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Axial Skeleton Bone Marrow Changes in Inflammatory Rheumatologic Disorders

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Abstract

Magnetic resonance imaging (MRI) of the axial skeleton, spine, and sacroiliac (SI) joints is critical for the early detection and follow-up of inflammatory rheumatologic disorders such as axial spondyloarthritis, rheumatoid arthritis, and SAPHO/CRMO (synovitis, acne, pustulosis, hyperostosis, and osteitis/chronic recurrent multifocal osteomyelitis). To offer a valuable report to the referring physician, disease-specific knowledge is essential. Certain MRI parameters can help the radiologist provide an early diagnosis and lead to effective treatment. Awareness of these hallmarks may help avoid misdiagnosis and unnecessary biopsies. A bone marrow edema-like signal plays an important role in reports but is not disease specific. Age, sex, and history should be considered in interpreting MRI to prevent overdiagnosis of rheumatologic disease. Differential diagnoses—degenerative disk disease, infection, and crystal arthropathy—are addressed here. Whole-body MRI may be helpful in diagnosing SAPHO/CRMO.

Keywords

- spondyloarthritis
- magnetic resonance imaging
- sacroiliitis
- SAPHO
- inflammatory rheumatologic disease

The two major inflammatory diseases affecting the axial skeleton, spine, and sacroiliac (SI) joints are spondyloarthritis (SpA) and rheumatoid arthritis (RA). Advances in the treatment of inflammatory rheumatologic disorders have had an impact on radiology practices. Conventional radiographs are performed as a baseline imaging method in inflammatory disorders: axial spondyloarthritis (axSpA), RA, and SAPHO/CRMO (synovitis, acne, pustulosis, hyperostosis, and osteitis/chronic recurrent multifocal osteomyelitis). However, advanced imaging modalities provide a higher sensitivity to detect inflammation than physical examination and radiographs. MRI is used because it can detect bone marrow edema (BME)-like signal changes.[1] BME is important in detecting early disease and in the follow-up of treatment. The radiologist needs disease-specific knowledge to provide a practical report for the clinician. In addition, attention must be paid to a differential diagnosis. This overview may help determine a correct diagnosis and avoid unnecessary invasive procedures with a focus on MRI of the axial skeleton.

This article (1) describes the MRI findings of the spine and SI joints in inflammatory rheumatologic diseases with a focus on SpA, (2) addresses the role in diagnosis and management of (whole-body) MRI in SAPHO including inflammatory rheumatologic disease in children (chronic recurrent multifocal osteomyelitis [CRMO]), and (3) identifies parameters for a differential diagnosis, such as degenerative disk disease, infection, and crystal arthropathy.

Histology of Bone Marrow Edema

In inflammatory arthritides, BME-like signal is an important MR feature. It is visualized in early as well as late disease and used for early diagnosis and follow-up of treatment. The term BME is used for areas within bone of high signal intensity on fat-suppressed fluid-sensitive sequences and low signal intensity

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on T1-weighted turbo spin-echo (TSE) sequences (T1TSE). Several studies have shown that BME is depicted equally on T2 fat-saturated (FS) or short tau inversion recovery (STIR) versus gadopentetate dimeglumine (Gd)-chelate enhanced T1TSE sequences with frequency-selective fat saturation (T1Gd).[1–5]

Interestingly, BME is not disease specific and seen in orthopaedic diagnoses (e.g., osteoarthritis, stress fractures, or bone bruises) and rheumatologic diseases as early arthritis and RA.[2–5] In ankylosing spondylitis, bone biopsy of the zygapophyseal joints was performed and showed osteitis in correspondence to BME on MRI.[6] In RA, the histology of BME represents osteitis, featuring a vascular lymphocytic infiltrate with replacement of marrow fat and sometimes an associated cortical break (erosion).[7–9]

BME lesions in osteoarthritis are somewhat different histologically, featuring marrow fat necrosis, fibrosis, and healing trabecular microfractures as described by Zanetti et al[10] and Taljanovic et al.[11] In a study correlating MRI and histology, BME cannot be reliably distinguished from osteomyelitis. Active inflammatory osteitis replaces the normal marrow fat. Using Gd improved the delineation of soft tissue inflammatory masses.[12] In SAPHO syndrome, sterile inflammatory osteitis is believed secondary to low-virulence pathogens, triggering an exaggerated autoimmune inflammatory bone marrow response in genetically susceptible individuals, leading to a form of "reactive osteitis."[13] Thus BME is seen in several conditions and aspecific.

Magnetic Resonance Imaging Protocol

- For inflammatory rheumatic diseases of the spine, a standard protocol includes sagittal T1TSE and fat-suppressed fluid-sensitive sequences (such as STIR, T2FS, or Dixon water) in the sagittal plane (C2–T11;T8–S1).[14]
- For the SI joint, coronal oblique T1TSE sequence and fat-suppressed fluid-sensitive sequences are recommended. The axis of the sacrum on the scout view is used as a reference; slices are parallel to the dorsal surface of the S2 vertebra.[15] An axial oblique fat-suppressed fluid-sensitive sequence can be more valuable for the exact localization of findings and differential diagnosis. A coronal oblique sequence to detect erosions of the articular surface might be added (such as a three-dimensional [3D] T1TSE fat-suppressed sequence).[14] Intravenous contrast has no additional value in the detection of BME.[2,14,16] It is only used whenever an infectious spondylodiskitis or sacroiliitis is suspected clinically.
- Modified Dixon series have shown good performance in axSpA of the SI joints compared with T1TSE and STIR images and might also be used.[1,17] The modification of Dixon techniques now allows high-resolution high-contrast water and/or fat images in a time-efficient way.[18] The advantage is the short acquisition time and less susceptibility to artifacts.[1]
- In children with CRMO, whole-body MRI is performed using standard T1TSE and STIR sequences in the coronal plane with additional sagittal imaging of the spine. It reveals more lesions compared with limited axial (lumbar and pelvic) studies, especially in the thoracic spine and thoracic wall, pelvic and shoulder girdles, and peripheral entheses and joints.[19]
- Diffusion-weighted imaging plays no role in inflammatory diseases unless a malignancy is in the differential diagnosis.

Spondyloarthritis

SpA, Axial SpA, and Peripheral SpA

The clinical diagnosis of spondyloarthritis (SpA) is challenging. Chronic low back pain is a common complaint in the general population, and only a small percentage has inflammatory back pain (> 3 months, morning stiffness, response to nonsteroidal anti-inflammatory drugs), and not all of these patients have SpA.

SpA includes a group of inflammatory rheumatic diseases that are clinically and genetically related. Classically, these disorders comprise ankylosing spondylitis (AS), psoriatic arthritis, reactive arthritis, arthritis associated with inflammatory bowel disease, and a group of patients with undifferentiated arthritis.[20] Genetically, the diseases are associated with the major histocompatibility complex class 1 antigen HLA-B27, and clustering in families is seen.

Involvement of the axial skeleton manifests as spondylitis and sacroiliitis (uni-or bilaterally). The peripheral articular manifestations include enthesitis, dactylitis, and arthritis. In addition, extra-articular expression of inflammation may be present in the skin (psoriasis), bowel, and uvea.[21] To characterize these patients, two groups are defined: one with a dominant involvement of the spine and SI joints called axial spondyloarthritis (axSpA) and another with a preference for peripheral joint inflammation called peripheral SpA.[22] This classification into axial and peripheral SpA helps with earlier detection of patients with inflammatory back pain and early treatment options.[23,24]

Early treatment decreases pain and stiffness and also prevents structural damage over time, under investigation by the Assessment in SpondyloArthritis international Society (ASAS) and others.[21] The axial skeleton is the focus of this article, and AS is the prototype of axSpA, discussed here. The incidence peaks between 20 and 40 years, evenly divided between male and female patients. The average delay in diagnosis is 9 years.[25] The prevalence of AS is generally believed to be between 0.1% and 1.4% globally.[26]

Thus the early diagnosis of axSpA is a challenge, and the ability to show BME makes MRI a useful imaging modality.

Magnetic Resonance Imaging

AxSpA affects the synovial joints, cartilaginous joints, and the entheses. Early findings are most often found at the SI joints and the thoracolumbar and lumbosacral junction. Significant changes in the spine are usually seen combined with SI joint involvement. When in doubt, it is useful to extend the MRI protocol of the spine to the SI joints. In screening for axSpA, MRI of the SI joints may be sufficient.[27]

Enthesitis

For MRI, inflammation of the enthesis (enthesitis) as a hallmark of axSpA must be appreciated. Entheses are the insertion sites of tendons and ligaments to the bone surface. In addition, "functional" or articular "fibrocartilaginous" entheses may be distinguished conceptually.[28] The understanding of enthesitis remains limited, as recently summarized in a review article.[29]

Osteitis refers to the inflammation of bone and may include the cortex, the medullary cavity, or both. In the spine, the earliest inflammatory sign is BME, typically at the site of the enthesis.[21,29,30]

Inflammation of tendon and ligamentous insertions leads to a cascade of secondary changes in soft tissue and bone.[31] On radiographs of the spine, for example, chronic changes associated with enthesitis can be detected as erosions, paravertebral ossifications (syndesmophytes) with ankylosis as an end stage. These syndesmophytes can be differentiated from degenerative spondylophytes based on their origin and growth.[32] On radiographs of the SI joints, subchondral erosions, sclerosis, and ankylosis can be appreciated, and the modified New York criteria were developed to classify patients with structural damage of the SI joints.[33]

Magnetic Resonance Imaging of SI Joints

Sacroiliitis is the hallmark of axSpA. The imaging parts of SI joint involvement are divided into active inflammatory lesions and structural (chronic) changes,[21,34] and SI involvement can present as asymmetric and unilateral SI inflammation in early disease, all the way to bilateral ankylosis.

Acute inflammatory lesions: BME: Typical axSpA BME lesions are located in the subchondral and periarticular area of the SI joint[15] (►**Fig. 1**). Typical BME lesions for the diagnosis of sacroiliitis are multifocal, on multiple surfaces (either uni- or bilateral), present on multiple slices, and usually associated with multiple other SpA findings.[34,35]

Enthesitis: Inflammation at the attachment of tendons and ligaments to bone is defined as increased signal on fat-suppressed fluid-sensitive images in soft tissues and/or bone. Examples are the hamstring insertion on the tuber ischiadicum, gluteus muscle insertion on the pelvis, or the insertion of the ligamentous part of the SI joints.[36]

Capsulitis: Inflammation of the capsule of the joint, defined as increased signal on fat-suppressed fluid-sensitive images in the perimeter of the joint. This is a specific finding in the clinical setting of SpA, however rarely seen, thus of low sensitivity.[37]

Synovitis: Enhancement of the periphery of the joint cavity after intravenous gadolinium injection.

Joint space fluid: Increased signal in the SI joint cavity on fat-suppressed fluid-sensitive images.

Structural chronic lesion: Erosions: Defined as a defect in the subchondral bone with loss of the dark signal of the subchondral bone plate. Erosions are best detected on T1-weighted or (3D) T1TSE fat-suppressed sequences, and they may be seen with surrounding BME on fat-suppressed fluid-sensitive sequences representing active erosions.[38]

Subchondral sclerosis: Defined as a subchondral area of decreased signal on both T1-weighted and fat-suppressed fluid-sensitive sequences (►**Fig. 1**).

Fatty conversion of bone marrow (fat lesions/fatty repair): Subchondral high signal on T1-weighted sequence, low signal on fat-suppressed sequences (►**Fig. 1**).[39,40]

Bony bridges and ankylosis: Continuity of the high signal on T1-weighted sequences similar to bone marrow signal between two bones with loss of the low signal of the cortex. Bony appositions, end-stage disease with union across a joint.

Magnetic Resonance Imaging of the Spine

Acute inflammatory lesions: Enthesitis and osteitis are seen as BME at the insertion sites typically involving the anterior corners of the vertebral body (►**Fig. 2**).

Structural (chronic) changes: Erosions, fatty lesions (repair), or sclerosis of anterior vertebral corners (►**Fig. 2**).

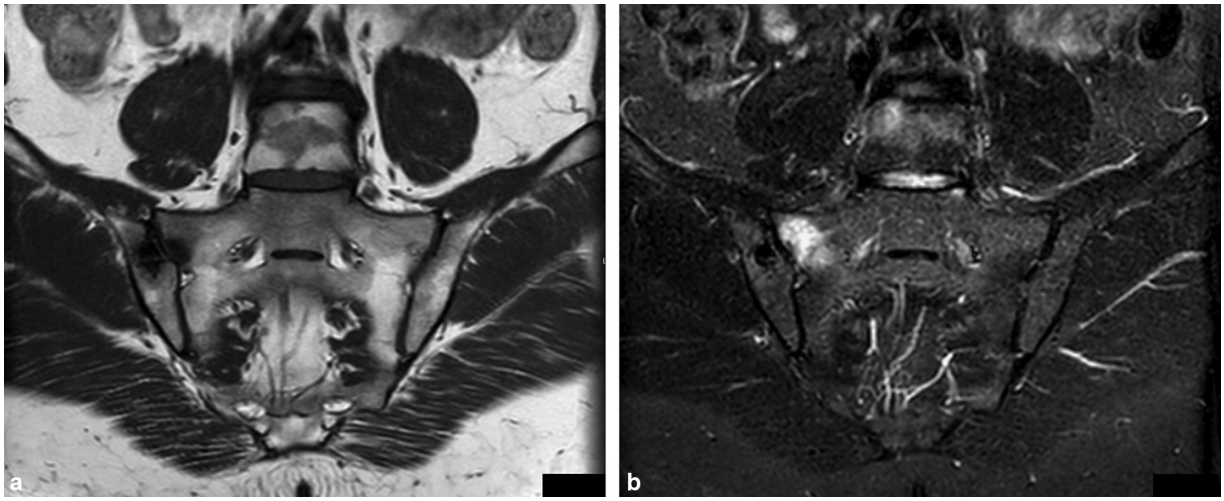

Fig. 1 Chronic sacroiliitis with active component. (**a**) Coronal oblique T1-weighted turbo spin-echo (T1TSE) and (**b**) short tau inversion recovery (STIR) images of the sacroiliac (SI) joints of a 38-year-old man with axial spondyloarthritis (axSpA). The right SI joint shows focal low signal intensity on T1TSE, consistent with subchondral sclerosis at the iliac side (low on STIR) and bone marrow edema (BME) at the sacral side (high on STIR). Fatty replacement is seen at the sacral side of both SI joints. Note the BME and fatty lesions in L5.

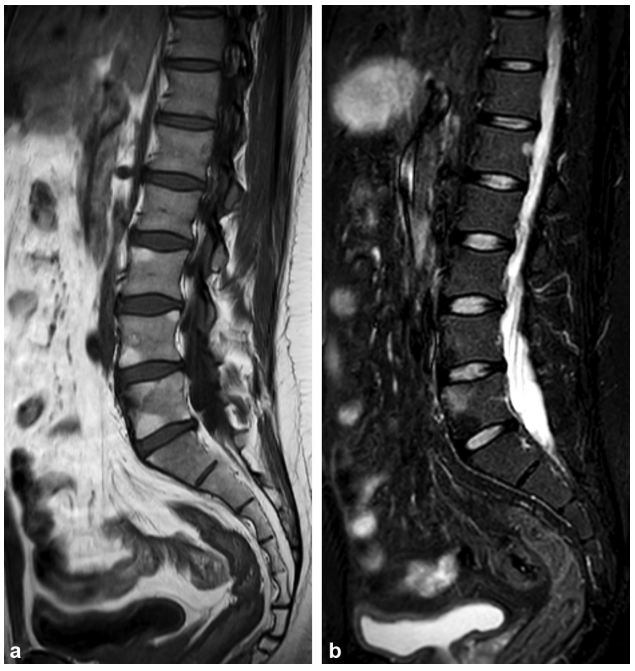

Fig. 2 (**a**) Sagittal T1-weighted turbo spin-echo (T1TSE) and (**b**) short tau inversion recovery (STIR) images of the lumbar spine of the same patient with axial spondyloarthritis as in ►**Fig. 1**. Multiple fatty lesions are present at the anterior and posterior corners of the end plates L3–S1. Bone marrow edema is present in the anterior corner of L5 consistent with active disease. Note the normal high signal intensity of the disks on STIR.

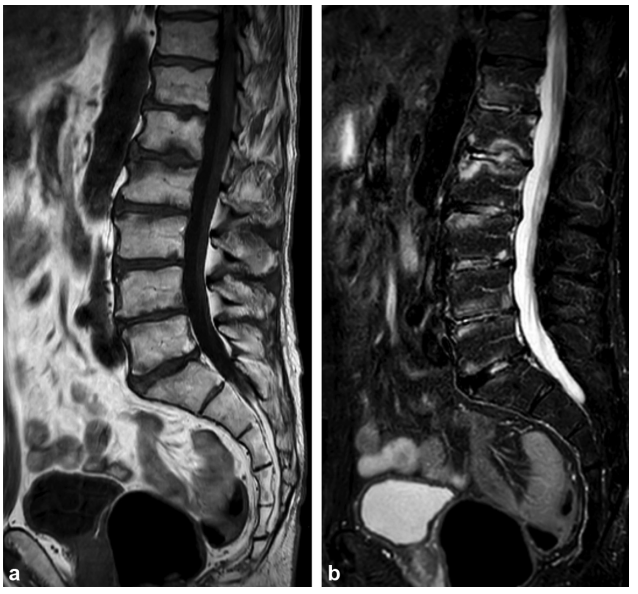

Fig. 3 (**a**) Sagittal T1-weighted turbo spin-echo (T1TSE) and (**b**) short tau inversion recovery images (STIR) of the lumbar spine in a 70-year-old man with axial spondyloarthritis with structural lesions and active disease. The anterior end plates show erosions. All end plates show irregularities and disk height loss with bone marrow edema.

Erosions can also be diskovertebral at the site of the cartilage. In more advanced stages, syndesmophytes are formed and ankylosis is seen.

Vertebral corner inflammatory lesions, central inflammatory lesions (non-corner lesions), and BME in the lateral spinal segment (pedicle, costotransverse, and costovertebral joint) are characteristic of SpA[41] (►**Fig. 3**).

Lesions in the spine associated with axSpA are well documented. Scoring methods have been developed and used in research.[34]

Rheumatoid Arthritis

RA is a chronic systemic inflammatory immune-mediated disease characterized by symmetrical polyarthritis. RA affects 0.5% to 1% of adults. The disorder is typical in women (female-to-male ratio is 3:1) and older adults. Without treatment, erosive joint destruction leads to deformation of joints. Disease-modifying antirheumatic drugs reduce synovitis and systemic inflammation and improve function.[42] Due to the availability of effective medication, earlier disease detection, and early treatment, chronic RA changes and the disease burden have significantly decreased.[43] In early disease, a variety of symptoms may be present, and no single sign or symptom is specific for RA. The diagnosis is based on more investigations and pattern recognition.[44]

Synovitis

RA is a disease of the synovium, and the hallmark is synovitis. MRI of the hand and feet shows the earliest signs of disease (tenosynovitis, synovitis, and BME) and helps identify patients who will develop RA among those presenting with undifferentiated arthritis (UA), according to European Alliance of Associations for Rheumatology recommendations. A recent large cohort study showed that MRI is most valuable in anti-citrullinated protein antibody–negative UA patients with oligoarthritis; a negative MRI could help prevent overtreatment.[45] Short MRI protocols are under investigation for implementation of RA screening.[1] The presence of persistent BME is strongly associated with secondary erosion of that specific bone.[46]

Magnetic Resonance Imaging of the Spine

RA involvement of the cervical spine, especially the atlantoaxial joint, has been an important indication for MRI. It is usually performed to assess the presence of inflammation and possible complications. The synovial proliferation, also called pannus formation, causes BME, dens erosions, ligamentous destruction, and horizontal atlantoaxial subluxation, as well as subaxial subluxation. Synovitis of the apophyseal and/or uncovertebral joints can cause instability at the C2–T1 level, resulting in the so-called stepladder phenomenon. Of special interest are the identification of potential neurologic complications including cord compression and vertical atlantoaxial subluxation with a basilar impression.[47,48] SI joint involvement is late in RA, and MRI of the SI joints has limited value.

SAPHO and CRMO

SAPHO, an acronym for a syndrome combining synovitis, acne, pustulosis, hyperostosis, and osteitis, is an inflammatory

clinical condition with aseptic osteoarticular involvement and characteristic skin lesions. The age at presentation varies from children to adults, and a wide variety of clinical and imaging findings can be appreciated, depending on the stage of the disease.[49] SAPHO is an umbrella term for a collective group of disorders, including CRMO in children (first 2 decades of life), with a predilection for the metaphysis of the long bones, and in the fourth to sixth decade of life sternoclavicular hyperostosis.[49]

SAPHO is considered a chronic relapsing inflammatory and rare disease with an unknown prevalence. Because of confusing symptoms and lack of skin involvement, it is probably underestimated.[50] Osteoarticular manifestations of the SAPHO syndrome are synovitis, hyperostosis, and osteitis. Synovitis is commonly seen in the anterior chest wall (sternoclavicular, costoclavicular, and manubriosternal joints). but (unilateral) sacroiliitis may also be observed. The most important hallmarks, however, include hyperostosis and osteitis, and main targets are the anterior chest wall, spine, and peripheral skeleton. In the presence of typical bone lesions at characteristic sites, the diagnosis is straightforward; however, the atypical sites and absence of skin involvement can make it more difficult.[51]

Magnetic Resonance Imaging of the Spine

The spine is often involved (32–52% of all adult patients), and all vertebrae from midcervical to the sacrum can be affected, with a preference for the thoracolumbar spine. In a review article, Leone et al revisited the SAPHO syndrome with a focus on the spine. The axial skeleton manifestations of SAPHO can take six forms and occur in various combinations[51] (►**Fig. 4**). These include *acute inflammatory lesions* and *structural (chronic) changes.*

- Vertebral body corner lesions (enthesitis)
- Nonspecific spondylodiskitis, mimicking infectious spondylodiskitis (in the early stages, anterior and central part of one end plate with a normal intervertebral disk space)
- Vertebral body BME (osteitis) and microfractures; the development of osteolytic lesions with variable degrees of vertebral body collapse (adults and children)
- Osteosclerosis of one or more vertebral bodies with the development of hyperostosis
- Paravertebral ossification (somewhat similar to psoriatic SpA)
- Sacroiliitis (unilaterally; predominantly in adults)

SAPHO syndrome has overlapping features with seronegative spondyloarthropathies. In a comparative analysis, whole-spine MRI was used to differentiate SAPHO syndrome and SpA.[52] It showed that contiguous involvement of BME in the anterior spinal corner, concurrent bone erosion of the anterior thoracic wall and mobile spine, spondylodiskitis, and paravertebral soft tissue thickening were significant factors in distinguishing between the two groups, favoring the diagnosis of SAPHO. McGauvran et al reported a semicircular pattern of contiguous vertebral body BME was seen in 63% of SAPHO patients.[53]

In a 2022 review article by Shah et al, spine involvement of patients diagnosed with CRMO had a high morbidity and was reported in 19 to 30% of cases; moreover, it can lead to kyphosis, scoliosis, and impairment of growth. Early diagnosis and treatment can prevent the spinal deformity mentioned in 22 to 33% of patients.[54] For the differential diagnosis, several imaging signs are useful. An associated soft tissue mass is not seen in CRMO but can be a

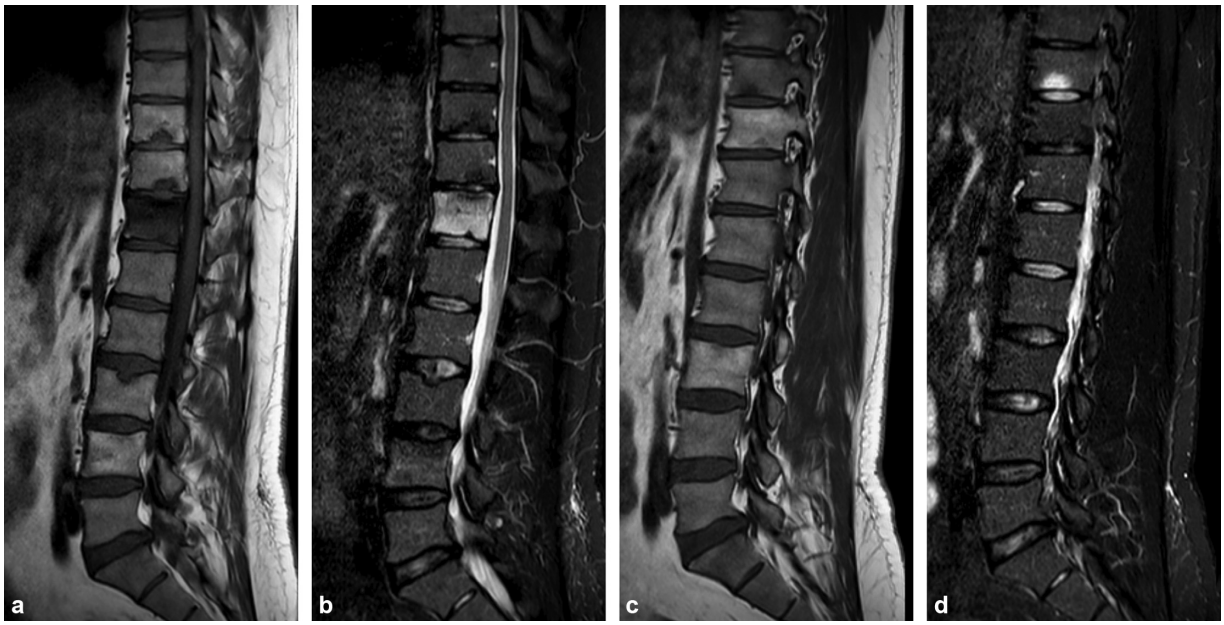

Fig. 4 Sagittal T1-weighted turbo spin-echo (T1TSE) and short tau inversion recovery (STIR) images (a,b after two years; c,d at baseline). (**c, d**) Showing the chronic inflammatory pattern of relapsing osteitis in a 43-year-old man with SAPHO. The bone marrow edema (BME) in vertebra T12 is new (b); multiple end plates developed irregular height loss (a, b). Note the previous BME in end plate T10.

Table 1 Characteristics of inflammatory rheumatologic disorders

	AxSpA	RA	SAPHO SCCH	CRMO
Age	20-40 y	> 60 y	40-60y	10-20y
Gender	F = M	F:M= 3:1	F > M	F:M- 4:1
Clinical symptoms	Inflammatory Back Pain	Poly-arthritis	Aspecific pain of site involved +/- skin diseasev	Aspecific pain of site involved +/- fever
Prevalence	0.1-1.4% population	0.5-1% population	unknown-rare	unknown
SI joint	earliest	late	unilateral	unilateral
Spine	early	late	early (30-50%)	early (+/- 30%)
Spine level	thoracolumbar / lumbosacral	cervical	thoracolumbar	thoracic

Abbreviations: AxSpA, axial spondyloarthritis; RA, rheumatoid arthritis; SAPHO, synovitis, acne, pustulosis, hyperostosis and osteitis; SCCH, sternoclavicular hyperostosis; CRMO, chronic recurrent multifocal osteomyelitis.

presentation of Langerhans cell histiocytosis or a primary small round cell tumor (lymphoma, Ewing's sarcoma).

The involvement of the intervertebral disk is uncommon in CRMO, and the extension into adjacent end plates including abscess formation suggests (septic) spondylodiskitis.[54] Juvenile idiopathic arthritis or axSpA need to be considered.[52,53] The intervertebral disk is generally preserved in a vertebral fracture. Kyphosis secondary to multilevel wedging of thoracic vertebrae with osteochondrosis of the end plates without BME may lead to the diagnosis of Scheuermann's disease.[54] Whole-body MRI, including coronal T1-weighted and STIR images, as well as sagittal whole spine, is used to evaluate multifocal bone lesions, assessing (asymptomatic) disease activity, and in follow-up.[52,55]

►**Table 1** lists the characteristics of the discussed inflammatory disorders.

Differential Diagnosis of Inflammatory Rheumatologic Disorders

Spine

Combining clinical findings, history, and age with specific findings on MRI is essential. The diskovertebral complex has a uniform response to different external factors.

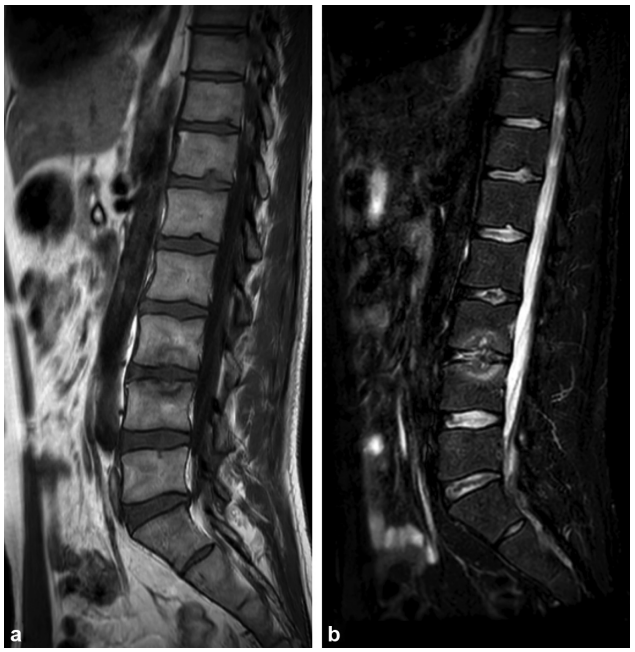

Fig. 5 A 30-year-old male patient with low back pain and no axial spondyloarthritis. (a) Sagittal T1TSE and (b) STIR images. Single-level finding of Schmorl's nodes with a rim of bone marrow edema at end plates L3–L4. The disk shows a normal signal intensity, similar to the other levels, and some decrease in height. The nuclear cleft sign is present, favoring degenerative change. Magnetic resonance imaging (MRI) of sacroiliac joints is normal. The differential diagnosis on spine MRI alone is inflammatory spondylodiskitis.

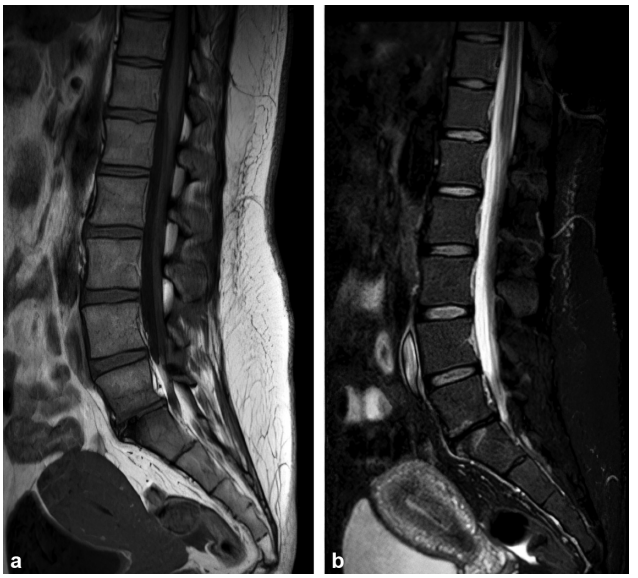

Fig. 6 (**a**) Sagittal T1-weighted turbo spin-echo (T1TSE) and (**b**) short tau inversion recovery (STIR) images of the lumbar spine in a 31-year-old female patient with low back pain. Level L5–S1 shows disk space loss and low disk signal intensity on STIR. The anterior part of the end plates shows adjacent bone marrow edema with reactive bone formation. Image is consistent with Modic type 1 changes.

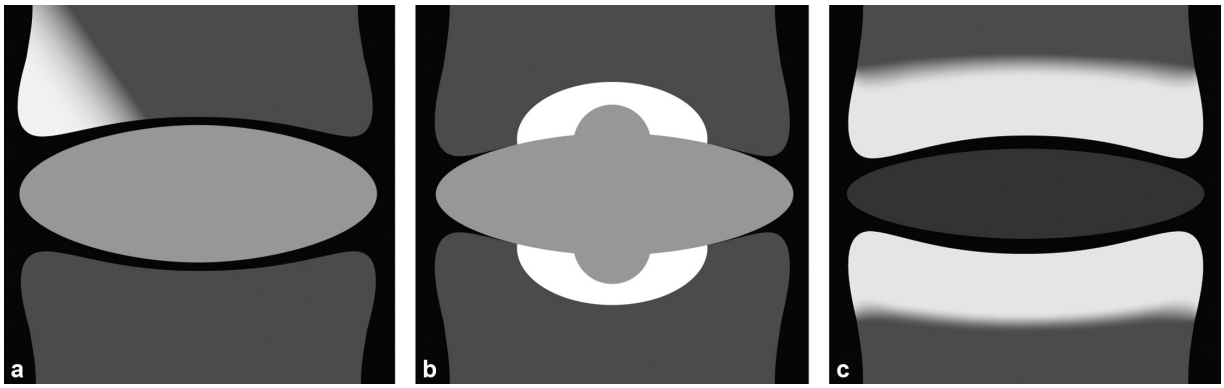

Fig. 7 Drawings of a vertebral unit on short tau inversion recovery images. White is bone marrow edema on a background of normal gray fat-suppressed bone marrow. (**a**) Axial spondyloarthritis: single-sided bone marrow edema (BME) at the anterior end plate with a normal hydrated disk. (**b**) Schmorl's node centrally located with a zone of BME: normal hydrated disk. (**c**) Modic type 1 degenerative disk disease: dehydrated disk with adjacent BME that can extend over the whole length of both end plates.

Degenerative Changes (Degenerative Disk Disease)

Physiologic changes in the spine are seen as young as 16 years.[56] Common findings include Schmorl's nodes with or without BME, disk space loss, and secondary vertebral end-plate changes (►**Figs. 5** and **6**). Schmorl's nodes correspond to herniation of nucleus material through the end plate of the vertebral bodies into the subchondral bone[27] (►**Fig. 5**). End-plate changes are classified by Modic types based on the presence of BME (type 1) (►**Fig. 6**), fatty change (type 2), and sclerosis (type 3), respectively.[57] In two large spondyloarthritis studies, SPACE (SpondyloArthritis Caught Early) and DESIR (DEvenir des Spondylarthropathies Indifférenciées Récentes), including patients with short-term inflammatory back pain, the prevalence of degenerative changes of the spine on MRI and radiographs was assessed.[56,58] Degenerative changes were found in respectively 245 of 274 (89%) and 456 of 648 patients (70.4%), and trained readers made the distinction between degenerative changes and axSpA lesions.[49,56] Schmorl's nodes had a high prevalence, most often found in the lower thoracic spine, and only a small number were surrounded by BME. BME due to osteitis in axSpA was not misinterpreted by the degenerative readers. Knowledge of the definitions in the literature was of significant help, and in case of doubt, the distribution pattern. In the lower lumbar spine, degenerative disorders were predominantly seen, whereas axSpA lesions were present in the whole spine[58] (►**Fig. 7**) (►**Table 2**).

Diffuse Idiopathic Skeletal Hyperostosis

In the early stage of diffuse idiopathic skeletal hyperostosis, BME can be seen at the entheses on MRI. Correlating these findings with early radiographic changes leads to a correct diagnosis. Also, in more advanced stages, disease activity can be noted on MRI and radionuclide studies. The flowing calcifications and ossifications along the anterolateral parts of (at least four) contiguous vertebrae are typical and easily differentiated from inflammatory rheumatologic diseases. The relative normal intervertebral disk spaces at these levels and the absence of apophyseal joint bony ankylosis and SI joint erosion, sclerosis, or bony SI fusion adds to the

Table 2 Key learning points on MRI of the spine differentiating axSpA from degenerative changes

Discriminating factor	Degenerative disorder	AxSpA
Location	Predominantly lower lumbar and to lesser extent lower cervical spine	Evenly distributed in spine with slightly higher prevalence in lower thoracic spine
Additional findings	Low disc signal (STIR sequence) on MRI and loss of disc height on radiograph	
High signal on vertebral endplate on STIR sequence (MRI)	Modic change I; Full width of vertebral endplate	BME; Typically located in the anterior and posterior corner of vertebral body
Low signal on vertebral endplate on STIR sequence (MRI)	Modic change II; Full width of vertebral endplate	Fatty lesions; Typically located in the anterior and posterior corner of vertebral body
Contour defect of vertebral endplate (MRI)	Schmorls node; center of one vertebral endplate without erosive margins	(Non corner) Erosions; Typically located in anterior or posterior endplate with irregular margins
Bony spur arising from vertebral body (radiograph)	Spondylophyte; Less than 45 degrees angle with vertebral endplate, often accompanied by disc loss and located in the lower lumbar spine	Syndesmophyte; Bony spur with greater than 45 degrees angle with vertebral endplate.

Abbreviations: axSpA, axial spondyloarthritis; BME, bone marrow edema; MRI, magnetic resonance imaging; STIR, short tau inversion recovery.
Courtesy of Freek de Bruin.

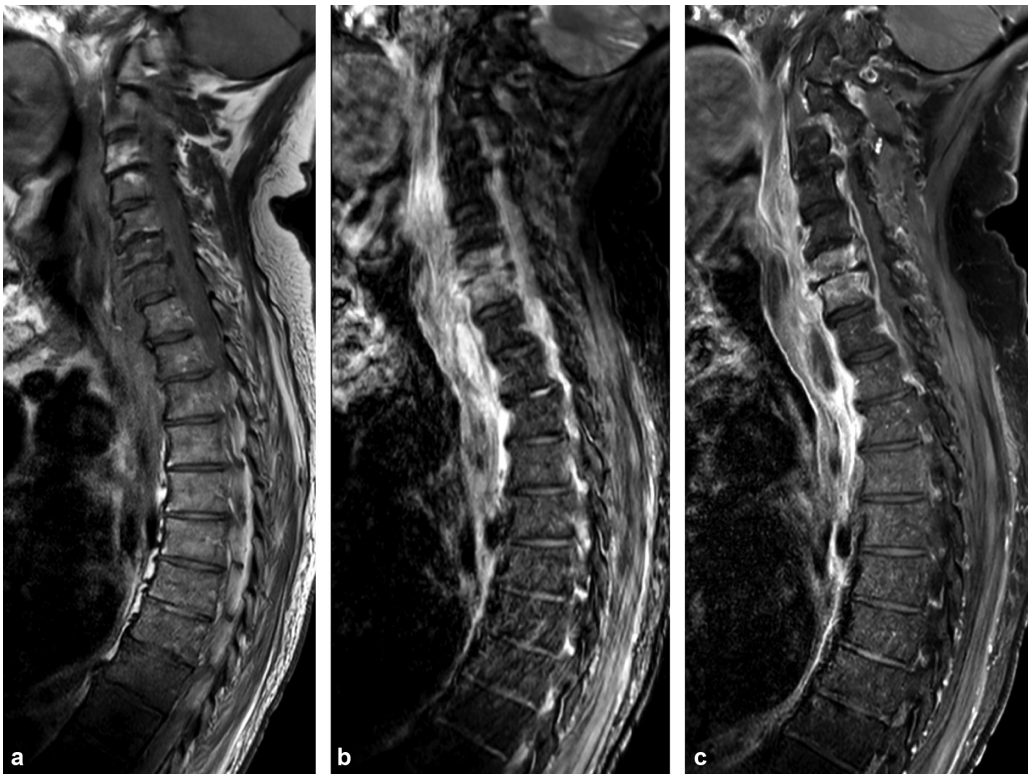

Fig. 8 A 79-year-old man with infectious spondylodiskitis C5-6. (**a**) Sagittal T1-weighted turbo spin-echo (T1TSE), (**b**) T2 Dixon, and (**c**) T1TSE fatsat after intravenous gadolinium. There is disk height loss, bone marrow edema in vertebrae C5 and C6, and a large soft tissue component with high signal intensity on T2 Dixon. Rim enhancement after contrast administration reveals abscesses both anterior and in the epidural space extending from C2 to C7.

radiographic criteria.[59] MRI is not indicated unless neurologic complaints need to be evaluated. The spinal canal at the cervical spine can be decreased secondary to hyperostosis of the posterior vertebral body, osteophytes, or ossification of the posterior longitudinal ligament.[32]

Spondylodiskitis

MRI of diskovertebral infection is typically characterized by a high T2-weighted signal in the disk and BME in the adjacent end plates, extending to the vertebral bodies. Paravertebral soft tissue inflammation can be identified. Using intravenous contrast administration enables the detection of abscess formation in the epidural space[35] (►**Fig. 8**).

Crystal Deposition Disease

Crystal arthropathies are a group of joint disorders due to the deposition of crystals in and around joints that leads to joint destruction and soft tissue masses. The most important crystal-induced diseases include calcium hydroxyapatite crystal deposition disease (HADD), calcium pyrophosphate dihydrate (CPPD) crystal deposition disease, and gout.[32,60] Spine involvement is frequent in CPPD and HADD but rare in gout. The spine may be the only site affected, with a preference for the annulus fibrosis and can produce severe erosive and inflammatory degenerative disk disease at MRI. Involvement of ligaments is seen at C1–C2 (transverse and alar ligaments) and at the thoracic and lumbar level with a L2–L3 preference (ligamentum flavum, posterior longitudinal ligament). It is usually asymptomatic, seen in older adults. It may become clinically relevant: It can cause myelopathy (direct compression) or inflammation (secondary to calcific resorption /release). Awareness of crystal disease is important in patients with unknown inflammation and needs to be differentiated from infection, tumor, axSpA, and degeneration[32,60] (►**Fig. 9**).

Sacroiliac Joints

In interpreting MRI, the clinical context is important. Age, sex, and history matter. The hallmark of active axSpA is BME of the SI joints; the diagnosis of sacroiliitis is not always straightforward.[34] The diagnosis of axSpA should not rely on isolated findings such as single and small ($<$ 1 cm) BME lesions, only seen on one slice and without associated structural findings in the SI joints (e.g., erosions, subchondral sclerosis, or fatty lesions).[21,35]

Mechanical Stress

Great forces on the SI joint can induce acute and structural changes. Repetitive strain injury to the axial skeleton may lead to BME lesions on MRI. Especially in the young age group, correlation of MRI findings with a history of physical activities (sports, runners, military recruits) and, in women, pregnancy and childbirth is useful. In a recent study on young athletes (recreational runners and elite ice hockey players), active sacroiliitis similar to axSpA was found in 30 to 41% of cases. The preferential location is the posterior lower ilium;

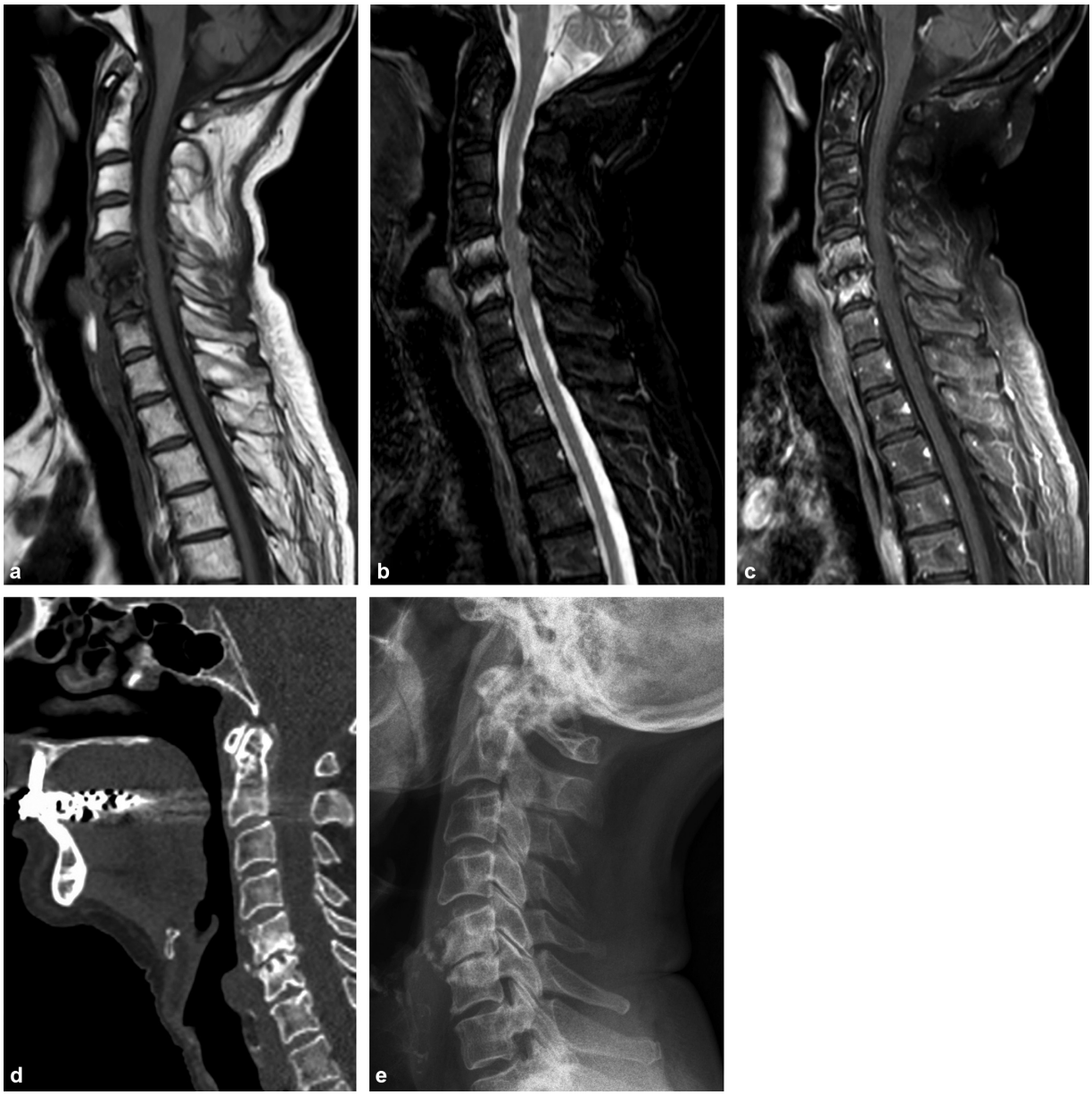

Fig. 9 (**a**) Sagittal T1-weighted turbo spin-echo (T1TSE), (**b**) T2 Dixon, and (**c**) T1TSE fatsat after intravenous gadolinium. Erosive spondylodiskitis secondary to calcium pyrophosphate dihydrate crystal deposition disease (CPPD). A 76-year-old woman with inflammatory pain and stiffness of the cervical spine, with increased acute-phase reactants; two radiography-guided biopsies were sterile. Note the absence of a soft tissue mass in the presence of vertebral body BME in C5 and C6. The disk is low on signal on T2 Dixon and enhances after contrast. (**d**) Sagittal reconstructed computed tomography and (**e**) lateral radiograph showed demarcated erosions and subchondral sclerosis of end plates C5 and C6. In addition, calcifications in the anulus fibrosis, ligamentous calcification around the dens, and ligamentum longitudinale posterior are consistent with CPPD depositions.

to a lesser extent, the anterior upper sacrum is affected.[61] These BME lesions are usually small, and no other associated findings are seen. Occasionally a vertically oriented stress fracture can be detected, surrounded by BME.

Osteitis Condensans Ilii

Osteitis condensans ilii is considered a mechanical stress phenomenon and seen as a triangular demarcated area of subchondral sclerosis at the inferior iliac side of the SI joints, bilateral and symmetrical, mostly seen in childbearing women. In the perinatal period, related BME lesions are focused on the anteroinferior part of the SI joint. In a study of early postpartum women, BME was found in 63% of cases at the SI joints and mimicked acute sacroiliitis secondary to axSpA.[62] A study by Germann et al showed that pregnancy/childbirth has no impact on long-term BME on SI joints; however, it may cause long-term subchondral sclerosis similar to SpA-associated sclerosis. Also, a greater number of children is positively correlated with SI joint sclerosis.[63]

Osteoarthritis

If BME is present in a degenerative SI joint, it is a small subchondral area at the iliac or sacral site at the corner edge. Some subchondral sclerosis, subchondral cysts, or focal joint

irregularity may be seen. Osteophytes can be better detected on radiographs.[35]

Infectious Sacroiliitis

The diagnosis of unilateral sacroiliitis of infectious origin in the early stage can be delayed due to the variable presence of clinical and laboratory findings. In axSpA, early SI joint involvement was also noted as unilateral.[21,34] In reading the MR images, special attention should be paid to soft tissue inflammation; periarticular muscle edema is an important predictor of infectious sacroiliitis.[64] Thick capsulitis (> 5 mm) and an extracapsular fluid collection are more clues. In axSpA, iliac-sided BME predominates, and joint space enhancement is more commonly noted. In case of doubt in the early phase, repeated MRI might be useful. In infectious spondyloarthritis, the BME becomes more intense on both sides, excessive fluid and synovitis in the joint is seen, and abscess formation in the iliac muscle can be appreciated. Chronic structural changes can develop.[34]

Crystal Deposition Disease

The involvement of the SI joints by crystal deposition disease is uncommon. The deposition of manifestations in other joints and in case of gout hyperuricemia may help in the diagnosis.

Conclusion

BME is not disease specific, so age, sex, and history should be considered in interpreting MRI of the spine and SI joints to prevent overdiagnosis of rheumatologic disorders. For MRI interpretation, it is useful to appreciate inflammation of the enthesis (enthesitis) as a hallmark of axSpA and inflammation of the synovium as a hallmark of RA. The distribution of areas of BME contributes to a radiologic diagnosis. The correlation of MRI and radiographs may help in making a correct diagnosis. MRI is the method of choice for early detection of involvement of the spine and SI joints in inflammatory rheumatologic disease. Whole-body MRI might help in SAPHO/CRMO.

Conflict of Interest
None declared.

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