Articular void sign on MRI in intra-articular distal radius fracture patients

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Abstract

Introduction:

The purposes of this study are 1) to investigate whether MRI can detect ischemic changes in the subchondral bone and intra-articular fibrosis, 2) to investigate the relationship between MR imaging and wrist function, and 3) to investigate the compatibility of MR imaging and simple radiographic imaging in patients with intra-articular distal radius fracture treated using volar locking plate.

Materials and methods:

The plain radiographs, CT scans, and MRI findings of 27 patients were examined. The mean follow-up was 2 years (1 year − 3 years and 6 months). The range of motion of the wrist joint was evaluated as % arc, which is the ratio of the range of motion to that on the healthy side, expressed as a percentage.

Results:

In 27 patients, there were 6 type C1, 3 C2, and 18 C3 fractures. The mean step measured on plain radiographs was $0.4 \pm 0.7$ mm (range, 0 to 2 mm), and that on T1-weighted MR image was $0.6 \pm 0.9$ mm (range 0 to 3 mm). Comminuted central impaction fractures were observed in 9 patients on CT sections. The mean % arc was $88.1 \pm 11.3\%$ (range, 48.5 to 100%). Plain radiographs showed an area of sclerotic change in the subchondral bone in three patients. These three patients were consistent with those three patients whose % arc was smaller than the standard deviation.

In two of the three patients, the area corresponding to this sclerotic area was a homogenic low intensity area on the T1-weighted MR images. Nevertheless this area consists of components with unspecified shape and intensity on T2-weighted MR images. These areas were tentatively designated as “articular void”.

Conclusions:

This articular void was considered to include necrotic bone, fibrous tissue and suggested to be one of a cause of impairment of joint function.

Introduction

Osteoarthritis of the articular surface [1] and fibrosis spreading into the joint [2] have been described as the main causes of functional impairment of the wrist joint after intra-articular distal radius fracture. An incongruency of the articular surface has been said to be the cause of osteoarthritis at the intra-articular distal radius fractures [1]. Nevertheless, there are many reports that one of the major causes of OA in knee joints is impaired subchondral bone circulation [3, 4, 5, 6]).
As for the fibrosis in the wrist joint after intra-articular distal radius fracture, Gabl et al. detected arthrobrosis spreading from the fracture line into the joint space using arthroscopic observations of wrist at the time of plate removal after bone fusion in 20 patients [2]. Arthrobrosis in the knee and ankle joints was previously evaluated by magnetic resonance imaging (MRI) not only by the arthroscopy [7, 8].

While there are no reports of MRI evaluation of fibrosis for distal radius fractures, MRI provides a lot of information about the wrist joint, including suspected scaphiod fractures [9] and ischemic changes of the lunate [10]. However, the distal radius fracture after surgery with a volar locking plate (VLP) is difficult to visualize on MRI due to metal artifacts. Yamamoto et al. reported that the most common reason for the removal of hardware was routine removal [11]. VLPs were removed routinely after bone fusion at our institution as well. And these patients requested MRI.

We hypothesized that 1) MRI could detect circulatory disturbances in the subchondral bone after intra-articular distal radius fractures, 2) MRI could show fibrosis in the wrist joint, and 3) these subchondral bone ischemia and fibrosis in joint might affect wrist function.

The primary objective of this study is, In order to examine these hypotheses, to retrospectively investigate the MRI findings and wrist function of the patients with an intra-articular distal radius fractures treated with VLP after removal of hardware. In addition, since VLPs are still often not removed, a second objective is to examine the compatibility of plain radiographs and MRI findings.

**Patients And Methods**

Between July 2010 and April 2014, 38 consecutive patients underwent open reduction and internal fixation (ORIF) for intra-articular DRF. ORIF using VLP (SmartLock, Stryker Germany) was performed. As three patients moved and one dead of stroke 6 months after surgery, four patients were lost of the follow up. Therefore, 34 patients were followed up for more than one year after surgery, and all had their hardware removed. Until April 2015 at our institution, hardware was removed as a routine procedure in all patients after bone fusion was obtained. Twenty-seven out of 34 patients requested MRI. In these 27 patients the plain radiographs, CT scans, MRI findings and wrist function of these patients were retrospectively evaluated with approval by the Ethics Committee of our institution. And informed consent was obtained from all patients. The mean postoperative follow-up of 27 patients was 2 years (range, between 1 year and 3 years and 6 months). At the time of surgery, the mean age of patients was 66.3 years (range, between 45 and 82 years).

Before surgery, posteroanterior, lateral, and oblique radiographs of injured and uninjured wrists were acquired. and CT sections (BrightSpeed Elite, GE Yokokawa Medical System, Tokyo, Japan) of the wrist were acquired. AO/OTA classification was performed based on plain radiographs and CT images. Plain radiographs of the injured side were obtained immediately, 1, 3, 6, 9 months and 1 year after surgery, on the date of pre and post removal of the hardware and the last survey. MRI was performed after hardware removal. The mean time from surgery to MRI was 12 months (range, between 5 and 36 months), while that from plate removal to MRI was 7 weeks (range, between 1 and 37 weeks). Patients underwent MRI
on the wrist using 1.5 T Philips Achieva (Philips Healthcare, the Netherlands). Conventional sequences that included coronal, sagittal, and axial T1-weighted images (TR = 650 ms, TE = 22 ms, field of view (FOV) = 12 x 12 cm, slice thickness = 3 mm) and coronal T2-weighted images (TR = 3000 ms, TE = 90 ms, FOV = 12 x 12 cm, slice thickness = 3 mm) were used. On plain radiographs, gaps and steps on the surface were measured in the vertical and parallel directions relative to the axis of the radius respectively, as previously described by Kreder et al [12] in 0.5-mm increments (Fig. 1). On MRI, the decreased intensity area, which was lower than the surrounding bone marrow in coronal T1-weighted images, was measured in 0.5-mm increments as a tentative gap (Fig. 1).

The step and gap in MRI was measured in coronal T1-weighted images as well as in plain radiographs to measure the step of the subchondral bone in 0.5-mm increments. The images of patients with characteristic features were investigated in detail and the results of physical examinations documented in medical records were examined. The range of motion of the wrist joint was evaluated as % arc, which is the ratio of the total value of palmar flexion and dorsiflexion to the value on the healthy side, expressed as a percentage.

**Statistical analysis**

Power analysis was not performed due to the low number of patients in general. The relationship between two groups was assessed using a single regression analysis (StatView-J5.0, SAS, Cary, NC). All data are shown as means ± standard deviation and ranges. And ranges of 95% confidence intervals were calculated and shown in graphs. P-values of < 0.05 were considered to indicate significance.

**Results**

According to the AO/OTA classification, there were 6 type C1, 3 C2, and 18 C3 fractures. Comminuted central impaction fragments were observed in 9 patients on CT sections. The mean % arc was 88.1 ± 11.3% (range, 48.5–100% degrees). There were three patients whose % arc was smaller than the standard deviation. Plain radiographs showed sclerotic change of the subchondral bone in three patients. These three patients were consistent with those three patients who had smaller % arc. Those values of them were 66.7%, 68.8% and 48.5%. In current report they were designated as patient-1, patient-2 and patient-3, respectively.

There were 5 patients with the largest 3 mm gap, and their % arcs were 82.4%, 85.3%, 68.8%, 93.5%, and 93.6%, respectively. Of these, only patient-2, with a % arc of 68.8%, was included in the three patients whose % arc was smaller than the standard deviation mentioned above. The mean gap measured on T1-weighted MR images was 1.9 ± 3.4 mm (range 0 to 15 mm).

The % arc of patients with the largest 15 mm and next largest 9 mm Gap was 66.7% and 68.8%, respectively, and these were for patient 1 and patient 2, respectively, which were lower than the standard deviation.
The area measured as a gap in T1-weighted MR images was a homogeneous low density area in T1-weighted MR images, while it was a heterogeneous intensity area in T2-weighted MR images, containing cord-like tissue from the subchondral bone into the joint.

The mean step measured on plain radiographs was $0.4 \pm 0.7$ mm (range, 0 to 2 mm), and that on T1-weighted MR image was $0.6 \pm 0.9$ mm (range 0 to 3 mm). Only one patient showed a 2 mm step on plain radiograph with a % arc of 93.5%. The largest step among the 27 patients was 3 mm on coronal T1-weighted MR image in one patient. This patient was patient 3 of the above 3 patients whose % arc was less than the standard deviation.

Clinical case

Patient-1.

A 67-year-old female. While walking, the patient fell. A plain radiograph (Fig. 2a) and CT scan showed AO type C3.2 and central impaction fragment (Fig. 2b). One week later, ORIF was performed using VLP and no gap and step were demonstrated on a plain radiograph at immediately after surgery (Fig. 2c). A plain radiograph at 6 months postoperatively showed no obvious gap or step, but a sclerotic change in the subchondral bone (Figs. 2d). The plate and screws were removed 9 months after surgery. MRI was performed 11 months after surgery. A coronal T1-weight image showed a low intensity area at the subchondral bone area with a width of 9 mm (Fig. 3a). On a sagittal T1-weighted image, a low intensity area was detected at the subchondral area (Fig. 3b). The axial T1-weighted image showed a hypointense area in the center of the articular surface (Fig. 3c). The T2-weighted image showed that this area was heterogeneous and contained cord like iso-intensity tissue spanning from the subchondral bone to the scaphoid and lunate periphery (Fig. 4). One year after surgery (1 month after MRI), a plain radiograph revealed sclerotic change of the subchondral bone and joint space narrowing without no gap or step (Fig. 2e). The osteosclerotic area on plain radiographs and the low intensity area on MR images were in the same location (Figs. 2e, 3a and 4). A % arc of 66.7%. 3 years 6 months after surgery, plain radiograph showed subchondral bone sclerosis and joint space narrowing one year as with that at one year postoperatively.

Patient-2.

A 48-year-old male. The patient fell on his left hand at work. A plain radiograph (Fig. 5a) and CT scan (Fig. 5b) demonstrated an AO type C3.1 fracture. And while it was difficult to see on plain radiograph, the presence of comminuted central impaction fragments was confirmed on CT scan (Fig. 5b). Three days later, the patient underwent ORIF using VLP, and plain radiographs immediately after surgery showed a 1-mm gap and 1-mm step (Fig. 5c). A plain radiograph at 9 months postoperatively showed a sclerotic subchondral bone (Figs. 5d). The hardware was removed 14 months after surgery. And after the removal, a plain radiograph showed a 3-mm gap, 1-mm step, and sclerotic change at contiguous subchondral area (Fig. 5e). MRI was performed one week after hardware removal (14 months after surgery). Coronal T1-weighted MRI showed a homogeneous low intensity area at the subchondral area with a width of 15 mm.
The location of this low intensity area on T1-weighted images corresponded to that of the combined area of gap and its contiguous sclerotic area on plain radiograph (Figs. 5e and 6a). A sagittal T1-weighted image showed a low intensity area at subchondral bone (Fig. 6b). On an axial T1-weighted image, a low intensity area was depicted in the center of the articular surface (Fig. 6c). The homogenous low intensity area on this T1-weighted MR image was heterogeneous in the T2-weighted MR image. And this area contained a cord-like configuration which existed in the area of the subchondral bone to the ulnar side of the lunate bone (Fig. 7). The % arc was 68.8%. Since this was a work-related injury, the follow-up was completed after 1 year and 6 months due to insurance restrictions.

Discussion

In this study, there were three out of 27 patients whose % arc was lower than the mean subtracted standard deviation value. And three patients were found to have subchondral bone sclerosis on plain radiographs, and all of whom were the same patient. Therefore, these three patients were designated as patient-1, patient-2, and patient-3. Of these, the MRI feature common to both patient-1 and patient-2 was a homogeneously low intensity area on T1-weighted images (Figs. 3 and 6). And these homogeneously low intensity areas on T1-weighted images coincided to a gap at joint surface and its contiguous sclerosis area of subchondral bone on plain radiographs (Figs. 2, 3, 4 and 5). Nevertheless, this area was heterogeneous on T2-weighted images, and was a combination of various intensities and shape components. We tentatively called it “articular void” because this area may not consist of certain components.

The subchondral region has abundant arterial and venous vessels that branch into the calcified cartilage of the adjacent articular cartilage [13]. Saini and Saifuddin mentioned that the most common trigger of osteonecrosis is trauma [14]. As for features on the image, in the early stages of Kienböck syndrome, ischemia causes bone marrow edema and bone marrow intensity is low on T1-weighted images and high on T2-weighted images [15]. Complete bone marrow necrosis results in loss of signal intensity in both T1-weighted and T2-weighted images [16]. Saini and Saifuddin reported that advanced cases of osteonecrosis showed combinations of two or more tissue characteristics, such as bone sclerosis and fibrosis, within the same region [14]. For example, osteonecrosis of the femoral head, Vande Berg et al also detected focal regions that were homogeneous or heterogeneous, wedge-shaped, ovoid, bands, lines, rings, or crescents as other patterns [16]. The images of the articular void sign of the current patient-1 and patient-2 are very similar to the above (Figs. 3, 4, 6 and 7), it was thought that at least the articular void sign on MRI included bone ischemic necrosis. And sclerotic bone on the plain radiograph suggested a probability of bone ischemic necrosis.

On the other hand, Gabl et al. performed an arthroscopic examination at the time of plate removal on 20 patients after intra-articular DRF and found that fibrous tissue had expanded from the gap in the articular surface to the interosseous ligament and/or capsule [2]. Nevertheless, we did not find any MRI report of articular fibrosis after intra-articular distal radius fracture, Linklater and Fessa identified an intermediate signal on proton-density MRI due to edema and granulation in the early stages (approximately 6 months
after surgery) in the ankle joint, whereas tissue was more organized with a lower intensity in long-term cases [17].

In current two patients, T2-weighted images, tissue with a iso or slightly high intensity signal, appeared to be continuous in a cord-like pattern from subchondral area to the carpal bone (Figs. 4, 7). This cord-like tissue was considered to be arthrobrosis because it was in the joint space in which no bony component was observed on plain radiographs. It was suggested that the articular void sign in current patient-1 and patient-2 includes and fibrosis tissue ischemic as well as bone necrosis at least.

Patient-3 had a 3 mm step that could not be detected by plain radiograph but was revealed by tomography with MRI. Plain radiograph showed a sclerotic change of the subchondral bone, but MR image did not show any abnormal intensity in this area. In patient-3, the osteoarthritis change could be due to incongruency of the articular surface as reported by Knirk and Jupiter [1],

Currently, in many institute, the hardware is rarely removed after distal radius fracture surgery, and MR images are often not available. Nevertheless, in case that the postoperative plain radiograph shows osteosclerosis of the subchondral bone and is accompanied by dysfunction of the wrist joint, it is necessary to keep in mind the possibility that the step remains in the tomographic plane and that the subchondral bone of the articular surface has circulatory disturbance.

Another common preoperative features of current two patients with articular void sign are the presence of a central impaction fragments on preoperative CT scans. In this study, among 27 patients with intra-articular fractures of the distal radius, nine had central impaction fragments on preoperative CT, and two of these nine had articular void signs. Central impaction fragments are not connected to surrounding soft tissues such as ligaments or joint capsules, which may be unfavorable to blood circulation.

There are two limitations in this report 1) the sample size was small. and 2) a histological examination was not performed.

**Conclusion**

In the present study, we discussed the presence of articular void at the distal end of the radius that exhibited a different intensity from that of normal bone marrow on MRI and sclerotic change on plain radiograph. It may contain extensive osteonecrosis of the subchondral bone and fibrosis which indicate joint surface impairment.

**Declarations**

Conflict of Interest: The authors have no financial or proprietary interests in any material discussed in this article.

Funding: No funds, grants, or other support was received.
Ethical approval: The Ethics Committee at local institution approved for this study.

Informed consent: Informed consent was obtained from all patients.

References


**Figures**

![Figure 1](image_url)

**Figure 1**

Measurement Examples. 70-year-old woman. Left: example of gap and step measurement of a plain radiograph obtained immediately after 10 months after surgery. The central axis was drawn according to Kreder’s method from the midpoint 3 and 5 cm below the articular surface. Step was defined as the maximum level difference in the tidemark of the subchondral plate in the longitudinal direction relative to the axis of the radius, and gaps on the surface were measured quantitatively in the vertical direction relative to the axis of the radius. The gap was 2.5 mm (arrows), and the step was 2 mm (open arrows). Right: On a coronal T1-weighted image (right) 9 months after surgery, the gap was 4 mm (arrows) and the step was 2.5 mm (open arrows).
Figure 2

Patient 1, A 67-year-old female. (a) On preoperative plain radiograph, an AO type C3.2 intra-articular distal radius fracture was observed. (b) Preoperative CT scan showed a central impaction fragment. (c) On plain radiograph immediately after surgery, no step or gap was present. (d) At 6 months postoperatively a plain radiograph showed a sclerotic image of the subchondral change through the plate (open arrows). (e) One year after surgery, there was no obvious step or gap; however, sclerosis of the subarticular bone was detected (open arrows) at the distal end of the radius and narrowing of the articular cleft (open arrow heads).
Figure 3

Patient 1. MRI 11 months after surgery. (a) A coronal T1-weighted image showed a low signal intensity area (arrows) bordering the articular surface with a width of 9 mm. (b) Sagittal T1-weighted image demonstrated a low signal intensity area. (c) Axial T1-weighted images also represented a low signal intensity area (arrows) which was surrounded by a region of iso-intensity in the center of the articular surface.
Figure 4

Patient 1. A coronal T2-weighted image showed a heterogeneous low and iso signal intensity area (open arrows). An iso-intensity cord-like tissue ran from the subchondral bone area to the joint space around the lunate scaphoid (closed arrows).
Figure 5

Patient 2, A 48-year-old male. (a) Preoperative plain radiographs showed an AO type C3.1 intra-articular distal radius fracture. (b) Preoperative coronal (left), sagittal (middle) and axial (right) CT sections showed an AO type C3.1 fracture and central impaction fragments (arrows). (c) A plain radiograph obtained immediately after open reduction and internal fixation. A 1-mm gap and 1-mm step were observed on the anteroposterior radiograph (arrow). (d) A plain radiograph at 9 months postoperatively showed a sclerotic subchondral bone (open arrows). (e) Fifteen months after surgery, just after plate and screw removal. An anteroposterior radiograph showed a 3-mm gap, 1-mm step, and subchondral bone sclerosis. Narrowing of the joint space was not observed.
Figure 6

Patient 2. (a) Fifteen months after ORIF. A coronal T1-weighted image (left) shows a homogenous low signal intensity area that was lower than the surrounding bone marrow, including 15 mm of the articular surface. (b) A sagittal T1-weighted MR image (middle) also showed a decreased signal intensity area in the articular surface (open arrows). (c) On an axial T1-weighted image, a low signal intensity area occupied the central part of the joint (open arrows).
Figure 7

Patient 2. Coronal T2-weighted MRI. In the low intensity area of the subchondral bone, slightly high intensity cord-like tissue ran from the subchondral bone to the area around the lunate bone (arrows).