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RESEARCH

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Clarifying the relation between the marrow contusion pattern around the knee and the types of concomitant intra-articular soft tissue injuries

Mohamed H. Faheem[1*], Ahmed R. Saddik[1] and Medhat M. Refaat[1]

Abstract

Background Acute knee injuries represent a prevalent cause of morbidity among athletes and, if overlooked, could potentially lead to the development of chronic functional limitations. This study aimed to identify marrow contusion patterns around the knee and find the relation between each pattern and the intra- and extra-articular soft tissue injuries. This was a retrospective cross-sectional study carried out on 109 patients who presented to the hospital where the study was held with recent knee joint injury, for which magnetic resonance imaging was requested from January 2017 to January 2019.

Results The entire patient population under investigation had a mean age of 30.2 ± 9.7 years. Regarding gender distribution, the study comprised 90 males (82.6%) and 19 females (17.4%). Regarding bone marrow contusion patterns in all studied patients, it was pivot shift in 58 patients (53.2%), clip injury in 11 patients (10.1%), dashboard injury in 7 patients (6.4%), hyperextension injury in 3 patients (2.8%), lateral patellar dislocation in 15 patients (13.8%), and others in 15 patients (13.8%). In the pivot shift pattern group, anterior cruciate ligament (ACL), medial meniscus, and medial collateral ligament (MCL) injuries were most commonly seen in 94.8, 50, and 44.8% of patients, respectively. Among the clip pattern group, MCL, ACL, and medial meniscus injuries were most common in 90.9, 36.4, and 36.4%, respectively. Regarding the dashboard injury group, posterior cruciate ligament (PCL), ACL, and medial and lateral menisci were the most common injury structures (100, 57.1, 42.9, and 42.9%, respectively). Despite the hyperextension pattern being found in a small number of patients, it shows 100% medial meniscal and 66.7% PCL injuries. Within the group of lateral patellar dislocation patterns, 100% of cases exhibited injuries to the medial patellofemoral ligament.

Conclusions Precise localization of the marrow contusion around the knee and defining its pattern help to anticipate the most probable associated soft tissue injuries and, thus, can increase our sensitivity in their detection. This can have a better impact on patients' management outcomes.

Keywords Knee injuries, Bone marrow contusion, MRI, Soft tissue injuries

Background

Acute knee injuries frequently contribute to morbidity among athletes, and if not adequately addressed, they have the potential to lead to chronic functional impairment [1].

Magnetic resonance imaging (MRI) is used more commonly for knee injuries than for trauma to other joints. It

*Correspondence:
Mohamed H. Faheem
mohamed.hosny@bmed.bu.edu.eg; dr.hosny.rad@gmail.com
[1] Radiology Department, Benha Faculty of Medicine, Benha University, El-Shaheed Farid Nada, Qism Banha, Second Banha 6470031, Al-Qalyubia Governorate, Egypt

serves as a valuable diagnostic tool for clinicians, facilitating the assessment of soft tissue injuries, osseous structures, and articular surfaces. Consequently, MRI plays a pivotal role in guiding clinical decision-making [2].

Traumatic bone marrow edema can occur from direct or indirect trauma [3]. It is demonstrated in MRI as a diffuse or localized hypointense signal intensity on T1-WIs and increased signal intensity on T2-WIs, STIR, and other fat-suppressed MRI sequences. This appearance is believed to correspond to regions of edema, hemorrhage, or infarction resulting from trabecular microfractures, all of which can collectively contribute to changes in marrow signal. The distribution of bone contusion areas observed in MRI can offer insights into the injury mechanism and may aid in predicting and confirming ligamentous injuries [4].

The pattern of bone marrow edema resembles a footprint left in the aftermath of an injury, offering valuable insights into the injury mechanism and any accompanying soft tissue injuries [5].

This study aimed to identify marrow contusion patterns around the knee and find the relation between each pattern and the intra- and extra-articular soft tissue injuries.

Methods

This was a retrospective cross-sectional study; the cases enrolled in this study represent the post-traumatic knee MR studies archived to the PACS system (PaxeraUltima worklist version: 7.9.7.0 and viewer version: 6.1.3.7) of the Radiology Department in the hospital where the study was held during the period from January 2017 to January 2019.

Inclusion criteria were patients within the age group of 10–50 years old with knee pain following a recent traumatic insult (less than 6 weeks). The wide age group was a limitation of this study and may bias our research findings.

The study sample size was 147 patients; 38 were excluded due to being outside the age range ($n=11$), presence of metallic hardware ($n=5$), poor image quality ($n=14$), unavailable patients' clinical data ($n=5$), or unavailable patients' consent ($n=3$). The remaining 109 patients (109 knees, a single knee for each patient) were enrolled in this study (Fig. 1).

The research ethics committee of Benha Faculty of Medicine approved the study.

All patients were subjected to full history taking and clinical examination (vital signs and local knee examination by the orthopedician). The positive findings were collected from the patients' records. We collected the following information for all patients:

- Demographics (age and sex).
- Injury details including date of injury, etiology (sports injury, road traffic accident, etc.), and mechanism of injury (twisting injury, dashboard injury, varus injury, etc.).
- MRI examination: The patients underwent an MRI of the affected knee joints to evaluate the marrow contusion pattern and associated soft tissue injuries.

Technique of MR examination

Patient preparation: The patients were instructed to remove metallic objects from their bodies.

Positioning: Supine, feet first, and surface knee coil was applied to the affected knee. The knee was immobilized by sliding the small cushions between the knee and coil.

Protocol: Patients were scanned using 1.5 Tesla Siemens MAGNETOM and 1.5 Tesla Philips Ingenia. The knee joint was evaluated using various imaging sequences, including coronal (STIR/mFFE), sagittal (T1, T2, PD, and PDFS), and axial (T2 and PDFS) sequences. Table 1 shows the different sequence parameters.

Two radiologists (11 and 8 years' experience in MR interpretation) examined the studies in a double-blind pattern. The findings were approved as positive if agreed upon by both radiologists.

Data management

The patients were classified into five groups based on the mechanism of injury, according to Sanders et al. [6]. These groups are clip, pivot shift, hyperextension, dashboard, and lateral patellar dislocation.

We delineated the bone marrow contusion pattern and concurrent soft tissue injuries within each group. The observed marrow contusion pattern and the prevalence of soft tissue injuries were graphed and analyzed to identify any significant correlations.

Soft tissue injuries were categorized as either being present or absent. Meniscal tears were radiologically graded from I to III (tear, root tear, and bucket handle tear). Cruciate ligament injuries were radiologically graded as sprain, partial tear, and complete tear. Collateral ligament injuries were graded from I to III (sprain, partial tear, and complete tear).

Statistical analysis

Data analysis was conducted using the Statistical Package for the Social Sciences (SPSS) version 24. Quantitative data were summarized as mean ± SD, where "mean" is the average of a set of numbers, calculated by dividing the total sum by the count of numbers. "Standard deviation (SD)" is used to quantify the variation or spread of these numbers. A smaller SD indicates that the numbers are closer to the mean, whereas a larger SD shows that the

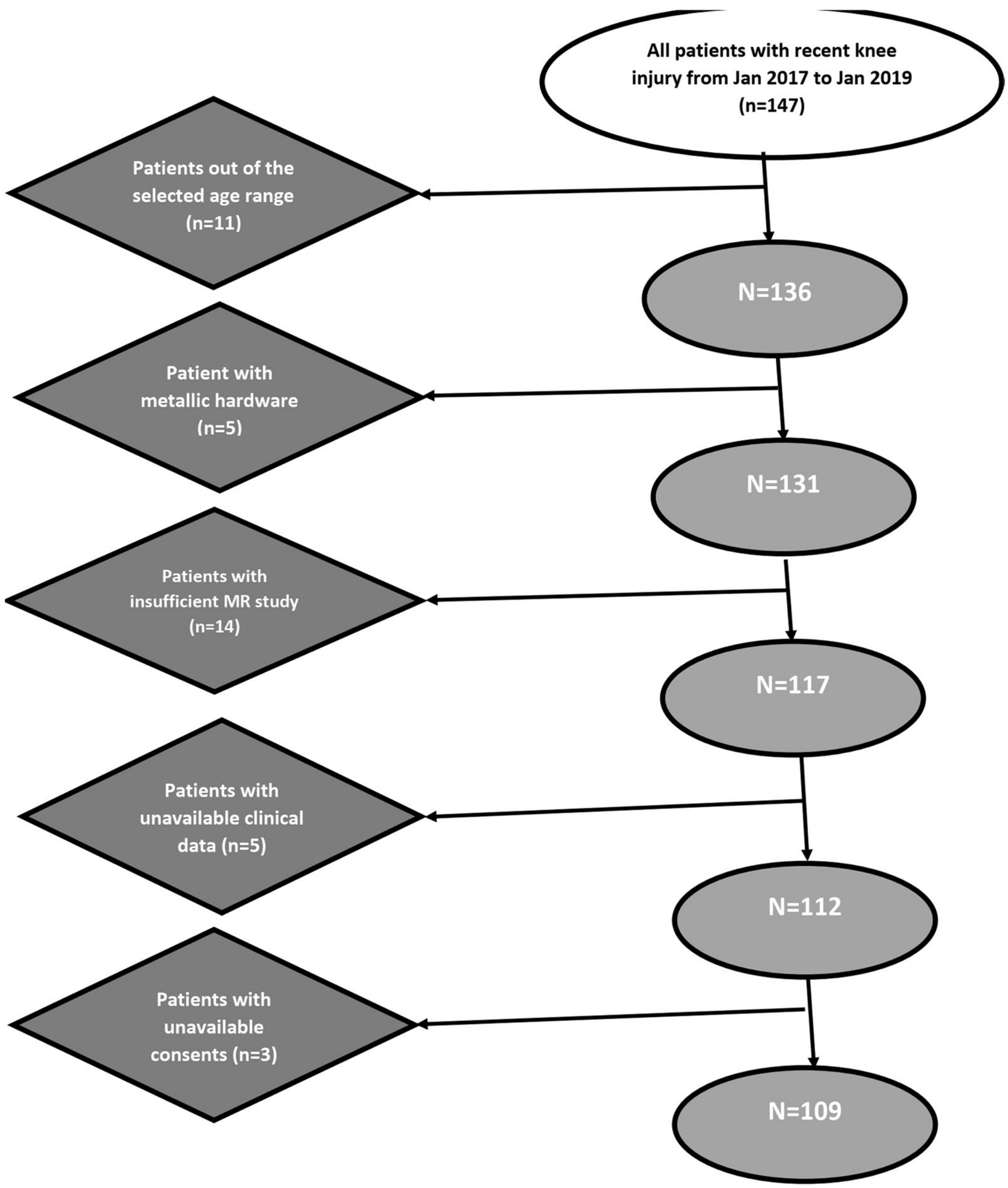

Fig. 1 Flowchart showing how the study population was selected

Table 1 Parameters of the MR sequences

	TR (ms)	TE (ms)	Flip angle	FOV	Slice thickness	Matrix
Sagittal T1	800	8	90°	160 mm	3 mm	268×273
Sagittal T2	4500	90	90°	160 mm	3 mm	320×263
Sagittal PD	3500	14	90°	160 mm	3 mm	358×314
Sagittal PDFS	1500	30	90°	160 mm	3 mm	240×230
Coronal STIR	4000	60	100°	160 mm	3 mm	228×185
Coronal T2*	850	14	30°	160 mm	3 mm	272×218
Axial T2	4000	110	90°	160 mm	3.5 mm	268×215
Axial PDFS	3500	30	90°	160 mm	3.5 mm	268×215

numbers are spread out over a wider range. Qualitative data were represented as frequencies and percentages. The Chi-square test was employed to compare non-parametric data. Probability (P-value): A P-value of less than 0.05 was deemed statistically significant.

Results

The number of patients enrolled in our study was 109 (109 knees, one knee for each patient). The average age of the entire patient cohort was 30.2 ± 9.7 years, ranging from 12 to 50 years. Among the studied patients, there were 90 males (82.6%) and 19 females (17.4%) (Table 1).

Regarding the mechanism of injury in the study patients, it was pivot shift in 58 patients (53.2%), clip injury in 11 patients (10.1%), dashboard injury in 7 patients (6.4%), hyperextension injury in 3 patients (2.8%), lateral patellar dislocation in 15 patients (13.8%), and others in 15 patients (13.8%) (Table 2).

Table 2 Demographic characteristics and description of BM contusion pattern in all studied patients

		Studied patients (*n* = 109)	
Sex	Male	90	82.6%
	Female	19	17.4%
Age (years)	Mean ± SD	30.2 ± 9.7	
	Min–max	12–50	
BM contusion patterns	Pivot shift injury	58	53.2%
	Clip injury	11	10.1%
	Dashboard injury	7	6.4%
	Hyperextension injury	3	2.8%
	Lateral patellar dislocation pattern	15	13.8%
	Others	15	13.8%

The distribution and location of bone marrow edema in all contusion injury patterns are shown in Table 3

Pivot shift marrow contusion pattern and associated soft tissue injuries

In the study of the pivot shift marrow contusion pattern, a significant association was observed between this injury pattern and anterior cruciate ligament (ACL) injuries, with ACL damage present in 94.8% (55 instances) of cases ($P < 0.001$). Medial meniscus injury was the subsequent most common soft tissue damage identified in cases with a pivot shift injury mechanism, occurring in 50% (29 cases) of the cases. This was followed by medial collateral ligament (MCL) injuries, found in 44.8% (26 cases). Additional soft tissue injuries included lateral meniscus injuries in 34.5% (20 cases) and lateral collateral ligament (LCL) injuries in 15.5% (9 cases) of the cases (Fig. 2).

Clip injury marrow contusion pattern and associated soft tissue injuries

A notable association was found between MCL injuries and the clip injury bone marrow edema pattern, with MCL injuries detected in 90.9% (10 cases) within this category ($P < 0.001$). The subsequent most frequent soft tissue damages were to the ACL and medial meniscus, each occurring in 36.4% (four instances), and posterior cruciate ligament (PCL) injuries were present in 27.3% (three instances).

The combination of MCL, ACL, and medial meniscus injuries, known as O'Donoghue's triad, was observed

Table 3 Location of BM edema in all contusion injury patterns

Side	Contusion pattern	*N*	%
Pivot shift injury (*n* = 58)	Lateral mid-femoral condyle + posterolateral tibial plateau	26	44.8
	Lateral mid-femoral condyle + posterolateral tibial plateau + posteromedial tibial plateau	22	37.9
	Lateral mid-femoral condyle + posterolateral tibial plateau + posteromedial tibial plateau + medial femoral condyle	10	17.2
Clip injury (*n* = 11)	Lateral femoral condyle + lateral tibial plateau + small area at medial femoral condyle	6	54.5
	Lateral femoral condyle + small area at medial femoral condyle	5	45.5
Dashboard injury (*n* = 7)	Anterior aspect of the tibia	6	85.7
	Anterior aspect of the tibia + posterior surface of the patella	1	14.3
Hyperextension injury (*n* = 3)	Kissing contusion at anterior aspect of proximal tibia and distal femur	2	66.4
	Kissing contusion at the medial aspect of the proximal tibia and distal femur	1	33.3
Lateral patellar dislocation (*n* = 15)	Anterolateral aspect of the lateral femoral condyle + inferomedial aspect of the patella	15	100
Others (*n* = 15)	Lateral tibial plateau	4	26.7
	Medial femoral condyle	5	33.3
	Medial tibial plateau	6	40

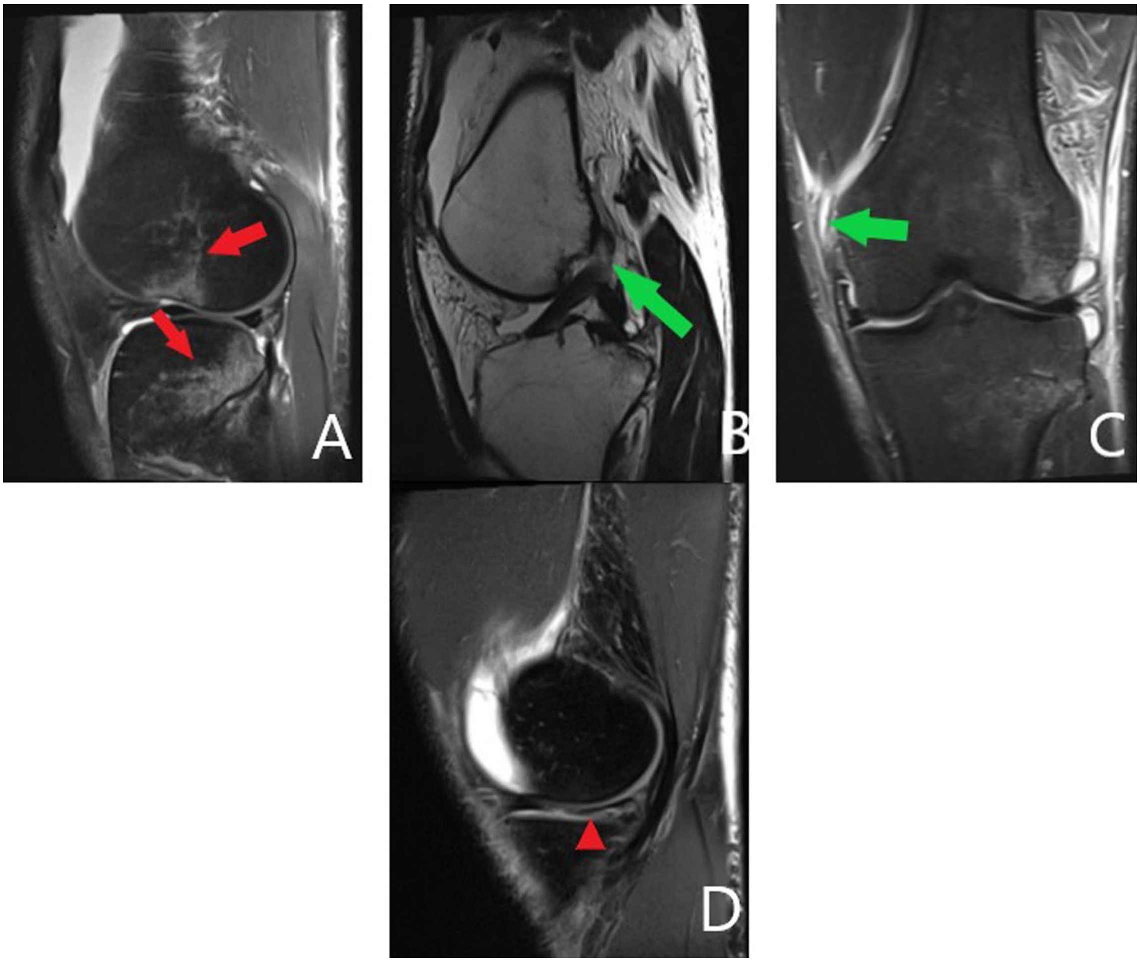

Fig. 2 A 36-year-old male patient presented with the left knee pain and swelling a few days after a football injury. **A**: Sagittal PDFS MR image shows classical pattern of pivot shift bone marrow edema, involving posterolateral tibial and lateral femoral condyles (red arrows), **B**: Sagittal oblique T2 MR image shows torn ACL at its femoral attachment (green arrow), **C**: Coronal STIR MR image shows grade II injury of the MCL (green arrow), and D: Sagittal PDFS MR image shows oblique tear of the posterior horn medial meniscus (red triangle)

in 20.7% (12 instances) of pivot shift injuries and 27.3% (three instances) of clip injuries (Fig. 3).

Dashboard injury marrow contusion pattern and associated soft tissue injuries

A very strong correlation was found between PCL injuries and the dashboard pattern of bone marrow edema, with PCL injuries present in 100% (all seven instances) of the cases ($P < 0.001$). The second most frequently observed soft tissue injury was ACL injury, present in 4 cases (57.1%), followed by medial and lateral meniscus (LM) injuries, each observed in 3 cases (42.9%). Other soft tissue injuries observed were MCL in 2 cases (28.6%) (Fig. 4).

Hyperextension injury marrow contusion pattern and associated soft tissue injuries

The group number was very small (three patients). However, each PCL, ACL, and MCL were found in two cases (66.7%), while medial meniscus (MM) injury was seen in 3 cases (100%).

Lateral patellar dislocation injury marrow contusion pattern and associated soft tissue injuries

A highly significant association was found between injuries to the medial patellofemoral ligament (MPFL) and the pattern of lateral patellar dislocation, with injuries to the medial patella-femoral ligament occurring in all cases within this group. Injuries to the ACL and MCL were each observed in one case (6.7%) (Fig. 5).

Fig. 3 A 25-year-old male patient presented with the left knee pain shortly after a sport injury. **A**: Coronal STIR MR image shows clip injury pattern of edema involving the lateral femoral condyle (white arrow) with associated grade II sprain of the MCL (red arrowheads) and **B**: Axial T2 MR image shows grade II sprain of MCL (red arrowhead)

Discussion

Bone marrow edema commonly occurs after trauma. The distribution of the marrow edema areas in MRI can reflect the thumbprint of the injury mechanism and, hence, can predict the associated soft tissue injury.

This study aimed to identify marrow contusion patterns around the knee and find the relation between each pattern and the associated soft tissue injuries.

Sanders and colleagues [6] identified five key mechanisms of knee injury: pivot shift injury, dashboard injury, clip injury, hyperextension injury, and lateral patellar dislocation. By examining the patterns of edema distribution, one can determine the injury mechanism and, thus, make relatively precise forecasts about the existence of particular soft tissue injuries.

Our study found a bone marrow contusion pattern in all studied patients. The main type was pivot shift in 58 patients (53.2%), followed by lateral patellar dislocation in 15 patients (13.8%), clip injury in 11 patients (10.1%), dashboard injury in 7 patients (6.4%), hyperextension injury in 3 patients (2.8%), and others in 15 patients (13.8%).

According to this study, pivot shift injury was the most common marrow contusion pattern involving 58 cases (53.2%). This was comparable with Sahoo et al.'s [7], in which the most common pattern was pivot shift injury, which accounted for 56.5% of patients, and with Bhatnagar and Rathore study [8], in which pivot shift injury was found in 55.5% of cases. Conversely, Berger and colleagues [9] found that the clip injury was the most frequently observed pattern of bone marrow contusion, followed by the pivot shift injury as the second most prevalent pattern.

In the current study, the most frequently observed soft tissue injury associated with pivot shift was ACL tear, affecting 55 patients (94.8%), and this association was found to be statistically significant ($P < 0.001$). The second most common soft tissue injury was MM injury, which occurred in 29 patients (50%), followed by MCL injury, observed in 26 cases (44.8%). These results are consistent with those reported in a study by Bhatnagar and Rathore [8], where ACL injury was the most prevalent soft tissue injury (96.4%), followed by MM injury (45.9%) and MCL injury (41.4%).

In research by Liu and associates [10] on the MR diagnosis and clinical relevance of knee bone contusions, comparable findings were observed. The study highlighted that ACL ruptures, medial meniscus damages, and MCL tears were the most common soft tissue injuries associated with pivot shift injuries. Also, Yadav et al. [11] and Ferretti et al. [12] found that pivot shift mechanism is one of the most common injury mechanisms associated with ACL tear.

The lateral patellar dislocation injury marrow contusion pattern was our study's second most common pattern, observed in 15 patients (13.8%). It was the fifth common pattern in Sahoo et al. [7], found in 2.2% of their study sample. Moreover, it was the third common pattern in the Bhatnagar and Rathore study [8], found in 9% of their study cases.

In this study, focusing on soft tissue injuries linked with the lateral patellar dislocation injury marrow contusion pattern, injury to the MPFL was observed in all patients within the group. Injuries to the ACL and MCL were recorded in just 6.7% of cases (one instance for each injury type). These findings are consistent

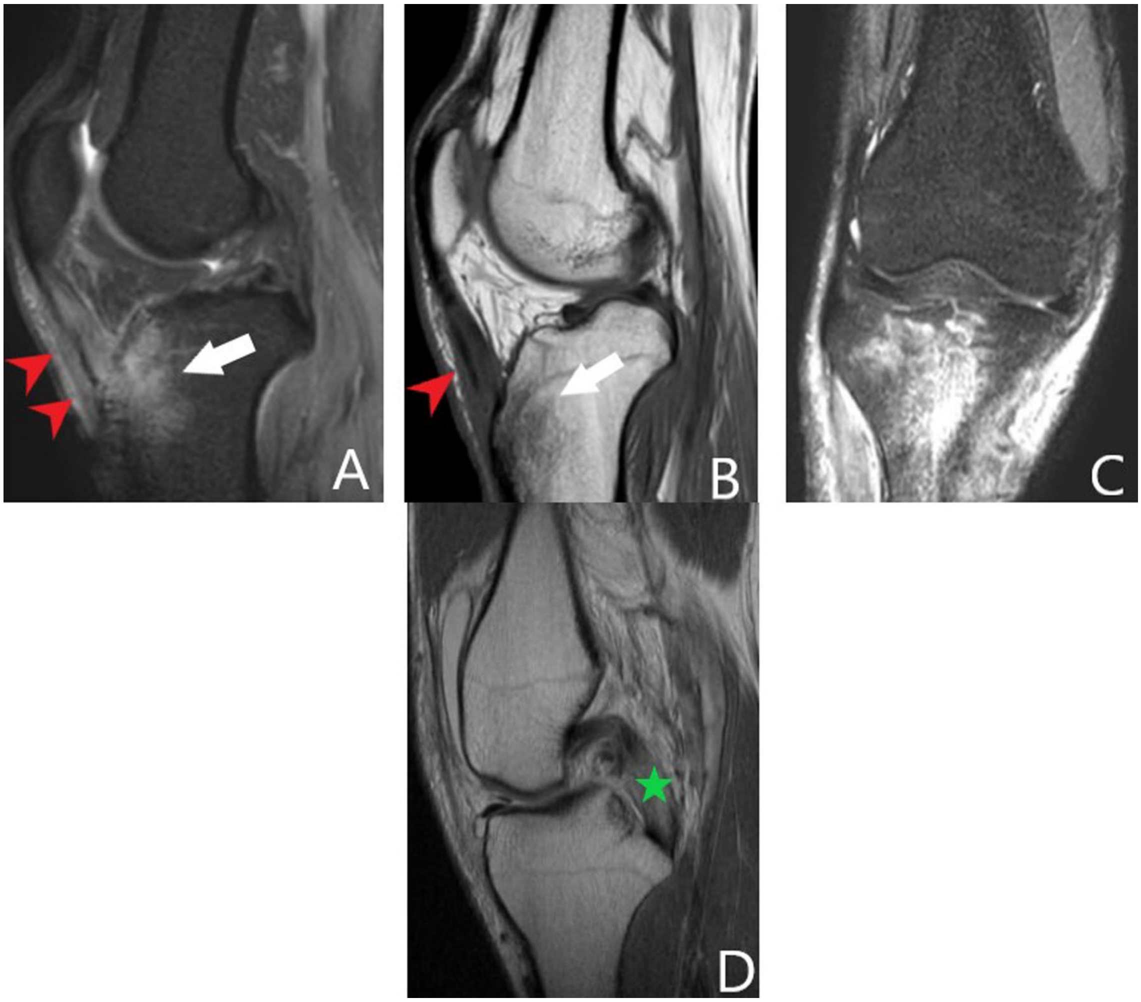

Fig. 4 A 28-year-old male patient presented with the left knee pain shortly after a road traffic accident. **A** and **B**: Sagittal PDFS and T1 MR images show the classical pattern of dashboard injury: marrow edema signal involving the anterior aspect of the proximal tibia (white arrows). Patellar tendon sprain evidenced by its swelling and elevated intrinsic signal (red arrowheads), **C**: Coronal STIR image shows same marrow edema pattern of the anterior aspect of the proximal tibia, and D: Sagittal T2 MR image shows complete PCL tear (green asterisk)

with those from the study conducted by Bhatnagar and Rathore [8], which found the MPFL to be the most commonly injured soft tissue in lateral patellar dislocation, present in 94.45% of cases. Furthermore, their research found a significant correlation between lateral patellar dislocation and MPFL tears (P value < 0.001). In contrast, ACL injuries were found to be more common in their study, occurring in 37.5% of the cases.

Clip injury was the third most common pattern in our study (10.1%), which was comparable with Bhatnagar and Rathore [8], where clip injury was detected in (13%), and to a lesser extent with the Sahoo et al. [7], as clip injury was accounted for 28.3% (39 cases), but it was in the 2nd rank.

Our findings demonstrate a strong correlation between clip injuries and MCL injuries, observed in 90.9% (10 patients) of cases, with this correlation being statistically significant ($P < 0.05$). Injuries to the ACL and medial meniscus were the subsequent most frequent soft tissue injuries, occurring in 36.4% of cases. These results are consistent with the findings of Bhatnagar and Rathore [8], in which the MCL tear was the most commonly observed soft tissue injury associated with clip injuries, present in 88.46% of cases. This was followed by ACL tears in 61.54% and medial meniscus injuries in 53.85% of cases. Their study also noted a significant association between clip injuries and ACL tears ($P < 0.001$).

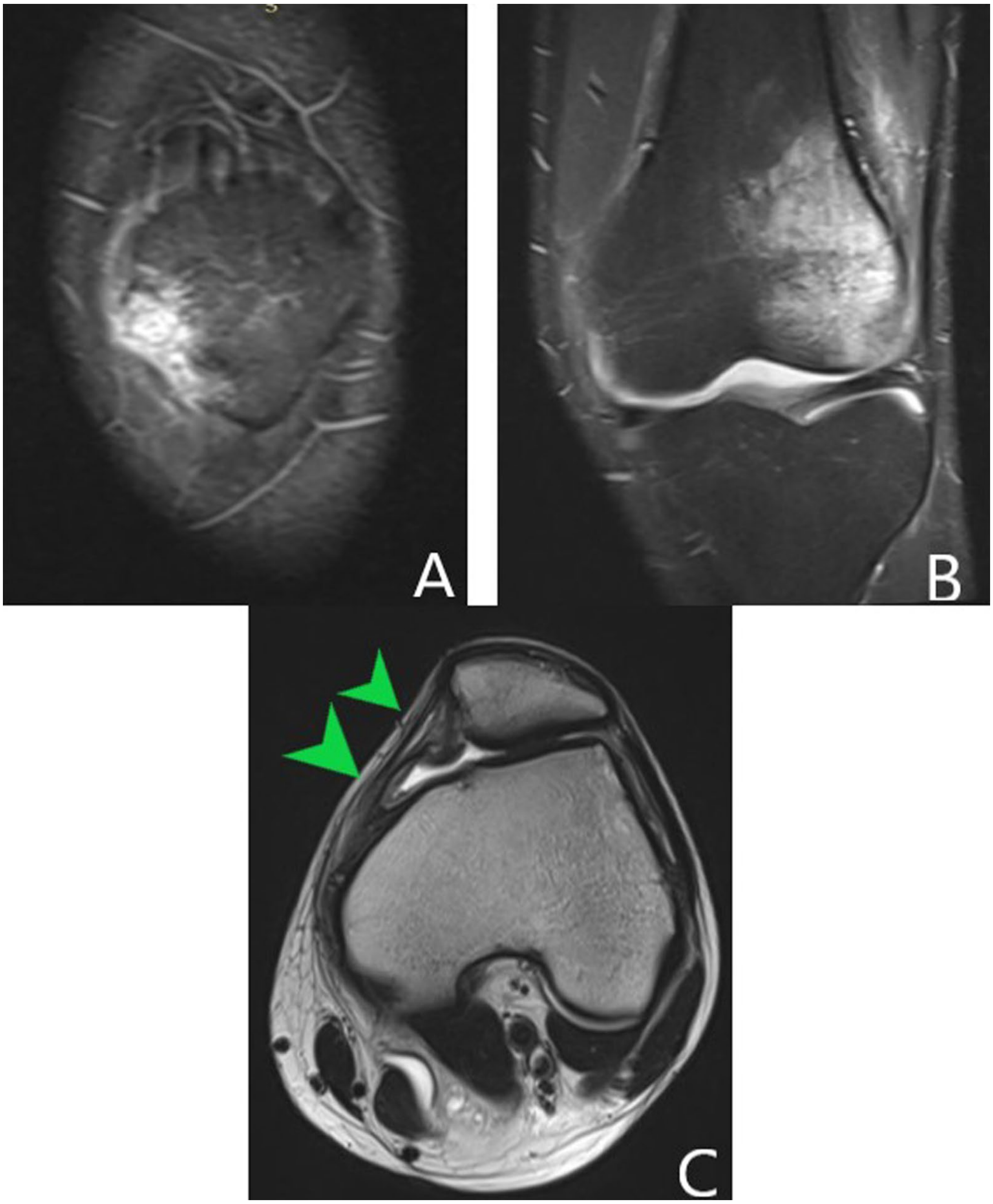

Fig. 5 A 24-year-old male patient presented with anterior left knee pain after falling while he was riding a horse. **A** and **B**: Coronal STIR MR images of the left knee show a classical pattern of lateral patellar dislocation marrow edema involving the medial side of the patella and the lateral femoral condyle. **C**: Axial T2 MR image shows interstitial tear of the medial patella-femoral ligament (MPFL), evidenced by its swelling and elevated intrinsic signal (green arrows)

In contrast with our findings, the study conducted by Sahoo et al. [7] reported that the ACL was involved in 100% of cases, followed by the medial meniscus (89.7%) and MCL (79.5%). Similarly, the study by Berger et al. [9] showed that the ACL was the most commonly involved structure (51.4%), followed by the medial meniscus (60%) and MCL (35.4%).

According to our study, the dashboard injury pattern was the fourth most common bone marrow contusion pattern, accounting for 6.4% of cases. These results are comparable to those found by Bhatnagar and Rathore [8], where this type of injury accounted for 8.5% of cases, ranking fourth in their study. In the study by Sahoo et al. [7], dashboard injury was identified as the third most common mechanism of injury, comprising 5.7% of cases (eight cases).

In the current study, dashboard injury showed a high statistically significant ($P < 0.001$) incidence of PCL injury (7 patients, 100%). Still, no statistical significance was found regarding the incidence of ACL, MCL, LCL, MM, LM, and MPFL injuries ($P > 0.05$).

Similarly, Sahoo et al. [7] found that the PCL was involved in 100% of dashboard injuries in their study. Bhatnagar and Rathore [8] also observed that the PCL was the soft tissue most frequently damaged in cases of dashboard injury, present in 88.23% of such cases. This incidence was significantly higher than that of ACL injuries in dashboard injury cases, which stood at 11.76%. A significant correlation between dashboard injuries and PCL tears ($P < 0.001$) was noted in their research. Additionally, dashboard injuries were identified as the most common cause of avulsion fractures of the PCL, accounting for 57.14% of cases in their analysis.

Following the same theme, studies by Sanders et al. [6], Liu et al. [10], and Hayes et al. [13] on bone marrow edema patterns also identified the PCL as the most frequently injured soft tissue in dashboard injuries.

In our study, hyperextension injury was ranked as the fifth pattern, involving three patients (2.8%), aligning with the findings of Bhatnagar and Rathore [8], where hyperextension injury was the least common, comprising 3% of cases. There was a statistically significant increase ($P < 0.05$) in the percentage of MM and PCL injuries among patients with hyperextension injuries (100% for MM in three patients and 66.7% for PCL in two patients, respectively). No statistically significant difference was observed in patients with hyperextension injuries regarding ACL and MCL injuries (66.7% for both ACL and MCL in two patients) and injuries to the LCL, LM, and MPFL.

In the study by Bhatnagar and Rathore [8], ACL and medial meniscus injuries were the most frequently injured structures in hyperextension injuries, seen in 50% of cases, followed by MCL injuries in 33.34% of cases and PCL injuries in 16.67%. According to Sahoo et al. [7], the most commonly associated ligamentous injury was the ACL (100%), followed by the PCL (75%), medial meniscus (75%), lateral meniscus (50%), and lateral collateral ligament (25%). These observations are consistent with the findings of Sanders et al. [6], who reported that the ACL, PCL, and menisci were the soft tissues most commonly injured in hyperextension injuries.

The limitations of this study included the fact that it was a retrospective study and that there were a small number of patients in some of the groups, especially the hyperextension group. The wide, undivided age range of the patients may affect the generalizability of the results. The study's methodology did not examine the inter- and intraobserver agreement between the two observers and did not compare the results between the two machines used in the study. So, a dedicated study focusing on these topics is recommended.

Conclusions

Precise localization of the marrow contusion and determination of its pattern in post-traumatic knee MRI are crucial. It allows us to anticipate the more likely associated soft tissue injuries, focus attention on such soft tissue examination, and, thus, avoid missing any concomitant injuries. This can improve patient management.

Abbreviations

BM	Bone marrow
ACL	Anterior cruciate ligament
PCL	Posterior cruciate ligament
MM	Medial meniscus
MRI	Magnetic resonance imaging
LCL	Lateral collateral ligament
LM	Lateral meniscus
MPFL	Medial patella-femoral ligament

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Author contributions

M.F helped in revision of cases and scientific writing. A.R helped in review of the literature—review of cases and biostatistical work. M.R worked in academic supervision.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was approved by the research ethics committee of Benha Faculty of medicine, with study number: MD.5.10.2019. Informed consents were taken from all the participating patients in the study.

Consent for publication

Consents of publications were taken from the participating patients regarding their MRI studies images.

Competing interests

The authors declare that they have no competing interests.

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References

1. Naraghi AM, White LM (2016) Imaging of athletic injuries of knee ligaments and menisci: sports imaging series. Radiology 281(1):23–40

2. Chien A, Weaver JS, Kinne E, Omar I (2020) Magnetic resonance imaging of the knee. Pol J Radiol 85:e509–e531
3. Baumbach SF, Pfahler V, Bechtold-DallaPozza S, Feist-Pagenstert I, Fürmetz J, Baur-Melnyk A et al (2020) How we manage bone marrow edema-an interdisciplinary approach. J Clin Med 9(2):551
4. Maraghelli D, Brandi ML, MatucciCerinic M, Peired AJ, Colagrande S (2020) Edema-like marrow signal intensity: a narrative review with a pictorial essay. Skelet Radiol 50(4):645–663
5. Sadineni RT, Pasumarthy A, Bellapa NC, Velicheti S (2015) Imaging patterns in MRI in recent bone injuries following negative or inconclusive plain radiographs. J Clin Diagn Res 9(10):TC10
6. Sanders TG, Medynski MA, Feller JF, Lawhorn KW (2000) Bone contusion patterns of the knee at MR imaging: footprint of the mechanism of injury. Radiographics 20:S135–S151
7. Sahoo K, Garg A, Saha P, Dodia JV, Raj VR, Bhairagond SJ (2016) Study of imaging pattern in bone marrow oedema in MRI in recent knee injuries and its correlation with type of knee injury. J Clin Diagn Res JCDR 10(4):TC06. https://doi.org/10.7860/JCDR/2016/18843.7704
8. Bhatnagar A, Rathore B (2020) Correlation between patterns of bone marrow edema and their associated soft-tissue injuries, as seen on magnetic resonance imaging of knee joint in patients with a recent history of trauma. Int J Sci Study 8(4):15–23
9. Berger N, Andreisek G, Karer A, Seifert B, Ulbrich E (eds) (2013) Correlation of bone bruise pattern of the knee joint with trauma mechanism and soft-tissue knee injuries. In: European Congress of Radiology-ESSR 2013
10. Liu W, Yang J, Shao K-w, Zhu C-s, Zhu Y, Zhai L-l (2000) The MR diagnosis and clinical significance of bone contusion of knee. Chin J Radiol 41:1319–1322
11. Yadav S, Dhakshanamoorthy R, Kumar I, Prakash A, Nagarajan R (2022) Bone bruise patterns in ligamentous injuries of the knee with focus on anterior cruciate ligament. Cureus 14(12):e32113. https://doi.org/10.7759/cureus.32113
12. Ferretti A, Monaco E, Gaj E, Andreozzi V, Annibaldi A, Carrozzo A, Vieira TD, Sonnery-Cottet B, Saithna A (2020) Risk factors for grade 3 pivot shift in knees with acute anterior cruciate ligament injuries: a comprehensive evaluation of the importance of osseous and soft tissue parameters from the SANTI Study Group. Am J Sports Med 48(10):2408–2417. https://doi.org/10.1177/0363546520935866
13 Hayes CW, Brigido MK, Jamadar DA, Propeck T (2000) Mechanism-based pattern approach to classification of complex injuries of the knee depicted at MR imaging. Radiographics 20:S121–S134

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