



HAL
open science

Comparison of whole-body MR imaging and conventional X-ray examination in patients with multiple myeloma and implications for therapy

Dietmar Jörg Dinter, Wolfgang K. Neff, Johanna Klaus, Christoph Böhm, Jan Hastka, Christel Weiss, Stefan O. Schoenberg, Georgia Metzgeroth

► To cite this version:

Dietmar Jörg Dinter, Wolfgang K. Neff, Johanna Klaus, Christoph Böhm, Jan Hastka, et al.. Comparison of whole-body MR imaging and conventional X-ray examination in patients with multiple myeloma and implications for therapy. *Annals of Hematology*, 2008, 88 (5), pp.457-464. 10.1007/s00277-008-0621-6 . hal-00477984

HAL Id: hal-00477984

<https://hal.science/hal-00477984>

Submitted on 30 Apr 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Comparison of whole-body MR imaging and conventional X-ray examination in patients with multiple myeloma and implications for therapy

Dietmar Jörg Dinter · Wolfgang K. Neff ·
Johanna Klaus · Christoph Böhm · Jan Hastka ·
Christel Weiss · Stefan O. Schoenberg ·
Georgia Metzgeroth

Received: 14 November 2007 / Accepted: 23 September 2008 / Published online: 22 October 2008
© Springer-Verlag 2008

Abstract Skeletal X-ray survey is the established method of diagnosis in patients with multiple myeloma; however, whole-body magnetic resonance imaging (wb-MRI) has become an important additional tool. The aim of this study was to compare the different patterns of infiltration on conventional X-ray examinations (X-ray survey) with findings from wb-MRI to subsequently determine the influence of wb-MRI on therapy changes. In 60 patients with a mean age of 65.1 ± 11.7 years, wb-MRI examinations were correlated with a recent X-ray survey. The results were independently assessed by two radiologists and the patterns of infiltration were described in both modalities. Subsequently, the disease was staged according to Salmon and Durie and Salmon and Durie PLUS. Additionally, the influence of MRI on potential changes in therapy was assessed using a three-range Likert-type scale. In all, 480 skeletal regions were compared. In 183 skeletal regions, an increased degree of infiltration was identified on wb-MRI. Significant differences ($p < 0.05$) between the modalities

could be found in the thorax, spine, pelvis, and both lower extremities. Based on wb-MRI, tumor stage was upgraded in 19 of the 60 patients using the Durie and Salmon PLUS classification. In ten out of these 19 patients (42%), the wb-MRI result was essential for making the decision to initiate further therapy due to the degree of infiltration, extramedullary tumor extension, and/or further risk of fracture. Whole-body MRI provides a more detailed assessment of the pattern of bone marrow infiltration and strongly influences therapeutic strategies.

Keywords Multiple myeloma · Magnetic resonance imaging · X-ray skeletal survey · Whole-body imaging · Salmon and Durie PLUS

Introduction

Multiple myeloma, a malignant monoclonal plasma cell disease, is the most common tumor of the bone marrow; nevertheless, the incidence of this tumor is only four in 100,000 per year. However, the diagnosis has great implications in the clinical setting because of the long-term prognosis for these patients, extending over decades [1]. According to the Salmon and Durie classification, no relevant decrease in life span is seen in patients with stage I myeloma. In stage II and even more so in stage III disease, however, a significant decrease in life expectancy is observed, where only 20% of patients survive more than 2 years if they do not receive appropriate treatment [2]. Therefore, efficient staging is crucial in multiple myeloma because of the implications for initiating adequate therapy [3]. The therapeutic strategies consist of various chemo-

D. J. Dinter (✉) · W. K. Neff · J. Klaus · C. Böhm ·
S. O. Schoenberg
Department of Clinical Radiology and Nuclear Medicine,
University Medical Center Mannheim,
Mannheim, Germany
e-mail: dietmar.dinter@medma.uni-heidelberg.de

C. Weiss
Department of Medical Statistics,
University Medical Center Mannheim,
Mannheim, Germany

J. Hastka · G. Metzgeroth
III. Medical Clinic, University Medical Center Mannheim,
Mannheim, Germany

therapy regimens and stem cell transplantation as an additional therapeutic option that increases the clinical response and life expectancy [4].

A worldwide accepted staging system has been established by Durie and Salmon [5], who demonstrated a significant correlation between the clinical and laboratory findings and tumor load with life expectancy. Due to the limitations of this staging system, mainly related to false-negative findings in conventional X-ray examination in the initial stages of the disease, some authors suggested implementing magnetic resonance imaging (MRI) into the staging system [6]. This so-called Durie and Salmon PLUS staging system introduced stage IA, either no lesion or a solitary lesion on MRI; stage IB, less than five lesions or mild diffuse infiltration; stage IIA/B, five and up to 20 focal lesions or moderate diffuse infiltration; and stage IIIA/B, more than 20 focal lesions or extensive diffuse infiltration [3, 4, 7].

Therefore, MRI is playing an increasing role in the diagnosis of multiple myeloma [8]. Various authors have demonstrated the high sensitivity of MRI in detecting plasma cell infiltrations [2, 6, 7, 9–12]. In contrast to conventional skeletal X-ray surveys (X-ray survey), MRI can precisely evaluate the bone marrow. The pathomorphological features of the plasma cell clusters such as increased cellular density, loss of the fatty bone marrow components, and neovascularization of tumor cells can be visualized and more accurately differentiated [13].

As a result of technical improvements that have enabled the clinical use of a whole-body MRI protocol (wb-MRI), patient examinations are completed within 40 min. By implementing new coil concepts for whole-body imaging with stepwise table movement and in conjunction with parallel acquisition techniques, wb-MRI can now be employed in clinical routine [14]. This new technique has been established as a reliable method for the diagnosis of bone metastases, solid tumors, and lymphomas [8, 15–17]; however, the sensitivity of wb-MRI for detecting bone marrow infiltration has not yet been evaluated extensively [18].

The aim of this study, therefore, was to compare the sensitivity of wb-MRI with that of X-ray survey in detecting myeloma clusters in the bone by classifying the different patterns of infiltration. Furthermore, the impact of wb-MRI on staging patients according to Durie and Salmon PLUS versus the classic Durie and Salmon scheme was analyzed. Finally, the influence of wb-MRI on changing therapy was evaluated.

Material and methods

Patients

Sixty patients with clinically proven multiple myeloma in different stages (Table 1) were prospectively evaluated with

wb-MRI between January 2005 and January 2007. The sample size calculation was based on the examples of eight sections and provided about 60 cases for each region.

Conventional X-ray skeletal survey of the entire axial skeleton was performed within 12.3 ± 3.5 days. The patient age range was 37–93 years (mean 65.1 ± 11.7 years). The institutional review board and the local ethics committee approved the protocol and the study was performed according to the guidelines of Helsinki. Written informed consent was obtained from all patients.

Clinical data

The clinical data of the patients were evaluated retrospectively by using the patient charts. The maximum interval between assessment of the clinical data and the wb-MRI examination was ± 2 weeks. The date of first diagnosis, initial stage, type of multiple myeloma, and laboratory findings (serum and urine protein, electrophoresis, hemoglobin levels, 24-h urinary protein excretion, serum β_2 -microglobulin, and results of electrophoresis) were recorded for all patients. In addition, the results of bone marrow aspiration were available for 40 of the 60 patients. Patients with a secondary malignoma were excluded from the study.

Imaging

X-ray survey of the entire axial skeleton was performed using a standard X-ray unit (Multix Top, Siemens Medical Solutions, Erlangen, Germany) and standard imaging parameters for each skeletal region. Radiographs were available for the diagnostic regions of interest, which included the skull and spine in two planes and thorax, pelvis, arm and forearm, and upper and lower leg in one plane each.

wb-MRI was performed using a 1.5-T magnetic resonance system with matrix coils, 18 independent receiver channels, and a 205-cm range of table movement for whole-body imaging (Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany). The examination protocol consisted of coronal T1- and T2-STIR-weighted images at four table positions. Furthermore, sagittal T1- and T2-

Table 1 Patient grading by the different staging systems

Stage	Durie and Salmon (<i>n</i>)	Durie and Salmon PLUS (<i>n</i>)
I	16	12
II	21	6
III	23	42

STIR-weighted images of the spine were acquired (Table 2). The entire examination protocol took 37 min 23 s, with a maximum room time of between 45 and 50 min.

Image analysis

For comparison of wb-MRI with the X-ray survey, the body was divided into eight different segments: skull, spine, thorax, right and left upper extremity, pelvis, and right and left lower extremity. A total of 60 MRI examinations with 480 segments were available for comparative analysis. For both the X-ray survey and the wb-MRI examinations, the written reports were used as the primary source for analyzing the findings. An experienced radiologist blinded to the results of the initial reports analyzed the results a second time. For discrepant findings, a final consensus analysis together with another blinded radiologist with more than 8 years of experience in reading musculoskeletal MRI was carried out. To account for the different types of bone marrow involvement by multiple myeloma, different MRI patterns of infiltration were defined: normal finding, focal infiltration, multifocal infiltration (>ten focal lesions), diffuse infiltration, and mixed focal–diffuse infiltration, as described by Baur-Melnyk et al. [7]. In the X-ray survey, patterns of infiltration were described according to the Durie and Salmon classification [5]: normal or solitary lesion (stage I), multiple osteolysis or generalized striated osteoporosis (stage III), and stage II (neither I nor III). To assess the effect of wb-MRI on staging, all patients were categorized after acquiring all relevant clinical data according to the standard classification of Durie and Salmon and also according to Durie and Salmon PLUS with regard to the wb-MRI findings. Thereby, the two different clinical

staging systems could be directly compared based on the individual scores for the tumor stage.

Using a modified Likert-type scale, the degree of influence of wb-MRI on further treatment was assessed by two board-certified oncologists with more than 3 years of special training in hematooncology. This assessment also included the pathologic laboratory ranges and X-ray survey findings. Pathologic laboratory parameters were defined as follows: (1) paraprotein IgG >5 g/dl, IgA >3 g/dl; (2) hemoglobin <10 g/dl; and (3) elevated serum calcium levels. The Likert-type scale had three ranges, with increasing influence of wb-MRI on the therapeutic decision:

- Grade I: wb-MRI did not influence therapy because three or four other parameters (paraprotein, hemoglobin, X-ray survey, or serum calcium levels) already indicated the need for a specific therapy.
- Grade II: wb-MRI had a minor influence on therapy because one or two other parameters as mentioned above were abnormal, indicating the need for further treatment.
- Grade III: wb-MRI was essential for initiation of therapy without further parameters influencing the therapeutic decision.

Statistical methods

For statistical analysis, the symmetry test by Bowker [19] was applied. This test examines whether the matrix for the frequency of wb-MRI and X-ray survey findings is symmetric or not. A *p* value of less than 0.05 indicated that the matrix is not symmetrical with respect to the main diagonal. Because of the differences in the types of

Table 2 Examination protocol of the whole-body MRI

Sequence	T1 SE	T2 STIR	T1 SE	T2 STIR	T1 SE	T2 STIR	T1 SE	T2 STIR	T1 SE	T2 STIR	T1 SE	T2 STIR
Region	Total spine	Total spine	Head–neck	Head–neck	Thorax–abdomen	Thorax–abdomen	Pelvis	Pelvis	Femur	Femur	Lower leg	Lower leg
TR/TE	628/12	3,770/83	628/12	6,260/121	579/11	5,500/121	579/11	6,260/121	450/11	6,260/121	450/11	6,260/121
Matrix	512×90%	448×90%	384×80%	512×50%	384×80%	512×50%	384×80%	512×50%	384×80%	512×50%	384×80%	512×50%
FoV	440	440	500	500	500	500	500	500	500	500	500	500
Resolution (mm ³)	1×0.9×4	1.1×1×4	1.6×1.3×6	2×1×6	1.6×1.3×6	2×1×6	1.6×1.3×6	2×1×6	1.6×1.3×6	2×1×6	1.6×1.3×6	2×1×6
TA (min, s)	2.34	2.45	3.12	3.2	2.58	4.1	2.58	3.2	2.43	3.2	2.43	3.2

TR repetition time, *TE* echo time, *FoV* field of view, *TA* acquisition time, *T1 SE* T1-weighted spin echo sequence, *T2 STIR* T2-weighted short Tau inversion recovery sequence

infiltration, a weighted scale was defined with different values for the discrepant findings between normal, focal, multifocal, diffuse, and focal–diffuse. For further evaluation, the weighted symmetry test was performed, thus providing more reliable results. All statistical calculations were done using SAS software (release 8.02; SAS Institute Inc., Cary, NC, USA).

Results

Comparison of wb-MRI and conventional X-ray

Concordance between X-ray survey and wb-MRI was present in 293/480 regions (61%); in four cases (0.8%), a focal infiltration was detected by X-ray survey alone without being identified by wb-MRI. However, in 183/480 regions (38%), wb-MRI revealed additional findings formerly not diagnosed by means of conventional X-ray examination. In 60 of these 183 regions (33%), wb-MRI provided more detailed information about the degree of infiltration. As demonstrated in Table 3, in 13 of these regions, a multifocal infiltration could be shown; in 14 regions, a diffuse infiltration was demonstrated, and, in 33 of the regions, a combination of multifocal lesions and diffuse infiltration could be found that had not been diagnosed previously by conventional X-ray examination. In 123 of the 183 regions (67%), wb-MRI was able to diagnose infiltration in the bones that had not been detected by conventional X-ray alone. In particular, as shown in Table 3, the bone tissue had been normal in these regions on the X-ray survey. Using wb-MRI, 35 regions had additional focal lesions, 17 regions newly diagnosed multifocal lesions, 57 regions a diffuse infiltration formerly described as normal, and 14 regions multifocal lesions in combination with a diffuse infiltration pattern. Symmetry testing according to the Bowker method (weighted and unweighted) led to p values <0.0001 . Table 3 demonstrates

the significant asymmetry in the pattern of infiltration in favor of wb-MRI. The most common reason for discordance between the two modalities was a diffuse infiltration on wb-MRI with a normal finding on X-ray survey. Diffuse infiltration was found by X-ray survey in 23 regions, by wb-MRI in 91 regions (discordance of 75%). In 84%, a diffuse infiltration with multifocal lesions could not be detected by the X-ray survey (nine vs. 56 regions). Comparing the different regions according to the pattern of infiltration as detected by both methods, a statistically significant difference was seen in favor of wb-MRI in the thorax, spine, pelvis, and the lower extremities on both sides (Table 4). The most important difference was found in the spine: Here, a concordance in the findings was only observed in 24/60 patients. In 24/36 patients, the conventional X-ray gave false-negative results without demonstrating any pathologic findings, and, in 12/36 patients, more detailed information about the pattern of infiltration was found. In particular, diffuse infiltration of the spine was found in only two of 60 patients, whereas wb-MRI revealed this in 15/60 patients. In the regions spine, thorax, pelvis, head, and right upper and left lower extremity, conventional X-ray did not provide any further information about infiltration of the bone. Figures 1 and 2 demonstrate examples for the comparison.

Influence of wb-MRI on the staging

The results for the modified staging according to Durie and Salmon PLUS including the findings of wb-MRI are shown in Table 1. As a result of this, the tumor stage was upgraded in 41 of the 60 patients by additionally considering the wb-MRI findings.

Influence of wb-MRI on therapy management

In 36 of the 60 patients, no further therapy was required according to a summary of the different laboratory findings, X-ray survey, and wb-MRI, with respect to the previously described Likert-type grading system. In 24 patients, the intention to treat was proposed after consideration of all parameters. The degree of influence of wb-MRI on the therapeutic decision is demonstrated in Table 5. In ten of the 24 newly treated patients (42%), wb-MRI was the most important diagnostic method for deciding on further therapy.

In four of ten patients for whom wb-MRI was crucial for deciding on treatment, the examination demonstrated a pattern of infiltration that could not be detected by X-ray survey or by laboratory findings. These patients were graded as stage III after Durie and Salmon PLUS, which resulted in further therapy. In six of ten patients, an extramedullary localization could be detected; three of six

Table 3 Pattern of infiltration on X-ray survey and wb-MRI

Wb-MRI	X-ray survey					Total
	a	b	c	d	e	
a	182	4	0	0	0	186
b	35	36	0	0	0	71
c	17	13	46	0	0	76
d	57	8	6	20	0	91
e	14	25	5	3	9	56
Total	305	86	57	23	9	480

a normal, *b* focal lesions, *c* multifocal lesions, *d* diffuse infiltration, *e* multifocal lesions and diffuse infiltration

Table 4 *p* values of the comparison between the modalities resulting from the Bowker test and the Bowker test with weighted counts

	Head	Thorax	Spine	r.u.e.	l.u.e.	Pelvis	r.l.e.	l.l.e.
Bowker	0.725	0.021	<0.0001	0.151	0.099	<0.001	0.003	0.002
Weighted Bowker	0.87	0.091	0.001	0.346	0.278	0.008	0.016	0.016

r.u.e. right upper extremity, l.u.e. left upper extremity, r.l.e. right lower extremity, l.l.e. left lower extremity, *p* level of significance

patients were additionally endangered by an impending fracture. Furthermore, in one of the 60 patients who suffered from an ascretory myeloma, wb-MRI examination was the only modality that confirmed the diffuse infiltration pattern in the spine as there were no changes in laboratory values. In the remaining 14/24 patients presenting with an immediate need to treat, the clinical data were considered more important for the treatment decision than wb-MRI. In these patients, highly pathologic clinical parameters were found, for example, massive elevated paraprotein (five of 14 patients), massive anemia (three of 14 patients), increase in β_2 -microglobulin (three of 14 patients), or a combination of the different clinical parameters (three of 14 patients).

Discussion

In the present study, the clinical value of wb-MRI in patients with multiple myeloma was systematically evaluated in terms of diagnostic accuracy, impact on tumor staging, and influence on therapeutic management. This was achieved by comparing this modality to conventional X-ray skeletal survey in detecting focal and diffuse infiltration, by evaluating the Durie and Salmon PLUS versus the standard staging system, and by ranking the influence of wb-MRI against established laboratory and clinical findings.

In the past few years, wb-MRI has become an established tool in the diagnostic workup for lymphomas,

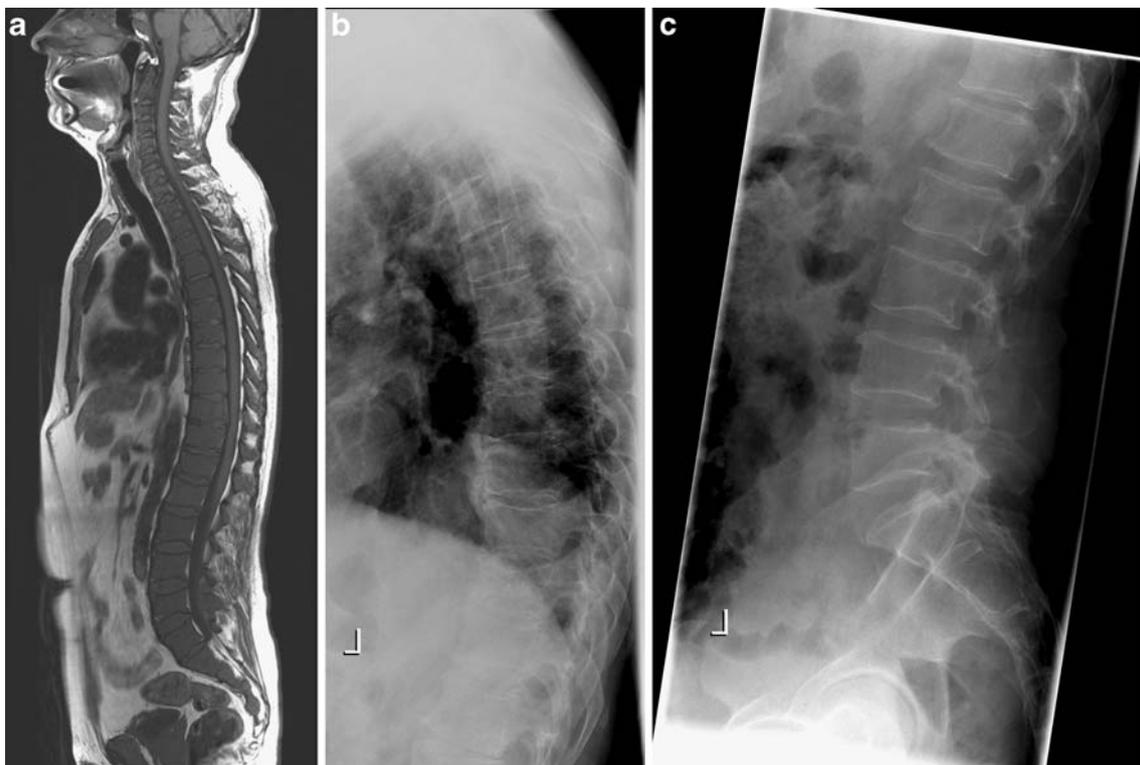


Fig. 1 **a** T1-weighted sagittal image of the spine, **b** lateral views of thoracic and lumbar spine X-ray. The T1-weighted image demonstrates complete hypointensity of the bone marrow of the spine, corresponding to a diffuse pattern of infiltration. The lateral views of

the thoracic and lumbar spine show no significantly increased translucency. The patient was upgraded from stage I after Salmon and Durie into stage III

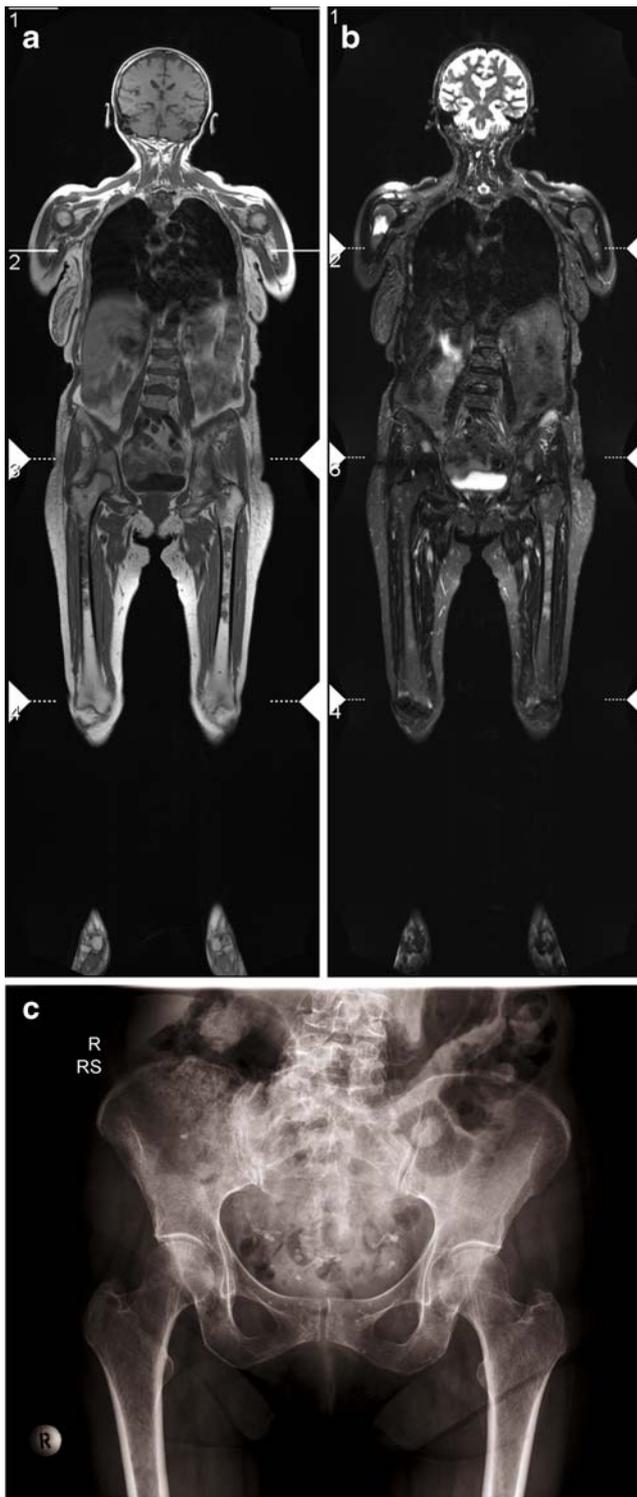


Fig. 2 **a** T1 and **b** T2-STIR-weighted coronal wb-MR image demonstrating the change in the bone marrow of the proximal femur. **c** X-ray of the pelvis and of the proximal femur does not show pathologic changes, thus leading to a stage I disease in X-ray and—because of further intramedullary lesions and a diffuse infiltration of the spine—stage III in wb-MRI

Table 5 Influence of wb-MRI on the treatment decision by laboratory findings and conventional X-ray according to the three-range Likert-type scale

Degree of influence	Number of patients	Percentage
1	11/24	46
2	3/24	12
3	10/24	42

bone metastasis, and also multiple myeloma [2, 6, 7, 14, 18, 20, 21]. With wb-MRI, the pathomorphological features of the bone marrow such as increased cellular density, neovascularization, and a decreased fat signal in the spongy structures due to the myeloma infiltration could be detected to give a direct and exact assessment of the bone marrow [13, 22]. Especially in early stages of the disease, infiltration can be detected by wb-MRI, while the X-ray survey does not reveal any osteolysis or osteopenia [2, 23–25], however, because a minimum loss of 30% of spongy structures is needed to detect this [26]. Using other methods such as positron emission tomography, even with ^{18}F -fluoro-2-deoxyglucose, spatial resolution is too low and tracer uptake is too inconsistent in multiple myeloma to make a clinically acceptable diagnostic assessment [27]. According to Baur et al. [28], wb-MRI in combination with clinical staging according to Durie and Salmon can be considered the new gold standard for the detection of focal myeloma.

In the present study, the advantage of wb-MRI over X-ray survey could be confirmed: 21% of the focal and multifocal myeloma lesions, 75% of the diffuse, and 84% of the focal–diffuse infiltration could only be detected by wb-MRI. Age at presentation, diagnostic methods, time interval between X-ray and wb-MRI, and exclusion criteria were comparable to those used in studies previously published in the literature [6, 14, 18].

The kind and pattern of infiltration detected on wb-MRI correlate significantly with the stage according to Durie and Salmon and therefore define the prognosis for these patients [5, 6]. In addition to focal infiltration, multiple myeloma can also present with diffuse and focal–diffuse infiltration, which are significantly associated with a higher disease stage [10, 29]. This is either not detected by X-ray survey or is seen as sparse osteoporosis, which is difficult to distinguish from physiologically or medication-induced osteoporosis. In these patients, wb-MRI is a more sensitive technique [6, 30], which has been confirmed by the present study where diffuse infiltration was not visualized in 75% and focal–diffuse infiltration in 84% of the patients on X-ray survey. In line with other studies in the literature, the examinations were performed with T2-weighted STIR sequences, as first described by Rahmouni et al. [31], and with T1-weighted sequences [9], which have a high

sensitivity for delineating myeloma cell clusters. No contrast media were used, following the studies by Rahmouni et al. and Wasser et al. [31, 32] who demonstrated that the administration of contrast media does not provide valuable additional information for diagnosis.

One limitation of biopsy is the proof of the lesions—whether they are infiltrated or not—as demonstrated by Buss et al. [33] who reported false-negative results in 26% of the biopsy specimens. In some studies, it could be shown that a diffuse pattern of infiltration as seen on the skeletal survey correlates significantly with the histologic findings. Regarding focal lesions, no significant correlation could be detected between MRI and histology. One limitation of these studies is that different regions of the body are being compared, the biopsy of the iliac crest with MRI of the spine [6, 34]. This limitation has been successfully eliminated in the present study by implementing a wb-MRI protocol with T1- and T2-STIR-weighted sequences integrating the area of biopsy.

Accurate staging of patients with multiple myeloma is highly important since it determines adequate therapy and thus prognosis. Referring to Baur et al. [2, 30], the staging system according to Durie and Salmon was modified by adding MRI of the spine to improve the prognostic impact of the different stages and to refine therapy. Vande Berg et al. [23] compared conventional X-ray imaging in patients with multiple myeloma stage I after Durie and Salmon with corresponding MRI of the spine, pelvis, and proximal femurs. The authors found that in 29% of the patients focal lesions could be demonstrated by MRI without there being a correlation on X-ray. A further study of the same group [24] that aimed to compare the different diagnostic methods in patients with monoclonal gammopathy of undetermined significance ($n=37$) concluded that focal myeloma lesions could be found on MRI in 19% of the patients. A further examination by Mariette et al. [11] demonstrated, in five of 17 patients (31%) with asymptomatic multiple myeloma, focal or even diffuse infiltration already in stage I disease. In all these studies, pathologic findings were found on MRI scans in approximately 30% of the patients, resulting in a classification as advanced stage, which implies immediate initiation of chemotherapy. The results of the aforementioned studies are in agreement with the present findings, in which 19 of the 60 patients were classified in a higher stage after wb-MRI. Four of these patients were shifted from stage I to stage II ($n=1$) or to stage III ($n=3$). According to the literature, these patients benefit from the immediate initiation of chemotherapy [23]. In an additional 15/60 patients, stage II was upgraded to stage III on the basis of wb-MRI.

So far, only few studies have demonstrated that MRI is an adequate method for follow-up of patients with multiple myeloma since changes in the signal intensity and the morphology of the lesions are seen during therapy and these

changes correlate with the clinical parameters [35]. Up to now, however, no publication has evaluated the influence of MRI using a whole-body approach on the decision to initiate further specific therapy. In the present study, both wb-MRI and the other parameters for staging influenced the treatment decision to various degrees. But—as described in the “Results” section—wb-MRI was primarily responsible for starting a new therapy in ten of 24 patients and had a moderate influence in another four of 24 patients.

One study limitation is that most patients had initially already been treated with conventional chemotherapy (e.g., melphalan in combination with prednisolone) or high-dose chemotherapy with stem cell transplantation. However, the aim of this study was to evaluate the influence of wb-MRI on a further therapeutic strategy with a new chemotherapy regimen. Another limitation is the problem of defining objective criteria for evaluating the influence of MRI on the initiation of a new therapy. Involving two independent and experienced hematologists into this study who ranked the influence of the different parameters in consensus solved this problem.

In conclusion, in the present study, we demonstrated that wb-MRI is more sensitive than conventional X-ray and can detect both focal and diffuse patterns of infiltration with a high certainty. Furthermore, wb-MRI can strongly influence the therapeutic decision in patients with multiple myeloma.

References

- Kelly JJ (1999) Neuropathies of monoclonal gammopathies of undetermined significance. *Hematol Oncol Clin North* 13 (6):1203–1210
- Baur A, Stähler A, Nagel D, Lamerz R, Bartl R, Hiller E, Wendtner C, Bachner F, Reiser M (2002) Magnetic resonance imaging as a supplement for the clinical staging system of Durie und Salmon? *Cancer* 95(6):1334–1345
- Durie BG (2006) The role of anatomic and functional staging in myeloma: description of Durie/Salmon plus staging system. *Eur J Cancer* 42(11):1539–1543
- Durie BG, Kyle RA, Belch A, Bensinger W, Blade J, Boccadoro M, Child JA, Comenzo R, Djulbegovic B, Fantl D, Gahrton G, Harousseau JL, Hungria V, Joshua D, Ludwig H, Mehta J, Morales AR, Morgan G, Nouel A, Oken M, Powles R, Roodman D, San Miguel J, Shimizu K, Singhal S, Sirohi B, Sonneveld P, Tricot G, Van Ness B, Scientific Advisors of the International Myeloma Foundation (2003) Myeloma management guidelines, a consensus report from the Scientific Advisors of International Myeloma Foundation. *Hematol J* 4(6):379–398
- Durie BG, Salmon SE (1975) A clinical staging system for multiple myeloma. Correlation of measured myeloma cell mass with presenting clinical features, response to treatment, and survival. *Cancer* 36(3):842–854
- Baur A, Stähler A, Bartl R, Lamerz R, Reiser M (1996) Infiltration patterns of plasmacytomas in magnetic resonance tomography. *RoFo* 164(6):457–463

7. Baur-Melnyk A, Buhmann S, Dürr HR, Reiser M (2005) Role of MRI for the diagnosis and prognosis of multiple myeloma. *Eur J Radiol* 55(1):56–63
8. Eustace S, Tello R, Decarvalho V, Carey J, Wroblecka JT, Melhem ER, Yucel EK (1997) A comparison of whole body turbo STIR MR imaging and planar ⁹⁹Tc-methylene diphosphonate scintigraphy in the examination of patients with suspected skeletal metastases. *AJR Am J Roentgenol* 169(6):1655–1661
9. Lecouvet FE, Vande Berg BC, Michaux L, Malghem J, Maldague BE, Jamart J, Ferrant A, Michaux JL (1998) Stage III multiple myeloma: clinical and prognostic value of spinal bone marrow MR imaging. *Radiology* 209(3):653–660
10. Lecouvet FE, Malghem J, Michaux L, Michaux JL, Lehmann F, Maldague BE, Jamart J, Ferrant A, Vande Berg BC (1997) Vertebral compression fractures in multiple myeloma. Part II. Assessment of fracture risk with MR imaging of spinal bone marrow. *Radiology* 204(1):201–205
11. Mariette X, Zagdanski AM, Guermazi A, Bergot C, Arnould A, Fria J, Brouet JC, Femand JP (1999) Prognostic value of vertebral lesions detected by magnetic resonance imaging in patients with stage I multiple myeloma. *Br J Haematol* 104:723–729
12. Steinborn M, Tilling R, Heuck A, Brügel M, Gauger L, Reiser M (1999) Whole-body bone marrow MRI in patients with metastatic disease to the skeletal system. *J Comput Assist Tomogr* 23:123–129
13. Baur A, Bartl R, Pellengahr C, Baltin V, Reiser M (2004) Neovascularization of bone marrow in patients with diffuse multiple myeloma: a correlative study of magnetic resonance imaging and histologic findings. *Cancer* 101:2599–2604
14. Lecouvet FE, Malghem JL, Michaux L, Maldague B, Ferrant A, Michaux JL, Vande Berg BC (1999) Skeletal survey in advanced multiple myeloma: radiography versus MRI survey. *Br J Haematol* 106(1):35–39
15. Ghanem N, Altehöffner C, Högerle S, Schäfer O, Winterer J, Moser E, Langer M (2002) Comparative diagnostic value and therapeutic relevance of magnetic resonance imaging and bone marrow scintigraphy in patients with metastatic solid tumor of axial skeleton. *Eur J Radiol* 43(3):256–261
16. Ghanem N, Uhl M, Brink I, Schafer O, Kelly T, Moser E, Langer M (2005) Diagnostic value of MRI in comparison to scintigraphy, PET, MS-CT and PET/CT for the detection of metastases of bone. *Eur J Radiol* 55(1):41–55
17. Schäfer FJ, Fischmann A, Lichy M, Vollmar J, Fenchel M, Claussen CD, Schlemmer HP (2004) Oncologic screening with whole-body MRI: possibilities and limitations. *Radiologe* 44:854–863
18. Ghanem N, Lohrmann C, Engelhard M, Pache G, Uhl M, Saueressig U, Kotter E, Langer M (2006) Whole-body MRI in the detection of bone marrow infiltration in patients with plasma cell neoplasms in comparison to radiologic skeletal survey. *Eur Radiol* 16(5):1005–1014
19. Bowker AH (1948) A test for symmetry in contingency tables. *J Am Stat Assoc* 43:572–574
20. Ludwig H, Frühwald F, Tscholakoff D, Rasoul S, Neuhold A, Fritz E (1987) Magnetic resonance imaging of the spine in multiple myeloma. *Lancet* 2(8555):364–366
21. Frühwald F, Tscholakoff D, Schwaighofer B, Wicke L, Neuhold A, Ludwig H, Hajek PC (1988) MRI of the lower vertebral column in patients with multiple myeloma. *Invest Radiol* 23(3):193–199
22. Vacca A, Ribatti D, Roccaro AM, Frigeri A, Dammacco F (2001) Bone marrow angiogenesis in patients with active multiple myeloma. *Semin Oncol* 28(6):543–550
23. Vande Berg BC, Lecouvet FE, Michaux L, Labaisse M, Malghem J, Jamart J, Maldague BE, Ferrant A, Michaux JL (1996) Stage I multiple myeloma: value of MRI in the bone marrow in the determination of prognosis. *Radiology* 201(1):243–246
24. Vande Berg BC, Michaux L, Lecouvet FE, Labaisse M, Malghem J, Jamart J, Maldague BE, Ferrant A, Michaux JL (1997) Nonmyelomatous monoclonal gammopathy: correlation of bone marrow MR images with laboratory findings and spontaneous clinical outcome. *Radiology* 202(1):247–251
25. Mouloupoulos LA, Dimopoulos MA, Smith TL, Weber DM, Delasalle KB, Libshitz HI, Alexanian R (1995) Prognostic significance of magnetic resonance imaging in patients with asymptomatic multiple myeloma. *J Clin Oncol* 13(1):251–256
26. Walker R, Barlogie B, Haessler J, Tricot G, Anaissie E, Shaughnessy JD Jr, Epstein J, van Hemert R, Erdem E, Hoering A, Crowley J, Ferris E, Hollmig K, van Rhee F, Zangari M, Pineda-Roman M, Mohiuddin A, Yaccoby S, Sawyer J, Angtuaco EJ (2007) Magnetic resonance imaging in multiple myeloma: diagnostic and clinical implications. *J Clin Oncol* 25(9):1121–1128
27. Antoch G, Vogt FM, Bockisch A, Rühm SG (2004) Whole-body tumor staging: MRI or FDG-PET/CT? *Radiologe* 44(9):882–888
28. Baur A, Stäbler A, Steinborn M, Schnarkowski P, Pistitsch C, Lamerz R, Bartl R, Reiser M (1998) Magnetic resonance tomography in plasmacytoma: ranking of various sequences in diffuse and focal infiltration patterns. *RoFo* 168(4):323–329
29. Mouloupoulos LA, Dimopoulos MA (1997) Magnetic resonance imaging of bone marrow in hematologic malignancies. *Blood* 90(6):2127–2147
30. Baur-Melnyk A, Reiser M (2004) Staging of multiple myeloma with MRI: comparison to MSCT and conventional radiography. *Radiologe* 44(9):874–881
31. Rahmouni A, Divine M, Mathieu D, Golli M, Dao TH, Jazaerli N, Anglade MC, Reyes F, Vasile N (1993) Detection of multiple myeloma involving the spine: efficacy of fat-suppression and contrast-enhanced MR-imaging. *AJR Am J Roentgenol* 160(5):1049–1052
32. Wasser K, Möhler T, Nosas-Garcia S, Rehm C, Bartl R, Goldschmidt JH, Düber C, Kauczor HU, Delorme S (2005) Correlation of MRI and histopathology of bone marrow in patients with multiple myeloma. *RoFo* 177(8):1116–1122
33. Buss DH, Prichard RW, Hartz JW, Cooper MR, Feigin GA (1986) Initial bone marrow findings in multiple myeloma. Significance of plasma cell nodules. *Arch Pathol Lab Med* 110(1):30–33
34. Schmidt GP, Baur A, Stäbler A, Schönberg SO, Steinborn M, Baltin V, Reiser MF (2005) Estimation of diffuse bone marrow infiltration of the spine in multiple myeloma: correlation of MRT with histological results. *RoFo* 177(5):745–750
35. Rahmouni A, Divine M, Mathieu D, Golli M, Hajoun C, Dao T, Anglade MC, Reyes F, Vasile N (1993) MR appearance of multiple myeloma of the spine before and after treatment. *AJR Am J Roentgenol* 160(5):1053–1057