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Association of Bone Marrow Edema with Knee Pain, Mechanical Symptoms and Meniscal Tear Severity on MRI

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ABSTRACT

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Knee pain and mechanical symptoms are common clinical manifestations of knee joint disorders and frequently lead to referral for MRI. MRI gives detailed assessment of the menisci, subchondral bone, ligaments, and other intra-articular structures. BME also referred to as a bone marrow lesion, is a frequent MRI finding and may reflect underlying mechanical stress or structural pathology. Meniscal abnormalities may also contribute to altered knee biomechanics, pain, and mechanical symptoms. However, the relationship between BME, clinical symptoms, and meniscal (MRI) Magnetic Resonance imaging grade within the same patient population remains insufficiently explored. The study aimed to determine the association of BME (Bone marrow edema) with knee pain severity, mechanical symptoms, and meniscal MRI grade in patients undergoing knee MRI. Prospective cross-sectional study was conducted among 60 participants referred for knee MRI at the Department of Radiology, Services Hospital, Lahore. Clinical information including knee pain, pain severity, and mechanical symptoms such as catching, locking, giving, and clicking way was recorded using a structured data collection proforma. MRI examinations were assessed for the presence, location, and extent of BME and for meniscal abnormalities according to MRI grading. Whole Data was analyzed using Statistical SPSS version 25. Descriptive statistics were used to summarize demographic, MRI finding and clinical. Chi-square and Fisher's Exact tests were used to assess associations between categorical variables, while Spearman's rank correlation was used to assess the relationship between BME extent and meniscal MRI grade. A p-value of <0.05 was considered statistically important. The average age of participants was 45.57 ± 12.37 years, with an age range of 19–69 years. There were 29 males (48.3%) and 31 females (51.7%). BME was present in 45 participants (75.0%), while meniscal abnormalities were identified in 50 participants (83.3%). A statistically significant association was observed between BME and knee pain severity ($\chi^2 = 29.385$, $df = 2$, $p < 0.001$). Severe pain was reported by 77.8% of participants with BME compared with 13.3% of those without BME. Mechanical symptoms were present in 68.9% of participants with BME compared with 33.3% without BME, demonstrating a statistically significant association ($\chi^2 = 5.926$, $df = 1$, $p = 0.015$; Fisher's Exact $p = 0.031$). A significant positive correlation was found between BME extent and meniscal MRI grade (Spearman's $\rho = 0.665$, $p < 0.001$). The frequency of BME increased across meniscal MRI grades, from 40.0% in participants without meniscal abnormality to 96.8% in those with Grade III abnormality ($\chi^2 = 21.912$, $df = 3$, $p < 0.001$). BME was a common MRI finding among patients presenting with knee pain and was significantly associated with greater pain severity, mechanical symptoms, and higher meniscal MRI grades. The increasing frequency of BME across meniscal MRI grades suggests that BME may be an important accompanying imaging finding in patients with more pronounced meniscal abnormalities. However, the cross-sectional design permits interpretation of these findings as associations only and does not establish causality.

Introduction

The joint of knee is a synovial joint which is one of biggest and most complex in the human body. It is important for weight-bearing, mobility, and performing daily activities or tasks [1]. The knee is susceptible to a variety of traumatic and degenerative diseases, as a result of its anatomical features and constant mechanical forces. Knee joint disorders are significant sources of severe pain, functional restriction, disability, and decreased quality of life [2].

Knee pain is a common Musculo-skeletal pain disorder seen in general and orthopedic practice. Mechanical symptoms like locking, catching, clicking, or the knee feeling unstable may also occur in patients with knee pain [3]. These symptoms can make it difficult to move the joint normally, make everyday activities difficult, and can be the first signs of a structural problem in knee. In patients with pain and mechanical complaints, meniscal pathology is one of the salient structural pathologies to be taken into account [4].

Patients with knee pain and mechanical symptoms can be difficult to assess clinically because the signs and symptoms of each knee disorder can occur concurrently. Therefore, MRI is an important part of the evaluation of internal rearrangement of the knee. With MRI, the menisci, ligaments, subchondral bone, and other intra-articular structures can be viewed in detail, and structural abnormalities can be evaluated comprehensively [3].

A commonly recognized abnormality that is seen in the knee on MRI is a tear of the meniscus. Can be seen after a sudden twist or turn injury or develop slowly with degenerative changes. A meniscal tear can be severe and/or morphological, and the grading of such abnormalities can be done through MRI. If the tear is more extensive or complicated, it may disrupt normal knee function and can lead to ongoing symptoms and functional impairment [5].

Another common MRI finding on the knee is bone marrow edema (BME). It is characterized by hyperintense signal in the bone marrow on fluid-sensitive MRI sequences, and can be a marker for several underlying pathological processes such as mechanical overload, inflammation, increased bone turnover, and subchondral bone microfractures [6]. Thus, BME could be a significant imaging indicator of stress or structural abnormality of the knee and not just a by-product of an MRI study.

BME has come into the spotlight due to its reported association with knee pain. Previous studies have shown that bone marrow lesions are common in painful knees, and there is evidence that the size and/or severity of these lesions can change concurrently with changes in knee pain [7]. This implies that BME could be involved in the clinical symptoms of the patient and may give useful information when evaluating knee MRIs and their results [8].

BME is also clinically relevant because of the association with meniscal pathology. A meniscal injury can alter the distribution of load over the knee joint and can cause it to be under more mechanical stress [9]. This altered biomechanics may be related to the development of BME. Therefore, the presence of BME may give further clues about the structural health of the knee and the degree of derangement within the knee [10].

Mechanical symptoms are generally thought to be indicative of meniscal pathology, but previous studies have demonstrated that these symptoms do not necessarily distinguish the presence or degree of a meniscal tear [11]. Likewise, MRI can sometimes not directly correlate with the severity of a patient's symptoms. This emphasizes the need to consider the clinical symptoms and the MRI findings as a whole and not in isolation [12].

Frequently, BME occurs as a secondary finding on the MRI and may be overlooked, and more often than not, abnormalities of the menisci or ligaments are also noted. Therefore, the contribution of the potential knee pain and mechanical symptoms may be underestimated [13]. Thus, correlating BME with clinical presentation and severity of the meniscal tear may give a better understanding of the structural and symptomatic characteristics of those who present for knee MRI [14].

Clinical symptoms and MRI can be measured together in a standardized way to investigate these relationships in prospective assessment. The synopsis brings forth limited local prospective evidence that has studied the relationship between BME, knee symptoms, and severity of meniscal tears in the same patient population in the context of Pakistan [15]. Thus, the study of these relationships could provide relevant regional evidence and aid in better understanding MRI results of individuals with mechanical knee symptoms and pain.

This study is therefore aimed at assessing the relationship between bone marrow edema and knee pain, mechanical symptoms, and the degree of meniscal tears on the knee MRI. The study will evaluate clinical signs in combination with MRI to see if BME is linked to significant clinical signs and various degrees of meniscal pathology. The results may help understand the clinical importance of BME and the connection between BME and IDK [16].

The evidence available, however, does not always provide a direct explanation for the relationship of BME to knee pain, mechanical symptoms, and the severity of meniscal tears in the same population. A few of the studies in the past have mainly concentrated on the relationship between bone marrow lesions and pain, or the relationship between meniscal damage and symptoms or bone marrow abnormality. So the overall relationship between these clinical and MRI factors are not been fully studied [38].

Another significant gap in the literature is the lack of prospective data from Pakistan that included BME along with clinical symptoms and the severity of the meniscal tear. A search of the available literature reports on various populations and study designs, and there are few local data to examine these variables in a single prospective cohort of patients who underwent knee MRI [39].

The present study is significant because it aims to provide a clearer understanding of the relationship between bone marrow edema (BME), knee pain, mechanical symptoms, and meniscal tear severity on magnetic resonance imaging (MRI). BME is increasingly recognized as an important MRI finding in patients with symptomatic knee disorders; however, it may sometimes be considered a secondary finding rather than being evaluated in relation to the patient's clinical presentation and other structural abnormalities. Examining these findings together may provide a more comprehensive understanding of the condition of the knee [23].

The study is also significant in the local research context because the synopsis identifies limited prospective evidence from Pakistan examining BME, knee symptoms, and meniscal tear severity together. Generating local evidence from patients undergoing knee MRI may contribute to the available body of musculoskeletal imaging research and provide a basis for comparison with findings reported in other populations [39].

Methodology

Study Design and Setting

This study used a cross-sectional design to assess the relationship between bone marrow edema (BME) and knee pain, mechanical symptoms, and the severity of meniscal tears identified on knee MRI. The study was conducted at the Department of Radiology, Services Hospital, Lahore, over a period of four months after approval of the synopsis.

Sample Size and Sampling

The sample size was calculated using Cochran's formula for a single proportion and was rounded up to 60 participants. Non-probability purposive sampling was used to select patients who met the predefined inclusion criteria and were undergoing knee MRI at the study institution.

Participants

Patients presenting with knee pain, with or without associated mechanical symptoms, who had been referred for knee magnetic resonance imaging (MRI), were willing to participate and provide informed consent, and fulfilled the study requirements were included. Patients with previous knee surgery, known inflammatory or infectious disorders of the knee, poor-quality or inadequate MRI examinations, contraindications to MRI, or who did not fulfill the inclusion criteria or were unwilling to provide informed consent were excluded.

Data Collection and MRI Assessment

Data were collected prospectively using a structured data collection proforma. Pain severity was assessed using the 0–10 Numeric Rating Scale (NRS) and categorized as mild (1–3), moderate (4–6), or severe (7–10). Mechanical symptoms including locking, catching, clicking, and giving way or instability were documented. Routine knee MRI examinations were reviewed to identify BME and meniscal abnormalities. BME was recorded as present or absent and, when present, its location and extent were documented. Meniscal abnormalities were graded according to the modified Stoller grading system. Grade III represented increased intra-meniscal signal extending to an articular surface and indicating a definite tear.

Statistical Analysis

Data were analyzed using Statistical Package for the Social Sciences (SPSS), version 25. Descriptive statistics were used to summarize demographic, clinical, and MRI characteristics. Chi-square and Fisher's exact tests were used to assess associations between BME and categorical clinical and MRI variables. Spearman's rank correlation was used to assess the relationship between BME-related findings and ordinal meniscal MRI grades. A p-value of less than 0.05 was considered statistically significant.

Ethical Consideration

Ethical approval was obtained from the Institutional Review Board (IRB) or Ethical Review Committee of Superior University, Lahore before data collection. Written informed consent was obtained from all participants. Participation was voluntary, confidentiality was maintained, and all data were used solely for research purposes.

Results

Demographic Characteristics

A total of 60 participants were included. The mean age was 45.57 ± 12.37 years, with an age range of 19–69 years. There were 29 male participants (48.3%) and 31 female participants (51.7%). The right knee was involved in 33 participants (55.0%), the left knee in 19 (31.7%), and both knees in 8 (13.3%). Moderate physical activity was the largest occupational category (38.3%).

Table 1: Demographic Characteristics of Study Participants (N = 60)

Variable	Category	Frequency (n)	Percent (%)
Gender	Male	29	48.3
	Female	31	51.7
Affected knee	Right	33	55.0
	Left	19	31.7
	Both	8	13.3
Occupation	Sedentary	22	36.7
	Moderate activity	23	38.3
	Heavy physical work	15	25.0

Clinical Characteristics and Mechanical Symptoms

All 60 participants (100.0%) presented with knee pain. Pain duration was less than one month in 13 participants (21.7%), one to three months in 25 (41.7%), and more than three months in 22 (36.7%). Severe pain was reported by 37 participants (61.7%), followed by mild pain in 12 (20.0%) and moderate pain in 11 (18.3%). Mechanical symptoms were reported by 36 participants (60.0%). Clicking was the most frequent individual symptom (46.7%), followed by locking (38.3%), catching (30.0%), and giving way (20.0%).

Table 2: clinical characteristics and mechanical symptoms (n = 60)

Variable	Category	Frequency (n)	Percent (%)
Knee pain present	Yes	60	100.0
Duration of pain	< 1 month	13	21.7
	1–3 months	25	41.7
	> 3 months	22	36.7
Pain severity	Mild	12	20.0
	Moderate	11	18.3
	Severe	37	61.7
Mechanical symptoms present	Yes	36	60.0
	No	24	40.0

Locking	Yes	23	38.3
Catching	Yes	18	30.0
Clicking	Yes	28	46.7
Giving way	Yes	12	20.0
Mechanical symptoms affecting daily activities	Yes	23	38.3
	No	37	61.7

Frequency and Distribution of Bone Marrow Edema

Bone marrow edema was identified on knee MRI in 45 participants (75.0%), while 15 participants (25.0%) had no BME. Among participants with BME, mild BME was recorded in 16 (35.6%), moderate BME in 15 (33.3%), and severe BME in 14 (31.1%). The medial femoral condyle was the most common location, identified in 21 participants (46.7%), followed by the lateral femoral condyle and medial tibial plateau (20.0% each).

Table 3: Frequency and extent and location of bone marrow edema on knee mri (n = 60)

BME variable	Category	Frequency (n)	Percent (%)
BME status	Present	45	75.0
	Absent	15	25.0
BME extent	Mild	16	35.6
	Moderate	15	33.3
	Severe	14	31.1
Location	Medial femoral condyle	21	46.7
	Lateral femoral condyle	9	20.0
	Medial tibial plateau	9	20.0
	Lateral tibial plateau	6	13.3

Distribution and Severity of Meniscal Abnormalities

A meniscal abnormality was identified on MRI in 50 participants (83.3%), while 10 (16.7%) had no meniscal abnormality. Grade I abnormalities were present in 12 participants (20.0%), Grade II in 7 (11.7%), and Grade III in 31 (51.7%). Among participants with meniscal abnormality, the medial meniscus was involved most frequently (46.0%), followed by the lateral meniscus (40.0%) and both menisci (14.0%).

Table 4: distribution and severity of meniscal abnormalities on mri (n = 60)

Variable	Category	Frequency (n)	Percent (%)
Meniscal tear present	Yes	50	83.3
	No	10	16.7
Meniscal MRI grade	Grade I	12	20.0
	Grade II	7	11.7
	Grade III	31	51.7

	None	10	16.7
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Meniscal abnormalities were present in 83.3% of participants. Grade III abnormalities were the most frequent category, accounting for 51.7% of the total study population.

Association of Bone Marrow Edema with Knee Pain Severity

Because all participants in the study presented with knee pain, the presence or absence of pain could not be compared between BME groups. Among participants without BME, 10 of 15 (66.7%) reported mild pain, 3 (20.0%) moderate pain, and 2 (13.3%) severe pain. In contrast, among participants with BME, 2 of 45 (4.4%) reported mild pain, 8 (17.8%) moderate pain, and 35 (77.8%) severe pain. The Pearson Chi-square test indicated a statistically significant association between BME status and pain severity, $\chi^2(2, N = 60) = 29.385$, $p < 0.001$. A Monte Carlo exact significance procedure also confirmed the association (exact $p < 0.001$).

Table 5: association between bme status and pain severity (n = 60)

BME status	Mild n (%)	Moderate n (%)	Severe n (%)	Total
No	10 (66.7)	3 (20.0)	2 (13.3)	15
Yes	2 (4.4)	8 (17.8)	35 (77.8)	45
Total	12	11	37	60

Association of Bone Marrow Edema with Mechanical Symptoms

Mechanical symptoms were present in 31 of 45 participants (68.9%) with BME compared with 5 of 15 participants (33.3%) without BME. A statistically significant association was found between BME and mechanical symptoms ($\chi^2(1, N = 60) = 5.926$, $p = 0.015$; Fisher's Exact $p = 0.031$).

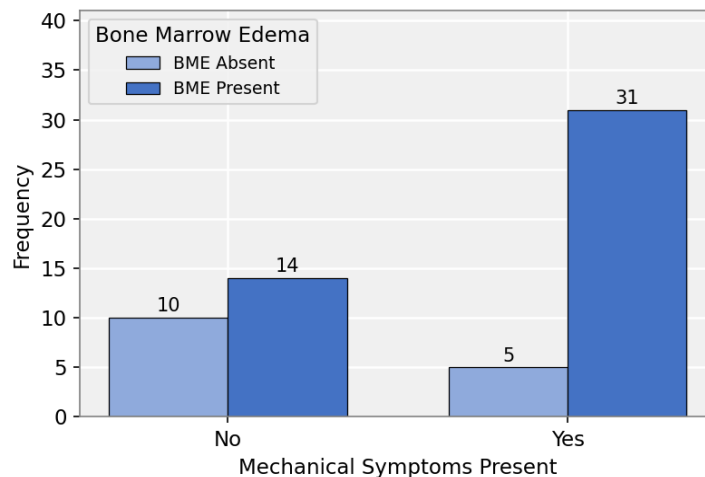


Figure 1: Association between BME status and mechanical symptoms

Association between BME Extent and Meniscal MRI Grade

A statistically significant positive correlation was observed between BME extent and meniscal MRI grade (Spearman's $\rho = 0.665$, $p < 0.001$, $N = 60$). BME was present in 40.0% of participants with no meniscal abnormality, 41.7% with Grade I abnormalities, 85.7% with Grade II abnormalities, and 96.8% with Grade III abnormalities. The Pearson Chi-square test demonstrated a statistically significant association between BME status and meniscal MRI grade, $\chi^2(3, N = 60) = 21.912$, $p < 0.001$. The association was confirmed using a Monte Carlo exact significance procedure (exact $p < 0.001$).

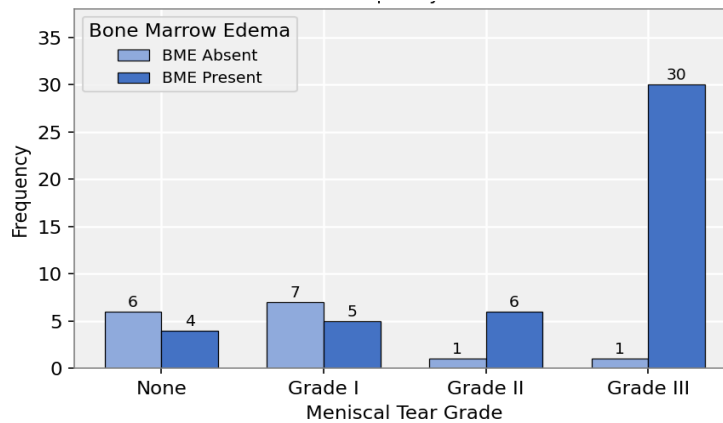


Figure 2: BME According to Meniscal MRI Grade

Discussion

The present study was conducted to determine the association of bone marrow edema (BME) with knee pain, mechanical symptoms, and meniscal tear severity on magnetic resonance imaging (MRI). A total of 60 participants were included in the study. The mean age was 45.57 ± 12.37 years, with an age range of 19–69 years. There were 29 male participants (48.3%) and 31 female participants (51.7%). The right knee was the most frequently affected side, accounting for 33 participants (55.0%), followed by the left knee in 19 participants (31.7%) and bilateral involvement in 8 participants (13.3%).

Bone marrow edema was present in 45 participants (75.0%; 95% CI 62.8–84.2), whereas 15 participants (25.0%) had no BME. Meniscal abnormalities were identified in 50 participants (83.3%), with Grade III abnormalities being the most frequent category, observed in 31 participants (51.7%). Among participants with BME, the medial femoral condyle was the most common site, accounting for 21 cases (46.7%). These findings demonstrate that BME and meniscal abnormalities were common MRI findings in this symptomatic study population.

An important consideration in interpreting the present findings is that all 60 participants had knee pain because the presence of knee pain was part of the study's inclusion criteria. Therefore, the study could not compare BME with the presence versus absence of knee pain. Instead, the relationship between BME and the severity of knee pain was assessed.

The findings demonstrated a statistically significant association between BME and pain severity. Among the 15 participants without BME, 10 (66.7%) reported mild pain, 3 (20.0%) reported moderate pain, and only 2 (13.3%) reported severe pain. In contrast, among the 45 participants with BME, only 2 (4.4%) reported mild pain, 8 (17.8%) reported moderate pain, and 35 (77.8%) reported severe pain. The Pearson Chi-square test showed a statistically significant association between BME status and pain severity, $\chi^2(2, N = 60) = 29.385$, $p < 0.001$. However, BME should not be interpreted as an independent cause of pain because the cross-sectional nature of the study does not establish a temporal or causal relationship.

Mechanical symptoms were reported by 36 participants (60.0%) overall. Among participants with BME, mechanical symptoms were present in 31 of 45 participants (68.9%), compared with 5 of 15 participants (33.3%) without BME. The Pearson Chi-square test demonstrated a statistically significant association between BME status and mechanical symptoms, $\chi^2(1, N = 60) = 5.926$, $p = 0.015$. Fisher's Exact Test was also statistically significant ($p = 0.031$). These findings indicate that mechanical symptoms were more frequently observed among participants with BME. In the present study, meniscal abnormalities were also common, occurring in 83.3% of participants.

The present study demonstrated a statistically significant positive relationship between BME extent and meniscal MRI grade. Spearman's rank correlation showed a correlation coefficient of $\rho = 0.665$ with $p < 0.001$ ($N = 60$). The positive correlation indicates that participants with higher meniscal MRI grades tended to have greater BME extent. BME was present in 4 of 10 participants (40.0%) without a meniscal abnormality, 5 of 12 participants (41.7%) with Grade I abnormalities, 6 of 7 participants (85.7%) with Grade II abnormalities, and 30 of 31 participants (96.8%) with Grade III abnormalities. The Pearson Chi-square test demonstrated a statistically significant association between BME status and meniscal MRI grade, $\chi^2(3, N = 60) = 21.912$, $p < 0.001$.

The BME prevalence of 75.0% observed in the present study is higher than the figures generally reported in community-based osteoarthritis cohorts. Felson et al. reported that bone marrow lesions were substantially more frequent in painful than in

painless knees, and later demonstrated longitudinally that enlarging lesions were associated with the development of new knee pain [7, 34]. The present finding that 77.8% of participants with BME reported severe pain, compared with 13.3% of those without BME, is consistent in direction with that literature, although the magnitude of the difference in this study is larger. Unay et al. similarly reported a relationship between the size of bone marrow edema and the severity of knee pain [32], which is in keeping with the graded pattern observed here.

The correlation between BME extent and meniscal MRI grade ($\rho = 0.665$) is consistent with Lo et al., who demonstrated a strong association between MRI-detected meniscal derangement and bone marrow lesions in knees with osteoarthritis [33]. Damasena et al. similarly reported that meniscal extrusion and signal change were associated with subchondral change [36], supporting a biomechanical explanation in which impaired load distribution across a damaged meniscus increases subchondral stress.

The findings regarding mechanical symptoms warrant a more cautious comparison. Thorlund et al. found that catching and locking occurred with broadly similar frequency in patients with and without meniscal tears [46], and McHugh et al. concluded that mechanical symptoms are only moderately sensitive and specific for meniscal tear [11]. The present study did not test mechanical symptoms against meniscal status directly, but did find them significantly more frequent in participants with BME (68.9% versus 33.3%; $\chi^2(1) = 5.926$, $p = 0.015$, $\phi = 0.314$). Differences in study population, sample size, MRI field strength and protocol, definitions of BME extent, and meniscal grading systems all influence the strength of reported associations. The present findings should therefore be considered supportive of an association rather than definitive evidence of a causal pathway.

Conclusions

The findings of this study demonstrate that bone marrow edema (BME) is common in patients who get knee MRIs and have knee pain. Bone marrow edema (BME) is strongly linked to intense pain, mechanical symptoms and higher meniscal MRI grades in this group. The medial femoral condyle was the common place for bone marrow edema (BME) among those with bone marrow edema (BME). The study showed a significant link between bone marrow edema (BME) and how severe knee pain was, with severe pain being most common in participants who did have bone marrow edema (BME). A significant link was also seen between bone marrow edema (BME) and mechanical symptoms. The study also showed a positive relationship between how much bone marrow edema (BME) there was and the meniscal grade seen on MRI, where larger bone marrow edema (BME) areas often matched higher meniscal MRI grades in the sample. The number of cases of bone marrow edema (BME) grew across the meniscal MRI abnormality categories, with the highest occurrence seen in participants with Grade III abnormality. The fact that bone marrow edema (BME) appears often with higher meniscal grades suggests that bone marrow edema (BME) may be an important extra sign on MRI, in patients who have more serious meniscal problems. However, because the study looked at data at one point in time these findings only show associations. They should not be taken as proof that bone marrow edema (BME) causes pain, mechanical symptoms or meniscal damage.

Limitations

- The study used a prospective cross-sectional design; therefore, temporal and causal relationships between BME, pain, mechanical symptoms, and meniscal abnormalities could not be established.
- The study was conducted in a diagnostic imaging setting, so the study population may differ from patients attending other hospitals, diagnostic centers, or healthcare facilities.
- Consecutive non-probability sampling was used, which may limit the generalizability of the findings to the wider population.
- The study included 60 participants. A larger sample would provide greater statistical precision and allow more detailed subgroup analysis.
- Since knee pain was an inclusion criterion, all participants had knee pain. Therefore, BME could not be compared between patients with and without knee pain; instead, pain severity was assessed.

Recommendations

- Future studies should use a larger sample size to improve precision and better represent patients with knee problems.
- Studies in different imaging centers and hospitals could improve the applicability of findings and allow comparison of different patient groups.
- Where possible, probability-based sampling should be used to reduce bias and improve representativeness.

- Future research could include a comparison group without knee pain to assess differences in BME between symptomatic and asymptomatic individuals.
- Longitudinal research could assess changes in BME, meniscal abnormalities, pain, and mechanical symptoms over time.
- More studies are needed to determine whether the presence and extent of BME provide clues about symptom severity and overall knee health.

Declarations

Author Contributions: Nishat Fatima: study planning, data acquisition, statistical analysis, and preparation of the initial manuscript. Dr. Saima Haider: academic supervision, development of the study concept, and manuscript editing. Wajeeha Tariq: provided methodological guidance and assisted with the interpretation of the findings and critical review of the manuscript. All authors reviewed and approved the final version of the manuscript.

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