Article published online: 2024-07-19

Subchondral insufficiency fractures: overview of MRI findings from hip to ankle joint

Subchondrale Insuffizienzfrakturen: Überblick der MRT-Zeichen vom Hüftgelenk zum Sprunggelenk

Authors
Monica Maria Buturoiu[1], Sorin Ghiea[2], Marc-André Weber[3]

Affiliations
1 Radiology, University of Medicine and Pharmacy Carol Davila Bucharest, Bucharest, Romania
2 Imaging Department, Monza Hospital, Bucharest, Romania
3 Rostock University Medical Center, Institute of Diagnostic and Interventional Radiology, Pediatric Radiology and Neuroradiology, Rostock, Germany

Keywords
Subchondral insufficiency fracture, Hip, Knee, ankle, Magnetic resonance imaging

received 12.1.2024
accepted after revision 4.6.2024
published online 19.7.2024

Bibliography
Fortschr Röntgenstr 2024; 196: 1143–1154
DOI 10.1055/a-2344-5337
ISSN 1438-9029

Georg Thieme Verlag KG, Rüdigerstraße 14, 70469 Stuttgart, Germany

Correspondence
Monica Maria Buturoiu
Radiology, University of Medicine and Pharmacy Carol Davila Bucharest, Bucharest, Romania
monicabuturoiu@gmail.com

ABSTRACT

Background Subchondral insufficiency fracture (SIF) represents a potentially severe condition that can advance to osteoarthritis, with collapse of the articular surface. SIF manifests as a fracture in bone weakened by non-tumorous disease, precipitated by repetitive physiological stress, without a clear history of major trauma. It is observed along the central weight-bearing region of the femoral condyle, with a higher incidence in the medial femoral condyle, but also in other large weight-bearing synovial joints, such as the femoral head, tibial plateau, or talus.

Method A review of the literature from the past six years was performed by searching PubMed and ScienceDirect databases, using the keywords "subchondral insufficiency fracture" and "spontaneous osteonecrosis of the knee". The inclusion criteria were scientific papers presented in the English language that reported on the magnetic resonance imaging (MRI) aspects of SIF of the lower limb.

Results and Conclusion Detecting SIF at the level of the hip, knee, and ankle may present challenges both clinically and radiologically. The MRI appearance is dominated by a bone marrow edema-like signal and subchondral bone changes that can sometimes be subtle. Subchondral abnormalities are more specific than the pattern of bone marrow edema-like signal and are best shown on T2-weighted and proton-density-weighted MR images. MRI plays an important role in accurately depicting even subtle subchondral fractures at the onset of the disease and proves valuable in follow-up, prognosis, and the differentiation of SIF from other conditions.

Key Points

- Subchondral insufficiency fractures may affect the hip, knee, and ankle.
- Subchondral insufficiency fractures may heal spontaneously or progress to collapse.
- MRI is important for the detection, follow-up, and prognosis of subchondral insufficiency fractures.
- Differential diagnosis may include transient osteoporosis and osteonecrosis of systemic origin.

Citation Format

- Buturoiu MM, Ghiea S, Weber M. Subchondral insufficiency fractures: overview of MRI findings from hip to ankle joint. Fortschr Röntgenstr 2024; 196: 1143–1154

ZUSAMMENFASSUNG

Hintergrund Die subchondrale Insuffizienzfraktur (SIF) stellt eine potenziell ernste Erkrankung dar, die zu einer Osteonekrose und oder einem Fortschreiten der Arthrose mit Kollaps der Gelenkoberfläche führen kann. SIF manifestiert sich als Fraktur im durch nicht-neoplastische Krankheiten geschwächten Knochen. Diese Fraktur wird ausgelöst durch wiederholten physiologischen Stress, jedoch ohne klare Anamnese eines schwerwiegenden Traumas. Sie tritt entlang der zentralen, gewichtstragenden Region der Femurkondyle auf, mit einer höheren Inzidenz im medialen Femurkondylus, aber auch in anderen großen, gewichtstragenden mit Synovia ausgekleideten Gelenken, wie dem Knie- und Sprunggelenk.

Methode Es wurde eine retrospektive Literaturanalyse der letzten sechs Jahre durchgeführt, indem PubMed- und ScienceDirect-Datenbanken nach den Schlüsselwörtern „subchondrale Insuffizienzfraktur“ und „spontane Osteonekrose des Knies“ durchsucht wurden. Die Einschlusskriterien waren wissenschaftliche Arbeiten in englischer Sprache, die sich mit den magnetresonanztomografischen (MRT) Aspekten der SIF der unteren Extremität befassten.

Ergebnisse und Schlussfolgerung Die Detektion von SIF im Bereich von Hüfte, Knie und Sprunggelenk kann sowohl klinisch als auch radiologisch herausfordernd sein. In der MRT zeigen sich Veränderungen, wie sie auch bei einem Knochenmarködem festzustellen sind. Außerdem zeigen sich subchondrale Knochenveränderungen, die manchmal auch nur subtil sein können. Subchondrale Abnormalitäten sind spezifischer als das eher unspezifische Knochenmarködem und werden am besten auf T2-gewichteten und Protonendichte-gewichteten MRT-Sequenzen dargestellt. Die MRT spielt eine wichtige Rolle dabei, auch subtile subchondrale Frakturen zu Beginn der Erkrankung genau darzustellen und erweist sich als wertvoll bei der Verlaufskontrolle, Prognose und Differenzierung von SIF zu anderen Pathologien.

Kernaussagen
- Subchondrale Insuffizienzfrakturen können spontan heilen oder zu einem Kollaps fortschreiten.
- MRT ist wichtig für die Erkennung, Nachsorge und Prognose von subchondralen Insuffizienzfrakturen.
- Die Differentialdiagnose kann transiente Osteoporose und Osteonekrose systemischen Ursprungs umfassen.

Introduction

Subchondral insufficiency fracture (SIF) represents a potentially severe condition that can advance to osteoarthritis and collapse of the articular surface. SIF manifests as a fracture in bone weakened by non-tumorous disease, precipitated by repetitive physiological stress, without a clear history of major trauma. This fracture occurs in areas of the bone unable to withstand normal loads, primarily due to mechanical factors. It is commonly observed along the central weight-bearing region of the femoral condyle, with a higher incidence in the medial femoral condyle. However, SIF may also manifest in other large weight-bearing synovial joints, such as the femoral head, tibial plateau, or talus, particularly in areas subjected to mechanical loading [1, 2, 3].

With its heightened sensitivity and notable specificity, magnetic resonance imaging (MRI) plays a crucial role in accurately depicting even subtle subchondral fractures at the onset of the disease. Additionally, MRI proves valuable for follow-up and prognosis, as radiographs exhibit limited sensitivity until the disease has progressed significantly.

This review will focus on the key imaging characteristics of SIF, emphasizing the pivotal role of MRI and underscoring the significance of early detection. Moreover, due to the diverse origins and pathophysiological processes associated with an epiphyseal bone marrow edema (BME)-like signal, attributed to the nonspecific nature of this MRI finding, this paper will provide a brief discussion of the non-tumoral differential diagnosis of SIF.

Methods

A systematic review of the literature from the past six years was performed by searching the PubMed and ScienceDirect databases, using the keywords subchondral insufficiency fracture and spontaneous osteonecrosis of the knee. The queries were performed on December 12 and 13, 2023. The inclusion criteria were scientific papers presented in the English language that reported on the MRI aspects of subchondral insufficiency fracture of the lower limb. Nonhuman studies, case reports with fewer than 3 patients, cost-effectiveness studies, technical reports, editorial articles, surveys, letters to the editor, book chapters, and personal correspondence were excluded (n = 34). Furthermore, articles not primarily focused on MRI imaging and diagnosis were excluded (N = 58). This includes articles with a primary emphasis on surgical, therapeutic, or non-imaging aspects of subchondral insufficiency fracture. This search identified 108 articles including duplicates with 16 individual articles meeting our criteria.

Terminology: historical perspective, current state, and prospective outlook

Insufficiency fractures represent a form of stress injury associated with a fracture line. Stress injuries range from stress reactions (without a radiologically visible fracture line) to stress fractures, indicating a mismatch between the native strength of the bone and the prolonged mechanical stress exerted on it. This imbalance can result from fatigue, involving abnormal stress on a normal bone structure, or from insufficiency, where normal stress is applied to a bone with abnormal architecture [4, 5].

Numerous publications address the terminology of SIF at the level of the knee (SIFK). The term “spontaneous osteonecrosis of the knee” (SONK) was first described by Ahlbäck et al. in 1968 as a clinical condition primarily observed in elderly women. These individuals typically presented with abrupt, severe knee pain without any associated trauma [6]. Despite histological examinations revealing minimal osteonecrosis, this lesion was initially attributed to osteonecrosis [6].

With the introduction of MRI, the terminology of SIF began to take shape in 1998 when Lecouvet FE et al. described the primary imaging characteristics of transient epiphyseal lesions within the distal femoral epiphysis [7]. The goal was to distinguish them from irreversible osteonecrosis of the femoral condyles [7]. Subsequent studies by Lecouvet FE et al. in 2005 [8], complemented by the studies of Yamamoto and Bullough [9] and Takeda et al. [10], substantiate these initial findings.

To elaborate further, in 2000, Yamamoto and Bullough's histological study on surgically treated lesions initially diagnosed as "SONK" identified two types: those with a subchondral fracture line without associated osteonecrosis, and those with a subchondral fracture line with focal osteonecrosis. The osteonecrotic area, strictly confined between the fracture line and the articular surface, led the authors to conclude that the fracture is likely the primary event [9].

In 2008, the histological study by Takeda et al. on "SONK" lesions disclosed that, in early stages without collapse, osteonecrosis was absent, but it became apparent in later stages, confined to the area distal to the fracture site, suggesting compromised healing [10].

The confusion about terminology has been discussed in recent papers. One source of ambiguity is the utilization of the term "SONK", which is inconsistently applied to describe both spontaneously healing lesions and those complicated by collapse [11]. Additionally, some have used the term SIF for both types of lesions, those healing spontaneously and those progressing to collapse [12, 13]. In 2018 it became widely accepted that SONK is indeed a form of SIF that advances to joint collapse, characterized by secondary necrosis observed in the collapsed specimens [1]. Furthermore, recent papers recommend completely abandoning the term "SONK" in favor of "SIF" [14, 15].

In a recent review paper, the authors describe two types of spontaneous epiphyseal lesions, under a common nosological entity with different prognoses [16]. They use two terms to distinguish between lesions that undergo healing (referred to as simple subchondral insufficiency fractures) and lesions that progress unfavorably, leading to osteonecrosis and collapse (referred to as osteonecrosis complicating insufficiency fractures) [16].

Clinical Context

Notably, most of the research has been conducted on knee studies, revealing that SIF primarily affects individuals over 60 years of age, predominantly females, without a specific history of metabolic disorders or therapeutic intervention [17, 18]. Some studies suggest a potential link with underlying osteopenia [18, 19]. Conditions leading to bone fragility, such as renal and liver transplant recipients, osteomalacia, or systemic lupus erythematosus may contribute to more numerous insufficiency fractures [3, 16, 20, 21].

The onset of symptoms is typically sudden, occurring after minor trauma or without any history of trauma. Patients can recall the exact moment when the pain started, and it intensifies with weight bearing, persisting even at rest. Physical examination commonly reveals tenderness and joint effusion [6, 17].

SIFs are thought to result from a combination of factors including compromised osseous infrastructure, abnormal bone repair mechanisms, reduced protective function of surrounding soft tissues, including cartilage or meniscal injury, as well as exposure to abnormal forces [2, 19].

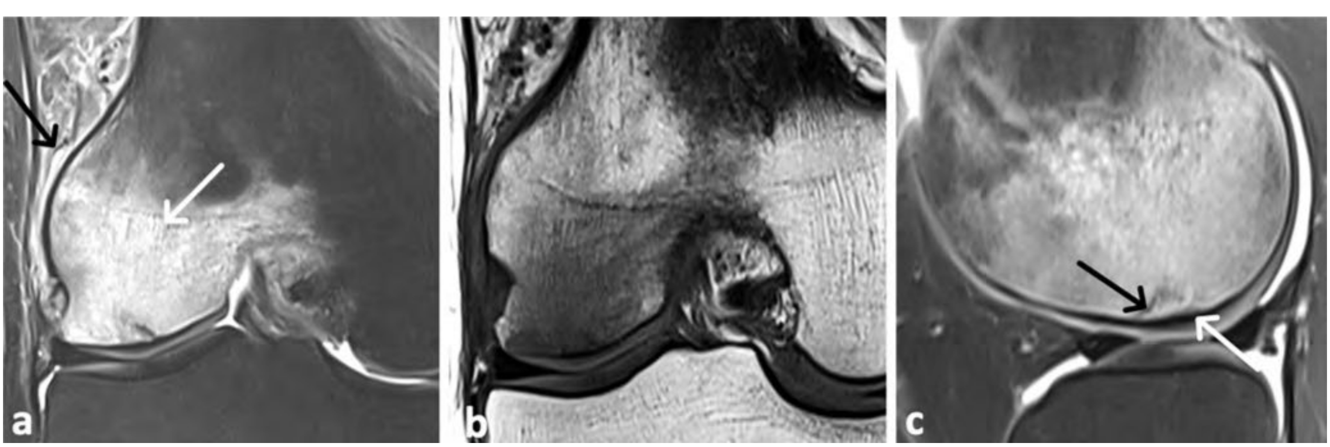
SIF – General Findings on MRI

The early fracture line in SIF is often unclear on radiographs, leading to initial negative evaluation. As the lesion advances, radiographic abnormalities appear but lack sensitivity for early detection. MRI, in contrast, proves to be an excellent imaging modality for detecting osteochondral lesions and is optimal for early diagnosis [22]. The MRI findings related to SIF will be outlined, with each aspect discussed individually.

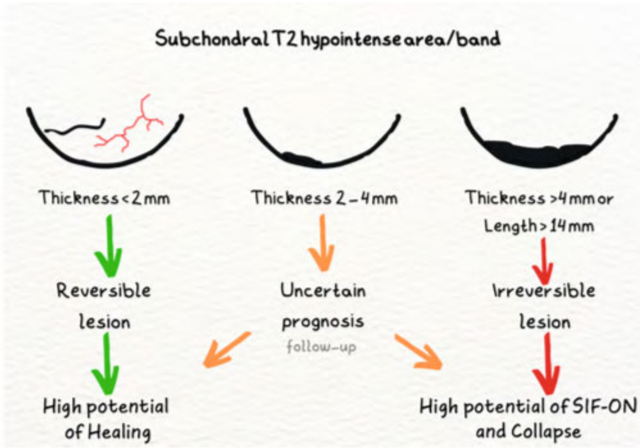
In addition to morphological examination, newer imaging methods capable of identifying biochemical and structural changes in cartilage, such as T2 and T2* mapping, T1ρ imaging, dGEMRIC (delayed gadolinium-enhanced MRI of cartilage), and sodium MRI, might play a role in the early identification of cartilage involvement in SIF. Further research is necessary to assess their potential prognostic value in SIF and their possible role in SIF management.

BME-like signal

Understanding of the term "bone marrow edema", initially introduced by Wilson et al. in 1988 to describe abnormal bone marrow



▶ **Fig. 1** Coronal T2-weighted fat-suppressed **a**, coronal T1-weighted **b**, and sagittal proton-density-weighted fat-suppressed **c** MR images showing low-risk SIF at the level of the lateral femoral condyle, with extensive ill-defined bone marrow edema-like signal (white arrow in **a**), irregular hypointense line (black arrow in **c**), very subtle hypointense subchondral area (white arrow in **c**) and no cortical deformity. Note the metaphyseal burst sign (black arrow in **a**).

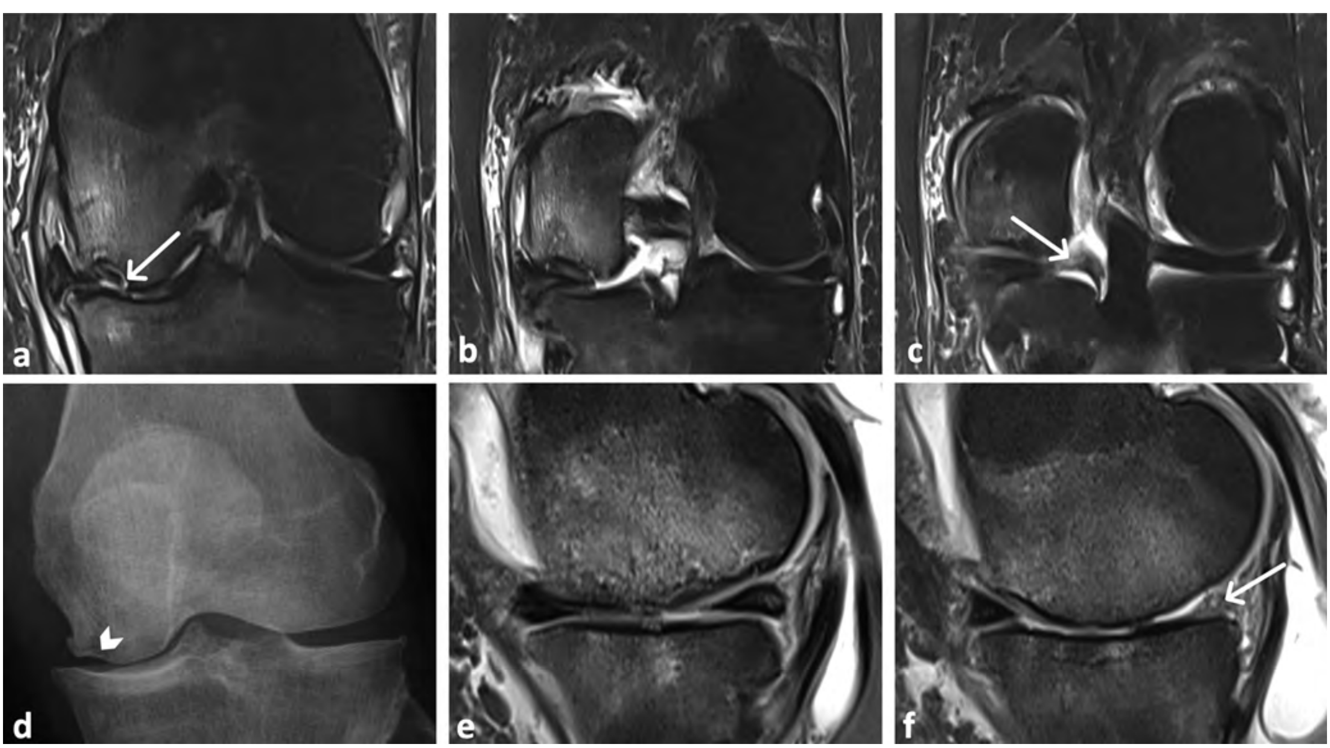


▶ **Fig. 2** Diagram showing the prognostic importance of the subchondral hypointense area/band on T2-weighted images. Lesions with areas measuring over 4 mm in thickness or 14 mm in length predict irreversible changes. Instead, lesions with subchondral hypointesity areas between 2 and 4 mm have an uncertain prognosis and may progress either to healing or collapse. Additionally, a pathogenic hypothesis suggesting the potential for SIF to heal is based on determining whether there is continuity between the area located between the fracture line and the articular surface and the rest of the epiphyseal region, indicating ongoing vascular supply in that area. Diagram adapted based on Malghem J et al., 2023 Figure 13 and Figure 21 [16].

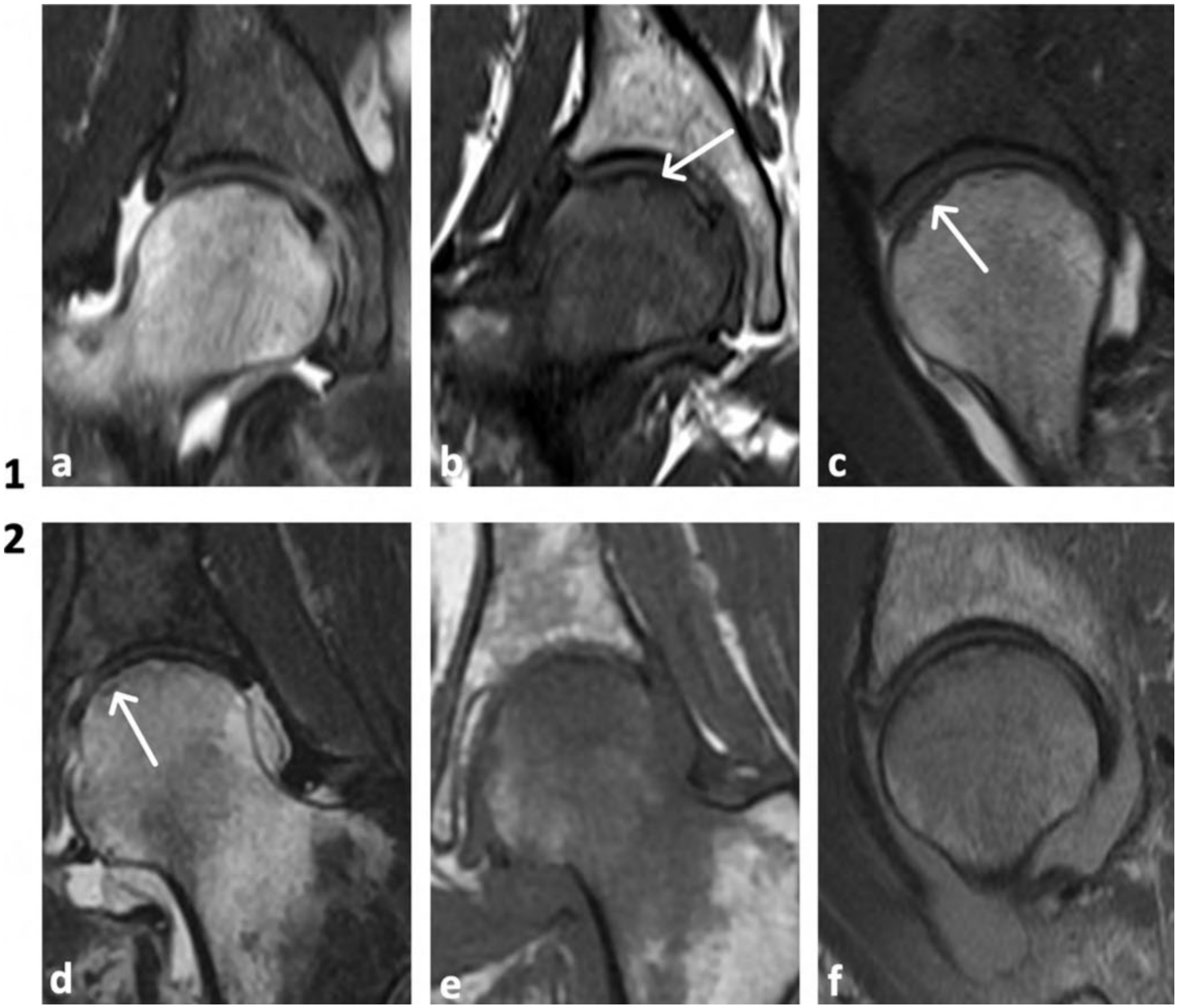
signal intensity on MRI, has evolved over time [23]. It was originally described as subtle low signal intensity on T1-weighted images and subtle high signal intensity on fat-suppressed T2-weighted images in patients with knee pain [23]. However, subsequent research revealed that the observed signal abnormalities, initially thought to be edema, constitute a complex mixture of lymphoid infiltrates, fibrosis, increased vascularization, blood products, microfracture and callus formation, granulomatous foci, and cartilage debris, depending on the etiology [14, 24, 25].

As the use of MRI expanded, this bone marrow signal abnormality was observed in various knee conditions, including SIF, osteoarthritis, trauma, inflammation, and tumors, indicating a lack of specificity. Due to the diverse histological components, it is recommended to use the term “bone marrow edema-like signal” rather than “bone marrow edema” in imaging descriptions [14, 15].

In SIF, the key finding is the BME-like signal, but its extent on MRI does not correlate with the prognosis [1, 7]. It manifests as an ill-defined area of bone marrow with moderately decreased signal intensity on T1-weighted images and increased signal intensity on T2-weighted images, especially evident on fat-suppressed fluid-sensitive images (▶ **Fig. 1**) [1]. The location and extension of BME-like signal changes vary with the underlying condition, with the signal changes being near the articular surface and extending over a variable portion of the epiphysis in SIF [16]. Conversely, BME-like abnormalities in osteoarthritis are typically



▶ **Fig. 3** Irreversible SIF of the medial femoral condyle, with articular collapse, in a 62-year-old woman who presented with 4 months of diffuse knee pain. Coronal T2-weighted fat-suppressed **a, b, c** and sagittal proton-density–weighted fat-suppressed **e, f** MR images show articular surface collapse, a fluid-filled cleft underlying the subchondral bone plate (arrow in **a**), and BME-like signal confined to the periarticular region. Saucerized defect (arrowhead in **d**) of the epiphysis can be observed on the knee AP view radiograph **d**. A medial meniscal posterior root tear is associated (arrows in **c** and **f**).



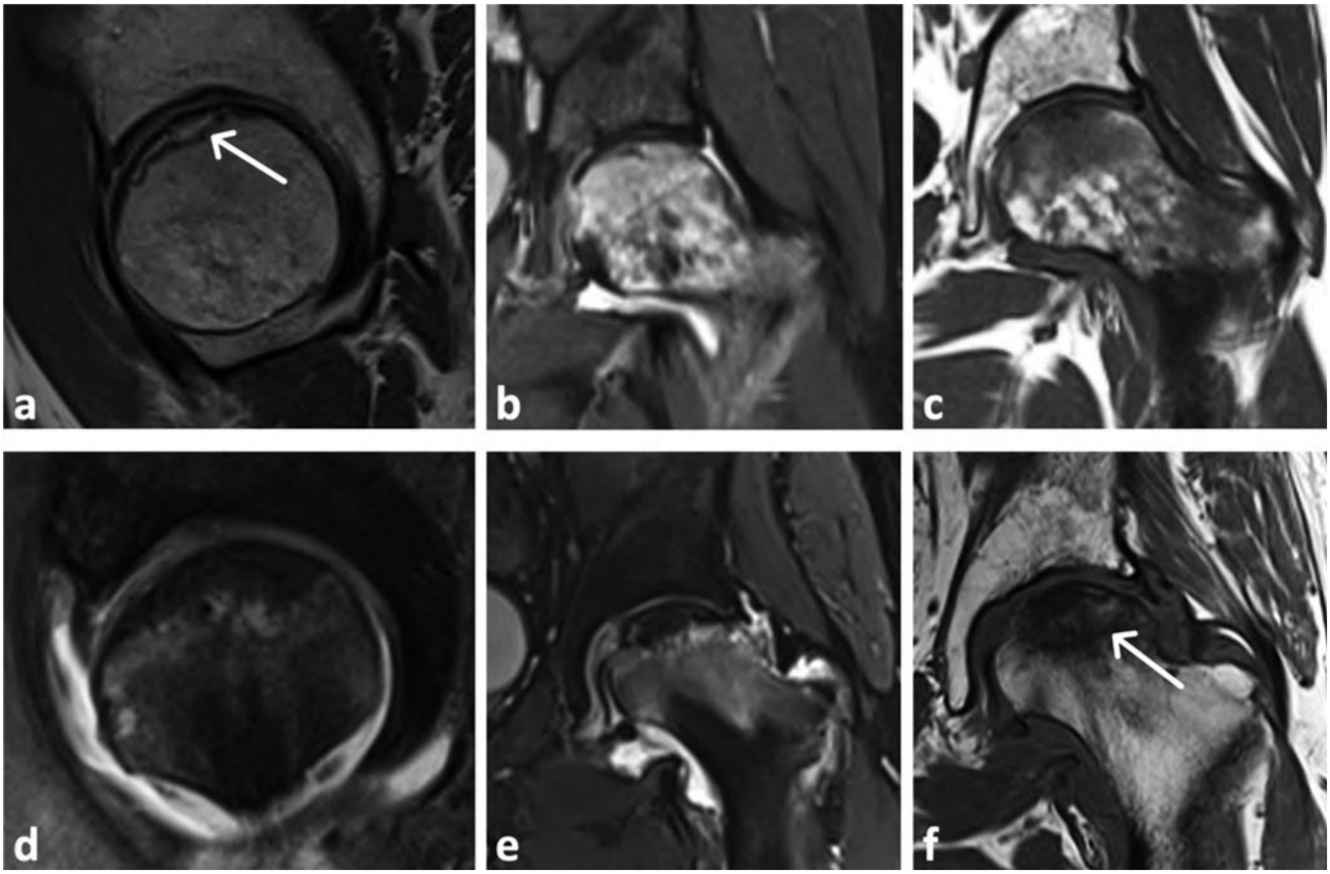
▶ **Fig. 4** Two cases of SIF of the hip (**1** and **2**). Coronal proton-density-weighted fat-suppressed **a, d**, coronal T1-weighted **b, e**, sagittal proton-density-weighted fat-suppressed **c**, and sagittal proton-density-weighted **f** MR images show: a hypointense line that is irregular and discontinuous (arrow in **c** and **d**), hypointense area immediately subcortical (arrow in **b**) and marked bone marrow edema-like signal visible on both sides of the fracture line.

more confined [1]. Moreover, the BME-like signal in SIF lacks well-defined borders, distinguishing it from osteonecrosis of systemic origin, where the lesion is surrounded by a distinct geographic rim of sclerosis or a low signal intensity line [1].

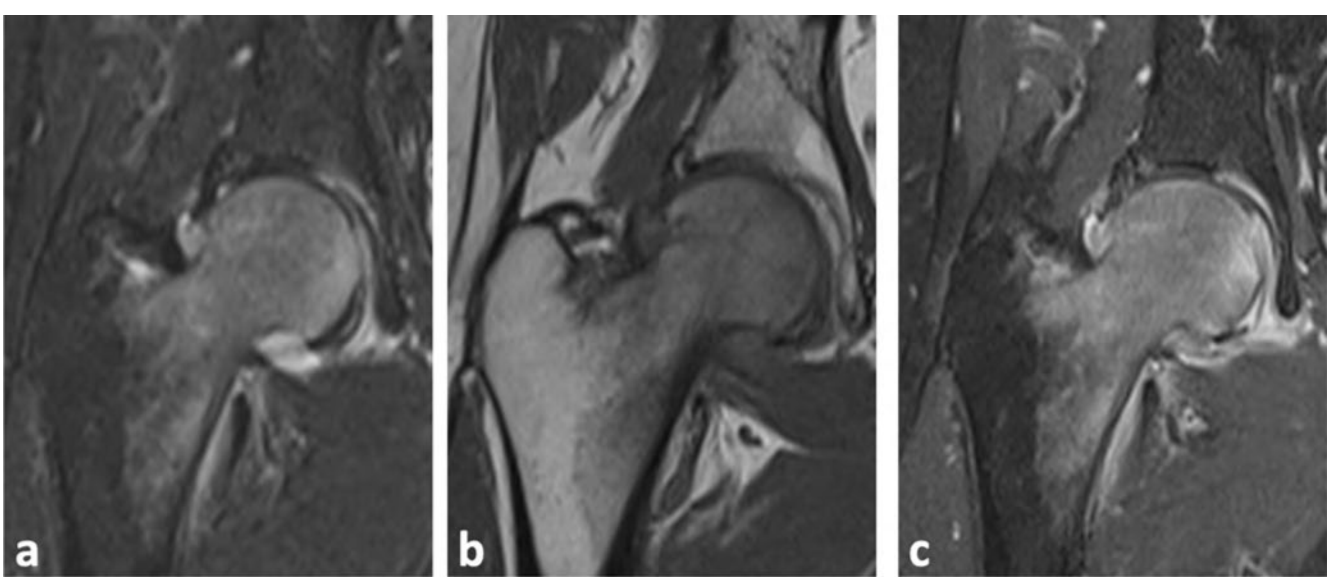
Subchondral hypointense fracture line

In SIF, a subchondral hypointense line on T2-weighted and proton density-weighted images is a more specific feature [14]. This line consistently displays low signal intensity across all sequences, including fluid-sensitive MR sequences and histologically corresponds to a fracture callus, thickened collapsed bone trabeculae, and granulation tissue [9]. Often this fracture line is thin, irregular, parallel, or curvilinear with respect to the subchondral plate a few millimeters away from the epiphyseal surface, and may also be discontinuous or open-ended [14, 26]. In SIF, the BME-like signal is present on both sides of the fracture line [16].

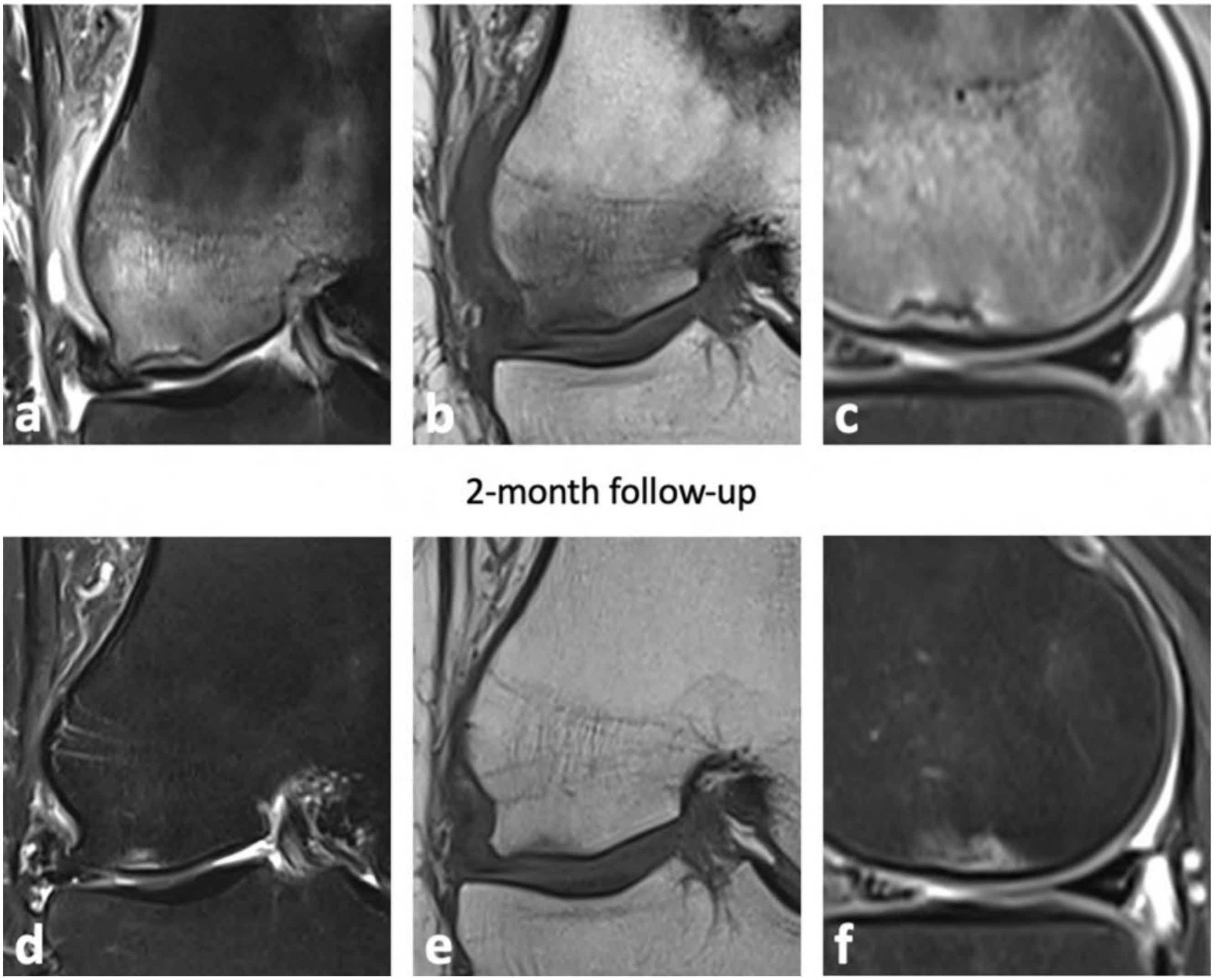
A potential pathogenic hypothesis suggests that the fate of a SIF, whether progressing to an irreversible lesion or healing, may be influenced by how the fracture line completely isolates the adjacent subchondral area [16]. Complete isolation of the subchondral bone between the fracture and the articular surface may compromise vascularization, possibly leading to necrosis [16]. This theory is based on the presumption that the normal vascular supply of the epiphyseal subchondral bone relies on a network of anastomotic terminal arterioles [27]. However, even with persistent communication, inadequate blood flow may occur, especially if the area is too large to be fully supported by the remaining micro-arterial network [16].



► **Fig. 5** The shape of the low-intensity line is useful for the differentiation of SIF (top row, **a, b, c**) from ON (bottom row, **d, e, f**). In SIF the low-intensity line is irregular, convex to articular surface (arrow in **a**), associated with a bone marrow edema-like signal on both sides of the line. In ON the low-intensity line is a concave to articular surface and circumscribes all necrotic segments (arrow in **f**), associated with a bone marrow edema-like signal outside of the necrotic area. Sagittal proton-density-weighted **a**, coronal proton-density-weighted fat-suppressed **b, e**, coronal T1-weighted **c, f**, and sagittal proton-density-weighted fat-suppressed **d** MR images.



► **Fig. 6** A 49-year-old man with transient osteoporosis of the hip (TOH). Coronal STIR **a**, coronal T1-weighted **b**, and coronal T1-weighted fat-suppressed post-gadolinium **c** MR images show an ill-defined BME-like signal at the femoral head extending into the intertrochanteric region, with no other subchondral abnormalities.



▶ **Fig. 7** Favorable evolution of SIF at the level of the lateral femoral condyle. A 50-year-old woman with acute onset of knee pain and no recent injury. Coronal T2-weighted fat-suppressed **a, d**, coronal T1-weighted **b, e**, and sagittal proton-density–weighted fat-suppressed **c, f** MR images showing favorable evolution of SIF with conservative treatment, with reduction of the bone marrow edema-like signal, granulation tissue at the site of the subchondral fracture, and remodeling of the cortex, without its collapse.

Subchondral hypointense area or band

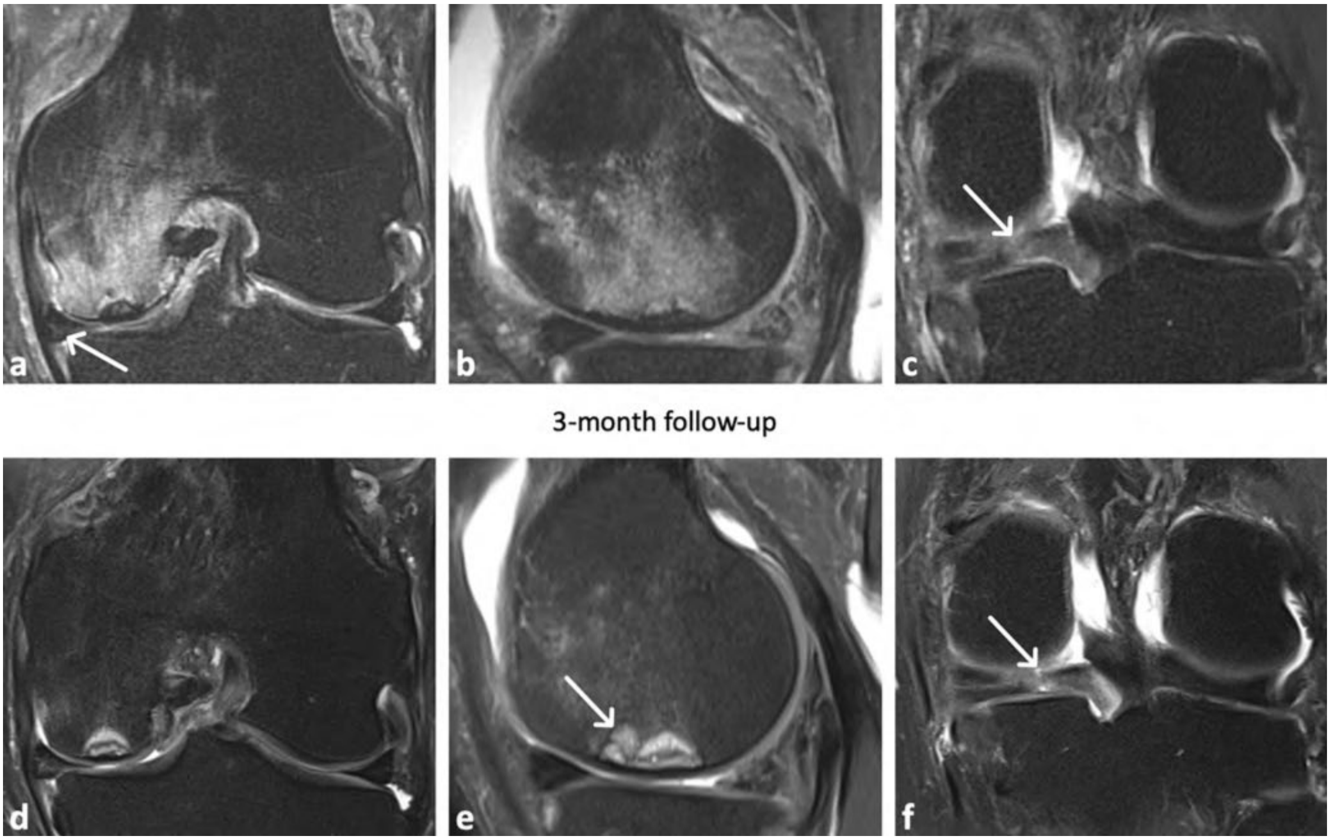
A subchondral area with low signal intensity on T2-weighted images may be observed, comprising a mixture of fracture callus, granulation tissue, and secondary osteonecrosis in the superficial layer [1]. When subtle, this subchondral region is often integrated in the subchondral plate, resembling a thickened subchondral plate, and radiologists should not overlook it [1]. This area shows no enhancement on post-contrast T1-weighted images [25].

An area thinner than 2 mm typically indicates a reversible lesion [7]. Instead, lesions featuring subchondral low T2 signal intensity areas between 2 and 4 mm should be regarded as having an uncertain prognosis and require follow-up [7].

The predictive importance of low signal intensity in bone marrow on T2-weighted images was recognized as early as 1990 [28]. Subchondral areas with low T2 signal intensity exceeding 4 mm in thickness or 14 mm in length have been demonstrated to predict irreversible lesions, with high sensitivity and specificity [7]. Therefore, in the early stages, analysis of this subchondral area can aid in identifying the risk of progression to the irreversible form of SIF, i. e., SIF with osteonecrosis (▶ **Fig. 2**) [16].

Subchondral cortical deformity. Fluid-filled cleft

In SIF, the primary anomaly is the initial appearance of the BME-like signal, while the fracture line remains undetectable, potentially due to microfractures in the trabecular bone that are not visible on MRI. As the causative mechanism of injury progresses, these microfractures merge, forming the distinctive subchondral image described above. If the injury mechanism persists, impaction or collapse of the subchondral cortical bone and/or cortical bone discontinuity may occur (flattening or a focal depression). The extension of the fracture line into the joint cavity enables intra-articular fluid to enter the fracture, creating a subchondral image with signal intensity resembling that of fluid on the fracture topography (fluid-filled cleft, inconstant feature) (▶ **Fig. 3**) [1]. The cortical



▶ **Fig. 8** Coronal **a, c, d, f** and sagittal proton-density–weighted fat-suppressed **b, e** MR images at presentation and at 3-month follow-up in a 63-year-old man showing unfavorable evolution of SIF at the level of the medial femoral condyle, with irreversible findings. Despite a decrease in the BME-like signal, the findings reveal extensive subchondral bone remodeling with heterogeneous high signal intensity and geode-like areas (arrow in **e**), and a small depression of the subchondral surface. Additionally, MR images show an associated medial meniscal posterior horn tear (arrow in **c** and **f**) and extrusion (arrow in **a**), suggesting a poor prognosis.

collapse and the fluid-filled cleft indicate advanced lesions with an unfavorable prognosis.

Hip

SIFs typically manifest in the anterior segment of the femoral head for most patients (▶ **Fig. 4**). Early MRI indicators associated with a high risk of epiphyseal collapse and, consequently, an unfavorable prognosis are lateral location, nonparallel course, extensive fractures, substantial cartilage defects, and advanced patient age [29, 30]. SIF likely accounts for most cases classified as rapidly progressive osteoarthritis of the hip [29, 31].

It is important to differentiate SIF from osteonecrosis of systemic origin (ON), as early diagnosis would have an impact on the treatment and its overall management. ON is commonly observed in the hip, shoulder, and knee of individuals with typical risk factors, including corticosteroid medication, alcoholism, hematologic diseases, and various other conditions [32].

SIF can be differentiated from ON by the shape of the low intensity band on T1-weighted images. In SIF, the band is irregular, convex to the articular surface, and often discontinuous. Instead, in ON, the band is well circumscribed, smooth, concave, and a mirror image of the articular surface, representing a reactive interface between live and necrotic bone (▶ **Fig. 5**) [1, 14, 32, 33]. Ikemura et al. proposed evaluating not just the shape but also the depth of the low-intensity band on coronal T1-weighted images. The authors noted its significantly lower depth in the SIF group compared to the osteonecrosis group [34]. Moreover, in ON, MR images show a double line sign (an outer band of low signal associated with an inner band of high signal) on T2-weighted sequences and a geographic pattern [1, 32].

Another area of debate centers on distinguishing between transient osteoporosis of the hip (TOH) and SIF (▶ **Fig. 6**). They are distinct entities. TOH is a benign, self-limiting condition with an idiopathic substrate, characterized by diffuse, ill-defined bone marrow edema-like signal intensity in the femoral head and neck, and occasionally, the acetabulum [14, 32]. This condition lacks other subchondral hip findings and shows no clinical evidence of infection or underlying rheumatologic disease [35]. In some TOH cases, besides the BME pattern, subchondral low-intensity bands on T1-weighted images have been observed. However, their visibility on MRI and CT scans may vary based on the examination timing and the self-limiting quality, low-resolution of MR images [35, 36]. Some authors recommend dedicated small field-of-view (FOV) images of the affected hip to detect any subchondral abnormalities [14, 35]. The diagnosis of TOH should be made when images reveal only a diffuse, ill-defined bone marrow edema-like signal intensity in the hip. If other associated abnormal subchondral signals are present, the differential diagnosis broadens to include SIF and osteonecrosis [14].

When this condition transitions between joints, it is termed migratory osteoporosis, also known as complex regional pain syndrome type 1 (CRPS 1). The clinical features exhibit low specificity, and there are no definitive criteria for establishing the diagnosis. The migration of the BME-like pattern from one portion of the epiphysis to another or from one epiphysis to another is observed on follow-up MRI. This migration of the BME-like pattern is the only distinctive finding on MRI that sets CRPS 1 apart from SIF [37, 38].

Knee

SIFK is most common in the weight-bearing area of the medial femoral condyle [18]. It less frequently occurs in the medial tibial condyle, lateral femoral condyle, and lateral tibial condyle (▶ **Fig. 1**, ▶ **Fig. 7**) [18, 19, 39]. This might be explained by the difference in arterial supply, as observed in a cadaveric study by Reddy and Frederick. Their research indicated that the medial femoral condyle exhibited a worse intraosseous blood supply with watershed areas compared to the lateral femoral condyle [27].

Numerous studies have mentioned the link between meniscal tears and SIFK, with a prevalent occurrence of medial meniscal tears, often found ipsilateral to the SIFK [1, 12, 19, 40, 41, 42]. The most common tear is a posterior root tear, followed by a radial tear in the posterior horn (▶ **Fig. 3**, ▶ **Fig. 8**) [42, 43]. Some reports suggest an association between SIFK and medial meniscal extrusion of 3 mm or beyond (▶ **Fig. 8**) [12, 18, 43]. SIF may also occur after meniscectomy [1, 44]. Medial meniscus posterior root tears, meniscal extrusion, high-grade chondrosis, larger lesion sizes, and articular surface collapse are associated with high-grade SIF with a poor outcome [12, 19, 43, 45].

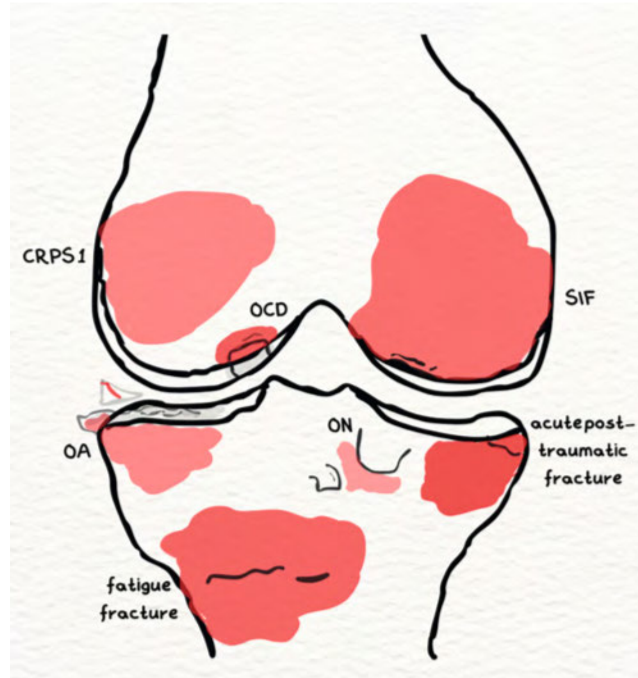
A soft-tissue edema signal adjacent to the BME-like signal is common in SIF, especially in cases affecting the femoral condyle [18, 46]. Vidoni et al. introduced an indirect MRI sign known as the metaphyseal burst sign (▶ **Fig. 1**) [46]. This sign represents edema of the tissues overlying the metaphyseal region of the affected condyle where the nutrient vessels enter the bone to supply blood to the adjacent bone [46].

Concerning the differential diagnosis of SIFK, various conditions are considered including CRPS 1, ON, osteoarthritis, acute post-traumatic subchondral fracture, and osteochondritis dissecans (OCD) as discussed below (▶ **Fig. 9**, ▶ **Fig. 10**). While various MRI features associated with the trauma event aid in distinguishing SIF from acute traumatic subchondral fractures, the clinical history remains crucial. In equivocal cases, follow-up imaging may be necessary to monitor healing.

Ankle

SIF of the talus is a rare condition that can impact both the talar dome and the head, where it articulates with the distal tibia and the navicular, respectively (▶ **Fig. 11**) [48, 49].

Differentiating SIF from OCD of the talus can be challenging, as both are associated with a BME-like pattern and involve the subchondral bone (▶ **Fig. 10**). In SIF, there is no history of acute trauma, and low-grade lesions lack contour deformity or overlying cartilage defects. In contrast, the appearance of OCD on imaging

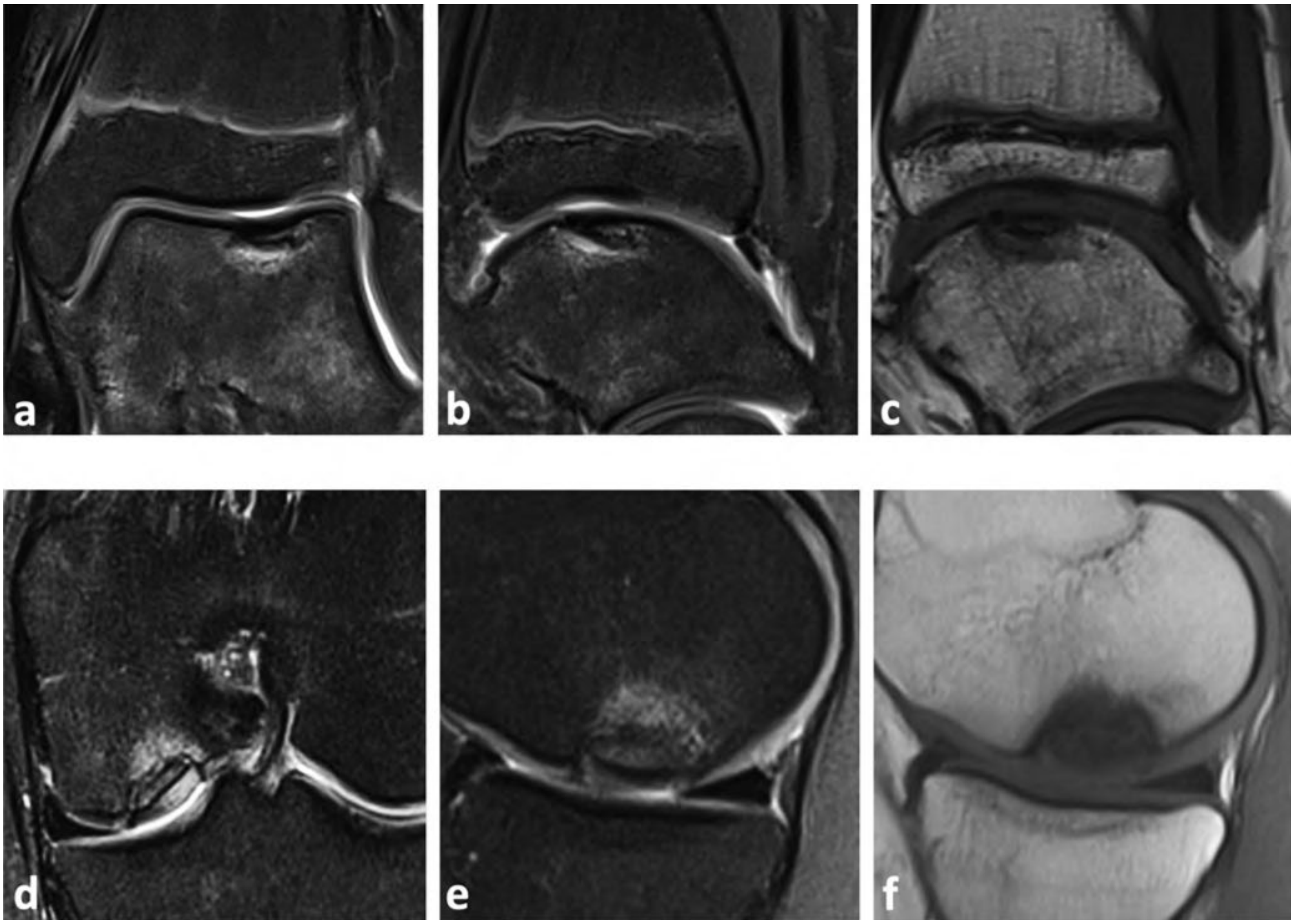


▶ **Fig. 9** Schematic representation of potential differential diagnosis for SIF (subchondral insufficiency fracture): CRPS 1 (complex regional pain syndrome type 1) as a diagnosis of exclusion in the absence of other morphological changes; OCD (osteochondritis dissecans) with particular demographic conditions; OA (osteoarthritis) associated with other specific radiological changes; ON (osteonecrosis) of systemic origin with typical risk factors; acute post-traumatic fracture with a recent history of trauma, and fatigue fracture with different demographics and specific overuse activities. The diagram shows various patterns of the bone marrow edema-like signal (depicted in nuances of red) in terms of extent and signal intensity (greater transparency indicating lower intensity). Diagram based on data from Breitenseher MJ et al., 2006 Figure 1 [47].

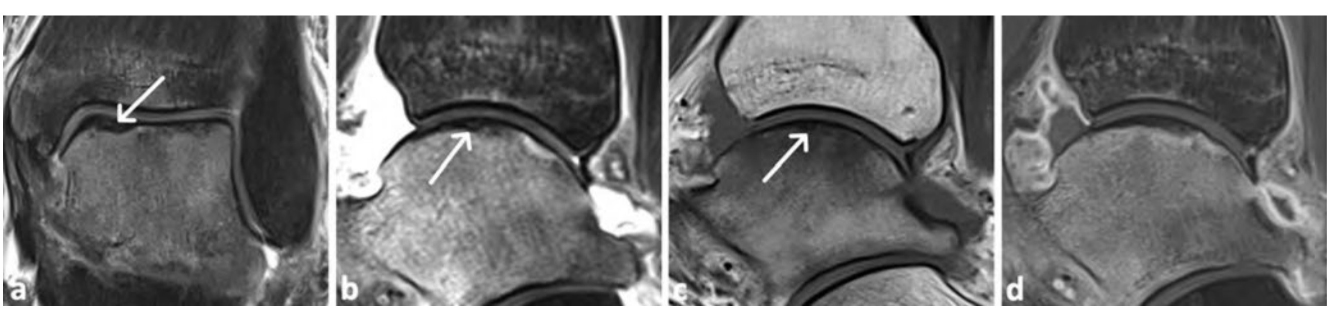
varies based on lesion size, mineralization, signs of instability, and the patient's skeletal maturity, ranging from lesions covered by intact cartilage to dislocated osteochondral fragments [1, 14]. The demographics of these two conditions differ, with SIF predominantly affecting the elderly, while OCD commonly occurs in childhood to young adulthood in the classic anatomic locations (lateral intercondylar aspect of medial femoral condyle, lateral femoral condyle, talus, capitellum, patella) [1, 14].

Treatment

In the early stages of subchondral insufficiency fractures, conservative treatment is the primary option. This includes practices such as protected weight-bearing, insole therapy, the use of nonsteroidal anti-inflammatory drugs, and, in some studies, consideration of bisphosphonates, prostacyclin, and more recently, teriparatide – an osteoporosis drug. If conservative management proves ineffective or in advanced cases with collapse, surgical intervention is chosen based on the size and progression of the lesion. Both MRI and radiographic assessments play a crucial role in the decision-making process for treatment [2, 3, 17, 50, 51].



▶ **Fig. 10** Two cases of osteochondritis dissecans (OCD). A 10-year-old male with OCD of the talus (top row, **a, b, c**). Coronal proton-density-weighted fat-suppressed **a**, sagittal T2-weighted fat-suppressed **b**, and sagittal T1-weighted **c** MR images show heterogeneous low signal of the subchondral bone fragment. A 27-year-old female tennis player with chronic OCD of the medial femoral condyle (bottom row, **d, e, f**). Coronal **d** and sagittal **e** proton-density-weighted fat-suppressed, and sagittal T1-weighted **f** MR images show an impacted osteochondral fragment with irregularities of the overlying cartilage and an adjacent bone marrow edema-like signal.



▶ **Fig. 11** SIF of the ankle. A 48-year-old man with sudden onset of ankle pain, without a traumatic event. Coronal proton-density-weighted fat-suppressed **a**, sagittal T2-weighted fat-suppressed **b**, sagittal T1-weighted **c**, and sagittal T1-weighted fat-suppressed post gadolinium **d** MRI images show a curvilinear hypointensity line (arrow in **b** and **c**), bone marrow edema-like signal and a hypointense subchondral area (arrow in **a**) without gadolinium enhancement **d**.

Conclusion

Detecting subchondral insufficiency fractures at the level of the hip, knee, and ankle may present challenges both clinically and radiologically. MRI plays an important role in accurately depicting even subtle subchondral fractures at the onset of the disease and proves valuable in the follow-up, prognosis, and differentiation of SIF from other conditions associated with an epiphyseal bone marrow edema-like signal. A comprehensive understanding of MRI features, in conjunction with the clinical and demographic context, enhances confidence in achieving an accurate diagnosis and aids in preventing confusion with other entities that may require different treatments. Further investigation to improve the identification and classification of high-risk SIF lesions is essential to determine optimal management strategies for this pathology.

Declarations

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Availability of data and material: The datasets used and/or analyzed during the study are available upon reasonable request.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] Gorbachova T, Melenevsky Y, Cohen M et al. Osteochondral Lesions of the Knee: Differentiating the Most Common Entities at MRI. Radiographics 2018; 38: 1478–1495. doi:10.1148/rg.2018180044

[2] Lee S, Saifuddin A. Magnetic resonance imaging of subchondral insufficiency fractures of the lower limb. Skeletal Radiol 2019; 48: 1011–1021. doi:10.1007/s00256-019-3160-4

[3] Chen M, Wang X, Takahashi E et al. Current Research on Subchondral Insufficiency Fracture of the Femoral Head. Clin Orthop Surg 2022; 14: 477–485. doi:10.4055/cios22175

[4] Kiuru MJ, Pihlajamaki HK, Ahovuo JA. Fatigue stress injuries of the pelvic bones and proximal femur: evaluation with MR imaging. Eur Radiol 2003; 13: 605–611. doi:10.1007/s00330-002-1562-4

[5] Thierfelder KM, Gerhardt JS, Langner S et al. Spezielle Aspekte bei Stressfrakturen. Radiologe 2020; 60: 506–513. doi:10.1007/s00117-020-00657-7

[6] Ahlbäck S, Bauer GC, Bohne WH. Spontaneous osteonecrosis of the knee. Arthritis Rheum 1968; 11: 705–733. doi:10.1002/art.1780110602

[7] Lecouvet FE, van de Berg BC, Maldague BE et al. Early irreversible osteonecrosis versus transient lesions of the femoral condyles: prognostic values of subchondral bone and marrow changes on MR imaging. AJR Am J Roentgenol 1998; 170: 71–77. doi:10.2214/ajr.170.1.9423603

[8] Lecouvet FE, Malghem J, Maldague BE et al. MR imaging of epiphyseal lesions of the knee: current concepts, challenges, and controversies. Radiol Clin North Am 2005; 43: 655–672. doi:10.1016/j.rcl.2005.02.002

[9] Yamamoto T, Bullough PG. Spontaneous osteonecrosis of the knee: the result of subchondral insufficiency fracture. J Bone Joint Surg Am 2000; 82: 858–866. doi:10.2106/00004623-200006000-00013

[10] Takeda M, Higuchi H, Kimura M et al. Spontaneous osteonecrosis of the knee: histopathological differences between early and progressive cases. J Bone Joint Surg Br 2008; 90: 324–329. doi:10.1302/0301-620X.90B3.18629

[11] Hatanaka H, Yamamoto T, Motomura G et al. Histopathologic findings of spontaneous osteonecrosis of the knee at an early stage: a case report. Skeletal Radiol 2016; 45: 713–716. doi:10.1007/s00256-016-2328-4

[12] Sayyid S, Younan Y, Sharma G et al. Subchondral insufficiency fracture of the knee: grading, risk factors, and outcome. Skeletal Radiol 2019; 48: 1961–1974. doi:10.1007/s00256-019-03245-6

[13] Husain R, Nesbitt J, Tank D et al. Spontaneous osteonecrosis of the knee (SONK): The role of MR imaging in predicting clinical outcome. J Orthop 2020; 22: 606–611. doi:10.1016/j.jor.2020.11.014

[14] Gorbachova T, Amber I, Beckmann NM et al. Nomenclature of Subchondral Nonneoplastic Bone Lesions. AJR Am J Roentgenol 2019; 213: 963–982. doi:10.2214/AJR.19.21571

[15] Palmer W, Bancroft L, Bona F at al. Glossary of terms for musculoskeletal radiology. Skeletal Radiol 2020; 49: 1–33. doi:10.1007/s00256-020-03465-1

[16] Malghem J, Lecouvet F, Vande Berg B et al. Subchondral insufficiency fractures, subchondral insufficiency fractures with osteonecrosis, and other apparently spontaneous subchondral bone lesions of the knee-pathogenesis and diagnosis at imaging. Insights Imaging 2023; 14: 164. doi:10.1186/s13244-023-01495-6

[17] Ochi J, Nozaki T, Nimura A et al. Subchondral insufficiency fracture of the knee: review of current concepts and radiological differential diagnoses. Jpn J Radiol 2022; 40: 443–457. doi:10.1007/s11604-021-01224-3

[18] Wilmot AS, Ruutiainen AT, Bakhru PT et al. Subchondral insufficiency fracture of the knee: a recognizable associated soft tissue edema pattern and a similar distribution among men and women. Eur J Radiol 2016; 85: 2096–2103. doi:10.1016/j.ejrad.2016.08.016

[19] Farrell TP, Deely DM, Zoga AC et al. Lateral femoral condyle insufficiency fractures: imaging findings, demographics, and analysis of outcomes. Skeletal Radiol 2021; 50: 189–199. doi:10.1007/s00256-020-03548-z

[20] Iwasaki K, Yamamoto T, Nakashima Y et al. Subchondral insufficiency fracture of the femoral head after liver transplantation. Skeletal Radiol 2009; 38: 925–928. doi:10.1007/s00256-009-0706-x

[21] Yamamoto T, Schneider R, Iwamoto Y et al. Subchondral insufficiency fracture of the femoral head in a patient with systemic lupus erythematosus. Ann Rheum Dis 2006; 65: 837–838. doi:10.1136/ard.2005.041095

[22] Fotiadou A, Karantanas A. Acute nontraumatic adult knee pain: the role of MR imaging. Radiol Med 2009; 114: 437–447. doi:10.1007/s11547-009-0380-z

[23] Wilson AJ, Murphy WA, Hardy DC et al. Transient osteoporosis: transient bone marrow edema? Radiology 1988; 167: 757–760. doi:10.1148/radiology.167.3.3363136

[24] Kosaka H, Maeyama A, Nishio J et al. Histopathologic evaluation of bone marrow lesions in early stage subchondral insufficiency fracture of the medial femoral condyle. Int J Clin Exp Pathol 2021; 14: 819–826

[25] Eriksen EF, Ringe JD. Bone marrow lesions: a universal bone response to injury? Rheumatol Int 2012; 32: 575–584. doi:10.1007/s00296-011-2141-2

[26] Musbahi O, Waddell L, Shah N et al. Subchondral Insufficiency Fractures of the Knee: A Clinical Narrative Review. JBJS Rev 2023; 11. doi:10.2106/JBJS.RVW.23.00084

[27] Reddy AS, Frederick RW et al. Evaluation of the intraosseous and extraosseous blood supply to the distal femoral condyles. Am J Sports Med 1998; 26: 415–419. doi:10.1177/03635465980260031201

[28] Björkengren AG, AlRowaih A, Lindstrand A et al. Spontaneous osteonecrosis of the knee: value of MR imaging in determining prognosis. AJR Am J Roentgenol 1990; 154: 331–336. doi:10.2214/ajr.154.2.2105026

[29] Yamamoto T, Bullough PG et al. The role of subchondral insufficiency fracture in rapid destruction of the hip joint: a preliminary report. Arthritis Rheum 2000; 43: 2423–2427

[30] Iwasaki K, Yamamoto T, Motomura G et al. Common site of subchondral insufficiency fractures of the femoral head based on three-dimensional magnetic resonance imaging. Skeletal Radiol 2016; 45: 105–113. doi:10.1007/s00256-015-2258-6

[31] Boutry N, Paul C, Leroy X et al. Rapidly destructive osteoarthritis of the hip: MR imaging findings. AJR Am J Roentgenol 2002; 179: 657–663. doi:10.2214/ajr.179.3.1790657

[32] Woertler K, Neumann J. Atraumatic Bone Marrow Edema Involving the Epiphyses. Semin Musculoskelet Radiol 2023; 27: 45–53. doi:10.1055/s-0043-1761498

[33] Ikemura S, Yamamoto T, Motomura G et al. MRI evaluation of collapsed femoral heads in patients 60 years old or older: Differentiation of subchondral insufficiency fracture from osteonecrosis of the femoral head. AJR Am J Roentgenol 2010; 195: W63–W68. doi:10.2214/AJR.09.3271

[34] Ikemura S, Mawatari T, Matsui G et al. The depth of the low-intensity band on the T1-weighted MR image is useful for distinguishing subchondral insufficiency fracture from osteonecrosis of the collapsed femoral head. Arch Orthop Trauma Surg 2018; 138: 1053–1058. doi:10.1007/s00402-018-2948-3

[35] Miyanishi K, Kaminomachi S, Hara T et al. A subchondral fracture in transient osteoporosis of the hip. Skeletal Radiol 2007; 36: 677–680. doi:10.1007/s00256-006-0248-4

[36] Miyanishi K, Yamamoto T, Nakashima Y et al. Subchondral changes in transient osteoporosis of the hip. Skeletal Radiol 2001; 30: 255–261. doi:10.1007/s002560100350

[37] Karantanas AH, Nikolakopoulos I, Korompilias AV et al. Regional migratory osteoporosis in the knee: MRI findings in 22 patients and review of the literature. Eur J Radiol 2008; 67: 34–41. doi:10.1016/j.ejrad.2008.01.054

[38] Moosikasuwan JB, Miller TT, Math K et al. Shifting bone marrow edema of the knee. Skeletal Radiol 2004; 33: 380–385. doi:10.1007/s00256-004-0783-9

[39] Lotke PA, Nelson CL, Lonner JH. Spontaneous osteonecrosis of the knee: tibial plateaus. Orthop Clin N Am 2004; 35: 365–370. doi:10.1016/j.ocl.2004.02.009

[40] Hussain ZB, Chahla J, Mandelbaum BR et al. The Role of Meniscal Tears in Spontaneous Osteonecrosis of the Knee: A Systematic Review of Suspected Etiology and a Call to Revisit Nomenclature. Am J Sports Med 2019; 47: 501–507. doi:10.1177/0363546517743734

[41] Yamagami R, Taketomi S, Inui H et al. The role of medial meniscus posterior root tear and proximal tibial morphology in the development of spontaneous osteonecrosis and osteoarthritis of the knee. Knee 2017; 24: 390–395. doi:10.1016/j.knee.2016.12.004

[42] Yao L, Stanczak J, Boutin RD. Presumptive subarticular stress reactions of the knee: MRI detection and association with meniscal tear patterns. Skelet Radiol 2004; 33: 260–264. doi:10.1007/s00256-004-0751-4

[43] Hashimoto S, Terauchi M, Hatayama K et al. Medial meniscus extrusion as a predictor for a poor prognosis in patients with spontaneous osteonecrosis of the knee. Knee 2021; 31: 164–171. doi:10.1016/j.knee.2021.06.003

[44] Barras LA, Pareek A, Parkes CW et al. Post-arthroscopic Subchondral Insufficiency Fractures of the Knee Yield High Rate of Conversion to Arthroplasty. Arthroscopy 2021; 37: 2545–2553. doi:10.1016/j.arthro.2021.03.029

[45] Allam E, Boychev G, Aiyedipe S et al. Subchondral insufficiency fracture of the knee: unicompartmental correlation to meniscal pathology and degree of chondrosis by MRI. Skeletal Radiol 2021; 50: 2185–2194. doi:10.1007/s00256-021-03777-w

[46] Vidoni A, Shah R, Mak D et al. Metaphyseal burst sign: A secondary sign on MRI of subchondral insufficiency fracture of the knee. J Med Imaging Radiat Oncol 2018; 62: 764–768. doi:10.1111/1754-9485.12781

[47] Breitenseher MJ, Kramer J, Mayerhoefer ME et al. Differenzialdiagnosen des Knochenmarködems am Kniegelenk. Radiologe 2006; 46: 46–54. doi:10.1007/s00117-005-1304-0

[48] Rios AM, Rosenberg ZS, Bencardino JT et al. Bone marrow edema patterns in the ankle and hindfoot: distinguishing MRI features. AJR Am J Roentgenol 2011; 197: W720–W729. doi:10.2214/AJR.10.5880

[49] Long NM, Zoga AC, Kier R et al. Insufficiency and nondisplaced fractures of the talar head: MRI appearances. AJR Am J Roentgenol 2012; 199: W613–W617. doi:10.2214/AJR.11.7313

[50] Bonadio MB, Filho AGO, Helito CP et al. Bone Marrow Lesion: Image, Clinical Presentation, and Treatment. Magn Reson Insights 2017; 10: 1–6. doi:10.1177/1178623x17703382

[51] Sibilska A, Góralczyk A, Hermanowicz K et al. Spontaneous osteonecrosis of the knee: what do we know so far? A literature review. Int Orthop 2020; 44: 1063–1069. doi:10.1007/s00264-020-04536-7

