MRI findings of radiation induced sacral insufficiency fractures

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Learning objectives

1- Review the state of the art in diagnosing radiation induced sacral insufficiency fractures (RISIF) by MRI.

2- To describe the salient findings of this entity.

3- The pathophysiology and clinical details will also be reviewed.

Background

ANATOMY OF THE SACRUM

The sacrum is a large triangular bone located between the lumbar and coccygeal portions of the caudal spinal axis. It is said that sacrum is a shield-shaped bone which has a pelvic or inner surface and a convex outer surface articulating superiorly with L5, inferiorly with the coxis and the sacral wings bilaterally with the iliac bones (Fig. 1) on page 4.

Related to spinal axis, the sacrum projects posteriorly forming the lumbosacral angle and consequently being a subject to shearing forces\(^1\)\(^,\)\(^2\) (Fig. 2) on page 4. It is composed by five fused vertebral segments, being the S1 the one which provides most support during axial loading due to its cruciate pattern of trabecula and its anterosuperior lip bone.

Histologic study of the sacral wings demonstrate decreased trabecular density (alar voids), this may explain the propensity for sacral stress fractures to occur in this site\(^1\). Denis et al. divided the sacrum into three zones, being the zone 1 the location where most of RISIF tends to develop\(^3\) (Fig. 3) on page 5.

DEFINITION OF RISIF

Pelvic insufficiency fractures were first described in 1982 by Lourie\(^4\). Sacrum is the most affected bone, being RISIF a subtype of stress fracture that results from normal stress applied to abnormal bone that has lost its elastic resistance due to radiation\(^4\),\(^5\).
PATHOPHYSIOLOGY

Radiation has a direct effect on bone and also an indirect effect associated with vascular changes. A reduction in the number of osteoblast cells after irradiation associates decreased collagen production and alkaline phosphatase activity leading to osteopenia. Moreover, after bone marrow radiation, an acute inflammatory reaction develops called "radiation osteitis" with necrosis of blood-forming elements\(^4,\,6\). This radiation-induced inflammatory response may lead fracture of trabecular and cortical bone.

Mature bone tolerates doses in the 65 to 70 Gy range and although conventional megavoltage equipment irradiates lower doses to the pelvic bones (Fig. 4) on page 6, RISIF could be a secuela\(^4\), most likely when other factors are associated (e.g. osteoporosis in postmenopausal women or elderly men)\(^6\). Consequently, the ability of bone to react to physiological stress through strengthening its internal trabecular scaffold is substantially reduced\(^3\). Cyclic loading in this deficient underlying bone results in insufficiency fracture\(^2\).

The time to develop a fracture is said to happen between 1 and 190 months but is unpredictable\(^4\). Patients may have or not a previous minor trauma\(^7,\,8\). Although it is known that concurrent chemotherapy also increases the toxicity of radiation there is a study in which the prevalence of pelvic insufficiency fractures in patients undergoing chemotherapy was not significantly higher than that of patients not undergoing concurrent chemotherapy\(^4\). Osteoporosis and use of corticoids are said to be predisposing factors to develop this condition\(^3\).

Other potential risk factors include rheumatoid arthritis, multiple myeloma, renal osteodystrophy, hyperparathyroidism, fibrous dysplasia, heparin or phenytoin use, diabetes mellitus, low body weight (<58 kg), current smoking, Cushing’s syndrome, primary biliary cirrhosis, osteomalacia, Paget’s disease and total hip prosthesis\(^3,\,4,\,8\).

EPIDEMIOLOGY

RISIFs commonly affect people with a mean age between 70 and 75 years, concretely elderly women who have undergone pelvic radiation for a gynecological tumor and specially with the use of high megavoltage equipment\(^4,\,9\). Some studies have shown that the incidence can be as high as 89%\(^5\).
CLINICAL SYMPTOMS

Clinical symptoms are frequently vague and nonspecific and may mimic other pathologies including radiculopathy and metastatic disease\(^2\).

Some of the symptoms include: diffuse low back pain radiating to the buttock, hip or groin and sacral radiculopathy (up to 70\%)\(^3,5\); objective neurological abnormalities such as esfincter dysfunction or leg paraesthesia are uncommon (2-14\%)\(^3\). It is important to bear in mind this entity because delayed diagnosis can lead to immobility and complications such as deep vein thrombosis, loss of strength, decreased cardiac output, depression and increased bone resorption and calcium excretion\(^7\).

Images for this section:

![Image A on the left shows a diagram of the normal anatomy of the anterior sacrum with the five fused vertebral bodies (S1 to S5), sacral wings (red arrowheads), sacral foramina (blue dashed arrows) and lateral masses (blue arrowheads). Image B on the right shows a coronal oblique T1W image in which S1 and S1 sacral bodies are demonstrated. L5-S1 articulation (blue arrow) and sacroiliac joints (red arrows) are also depicted.](image)

**Fig. 1:** Image A on the left shows a diagram of the normal anatomy of the anterior sacrum with the five fused vertebral bodies (S1 to S5), sacral wings (red arrowheads), sacral foramina (blue dashed arrows) and lateral masses (blue arrowheads). Image B on the right shows a coronal oblique T1W image in which S1 and S1 sacral bodies are demonstrated. L5-S1 articulation (blue arrow) and sacroiliac joints (red arrows) are also depicted.
Fig. 2: Image A on the left shows the anatomy of the sacrum in a sagital plain with the lumbosacral angle which is formed by the intersection of the longitudinal axis of the fifth lumbar vertebral body with the longitudinal axis of the first vertebral body of the sacrum. Its normal measurement is 140 °. Image B shows a sagital T1W image where the blue arrow and the red arrow depict inner and outer surface of the sacrum respectively.

Fig. 3: Image A on the left shows the labels which denote the classification system proposed by Denis et al. Zone 1 contains the sacral wings and portions of the the sacrum lateral to the neural foramina. Zone 2 contains the foramina, Zone 3 contains the sacral bodies. Image B on the right shows a coronal oblique T1W image where a superimposed green area depicts Zone 1 of Denis. This is the zone where most of fractures appear.
Fig. 4: Transverse plane image of 46-year-old woman treated with four fields shows dose distribution: 97% of prescribed dose is focused in target (green area). Sacrum and iliac bones are partially included in radiation fields.
Imaging findings OR Procedure details

We studied cases from the last five years at our institution. The presented cases include normal anatomy of the sacrum bone, and pathologic RISIF fractures aiming to highlight the condition, discuss the expected imaging features and show some of the potential imaging pitfalls.

A search was performed with the keyword "sacrum insufficiency fractures" and there were 7 patients identified. At our institution, approximately 200 patients undergo pelvic radiation therapy annually, with doses exceeding 40 Gy. The 7 patients presented herein represent only a small subset of these patients and probably do not indicate the real frequency of RISIF.

FINDINGS WITH MRI

Although there are other imaging modalities to study RISIF, MRI has become the most important one due to its sensitiveness to mild changes in bone marrow signal.

A good protocol in patients with suspicion of RISIF should include coronal or sagittal T1 W sequences, and STIR coronal sequence. Axial T1W imaging would be helpful for demonstrating coexisting fractures in the pubic bones.

After radiation therapy, tissue component of the bone marrow changes into fat producing high signal on T1 and low signal on STIR images. The change most frequently seen in RISIFs is marrow edema, MRI imaging can detect early changes of edema specially with STIR sequences on page 9. It presents as areas of high signal intensity on T2 and STIR sequences and low SI on T1. A hypointense line corresponding to the fracture may potentially be seen on page 11. Coronal oblique images in the plane of the sacrum better demonstrate the vertically oriented fractures and should be included in the imaging protocol if there is clinical suspicion on page 11.

Most of RISIF occur in the sacral wings, lateral to the neural foramina and medial to the sacroiliac joints; however, it can also be seen a horizontal fracture through the sacral body connecting the bilateral vertical lines. This fracture is classified further according to the degree of angulation and displacement in the sagittal plain. Although they usually present bilaterally, unilateral presentation may happen. In this situation we must review
the radiotherapy planning because a protocol with higher overdose in one side may have been used (Fig. 4) on page 12.

It could be associated to fractures in other locations of the radiation field being the pubic rami and parasymphiseal region the most frequently associated fractures with a reported coincidence of 88% ⁵, thus identification of one type of insufficiency fracture should suggest that the imager scrutinize the pelvis for other insufficiency fractures ¹, ⁶, ⁹.

DIFFERENTIAL DIAGNOSIS

Bone marrow edema has the potential to be misinterpreted as metastasis in certain cases (e.g. elderly patient populations who have a known primary malignancy) ¹⁰. However, the detection of a fracture line or a vertical array instead of a focal or discrete mass lesion, will help us to differentiate between stress fractures and malignancy ⁴, ¹¹, ¹². Besides, adjacent soft tissue edema is poorly seen in RISIFs ⁸ (Fig. 5) on page 14, STIR and T2-weighted sequences are sensitive to fractures and the bone marrow edema pattern.

Although some authors use gadolinium-enhanced MRI to better differentiate insufficiency fracture from malignant disease ⁵, ⁴, ¹³, this enhancement may be seen in no metastatic disease ², moreover the increased risk of induced nephrogenic systemic fibrosis in patients with limited renal function (old people and undergoing chemotherapy) lead others not to use contrast ⁷.

So it can be difficult to determine whether there is a RISIF or not, and if a fracture line is not evident, correlative CT or follow-up imaging should be made ⁵, ⁹, ¹⁴ (Fig. 6) on page 14. Biopsy should not be performed because irradiated bone marrow has reduced blood supply so it is prone to infection and also irreparable changes including necrosis could appear after this procedure ⁶.

TREATMENT AND FURTHER EVALUATION

Conservative therapy including rest and analgesics have been the classic treatment of RISIFs ¹, however recent studies have shown that interventional procedures such as sacroplastia or sacral kyphoplastia could be and alternative ⁵. Besides, MRI can
determine the clinical activity of the disease depending on the presence or absence of signal intensity around the fractures (active or chronic), and can monitor the response to treatment of the active type of insufficiency fractures\textsuperscript{8}.

Images for this section:
Fig. 1: A-C. Bilateral RISIFs. (A) Axial T1W image of the sacrum shows bilateral hipointense areas in both sacral wings which appear hyperintense on T2 (B) in a context
of RISIF. However, in STIR sequence (C) the hyperintensity suggesting edema is better depicted.

**Fig. 2:** A-B. Bilateral RISIFs. (A) Coronal oblique T1W image of the sacrum shows an abnormality in bone signal affecting both sacral wings with low intensity areas (arrows) surrounding vertical hipointense lines (arrowheads) which corresponded to RISIFs. (B) The STIR sequence better depicts the edema due to higher sensitiveness, however, fracture lines are better seen in T1W images.
Fig. 3: A-B. Bilateral RISIFs. (A) Axial T1W image of the sacrum demonstrates bilateral decreased signal parallel to the SI joints with ill-defined margins (arrows). This areas surround hypointense lines of fractures in both sacral wings (arrowheads). (B) Coronal T2W image demonstrates this changes as increased signal through the sacrum in a context of RISIF and bone edema changes. (C), (D) Coronal oblique reconstructions better depict this abnormalities with the tipical vertically oriented fractures (arrows).
Fig. 4: A-C. Unilateral RISIF. (A) Axial T1W image of the sacrum demonstrates a hypointense area surrounding a line of fracture in the right sacral wing. (B) STIR sequence highlights the edema, shown as an area of hiperintensity. (C) The fact that only one wing is affected may lead us to suspect that a higher dose of radiation was administrated in one side, as in this case happened (purple area).

![Image of Fig. 4 A-C](image)

Fig. 5: A-E. Potential mimic of a RISIF. (A) Axial T1W image of the pelvis shows an abnormality in signal intensity affecting the caudal part of the left sacral wing (arrow). This is not the typical place for a RISIF to happen. (B) Coronal oblique T1W image better demonstrates this finding (arrow). (C) Sagital post-gadolinium enhanced T1 SPIR image shows an enhancement not only seen in the bone (arrow) but also slightly in the adjacent soft tissue (arrowhead), therefore, a metastasis was suspected. (D), (E) "Bone" window and "soft tissue" window of a CT scan through the pelvis respectively, showed that the lesion had developed, destructing the bone and acquiring a mass shape (arrows). This CT scan was made after the MRI confirming the presence of a metastasis.

![Image of Fig. 5 A-E](image)
Fig. 6: A-G. Not very clear RISIF with correlative CT. (A) Posterior view of isotope bone scan shows a symmetric H-shaped appearance of bilateral sacral insufficiency fracture (arrows) there is also uptake in the midline of the sacrum (arrowhead). (B) Coronal oblique T1W image of the sacrum demonstrates bilateral decreased signal paralell to the SI joints (arrows) and also a horizontal component involving the sacral bodies (arrowhead). No line of fracture was identified. (C) Coronal oblique STIR image better depicts this findings showing them as hyperintense areas. (D) Curved reconstructed CT image of the sacrum shows mottled sclerosis (dashed arrow) and a cortical break affecting the right sacral wing (arrow). (E) Curved reconstructed CT image anterior to D, shows also the sclerosis (dashed arrow) and the cortical break (arrow); it demonstrates also a line of fracture affecting the second and third sacral bodies (arrowheads). (F), (G) Retrospectively, a prior CT showed a marked lucency of the sacrum (dashed arrows) secondary to radiation induced osteoporosis, undoubtedly a determinant for a RISIF to happen.
Conclusion

MRI of the pelvic area is currently the best imaging method to evaluate postreated pelvic malignacies. Familiarity of the MRI features in RISIF fractures is crucial for diagnosis and proper management.

See RISIF basic characteristics on sidebar image (Fig. 1) on page 17.

Images for this section:

Fig. 1
Personal Information

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References


