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Chemical shift Dixon MR imaging to differentiate benign and malignant bone marrow lesions: A cross-sectional study.

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Abstract

Background:
Bone lesions encompass a wide spectrum of abnormalities ranging from benign growths, such as osteochondromas and enchondromas, to malignant tumors like osteosarcomas and Ewing's sarcomas.

Objective:
To quantify the percentage signal loss in bone marrow lesions resulting from replacement of the fatty marrow component by neoplastic tissue, to differentiate benign from malignant bone lesions.

Methods:
A total of 100 patients with bone lesions were included in this study. Patients of any age group presenting with bone tumors underwent an MRI scan in MR Omega (3 Tesla). The patients were thoroughly counselled, and no contrast agents were used. The % SI drop was calculated as follows: % SI drop = [(SIIP – SIOOP)/SIIP] × 100 (IP-In phase and OOP- Out of phase).

Results:
Most patients were male (62%). The mean age of the patients was 45.4 years. The majority of the patients had <20% signal intensity drop (54%). At a 20% drop in signal intensity, malignant and benign lesions had sensitivities of 80% and 85%; specificities of 85% and 88.9%; PPVs of 73.9% and 88.9%; NPVs of 82% and 73.9%; and accuracies of 82% and 82%.

Conclusion:
To describe localized and diffuse marrow abnormalities on standard non-contrast imaging, chemical shift imaging is a helpful supplementary magnetic resonance imaging approach. When it comes to detecting cancerous diseases, it is quite sensitive. In almost 46% of individuals with benign illness, a biopsy might be avoided despite its reduced specificity.

Recommendation:
Larger-scale studies across a wider range of bone marrow lesions to better quantify the percentage signal loss and assess the broader applicability of this MRI technique in clinical practice.

Keywords: *Chemical shift, Bone marrow lesions, In phase, Out of phase*
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Introduction
Bone lesions can be benign or malignant. Accurate characterization of these lesions is critical for determining appropriate treatment strategies and preventing complications (1). Conventional imaging techniques often fail to differentiate subtle marrow changes or early-stage lesions effectively. MRI is a sensitive imaging modality for evaluating bone marrow lesions. In contrast to other imaging techniques such as X-rays and CT scans, MRI provides better soft tissue contrast and in-depth visualisation

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of bone marrow and surrounding structures, making it the gold standard for assessing bone lesions (2-3).

The loss of normal fatty marrow can be focal or diffuse, and can present benign or malignant features. Different MRI sequences, such as T1- and T2-weighted images, fat-suppression sequences, diffusion-weighted imaging, MR spectroscopy, and post-contrast imaging, can be used to diagnose different marrow diseases. Musculoskeletal diseases are identified using a variety of fat-suppression methods, including frequency-selective fat saturation, inversion recovery, hybrid methods, chemical shift imaging (CSI), and the associated Dixon-based methodology.

CSI provides a detailed analysis of bone marrow chemical composition, highlighting early pathological changes that are not visible on standard MRI sequences (4-5). Fundamental CSI knowledge exploits the difference in the precession frequencies of water and fat molecules. Fat molecules offer more proton shielding than water molecules. As a result, compared to protons in water, protons in fat molecules precess at a somewhat lower frequency. The chemical shift effect is the term for this frequency variation. In CSI, this effect is used during In-phase (IP) and out-of-phase (OOP) imaging. OOP imaging is based on the phase difference between images acquired at different echo times. The angle of the magnetisation vector in the transverse plane is known as the phase. A few milliseconds after the initial stimulation, the phase of the protons in fat and water varies relative to one another due to their distinct precession frequencies.

The signal from fatty tissue is diminished or suppressed by OOP imaging. Signals from nearby water and lipids can be equivalent at the boundaries between fat and non-fatty tissue. The India ink artefact, also known as the black border artefact, is the resultant signal void at the interface between fatty and normal tissue. This function enables the recognition of OOP photos. Opposed-phase imaging is rapid and easy. Chemical shift imaging is mostly used to show intracellular or microscopic fat. Voxels containing both fat and water show a lower signal in the OOP images. Nevertheless, the macroscopic fat is not suppressed. The greatest benefit of this method is its ability to detect small amounts of fat and fat-water mixtures. However, only macroscopic fat is suppressed by imaging methods such as spectral attenuated inversion recovery and short tau inversion recovery (STIR). This imaging method is unaffected by static field heterogeneity as it relies on the phase difference between fat and water protons.

CSI helps in identifying marrow reconversion, bone metastases, or other infiltrative processes, aiding clinicians in diagnosing conditions like marrow edema, stress fractures, and myeloma. CSI enhances diagnostic confidence in complex cases, such as pediatric bone lesions or regions with abundant red marrow, where conventional imaging may yield ambiguous results. Integrating CSI into the evaluation of bone lesions not only improves diagnostic accuracy but also provides a non-invasive means to assess the biochemical and structural characteristics of lesions, ultimately enhancing patient care. Hence, this study was undertaken to determine the role of Chemical Shift Dixon magnetic resonance imaging in differentiating benign from malignant bone marrow lesions.

Methods

Study Design

This is a hospital-based analytical cross-sectional study carried out between 2023 and 2025.

Study Setting

Patients in this research, regardless of age, who exhibit probable neoplastic bone lesions, underwent an MRI scan on the MR Omega (3 Tesla) system for further assessment.

Study Population

A Study population of 100 patients presenting with bone tumours underwent MRI for further evaluation.

Sample Size Determination

In this study, patients of any age group presenting with bone tumours underwent an MRI scan on an MR Omega (3 Tesla) scanner for further evaluation.

Sampling Procedure

The patients were thoroughly counselled, and no contrast agents were used. The % SI drop was calculated as follows: % SI drop = [(SIIP – SIOOP)/SIIP] × 100 (IP-In phase and OOP- Out of phase)

Inclusion and Exclusion Criteria

Patients of any age group presenting with bone lesions were included. Patients with cardiac implantable electronic devices such as pacemakers, implantable cardioverter-defibrillators, and cardiac resynchronisation therapy devices; metallic intraocular foreign bodies; cochlear

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implants/ear implants; and pregnant and breastfeeding women were excluded from this study.

Variables

The Independent variables were the Dixon sequence, the In-phase signal, the Out-of-phase signal, the signal intensity ratio, and the percentage signal drop. The dependent variable was benign and malignant.

Data Collection Tools and Methods

A self-structured questionnaire was used to collect data for the study, with modifications based on variables used in previous studies. Histopathology data and laboratory findings were recorded for the study.

Validity and Reliability

MRI protocol standardised for all patients. Histopathology was considered the gold standard wherever feasible. Experienced radiologists independently evaluated study findings.

Study Procedure

Patients presenting with bone tumours underwent an MRI. Clinical history and demographic data were collected. Correlation with histopathology/clinical diagnosis. MRI examination, including Dixon sequences.

Bias

Consecutive patient recruitment and a clearly defined eligibility criterion. Variability in Region-of-Interest (ROI) placement and lesion sampling. Conditions such as Red marrow reconversion, osteomyelitis, and marrow edema may affect fat content and mimic malignant lesions.

Statistical Analysis

MS Excel 2016 was used to store the questionnaire data, and SPSS software version 20 was used for analysis. Tables, bar graphs, and pie charts are used to display data such as percentages and frequencies. Continuous data are presented as mean ± SD and median, whereas categorical variables are presented as counts and percentages (%). Statistical significance was defined as a p-value < 0.05.

Ethical Consideration and Informed Consent

The study was carried out after obtaining Ethical approval from the Institutional Ethics Committee (Ref. No/IEC/IMS.SH/SOA/2024/908), and informed consent was obtained from all study participants.

Result

Most patients were male (62%), while 38% were female (Table 1). The majority of patients (54%) had a <20% drop in signal intensity, while 46% had a≥20% drop. Most patients in the study (60%) had a malignant lesion as per the HPE report (Figure 1).

Table 1. Distribution of gender

Gender	Frequency	Percentage
Male	62	62%
Female	38	38%
Total	100	100%

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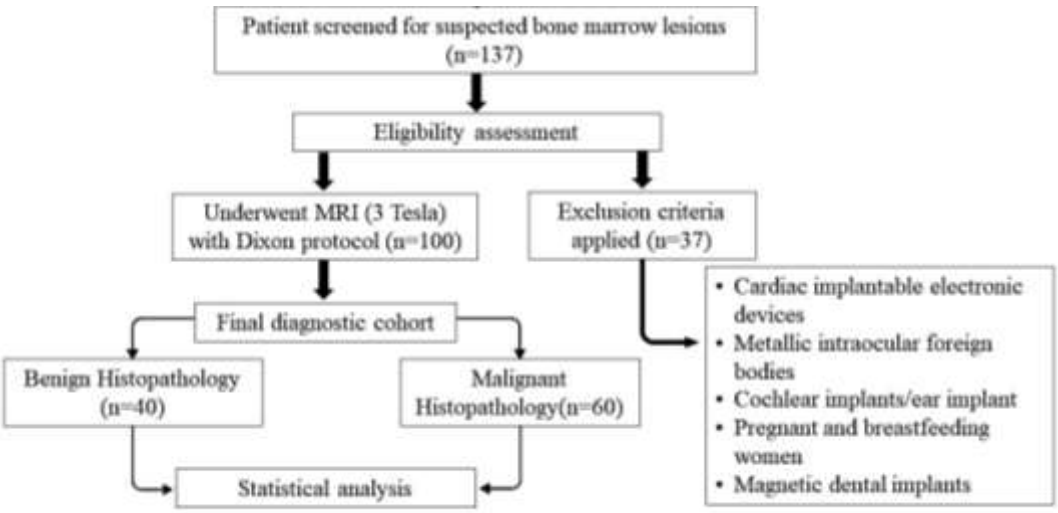

Figure 1. Selection criteria of the study population

The mean and median ages of the patients were 45.4 and 44.5 years, respectively. The mean and median in-phase signal for the patients were 996.3 and 1015.5, respectively. The mean and median out-of-phase signals of the patients were 757.5 and 702, respectively. At a 20% drop in signal intensity, malignant and benign lesions had sensitivities of 80%, 85%; specificities of 85%, 88.9%; positive predictive values of 73.9%, 88.9%; negative predictive values of 82%, 73.9%; and accuracies of 82%, 85%, respectively. Area Under Curve (AUC) to detect the malignant bone lesion = 0.886 ($p<0.001$). The study presented an exophytic lesion in the right proximal humerus. On MRI, CSI was performed, and the lesion demonstrated 14.44% signal loss on OOP images, suggesting a malignant lesion. On HPE, the lesion was malignant (Telangiectatic osteosarcoma) (Figure 2).

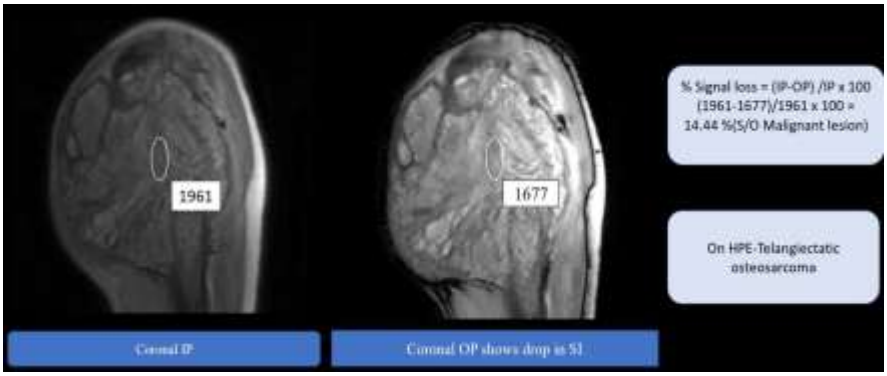

Figure 2. An exophytic lesion in the right proximal humerus.

An expansile soft tissue lesion in the right distal radius humerus. On MRI, CSI was performed, and the lesion demonstrated 4.5% signal loss on OOP images, suggestive of malignancy. On HPE, the lesion turned out to be malignant (Giant Cell tumor) (Figure 3).

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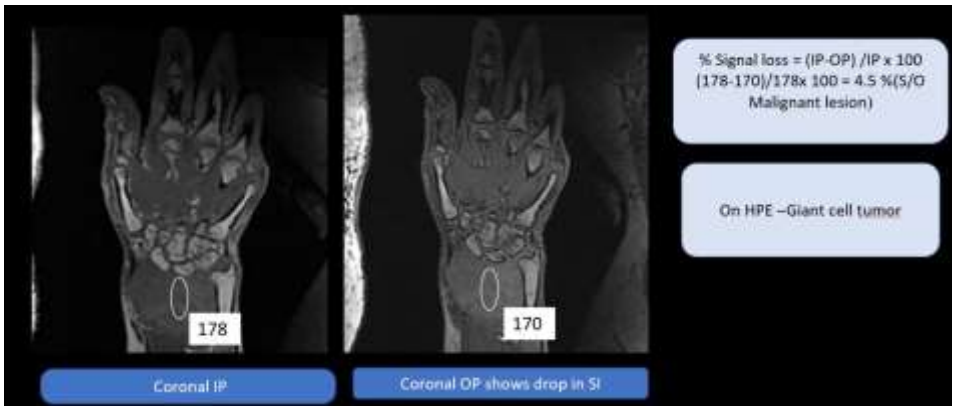

Figure 3. Soft tissue lesion in the right distal radius humerus.

Rectosigmoid cancer had undergone CE-MRI spine to rule out metastasis. On MRI, there were multiple altered signal (T1/T2 hypointense) lesions involving D3 and D5 vertebrae. CSI was performed, and the lesion demonstrated 17% signal loss on OOP images, suggestive of a malignant lesion. On HPE, the lesion was malignant (Metastatic) (Figure 4).

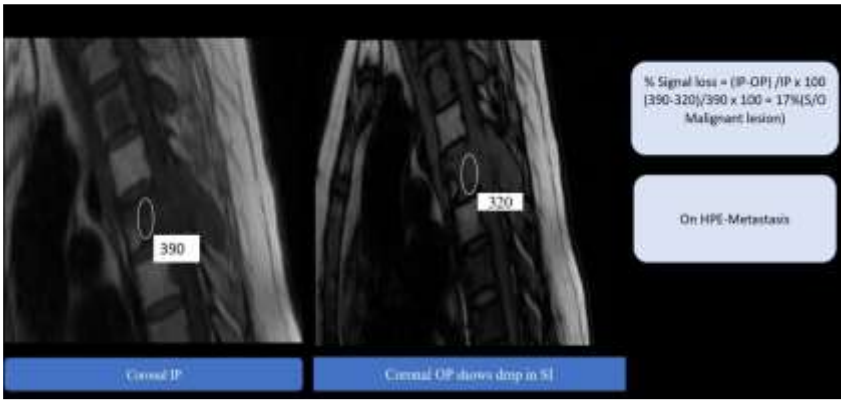

Figure 4. The case of rectosigmoid cancer had undergone CE-MRI spine to rule out metastasis.

On MRI, the dorso-lumbar vertebrae, bilateral pelvic bones, and the visualized bilateral proximal femur showed altered marrow signal intensity (hypointense on T1, T2/STIR hyperintense with e/o restricted diffusion). CSI was performed, and the lesion demonstrated 11% signal loss on OOP images, suggestive of a malignant lesion. On HPE, the lesion turned out to be Malignant (Lymphoma) (Figure 5).

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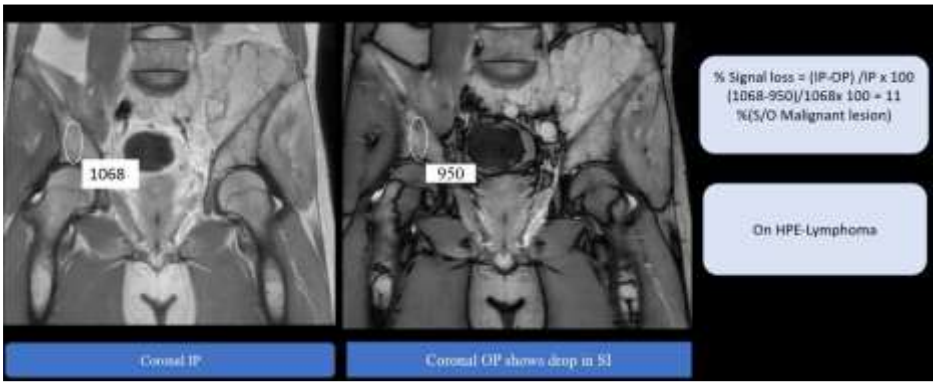

Figure 5. Soft tissue lesion in the left pelvic bone.

Discussion

Two-thirds of patients were males (62%). The mean age of the patients was 45.4 years (SD 18.6). In this study, patients with bone marrow lesions had an average age of 58 years, which is higher than in our study (6). In the study by Taheri et al., the average age was 53, which is higher than that of our study participants (7). The gender distribution (55% males) was similar in both studies, where male predominance was observed. However, the van-Vucht et al. study included females at 50% or more. The age distributions of patients in van-Vucht et al. and our study were similar (44 and 45.4 years, respectively) (8). 54% of patients had a signal drop intensity below 20%. The mean and median out-of-phase signals of the patients were 757.5 and 702, respectively. Tadros & Louka observed that among patients with malignant lesions, 6% (1/16) showed signal loss, whereas among patients with benign lesions, 71% (10/14) showed signal loss, suggesting that signal loss was higher in benign lesions, a finding similar to ours (9). In a similar study by Kohl et al. (37), the CSI technique (10) was used to assess pelvic bone marrow lesions. This study included patients with 54% malignant lesions, similar to our study. Furthermore, at a cut-off of 20% signal intensity drop, the CSI was able to pick all the malignant cases, i.e., 100% sensitivity; however, the specificity was low (61%), picking higher false positive cases, which indirectly increases the burden to healthcare and unnecessary out-of-pocket expenditure to patients to follow up for the evaluation of malignant lesions. However, the AUC was 0.88, similar to that in our study. Our findings were similar to those of previous studies, such as Tadros & Louka and Kohl et al., which showed that CSI demonstrated high sensitivity for detecting malignant lesions (9-10).

Van-Vucht et al.'s study showed that CSI differentiates the malignant bone marrow lesion with 53.1%, which is lower than our study (8). The difference might be due to the calculated signal intensity ratios in CSI, which may overlap between benign and malignant lesions, reducing their specificity. CSI relies on detecting differences in the water-to-fat ratio within the marrow. However, the resolution may be insufficient to differentiate small or mixed lesions where malignant and benign components coexist. Technical factors such as CSI measures voxel-level interactions between fat and water; infiltrative or sclerotic malignancies disrupt these interactions, leading to reduced signal cancellation. The presence of fat in benign lesions leads to greater phase cancellation, a hallmark of benign pathology in CSI. Malignant lesions often replace normal marrow elements, leading to reduced or absent fat content and, thus, diminished SI loss. Acute benign fractures can mimic malignancy due to edema or cellular proliferation, but these typically resolve over time, reaffirming their benign nature. X-ray and CT scans primarily provide structural imaging and fail to detect changes in bone marrow composition until the lesion becomes large. Both X-ray and CT often rely on density differences to identify lesions, which can lead to missed diagnoses of early-stage or small malignant lesions. X-ray imaging involves ionizing radiation, which limits its repeated use, whereas MRI is a non-invasive and safer imaging technique. PET scans, while valuable for detecting metabolic activity and identifying areas of increased cellular activity, have limitations in precisely characterising the tissue composition of bone marrow lesions. They carry a risk of false positives due to radiotracer uptake from benign processes or inflammation, complicating the interpretation of results.

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Generalizability

Dixon chemical-shift MRI is a widely available technique on modern MRI systems, so the method is potentially applicable in many radiology departments. This biological principle (malignant lesions replace marrow fat, whereas many benign lesions retain marrow fat) holds across different populations. Further studies and meta-analyses have shown that chemical-shift imaging performed well in differentiating benign from malignant marrow lesions and have supported its more widespread application.

Conclusion

Chemical-shift imaging was key to distinguishing benign from malignant bone marrow lesions. CSI demonstrates improved clinical differentiation, offering a more reliable diagnostic tool. In regular non-contrast pelvic imaging, CSI is a helpful supplemental MR method for characterising localised and diffuse marrow abnormalities. When it comes to detecting malignant illness, it is quite sensitive.

Limitations

To further validate these findings, conducting larger-scale studies across a wider range of bone marrow lesions to better quantify the percentage signal loss and assess the broader applicability of this MRI technique in clinical practice.

Recommendation

Chemical shift MRI using the Dixon technique is a useful adjunct to conventional MRI for the characterisation of bone marrow lesions, as it assesses the extent of residual intralesional fat. Malignant marrow-replacing lesions typically lose normal marrow fat, whereas many benign lesions retain microscopic fat and show signal loss on opposed-phase/out-of-phase images.

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Data Availability Statement

The datasets generated and analysed during the current study are not publicly available due to institutional restrictions and the presence of sensitive patients' information, but are available from the corresponding author on reasonable request and with permission from the Institutional Ethics Committee.

Funding

No specific grant from a public, private, or nonprofit organization was given for this research.

List of Abbreviations

MRI: Magnetic Resonance Imaging
SI: Signal intensity
IP: In-phase
OOP: Out of phase
CSI: Chemical Shift Imaging
STIR: Short Tau Inversion Recovery
ROI: Region of Interest
SPSS: Statistical Package for the Social Sciences
SD: Standard Deviation
HPE: Histopathological Examination
AUC: Area under the curve
CE-MRI: Contrast-Enhanced Magnetic Resonance Imaging

Conflict of Interest

The authors have declared that no conflict of interest.

Author contribution

All the authors contributed to the study concept and design. SG prepared the approval documents for presentation to the ethics committee and the primary investigation, drafting the original. SKP compiled the data and conducted the primary investigation. SP- supervised, conceptualised, and wrote the first draft of the manuscript. MC- acquired and analysed the data. All authors provided substantial contributions to subsequent versions of the manuscript, read and approved the final version for submission and publication.

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