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Traumatic Bone Bruises in the Athlete's Knee

Joseph P. DeAngelis, MD,* and Kurt P. Spindler, MD^{†‡}

Context: Mobile water within the bone marrow is a physiological phenomenon that is identifiable on magnetic resonance (MR) imaging, and signal changes can result from blood pooling, reactive hyperemia, edema, and microfracture. When these MR lesions are associated with an acute traumatic event, the findings are referred to as *bone bruises* and so represent a unique manifestation of injury. This review discusses bone bruises in anterior cruciate ligament (ACL) tears, patella dislocations, occult fractures, and contusions.

Methods: A PubMed search of the literature from 1982 to December 2009 was conducted with the terms *knee* and *bone bruise*.

Results: Bone bruises are associated with ACL tears, patella dislocations, occult fractures, and contusions. For each injury, a unique pattern of bone bruising is found on MR imaging, which results from the acute trauma. When acute trauma produces a subchondral lesion with low T1-weighted and high T2-weighted signal intensity, the resulting bony contusion is best described as a bone bruise.

Conclusions: Bone marrow edema is identified using MR imaging and may result from traumatic or atraumatic causes. Bone bruises can be characterized by their pattern at presentation, by the mechanism of injury, and by their associated injuries. This type of bone edema can accompany contact and noncontact ACL ruptures as well as patella dislocations. Although increased marrow edema can be associated with an occult fracture, the long-term significance of these lesions is unclear.

Keywords: bone marrow edema; bone bruises; magnetic resonance imaging; anterior cruciate ligament; occult fracture; patella dislocation

In 1988, Wilson et al introduced the term *bone marrow edema* in describing a group of patients with atraumatic debilitating knee and hip pain.³⁰ On T2-weighted magnetic resonance (MR) images, they recognized an ill-defined hyperintensity in the bone marrow where standard radiographs showed nonspecific osteopenia or normal findings. This discrepancy in the imaging studies was labeled *bone marrow edema* owing to the “lack of a better term and to emphasize the generic character of the condition.”³⁰ The proposed pathogenesis of these marrow changes asserts that increased blood pooling, edema, reactive hyperemia, and possible microfracture of the trabecular subchondral bone alter the marrow signal intensity.²⁰ In time, bone marrow edema earned the moniker *bone bruise* to reflect its traumatic nature.

The ability to identify a bone bruise is unique to MR studies.²¹ On T1-weighted images, the alterations in the subchondral

bone marrow signal are characterized by ill-defined low signal intensity, compared with the unaffected bone marrow. In contrast, on T2-weighted, proton density-weighted, fat-suppressed fast spin echo or short tau inversion recovery images, these lesions are characterized by areas of high signal intensity.^{28,30,33} The hypervascularity in the involved areas is clearly illustrated as the administration of intravenous contrast agents results in further enhancement of these bone marrow signal alterations.^{18,24}

However, the term *bone bruise* should be applied exclusively to subchondral lesions that exhibit the typical MR findings. These lesions are acute traumatic noncystic areas of bone marrow edema, and they can be distinguished from cystic lesions and atraumatic presentations.^{13,21} The pathophysiology of bone marrow edema is currently nonspecific, and

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Table 1. Differential diagnosis of bone marrow lesions.²¹

Traumatic	Contusions (subchondral impaction)
	Fractures (chondral, subchondral, osteochondral, insufficiency, stress)
	Spontaneous osteonecrosis of the knee
	Overuse (repetitive microtrauma)
Nontraumatic	Vascular (periarticular bone infarction)
	Osteoarthritis associated
	Transient bone marrow edema syndrome
	Osteochondritis dissecans
	Reactive inflammatory (polyarthritis, reactive arthritis, bacterial arthritis, osteomyelitis)
Tumor / malignant marrow infiltration	Lymphoma, multiple myeloma, etc
Other	Postoperative, subchondral cysts, red marrow

differentiation of the different causes can be difficult. In particular, distinguishing among osteochondritis dissecans, spontaneous osteonecrosis of the knee, and idiopathic transient bone marrow lesion syndrome is difficult because ischemic and microtraumatic factors both contribute to their presentation.³² Although many causes may result in bone marrow lesions (Table 1), this review addresses acute traumatic noncystic bone marrow edema (bone bruises).

TRAUMATIC BONE BRUISES: ANTERIOR CRUCIATE LIGAMENT-RELATED INJURIES TO ARTICULAR CARTILAGE, SUBCHONDRAL BONE, AND MARROW

A bone bruise is clinically concerning: Not only has the geography of the lesion been used to estimate lifetime risk of osteoarthritis, but bone bruise was believed to be associated with knee pain after anterior cruciate ligament (ACL) tear.¹⁵ A bone bruise is associated with more than 80% of complete ACL ruptures, and a geographic lesion is present in one-third of these patients.^{2,25,28} Geographic lesions have a discrete focus of low signal intensity on a T1-weighted image that is confluent and in contiguity to the subchondral plate. (Other types are reviewed in the discussion of occult fractures.) At the time of ACL rupture, bone bruising results from the impact and translation of the femur on the tibia.^{2,25,26} The resulting phenomenon constitutes a “footprint” left at the time of the rupture, a telltale signature of the injury.²³ The characteristic bone bruise involves the posterior aspect of the lateral tibial plateau and the lateral femoral condyle at the sulcus terminalis (Figure 1).

Although the lateral compartment of the knee is commonly involved, marrow changes can be seen in the medial compartment.^{10,16,22,25,26} As such, a bone bruise is a static representation of the injury and may be used to gain insight

into the mechanism of rupture.²³ The extent of the anterior translation of the tibia on the femur can be appreciated by the relative location of the bruising in the sagittal plane.

CONTACT VERSUS NONCONTACT ACL RUPTURES

Contact ACL injuries occur when a valgus load is applied to a planted or fixed leg, resulting in the impaction of the lateral femoral condyle into the lateral tibial plateau.³ In contrast, noncontact ACL injuries can result from quadriceps loading of a slightly flexed knee, which culminates in a valgus moment about an internally rotated tibia.^{3,6,14,19} Noncontact injuries were traditionally hypothesized to result from a pure valgus force, leading to bruising mainly in the lateral compartment. However, prospective data have revealed that the injury pattern in noncontact ACL injuries is the product of anterior translation affecting the medial and lateral compartments.²⁹

In an evidence-based medicine level II cohort, Viskontas et al investigated how the degree of bone bruising was related to the energy of the injury (contact versus noncontact) and the prognosis of knee function.²⁹ They found that bone bruising was “more frequent, deeper, and more intense” on the lateral tibial plateau in the noncontact injuries. Additionally, medial compartment bone bruising was seen more frequently than previously reported, particularly in the noncontact group.

In the short term, the clinical significance of bone bruising is unclear. In 2007, an evidence-based medicine level II cohort study found no relationship between the presence of bone bruise and pain severity.⁴ A more recent cross-sectional cohort study found that the presence of a bone bruise on MR imaging concurrent with an ACL tear is not associated with patient-reported pain at time of index ACL reconstruction.⁸ The typical bone bruise pattern on a T2-weighted MR image resolves



Figure 1. Bone bruise pattern of acute anterior cruciate ligament tear, with sagittal view showing lateral femoral condyle bone bruise at sulcus terminalis or just superior to the anterior horn of the lateral meniscus. The lateral tibial plateau bone bruise is posterior. This T2-weighted image highlights the bone edema, indicating a recent event.

in 60 days.¹⁰ However, the long-term significance of bone bruise with ACL tear has not been studied in a multivariable analysis. In a longitudinal 12-year follow-up of a prospective ACL reconstruction cohort, the presence of bone bruise did not correlate with lower patient-reported International Knee Documentation Committee scores.¹¹ Owing to limited sample size, a multivariable analysis was not possible. This difficulty is compounded by the inability to predict future osteoarthritis using MR imaging.

In a qualitative investigation of 10 consecutive ACL-deficient patients with a concomitant geographic bone bruise, biopsy of articular cartilage overlying a bone bruise before ACL reconstruction revealed histologic evidence of chondrocyte damage in 35% of patients.¹⁵ Direct inspection during arthroscopy by the authors revealed softened cartilage with dimpling, fissuring, or overt chondral fracture. On histologic examination, chondrocyte degeneration was identified: loss of toluidine blue staining consistent with the loss of proteoglycan. Additional evidence of articular cartilage surface thinning has been seen on follow-up MR imaging in the area of the bone contusion from 1 to 6 years after the initial injury.^{5,9,22,28} Repeat MR imaging has demonstrated persistence of the bony lesion in some patients as late as 12 months after injury.^{22,28} When the most severe lesions have been followed longitudinally, thinning of the articular cartilage with depression has been observed more than 2 years following injury, whereas 29% of patients demonstrated residual sequelae of the original osteochondral lesion.⁵

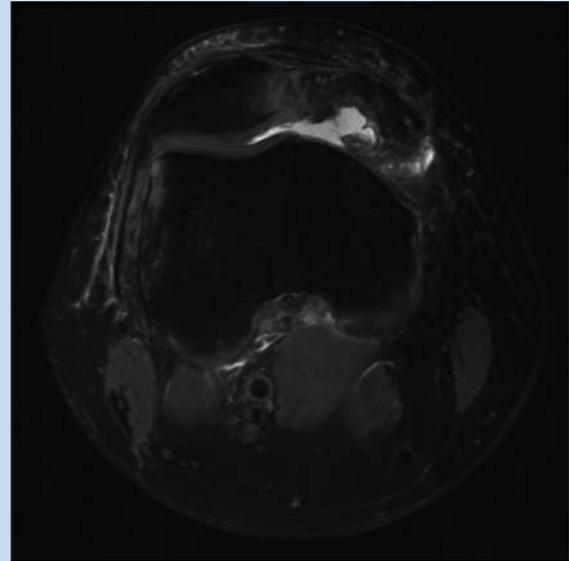


Figure 2. Bone bruise pattern at acute patellar dislocation with lateral side of lateral femoral condyle best seen on axial images and medial patella. Again, this T2-weighted image highlights the bone edema, indicating a recent event.

Future clinical studies are required to determine if the presence of a bone bruise is a risk factor for poorer patient-reported outcomes secondary to initiation of posttraumatic osteoarthritis.

BONE CONTUSIONS RELATED TO PATELLA DISLOCATION

Like ACL injuries, bone bruise presentation following patella dislocation occurs in a unique and predictable pattern on MR imaging. After an acute lateral dislocation, the impact results in focal marrow edema on the lateral aspect of the lateral femoral condyle and on the inferomedial patella (Figure 2). Increased signal is not present on the distal end of the lateral femoral condyle at the sulcus terminalis or on the lateral tibial plateau, distinguishing a patella dislocation from an acute ACL tear. On occasion, an osteochondral fracture of the lateral femoral condyle may accompany the dislocation. Careful inspection of the patella may reveal an osteochondral defect or a bone contusion related to the dislocation/relocation event on patella, often involving the medial or odd facets. The axial MR images may illustrate the depth of the lesion and the involvement of the subchondral plate, advancing understanding of the injury and its treatment options.

OCCULT FRACTURES

Whereas ACL ruptures and patella dislocations produce bone bruises, bony contusions are associated with subclinical, or occult, fractures. This type of traumatic injury is not visible on plain radiographs and has been classified on the basis of its MR appearance²⁸ (see Table 2). Vellet's system separates occult

Table 2. Modified magnetic resonance imaging classification of occult fractures of the knee.²⁸

A. Occult subcortical fractures
1. Reticular (bruises)
2. Geographic I/II ^a
3. Linear
B. Stress
1. Linear
2. Globular
C. Osteochondral
1. Chondral ^a
2. Displaced ^a
3. Impacted ^a
D. Tibial plateau
E. Femoral shaft

^aDenotes fractures of osteochondral significance.

fractures into 3 groups with subtypes: occult subcortical, stress, and osteochondral fractures. As a subtype, a reticular lesion has serpiginous regions of diminished T1-weighted signal intensity distant from the subchondral bone plate, whereas a geographic lesion has a discrete focus of low signal intensity on a T1-weighted image that is confluent and in contiguity to the subchondral plate. Linear subcortical fractures have

a discrete linear zone of diminished signal intensity on the T1-weighted images that is usually less than or equal to 2 mm wide, with a sharp zone of transition to the adjacent marrow fat. When depression of the articular surface occurs in conjunction with a geographic-type lesion, it is defined as an impaction fracture. However, if a geographic lesion has a discrete low-intensity interface that separates the lesion from the surrounding trabecular bone and communicates with the joint space, it is best described as an osteochondral fracture. Using this classification system, researchers of an evidence-based medicine level IV study found that isolated subcortical trabecular lesions had a favorable short-term recovery after restricted weightbearing and initial activity modification.³¹ Most athletes returned to sport within 6 months. Although several studies have indicated that blunt articular cartilage injury alters future cartilage metabolism, the long-term functional significance of MR-identified trabecular injury is not known.^{1,7,12,17,27,31} In middle-aged athletes, the presence of a subchondral fracture has been associated with the development of spontaneous osteonecrosis.³²

CONCLUSIONS

Bone marrow edema is identified with MR imaging and may result from traumatic or atraumatic causes. When acute trauma produces a subchondral lesion with low T1-weighted and high T2-weighted signal intensity, the resulting bony contusion is best described as a bone bruise. Table 3 shows these traumatic bone bruise patterns, mechanism of injury, and associated injuries. Predictable patterns of bone edema accompany contact and noncontact ACL ruptures, as well as patella dislocations. However, the long-term significance of the lesions is not known. Increased marrow edema can also be associated with an occult fracture.

Table 3. Traumatic bone bruise patterns, mechanism, and injuries.^a

No.	Location of Bone Bruise	Mechanism	Associated Injury
1 ^b	LFC above anterior horn LM	Anterior subluxation tibia impacting LFC	ACL tear
2 ^b	LTP below posterior horn LM	Anterior subluxation tibia impacting LFC	ACL tear
3 ^b	LFC lateral edge	Impaction LFC relocation lateral patellar dislocation	Patellar dislocation
4 ^b	Medial patellar facet	Impaction medial patella on LFC on relocation	Patellar dislocation
5	Anterior "lip" tibia	Hyperextension injury	Rule out ACL tear
6	Anterior tibia	Direct blow anterior tibia flexed knee	Rule out PCL tear
7	Linear fracture line LTP	Valgus overload	Occult fracture LTP
8	Matching bone bruise LFC + LTP	Valgus overload	Rule out MCL tear

^aLFC, lateral femoral condyle; LM, lateral meniscus; ACL, anterior cruciate ligament; PCL, posterior cruciate ligament; LTP, lateral tibial plateau; MCL, medial collateral ligament.

^bTwo bone bruise patterns are pathognomonic for injuries: ACL tear with Nos. 1 and 2 (LFC + LTP) and patellar dislocation with Nos. 3 and 4 (LFC + medial patella).

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