# MRI in Bone Marrow Imaging - A Prospective Study in a Tertiary Hospital

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# ABSTRACT

## BACKGROUND

MRI is a very sensitive technique for evaluating bone marrow as it differentiates normal from pathological marrow and displays changes at the cellular level. It is a useful technique for noninvasive evaluation of pathological bone marrow conditions. MRI serves as a screening method in bone marrow disorders and diagnosis can be established in context with clinical findings or by biopsy. We wanted to study the different imaging features of bone marrow disorders on MRI, correlate MRI imaging with plain radiograph, and correlate MRI imaging and radiographic features with clinical history.

# METHODS

110 patients referred from various departments with skeletal ailments were subjected to study under 1.5 T Siemens Avanto Machine using T1, T2, STIR and contrast procedure was done in indicated subjects.

## RESULTS

During the study period of eighteen months, MRI showed bone marrow changes in 110 cases with exclusion of trauma, haemangiomas and degenerative changes. MRI was confirmatory in majority of cases and no additional invasive investigations or otherwise required. Tubercular spondylitis accounted for the majority of cases in our study. Most of the lesions with diffuse involvement were benign and most of the malignant lesions showed focal involvement. Contrast enhancement was noted in both inflammatory and malignant cases although intense enhancement was noted in malignant cases. Bone marrow biopsy was done in 20 cases which were suspected as malignant in MRI but only 14 of them proved to be malignant. Differentiation between renal osteodystrophy and fluorosis is difficult based on MRI findings alone but integrating with clinical history, plain radiograph for ligament ossification, and serum creatinine levels were helpful in accurate diagnosis.

# CONCLUSIONS

Appearance of MRI signal in various sequences with age correlation is essential in identification and interpretation of various pathologies. MRI is found to be more sensitive in detecting diffuse and focal bone marrow pathology.

## **KEYWORDS**

T1, T2, STIR, Dynamic Contrast with Fat Saturated Imaging

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# BACKGROUND

Magnetic resonance imaging with its excellent spatial and contrast resolution can depict haematopoietic and fatty marrow separately and is therefore a useful technique for noninvasive evaluation of pathological marrow conditions.<sup>1</sup> The signal intensity, morphology and location of pathological findings on MRI can be used to provide more accurate diagnosis to guide treatment and to follow therapy related changes. MRI, however, provides the best overall view of both types of bone marrow and reconversion to normal marrow.<sup>2</sup> The MRI appearance of the bone marrow is determined by the relative amount of protein, water, fat and cells within the marrow<sup>3</sup> and depends on the pulse sequence on which it is being evaluated. The routine bone marrow evaluation on MRI typically includes T1 weighted, T2 weighted and STIR sequences.

MR Imaging Technique in the Evaluation of Bone Marrow: In young adult the predominantly it is red marrow and converts to yellow marrow as age advances. These changes vary and are defendant on factors such as disease, athletic activities and therapies.<sup>4,5</sup>

T1 Weighted Imaging: Yellow marrow has signal intensity comparable with subcutaneous fat, whereas red marrow has signal intensity lower than subcutaneous fat but higher than disc or muscle. The signal intensity of the marrow, however, is dependent on the proportion of red and yellow marrow. Cellular infiltration retains some intermixed fat, whereas replacement obliterates all fat within the bone marrow. This replacement of the bone marrow characteristically appears hypointense relative to disc and muscle on T1 weighted images and hypointense relative to normal marrow.<sup>6</sup>

T2 Weighted Imaging: Fatty marrow appears higher in SI than muscle and equal to or slightly lower in SI than subcutaneous fat. Because water and fat are closer in Signal intensity, there is decreased contrast of the spinal marrow in this sequence. Red marrow Signal intensity is slightly lower than that of yellow marrow. Although metastatic lesions are usually brighter than normal bone marrow on T2-weighted MRI due to their high-water content, they sometimes can be difficult to differentiate from normal marrow on T2-weighted sequences<sup>7</sup>.

STIR Imaging: Fatty marrow has low signal intensity and red marrow has intermediate signal intensity as equal to muscle. Normal marrow shows as signal void, red marrow has low signal intensity and pathological marrows shows high signal intensity on stir imaging.

T1 Fat Sat Contrast Imaging: Gadolinium-based contrast medium also helps distinguish oedema from viable tumour and allows an accurate determination of the degree of vascularisation. The basic principle that viable active tumoral tissue shows a higher degree of enhancement than non-tumoral / necrotic areas can also be applied to directing biopsies to viable cellular areas and noninvasive assessment

of response to therapies such as radiotherapy and chemotherapy<sup>8</sup>.

- Bone marrow disorders are classified into 5 categories
- 1. Reconversion.
- 2. Replacement.
- 3. Depletion.
- 4. Fibrosis.
- 5. Deposition of metabolic products.
- 6. Post-therapeutic changes.

**Reconversion<sup>9</sup>**: Physiological process occurring in all anaemias, high altitudes and smokers. Reconversion occurs in the reverse order of conversion, commencing proximally in regions that are composed of predominantly red marrow and progressing distally to areas of fatty marrow. Reconversion to haematopoietically active marrow can occur in the setting of malignancy, necrosis, fibrosis, oedema secondary to trauma or stress, replacement, infiltration, or infection, but the patient may be asymptomatic clinically.<sup>10</sup>

**Marrow Replacement:** It is seen in plasma cell disorders, leukemia, lymphomas, metastasis and in inflammation.

**Aplastic Anaemia:** There is homogeneous increase in signal intensity in the hematopoietic marrow on T1W and T2W images approaching the signal intensity of fat because of the replacement by fatty marrow.

**Depletion of Myeloid Elements with Fibrosis:** In myelofibrosis MRI shows low signal intensity changes both in T1 and T2 weighted images due to replacement of marrow fat by collagen and reticulin fibres.<sup>11</sup>

**Post Therapeutic Changes:** Post radiation changes are dose related and preferentially affect the hematopoietic marrow. In the acute phase (day 1–3 of irradiation), the bone marrow develops an oedema, which appears hypointense on T1W, hyperintense on T2-weighted and STIR-images. Contrast enhanced T1-weighted images show a transiently increased enhancement of the bone marrow during this phase. Subsequently (day 4–10), focal T1-hyperintense and T2 / STIR-hypointense areas of haemorrhage may occur. The bone marrow ultimately undergoes a conversion to fatty marrow, which closely represents the irradiation field, and which appears very bright on T1-weighted MR images (close to subcutaneous fat) and dark on fat suppressed images.<sup>12</sup>

#### **Metabolic Disorders**

Osteoporosis<sup>13</sup>: The signal-intensity characteristics of bone marrow may allow the differentiation of neoplastic fractures from accompanying osteoporosis.<sup>14,15</sup>

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Renal Osteodystrophy: Sometimes the spine is osteopenic and exhibits heterogeneous T1 weighted signal. There is central demineralization with sclerosis of the margins. Low T1 weighted and T2 Weighted signal along the end plates give the characteristic rugger jersey spine.

Fluorosis: Generalized vertebral sclerosis, ligamentum flavum hypertrophy, thickened longitudinal ligaments, and narrowing of spinal foramina are the features of fluorosis. T1 and T2 weighted images shows hypointense signal.

#### Focal Disorders of the Bone Marrow

Causes are trauma, tumour, infection, ischemia.

#### Osteonecrosis

In the early stages when the radiograph is normal, focal subchondral lines of altered signal intensity, low signal intensity on T1W and high on T2W images. A double line sign consisting of two parallel stripes of low and high signal indicate irreversibility.

#### **Bone Infarction**

In the early stage there is decreased signal intensity on T1W and increased signal intensity on T2W images due to oedema. These changes are linear or geographical. Infarcts in late stages are generally calcified seen as decreased signal intensity on all sequences.

#### METHODS

This is a prospective observational study performed on Siemens Magnetom Avanto 18 Channel 1.5T MRI. Between Jan 2018 to June 2019 over 110 patients, those who were referred for MRI with various spinal and skeletal problems referred from various departments of Osmania General Hospital. Diagnosis drawn based on MR findings is correlated with plain radiograph, clinical history, blood investigations and in few cases bone marrow biopsy. Exclusion criteria: 1. h/o trauma 2. Degenerative changes 3. Spinal haemangiomas 4. Already known case of bone tumours

#### Technique

MRI was performed using 1.5T Siemens MRI unit with T1W, T2W, STIR, PD fat sat and gadolinium contrast-based images in required cases. Then who have abnormal bone marrow signal on MRI had correlated with plain radiograph, clinical history. In suspicious cases of malignancy, bone marrow biopsy was performed for confirmation. Then depending on the abnormality, patient is asked to give relevant history regarding any endemic area of fluorosis, steroid and smoking history, previous renal disease, previous plain radiographs, previous investigation reports like haemoglobin, complete blood picture, serum creatinine, calcium, phosphorous and any another primary tumour.



Coronal sections of pelvis MR showing well defined serpiginous irregular T1 hypointense, T2/STIR hyperintense lesion noted in upper metadiaphysis of left femur. Corresponding X-ray showing minimal sclerosis-features suggestive of bone infarct.



Sagittal and coronal sections of spine MR images showing diffuse T1 hypointensity, T2/STIR isointensity with decreased height of vertebral bodies on plain radiograph. Bone marrow biopsy proved as Acute Lymphoid Leukemia.

# Original Research Article



Sagittal and coronal MR images of dorsal spine showing T1/T2/STIR hypointensity of D9 vertebra and STIR hyperintensity of D8 and D10 vertebra. Postcontrast enhancement of D8 vertebra. Corresponding CT and XRAY images sclerosis of D9 vertebra noted. Biopsy proved as metastasis from prostate carcinoma.



Sagittal and coronal sections of MR showing few areas of T1 hypo, T2 /STIR hyperintensity noted in D9, D10, D11, D12 vertebrae with partial collapse of D9, D10 vertebrae with adjacent paravertebral collection. Corresponding PLAIN RADIOGRAPH image showing partial collapse of D9, D10 vertebrae-features suggestive of tubercular spondylitis



Sagittal and coronal sections of MR dorsal spine showing multiple tiny T1 hypo, T2/STIR hyperintense lesions in all vertebral bodies. Corresponding XRAY showing few lytic lesions. On skull x-ray showing multiple lytic lesions with rain drop appearance. Serum electrophoresis was done, and M spike noted-features suggestive of multiple myeloma.

# RESULTS

In the present study, peak age group is between 31-40 years with a mean age of 38.5 years Youngest in our study was 8 years and eldest in our study was 78 years.











In the present study, higher incidence of infective cases (63.8%) noted followed by metabolic cases (26.4%). In the present study lower incidence of physiological reconversion cases (2.2%) noted followed by post therapeutic changes (4.4%).

#### DISCUSSION

Total 110 cases are included in this study with various clinical problems and those who have an abnormal bone marrow signal on MRI and excluded patients with history of trauma, degenerative changes and skeletal haemangiomas. Majority of the cases were in the age group of 31-40 years followed by 41-50 year presented with chief complaints of skeletal problems followed by neurological deficit and showed affliction of lumbar spine (48%) followed by dorsal spine (29%). In the study group of 110 cases, 20 were suspected cases of malignancy, out of which only 14 cases are proved as malignancy on biopsy. Other cases are brown tumour <sup>(2)</sup>, tubercular spondylitis <sup>(3)</sup> and physiological reconversion due to smoking. <sup>(1)</sup>

We divided aetiological factors into physiological reconversion, infective, metabolic, ischemic, neoplastic, and post-therapeutic.

## Physiological Reconversion<sup>16</sup>

34-year-old male patient with h/0 smoking had complaint of severe back ache showed T1 hypointensity, T2/STIR hyperintensity noted in lumbar vertebrae compared to other vertebrae. Biopsy came as normal haematopoietic marrow and no evidence of malignant cells. In view of history, we arrived at a diagnosis of physiological reconversion likely due to smoking.

8-year-old male patient with complaint of seizure with history of thalassemia undergone MRI brain. There was thickening of skull vault with T1 hypo and T2 hyperintensity with hair on end appearance noted with thickened skull vault on x-ray.

Agata Malkeiwicz described that features indicating marrow reconversion on MRI. These include symmetric changes with high signal intensity on T1-weighted images and characteristic location in relation to the axial skeleton. The similar findings are noted in this study.

Metabolic causes were (21%). In this category, 8 were of osteoporosis, 8 were of fluorosis and 6 were of renal osteodystrophy and 12 were of brown tumours due to secondary hyperparathyroidism due to chronic renal Disease.

All 8 cases of osteoporosis were above 60 yrs. and 6 were females showed diffuse T1/T2 hyperintensity, STIR hypointensity noted in all cases.

Hee Sun Jung studied in 133 patients with vertebral fractures and described few findings which differentiate between acute osteoporotic compression fracture from malignant fracture are convex posterior border of the vertebral body, abnormal signal intensity of the pedicle or posterior element, an epidural mass, a focal paraspinal mass, and other spinal metastases are suggestive of metastatic compression fractures. A low-signal-intensity band on T1- and T2-weighted images with spared normal bone marrow signal intensity of the vertebral body, retropulsion of a posterior bone fragment, and multiple compression fractures are suggestive of acute osteoporotic compression fractures.

In the study population, 5 cases showed of osteoporotic fracture and collapse in the form of a low signal intensity band. Only 3 of 5 cases showed retropulsion of fragments. 5 of 5 cases showed single vertebral body only in contrast to the above study.

#### Fluorosis

8 cases showed diffuse T1/T2/STIR hypointensity spine. Corresponding X ray showed diffuse sclerosis in all cases. 2 of them showed sacrotuberous ligament ossification. 4 of them were from endemic areas of fluorosis. 1 of them showed anterior longitudinal ligament ossification. Serum creatinine was normal in all of them. These features are helpful in differentiating them from renal osteodystrophy.

#### Renal Osteodystrophy

6 cases showed diffuse T1/T2/STIR hypointensity in spine. Corresponding X ray showed diffuse sclerosis. Serum creatinine was elevated in 6 of them. According to present study, differentiation between fluorosis and renal osteodystrophy is difficult based on bone marrow signal alone because both show T1 and T2 hypointensity. But combined correlation of clinical history, lab findings and MRI with corresponding x-rays give better accuracy to the diagnosis.

#### **Brown Tumours**

2 cases showed T1/T2 iso, STIR hyperintensity with peripheral T2 hypointensity in D2, L2 vertebrae. Corresponding Xray showed lytic lesion. Serum creatinine parathyroid hormone levels were elevated. Skull x-ray showed salt and pepper appearance. Few lytic lesions noted in ribs on CXR.

## Infective

58 (51%) cases diagnosed as infective aetiology. In the study population, 40 were tubercular infections, 14 were bacterial osteomyelitis and 4 were septic arthritis.

#### Tuberculosis

In the study population, tubercular spondylitis was 34 involving spine, 2 in metacarpal and 2 cases of iliac bone and 2 cases of tarsal bones involvement. Tubercular Spondylitis, majority is between 31-40, 14 out of 34 cases (41%) and predominantly males (12) than females. Involvement of single vertebral body noted in 2 cases, two in 28 cases and three in 4 cases. Most common bone marrow

abnormality is T1 hypointensity, T2/STIR hyperintensity detected in 26 out of 34 cases (70%) followed by T1 isointensity, T2/STIR hyperintensity in 6 cases (17%). Only 2 (5%) cases showed T1/T2 isointensity, STIR hyperintensity. Sclerotic type (T1/T2 hypointensity) noted in only two (5%) cases.

#### Disc Involvement Noted in 24 Cases (65%).

The majority of the lesions noted at dorsal vertebrae 10 cases (29%), lumbar vertebrae 10 (29%) followed by dorsolumbar junction 8 cases (23%), cervical vertebrae 4 cases (11%). Khalequzzaman S<sup>1</sup> conducted a study in 42 patients. <sup>(17)</sup> In this study peak Age incidence was in 3<sup>rd</sup> decade with male predominance similar to present study. Highest occurrence was in double vertebra (42%) almost similar to our study. Paraspinal abscesses were noted in 80% cases similar to our study (75%).

#### Long Bone Osteomyelitis

14 osteomyelitis cases were noted (21.8%). 10 of them were acute osteomyelitis and 4 were chronic osteomyelitis. Out of 14, 10 cases showed T1 hypointensity, T2/PDFS hyperintensity. Other 4 cases showed T1 isointensity, T2/PDFS hyperintensity. I Carlos Pineda <sup>(18)</sup> described that The earliest finding of acute osteomyelitis on MRI is an alteration of the normal marrow signal intensity, which can be appreciated as early as 1 to 2 days after the onset of infection; the oedema and exudates within the medullary space produce an ill-defined low-signal intensity on the T1-weighted images and a high signal on T2-weighted and STIR or fat-suppressed sequences similar to present study.

## Ischaemic

8 cases (7.2%) showed ischemic aetiology. Among them 6 showed avascular necrosis of head of femur, 2 showed incidentally detected infarct in metadiaphseal region of upper end of femur. 4 cases showed radiographic abnormality. All of them showed serpiginous areas of T1 hypointensity, T2/PDFS hyperintensity.

Todd P. Pierce<sup>19</sup> described that Plain radiographs are commonly obtained, but magnetic resonance imaging (MRI) is now considered the gold standard of diagnosis for the earliest stages of osteonecrosis similar to our study.

## Neoplastic

In the study population, 14 cases (12.7%) showed neoplastic aetiology. Among them 2 are multiple myeloma, 1 is lymphoma, 1 is acute lymphoid leukemia and 10 are metastasis.

## Multiple Myeloma

60-year-old male patient showed diffuse T1 hypointensity, T2/STIR hyperintensity in lumbar spine. Corresponding XRAY showed multiple lytic lesions. Finally, biopsy proved as

multiple myeloma. He also had few lytic lesions in pelvic bones.

Wilfred<sup>20</sup> described that focal or diffuse T1 hypointensity, T2/STIR hyperintensity and enhancement after contrast are features of multiple myeloma similar to this case in present study.

## Acute Lymphoid Leukemia

8-year-old male case detected platyspondyly on XRAY. He underwent MR whole spine. Diffuse T1 hypointensity, T2/STIR isointensity noted.

Sinchun Hwang<sup>21</sup> described that due to the accumulation of lymphoid cells bone marrow visualized as diffusely hypointense on T1 and normal in T2W images in initial stages similar to present case. Finally, biopsy proved as acute lymphoid leukemia.

# Lymphoma

T1 hypointensity, T2/STIR hyperintensity noted in 3 vertebral bodies including posterior elements. Postcontrast they showed significant enhancement. Corresponding XRAY showed lytic lesions. First clinical suspicion was probably metastasis. Biopsy proved as lymphoma.

Anant Krishnan<sup>22</sup> described 3 patterns of lymphoma. One is lytic, another is blastic and mixed. In this study, cases belong to lytic type.

# Metastasis

8 were lytic metastasis and 2 were blastic metastasis. Primary for sclerotic metastasis was from prostatic carcinoma. Corresponding MR images showed T1/T2/STIR hypointensity and XRAY showed minimal sclerosis in vertebrae involving posterior elements.

Sungmin Woo<sup>23</sup> conducted a study in 308 patients with prostate cancer and concluded that abnormal bone marrow signal showing T1/T2 hypointensity with contrast enhancement similar to our case associated with metastasis.

Primary for lytic metastasis were 6 from lung carcinoma and 2 from breast carcinoma.

8 of them showed T1 hypointensity, T2/STIR hyperintensity and 5 of them showed significant enhancement. In all of them posterior elements were involved.

Sinchun Hwang described that due to the accumulation of lymphoid cells bone marrow visualized as diffusely hypointense on T1 and normal in T2W images in initial stages similar to this case.

Several characteristics of the signal can help to differentiate between malignant and non-malignant reconversion. Malignant aetiologies often cause asymmetric reconversion while non-malignant reconversion is more likely to be bilateral and symmetric. In addition, neoplastic marrow enhances more with gadolinium administration and the signal intensity on short TI inversion recovery (STIR) imaging is greater than the signal intensity of muscle. In this study contrast study was done in suspected cases of malignancy. Significant contrast enhancement noted in malignant cases and 3 inflammatory cases.

According to this study most of the inflammatory lesions are associated with adjacent soft tissue collection like paravertebral abscess in tubercular spondylitis.

# CONCLUSIONS

During the study period of eighteen months MRI showed bone marrow changes in 110 cases with the exclusion of trauma, haemangiomas, and degenerative changes. MRI was confirmatory in majority of cases and no additional invasive investigations were otherwise required. Tubercular spondylitis accounted for the majority of cases in our study. Most of the lesions with diffuse involvement were benign and most of the malignant lesions showed focal involvement. Contrast enhancement was noted in both inflammatory and malignant cases although intense enhancement was noted in malignant cases. Bone marrow biopsy was done in 20 cases which were suspected as malignant in MRI but only 14 of them proved to be malignant. Differentiation between renal osteodystrophy and fluorosis is difficult based on MRI findings alone but integrating with clinical history, plain radiograph for ligament ossification, and serum creatinine levels, were helpful in accurate diagnosis. MRI is found to be more sensitive in detecting diffuse and focal bone marrow pathology.

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