Musculoskeletal radiology

Screening for skeletal metastases of the spine and pelvis: gradient echo opposed-phase MRI compared with bone scintigraphy

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Abstract. Opposed-phase gradient echo (GRE) MRI at 0.5 T was compared with T1-weighted GRE MRI and bone scintigraphy regarding the detection of malignant bone marrow infiltrates of the spine and pelvis. Seventeen control patients and 41 patients with suspected skeletal metastases were studied with plain and gadolinium-enhanced MRI. In the control group only a vertebral haemangiomia showed contrast enhancement, while all metastases (confirmed histologically or by follow-up) were enhancing. Opposed-phase surface coil MRI showed a significantly higher contrast-to-noise ratio of skeletal metastases than T1-weighted images. In 28 patients body coil opposed-phase MRI detected more metastatic foci of the spine and pelvis than did bone scintigraphy (84 vs 56). No scintigraphically visualised lesion was missed by MRI. In conclusion, body coil gadolinium-enhanced opposed-phase GRE MRI may be applied as a screening method for skeletal metastases of the spine and pelvis at intermediate field strength.

Key words: Bone marrow, MR studies – Bone marrow, radionuclide studies – Chemical shift imaging – Gadolinium – MRI, skeletal metastases

Introduction

Pathological bone marrow changes can be depicted effectively with MRI [1]. The sensitivity of surface coil T1-weighted MR images (T1WI) in the detection of skeletal metastases has proved superior to that of bone scintigraphy [2–5]. Screening for bone metastases is difficult with surface coils, however, because of the small field of view (FOV). Body coil examinations with a larger FOV can be expected to have a lower sensitivity due to the poorer spatial resolution unless the signal intensity differences between normal marrow and metastases are increased.

To improve the visualisation of pathological tissues Dixon [6] first described a chemical-shift spin echo (SE) sequence (“proton spectroscopic imaging”) to generate opposed-phase images, in which the magnetisation vectors of fat and water protons are antiparallel during signal sampling. While conventional SE sequences are rather insensitive to moderate changes in the tissue’s fat content [7], the signal intensity (SI) in opposed-phase images is very sensitive to alterations of the relation between fat and water in the imaged tissue. In opposed-phase images red bone marrow has a low SI due to the comparable magnitudes of counteracting magnetisations of fat and water. Pathological changes in cell composition result in a disturbance of this equivalence and yield a higher SI. Unlike in T1WI, in which malignant marrow infiltrates usually are hypointense and contrast enhancement often diminishes the intensity difference compared with normal marrow, increasing SI after gadolinium-DTPA (Gd-DTPA) enhancement can be expected to further increase the SI differences between metastases and normal marrow in opposed-phase images. Setting the echo time (TE) to an appropriate value, opposed-phase MR images can also be generated with gradient echo (GRE) sequences [8], which were proposed by Tilling et al. [9] for the depiction of pathological bone marrow changes.

The purpose of our study was to assess the detectability of metastatic bone marrow infiltrates with a plain and Gd-DTPA enhanced opposed-phase GRE sequence, to evaluate the role of body coil GRE opposed-phase MRI as a screening method for vertebral and pelvic bone metastases at intermediate field strength compared with bone scintigraphy, and to estimate the value of bone marrow Gd-DTPA enhancement in patients with known malignant disease for identification and visualisation of metastatic infiltration.
Table 1. Data from MR examinations in patients with bone metastases (group II) T1WI, Tl-weighted images; OR, slice orientation; SL, slice thickness; DI, slice distance; NO, number of slices; TR, repetition time; TE, echo time; TI, examination time; Sag., sagittal; Cor., coronal

<table>
<thead>
<tr>
<th>Region</th>
<th>OR</th>
<th>SL (mm)</th>
<th>DI (mm)</th>
<th>NO</th>
<th>T1WI&lt;sup&gt;a&lt;/sup&gt;</th>
<th>TR (ms)</th>
<th>TE (ms)</th>
<th>TI (min)</th>
<th>Opposed-phase</th>
<th>TR (ms)</th>
<th>TE (ms)</th>
<th>TI (min)</th>
<th>No. of examinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spine</td>
<td>Sag.</td>
<td>5</td>
<td>0</td>
<td>13</td>
<td>400</td>
<td>14</td>
<td>14</td>
<td>6.9</td>
<td>400</td>
<td>22</td>
<td>6.9</td>
<td>9.2</td>
<td>18</td>
</tr>
<tr>
<td>Pelvis</td>
<td>Cor.</td>
<td>5-8</td>
<td>0-1.25</td>
<td>14-19</td>
<td>400</td>
<td>14</td>
<td>14</td>
<td>6.9</td>
<td>400-538</td>
<td>22</td>
<td>6.9-9.2</td>
<td>2</td>
<td>16</td>
</tr>
</tbody>
</table>

<sup>a</sup> Performed in all surface coil examinations and in 36 body coil examinations

Methods

Two groups comprising a total of 58 patients were studied. Group I (control group) consisted of 17 patients (10 women, 7 men; age 29–66 years, median age 60 years) with no evidence of malignancy in their history and no acute clinical signs of metastatic disease, who were examined because of suspected lumbar disc herniation or other benign diseases. Group II consisted of 41 patients (29 women, 12 men; age 32–88 years, median age 58 years) with known malignancy who showed increased nuclide uptake in bone scintigraphy suspicious for metastases. In 37 patients of group II the primary malignancy was confirmed histologically (19 breast carcinoma, 6 lung cancer, 3 prostatic cancer, 2 colorectal carcinoma, 2 hypernephroma, 1 each of urothelial carcinoma, thyroid cancer, malignant neuroectodermal tumour, malignant melanoma, malignant carcinoid). Four patients had malignant bone destruction with an unknown primary.

One patient showed a solitary focus of nuclide uptake in the spine which on follow-up proved to be degenerative. In the remaining patients of group II metastatic bone involvement was confirmed histologically (7 patients) or by follow-up with CT (21 patients) or radiographs including conventional tomography (12 patients).

All patients were examined with a 0.5 T Magnetom (Siemens AG, Erlangen, Germany) after giving informed written consent. All patients of the control group and 20 patients of group II were studied with a 30 cm FOV spine surface coil, and 28 patients of group II were studied with the 50 cm FOV body coil (so that 7 patients of group II had both surface and body coil studies). Each examination consisted of a GRE opposed-phase sequence with a repetition time (TR) of between 400 and 538 ms (the latter necessary to obtain 19 slices) and an echo time (TE) of 22 ms (flip angle 90°, acquisition matrix 256 × 256, 4 acquisitions), performed before and after intravenous administration of 0.1 mmol/kg Gd-DTPA. A TE of 22 ms was found to be the value that minimises the SI of normal bone marrow [10]. In all but 4 patients in-phase T1-weighted GRE images (TE 14 ms, TR 400 ms) were additionally generated before and after contrast administration with identical orientations and slices thicknesses. Slice orientations were sagittal for the spine and coronal for the pelvis. With the body coil, lower cervical to sacral spine or lower lumbar spine to proximal femora were imaged, respectively. Examination time for each sequence was 6.9 min for 14 slices (TR 400 ms) or 9.2 min for 19 slices (TR 538 ms). Fourteen patients underwent body coil examinations of the spine and pelvis in the same session, resulting in a total of 42 body coil examinations (see Table 1). All patients of group II had 99mTc-DPD bone scintigraphy prior to or after MRI (maximum interval 19 days).

The findings in the control group were evaluated regarding circumscribed SI differences and contrast-enhancing areas within the imaged skeleton. In the patients of group II skeletal SI differences were considered to be metastatic if they correlated with the bone destruction seen on radiographs or CT. On the basis that contrast enhancement was not observed in normal marrow of the control patients and that most of the confirmed metastases showed contrast enhancement, other enhancing lesions in the same patient were assumed to be metastatic also. SI differences not correlating with the radiological findings and which exhibited no contrast enhancement were not considered to be metastatic.

To assess quantitatively the contrast between metastases and normal bone marrow in the surface coil studies the contrast-to-noise ratio (CNR) of the lesions was calculated, as [11]:

\[
\text{CNR} = \frac{\text{SI(lesion)} - \text{SI(red marrow)}}{\text{SD(red marrow)}}
\]

where SI is signal intensity and SD is the standard deviation of SI.

The CNR was evaluated in plain and contrast-enhanced images and compared between in-phase and opposed-phase images (paired Wilcoxon test). To include the effect of inhomogeneities of the normal marrow, which may impair the conspicuity of lesions, the standard deviation of the normal marrow intensity was regarded as "noise". Because the examination time differences between the two sequences were considered not to be a critical factor in the clinical application, the values were not corrected with respect to different scan times. Additionally both sequences were compared regarding the contrast enhancement of the metastases by calculating the enhancement ratio, defined as:

\[
\text{Enhanced ratio} = \frac{\text{SI(lesion)}_{\text{post}} - \text{SI(lesion)}_{\text{plain}}}{\text{SD(lesion)}_{\text{plain}}}
\]

where SI(lesion)<sub>plain</sub> is the SI of the lesion before Gd-DTPA, SI(lesion)<sub>post</sub> is the SI of the lesion after Gd-DTPA, and SD(lesion)<sub>plain</sub> is the SI standard deviation of the lesion after Gd-DTPA.