The use of whole body magnetic resonance imaging in detecting bone marrow disorders – a valid alternative to imaging modalities that utilise ionising radiation

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Abstract Imaging modalities for investigation of bone marrow abnormalities have traditionally involved the use of ionising radiation. Now magnetic resonance imaging (MRI) offers an alternative to x-rays, computer tomography (CT), nuclear medicine bone scans and bone mineral densitometry. This study attempts to evaluate the sensitivity and specificity of whole body MRI in detecting bone marrow abnormalities, using T1 and short tau inversion recovery (STIR) weighted sequences. This was achieved by reviewing already acquired scan data to discover whether this method is more sensitive to marrow changes than conventional radiographic skeletal surveys and other imaging tests, involving ionising radiation.

The study involved 10 adult participants all of whom suffered from haematological malignancies, including multiple myeloma, plasma cell dyscrasia, non-Hodgkin’s lymphoma and acute lymphocytic leukaemia. Most of the study group presented with multiple myeloma. Abnormal skeletal MRI findings were reported in nine out of the 10 participants, i.e., a positive detection rate of 90%, using whole body MRI. All participants in the study who suffered from multiple myeloma or plasma cell dyscrasia showed positive MRI findings regardless of the stage of their disease. Four already had a confirmed diagnosis prior to the MRI scan, which was either visible on x-ray or bone scintigraphy. Three participants had positive serum/urine tests, but negative radiographic findings. The study therefore established that, when investigating possible marrow disorders, MRI was more sensitive to changes in the bone-marrow producing part of the skeleton and that MRI therefore must be considered a more suitable imaging tool.

Key words: bone marrow disorders, nuclear medicine bone scan, whole body MRI, radiographic skeletal survey

Introduction

With haematological disorders, the normal balance between the haematopoietically active red bone marrow and the non-active predominantly fatty yellow bone marrow is disrupted. This imbalance can be caused by a proliferation of malignant cells present in the red marrow and a conversion of yellow marrow back to red marrow.1

An accurate assessment of the extent of diseased marrow can help both prognosis for the individual and determine treatment options.2 Up to the present time, examinations to confirm bone marrow malignancies have often encompassed laboratory testing of blood and urine, as well as bone marrow biopsies and imaging tests.3

The traditional imaging tests used to evaluate the extent of bone marrow infiltration also involve radiographic skeletal survey and bone scintigraphy. Although a skeletal survey can be considered an easy, accessible and cost-effective examination, it involves ionising radiation. With this method, the sensitivity is somewhat limited because a significant loss of trabecular bone will have to occur before it is visible on x-rays4,5. The specificity of the skeletal survey can also be debated, because the radiographic finding of compression fractures in the vertebral column can be caused by malignant as well as benign conditions, like osteoporosis.6

Newer imaging modalities such as MRI, however, may offer a valid alternative to conventional methods. MRI does not involve ionising radiation and can provide a non-invasive method of assessing bone marrow changes when a haematological disorder affects the common distribution of cellular and fatty marrow.7 A considerable number of studies have suggested the greater sensitivity of MRI in detecting bone marrow abnormalities compared to other modalities.8,9,10 The aim of this retrospective study was to evaluate if MRI could offer a valid alternative to imaging tests, incorporating radiation.

Methods

The project formed part of the author’s postgraduate studies in magnetic resonance technology and adheres to the University of Queensland Guidelines for Ethical Review of Research Involving Humans. It was carried out as a retrospective study and involved 10 adults who all underwent a whole body MRI to investigate already known or suspected bone marrow abnormalities. Most of the participants had previously had other imaging tests, including skeletal surveys, nuclear medicine bone scans and CT. The results of these examinations were correlated to identify which test had yielded the greater sensitivity. To ensure patient confidentiality all scan data was de-identified and replaced with a code by an independent third party before it was given to the author for analysis. Finally, a literature search was conducted to see whether the project findings were supported by literature from the past two decades.

The whole body scans were carried out at the Queensland X-ray Mater Private MRI department, Brisbane. Imaging was obtained
in a coronal imaging plane, covering from the skull down to the ankles, using both T1- and STIR weighted sequences. The images were acquired on a General Electric (Milwaukee, Wisconsin, USA) 1.5 Tesla Signa Infinity TwinSpeed Short Bore Magnetic Resonance System in five stations with the scan bed moving between each station. The examination time approximates 6 minutes for the T1-weighted sequences and 25 minutes for the STIR-weighting. Participants were in a supine position on the bed and entered the bore of the magnet feet first. Once the scans had been completed, the five stations of both sequences had to be fused with a suitable overlap to form coronal whole body images, using a post-processing technique known as binding.11 The images are displayed in a three-on-one mode as demonstrated in Figure 1. The MRI results (i.e. positive versus negative findings) were compared to the outcomes of other diagnostic imaging, which participants had previously undergone for hematological disorder investigation.

**Results**

The study group involved four females and six males, aged 18–74, with an average age of 55 years. As mentioned previously, all participants in this study presented with hematological malignancies, including multiple myeloma, plasma cell dyscrasia, non-Hodgkin’s lymphoma and acute lymphocytic leukemia. See distribution diagram (Figure 2).

Abnormal skeletal MRI findings were reported in nine out of the 10 participants, i.e. a positive detection rate of 90% using whole body MRI. Seven patients in the study had skeletal surveys, compared to the outcomes of other diagnostic imaging, which participants had previously undergone for hematological disorder investigation.

**Figure 1** Example of T1-weighted coronal whole body MR image. Courtesy of Queensland X-ray, 2003

**Figure 2** Distributions of hematological disorders in the study group.
one had CT and one patient had bone scintigraphy; all of these patients were suffering from multiple myeloma, plasma cell disorder or non-Hodgkin’s lymphoma. The findings of the whole body MRI, skeletal surveys and other imaging tests are presented schematically in Table 1.

The MRI revealed abnormal bone marrow changes or bony destruction involving the axial skeleton in the majority of the study group; one patient had a solitary lesion in the right hip. The abnormalities were either described as diffuse infiltrations or localised foci and the changes could be observed in both participants with early or advanced stage malignancies. No participants presented with absolute contraindications for the MRI prior to the examination and none had encountered problems, such as claustrophobia or peripheral nerve stimulation, during the scan. Three participants, however, found it difficult to stay still during image acquisition due to severe back pain when lying supine on the scan table.

When the skeletal surveys were correlated with the results of the whole body MRI, it was found only four of the seven skeletal surveys showed up abnormalities; these positive x-ray findings were all seen in participants with known advanced stage disease. For the three participants who presented for investigation with suspected myeloma and in whom an accurate staging was critical for diagnosis and treatment, skeletal x-rays were reported as normal. The sensitivity of the radiographic surveys here was just 57%.

A CT scan was undertaken on one participant that covered the axial skeleton (neck/chest/abdomen/pelvis), with thin-slice reconstructed bone windows. No skeletal abnormality was detected using this modality. On the other hand, MRI showed diffuse marrow changes in the entire axial skeleton.

A bone scintigraphy undertaken on one other participant showed an increased uptake in two lumbar vertebrae, one ‘hot spot’ was probably due to a known pathological fracture caused by myeloma infiltration and the other focus was reported as intervertebral disc disease and reactive sclerosis, which was not directly related to the haematological disorder.

Discussion

Seven of the ten participants had had skeletal surveys prior to the whole body MRI. In three cases, radiographic surveys had revealed nothing abnormal, despite the myeloma-related changes later found through MRI. The lack of sensitivity of the x-ray surveys presented here has been confirmed in other studies. And although x-ray examinations are often easier and more accessible to the non-metropolitan population, the radiographic survey cannot provide the precise results offered by MRI.

Only one participant in the study, with advanced stage multiple myeloma, involving the vertebral column and an associated crush fracture in the lumbar spine, had undergone a bone scan. Just two of the five tumour foci, found on the MRI, could be verified on the nuclear medicine bone scan. The validity of this result based on one participant only can be questioned. However, based on the findings presented in the literature review, bone scintigraphy is neither sensitive nor specific enough to provide adequate imaging information when diagnosing multiple myeloma. Only in the later stages of the disease, where neoplastic cells have produced so much bone destruction that vertebral crush fractures may occur, can these areas display increased uptake, as was observed in this patient.

The use of bone scintigraphy can, nevertheless, be justified as a tool for limiting a differential diagnosis, as secondary bone lesions can often clinically and biochemically mimic multiple myeloma. What happens is that, instead of confirming the presence of solitary plasmacytoma or multiple myeloma by the absence of uptake, scintigraphy can exclude malignancies that will show an increased uptake on the bone scan, such as metastatic bone disease.16

The results of the project definitely indicate a greater MRI sensitivity compared to other imaging modalities. This finding is supported by the works of several other studies10,13,17 that conclude that MRI was better at detecting marrow changes.

However, when evaluating the specificity of the whole body MRI, it was found to be low. The presence of various abnormality patterns could not be directly related to the type of haematological disorder the participants presented. Among both the multiple myeloma and lymphoma participants, whole body MRI were reported as showing extensive diffuse marrow infiltrations, it was not possible to differentiate between the two patient groups without the clinical histories.

Nyman et al.,19 who concluded that MRI had a good specificity but a low specificity when assessing bone marrow disorders, together with Lecouvet et al. who also mentioned this lack of specificity, support this finding.

The debate remaining is whether the whole body MRI in its current form can replace the skeletal x-ray survey. In order to answer this question it is necessary to look at some of the limitations of MRI. The absolute contraindications for having an MRI examination, such as cardiac pacemakers, non-MRI compatible aneurysm clips and metallic intra-ocular foreign bodies will automatically exclude some patients from this test. The design of the magnet (open versus non-open configuration) can prove an obstacle for claustrophobic people, who may require sedation or even a general anaesthetic to go through with a scan.

A patient’s bodily habitus will also be an influence if a sufficient coverage can be achieved, or if the test can be carried out at all. Apart from the patient’s particular circumstances, certain technical factors need to be mentioned. In the adult skeleton, red bone marrow is present in the skull, sternum, ribs, vertebrae, pelvis and proximal aspects of the femur and humerus.20 Marrow lesions caused by haematological malignancies will manifest themselves in these parts of the skeleton and it is therefore imperative that the entire haematopoietically marrow-containing region is examined during a screening test.21 Although all participants in the study were scanned from vertex of the skull down to the feet, during the ‘binding’ post-processing operation some of the image information on top of the skull and the inferior part of the feet was lost. Another area that has not been displayed sufficiently during the whole body MRI in this study was the ribs and sternum. The study population who presented with a query of Multiple Myeloma therefore had x-rays of the skull and chest, in conjunction with the MRI, to ensure a complete coverage of the region of interest.

Likewise Chan et al.22 mentioned in their study of whole body MRI, that the detection of lesions in the ribs and skull was low. Hence, if whole body MRI is to completely replace the traditional radiographic skeletal survey, it will be necessary for the above-mentioned anatomical areas to be adequately covered on the scans.

Even though MRI has been suggested as appropriate to use only for patients with normal x-ray, based on the initial cost associated with a scan, it is necessary to consider all the factors that are in favour of using MRI as a screening tool.
advantage is; first, the absence of ionising radiation; second, the
time it takes to perform a whole body MRI is less than a conven-
tional radiographic skeletal survey; and third, because MRI is
significantly more sensitive compared to x-ray in all the studies
presented here. Finally, the staging is much more accurate. A
more precise staging can, in return, yield an advanced prognostic
relevance with respect to treatment options and outcomes for the
individual patient,7 which, in turn may prove to be more cost-
effective.

Conclusion

Even though, traditionally, the radiographic skeletal survey has
been the modality of choice for evaluating patients with suspected
bone marrow abnormality, in particular multiple myeloma, the
lack of sensitivity as represented in this study, as well as in several
other publications, speaks against using the x-ray survey as the
gold standard. Advanced stage malady can be documented on x-
rays but subtle bone marrow changes in the early stage of disease
cannot be appreciated.

Based on the results of this study, MRI is demonstrated to be
significantly more receptive to bone marrow changes than any of
the other imaging modalities mentioned. This finding is supported
by a substantial number of articles that have been reviewed. The
low specificity of the whole body MRI, on the other hand, means
that laboratory testing plays just as important role in the manage-
ment of patients with bone marrow diseases.

Although the whole body MRI examination is an emerging
technique, there is little doubt that it has several advantages over
traditional bone marrow imaging modalities. Its future applica-
tion may include monitoring of treatment response both during
and after therapy, in addition to initial screening. As a guide for
bone marrow biopsies, it can depict areas of marrow involvement
accurately.21 Furthermore, the greater sensitivity, which was a sig-
nificant 90% in the study, combined with good image resolution,
speed and the lack of ionising radiation makes this modality bet-
ter suited for repeated studies of bone marrow changes in all age
groups, with only very few absolute contraindications. The goal
of an imaging test for screening purposes must, in this author’s
opinion, be to provide the most accurate result achieved within
a reasonable timeframe and with the least possible discomfort to
the patient. Based on the results presented in this study, it is my
contention that the whole body MRI offers such features.

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