication, the type of study (monocentric or multicentric), patients' enrollment (retrospective or prospective), number of subjects enrolled in the study, their gender and average age when provided. Results were also grouped by imaging techniques (Radiographs, US, CT, MRI) and their main conclusion was indicated.

2.6. Selected articles quality assessment

The QUADAS-2 Assessment Tool was used to assess the quality of the selected articles by two separated authors (MPAF, SI).

2.7. Systematic review quality assessment

The systematic review evaluation was carried out and assessed by one author, not implied in the article selection and data extraction (GF) using the "Scale for the assessment of Narrative Review Articles" (SANRA). SANRA is an assessment tool specifically implemented to evaluate systematic narrative reviews [14]. SANRA has been used instead of PRISMA, because PRISMA is designed to assess systematic reviews and meta-analyses, but not specifically for narrative reviews [15].

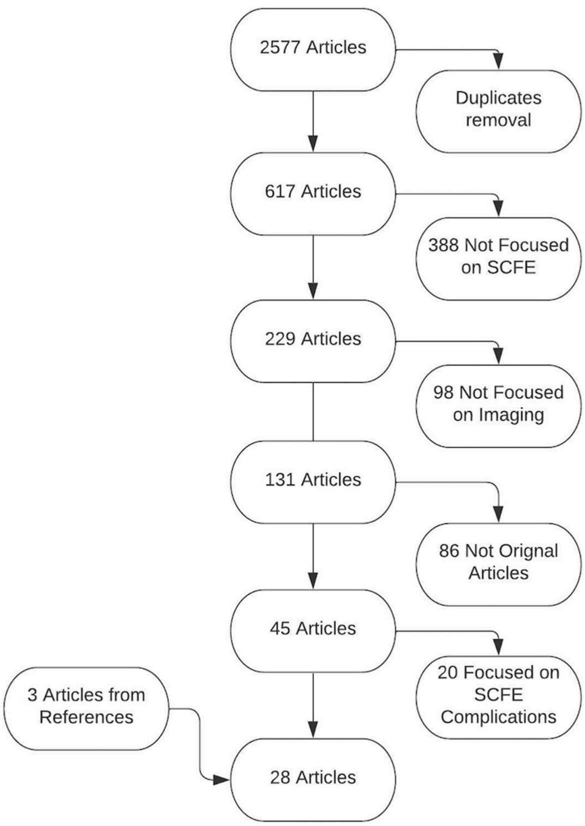

Fig. 1. Article Selection – Flowchart resuming article search and selection process.

Table 1
Results.

	Author (Year of Publication)	Mono/ Multicentre	Patients	Se x (H/F)	Age	Type of Study	Technique	Main Conclusion
1	Loder et al. (2008) [5]	Monocentre	97	67/30	12,3	Retrospective	X-ray	Klein's line is a useful too but not very sensitive.
2	Green et al. (2009) [16]	Monocentre	30	N/A	N/A	Retrospective	X-ray	Modified Klein's Line is more sensitive than Klein's line (79% vs 40,3%)
3	Belangero et al. (2011) [17]	Monocentre	17	8/9	12	Retrospective	X-ray	Head/Neck Ratio of contralateral head are smaller in patients with SCFE (0,255 vs 0,282). The head length is similar between sides.
4	Zide et al. (2011) [25]	Monocentre	30	N/A	N/A	Retrospective	X-ray	Revision of the mOBS to a consistent 0 to 2 (range: 0 to 10) system greatly enhanced the observers ability to recall the scoring system.
5	Song et al. (2011) [18]	Monocentre	25	20/5	N/A	Retrospective	X-ray	Acetabulotrochanteric distance (ADC) difference >2 mm between sides is a reliable diagnostic tool.
6	Popejoy et al. (2012) [24]	Monocentric	260	174/ 86	13	Retrospective	X-ray	The modified Oxford bone age score is the best predictor of the risk of development of a contralateral SCFE in patients presenting with a unilateral slip
7	Mestriner et al. (2012) [38]	Monocentre	61	33/28	N/A	Retrospective	X-ray	Southwick angles in lateral view and posterior sloping angles showed an important correlation with risk of appearance of bilateral SCFE.
8	Lehmann et al. (2013) [39]	Monocentre	2072	873/ 1199	18,6	Retrospective	X-ray	Radiological signs of prior SCFE in population are more common than expected (6,6%)
9	Lehmann et al. (2013) – [6]	Monocentre	100	33/67	19	Retrospective	X-ray	General inaccuracy of radiographic measurements (low ICC inter-observer and intra-observer)
10	Pinkowsky et al. (2013) [7]	Monocentre	23	10/13	12.2	Retrospective	X-ray	The findings of the current study support abandoning the routine use of the Klein line on the AP pelvis radiograph.
11	Nicholson et al. (2016) [26]	Monocentre	94	N/A	10,5	Retrospective	X-ray	Calcaneal stages 0–3 correspond entirely to modified Oxford scores indicating elevated risk of contralateral SCFE.
12	Kohno et al. (2017) [29]	Multicentre	67	45/22	11,3	Retrospective	X-ray	Approximately 70 % of contralateral hips in unilateral SCFE patients had subclinical posterior inclination of the capital femoral epiphysis, indicating the possibility of bilateral involvement. The contralateral PSA was a reliable predictor of a contralateral slip and a PSA of 19° was the cutoff value for developing SCFE.
13	Maranho et al. (2018) [20]	Monocentric	250	132/ 118	12,5	Retrospective	X-ray	A perituberde lucency is an early imaging sign, present in >80% of contralateral slips following an initial presentation of unilateral SCFE.
14	Rebich et al., 2018) [19]	Monocentre	62	N/A	N/A	Retrospective	X-ray	A combination of the S-sign and Klein's line yielded an overall sensitivity of 96.5% (mild SCFE - 81.4%, moderate SCFE - 99.7%, severe SCFE - 100%) and a specificity of 85.0%.
15	Maranho et al. (2020) [27]	Monocentre	250	132/ 118	12,5	Retrospective	X-ray	The presence of crossover sign increased two and half times the odds for a contralateral slip. Acetabular retroversion, but not acetabular overcoverage or increased acetabular depth, was associated with contralateral SCFE development in patients with unilateral SCFE.
16	Yang et al. (2020) [40]	Monocentre	57	31/12	12.1	Retrospective	X-ray	Within the Asian population, the authors recommend that the decision to pin the contralateral hip should not be based on PSA treatment thresholds due to potential unnecessary surgery and costs
17	Brown et al. (2021) [22]	Monocentre	N/A	N/A	N/A	Retrospective	X-Ray	Limited intraobserver (78%) and interobserver (29%) reproducibility of peritubercule lucency sign
18	Monazzam et al. (2013) [31]	Monocentre	19	N/A	N/A	Retrospective	CT	Axial-oblique and sagittal planes represent maximum of SCFE displacement while RX may underestimate displacement. HNAD (head-neck angle difference) of >30° in these planes indicates surgery.
19	Datti et al. (2017) [19]	Monocentre	21	14/7	13.9	Retrospective	CT	Significant differences between RX and CT measurements, the latter being more accurate.

(continued on next page)

Table 1 (*continued*)

	Author (Year of Publication)	Mono/ Multicentre	Patients	Se x (H/F)	Age	Type of Study	Technique	Main Conclusion
1	Loder et al. (2008) [5]	Monocentre	97	67/30	12,3	Retrospective	X-ray	Klein's line is a useful too but not very sensitive.
20	Hesper et al. (2017) [20]	Monocentre	72	N/A	N/A	Retrospective	CT	In SCFE, the acetabulum has reduced version but is not deeper, nor is there acetabular overcoverage.
21	Jones et al. (2018) [21]	Monocentre	N/A	N/A	N/A	Prospective	RX/CT	Small positioning errors in moderate and severe slips can cause a >10° LHNA error; additional three-dimensional imaging should be considered.
22	Bland et al. (2019) [22]	Monocentre	22	N/A	N/A	Retrospective	CT	New Angle Theta to measure proximal femoral deformity in patients with slipped capital femoral epiphysis. It can be defined by measuring displacement of the epiphysis in all three dimensions in relation to the femoral neck axis.
23	Filschier-Cobrie et al. (2020) [23]	Monocentre	27	12/15	12,4	Retrospective	CT	The concordance between CT stability and intraoperative stability of 78% suggests moderate to high accuracy for identifying epiphyseal stability. The specificity of 82% for CT grading alludes to the notion that a clear fracture line, particularly in the absence of callus, is helpful for accurately identifying an unstable SCFE that could be falsely identified as being stable by the Loder classification.
24	Novais et al. (2020) (41)	Monocentre	51	28/23	12,7	Retrospective	CT	The epiphyseal tubercle is smaller in hips with SCFE when compared with normal hips. These changes may be secondary to the mechanical stress associated with the slip. Alternatively, a smaller epiphyseal tubercle may be a predisposing factor that reduces the stability of the physis and increases susceptibility to a slip.
25	Wensaas et al. (2017) [35]	Monocentre	22	14/8	13.3	Retrospective	MR	MR performed at primary diagnosis could not predict future contralateral SCFE.
26	Balch-samora et al. (2018) [36]	Monocentre	69	40/29	12,5	Prospective	MR	Findings consistent with pre-slip pathology present in 67% of patients who went on to a sequential slip
27	Gao et al. (2020) [37]	Monocentre	32	27/5	10,7	Retrospective	MR	Hip muscle atrophy is associated with SCFE severity in patients with unilateral SCFE.
28	Maranho et al. (2020) [27]	Monocentre	71	35/36	12,6	Retrospective	MR	The perituberclelucency sign on radiographs is accurate and reliable for the early diagnosis of SCFE compared with MRI as the gold standard.

3. Results

3.1. Search strategy

Our search strategy was used to select articles published between January 2000 and March 2023. The research resulted in 1230 records for Science Direct, 604 for Scope, 743 for Pubmed for a total of 2577 articles. After removal of duplicates there was a total of 617 abstracts. Three-hundred-eighty-eight abstracts were excluded because they were not focused solely on SCFE. Ninety-eight were excluded because they were not focused on imaging techniques. Eighty-six were excluded they were not original articles (43 reviews, 43 case reports). Twenty articles were focused on the role of imaging in SCFE complications. Eventually, 25 original articles focused on SCFE diagnosis were selected for full-text analysis. Reference tracking of potentially relevant articles resulted in the inclusion of 3 articles, for a total of 28 articles. All 28 articles were included in the final analysis after full-text examination. The selection flowchart is showed in Fig. 1.

3.2. Data extraction

Data collected from selected articles are summarized in Table 1. Articles were grouped according to the imaging technique on which the study was focused (Radiographs, US, CT, MR). Articles in each group are in order of year of publication. We populated the worksheet to collect for every article included for the analysis the following data: type of study (monocentric or multicentric), the type of enrollment of patients (retrospective or prospective), the number of subjects enrolled in the study, their gender and average age, main conclusion of the article.

Seventeen articles were focused on Radiographs, 6 on CT, 1 on both Radiographs and CT, 4 on MRI. All studies were monocentric studies except one. All studies were retrospective studies except one. When indicated, we observed an overall majority of male patients.

The average age of patients varied between 10,7 and 19 years.

3.3. Critical appraisal

Critical appraisal of the methodological quality using the “Scale for the assessment of Narrative Review Articles” (SANRA) tool is shown in Annexe 2. All SANRA criteria were judged as matched by our reviewer (GF), with an overall score of 11 out of 12.

Results of QUADAS-2 Assessment Tool to assess the quality of selected articles are shown in Annexe 3 (MPAG, IS). Both authors found most articles difficult to evaluate regarding the index test. Overall, the evaluation shows an overall low risk of bias for most articles for both authors, except regarding patient selection in some articles.

4. Discussion

The study highlighted some significant advances in SCFE diagnosis in the last two decades.

4.1. Radiographs

Radiographs have been a first-line modality in daily routine in SCFE diagnosis. Antero-posterior (AP) and frog-leg lateral views (FL) are routinely performed in clinical setting. Klein’s line is used in AP views to diagnose SCFE while Southwick angle is used in FL views to assess its severity. However, both measurements have showed limited sensitivity et specificity (sensitivity of 68,3% and specificity of 89% and a sensitivity 71% and specificity 89% respectively), especially in mild SCFE (Southwick’s angle <30°) [5–9]. Hence, new measurements and signs were proposed to improve radiographs sensitivity for early SCFE (SCFE with no radiographic evidence) and to predict a SCFE of the opposite side (risk assessment without radiological evidence). Green et al. proposed a modified Klein Line [16]. This line is drawn on bot hips in AP view, then the width of femoral head is measured lateral to Klein’s line is measured. A difference of more than 2 mm between sides suggests a slippage. The modified Klein’s line has an improved sensitivity (68,3%) compared to the original version (40,3%) (Fig. 1) [16]. Rebich et al. proposed the S-sign. It is a S-shaped line drawn on the posterior and inferior part of femoral head and neck, on frog-lateral view. A disrupted or irregular line indicates a slippage (Fig. 2). The S sign is especially useful in association with a positive Klein’s line, with a overall sensitivity of 96,5% using both sign. However, the sensitivity is limited (overall 70%) in mild SCFE (Southwick angle <30°) (Fig. 3) [17].

Hence, modified Klein’s line and S-sign could be used in clinical routine to improve the accuracy of classic Klein’s line and Southwick’s angle.

Several other measurements were proposed by other authors to improve SCFE, such as acetabulotrochanteric distance or head/neck ratio, but the majority must be confirmed in large investigations [18,19].

Radiographs may also allow to diagnose SCFE at a pre-slip stage (SCFE without detectable slippage). In 2020 Maranho et al. observed that as early as 9 months prior to slippage, a lucency zone can be found around the epiphyseal tubercule (Fig. 4). The reported accuracy was as high as 90% among users regardless their experience [20]. The same authors investigated the peritubercule lucency sign using MRI as standard reference, showing that the lucency zone corresponded to signal abnormalities on metaphysis seen on MRI at a pre-slip stage (Fig. 4) [21].

The accuracy of peritubercule lucency sign has been questioned by Brown et al. who observed a limited intraobserver (average 74.8%) and a poor interobserver agreement (29% overall) [22]. This suggests that the peritubercule lucency sign may depend on radiologist experience.

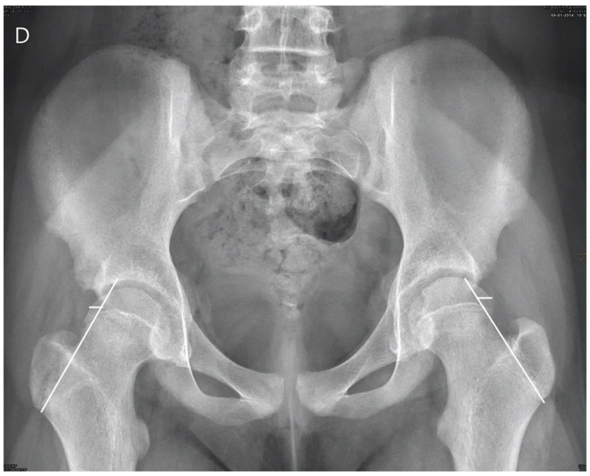

Fig. 2. Modified Klein’s Line – Modified version of classic Klein’s line: this sign is considered positive if there is a difference of more than 2 mm between sides.

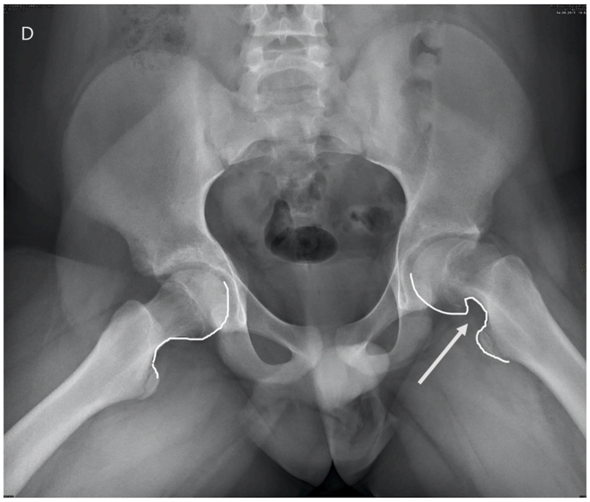

Fig. 3. S-sign – This line, drawn on frog-lateral view, is disrupted on the affected side (arrow).

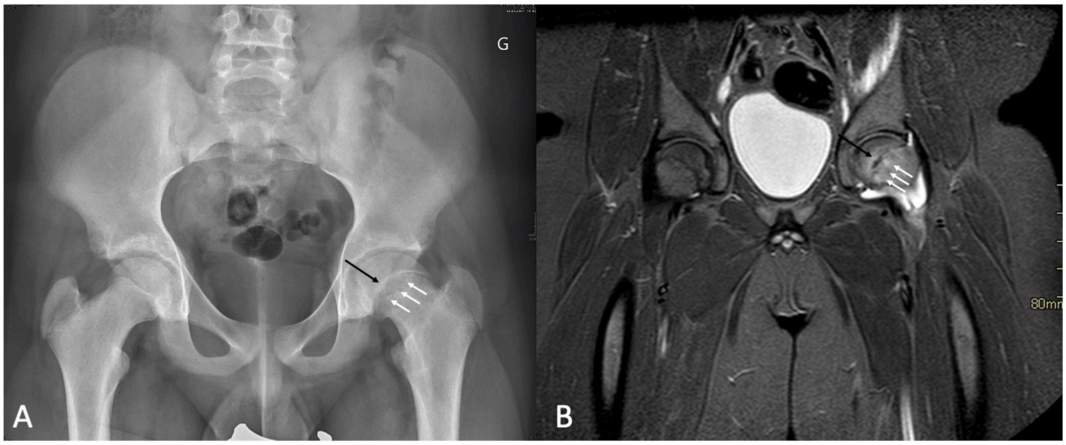

Fig. 4. Peritubercule Lucency Sign – (a) A lucency zone (white arrows) can appear around the tubercle (black arrow) up to 9 months prior to slippage. (b) The sign corresponds to signal abnormalities (white arrows) around the tubercule (black arrow) on MRI in early SCFE.

4.2. Contralateral SCFE risk assessment

Once a SCFE is diagnosed, it is crucial for surgeons to evaluate the risk of contralateral SCFE and plan a prophylactic treatment if necessary. Risk prediction of late contralateral SCFE can be assessed using radiographs. It is known that the risk of future contralateral slippage decreases with skeletal bone maturity at the time of first diagnosis [23]. Modified Oxford Bone Age Score (mOBS) for assessing skeletal maturity showed a good correlation with the risk of late contralateral SCFE. In patients with a cumulative score from 16 to 18 and a triradiate score of 1, risk of late contralateral SCFE can be as high to 96%, and preventive treatment can be advised, regardless the absence of radiological evidence [24]. However, mOBS is time-consuming and complex to be used in clinical practice. For this reason, Zide et al. proposed a revised and fast version of mOBS using a 10-point score that make its clinical use more time-effective [25]. Calcaneal score alone can also predict risk of contralateral slippage, with a lower irradiation exposure. Patients with a score from 0 to 3 present a risk of contralateral SCFE as high 96% [26].

Other isolated features, like acetabular retroversion, may also predict the risk of contralateral SCFE. A crossover sign increases the risk as high as two time and half [27].

Severity of slippage is a standalone predictor of contralateral SCFE. Hesper et al. showed that posterior slope angle (PSA) shows a positive correlation with the risk. If the PSA is above $>19^{\circ}$ preventive surgery is advised [28,29].

All these signs should be introduced in clinical practice to help identify patients affected with SCFE who would benefit of preventive pinning of contralateral hip. In fact diagnostic accuracy of the combined use of all these signs to predict a controlateral SCFE has not yet been studied.

4.3. Computer Tomography

4.3.1. SCFE severity and intraoperative stability prediction

CT is performed with caution in pediatric patients due to irradiation, but it offers a better diagnostic performance compared to radiographs in SCFE patients, especially to assess slippage severity [30–32]. Measurements should be done on axial-oblique and sagittal planes, where CT shows the greater physis displacement [31].

CT performed before surgery can be used to predict SCFE intraoperative stability. Fischer-Colbrie et al. showed that CT signs like fractures lines through the physis or through a formed callus can be highly predictive of intraoperative instability (Fig. 5). These signs seem to predict intraoperative instability better than Loder classification, which is based on clinical features. Also, associations of CT signs and Loder classification has a high negative predictive value for intraoperative instability [33]. Also, CT showed a smaller epiphyseal tubercule in hips with SCFE compared to normal hips [34].

CT performed before surgery may help improve prediction of severe SCFE and intraoperative instability, thus tailoring surgery procedure for each patient (screw fixation vs osteotomy). The irradiation risk and the benefits of performing a systematic preoperative CT should be further investigated.

4.4. Magnetic Resonance

4.4.1. Early diagnosis and prediction of contralateral SCFE

In the last two decades, MRI has been emerged as the more accurate modality for early diagnosis without irradiation. Joint effusion and signal anomalies in the epiphysis and metaphysis (Fig. 6), especially if the patient has a persistent triad cartilage, are consistent with a SCFE in a pre-slip stage [35] MRI has also the advantage of making diagnosis of simultaneous bilateral involvement [36]. Nevertheless, when SCFE is diagnosed on one side, even at an early stage, MRI alone cannot predict a future contralateral slippage [36]. Gao et al. observed on MRI that hip muscle atrophy is correlated to SCFE severity [37].

Therefore, MRI should be systematically performed in patients with a negative radiograph but persistent hip pain. MRI should be always associated with radiographs to assess risk of contralateral SCFE.

4.5. Limitations

This study presents several limitations. Even if our search was performed on different databases and reference search was systematically conducted, some articles may have been missed. Most selected studies were retrospective and monocentric, had a limited number of patients and lacked external validation.

Also, due to heterogeneity of selected articles, only a narrative review could be performed.

Fig. 5. Signs suggesting slippage instability on CT – Some features on CT, like a callus around the tubercule (white arrow) may suggest intraoperative instability better than clinical signs.

Fig. 6. Signs of early SCFE – MRI is the most sensitive method to diagnose SCFE at an early stage, showing signal abnormalities around the physis (white arrow) and joint effusion (dotted arrow).

5. Conclusions

In the last two decades, several articles were published introducing novelties in SCFE diagnosis. Use of modified Klein's line and S-sign may improve radiographs accuracy in daily routine. Lucency sign may help in early diagnosis on radiographs but should be further investigated. Preoperative CT may be useful in planning a tailored treatment predicting SCFE severity and instability. MRI is the most accurate modality to diagnose SCFE at early stage, when there is no radiographic evidence. Nevertheless, it cannot be used to predict the risk of contralateral SCFE. Risk prediction can be easily assessed with radiographs, using a new rapid mOBS version or calcaneal score.

CRediT authorship contribution statement

R. De Angelis: Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **M.P. Aparisi Gomez:** Writing – review & editing, Data curation. **G. Negro:** Data curation. **S. Ikhlef:** Validation. **G. Fichera:** Validation. **A. Bazzocchi:** Supervision. **P. Simoni:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e28734.

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