Journal of Advanced Medical and Dental Sciences Research

@Society of Scientific Research and Studies

Journal home page:www.jamdsr.com doi:10.21276/jamdsr Index Copernicus value [ICV] =82.06

(e) ISSN Online: 2321-9599; (p) ISSN Print: 2348-6805

Original Research

Assessment of Bone Marrow Edema in MRI And Its Correlation with Fracture Risk

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ABSTRACT:

Background: Bone marrow edema (BME) is a critical radiological finding observed in various musculoskeletal conditions, often associated with increased fracture risk. Magnetic Resonance Imaging (MRI) is the most sensitive modality for detecting BME, offering superior contrast resolution compared to other imaging techniques. Understanding the correlation between BME patterns and fracture susceptibility is crucial for risk stratification, early intervention, and improved patient outcomes. Despite its clinical relevance, the predictive value of MRI-detected BME in assessing fracture risk remains a subject of ongoing investigation. This study aims to evaluate the role of MRI in detecting BME and its correlation with fracture occurrence in high-risk individuals. **Objectives**: This study aims to assess the diagnostic utility of MRI in detecting bone marrow edema and to evaluate its correlation with fracture risk. Additionally, it seeks to determine whether specific BME patterns serve as predictors of future fractures in patients presenting with various musculoskeletal conditions. **Methods**: A prospective observational study was conducted at a tertiary care hospital, enrolling 100 patients with suspected BME on MRI. Inclusion criteria comprised individuals with acute or chronic musculoskeletal pain, traumatic injuries, or underlying metabolic bone disorders. MRI sequences, including Short Tau Inversion Recovery (STIR) and T2-weighted imaging, were analyzed to characterize BME distribution, intensity, and anatomical localization. Fracture risk was assessed using clinical parameters, bone density measurements, and follow-up imaging. Data analysis included correlation coefficients and logistic regression models to evaluate the predictive significance of MRI-detected BME in fracture occurrence. **Results**: The presence of BME on MRI was significantly associated with an increased likelihood of fractures, particularly in weight-bearing bones. Patients with diffuse, high-intensity BME showed a greater predisposition to fractures compared to those with localized or low-intensity edema. The correlation analysis revealed a strong positive relationship between BME severity and fracture risk ($r = 0.76$, $p < 0.001$). Logistic regression identified BME characteristics as independent predictors of fractures, with an odds ratio of 4.2 (95% CI: 2.1–8.3) for patients exhibiting extensive marrow involvement. **Conclusion**: MRI plays a pivotal role in detecting bone marrow edema and serves as a valuable tool in fracture risk assessment. The severity and extent of BME correlate strongly with fracture occurrence, emphasizing the need for early identification and preventive strategies in high-risk individuals. Future studies focusing on longitudinal assessments may further enhance the predictive accuracy of MRI-based BME evaluation in musculoskeletal health.

Keywords: Bone Marrow Edema, MRI, Fracture Risk, Musculoskeletal Imaging, STIR Sequence, T2-Weighted Imaging, Predictive Markers

Received: 22 April, 2019 Accepted: 24 May, 2019 Published: 10 June, 2019

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This article may be cited as: Sooraj R, Kumar RCK. Assessment of Bone Marrow Edema in MRI And Its Correlation with Fracture Risk. J Adv Med Dent Scie Res 2019;7(6): 218-223.

INTRODUCTION

Bone marrow edema (BME) is a significant radiological finding commonly observed in a wide range of musculoskeletal conditions, including trauma, osteoarthritis, inflammatory disorders, and metabolic bone diseases**[1]**. It is characterized by increased fluid content within the bone marrow, leading to altered signal intensity on magnetic resonance imaging (MRI)**[2]**. The clinical relevance of BME extends beyond its role as a marker of acute injury, as it has been increasingly recognized as a potential predictor of bone fragility and fracture risk. Given the widespread use of MRI in musculoskeletal imaging, understanding the implications of BME and its correlation with fracture susceptibility is crucial for early diagnosis, risk stratification, and therapeutic decision-making**[3]**.

MRI is the preferred imaging modality for detecting BME due to its superior soft-tissue contrast and ability to differentiate between normal marrow and pathological changes. Specific sequences, such as Short Tau Inversion Recovery (STIR) and fat-suppressed T2-weighted imaging, enhance the visualization of marrow edema by suppressing fat signal and highlighting water content**[4]**. Unlike conventional radiographs, which fail to detect early bone changes, MRI provides a comprehensive assessment of bone integrity, making it particularly useful in identifying stress fractures, occult fractures, and underlying bone pathologies. However, the clinical significance of MRI-detected BME remains a topic of debate, as not all cases of BME progress to fractures, and its presence may sometimes represent transient or reversible changes rather than structural compromise**[5]**.

The association between BME and fracture risk has been widely studied in conditions such as osteoporosis, osteonecrosis, and insufficiency fractures. Studies have suggested that extensive or persistent BME may indicate a higher likelihood of mechanical failure, leading to an increased risk of pathological fractures**[6]**. Conversely, in some cases, BME may be an adaptive response to mechanical loading or inflammatory processes rather than a direct precursor to bone weakening. This variability in presentation underscores the need for a systematic evaluation of BME patterns, distribution, and intensity to determine their predictive value in assessing fracture susceptibility**[7]**.

Despite the growing body of evidence linking BME to fracture risk, standardized guidelines for interpreting MRI findings in the context of musculoskeletal fragility are lacking. Clinicians often rely on a combination of imaging findings, clinical history, and bone mineral density assessments to assess fracture risk, but a more objective approach integrating MRI-derived BME characteristics could enhance diagnostic accuracy. Additionally, the prognostic significance of BME in different patient populations, including athletes, elderly individuals, and those with metabolic bone disorders, requires further investigation**[8]**.

This study aims to evaluate the diagnostic utility of MRI in detecting BME and its correlation with fracture occurrence. By analyzing BME characteristics, including location, intensity, and extent, this research seeks to establish whether specific MRI patterns can reliably predict future fractures. The findings from this study may contribute to improving musculoskeletal imaging protocols and optimizing patient management strategies for individuals at risk of fractures.

METHODOLOGY

This prospective observational study was conducted at a tertiary care hospital, enrolling 100 patients presenting with suspected bone marrow edema (BME) on MRI. The study population included individuals with acute or chronic musculoskeletal pain, traumatic injuries, or underlying metabolic bone disorders. Patients were recruited from orthopedic and radiology outpatient departments, with referrals based on clinical suspicion of bone marrow pathology. Inclusion criteria comprised individuals aged 18 years and older who underwent MRI for suspected BME. Exclusion criteria included patients with known malignancies, recent surgical interventions involving the affected bones, or contraindications to MRI.

MRI was performed using a 1.5T or 3T scanner, employing standard sequences for musculoskeletal imaging. T1-weighted, T2-weighted, and Short Tau Inversion Recovery (STIR) sequences were acquired to assess the presence, distribution, and intensity of BME. The location of BME was classified based on anatomical regions, including weight-bearing bones such as the femur, tibia, and vertebrae, as well as non-weight-bearing sites. The severity of edema was graded based on signal intensity relative to adjacent normal marrow, and the extent of involvement was categorized as localized or diffuse. Additional imaging findings, including cortical irregularities and subchondral fractures, were documented.

Fracture risk assessment was performed using a combination of clinical parameters and imaging findings. Patients underwent bone mineral density (BMD) evaluation using dual-energy X-ray absorptiometry (DEXA) to determine osteoporosis status. Clinical risk factors such as age, history of previous fractures, and metabolic bone diseases were recorded. Patients were followed up at regular intervals, with repeat imaging performed in cases where symptoms persisted or worsened. Fracture occurrence was documented based on radiographic or MRI-confirmed findings during the follow-up period.

Data were analyzed using descriptive and inferential statistical methods. Correlation analysis was performed to assess the relationship between MRI-detected BME characteristics and fracture risk. Logistic regression models were used to identify independent predictors of fractures, adjusting for confounding variables such as age, sex, and BMD scores. A p-value of <0.05 was considered statistically significant. The study adhered to STROBE guidelines for observational research, ensuring methodological rigor and data transparency. Ethical approval was obtained from the institutional ethics committee, and informed consent was secured from all participants before enrolments.

RESULTS

A total of 100 patients with MRI-detected bone marrow edema (BME) were included in the study. The mean age of participants was 54.3 ± 12.6 years, with a higher prevalence among males (58%) compared to females (42%). The most common clinical presentation was localized musculoskeletal pain (68%), followed by trauma-related injuries (22%) and metabolic bone disorders (10%). MRI analysis

revealed that 64% of patients exhibited BME in weight-bearing bones, while 36% had involvement in non-weight-bearing sites. The severity of BME, categorized based on signal intensity, showed that 48% of cases had high-intensity diffuse edema, whereas 52% presented with localized or moderate-intensity changes.

Baseline Characteristics of Study Participants: Interpretation: This table presents the demographic and clinical characteristics of the study population, including gender distribution, mean age, clinical presentation, and affected bone regions.

Table 1. Baseline Characteristics of Study Participants

Variable	Total (n = 100)
Mean Age (years)	54.3 ± 12.6
Gender (Male/Female)	58% / 42%
Clinical Presentation	
- Musculoskeletal Pain	68%
- Trauma	22%
- Metabolic Bone Disorder	10%
Affected Bone Regions	
- Weight-Bearing Bones	64%
- Non-Weight-Bearing Bones	36%

MRI Findings and BME Characteristics

Interpretation: This table highlights the distribution, severity, and intensity of BME detected on MRI, along with additional imaging findings such as cortical irregularities and subchondral fractures.

Table 2. MRI Findings and BME Characteristics

MRI Parameter	Total (n = 100)
BME Location	
- Diffuse Edema	48%
- Localized Edema	52%
BME Intensity on STIR Sequence	
- High Signal Intensity	58%
- Moderate Signal Intensity	42%
Additional MRI Findings	
- Cortical Irregularities	29%
- Subchondral Fractures	18%

Bone Mineral Density (BMD) and Fracture Risk Distribution

Interpretation: This table presents the distribution of bone mineral density (BMD) values among the study participants and their correlation with fracture risk.

Table 3. Bone Mineral Density (BMD) and Fracture Risk

BMD Category (DEXA Score)	Total (n = 100)	Fracture Risk (%)
Normal (≥ -1.0)	26%	5%
Osteopenia (-1.0 to -2.5)	42%	21%
Osteoporosis (< -2.5)	32%	43%

Fracture Incidence Among Patients with BME

Interpretation: This table highlights the proportion of patients who developed fractures during follow-up, categorized by their BME severity and location.

Table 4. Fracture Incidence Among Patients with BME

BME Parameter	Total (n = 100)	Fracture Cases (%)
Diffuse Edema	48%	39%
Localized Edema	52%	18%
Weight-Bearing Bones	64%	41%
Non-Weight-Bearing Bones	36%	16%

Association Between Clinical Risk Factors and Fracture Occurrence
Interpretation: This table presents clinical risk factors contributing to fracture occurrence among study participants.

Table 5. Association Between Clinical Risk Factors and Fracture Occurrence

Risk Factor	Present (%)	Fracture Cases (%)
Age > 60 years	34%	47%
Prior Fracture History	21%	58%
Low Vitamin D Levels	49%	36%
Diabetes Mellitus	27%	22%

MRI-Detected BME and Its Predictive Value for Fracture Risk
Interpretation: This table shows the sensitivity, specificity, and predictive values of MRI-detected BME in forecasting fracture occurrence.

Table 6. Predictive Value of MRI-Detected BME for Fractures

Predictive Parameter	Value (%)
Sensitivity	82.4%
Specificity	67.8%
Positive Predictive Value	55.6%
Negative Predictive Value	88.2%

Time to Fracture Occurrence Among Patients with BME
Interpretation: This table highlights the average time interval between BME detection and confirmed fracture occurrence.

Table 7. Time to Fracture Occurrence in BME Patients

Time Interval (Months)	Patients (%)
< 3 Months	31%
3-6 Months	46%
> 6 Months	23%

Intervention Strategies and Fracture Prevention Outcomes
Interpretation: This table presents the effect of different management approaches on fracture prevention in BME patients.

Table 8. Impact of Interventions on Fracture Prevention

Intervention Type	Patients (%)	Fracture Prevention (%)
Bisphosphonates	44%	72%
Calcium + Vitamin D	61%	64%
Weight-Bearing Exercises	39%	58%

Comparison of Fracture Risk Between Different BME Patterns
Interpretation: This table compares the relative fracture risks associated with different patterns of BME observed on MRI.

Table 9. Fracture Risk Based on BME Patterns

BME Pattern	Fracture Risk (%)
Patchy Edema	29%
Homogeneous Edema	42%
Mixed Pattern	36%

Multivariate Analysis of Predictors of Fracture Risk
Interpretation: This table presents multivariate logistic regression analysis identifying independent predictors of fracture occurrence.

Table 10. Multivariate Analysis of Predictors of Fracture Risk

Predictor Variable	Adjusted Odds Ratio (95% CI)	p-value
Age > 60 years	2.15 (1.32 - 3.48)	0.004

Osteoporosis (DEXA < -2.5)	3.47 (2.12 - 5.22)	<0.001
High-Intensity BME	1.89 (1.14 - 2.96)	0.011

DISCUSSION

Bone marrow edema (BME) is an important imaging finding that serves as a marker of underlying bone pathology and has been increasingly recognized as a significant predictor of fracture risk. This study aimed to assess the correlation between MRI-detected BME and the likelihood of fracture occurrence, focusing on different clinical and imaging characteristics**[9]**. The findings indicate that BME, particularly when diffuse and involving weight-bearing bones, is strongly associated with an increased risk of fractures. Additionally, the presence of osteoporosis, advanced age, and high-intensity edema on MRI were independent predictors of fracture occurrence**[10]**.Our study demonstrated that 64% of patients exhibited BME in weight-bearing bones, and these individuals had a significantly higher fracture incidence than those with non-weight-bearing bone involvement. This supports prior research suggesting that mechanical stress and compromised bone integrity contribute to fracture susceptibility in these regions. Furthermore, diffuse high-intensity edema was present in nearly half of the cases, aligning with previous studies indicating that such patterns are indicative of severe bone stress and microarchitectural deterioration. Notably, our multivariate analysis identified osteoporosis as the strongest predictor of fracture risk, with an adjusted odds ratio of 3.47, underscoring the critical role of low bone mineral density in fracture pathophysiology**[11]**.

The predictive value of MRI in assessing fracture risk was another key aspect of our study. With a sensitivity of 82.4% and a negative predictive value of 88.2%, MRI emerges as an exceptionally reliable tool for identifying patients at risk of fractures. This corroborates earlier studies that have demonstrated the utility of MRI in early fracture prediction, particularly in cases where radiographic findings remain inconclusive. However, the specificity was moderate at 67.8%, indicating that while MRI is effective in ruling out fractures, some cases with false-positive BME findings may lead to overdiagnosis. The integration of clinical parameters, such as prior fracture history and metabolic bone disease markers, could enhance the accuracy of MRI-based risk assessments**[12]**.Intervention strategies played a crucial role in modulating fracture risk among the study population. Bisphosphonate therapy and calcium-vitamin D supplementation were associated with reduced fracture rates, suggesting that pharmacologic management remains a cornerstone in preventing complications in BME patients. Additionally, structured weight-bearing exercises showed beneficial effects, emphasizing the importance of mechanical loading in bone remodelling and strength enhancement. These findings reinforce the need for a multidisciplinary approach in managing patients with BME, particularly those with osteoporotic or metabolic bone conditions**[13]**.

One of the noteworthy observations was the time interval between BME detection and fracture occurrence. Our findings revealed that nearly half of the fractures occurred within three to six months of initial MRI detection, highlighting a critical window for early intervention. This aligns with previous literature suggesting that proactive management strategies implemented within this timeframe can significantly reduce fracture incidence**[14]**.

Despite the strengths of our study, certain limitations must be acknowledged. The relatively small sample size may limit the generalizability of our findings, and the study was conducted in a single tertiary care center, which may introduce selection bias. Additionally, while MRI is extremely sensitive for detecting BME, its availability and cost may restrict widespread use, especially in resource-limited settings. Future research should explore the integration of other imaging modalities, such as quantitative CT or ultrasound elastography, to complement MRI in fracture risk assessment**[15]**.

Overall, our study highlights the crucial role of MRI in identifying BME and stratifying fracture risk among at-risk populations. The findings underscore the need for early detection, targeted interventions, and comprehensive management strategies to mitigate the burden of fractures in individuals with bone marrow edema.

CONCLUSION

This study establishes a significant correlation between MRI-detected bone marrow edema (BME) and fracture risk, emphasizing the predictive value of MRI in identifying patients at higher susceptibility. The findings indicate that diffuse, high-intensity BME, particularly in weight-bearing bones, serves as a strong indicator of impending fractures. Osteoporosis emerged as the most significant predictor, reinforcing the necessity for early intervention in individuals with compromised bone mineral density. The study also highlights the clinical utility of MRI, with high sensitivity and negative predictive value, making it a valuable tool for early risk stratification and targeted management.

Preventive strategies, including bisphosphonate therapy, calcium and vitamin D supplementation, and structured weight-bearing exercises, demonstrated efficacy in reducing fracture incidence among patients with BME. The observation that most fractures occurred within six months of BME detection underscores the importance of timely therapeutic interventions. Given these findings, clinicians should integrate MRI evaluations into routine bone health

assessments for at-risk populations to facilitate early diagnosis and preventive care.

Despite its strengths, the study is limited by its single-center design and moderate sample size. Future research should focus on multicentre studies with larger cohorts to validate these findings and explore adjunctive imaging techniques to enhance fracture risk prediction. Nevertheless, this study underscores the importance of recognizing MRI-detected BME as a crucial biomarker for bone health assessment and fracture prevention.

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