

Intramedullary fat globules related to bone trauma: a new MR imaging finding

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Abstract

Objective The purpose of this study is to describe intraosseous fat globules related to bone trauma that are detectable with magnetic resonance imaging (MRI), to define the relationship of this finding to fracture and bone contusion, to establish the frequency and associated findings. A proposed pathogenesis is presented.

Materials and methods We retrospectively reviewed 419 knee MRI examinations in patients with a history of recent injury and MRI findings of fracture or bone contusion. As a control population, 268 knee MRI examinations in patients without MRI findings of recent bone injury were also reviewed.

Results Eight of 419 (1.9 %) patients with acute or subacute knee injury with positive findings of osseous trauma on MRI demonstrated intraosseous fat globules. The mean age of patients with fat globules was greater than that of those without fat globules, and the finding was more commonly seen in

women. Fat globules were hyperintense to the normal fatty marrow present elsewhere in the bone on T1-weighted imaging and had a surrounding halo of high signal intensity on fluid-sensitive imaging.

Conclusions Intramedullary fat globules related to bone injury visible on MRI are thought to be due to coalesced fat released by the necrosis of fatty marrow cells. The pathogenesis is supported by histologic studies of fat globules related to osteomyelitis, bone contusions and fractures. As the medullary cavity of long bones in older patients contains more fat than hematopoietic bone marrow, it is likely that this finding is more common with advancing age.

Keywords Intramedullary · Fat globules · Fat necrosis · Fractures · Bone contusions · Intraosseous fat · Fat embolization

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Introduction

In our practice we have observed intramedullary fat globules on magnetic resonance imaging (MRI) related to recent fractures and bone contusions (Figs. 1, 2 and 3). Although such fat globules have been reported with MR imaging in cases of acute osteomyelitis [1–4], they have not been reported previously as an MRI finding after bone injury. Extrasosseous fat accumulation related to trauma is well known, appearing as systemic fat embolism [5], lipohemarthrosis [6], fat accumulation in the tendon sheaths [7, 8] and beneath the periosteum [9, 10] following fractures.

The purpose of this study is to describe the MRI appearance of intramedullary fat globules, to establish the frequency, demographics, and associated findings. A proposed pathogenesis for this finding is also presented.

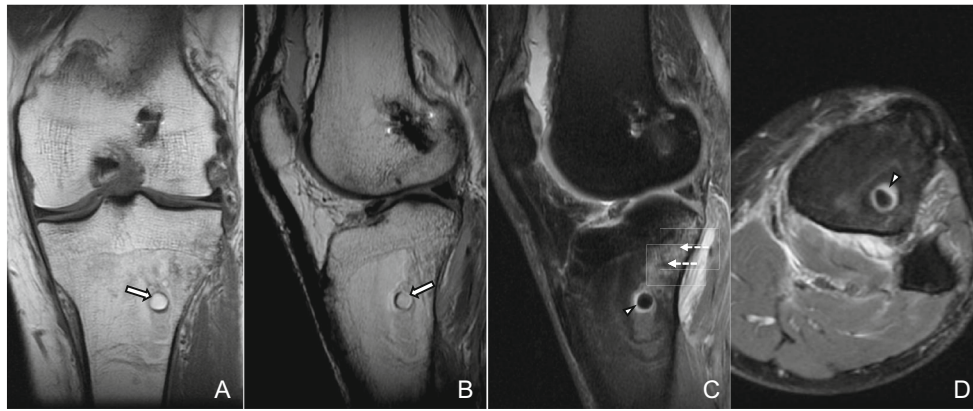


Fig. 1 A 40-year-old male 10 days after a skiing injury with a complete re-tear of his ACL reconstruction. A bone contusion is seen in the lateral tibial plateau. **a, b** Coronal and sagittal T1-weighted (T1W) images show a round intramedullary globule (*arrows*). **c, d** Sagittal and axial proton

density fat-saturated (PDFS) images show fat suppression of the fat globule with a surrounding hyperintense halo (*arrowhead*). The fat globule is not centered at the bone contusion of the lateral tibial plateau (*dashed arrows*)

Materials and methods

We chose to evaluate MRIs of the knees, as the knee is a commonly injured and imaged joint. The study was reviewed and approved for exemption by our institutional review board because of the retrospective nature of the investigation and because information would be recorded in such a manner that subjects could not be identified. An electronic search of our outpatient teleradiology database was performed to include knee MRIs obtained from 1 October 2010 to 30 December 2011. Consecutive MRI examinations with a history of “recent” or “acute” and “trauma” or “injury” and a final diagnosis of “fracture” or “contusion” were selected resulting in a total of 419 cases. These examinations will be referred to as the study cohort. Using the same electronic database, a control cohort without MRI findings of “fracture” or “contusion” was created during the same time interval, resulting in a total of 268 cases. This control cohort without MRI evidence of injury was further divided into two smaller groups: patients who did

not have a history of trauma (113 patients) and patients who did have a history of trauma (155 patients). All of the MRI examinations were performed at various outpatient sites with superconducting magnets ranging from 0.3–1.5 T. At least one non-fat suppressed T1-weighted sequence and several fluid-sensitive fat-suppressed sequences were available for all studies. In consensus, three MSK-trained radiologists with 1, 3 and 16 years of experience reviewed the 419 cases from the *study cohort* and 268 cases from the *control cohort*. The interpreters were not blinded to the patient’s history.

The patient demographics and elapsed time between the knee injury and MRI study were documented. Acute injury was defined as a time interval ≤ 14 days; subacute injury was defined as a time interval between 15–28 days; chronic injury was defined as a time interval > 28 days [11, 12]. The type of bone injury displayed with MR imaging, whether a bone contusion or fracture, was recorded. Bone contusions were denoted as ill- or well-defined areas of decreased T1 signal and increased signal on fluid-sensitive sequences involving

Fig. 2 A 66-year-old woman who fell 2 weeks earlier with a bony contusion of the lateral tibial plateau. **a** Coronal T1W image shows multiple small, round, T1 hyperintense intramedullary globules adjacent to and at the site of the bone contusion (*arrowheads*). **b** Coronal PDFS image shows fat suppression of the round foci in keeping with fat globules (*arrowheads*). There is a hyperintense halo surrounding the fat globules (*curved arrow*)

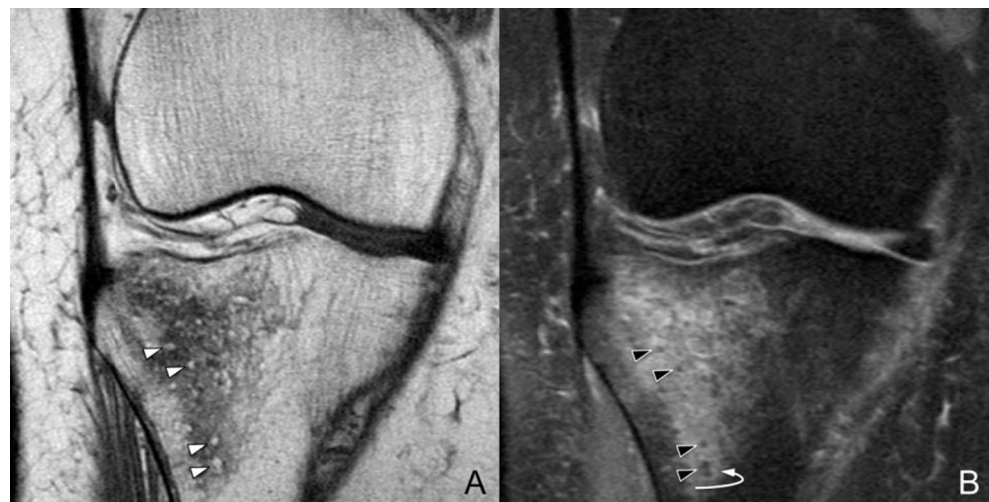
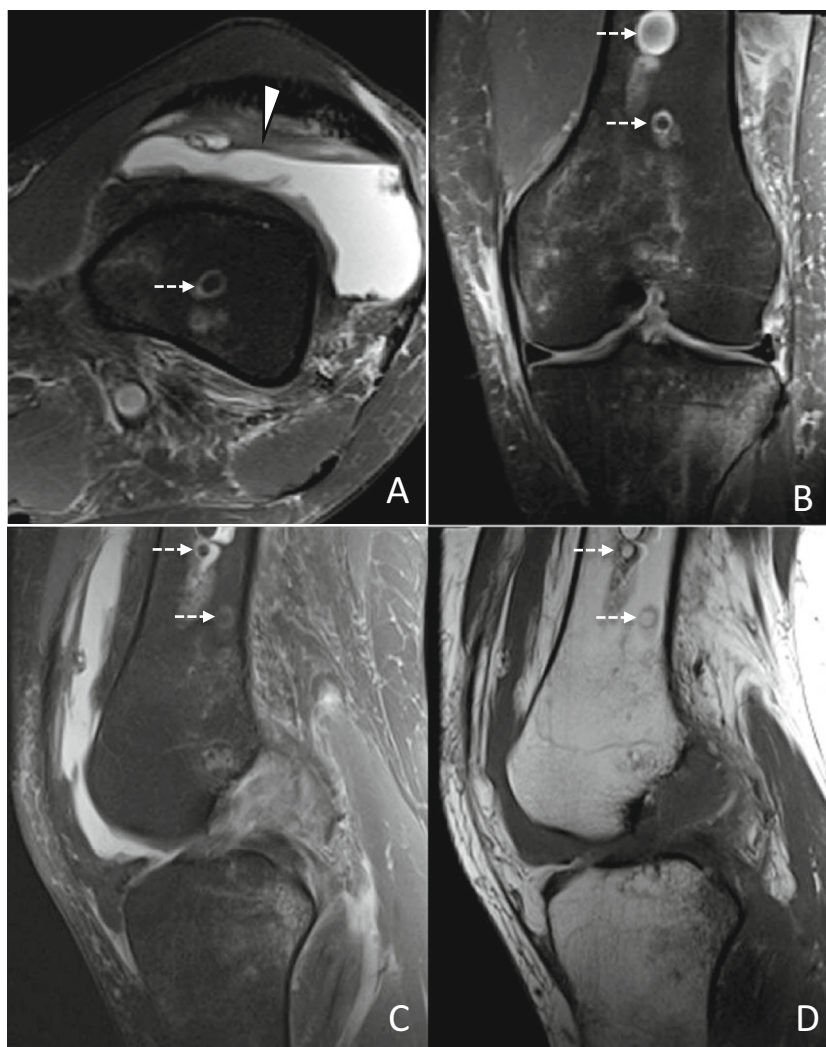


Fig. 3 A 63-year-old female with a bone contusion of the medial femoral condyle and fracture of the lateral tibial plateau. **a, b, c** Axial, coronal and sagittal PDFS images show multiple fat-suppressing round intramedullary globules with surrounding hyperintense halos (*arrows*). A lipohemarthrosis is also seen (*arrowhead*). **d** Sagittal T1W image shows the multiple fat globules



the medullary bone with possible extension to the cortex or subchondral bone plate, without a macroscopic fracture line. An osteochondral fracture was defined as a fracture that disrupted the subchondral bone as well as the overlying cartilage [13]. A subchondral fracture was defined as a subchondral linear, crescentic or arcuate signal change but with an intact overlying subchondral bone plate and articular cartilage [13]. An extraarticular fracture was defined as a linear or curvilinear low T1 and T2 region that violated the cortical bone with associated bone marrow edema. An insufficiency fracture was defined as a band-like area of central low signal intensity in the subchondral bone plate, with surrounding ill-defined low signal intensity on T1-weighted images and high signal intensity on T2-weighted images, usually in the medial femoral condyle of older patients without other acute pathology [14–16]. Studies were excluded if there was a signal artifact, for example, from hardware, or a severe motion artifact or if the study was incomplete. Cases with marrow deposition abnormalities (such as malignancy or metabolic

disease) or focal marrow pathology (such as avascular necrosis) were also excluded.

A fat globule was defined as a spherical T1 hyperintense lesion with signal intensity similar to or higher than that of subcutaneous fat that demonstrated complete fat suppression [1, 2, 17]. To be considered present, a fat globule had to be at least 2 mm in size and detectable in at least two planes of imaging. The globules could be single or multiple. The location and size of each fat globule and its distance from the central site of injury when not present within it were recorded. The presence or absence of a surrounding halo of high signal intensity on fluid-sensitive sequences was noted [17, 18]. In cases of fracture, the type of fracture (osteochondral, subchondral impaction, extraarticular or insufficiency fracture) was noted. The presence and location of any ligamentous injury, the presence of a joint effusion and any additional sites of fat accumulation (such as a lipohemarthrosis) were also documented.

There were four equivocal cases with disagreement among the three observers. In these cases, the equivocal fat globules

were difficult to characterize because of their small size and their being located at the periphery of the field of view. In some instances the lesion may have represented a focus of normal fatty marrow within a region of marrow edema.

Statistical analyses were performed using the SPSS software package (version 21; SPSS, Chicago, IL, USA). Descriptive statistics for demographic data were calculated for the *study cohort*. Bivariate statistical analyses were performed using Fisher's exact test for binary variables and the Mann-Whitney U test for continuous and multicategorical ordinal variables. *P* values <0.05 were considered statistically significant. Kappa statistics with 95 % confidence intervals were calculated for the interobserver reliability statistics. Kappa statistics were interpreted as 0 to 0.2, slight; 0.21 to 0.4, fair; 0.41 to 0.6, moderate; 0.61 to 0.80, substantial; 0.81 to 1.0, almost perfect [19].

Results

As indicated earlier, 419 patients met the inclusion criteria for the study cohort [179 women, mean age 39.6 years, standard deviation (SD) 21.7 years, ranging from 6 to 90 years; 240 men, mean age 32.0 years, SD 17.2 years, ranging from 8 to 79 years]. There were 133 patients with an acute injury, 37 patients with a subacute injury and 58 patients with a chronic injury at the time of MRI. The specific date of injury was not provided in 191 patients. Seventy-three patients had fractures, 235 patients had bone contusions without fractures, and 53 patients had both fractures and bone contusions at different sites. Fifty-eight patients had insufficiency fractures. Ten patients had a lipohemarthrosis. No other findings of extramedullary fat accumulation were evident.

Eight out of the 419 patients (1.9 %) in the study cohort revealed intramedullary fat globules (Table 1). The mean age

of patients with fat globules was greater than those without fat globules (62.6 years, SD 20.7 years versus 34.8 years, SD 19.3 years, respectively; $p=0.001$) (Fig. 4). The incidence of a frank fracture was greater in the group with fat globules (7/8, 88 %) compared with the group without fat globules (117/411, 28 %) ($P=0.05$). Additionally, there was no significant difference in time interval between injury and MRI in the patients with and without fat globules.

All fat globules were subjectively hyperintense to the normal fatty marrow compared to the adjacent or nearby normal bone marrow on T1-weighted imaging, and similar to subcutaneous fat. The fat globules were in either the metaphysis or diaphysis of the bone, either within or adjacent to patchy, intense marrow edema, and were near but not necessarily at the site of bone injury. All fat globules had a surrounding halo of high signal intensity on fluid sensitive imaging (Fig. 5).

No intramedullary fat globules were seen in either of the control cohort groups, i.e., those patients without MRI findings of bone injury, with or without a history of trauma. The pathology observed in most of the cases in the control cohort was meniscal tears and osteoarthritis.

The kappa value for the interobserver reliability statistics ranged from 0.80 to 0.95, which was substantial to almost perfect.

Discussion

Based on our results, intramedullary fat globules are an uncommon MRI finding, occurring with a frequency of 1.9 % in 410 patients with both a history of knee injury and MRI evidence of a bone contusion or fracture. If we had included our four equivocal cases, the finding would have been slightly more frequent. As no fat globules were seen in our control group consisting of patients without MRI evidence of bone

Table 1 Patients with traumatic fat globules

Patient	Age (sex)	Time since injury (days)	Description of fat globule				Presence of halo	Type of bone injury	Associated injuries	Additional sites of fat accumulation
			Number	Site	Size (cm)	Distance from bone injury (cm)				
1	85 (F)	12	Single	Femur Meta	0.4	1.3	Yes	EAF	None	None
2	80 (F)	19	Multiple	Tibia Dia	0.3	6	Yes	C	None	None
3	74 (M)	Not provided	Multiple	Femur Meta	0.2	2	Yes	OCF	None	None
4	72 (F)	Not provided	Single	Tibia Meta	0.8	1.8	Yes	EAF	None	None
5	68 (F)	20	Multiple	Tibia Dia	0.4	4	Yes	OCF	None	None
6	54 (F)	6	Single	Tibia Meta	0.9	0	Yes	OCF	MSS	None
7	45 (M)	11	Multiple	Tibia Meta	0.7	0.6	Yes	OCF	MSS, ACL	Lipohemarthrosis
8	23 (M)	Not provided	Multiple	Tibia Dia	0.3	4	Yes	EAF	MSS, LSS, ACL	None

Meta Metaphysis, *Dia* diaphysis, *EAF* extraarticular fracture, *OCF* osteochondral fracture, *C* contusion, *OCF* osteochondral fracture, *MSS* medial supporting structures, *LSS* lateral supporting structures, *ACL* anterior cruciate ligament

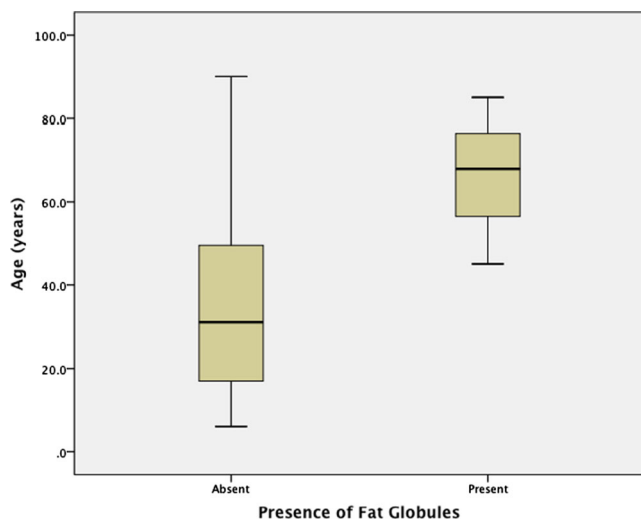


Fig. 4 Boxplots demonstrate greater age of patients with fat globules compared with those without fat globules ($p=0.028$). The median is demonstrated with a thick horizontal line, and solid boxes include the first to third quartiles. Whiskers extend to the farthest points that are not outliers

injury, we believe that the fat globules are related to such injury. The fat globules were seen only in the acute or subacute period, suggesting that they are associated with recent injury. There was a trend for fat globules to be seen in older patients and more commonly in patients with fractures rather than bone contusions alone.

Although our study does not have direct histologic correlation, due to the retrospective nature of the study, other histopathologic studies support a proposed pathogenesis. The trabecular architecture of long bones and the pathophysiology related to bone contusions and fractures can explain the formation of intraosseous fat globules in cases of acute injury. Histologic studies have confirmed microfractures and

macrofractures of trabecular bone following bone contusions [20] and fractures, related in part to shear forces [21]. With osseous injury, there is cell death and disruption of the blood supply with resultant hemorrhage and reactive inflammation in the fatty marrow [20–22], causing histologically evident necrosis of the fatty marrow cells in the region of the fractures and bone contusions [20, 23]. The dead marrow cells release liquefied fat, which coalesces. This liquefied fat has been documented histologically; following a fracture, oil cysts, ringed by inflammatory cells have been detected [21]. A sequence of similar events has been proposed to explain the presence of intramedullary fat globules in cases of acute osteomyelitis in which there is release of fat globules from necrotic marrow lipocytes related to the increased intramedullary pressure that accompanies hyperemia, edema and exudate formation [1]. There has been histologic demonstration of loss of lipocytes, which causes acellular marrow spaces that fill with lipid from necrosed lipocytes correlating to regions of globular fat related to acute osteomyelitis on MRI [1]. The fat globules related to osteomyelitis have been shown to have an appearance similar to that in our cases [1, 2, 4, 24].

Although fat globules seen in the younger adults in our study can be explained by the same mechanism as with osteomyelitis [1], fat globules may be more commonly seen in older patients because of age-related bone loss. The medulla of long bones is formed by trabecular bone, which is porous and composed of a bony matrix filled with hematopoietic or fatty marrow or both, with the percentage of fatty marrow increasing with advancing age [25]. With age, the bone is less compact, with resorption of the horizontal trabeculae especially in women, leaving vacant intertrabecular marrow cavities [26–28]. Intraosseous fat-fluid accumulation following a fracture was previously thought to be unlikely because of the

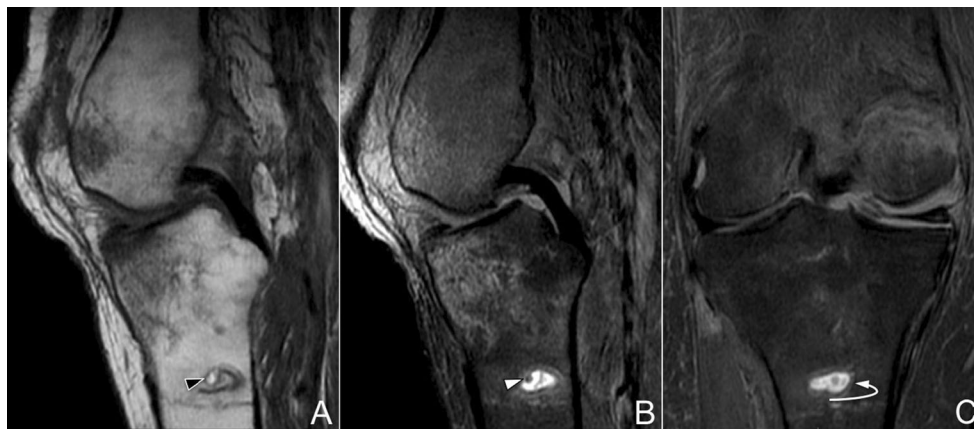


Fig. 5 A 68-year-old woman with injury 20 days before with an osteochondral fracture of the medial tibial plateau and a contusion in the medial femoral condyle. Several fat globules were seen. Images show the largest fat globule 4 cm away from the fracture site in the tibia. **a** Sagittal T1 image shows a small round T1 hyperintense fat globule in the

diaphysis of the tibia (*arrowhead*). Note the globule is hyperintense compared to normal fatty marrow. **b** Sagittal PD fat-suppressed image shows corresponding fat suppression of the fat globule (*arrowhead*). **c** Coronal PD fat-suppressed image shows a thick surrounding halo of hyperintensity (*curved arrow*)

improbability of cavity formation in trabecular bone [4]. However, the altered trabecular architecture that occurs with trauma and age allows the previously separated marrow cavities to communicate and the intramedullary fat globules to coalesce. The hemorrhage and edema at the site of injury increase the intramedullary pressure causing the coalesced fat to travel through the communicating trabecular chambers to sites distant from the injury. In our study, fat globules were seen up to 6 cm distant from the site for fracture, likely communicating through a large trabecular chamber. There are larger marrow cavities in the diaphysis than in the epiphyses of long bone, which may explain the frequency of fat globule accumulation in the diaphysis or metaphysis in all of our cases [29].

Yellow marrow is composed mostly of fat, which is high in signal on T1-weighted imaging. Adjacent water and mineralized bone matrix lower the resulting composite signal somewhat, however [30]. It is hypothesized that the increased signal in the fat globules in the T1-weighted images when compared to the normal adjacent fat marrow relates to the presence of a higher concentration of liquefied fat that is no longer intracellular in location as higher signal intensity on fat sensitive imaging is seen with higher concentration of lipids [31]. The T2 hyperintense halo surrounding the fat globules may relate to an inflammatory reaction to the foci of necrotic fat as seen in cases of fat necrosis in the subcutaneous tissues of the extremities and torso as well as in the breast [17, 32–36].

Our documentation with MRI of fat globules in the marrow following injury is also interesting as it supports the mechanical theory of the pathogenesis of fat embolism [37, 38]. The source of fat emboli following fracture and intramedullary reaming has long been debated [38, 39]. In the proposed pathogenesis of the mechanical theory, the disrupted fatty marrow cells in fractured bones release freed liquid fat that is then forced into torn veins because of the increased intramedullary pressure related to hemorrhage and inflammatory edema [5, 37–40]. The visualization of fat globules on MRI demonstrates this liquefied fat.

The main limitation of this study is the lack of histologic correlation owing to the retrospective nature of the study. Our proposed pathogenesis is inferred from previous histologic studies of bone aging, bone contusions and fractures [20–23, 25–29]. Histologic analysis of globular fat accumulation related to osteomyelitis seen on MRI also supports our proposed theory [1]. Other limitations to this study include the reliance on previous MRI interpretations to include the key words required for inclusion in the study. The study was also limited by the utilization of consensus rather than independent assessment. Although a large number of cases were reviewed, the study population was predominantly younger men with recent bone trauma. The frequency of this finding is likely higher in an older population and in women. Some of the studies were

also performed on low-field-strength magnets, which clearly lower the sensitivity to detection of small fat globules.

Intramedullary fat globules are seen in about 2 % of MRI examinations in patients with MRI evidence of acute bone injuries involving the knee. Although we have no confirmation regarding the accuracy of our proposed pathogenesis, we believe the finding will prove to be more common in the acute or subacute stage of injury and in older patients. The finding of fat globules on MRI confirms the theory that freed liquid fat from the bone marrow embolizes to the cardiovascular system following skeletal trauma. Although rare, intramedullary fat globules related to osseous trauma should be considered a benign entity and not mistaken for a more ominous fat-containing lesion such as osteomyelitis, an early bone infarct or a fat-containing neoplasm. With fluid-sensitive sequences, an intraosseous fat globule with a hyperintense halo could also be mistaken for an aggressive lesion such as a site of metastasis, which may reveal a T2 halo sign [18]. It is the presence of additional MRI features of skeletal trauma that provide the most important clue to correct diagnosis. Additional studies are required for histologic correlation and to determine the clinical significance of this finding, however.

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Conflict of interest The authors declare that they have no conflict of interest.

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