Low-Field Compact Magnetic Resonance Imaging System for the Hand and Wrist in Rheumatoid Arthritis

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Purpose: To investigate the feasibility of an originally developed compact MRI system for evaluating rheumatoid arthritis (RA), and determine its advantages and disadvantages as an imaging modality for evaluating RA.

Materials and Methods: We prospectively studied 13 healthy controls with no clinical symptoms of arthritis, and 13 patients with hand and wrist pains (including pain from RA) with a 0.2 T permanent-magnet compact MR imager. All MR images were obtained while the subjects were in a sitting position. Coronal three-dimensional spin-echo T1-weighted images and coronal two-dimensional short tau inversion recovery (STIR) images were obtained with image matrix = 256 x 128 and field of view (FOV) = 20.48 cm. Plain radiograph findings and MRI findings of patients were compared.

Results: In three of the patients with suspected early RA (N = 7), early RA was evaluated based on STIR images. All RA patients showed morphologic or signal intensity changes that allowed an evaluation of RA from MR findings. Four of five RA patients showed high signal intensity on STIR images in the wrist, proximal interphalangeal (PIP) joint, or metacarpophalangeal (MCP) joint that suggested synovitis. Multiple erosions in the hand and wrist were seen in four RA patients, with low signal intensity on T1-weighted images.

Conclusion: RA was correctly evaluated, and early RA could be identified with the compact MRI system. However, the current system has limitations, such as the nonselective STIR sequence used and magnetic field inhomogeneity.

Key Words: MR imaging; low-field MRI; rheumatoid arthritis; hand and wrist


Low-field dedicated-extremity MR machines are now commercially available and have been applied to the evaluation of RA. Taouli et al (13) reported that conventional high-field MRI and low-field dedicated-extremity MRI were equivalent for evaluating RA synovitis. Using low-field dedicated-extremity MRI, Savnik et al (14) achieved a diagnostic accuracy for synovitis, bone marrow edema, joint effusion, and bone erosion of RA comparable to that of a high-field MRI system. Crues et al (15) reported that a portable MR system (0.2T) showed superior sensitivity for detecting bone damage compared to radiographs of the wrists and metacarpophalangeal (MCP) joints. They reported that MRI identified bony erosion in 95% of patients, compared to 59% by radiographs. Peterfy (8) remarked that the introduction of effective therapies for RA has increased the technical requirements for imaging in rheumatology, and that low-field extremity MRI offers adequate performance at a lower cost and with greater comfort and convenience for the patient. However, one disadvantage of these low-field MRI systems is that the field of view (FOV) is too small to enable an examination of the hand and wrist in one examination or one sequence.

Low-field compact MRI system recently developed a compact MRI system for measuring bone density of the calcaneus, and demonstrated its potential for that purpose. Their
entire system consisted of a permanent magnet, gradient coil assembly, RF probe, and portable MR console. It was small and could be installed in a space of 2 m × 2 m. Kurimoto et al (17) developed two compact MRI systems for the hand, and reported that these systems successfully detected several hand injuries within a reasonable imaging time. These results suggest that compact MRI has the potential to be useful for imaging the musculoskeletal region. Accordingly, our purpose in this study was to investigate the feasibility of using our originally developed compact MRI with a relatively large FOV for evaluating RA with the subject in a sitting position, and to determine the advantages and disadvantages of this compact MRI system as an imaging modality for evaluating RA.

**MATERIALS AND METHODS**

We prospectively studied 13 normal controls with no clinical symptom of arthritis, and 13 patients with hand and wrist pains, with an originally developed compact MR imager (Fig. 1). The normal control group included eight men and five women (22–48 years old, mean age = 34.1 years). The patient group consisted of 13 women (29–68 years old, mean age = 50.2 years). Table 1 presents their clinical profiles. Before the MR examination was performed, seven patients were suspected of having early RA based on arthralgia and swelling of the hand joints, an inflammatory reaction, positivity for rheumatoid factor, morning stiffness, and duration of symptoms, but had not yet met the 1987 revised American Rheumatism Association (ARA) criteria for the classification of RA. These patients were defined as patients with suspected early RA. One of the seven patients with suspected early RA was later diagnosed with ovarian cancer, paraneoplastic syndrome, and amyopathic dermatomyositis, and one showed soft-tissue swelling of the hand and fever of unknown origin. Five patients already met the revised ARA criteria. These patients were defined as RA patients. Therefore, the patient group consisted of subjects with suspected early RA, RA, and soft-tissue swelling. The study was approved by the institutional review board of the institute in which the MR system was placed. Each control subject and patient gave written informed consent.

The compact MRI system consisted of a permanent magnet, gradient coil set, RF coil, and MRI console. The total installation space was ~6 m² (Fig. 1a). The magnet was placed in an electromagnetic shield room (1.6 m (W) × 2.0 m (H) × 2.4 m (D)) to prevent external noise. The specifications of the permanent magnet were as follows: magnetic field = 0.21 T; gap = 25 cm; homogeneity = 25 ppm over 15 cm diameter spherical volume (dsv); and weight = 1350 kg. For uniform RF ex-

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**Table 1**

<table>
<thead>
<tr>
<th>Patient #</th>
<th>Sex</th>
<th>Age</th>
<th>Clinical diagnosis</th>
<th>Duration of symptom (years)</th>
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<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>48</td>
<td>Early RA suspect</td>
<td>&lt;1</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>36</td>
<td>Soft tissue swelling, fever of unknown origin</td>
<td>&lt;1</td>
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<td>F</td>
<td>68</td>
<td>Early RA suspect</td>
<td>&lt;1</td>
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<tr>
<td>4</td>
<td>F</td>
<td>56</td>
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<td>&lt;1</td>
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<td>57</td>
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<td>&lt;1</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>29</td>
<td>Early RA suspect</td>
<td>&lt;1</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>55</td>
<td>Early RA suspect</td>
<td>&lt;1</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>61</td>
<td>Early RA suspect</td>
<td>&lt;1</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>29</td>
<td>RA</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>70</td>
<td>RA</td>
<td>34</td>
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<td>11</td>
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<tr>
<td>13</td>
<td>F</td>
<td>54</td>
<td>RA</td>
<td>12</td>
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</table>

The patient was later diagnosed with ovarian cancer, paraneoplastic syndrome, and amyopathic dermatomyositis.
citation over a hand, we developed a solenoid RF coil with an oval aperture (8.5 cm (H) × 21 cm (W)). The subject sat in front of the magnet and inserted his or her hand into the RF coil to generate MR images (Fig. 1b). Coronal three-dimensional (3D) spin-echo (SE) T1-weighted images (repetition time (TR)/echo time (TE) = 1100/16 msec for control group and 160/16 msec for patients) were obtained with an image matrix of 256 × 128 × 16, FOV of 20.48 cm × 20.48 cm × 6.4 cm, and one acquisition. The scan time was ~6.8 min for the control group and 5.5 min for the patients. Coronal two-dimensional (2D) short tau inversion recovery (STIR) images (TR/TE/inversion time (TI) = 1400/50/130 msec) were also obtained with an image matrix of 256 × 128, no slice selection, an FOV of 20.48 cm × 20.48 cm, and two acquisitions. The scan time was ~6 min. The scan time with TR/TE/TI = 1000/50/120 msec was shorter for one patient because of pain (scan time = 4.3 min). Both hands of each subject were scanned, and the total examination time, including patient positioning, was <40 min.

For all patients, plain radiographs of both hands were obtained prior to the MR examination and reported by radiologists in our institute as a routine reading. No normal control groups underwent plain radiographic examination. The MR images were read by a radiologist (H.Y.) who was unaware of the radiographic findings.

RESULTS

All but one of the 26 subjects underwent successful MR examinations of both hand and wrist without complications. The one exception was patient 11, who showed a motion artifact because of pain. Only one of the control subjects showed an abnormal finding (a cystic change in the proximal first metacarpal bone without any clinical symptoms).

The findings from the plain radiograph and MR images of the patients are shown in Table 2. In the patients with suspected early RA, three had an evaluation by MRI of early RA due to proximal interphalangeal (PIP) synovitis, wrist synovitis, and flexor tenosynovitis. The PIP synovitis showed soft-tissue swelling around the joint and high signal intensity in and around the joint on STIR images (Fig. 2). The evaluation of wrist synovitis was based on findings of high signal intensity on STIR images in the intercarpal and radiocarpal joints. Linear high signal intensity over the wrist and digits with the STIR sequence affirmed an evaluation of tenosynovitis (Fig. 3).

All RA patients showed morphologic changes, including dislocation or ankylosis, or signal-intensity changes that permitted an evaluation of RA from MR findings. Four of five RA patients showed a high signal intensity in the wrist, MCP, or PIP joint that suggested synovitis on STIR images. One patient (patient 10) showed no high signal intensity on STIR images, but had marked bilateral ulnar deviated deformity of the hand and wrist ankylosis. Multiple erosions in the hand and wrist were seen in four RA patients who exhibited low signal intensity on T1-weighted images (Fig. 4).

DISCUSSION

MRI has become an important imaging modality for evaluating RA. Bony erosion is an essential finding in the evaluation and assessment of RA, and MRI is highly sensitive for detecting erosions in the hands and wrists of patients with RA (3,5,10,15,18). Many MR studies have emphasized the usefulness of gadolinium contrast
material in assessing active synovitis and destructive pannus (3,19–22). Most of these MR examinations were performed with high-field MRI systems. These systems can provide images with higher signal-to-noise ratios (SNRs) and higher spatial resolution than low-field MRI systems. However, conventional whole-body, high-field MRI is expensive and inconvenient for patients and has some contraindications, such as the presence of metal objects (e.g., pacemakers, aneurysm clips, and cochlear implants) in the subject and claustrophobia. In general, the hand and wrist joints are among the first to be affected in RA, and they are of particular interest in the assessment of patients with suspected early RA (13,23). Therefore, for screening and early treatment of RA (especially early-stage RA), dedicated MRI of the hand may be useful for assessing RA if the system is less expensive, is more easily installed, improves patient comfort, and entails less patient risk than whole-body high-field MRI. The design of the low-field compact MRI system for the hand and wrist in this study was originally based on these concepts.

Taouli et al (13) and Savnik et al (14) recently compared low-field dedicated-extremity MRI with high-field MRI for evaluating RA of the hand and wrist. Taouli et al (13) reported that the two systems performed equally well for cross-sectional grading of bone erosions.

Figure 2. MRI of the left hand of a 29-year-old woman with suspected early RA (patient 6). Her second PIP joint was swollen and showed slightly low signal intensity on (a) the T1-weighted image, and high signal intensity on (b) the STIR image (arrow), suggesting early RA.

Figure 3. T1-weighted images (a: left; b: right) and STIR images (c: left; d: right) of both hands of a 55-year-old woman with suspected early RA (patient 7). Linear high signal intensities over the bilateral wrists and first finger, and the left fifth finger on STIR (arrows) suggest tenosynovitis.
space narrowing, and synovitis in RA. Both MRI techniques detected approximately twice as many erosions as detected by radiography (13). The Savnik et al (14) study showed that the volume of synovial membrane determined by extremity MRI was significantly correlated with and not significantly different from that determined with high-field MRI with gadolinium injection. Intraobserver variation was high for the two MR systems. Therefore, the performance of low-field dedicated-extremity MRI would be the same as that of high-field MRI for the evaluation of RA, including early-stage RA.

The use of dedicated-extremity MRI for the evaluation of RA has several advantages over whole-body MRI. Compared to a whole-body MRI system, dedicated-extremity MRI requires a smaller installation space, costs less, offers greater patient comfort, and eliminates the problem of claustrophobia and potential biohazards associated with the presence of metal in or on the patient, since only the limb of interest is placed into the magnet bore. Therefore, it may be more feasible than conventional high-field MRI for evaluating patients with arthritis of the small joints (13). Savnik et al (14) reported that 64% of patients with arthritis of the hand and wrist preferred 0.2T extremity MRI to 1.5T high-field MRI because the former was more comfortable, less claustrophobic, and quieter. Of their patients, 20% reported experiencing mild to severe claustrophobia during the high-field MR examination. Lindegaard et al (10) also reported advantages of extremity MRI over whole-body MRI with regard to cost, comfort, and claustrophobia. In our study, these three “Cs” (cost, comfort, and claustrophobia), along with the small installation space, no maintenance, and no ionizing radiation, were the greatest advantages of extremity MRI. In addition, it had the technical advantage of a larger FOV (20.48 cm × 20.48 cm), which allowed us to obtain MR images that included the wrist joint to the PIP joint. Some earlier studies of extremity MRI had to use a smaller FOV and thus had limited anatomic coverage (13–15). With a smaller FOV, fewer joints can be examined in a given imaging series. In the present study, examinations of both hands, including positioning of subjects, could be performed within 40 min. Low-field compact MRI is insensitive to metal objects implanted anywhere but in the hand and wrist, and thus reduces the risk associated with the presence of metal in the body. Also, as Crues et al (15) mentioned, the unique features of the portable MR system allow it to be readily used in an office or point-of-care setting (e.g., a rheumatology office or clinic), improving overall patient management and operational efficiency.

Generally, however, low-field dedicated-extremity MRI has the limitations of lower SNRs and longer acquisition times compared to conventional high-field MRI (13). Moreover, the present study had several limitations, as described below.

First, the STIR images were obtained with a non-slice-selective sequence because STIR with multiple
Maximum diameter. Our protocol uses 4-mm-thick images and treatment. In conclusion, normal controls and patients with hand and wrist pain, including those with suspected early RA and RA that met RA criteria, were examined with a prototype low-field hand and wrist dedicated compact MRI system. This system was able to evaluate RA correctly and suggest early RA. However, the system still has limitations, such as the use of a non-selective STIR sequence and magnetic field inhomogeneity. A large number of cohort studies are still necessary to improve the system.

REFERENCES


