Detection of bone marrow edema in wrist trauma using 3D fat-saturated proton density sequence with 3T MR imaging

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Purpose

As in other joints, BME of the wrist can be seen after musculoskeletal injuries. Literature regarding the subject is quite limited.

In USA the overall incidence of wrist trauma is 69 per 10000 per year. The most common mechanism of injury is a fall on outstretched hand (FOOSH). Trauma can cause both fractures of the forearm or carpals and non osseous injuries such as DRUJ disruption, TFCC tears, ligament injuries and cartilage lesions.

BME can be reactive or accompany an occult fracture. It is frequently of traumatic etiology and the underlying mechanism may be acute or chronic.

BME is only detected by MRI, and is preferably evaluated on fat saturated T2 weighted or STIR imaging sequences. With better imaging techniques, the detection of BME has significantly improved, although the clinical significance is not always clear.

Bony injuries can be classified as cortical fracture ("incomplete" fracture), bone contusion or bone bruise (bone marrow edema without associated cortical disruption), and as complete fracture. As for other joints, the term bone bruising is used for lesions not visible on normal radiographs, appearing as irregular foci of increased signal intensity on T2-weighted spin-echo (SE) MR images and decreased signal intensity on T1-weighted images. A fracture is seen on MR imaging as a low signal line extending across the bone on all sequences associated with bone marrow edema. A bone bruise consists of injury to trabeculae without other evidence of fracture.

There are different patterns of injury that can cause BME, and BME can be associated with both acute and chronic traumatic lesions. Impaction injuries, resulting from direct trauma, such as a fall on the outstretched hand, can lead to a focal bone bruise. Avulsive injuries can occur in carpal bones such as scaphoid, triquetrum, pisiforme, trapezium, lunate, etc. Because the cortical bone is involved rather than the trabecular bone, the resulting avulsion BME pattern is much less extensive than in impaction injuries and the osseous avulsion is better demonstrated on conventional radiographs or CT. Stress fractures, or fatigue fractures can happen in the wrist and hand, although more common in the weight-bearing lower limb. They occur when repetitive stress, sometimes accompanied by muscle fatigue, is applied to normal bone. This can lead to a pathologic continuum of microdamage that exceeds bony repair, leading to eventual structural failure and fracture.

The ability of MR imaging to accurately image cortical and medullary bone makes it an ideal modality for the diagnosis of radiographically occult bone injuries. Furthermore, MR imaging of the wrist to screen for radiographically occult scaphoid fractures at the time of initial presentation has already been shown to be a cost-effective method. An extra
advantage of MR imaging is that there is less loss of productivity for patients who are unnecessarily treated with casts or splints.

In a recent study Pierre Jerome et al. assessed the prevalence and distribution of multiple occult injuries of the carpal bones and the distal forearm. In a population of 125 patients with negative radiographs following trauma, occult bone injuries were present in 62%, and in 37% a visible fracture line was seen.

The objective of this study is to analyze the ability of different imaging sequences to detect BME on 3T MR system.

Methods and Materials

From January 2010 to April 2011, 149 MR examinations of the wrist were performed on 145 patients (60 women and 85 men; mean age, 36.7 years; age range, 9-73 years). The patients were referred for evaluation of acute or chronic wrist pain; all of them were included in the study. We tried to contact all patients to gather more information about the dominant side, date and mechanism of trauma, clinical history and present complaints.

MR Imaging Protocol

One hundred forty-nine MR examinations (102 contrast-enhanced MRI, 47 MR arthrography) were performed on a 3T MR imager (Achieva, Philips Medical Systems, Best, the Netherlands). We used a dedicated 8 channel phased array wrist coil. All subjects were placed in the MR imagers in the supine position with the coil placed at the side of the patient (in a comfortable position).

Contrast-enhanced MRI (Indirect MR arthrography) of the wrist was initiated after intravenous injection of gadopentetate dimeglumine (Magnevist, Schering, Berlin, Germany; 0.5 mmol/L). Immediately after injection, patients were instructed to move the injured wrist for a few minutes.

Direct MR arthrography consisted of a solution of 5 mL of iodinated contrast material (Hexabrix, Guerbet, France) and 0.1 mL MR contrast material (gadopentetate dimeglumine, Magnevist, Schering) diluted in 20 mL of a solution of saline, injected into the radiocarpal joint. A total volume of 3 to 4 ml was injected. All injections were performed under fluoroscopic guidance with a 24-gauge needle.

For the contrast-enhanced MRI, the imaging protocol included proton density (PD) weighted fast spin echo (TSE; repetition time msec/echo time msec, 4000/15) sequences
with and without fat saturation, a STIR (short tau inversion recovery; 3600/30) sequence in the coronal plane, a dual PD and T2-weighted fast spin echo (3300/12/110) sequence without fat saturation in the axial and sagittal plane. The slice thickness was 2mm (without intersection gap) for all these sequences.

The MR examination was completed by a 3D gradient echo sequence with dual echo and steady state precession (DESS or fast field echo FFE; 10/7, flip angle 30°) in the coronal plane (with 0,5 mm thick slices), followed by sagittal and axial reconstructions.

In 38 patients a fat saturated 3D PD sequence (1500/35, flip angle 35°) was added in the coronal plane (with 0,5mm thick slices), followed by sagittal and axial reconstructions.

The images obtained with 3D sequences were not purely isotropic (to keep reasonable acquisition time with Philips imager). The voxel size was respectively 0,35x0,35x0,5 for 3D DESS, and 0,35x0,4x0,5 for fat saturated 3D PD.

For the MR arthrography, the imaging protocol was the same as for contrast-enhanced MRI, except for the STIR sequence, which was not performed because of the interaction with the intra-articular contrast injection. A supplementary fat saturated T1 weighted sequence was added in the coronal plane.

The imaging time for a complete examination was about 40 minutes.

**Results**

**Presence and patterns of BME**

On a total of 149 wrist MR examinations (102 MRI; 47 MR arthrography) performed on 145 patients, BME was seen in 48 examinations. This is shown in table 1. BME was seen in 33 out of 102 contrast enhanced MR examinations and in 15 out of 47 MR arthrographies (MRA).

In our traumatic population, intramedullary bone edema was present in 42 out of 87 examinations. In 29 out of 56 examinations, the BME was seen on (contrast-enhanced) MRI and in 13 out of 31 on MRA (table 1).

**Table 1:**
Table 1: Presence of BME on contrast enhanced MRI or MR arthrography (MRA) in both traumatic and non-traumatic patients

<table>
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<tr>
<th></th>
<th>BME</th>
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<td><strong>MRI post trauma</strong></td>
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<td><strong>MRI without trauma</strong></td>
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<td><strong>TOTAL MRI</strong></td>
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<tr>
<td><strong>MRA post trauma</strong></td>
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<td>15</td>
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<td><strong>TOTAL post trauma</strong></td>
<td>42**</td>
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<td><strong>87</strong></td>
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<td><strong>TOTAL without trauma</strong></td>
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<td><strong>TOTAL</strong></td>
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<td>101</td>
<td><strong>149</strong></td>
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</table>

References: T. Backaert; Radiology, Brussels, BELGIUM

*: In all non traumatic patients BME was mostly subchondral.

**: In 14 out of 42 traumatic patients with intramedullary BME, subchondral BME was also present.

In 18 examinations there was an associated fracture present. Most fractures were visible on plain radiographs if available. One radius fracture was not visible on plain radiographs performed at Emergency Department and the patient was sent home without immobilization (case 1). The 43-year-old female was called to complete the X-ray with MR examination for study purposes. She complained of persisting pain and MR examination revealed a fracture of the radius, not recognized, even retrospectively on the first X-rays. Subchondral BME was seen in 14 of the traumatic patients.
In the population with overuse lesions, BME was present in 6 out of 62 examinations (including 4 detected on contrast-enhanced MRI and 2 on MR arthrography). In all non-traumatic patients, BME was located in the subchondral bone area. In case 2 an extensive BME is shown in the lunate (in a 14-year-old male). The edema is associated with positive ulnar variance and typical signs of chronic ulnocarpal impaction syndrome. In case 3, an advanced Kienbock’s disease is shown in a 19-year-old sports student. Intramedullary BME was present in all the surrounding carpal bones, probably corresponding to reactive edematous changes. Fragmentation was better depicted on computed tomography (CT). There was no associated ulnar negative variance in this particular case.

As shown in table 2, on a total of 42 cases of bone contusions, 26 were present in the carpal bones (including 9 in the scaphoid) whereas 16 were seen in the forearm. An example of BME of the scaphoid is shown in case 4. In the forearm, the radius was affected 12 times. In 4 cases, only the ulna was involved.

**Table 2:**

*The number of cases with an associated fracture is shown between brackets.*

*In total there were 42 patients. In 26 and 16 cases BME was detected in the carpus and the forearm respectively.*

*Carpal bone contusions (26) were seen more often than forearm bone contusions (16). In the carpus, 9 carpal bone injuries were seen in the scaphoid. The lunate was affected in 12 cases. In the forearm, the radius was affected 12 times. In 4 cases, only the ulna was involved. In 18 cases there was an associated fracture.*

<table>
<thead>
<tr>
<th>Age</th>
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<tr>
<td>Total</td>
<td>26 (8)</td>
<td>16 (10)</td>
<td>42 (18)</td>
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</tbody>
</table>

**Table 2:** Localisation of BME correlated to age in posttraumatic wrists

*References:* T. Backaert; Radiology, Brussels, BELGIUM

**Comparison of BME sensitive sequences**
The results obtained on the different BME sensitive sequences were compared in table 3. All detected cases of BME were visible on both fat saturated 2D PD and 3D PD sequences when available. In 3 patients, BME was not visible on STIR, while it was detected on fat saturated 2D PD and 3D PD when performed. This was the case in two examinations with a poorer spatial resolution and lower signal-to-noise ratio when performing STIR images with 2mm thickness. The resolution of the STIR images was too low to detect subtle subchondral or cartilage lesions, especially in females with small wrists. In the last case, the subtle edematous changes present in the fifth metacarpal base, as well as the slight subchondral bone changes of the ulnar fovea were only detected on fat saturated 2D PD and 3D PD sequences, and not on STIR, probably due to more disturbing chemical shift artefacts. When there is a doubt whether a hyperintense area is an artefact or an area of intramedullary BME on fat saturated PD or STIR images, the use of a T1-weighted sequence could help to make the difference. Theoretically fat saturated 3D PD has a lower resolution than fat saturated 2D PD, because the TR is much lower to keep the 3D acquisition in a reasonable time (TR was 4500 for fat saturated 2D PD and 1500 msec for 3D PD). However, in our study, both sequences were able to detect BME in all cases. A problem with sequences using spectral fat suppression is their high sensitivity to field homogeneities. Sometimes the fat suppression is not homogeneously obtained, especially in the sagittal and axial plane when the wrist is placed at the patient’s side close to the border of the tunnel. This can be compensated by the use of shimming prior to the measurement.

Table 3: Detection of BME

| REFERENCES: T. Backaert; Radiology, Brussels, BELGIUM |
| Sequence not performed V: BME visible X: BME not detected |

Table 3: Detection of BME

Comparison of the different imaging modalities capable of detecting BME. In three cases BME was not detected on all sequences.

<table>
<thead>
<tr>
<th>NUMBER OF EXAMINATIONS</th>
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<th>3D PD SPAIR VISTA</th>
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**Location of BME in different age groups and association with fractures**

The different locations of intramedullary BME in the wrist where correlated with the age of the patients. Posttraumatic patients were divided in three age groups (younger than 18, 18 to 55 and older than 55). The choice of the age groups was based on the fusion of the epiphyseal growth plates at 18 years of age and the higher frequency of osteopenia above 55 years of age. The location of intramedullary edema was first determined in the wrist bones, followed by the presence of fractures in every age group. As shown in table 2, patients older than 55 sustained more often a forearm injury, while carpal injuries were more common in the group of patients younger than 18. This is probably due to the fact that carpal injuries are more frequent in sport trauma, while injuries to the radius or ulna are more common in older populations with a higher prevalence of osteopenia. In the group of middle-aged patients (older than 18, but younger than 55), the results were intermediate.

**Evolution of BME in time**

The presence of BME was correlated with the time between the initial trauma and the MR examination. The patients were divided in 4 categories. The number of cases in every time category is shown in table 4. The first group of patients underwent MRI within the first 3 weeks following MRI. The second group of patients underwent MRI between 3 weeks to 6 months after trauma. The third group of patients sustained a trauma more than 6 months but less than 1 year before MRI. The last group of patients had MRI more than one year after trauma. The chart shows that BME is relatively less frequent if MRI is performed a long time after trauma. We should also take in mind that all our patients had one or more symptoms at the time of MRI, and that abnormal anatomy or wrist instability may have the same effect as repetitive trauma. If all our patients -even when asymptomatic- would receive a control MR examination 1 year after the initial trauma, the number of patients without BME would probably be much higher. BME can disappear after treatment which is shown in case 4.

**Table 4:**

*The presence of BME is correlated with the time between trauma and MRI. BME is relatively less frequent if MRI is performed a long time after trauma.*
Table 4: Evolution of BME in time

References: T. Backaert; Radiology, Brussels, BELGIUM

Case 1: Occult radius fracture detected by MRI.

The radiographs (including anteroposterior AP and lateral views) obtained the day after trauma was negative (A). Three days later, coronal (B, STIR, fat saturated 2D PD, PD, fat saturated 3D PD) and sagittal (C, PD, T2, reconstructed fat saturated 3D and 3D DESS) MR images revealed a radius fracture with extensive BME. Control radiographs 1 month (D) and 2 months (E) post trauma depict consolidation signs, better seen on the last ones.

Fig. 1: Case 1: A

References: T. Backaert; Radiology, Brussels, BELGIUM
Fig. 2: Case 1: B

References: T. Backaert; Radiology, Brussels, BELGIUM
Fig. 3: Case 1: C
References: T. Backaert; Radiology, Brussels, BELGIUM

Fig. 4: Case 1: D
References: T. Backaert; Radiology, Brussels, BELGIUM
Case 2: Extensive BME in the lunate associated with chronic ulnocarpal impaction syndrome.

On the coronal MR images obtained in fat saturated PD, T1, fat saturated 3D PD and STIR sequences (A) in a 14-year-old male without any fracture, BME is associated with positive ulnar variance, thinned and displaced TFCC (long arrow) as well as cartilage lesions (small arrow) at the lunate facet, corresponding to signs of chronic ulnocarpal impaction syndrome. The edema is limited at the ulnar side of the lunate (curved arrow) on the T1 weighted image (without intravenous contrast).

The positive ulnar variance is well demonstrated and can be measured on the anteroposterior radiograph (B).
**Fig. 6:** Case 2: A

**References:** T. Backaert; Radiology, Brussels, BELGIUM
Fig. 7: Case 2: B

References: T. Backaert; Radiology, Brussels, BELGIUM

Case 3: BME associated with avascular necrosis of lunate.
On coronal fat saturated PD, STIR and T1 weighted images obtained before and after intravenous contrast injection (A) in a 19-year-old sports student, intramedullary BME was present in the surrounding carpal bones, probably corresponding to reactive edema. The lunate has a decreased height and decreased signal intensity on all sequences, especially on T1 before and after contrast. There is an associated synovitis in the ulnar prestyloid recess (arrowheads) and lateral radiocarpal recess (arrow) with a low signal intensity on T1, enhancing on T1 after intravenous contrast injection (A). Coronal and sagittal reconstructions from a CT axial data set reveal fragmentation of the necrotic lunate. There was no associated ulnar negative variance (B).

Radiograph obtained before surgical carpectomy shows a subchondral osteolysis at the proximal side of the lunate. On the post-operative X-ray, scaphoid, lunate and triquetrum have been removed (C).

Fig. 8: Case 3: A

References: T. Backaert; Radiology, Brussels, BELGIUM
Case 4: Evolution of a scaphoid fracture with pseudarthrosis.

Radiograph obtained in ulnar deviation one month after trauma in a 17-year-old male disclosed an evident fracture of the middle third of the scaphoid (which was not visible on the first radiographs performed on the day of trauma) (A).

Since bone scintigraphy (B) performed one year after trauma was positive at the level of the scaphoid, MRI was obtained to exclude the development of avascular necrosis
at the proximal pole of the scaphoid. Coronal fat saturated PD, sagittal fat saturated T1 and coronal T1 obtained after intravenous contrast injection, as well as sagittal T2 weighted images (C) revealed an extensive BME of the whole scaphoid associated with pseudarthrosis without necrosis. There was a surrounding synovitis enhancing on T1 weighted images obtained after contrast injection.

On the control MR images (coronal T1, STIR and 3D DESS and axial fat saturated T1) performed 17 months after trauma, the BME was resolved and the fracture was healed (D).
Fig. 11: Case 4: A

References: T. Backaert; Radiology, Brussels, BELGIUM
Fig. 12: Case 4: B

References: T. Backaert; Radiology, Brussels, BELGIUM
Fig. 13: Case 4: C

References: T. Backaert; Radiology, Brussels, BELGIUM
Fig. 14: Case 4: D

References: T. Backaert; Radiology, Brussels, BELGIUM

Images for this section:
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Table 4: Evolution of BME in time

![Evolution of BME in time graph]

Table 4: Evolution of BME in time
Fig. 1: Case 1: A
Fig. 2: Case 1: B
Fig. 3: Case 1: C

Fig. 4: Case 1: D
Fig. 5: Case 1: E
Fig. 6: Case 2: A
Fig. 7: Case 2: B
Fig. 8: Case 3: A

Fig. 9: Case 3: B
Fig. 10: Case 3: C
Fig. 11: Case 4: A
Fig. 12: Case 4: B
Conclusion

MRI is the best imaging modality to detect bone marrow edema associated with fractures or bone contusions in acute and chronic wrist trauma. It should be considered in case of clinical dilemma and normal initial radiographs. MRI also allows the detection of some of the associated ligamentous injuries, and might influence the therapeutic management of injured wrists. In this preliminary observation, intramedullary BME was often associated with wrist trauma, especially in the acute and subacute phase. After 6 months BME was less often present. A higher prevalence of intramedullary BME was found within the carpal bones in patients younger than 18 (often secondary to fall during sports) and within the distal radius in patients older than 55 (often associated to osteopenia).

Patterns of BME include fractures and bone contusions. In the forearm, the radius was most frequently involved. In the carpus, the scaphoid and lunate were often affected. The comparison of the different BME-sensitive sequences on 3T MR examinations did not reveal any difference between fat saturated 2D and 3D PD. Fat saturated 2D PD sequence has the advantage of a higher resolution due to longer TR, while fat saturated 3D PD allows the use of thinner slices. Intramedullary and subchondral BME were detected on both sequences in all patients. STIR images, on the other hand, did not allow a good analysis of subchondral bone edema.

References


**Personal Information**